Wetland and Rice Cultivation in the Sacramento-San Joaquin Delta, San Francisco Estuary and the Coast of California – Draft Methodology for Reducing Greenhouse Gas Emissions and Sequestering Carbon, June 10, 2015

Preface

The overall objective of this document is to provide a methodology for Project Proponents in the Sacramento-San Joaquin Delta, San Francisco Estuary and on the coast of California to financially benefit from reducing greenhouse gas (GHG) emissions by accessing carbon markets through conversion of land to wetlands and rice. The methodology has been written in modules that include a Framework Module which provides background and an over-arching description of the methodology and remaining modules. The remaining modules provide guidance for baseline and project scenarios, methods, modeling and calculation of uncertainty. The entire methodology is presented here to facilitate review and comprehension. What modules will be utilized for any proposed project shall be selected depending on project and baseline conditions which are described in the Framework module.

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Wetland Restoration and Rice Methodological Module - Framework (WR-MF)

BACKGROUND

The overall objective is to provide a methodology for Project Proponents in the Sacramento-San Joaquin Delta, San Francisco Estuary and on the coast of California to financially benefit from reducing greenhouse gas (GHG) emissions by accessing carbon markets through conversion of land to wetlands and rice. Baseline or business-as-usual scenarios include agriculture, seasonal wetlands and open water areas. Baseline emissions and carbon stock changes result primarily from oxidation of organic soils. Project scenarios include tidal wetlands, permanently flooded managed non-tidal wetlands and rice cultivation in the Sacramento-San Joaquin Delta. Table 1 provides a list for relevant land uses and examples in the Delta and Estuary. The examples in Table 1 are not meant to imply that these are the only geographic application for the baseline or project scenarios.

Table 1. Relevant land use example and GHG relevancy.

	Land Use	Examples	GHG relevancy
Baseline	Agricultural	Farmed organic soils on Delta islands	Baseline GHG emissions due to oxidation of organic soils
	Agricultural/fallow/seasonal wetlands	Fallow areas or areas that have become impractical to farm due to excessive wetness	Baseline GHG emissions due to oxidation of organic soils
	Seasonal Wetlands	Seasonally flooded hunting clubs in Suisun Marsh	Baseline GHG emissions due to oxidation of organic soils
	Open water	Subsided salt ponds in the South Bay, Franks Wetland in the Delta	Likely net GHG emissions but no data
Project	Managed non-tidal wetlands	Twitchell and Sherman islands	Generally net GHG removal, methane emissions, stops baseline emissions
	Saline/brackish tidal wetlands	Rush Ranch, Suisun Marsh and others cited in Callaway and others[1]	Net GHG removal where there is minimal methane emitted
	Rice	Twitchell Island, Wright Elmwood Tract, Brack Tract, Rindge Tract, Canal Ranch Tract, Delta	Greatly reduces organic soil GHG emissions and provides net GHG emissions reductions on organic soils.

[1] Callaway, John C., Borgnis, Evyan L. Turner, R. Eugene & Milan, Charles S., 2012, Carbon Sequestration and Sediment Accretion in San Francisco Bay Tidal Wetlands, Estuaries and Coasts, (2012) 35:1163–1181

Baseline Conditions

Sacramento-San Joaquin Delta

A key area for carbon sequestration wetlands and rice is within the 750,000-acre Sacramento-San Joaquin Delta. The Delta is a critical natural resource, an important agricultural region and the hub for California's water supply. Since Delta islands were first diked and drained for agriculture in the late 1800s, more than 3.3 billion cubic yards of organic soils have disappeared. This loss has resulted in land surface elevations as low as 20-25 feet below sea level (Figure 1). The volume below sea level (accommodation space) of approximately 1.7 million acre feet represents a significant opportunity for carbon sequestration. The primary baseline emission and carbon stock change is due to oxidation of organic matter in farmed and grazed organic and highly organic mineral soils (Figure 2). This oxidation results in emission of CO_2 and relatively small amounts of CH_4. Also, N_2O is emitted as the result of organic matter oxidation and fertilizer use. These emissions have occurred since the late 1800s due to drainage and cultivation of these soils. Baseline emissions of CO_2, CH_4 and N_2O have been measured and modeled.

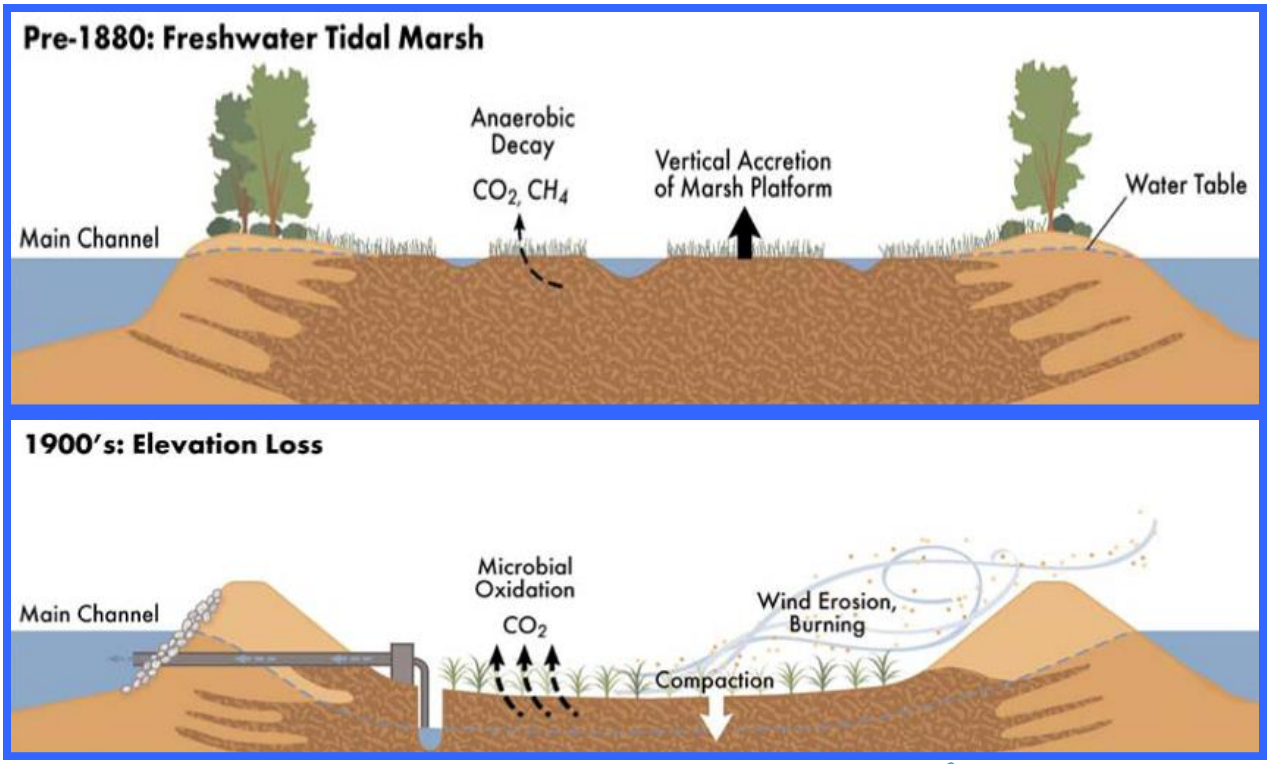

Figure 1. Evolution of Delta subsided islands (modified from Mount and Twiss[2]). During the last 6,800 years, organic soils accreted in a vast tidal marsh as sea level rose. Draining of the land for agriculture resulted in subsidence and loss of soil organic matter.

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[2] Mount J, Twiss R. 2005. Subsidence, sea level rise, seismicity in the Sacramento-San Joaquin Delta, San Francisco Estuary and Watershed Science.Vol. 3, Issue 1 (March 2005), Article 5. http://repositories.cdlib.org/jmie/sfews/vol3/iss1/art5

Subsidence of Delta organic soils began during the late 1800s and early 1900s when Delta islands were leveed and drained for agriculture. Recent research throughout the Delta demonstrates that present-day land subsidence in the Delta is caused primarily by oxidation of highly organic soils that contributes to GHG emissions. Oxidation of organic soils under typical Delta agricultural conditions releases CO_2 and N_2O and results in a net GHG emission and carbon loss.

Beginning in 1990, the US Geological Survey measured CO_2 emissions and correlated these with subsidence measurements[3,4,5] in pasture, grain and an asparagus fields in the western and central Delta (Sherman and Jersey islands and Orwood Tract). UC Berkeley researchers used eddy covariance techniques and chambers to determine CO_2, NO_2 and CH_4 emissions and the annual carbon balance in a pasture on Sherman Island starting in 2006[6,7]. Recently, UC Berkeley researchers have expanded the scope of their measurements to include areas on Twitchell and Sherman islands. During 2011 and 2012, the US Geological Survey used eddy covariance techniques to estimate annual carbon balances which included CO_2 and CH_4 emission determination on Staten Island in the central Delta[8]. Also, Miller[9] used chambers to measure GHG fluxes on Twitchell Island. Deverel and Leighton[10] developed a model for estimating baseline CO_2 emissions from the oxidation of organic soils. They estimated that baseline CO_2 emissions range from 2 to 18 metric tons CO_2 per acre per year throughout the Delta. Using the Deverel and Leighton model, an estimated 1.5 to 2 million metric tons of CO_2 are emitted from about 200,000 acres of organic and highly organic mineral soils in the Delta each year.

Carbon dioxide emissions from drained organic soils are proportional to soil organic matter content and are estimated to range from 2 to over 22 t CO_2-e $A^{-1}yr^{-1}$ for the Delta[11]. Recent measurements are generally consistent with these estimated values. The US Geological Survey reported 8.6 t CO_2-e $A^{-1}yr^{-1}$ on Staten Island during 2012[12]. UC Berkeley Biometeorology Laboratory personnel reported 6.6 and 8.5 t CO_2-e $A^{-1}yr^{-1}$ in pasture on Sherman Island and corn on Twitchell Island, respectively during 2012 and 2013[13 14]. Greenhouse gas emissions from and subsidence of peat soils are directly correlated with

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[3] Deverel SJ, Rojstaczer S. 1996. Subsidence of agricultural lands in the Sacramento—San Joaquin Delta, California: role of aqueous and gaseous carbon fluxes. Water Resources Research 32(8):2359–23672

[4] Rojstaczer, S., Deverel, S.J., 1993. Time-dependence in atmospheric carbon inputs from drainage of organic soils. Geophysical. Research. Letters. 20, 1383–1386

[5] Deverel, S.J., Wang, Bronwen, Rojstaczer, Stuart 1998, Subsidence in the Sacramento-San Joaquin Delta, *in* (Borchers, J.W., ed.) Proceedings of the Joseph Poland Subsidence Symposium, Association of Engineering Geologists, Special Publication No. 8, Star Publishing, Belmont, California, pp. 489-502

[6] Jaclyn A. Hatala*, Matteo Detto, Oliver Sonnentag, Steven J. Deverel, Joseph Verfaillie, Dennis D. Baldocchi, 2012, Greenhouse gas (CO2, CH4, H2O) fluxes from drained and flooded agricultural peatlands in the Sacramento-San Joaquin Delta, Agriculture, Ecosystems and Environment , 150,1-18

[7] Teh, Y.A., Silver, W.L., Sonnentag, O., Detto, M., Kelly, M., Baldocchi, D.D., 2011. Large greenhouse gas emissions from a temperate peatland pasture. Ecosystems 14, 311–325

[8] US Geological Survey, 2013, Assessing the role of winter flooding on baseline greenhouse gas fluxes from corn fields in the Sacramento– San Joaquin Bay Delta, Final Project Report for the California Energy Commission

[9] Miller, Robin, 2011, Miller, Robin L., 2011 Carbon Gas Fluxes in Re-Established Wetlands on Organic Soils Differ Relative to Plant Community and Hydrology, Wetlands DOI 10.1007/s13157-011-0215-2

[10] 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.

[11] ibid

[12] See footnote 8

[13] Knox SH, Sturtevant C, Matthes JH, Koteen L, Verfaillie J, Baldocchi D, 2014, Agricultural peatland restoration: effects of land-use change on GHG (CO2 and CH4) fluxes in the Sacramento-San Joaquin Delta, Global Change Biology, 21, 750–765.

[14] See footnote 7

depth to groundwater; deeper groundwater corresponds to larger GHG emissions and higher subsidence rates where other factors such as soil organic matter content and temperature are constant[15 16].
Under baseline agricultural conditions, N_2O is emitted as the result of fertilizer use and organic matter decomposition. Reported emissions due to organic matter decomposition in drained highly organic soils are substantially larger than those due to fertilizer applications[17 18]. Nitrous oxide emissions have been measured infrequently in the Delta. Assa and Horwath[19] measured an annual nitrous oxide emission of about 7.7 kilograms (kg) N_2O per acre (2.4 tons carbon dioxide equivalents per acre) in corn on Twitchell Island. Teh and others[20] reported similar values for pasture on Sherman Island. Ye and Horwath[21] reported annual N_2O emissions in rice ranging from 0 to 1 kg nitrogen per acre (0 to 0.3 t CO_2-e $A^{-1}yr^{-1}$). These studies demonstrated the episodic nature of N_2O emissions, large spatial variability and dependence on fertilizer amounts and soil organic matter content.

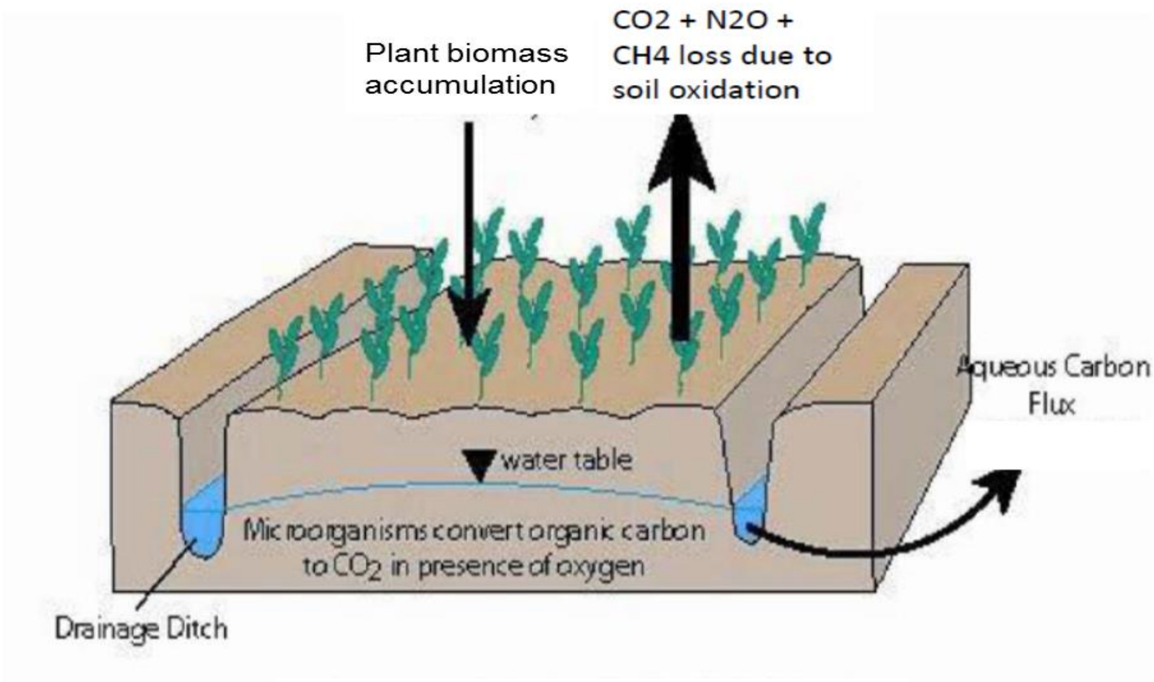

Figure 2. Agricultural baseline carbon fluxes. Under drained conditions for traditional agricultural crops, exposure and oxidation of organic soil to oxygen results in oxidation and net emissions of CO_2, CH_4, and N_2O.

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[15] Couwenberg J. and Hooijer A., 2013, Towards a robust subsidence-based soil carbon emission factors for peat soils, Mires and Peat, 12: 1-13

[16] Stephens J.C., Allen L.H., Chen E., 1984, Organic soil subsidence. In: Holzer T.L. (Ed.). Man-induced land subsidence. Reviews in Engineering Geology, Vol. VI. Boulder (CO): Geological Society of America.

[17] Kasimir-Klemedtsson A., Klemedtsson L., Berglund K., Martikainen P., Silvola J., Oenema, O., 1997, GHG emissions from farmed organic soils; a review. Soil Use and Management 13: 245-250.

[18] Li, Changsheng, Six J., Horwath W.R., Salas W., 2014, Calibrating, Validating, and Implementing Process Models for California Agriculture GHG Emissions, Final Report to the Air Resources Board. February 27, 2014.

[19] Assa Y. and Horwath W., 2011, Report on GHG emissions study in Twitchell Island in Corn and Rice Systems conducted in Spring 2010-Fall 2011.

[20] see footnote 7

[21] Ye, Rongzhong and Horwath, W.R., 2014, Influence of variable soil C on CH4 and N2O emissions from rice fields, presentation at UC Davis.

Table 2 summarizes the published and recently reported net carbon balance and model estimates for the Delta.

Table 2. Measured and modeled CO_2-e baseline emissions

Site	Soil carbon (%)	Average groundwater depth (cm)	Measured CO_2-e emissions (tons/A-year)	Modeled[22] CO_2-e (tons/A-year)
Twitchell Corn (UC Berkeley)[23]	16	82	9	9
Sherman Pasture (UC Berkeley)[24]	12.5	60	2.8 - 5.2	3.3 - 5.6
Sherman Pasture (USGS, 1991 - 92)[25]	14	70	5.2 - 8.2	6.7
Jersey pasture (USGS 1991 - 1992)	10	60	6.4	6.3
Staten Corn (USGS)[26]	10.5 - 16	130	8.6	8.6

San Francisco Estuary

In the San Francisco Bay region, the primary baseline emission is due to oxidation of soil organic matter in seasonal wetlands containing organic and highly organic mineral soils. This oxidation results in emission of CO_2 and CH_4 and possibly N_2O. Consistent with the description of the oxidation of drained organic soils above, in an evaluation of different wetland management practices on highly organic mineral soils, USGS researchers determined that seasonal wetlands (flooded during late fall, winter and early spring) resulted in a net GHG emission[27]. Consistently, there are large areas of organic and highly organic mineral soils that have subsided. For example, the Suisun Marsh area is composed of both organic and mineral soils. Reported organic matter content for these soils ranges from 15 to 70 percent[28]. Most of the land within the Marsh consists of diked wetlands which are flooded part of the year. Approximately 85 percent of these wetlands are drained from mid-July through mid-September when soil temperatures and organic matter oxidation rates are high. In Suisun Marsh, estimated median subsidence rates from the late 1940s to 2006 varied by soil type and ranged up to 2.5 cm/year

[22] Using the model described in Deverel and Leighton, 2010, See footnote 10
[23] Knox et al. see footnote 13
[24] Hatala et al. see footnote 6
[25] Deverel and Rojstaczer see footnote 3
[26] Anderson see footnote 8
[27]Deverel, S.J., Wang, Bronwen, Rojstaczer, Stuart ,1998, Subsidence in the Sacramento-San Joaquin Delta, *in* (Borchers, J.W., ed.) Proceedings of the Joseph Poland Subsidence Symposium, Association of Engineering Geologists, Special Publication No. 8, Star Publishing, Belmont, California, pp. 489-502
Robin L. Miller, Lauren Hastings, and Roger Fujii . 2000, Hydrologic Treatments Affect Gaseous Carbon Loss From Organic Soils, Twitchell Island, California, October 1995–December 1997, U.S. Geological Survey Water-Resources Investigations Report 00-4042
[28]Bates, Leland A., 1977, Soil Survey of Solano County, California, U.S. Dept. of Agriculture, Soil Conservation Service.

and were generally proportional to soil organic matter content.[29] The estimated volume below sea level based on the 2006 LIDAR data is 5,800 acre feet[30]. This is the approximate volume of organic soil that has been lost since initial diking and drainage. There have been few baseline measurements or estimates of GHG emissions in the Suisun Marsh or northern San Francisco Bay Area. Recently, the US Geological Survey deployed an eddy covariance tower at the Rush Ranch wetland in Suisun Marsh to measure GHG fluxes.

Open Water

An example area of applicability for this module is San Francisco Bay where diked and managed salt ponds preserved a large area of shoreline in an open state for salt crystallization. Former salt ponds are now open water areas that are undergoing phased conversion to tidal wetlands[31]. The South Bay Salt Pond Restoration Project is the largest tidal wetland restoration project on the West Coast. Over 15,000 acres have been reconnected to the bay or adjacent sloughs. Due to groundwater pumping in this area, many of the areas are substantially below sea level. These subsided lands are influenced by processes that occur outside the project boundaries. For example, allochthonous carbon can enter the subsided areas. Also, there can be large primary productivity and respiration rates in these open water areas thus demonstrating the potential for baseline GHG emissions and removals[32]. These ponds are critical habitat for millions of birds annually. The goals of the project are to 1) restore and enhance a mix of wetland habitats, 2) provide wildlife-oriented public access and recreation and 3) provide for flood management in the South Bay.

Project Conditions

Managed Permanently-Flooded Non-Tidal Wetlands on Subsided Lands

The unique, chemically reducing environment in managed permanently-flooded wetlands on subsided lands facilitates CO_2 sequestration and methanogenesis or production of CH_4. In permanently flooded wetlands, CO_2 accumulates in plant tissue which becomes litter and eventually accumulates as soil organic matter (SOM). The SOM can be converted to dissolved organic carbon (DOC), bicarbonate ($HCO3^-$), and CH_4. Dissolved organic carbon and CH_4 are byproducts of and leakages from the net accumulation of SOM and CO_2 sequestration (Figure 3).

Measurement of net wetland-surface accretion is accomplished through the use of documented techniques such as the use of sedimentation erosion table and collection and chemical analysis of cores of accumulating material. Collection and analysis of cores or material that accumulates above a marker horizon is also used to estimate the depth and carbon content of the accumulated materials in the marsh. These measurements of accumulated material represent a net quantification of carbon

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[29] HydroFocus, Inc., 2007, Technical Memorandum, Recent And Estimated Future Subsidence Rates and Land Surface Elevation Changes in the Sacramento-San Joaquin Delta And Suisun Marsh, Delta Risk Management Strategy, Department of Water Resources, Sacramento, CA

[30] ibid assuming an organic soil bulk density of 0.2 g cm^{-3} and 50% organic matter, this volume of 5,800 acre feet translates to about 1.3 million tons of CO_2

[31] http://www.southbayrestoration.org/Project_Description.html

[32] Thébault, Julien, Schraga, Tara S., Cloern, James E., Dunlavey, Eric G., 2008, Primary production and carrying capacity of former salt ponds after reconnection to San Francisco Bay, Wetlands, 28, 814-851

sequestered after losses of DOC, $HCO3^-$, and CH_4. The net climate benefit depends not only on the amount of CO_2 sequestered and greenhouse gases (primarily CH_4) emitted.

Wetlands may be considered a GHG sink as CO_2 is removed from the atmosphere and stored in the soil carbon pool. However, a wetland also acts as a GHG source because it emits CH_4, which contributes to the atmospheric absorption of infrared radiation. In general, the amount of CO_2sequestered relative to the amount of CH_4 emitted and the relative ability of these gases to absorb infrared radiation ultimately determine whether the wetland is a sink or source for the global warming potential. The instantaneous infrared absorption of CH_4 is about 25 times greater than $CO_{2.}$ Carbon fixation in the form of primary production is intimately connected with CH_4 production; the amount of CO_2 fixed on a daily basis has been positively correlated with CH_4 emissions[33]. The correlation of CH_4 emissions with Net Ecosystem Productivity to increases in organic substrates has been associated with root exudates, litter production, and plant turnover[34].

Since the late 1980s, there has been substantial interest in stopping and reversing the effects of subsidence by creating managed wetlands on subsided islands in the Sacramento-San Joaquin Delta. Under the hypothesis that construction of these permanently flooded impounded marshes would stop subsidence and carbon loss, experiments were conducted in 1,000-m^2 enclosures on Twitchell Island beginning in 1993. Deverel el al.[35] reported a net carbon gain in permanently flooded impounded marshes and thus demonstrated their ability to stop and reverse the effects of subsidence. These results and those of Miller et al.[36] led to the conversion of 6 ha of agricultural land to the impounded marsh demonstration project on Twitchell Island[37] in 1997 by Department of Water Resources, HydroFocus, Inc., Reclamation District 1601, and US Geological Survey California Water Science Center (USGSCWSC) personnel. Vertical accretion in the Twitchell marsh varied spatially and depended on water depth, plant community composition and colonization, degree of marsh maturity, and water residence time[38]. The largest rates occurred in the deeper-water pond within dense stands of *Schoenoplectus acutus* (hardstem bulrush) and Typha (cattail) species.

Studies conducted in the Twitchell Island wetland indicate annual GHG removal rates in the pilot wetland (both east and west ponds) ranging from about 2 to 14 tons carbon dioxide per acre[39]. The net

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[33] Whiting, G. J. and Chanton, J. P., 1993, Primary production control of methane emissions from wetlands. Nature 364, 794–795.

[34] Whiting, G.J. and Chanton, J.P., 2001, Greenhouse carbon balance of wetlands: methane emission versus carbon sequestration. Tellus, 53B, 521–528.

Net Ecosystem Production is defined as the difference between gross primary production and respiration and represents the amount of carbon available for storage.

[35] Deverel SJ, Wang B, Rojstaczer S. 1998. Subsidence in the Sacramento–San Joaquin Delta. In: Borchers JW, editor. Proceedings of the Joseph Poland Subsidence Symposium, Association of Engineering Geologists.

[36] Miller RL, Hastings L, Fujii R. 2000. Hydrologic treatments affect gaseous carbon loss from organic soils, Twitchell Island, California, October 1995-December 1997. U.S. Geological Survey Water-Resources Investigations Report 2000-4042, 21p.

[37] Miller RL, Fram MS, Wheeler G, Fujii R. 2008. Subsidence reversal in a re-established wetland in the Sacramento-San Joaquin Delta, California, USA. San Francisco Estuary and Watershed Science 6(3):1-24.

[38] Ibid

Knox SH, Sturtevant C, Matthes JH, Koteen L, Verfaillie J, Baldocchi D, 2014, Agricultural peatland restoration: effects of land-use change on greenhouse gas (CO2 and CH4) fluxes in the Sacramento-San Joaquin Delta, Global Change Biology, in press

[39] Knox SH, Sturtevant C, Matthes JH, Koteen L, Verfaillie J, Baldocchi D, 2014, Agricultural peatland restoration: effects of land-use change on greenhouse gas (CO2 and CH4) fluxes in the Sacramento-San Joaquin Delta, Global Change Biology, in press

Miller RL, Fram MS, Fujii R, Wheeler G (2008) Subsidence reversal in a re-established wetland in the Sacramento–San Joaquin Delta, California, USA. San Francisco Estuary Watershed Science 6(3). Available from: http://www.escholarship.org/uc/item/5j76502x greenhouse gas benefit equals the sum of CO_2 sequestered and baseline greenhouse gas emissions minus CH_4 emission. Nitrous oxide is generally not emitted from permanently flooded wetlands similar to those on Twitchell Island[40 41 42] where wastewater is not applied.

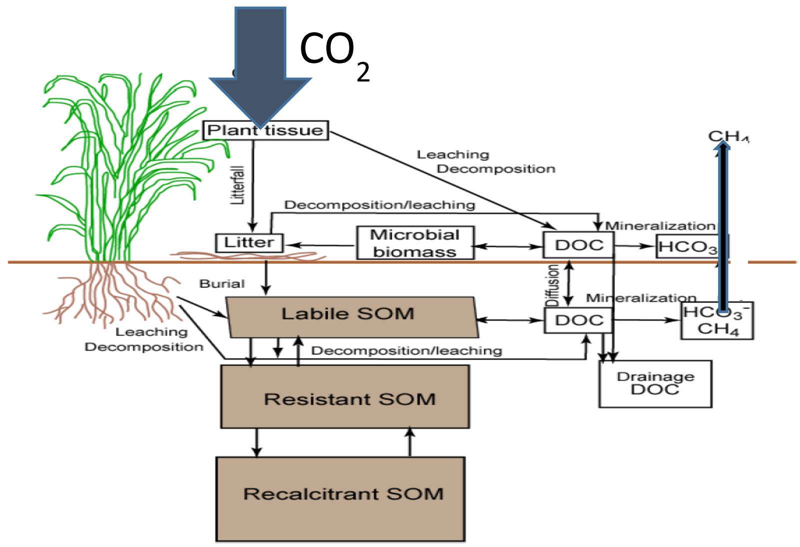

Figure 3. Carbon pathways in managed wetlands (adapted from Richards and Vespaskas[43]). Large amounts of CO_2 are stored in plant tissue and relatively small amounts of carbon are emitted as CH_4 to result in a net carbon sequestration.

Rice Cultivation on Subsided Lands in the Sacramento-San Joaquin Delta

Within the last 20 years, development of new rice varieties tolerant of low air and water temperatures resulted in Delta rice production with yields comparable to the Sacramento Valley. Available data indicates the combination of in-season and off-season flooding and addition of rice residues stop or greatly reduce oxidative soil loss. Rice has been successfully grown on over 3,000 acres on Delta islands for over 10 years. Data reported for CO_2 and CH_4 emissions in rice by Hatala et al. and Knox et al.[44] and

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[40]Smith CJ, DeLaune RD and Patrick Jr. WH (1983) Nitrous oxide emission from Gulf Coast Wetlands. *Geochimica et Cosmochimica Acta* 47: 1805-1814.

[41] John Couwenberg, Annett Thiele , Franziska Tanneberger , Ju¨rgen Augustin, Susanne Ba¨risch. Dimitry Dubovik, Nadzeya Liashchynskaya, Dierk Michaelis, Merten Minke, Arkadi Skuratovich, Hans Joosten, 2011, Assessing greenhouse gas emissions from peatlands using vegetation as a proxy, Hydrobiologia (2011) 674:67–89

[42] IPCC, 2013, 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands, see Chapter 3, Rewetted peatlands at http://www.ipcc-nggip.iges.or.jp/public/wetlands/

[43] Richardson, J.L., and Vepraskas, M.J. (ed.), 2000, Wetland Soils, Genesis, Hydrology, Landscapes and Classification, Taylor and Francis.

[44]Hatala JA, Detto M, Sonnentag O, Deverel SJ, Verfaillie J, Baldocchi DD (2012) Greenhouse gas (CO_2, CH_4, H_2O) fluxes from drained and flooded agricultural peatlands in the Sacramento-San Joaquin Delta. Agriculture, Ecosystems and Environment 150: 1-18.

Knox SH, Sturtevant C, Matthes JH, Koteen L, Verfaillie J, Baldocchi D, 2014, Agricultural peatland restoration: effects of land-use change on greenhouse gas (CO2 and CH4) fluxes in the Sacramento-San Joaquin Delta, Global Change Biology, in press

N_2O data reported by Ye and Horwath[45] demonstrate there is net GHG benefit for rice where soil organic carbon values range from 5 to 25 %. The average annual nitrous oxide emission for rice reported by UC Davis researchers range from -0.06 to 0.34 tons carbon dioxide equivalents per acre. The Hatala et al. data resulted in an average annual emission (of CO_2 and CH_4) of 1.7 tons CO_2 equivalents per acre. When compared to the Delta organic-soil agricultural baseline CO_2 emissions ranging from 3 to over 9 tons carbon dioxide equivalents per acre, rice cultivation can provide tangible GHG benefits.

Tidal Wetlands in San Francisco Estuary and California Coast

Tidal wetlands help to buffer climate change by sequestering carbon due to high primary productivity and low decomposition rates. Reported GHG removal rates across or within tidal wetland complexes vary widely and are affected by local plant species composition and productivity, decomposition rates, allochthonous sediment imports, salinity, tidal range, and human activities. There are several large-scale restoration projects underway or planned in the San Francisco Bay Estuary (e.g., Montezuma Wetlands in Suisun Bay, Hamilton Wetlands, the Napa-Sonoma Salt Pond Project, and the South Bay Salt Pond Project) and elsewhere (e.g., Bolsa Chica Wetlands in Huntington Beach and San Deiguito Lagoon in San Diego). In the San Francisco Bay Estuary, tidal wetlands are mostly dominated by perennial pickleweed, *Sarcocornia pacifica*. Using two different dating systems (cesium-137 and lead-210), Calloway et al.[46] estimated recent carbon sequestration rates in six natural and two restored wetlands in the San Francisco Estuary.

Calloway et al. reported long-term carbon sequestration rates in the San Francisco Estuary ranging from 0.6 to 2.8 tons CO_2-e/acre-year. The average long-term rate for tidal salt and brackish wetlands was 1.6 tons CO_2-e/acre-year. Drexler[47] estimated millennial rates ranging from 0.6 to 1.1 tons CO_2-e/acre-year in remnant freshwater and brackish tidal marshes in the Delta. Using the model results presented in Deverel et al[48], we estimated an average carbon sequestration rate during the last 50 years of 2.1 t CO_2-e $A^{-1}yr^{-1}$ on Franks Wetland in the Central Delta. Franks Wetland is a freshwater tidal marsh and is a mosaic of willows and emergent wetland vegetation. Schile et al[49] used the Marsh Equilibrium Model to estimate marsh accretion in the San Francisco Estuary for varying sea-level rise and sediment loading rates. Freshwater tidal wetlands emit methane at rates ranging from 2 to 5 t CO_2-e $A^{-1}yr^{-1}$ [50]. In

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[45]Ye, R. and Horwath, W.R.,2014 Influence of variable soil C on CH_4 and N_2O emissions from rice fields 2013-2014. Presentation at UC Davis.

[46]Callaway, John C., Borgnis, Evyan L. Turner, R. Eugene & Milan, Charles S., 2012, Carbon Sequestration and Sediment Accretion in San Francisco Bay Tidal Wetlands, Estuaries and Coasts, (2012) 35:1163–1181

[47] Drexler, J.Z., 2011, Peat Formation Processes Through the Millennia in Tidal Marshes of the Sacramento–San Joaquin Delta,California, USA, Estuaries and Coasts, DOI 10.1007/s12237-011-9393-7

[48] Deverel S.J., Ingrum T., Lucero C., Drexler J.Z., 2014, Impounded Marshes on Subsided Islands: Simulated Vertical Accretion, Processes, and Effects, Sacramento-San Joaquin Delta, CA USA. San Francisco Estuary and Watershed Science 12(2): http://escholarship.org/uc/item/0qm0w92c

[49] Schile LM, Callaway JC, Morris JT, Stralberg D, Parker VT, et al. (2014) Modeling Tidal Marsh Distribution with Sea-Level Rise: Evaluating the Role of Vegetation, Sediment, and Upland Habitat in Marsh Resiliency. PLoS ONE 9(2): e88760. doi:10.1371/journal.pone.0088760

[50] Abril, Gwenael and Vieira Borges, Alberto, 2004, Carbon dioxide and methane emissions from estuaries in Tremblay et al. (Eds.) GHG emissions fluxes and processes, hydroelectric reservoirs and natural environments, Environmental Science Series, Springer.
Whiting, G. J. and Chanton, J. P., 1993, Primary production control of methane emissions from wetlands. Nature 364, 794–795.
Bartlett K.B. and Harriss R.C., 1993, Review and assessment of methane emissions from wetlands, Chemosphere, 26:261-320.

contrast, saline coastal wetlands generally emit relatively little methane due to high inputs of sulfate which minimize methane production[51].

GENERAL GUIDANCE

A. Scope

This 'Wetland – Rice Cultivation Methodology Framework' outlines the basic structure of the modular methodology and includes descriptions of modules and tools for specific functions. Together with the modules and tools, it provides a complete offset project, baseline and monitoring methodology.

The modules and tools described here are applicable for quantification of greenhouse gas (GHG) removals and emission reductions for restoration of tidal wetlands (TW); managed, permanently flooded non-tidal wetlands (MW); and rice cultivation (RC) in the San Francisco Estuary and Sacramento-San Joaquin Delta and coastal areas located in the State of California, United States of America. The water quality of eligible activities ranges from fresh to saline and includes lands that are used for agriculture or where managed or non-managed seasonal wetlands, and where there is open water.

This carbon offset methodology does not attempt to provide guidance or applicability criteria for wetland construction, restoration or rice cultivation or project-specific implementation of guidelines and methodologies presented here. These activities require the expertise of designated experts such as but not restricted to certified wetland scientists, agronomists, hydrologists and civil and environmental engineers. The methodology assumes the Project Proponent has or engages the necessary expertise and requires that the activities implemented under this methodology comply with all applicable regulations.

B. Sources of Information

The methodology structure and text have been adapted from the following methodologies:
ACR Restoration of Degraded Deltaic Wetlands of the Mississippi Delta[52]
VCS Methodology for Coastal Wetland Creation[53]
VCS Methodology for Coastal Wetland Creation[54]
ACR Emission Reductions Methodology in Rice Management Systems

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[51] Bartlett, K.B., and R.C. Harriss. 1993. Review and assessment of methane emissions from wetlands. Chemosphere 26: 261–320.
Magenheimer, J.F., T.R. Moore, G.L. Chmura, and R.J. Daoust. 1996.Methane and carbon dioxide flux from a macrotidal salt marsh,Bay of Fundy, New Brunswick. Estuaries 19: 139–145.
Hanna J. Poffenbarger & Brian A. Needelman & J. Patrick Megonigal, 2011, Salinity Influence on Methane Emissions from Tidal Marshes, Wetlands (2011) 31:831–842

[52] http://americancarbonregistry.org/carbon-accounting/standards-methodologies/restoration-of-degraded-deltaic-wetlands-of-the-mississippi-delta

[53] http://www.v-c-s.org/methodologies/methodology-coastal-wetland-creation-v10

[54] Approved VCS Methodology VM0024 Version 1.0, 30 January 2014 Sectoral Scope 14 Methodology for Coastal Wetland Creation. Louisiana Coastal Protection and Restoration Authority. 182 pp.

C. Definitions and Acronyms

ACR	American Carbon Registry
A/R	Afforestation and or reforestation
ARR	Afforestation, reforestation, and revegetation
AFOLU	Agriculture forestry and other land use
Baseline	most likely management scenario in the absence of the project
C	Carbon
CDM	Clean development mechanism
CO_2	Carbon dioxide
CO_2-e	Carbon dioxide equivalent
CF	Carbon fraction
CH_4	Methane
ERT	Emission reduction ton
Ex-ante	'Before the event' or predicted response of project activity
Ex-post	'After the event' or measured response of project activity
GHG	Greenhouse gas
GIS	Geographic information system
GPS	Global positioning system
GWP	Global warming potential
Historical reference period	the historical period prior to the project Start Date that serves as the source of data for defining the baseline
i	Subscript used to represent a stratum
Leakage	Any change in carbon stocks or greenhouse gas emissions that occur outside a project's boundary (but within the same country) that is measurable and attributable to the project activity.
Module	Component of a methodology that can be applied on its own to perform a specific task
N_2O	Nitrous oxide
QA	Quality assurance
QC	Quality control
Stratification	A standard statistical procedure to decrease overall variability of carbon stock estimates by grouping data taken from environments with similar characteristics (e.g., vegetation type; age class; hydrology; elevation)
Tool	Guideline or procedure for performing an analysis (e.g., Tool for testing significance of GHG emissions in A/R CDM project activities) or to help use or select a module or methodology
VCS	Verified Carbon Standard

D. Modules and tools

The following modules and tools are available for use:

Baseline Modules:

BL-Ag - Estimation of agricultural baseline carbon stock changes and GHG emissions for wetland construction and rice cultivation where the project activity includes hydrologic management and infrastructural modification when there are agricultural activities in place immediately prior to the project commencement date

BL-SW - Estimation of baseline carbon stock changes and GHG emissions for seasonal wetlands used for waterfowl hunting and non-managed seasonal wetlands when the project case is wetland construction which includes hydrologic management and infrastructural modification.

BL-OW – Estimation of open water baseline carbon stock changes and GHG emissions for tidal wetlands restoration where the project activity includes hydrologic management and infrastructural modification in San Francisco Bay

Methods Modules:

MM-W/RC Estimation of carbon stocks in the soil organic carbon pool and in the above- and below ground biomass and estimation of greenhouse gas emissions

E-FFC Estimation of emissions from fossil fuel combustion

MODEL-W/RC Biogeochemical models to be used for estimation of emissions and carbon stock changes under baseline and project conditions.

Project Scenario Modules:

PS-MW Estimation of project scenario carbon stock changes and greenhouse gas emissions for construction of managed non-tidal permanently flooded wetlands where the project activity can include hydrologic management, infrastructural modification, and plantings or natural plant regeneration.

PS-TW Estimation of project scenario carbon stock changes and greenhouse gas emissions from tidal wetlands construction and restoration where the project activity can include levee breaching to create tidal influence, plantings, fill and salt flushing

PS-RC Estimation of project scenario carbon stock changes and greenhouse gas emissions from rice cultivation where the project activity can include hydrologic management, infrastructural modification, and rice cultivation

Miscellaneous Modules:

X-UNC	Estimation of uncertainty

Tools:

T-SIG	Tool for testing significance of GHG emissions in A/R CDM project activities
T-PERM	ACR's most recent permanent risk tool
T-PLOTS	Calculation of the number of sample plots for measurements within A/R CDM project activities

Table 3. Determination of mandatory (M), conditional (C), or optional (N/R), module/tool use.

Determination	Module/Tool	Managed Wetland Construction	Tidal Wetland Restoration	Rice Cultivation
Used by all projects	WR-MF T-PERM X-UNC	M M M	M M M	M M M
Baselines	BL-Ag BL- SW BL- OW	C C C	C C C	M C N/R
Carbon Stocks	MM-W/R	M	M	M
Emissions	MM-W/RC E-FFC	M C	M C	M M
Project Scenario	PS-MW PS-TW PS-RC	M N/R N/R	N/R M N/R	N/R N/R M

Modules marked with an M are mandatory: the indicated modules and tools must be used.
Modules marked with a C are conditional depending on the baseline scenario and emissions.
Modules marked with N/R are not required.
The indicated pools and sources (see Table 4) can be included or excluded as decided by the project proponent, but if included in the baseline they must also be included in the with-project scenario and be monitored accordingly.

E. Applicability Conditions

This Methodology describes modules and tools relevant to project activities for use by Project Proponents which include private individuals and businesses, as well as public entities (i.e., county, state, federal, tribal, etc.). Specific applicability conditions exist for each module and must be met for the module to be used. The GHG Project Plan shall justify use of modules relevant to the proposed project activities. This Methodology is applicable provided the Project Proponents demonstrate eligibility of project activities, and can document land and offsets title.

The baseline is defined as the counterfactual scenario that forecasts the likely stream of emissions or removals to occur if the Project Proponent does not implement the project, i.e., the "business as usual" case. It also reflects the sum of the changes in carbon stocks (and where significant, N_2O and CH_4 emissions) in the carbon pools within the project boundary that would occur in the absence of the Project Activity, where the land would remain degraded or continue to subside in the absence of the project activity. Eligible baseline scenarios include:

- Agricultural activities which result in continued organic soil loss in the Sacramento-San Joaquin Delta;
- Seasonal wetlands on organic soils which result in continued organic soil loss - these areas

include managed seasonally flooded wetlands and areas that have become too wet to farm and have become seasonal wetlands and hunting clubs;
- Open water areas in former salt ponds.

This methodology outlines procedures to estimate net greenhouse gas emission reductions and removals resulting from project activities implemented to construct and restore wetlands and halt organic soil loss. All project activities must be in regulatory compliance. Eligible project activities include:

- Managed permanently shallow flooded wetlands on subsided lands which include areas where the baseline includes agricultural areas and seasonal wetlands;
- Tidal wetland restoration in the San Francisco Estuary where the baseline is open water or seasonal wetlands;
- Rice cultivation on subsided lands where the baseline is farmed organic soils using crops that required a drained root zone in the Sacramento-San Joaquin Delta

Possible management strategies to achieve these project activities include:

- Alteration of hydrologic conditions, sediment supply, water quality and plant communities, nutrient management
- Earth moving
- Diversion of channel water into wetlands or rice fields
- Management of surface water levels and wetland outflow
- Levee breaching with appropriate permits

Ineligible management activities include:

- Drainage of wetland soils;
- Activities that cause deleterious impacts or diminish the GHG sequestration function of habitat outside the project area;
- Burning of wetland or agricultural vegetation;
- Activities required under Section 404 of the Clean Water Act to mitigate onsite or offsite impacts to wetlands;
- Activities that involve the use of natural resources within the project boundary that lead to further degradation (fishing, hunting, etc. that do not lead to degradation of the project area are permitted);
- Harvesting of wood products;
- Planting of non-native species;
- Activities that affect fish populations in Delta channels[55].

F. Applicable Project and Baseline Modules

Figure 4 shows the relationships between project and baseline modules. For the managed wetlands project activity, agricultural and/or seasonal wetlands baseline modules can be employed depending on baseline conditions. For the rice cultivation project activity, only the agricultural baseline is applicable. For tidal wetlands project activity, either the seasonal wetland or open water baseline modules are applicable.

[55] Siphoning of water for wetlands on subsided Delta islands may result in "take" of fish. Fish screens or an alternative mitigation measure may be required to avoid take.

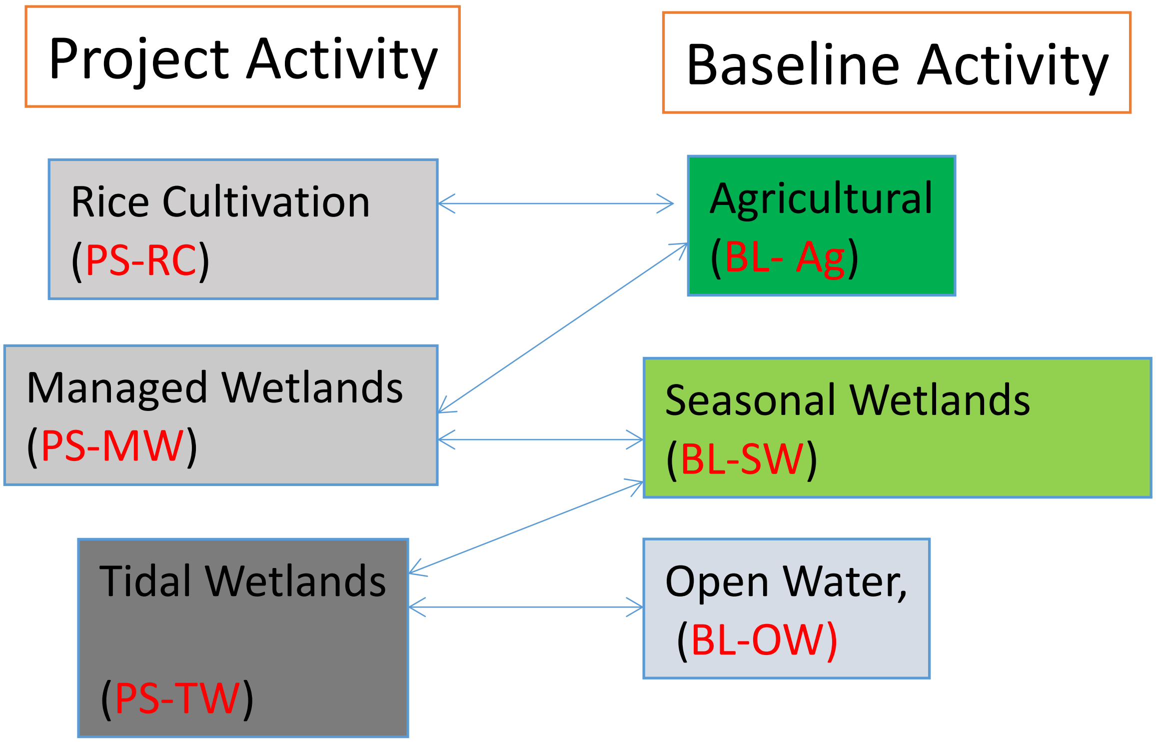

Figure 4. Project and baseline modules.

ASSESSMENT OF NET GREENHOUSE GAS BENEFIT

The project proponent shall implement the following steps to assess greenhouse gas reductions.

1. Identification of the baseline for project activity
2. Definition of project boundaries
3. Legal requirement test and performance standard evaluation
4. Development of a monitoring plan
5. Estimation of baseline carbon stock changes and GHG emissions
6. Estimation of project carbon stock changes and GHG emissions
7. Estimation of total net GHG emission reductions (project minus baseline and leakage)
8. Calculation of uncertainty
9. Assessment of reversal and termination risk
10. Calculation of ERTs

All steps are required *ex-ante*. For *ex-post*, steps 6 through 10 are applicable. For parameters that will be monitored or modeled subsequent to project initiation, *ex-ante* guidance is given in the relevant modules, MODEL–R/C, MM-R/C, and E-FFC.

Step 1. Identification of the baseline activities

Use the flow chart (Figure 4) to identify the appropriate project activity, baseline and relevant modules. A project can include areas with different activities/baselines. In such cases, project and baseline areas shall be delineated in the GHG Project Plan.

Proponents must identify credible Baseline Scenarios by describing what would have occurred in absence of the Project Activities and quantifying GHG emissions and removals. The Baseline Scenarios must be limited to the specified baseline land uses shown in Figure 4 and comply with the applicability conditions described in the framework and baseline modules.

Step 2. Definition of Project Boundaries

The following categories of boundaries shall be defined:
a. The geographic boundaries relevant to the project activity;
b. The temporal boundaries;
c. The carbon pools that the project will consider and;
d. The sources and associated types of GHG emissions

a. Geographic boundaries relevant to the project activity

The Project Proponents must provide a detailed description of the geographic boundary of project activities using a Geographic Information System (GIS). Note that the project activity may contain more than one discrete area of land, but each area must meet the project eligibility requirements. Information to delineate the project boundary may include:
- USGS topographic map or property parcel map where the project boundary is recorded for all areas of land. Provide the name of the project area (e.g., compartment number, allotment number, local name); and a unique ID for each discrete parcel of land
- Aerial map (e.g. orthorectified aerial photography or georeferenced remote sensing images)
- Geographic coordinates for the project boundary, total land area, and land holder and user rights
- Project proponents shall provide a GIS shapefile that includes relevant geographic features and the project boundaries

Further boundary requirements are detailed in the baseline module. The geographic boundaries of a tidal or managed wetland or rice cultivation project (*ex-ante*) may change over the Crediting Period[56] (40 years). Specifically, for aggregated projects, additional cohorts can be added with specific boundaries that do not change over the project crediting periods. Where multiple baselines exist there shall be no overlap in boundaries between areas appropriate to each of the baselines.

b. Temporal Boundaries

Projects with a Start Date of January 1, 2000, or later are eligible to receive offsets retroactively, if they can demonstrate that GHG mitigation was an objective from project inception and carbon stock changes can be documented adequately. The project Start Date is defined as the day Project Proponents began activities to increase carbon stocks and/or reduce GHG emissions. This methodology employs a 40-year Crediting Period, over which time monitoring must take place to ensure that there are no reversals of carbon stocks. Spatial and temporal patterns of tidal wetland loss/gain are dynamic, resulting from complex and interactive effects of natural and human-induced processes. Wetland areas can fluctuate between land and water categories, making wetland loss/gain difficult to quantify. Tidal wetland area estimates can vary substantially due to seasonality, wind, and water level fluctuations. Additionally, seasonal wetlands can fluctuate between land and water multiple times prior to persistent conversion

[56] The crediting period is the length of time in which credits are verified and reported which is 40 years for this methodology.

to open water.   These factors shall be accounted for in project reporting.

c. Carbon Pools and Sources

Tables 4 and 5 provide guidelines for determining the GHG assessment boundary. Exclusion of carbon pools and emission sources is allowed subject to considerations of conservativeness and significance testing or when inclusion may result in double counting. This can be the case for plant litter, above and below ground biomass and soil organic matter pools. Pools or sources may always be excluded if conservative, i.e. exclusion will tend to underestimate net GHG emission reductions or removal enhancements. Pools or sources can be excluded (i.e., counted as zero) if application of the tool T-SIG indicates that the source is insignificant, provided that each source, sink and pool is determined to be insignificant and excluded from accounting represents less than 3% of the *ex-ante* calculation of GHG emission reductions/removal enhancements (per ACR *Forest Carbon Project Standard*). Tables 3 and 4 refer to the use of calibrated and validated biogeochemical models which may be used to calculate changes in carbon stocks and emissions. Methods listed in Table 4 may be used alone or in tandem with other methods.   Models that include litter, above and below ground biomass and soil organic matter pools must demonstrate that there is no double counting of carbon stock changes including consideration of conservativeness and significance testing. Please see the model discussion in Step 5.

Table 4. Carbon pools to be considered for monitoring or modeling

Carbon pool	Status	Explanation/Justification	Quantification Methods
Above-ground non-woody biomass	Optional	Major carbon pool affected by Project activity. May be conservatively omitted from field measurements and monitoring to prevent double counting. Included when biogeochemical modeling is used to estimate GHG dynamics in the project and baseline scenario	Biogeochemical models calibrated and validated for project or baseline conditions, Digital photography and leaf area index (LAI), remote sensing, allometric and destructive methods and digital photography, peer-reviewed literature values.
Below ground biomass	Optional	Major Project carbon pool affected by project activity. May be conservatively omitted from field monitoring. Included when biogeochemical modeling is used to estimated GHG dynamics in the project and baseline scenarios	Biogeochemical model calibrated and validated for project or baseline conditions, field measurement, literature values.
Litter	Optional	Result of decaying wetland vegetation and contributes to soil organic carbon. May be conservatively omitted from field monitoring. Included when biogeochemical modeling is used to estimate GHG dynamics in the project and baseline scenario	Biogeochemical model calibrated and validated for project or baseline Conditions, litter bags, literature values.
Crop residue	Optional	Plant biomass (including rice) incorporated into the soil organic matter pool. May be conservatively omitted from field monitoring. Included when biogeochemical modeling is used to estimate GHG dynamics in the project and baseline scenario	Biogeochemical model calibrated and validated for project or baseline conditions, field measurements.
Soil organic matter	Included	Major baseline and project carbon pool. Soil organic carbon stock will likely increase due to the implementation of project activity Included when biogeochemical modeling is used to estimate GHG dynamics in the project and baseline scenario	Monitored using methods described in methods module (MM-W/RC). A biogeochemical model calibrated and validated for Project or Baseline conditions can be used (MODEL-W/R)
Harvested biomass	Included for Baseline	Key component of carbon balance for agricultural baseline and rice	Modeling or measurement of harvested product and estimation of carbon content as described in the methods module (MM-W/R)

Table 5. Greenhouse gas emissions to be considered within the project boundary

	Source	Gas	Status	Justification/Explanation	Quantification Method
Baseline	The production of methane by bacteria	CH_4	Optional	May be conservatively excluded	Field measurement as described in the methods module (MM-W/R) module and/or biogeochemical model calibrated and validated for Baseline Conditions (MODEL-W/R).
	Nitrogen transformations due to fertilizer application or organic soil oxidation	N_2O	Optional	May be conservatively excluded	Field measurement as described in the methods module (MM-W/R) module and/or biogeochemical model calibrated and validated for Baseline Conditions (MODEL-W/R).
	Oxidation of organic soils	CO_2	Included	Primary baseline emission	Field measurement as described in the methods module (MM-W/R) and/or biogeochemical model calibrated and validated for Baseline Conditions (MODEL-W/R).
	Emissions from Fossil Fuel Combustion	CO_2	Included	Primary fossil fuel emission	Calculations described in emissions module(E-FFC)
		N_2O	Excluded	Conservatively excluded	
		CH_4	Excluded	Conservatively excluded	
Project	The production of methane by bacteria	CH_4	Included	Primary project emission for all project scenarios. May be conservatively excluded in saline tidal marshes under conditions specified in the tidal wetland module (PS-TW).	Field measurement as described in the methods module (MM-W/R) module and/or biogeochemical model calibrated and validated for Project Conditions (MODEL-W/R).
	Nitrogen transformations due to fertilizer application or organic soil oxidation	N_2O	Optional	Must be included for rice cultivation	Field measurement as described in the methods module (MM-W/R) module and/or biogeochemical model calibrated and validated for Project Conditions ((MODEL-W/R).
	Oxidation of organic soils	CO_2	Included	Must be included for rice cultivation	Field measurement as described in the methods module (MM-W/R) module and/or biogeochemical model calibrated and validated for Project Conditions ((MODEL-W/R).).
	Emissions from fossil fuel combustion	CO_2	Optional	May be excluded if justified.	Calculations described in emissions module (E-FFC).
		N_2O	Excluded	Conservatively excluded	
		CH_4	Excluded	Conservatively excluded	

d. Leakage

Leakage is an increase in in GHG emissions outside the project boundaries that occurs because of the project action. The American Carbon Registry (ACR) requires Project Proponents to assess, account for, and mitigate for leakage above de-minimis levels. Project Proponents must deduct leakage that reduces the GWP benefit of a project in excess the applicable threshold specified in the methodology (3%). Activity-shifting leakage occurs when the land uses resulting in baseline emissions that operated in the project area before the project start date are relocated to another area outside of the project boundary.

This market-effects leakage is transmitted through market forces; a supply reduction can result in an upward pressure on price that may incentivize increased production and shifts in cropping patterns elsewhere. The change in the GWP as the result of these market-effects leakage shall be accounted for in the net project GHG removals. For the activities included in this methodology, the only market-effects leakage would result from replacement of crops currently grown in the Delta by wetlands and rice. All other project scenarios need no further leakage analysis and may use a leakage value of zero.

As part of this methodology development, a leakage analysis was conducted for replacement of traditional crops in the Delta with wetlands and rice. First an economic analysis was conducted to determine how crop acreages statewide would be affected by Delta land conversion. Next, the estimated the change in GWP was estimated as the result of this crop-area change. The report describing the results is included as a supplementary document.

A peer-reviewed, statewide agricultural economic model that simulates market-driven changes for over 6 million acres of California agriculture, was used to estimate crop acreage changes for the following alternatives in which land-use changes were simulated to occur by 2030; conversion of traditional field crops and pasture to wetlands or rice. Where a policy removed land from production and allocated it to wetlands, this acreage was not modeled specifically as a crop in the model but modeled as fallow land. Field crops and pasture predominate in areas where there are oxidizing organic soils that contribute to baseline carbon dioxide emissions.

1. No Action Alternative (NAA)
2. Remove 35,000 acres of field crops from the Delta and leave the land fallow
3. Remove 35,000 acres of field crops from the Delta and convert those acres to rice
4. Remove 10,000 acres of irrigated pasture from the Delta and leave the land fallow
5. Remove 10,000 acres of irrigated pasture from the Delta and convert those acres to rice

To estimate GWP changes, the results of statewide GHG modeling and field experiments for over 40 crops were used. The GWP changes were aggregated into the 7 groups used in the economic model analysis and the GWP was estimated on a per acre basis. We used the estimated GWP in tons of CO_2 equivalents per acre per year multiplied times the non-Delta acreage changes for the crop groups to estimate the potential GWP leakage for each scenario. In all alternatives except for alternative 4, the range of GWP changes by incorporating uncertainty was 3% or less relative to baseline emissions. For alternative 4, the range of GWP was 4% or less relative to baseline emissions. Therefore, for managed wetlands and rice projects implemented on agricultural lands that include less than 35,000 acres of crop land or 10,000 acres of pasture, no leakage deduction is required. Additional leakage analysis is required if wetlands and rice acreage in the Sacramento-San Joaquin Delta exceeds these acreages.

In addition to considering leakage, the Project Proponent must insure and verify that the project activity will not result in a reduction of wetland restoration activities or increase wetland loss outside of the project boundary.

Step 3. Legal requirement test and performance standard evaluation

Offset projects must meet relevant regulations, in addition to the requirements in this methodology. Eligible offsets must be generated by projects that yield surplus GHG reductions that exceed any GHG reductions otherwise required by law or regulation or any GHG reduction that would otherwise occur in a conservative business-as-usual scenario. These requirements are assessed through the Legal Requirement Test and the Performance Standard Evaluation.

Legal Requirement Test

Emission reductions achieved by a Rice Cultivation or Wetland project must exceed those required by any law, regulation, or legally binding mandate as required in the state of California. The following legal requirements apply to all Rice Cultivation and Wetland projects:

(A) The activities that result in GHG reductions and GHG removal enhancements are not required by law, regulation, or any legally binding mandate applicable in the offset project's jurisdiction, and would not otherwise occur in a conservative common practice business-as-usual scenario

(B) If any law, regulation, or legally binding mandate requiring the implementation of project activities at the field(s) in which the project is located exists, only GHG emission reductions resulting from the project activities that are in excess of what is required to comply with those laws, regulations, and/or legally binding mandates are eligible for crediting under this protocol

Performance Standard Evaluation

Emission reductions achieved by a Rice Cultivation or Wetland project must exceed those likely to occur in a conservative business-as-usual scenario and are subject to the following practice-based performance standard for wetlands and rice cultivation.

Practice-based Performance Standards

a. Managed Non-Tidal Permanently Flooded Wetlands on Subsiding Lands Where Organic and Highly Organic Mineral Soils are Present in the Sacramento-San Joaquin Delta

Managed, permanently flooded, non-tidal wetlands on lands which were formally in agriculture currently represent less than 2 percent of the approximately 200,000 acres where organic and highly organic mineral soils are present and subsiding to various degrees in the Sacramento-San Joaquin Delta[57]. Costs for conversion of agricultural land to managed non-tidal wetlands range from $600[58] to over $6,000[59] per acre. Because wetland restoration is not a common practice among Delta landowners, Managed Non-Tidal Wetland projects using this methodology are deemed "beyond business as usual" and therefore additional. Thus, a Managed Non-Tidal Wetland Project that occurs on agricultural land

[57]Steven J. Deverel, Christina E. Lucero, Sandra Bachand, 2014, Evolution of reduced arability on organic and highly organic mineral soils, Sacramento-San Joaquin Delta, California, in review, San Francisco Estuary and Watershed Science
[58]A. Merrill, S. Siegel, B. Morris, A. Ferguson, G. Young, C. Ingram, P. Bachand, Holly Shepley, Maia Singer, Noah Hume. 2010. Greenhouse Gas Reduction and Environmental Benefits in the Sacramento-San Joaquin Delta: Advancing Carbon Capture Wetland Farms and Exploring Potential for Low Carbon Agriculture. Prepared for The Nature Conservancy, Sacramento, California. Available at: (http://www.stillwatersci.com/)
[59]Brock, Bryan, Engineer, California Department of Water Resources, Personal Communication, June, 2011

where there are organic or highly organic mineral soils satisfies the Practice-Based Performance Standard.

b. Rice Cultivation on Subsiding Organic Soils and Highly Organic Mineral Soils in the Sacramento-San Joaquin Delta

Rice currently represents less than 3 percent of the approximately 200,000 acres where organic and highly organic mineral soils are present and subsiding to various degrees in the Sacramento-San Joaquin Delta. Costs for conversion of agricultural land farmed to traditional crops such as corn to rice range from $116[60] to over $1,000[61] per acre. Because Rice Cultivation is not common practice by Delta landowners, projects using this methodology are deemed “beyond business as usual” and therefore additional. Therefore, a Rice Cultivation Project that occurs on agricultural land where there are organic or highly organic mineral soils satisfies the Practice-Based Performance Standard.

c. Tidal wetlands in San Francisco Estuary

San Francisco Bay has lost an estimated 90 percent of its historic wetlands to fill or alteration[62]. Tidal wetlands currently represent about 16% of the approximately 208,000 acre area of historic wetlands in the San Francisco Estuary.[63] Because tidal wetlands restoration is not common practice, projects using this methodology are deemed “beyond business as usual” and therefore additional. Therefore, a Tidal Wetlands Project that occurs in the San Francisco Estuary in areas of former historic wetlands satisfies the Practice-Based Performance Standard.

Step 4. Monitoring Plan Development

Project Proponents shall include a single monitoring plan in the GHG Project Plan. For monitoring changes in wetland cover and carbon stock changes, the monitoring plan shall use the methods given in the model and methods modules (MM-W/R, MODEL-W/RC) and project modules (PS-MW, PS-RC, and PS-TW). All relevant parameters from the modules shall be included in the monitoring plan. Monitoring shall occur for the life of the project.

The monitoring plan shall include the following:

1. Definition and revision of the baseline[64] (as needed);
2. Monitoring of actual carbon stock changes and GHG emissions;
3. Estimation of *ex-post* net carbon stock changes and greenhouse gas emissions.

For each of these tasks, the monitoring plan shall include the following sections:

a. Technical description of the monitoring task
b. Data to be collected. The list of data and parameters to be collected shall be given in the GHG Project Plan

[60] Canivari, M., Klonski, K. M. And DeMoura, R.L., 2007, Sample costs to produce rice in 2007 for the Delta Region for continuous rice culture.
[61] Brock, Bryan, Engineer, California Department of Water Resources, Personal Communication, June, 2011
[62] Rubissov Okamoto, Ariel and Wong, Kathleen M., 2011, University of California Press, Berkeley, CA.
[63] Bayland Goals Technical Update, Chapter 7 – Carbon Accounting and GHG Flux
[64] Baselines are only revised at the end of the crediting period

c. Description of data collection and/or sampling procedures
d. Use of biogeochemical models for estimating emissions and carbon stock changes if used
e. Quality control and quality assurance procedures
f. Data archiving.
g. Organization and responsibilities of the parties involved in all the above

Step 5. Estimation of baseline carbon stock changes and greenhouse gas emissions

Per the ACR Standard, the GHG project baseline is a forecast of the likely stream of emissions or removals to occur if the Project Proponent does not implement the project, i.e., the "business as usual" case. There are various potential approaches to baseline determination, including existing actual or historical emissions or emissions of activities undertaken in a recent period in similar social, economic, environmental and technological circumstances. For example, the agricultural baseline emissions could be measured at the project site using methods described in the methods module (MM-W/R) or estimated using biogeochemical models. Alternatively, emissions could be measured for a reference site with similar agricultural practices, hydrologic conditions and soils. Forecasted emissions can be accomplished using biogeochemical models calibrated for the Delta.[65]

The following modules contain methods for estimating baseline carbon stock changes and greenhouse gas emissions for projects where wetlands and rice cultivation are planned are provided in (see Figure 4):

- Agriculture (BL-Ag)
- Seasonal wetlands (BL-SW)
- Open water or seasonally inundated (BL-OW)

A description of and justification for the identified baseline scenario and the results of the estimations shall be given in the GHG Project Plan.

Step 6. Estimation of project carbon stock changes and greenhouse gas emissions

Methods for estimation of project carbon stock changes and greenhouse described are described in the methods module (MM-W/R). They can also be estimated using biogeochemical models. Alternatively, emissions could be measured for a site with similar water- and land-management practices, hydrologic conditions and soils.

The following modules contain guidance for estimating project carbon stock changes and greenhouse gas emissions for projects where wetlands and rice cultivation are planned are provided in (see Figure 4):

- Managed wetlands (PS-MW)
- Tidal wetlands (PS-TW)
- Rice cultivation (PS- RC)

[65] E,g, Deverel and Leighton (2010) see footnote 10

Step 7. Estimation of total net greenhouse gas emissions reductions (project minus baseline and leakage)

The total net greenhouse gas project reductions are calculated as follows:

$$\Delta C_{ACR,t} = (\Delta C_{actual} - \Delta C_{BSL}) * (1-LK) \qquad (1)$$

where:

ΔC_{ACR} is the total net greenhouse gas emission reductions at time *t*; metric tons CO_2-e

ΔC_{actual} is the cumulative total carbon stock changes and greenhouse gas emissions under the project scenario since the last reporting period ; metric tons CO_2-e (from the selected project module)

ΔC_{BSL} is the cumulative total of the carbon stock changes and greenhouse gas emissions under the baseline scenario up to time t; metric tons CO_2-e (from the selected individual baseline, or the sum of selected baselines if the project includes more than one baseline).

LK is the cumulative total of the carbon stock changes and greenhouse gas emissions due to leakage up to time t; metric tons CO_2-e.

Note that based on the leakage analysis discussed above, no leakage deduction is required for projects included in this methodology.

Use of Models

Models can be useful tools for estimating GHG dynamics in the baseline and project scenarios. Process-based biogeochemical models may be used to estimate changes in various carbon pools and GHG sources in this methodology. Project proponents must validate and calibrate models for the soils, hydrologic and biogeochemical conditions in the proposed project area. Models must:

- Be documented in the peer-reviewed literature;
- Be validated in the Project Area or similar sites using peer-reviewed or other quality controlled data (i.e. collected as part of a Government soils inventory or experiment) data for baseline and project conditions;
- Be parameterized using peer-reviewed or other quality-controlled data appropriate to each identified strata;
- Be able to effectively simulate GHG emissions and removals and carbon stock changes for baseline and project conditions;
- Models that include litter, above and below ground biomass and soil organic matter pools must demonstrate that there is no double counting of carbon pools and include consideration of conservativeness and significance testing;
- Use of models shall be conservative in estimating GHG emission reductions.

Step 8. Calculation of uncertainty

Project proponents shall use X-UNC to integrate uncertainty information, calculate overall project uncertainty and estimate the uncertainty for total net GHG emissions reductions for every reporting period. If calculated total project uncertainty (UNC) exceeds 10% at the 90% confidence level, then $C_{ACR,t}$ (equation 1) shall be adjusted as follows:

$$Adjusted\ C_{ACR,t} = C_{ACR,t} * (100\% - UNC + 10\%) \quad (2)$$

where:

Adjusted C_{ACR} *is the* Cumulative total net GHG emission reductions at time *t* adjusted to account for uncertainty in metric tons CO_2-e

$C_{ACR,t}$ *is the* Cumulative total net GHG emission reductions at time *t* as metric tons of CO_2-e

UNC is the total project uncertainty (project and baseline) as derived in X-UNC in %

If the calculated total project uncertainty (UNC) in module X-UNC is less than or equal to 10%, then no adjustment shall be made for uncertainty.

Step 9. Risk Assessment

Wetland and rice projects in the San Joaquin Delta and San Francisco Estuary have the potential for termination or GHG reductions and removals to be reversed or when a project is subject to flooding, damage from wildlife, erosion; or intentional reversals or termination, such as landowners choosing to discontinue project activities before the project minimum term has ended. Wetland offsets are inherently at some risk of reversal or termination. This risk shall be assessed and mitigated, and the offset reductions thus made fungible with other offsets and allowances. Project Proponents shall commit to a minimum project term of 40 years, and assess and mitigate reversal and termination risk.

To assess the risk of reversal or termination, the Project Proponents shall conduct a risk assessment addressing internal, external and natural risks using guidance provided in the most recently ACR approved risk assessment tool. Internal risk factors include project management, financial viability, opportunity costs and project longevity. External risk factors include factors related to land tenure, community engagement and political forces. The primary natural termination risk to wetlands and rice projects in the in the San Joaquin Delta and San Francisco Estuary is flooding due to sea level rise and/or levee failure. Levee failure and flooding in managed non-tidal wetlands and rice on subsided islands in the Sacramento-San Joaquin Delta will result in termination GHG removals if the island is not reclaimed. The Delta Risk Management Strategy Project calculated the risk of levee failure throughout Delta and Suisun Marsh[66] for baseline conditions. However, risk of levee failure will be reduced by implementation of constructed non-tidal wetlands on subsided Delta islands.[67]

[66] http://www.water.ca.gov/floodsafe/fessro/levees/drms/docs/drms_execsum_ph1_final_low.pdf

[67] Deverel, Steven J.; Ingrum, Timothy; Lucero, Christina; & Drexler, Judith Z.(2014). Impounded Marshes on Subsided Islands: Simulated Vertical Accretion, Processes, and Effects, Sacramento-San Joaquin Delta, CA USA. San Francisco Estuary and Watershed Science, 12(2). jmie_sfews_12893. http://escholarship.org/uc/item/0qm0w92c

The output of ACR approved risk assessment tool is a total risk rating for the project which equals the percentage of offsets that must be deposited in the ACR buffer pool to mitigate the risk of reversal or termination (unless another ACR approved risk mitigation mechanism is used in lieu of buffer contribution). The Project Proponents shall conduct this risk assessment and propose a corresponding buffer contribution (if applicable). The risk assessment, overall risk rating, and proposed mitigation or buffer contribution shall be included in the GHG Project Plan.

Mitigation of Risk via the ACR Buffer Pool

For Project Proponents choosing the ACR buffer pool, the Project Proponents shall contribute either a portion of the project offsets, or an equal number of ERTs of another type and vintage, to a buffer account held by ACR in order to replace unforeseen losses of carbon stocks. The number of ERTs contributed to the buffer pool shall be determined through the Risk Assessment. Buffer contributions are made with each new issuance of ERTs to a project.

In lieu of making a buffer contribution of ERTs from either the project or purchased from another acceptable source, Project Proponents may use an alternate ACR-approved risk mitigation mechanism, or propose an insurance product or other risk mitigation mechanism to ACR for approval.

Step 10. Calculation of Emission Reduction Tons (ERTs)

$$ERTt = (C_{ACR,t2} - C_{ACR,t1}) * (1 - BUF) \quad (3)$$

where:

ERTt is the Number of Emission Reduction Tons during the reporting period in metric tons CO_2-e

$C_{ACR,t2}$ is the cumulative total net GHG emission reductions up to time t2, adjusted for uncertainty if applicable per equation (2) in metric tons CO_2-e;

$C_{ACR,t1}$ is the cumulative total net GHG emission reductions up to time t1 adjusted for uncertainty if applicable per equation (2) in metric tons CO_2-e ;

BUF Fraction of project ERTs contributed to a buffer pool, if applicable.

Per the *Forest Carbon Project Standard, BUF* is determined using an ACR-approved risk assessment tool. If the Project Proponent elects to make the buffer contribution in non-project ERTs, or elects to mitigate the assessed reversal risk using an alternate risk mitigation mechanism approved by ACR, *BUF* shall be set to zero.

PARAMETERS ORIGINATING IN OTHER MODULES

Data /parameter:	$\Delta C_{bsl,ag\ W/RC}$
Data unit:	t CO_2-e
Used in equations:	1
Description:	Cumulative total of the carbon stock changes and greenhouse gas emissions for the baseline scenario where there are agricultural activities in place immediately prior to the project commencement date.
Module parameter originates in:	BL-AG
Any comment:	

Data /parameter:	$\Delta C_{bsl,SW\ W/RC}$
Data unit:	t CO_2-e
Used in equations:	1
Description:	Cumulative total of the carbon stock changes and greenhouse gas emissions for the baseline scenario where baseline activities primarily include seasonal wetlands.
Module parameter originates in:	BL-SW
Any comment:	

Data /parameter:	$\Delta C_{bsl,OW\ W/RC}$
Data unit:	t CO_2-e
Used in equations:	1
Description:	Cumulative total of the carbon stock changes and greenhouse gas emissions for the baseline scenario where there is open water or seasonal inundation of non-vegetated areas such as former salt ponds in San Francisco Bay.
Module parameter originates in:	BL-OW
Any comment:	

Data /parameter:	$\Delta C_{ACTUAL-MW}$
Data unit:	t CO_2-e
Used in equations:	1
Description:	Cumulative total of carbon stock changes and greenhouse gas emissions for the project scenario where the project activity can include hydrologic management, infrastructure modification, and plantings or natural plant recruitment
Module parameter originates in:	PS-MW
Any comment:	

Data /parameter:	$\Delta C_{ACTUAL-TW}$
Data unit:	t CO_2-e
Used in equations:	1
Description:	Cumulative total of carbon stock changes and greenhouse gas emissions for the project scenario when the project activity can include levee breaching to create tidal influence, plantings, fill and salt flushing.
Module parameter originates in:	PS-TW
Any comment:	

Data /parameter:	$\Delta C_{ACTUAL-RC}$
Data unit:	t CO_2-e
Used in equations:	1
Description:	Cumulative total of carbon stock changes and greenhouse gas emissions for the project scenario when the project activity can include hydrologic management, infrastructural modification, and rice cultivation.
Module parameter originates in:	PS-RC
Any comment:	

Baseline modules

Wetland Restoration and Rice Methodological Module - Estimation of agricultural baseline greenhouse gas emissions and carbon stock changes (BL-Ag)

I. SCOPE, BACKGROUND, APPLICABILITY AND PARAMETERS

Scope

This module provides guidance for estimating carbon stock changes and GHG emissions for agricultural lands in the baseline case where the project activity will include hydrologic management and infrastructural modification for wetland construction or rice cultivation.

Applicability

The module is applicable for estimating baseline GHG emissions and carbon-stock changes for project areas planned for wetland construction and/or rice cultivation in the area where there are organic or highly organic mineral soils in the Sacramento-San Joaquin Delta (see Figure 1 in Deverel and Leighton[68]). Project activities will occur due to some combination of hydrologic management changes and infrastructural modification with assisted natural regeneration, and seeding. Infrastructural modification includes drainage modification and earth moving. Agricultural lands include those where crops are grown and/or animals are grazed. Agricultural land that is temporally fallow for a maximum of 2 years is also included. The project area must have been used as agricultural land within a 10-year period prior to the project start date.

Project activities shall meet the applicability conditions in the methodology framework listed under wetland construction and rice cultivation. All wetland construction and rice cultivation activities involving hydrologic management shall occur in compliance with applicable local, state and federal environmental regulations. The Project Proponents shall provide attestations and/or evidence (e.g. permits or permit applications) of environmental compliance to the American Carbon Registry (ACR) at the time of GHG Project Plan submission, and to the validation/verification body at the time of validation, and at each verification. Any changes to the project's regulatory compliance status shall be reported to ACR.

Parameter

This module provides procedures to determine the following parameter:

Parameter	SI Units	Description
$\Delta C_{BSL\ Ag\ W/RC}$	Metric tons CO_2-e	Cumulative total carbon stock changes and greenhouse gas emissions for the baseline agricultural scenario when the project activity will include managed wetlands or rice

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

II. PROCEDURE

This module proceeds in five steps:

- Step 1: Identification of baseline scenario and performance standard evaluation
- Step 2: Establishment and documentation of the project boundary
- Step 3: Baseline stratification
- Step 4: Baseline GHG emissions and carbon stock changes
- Step 5: Monitoring requirements for baseline renewal

Step 1. Identification of the baseline scenario and performance standard evaluation

Project Proponents must identify the most plausible and credible baseline scenario describing what would have occurred in absence of the Project Activities. Under this module, the baseline scenario must be limited to agricultural land uses. The geographical coordinates of the boundaries of each project area must be unambiguously defined and provided to the Validation/Verification Body (VVB) in shapefile format.

Performance Standard Evaluation

Emission reductions and carbon stock changes achieved by a rice cultivation or wetland project must exceed those likely to occur in a conservative business-as-usual scenario and are subject to a practice-based performance standard. Practice base performance standard requirements are detailed in the Wetland-Rice Methodology Framework Module (WR-MF).

Step 2. Project GHG boundary

The project GHG boundary describes the carbon pools and emissions sources that will be included or excluded from GHG accounting as defined in the WR-MF. It shall be demonstrated that each discrete parcel of land to be included in the project boundary is eligible as an ACR project activity. For the baseline case, the primary carbon pools include the soil organic carbon pool and emissions due to oxidation of soil organic matter and fertilizer use. Further, the project proponent must account for GHG emissions and removals that affect the determination of net baseline GHG emissions.

Hydrologic and agricultural management activities and infrastructural modification will result in GHG emissions due to fossil fuel use that must be accounted for. The Project Proponents using emission values from the literature or non-site data must make conservative estimates to determine the baseline and proposed project GHG emissions based on the uncertainty module (X-UNC) guidelines. Exclusion of carbon pools and emission sources is allowed subject to considerations of conservativeness and significance testing. This may be accomplished by using peer-reviewed literature, reference sample plots or field monitoring of similar sites, approved local or national parameters, the most recent default emission factors provided by IPCC, government reports and models. Pools or sources may be excluded if exclusion will tend to underestimate net project GHG emission reductions/removal enhancements relative to the baseline.

Pools or sources can be excluded (i.e., counted as zero) if application of the tool T-SIG (http://unfccc.int/home/items/2783.php) indicates that the source is insignificant, i.e. the source represents less than 3% of the *ex-ante* calculation of Project GHG emission reductions/removal enhancements. If monitoring of baseline and project emissions determines that an emission source(s) initially included in the GHG assessment boundary is insignificant using the tool T-SIG, monitoring may cease.

Step 3. Baseline stratification

Stratification is a standard procedure to decrease overall variability of carbon stock estimates by grouping data taken from environments with similar characteristics. When estimating baseline emissions, several strata can be assessed. If the project activity area is not homogeneous, stratification shall be implemented to improve the accuracy and precision of carbon stock estimates. Different stratifications may be required for the baseline and project scenarios, especially if there will be a change in hydrology, in order to achieve optimal accuracy and precision of the estimates of net GHG benefit. For estimation of baseline net GHG removals or emissions, or estimation of project net GHG benefit, strata should be defined based on parameters that affect GHG removals or emissions and/or are factors the influence measurement of changes in biomass stocks. These may include but are not limited to factors and practices shown in Table 6.

Table 6. Factors and practices that can be used for stratification and their effects on GHG emissions and removals.

Stratification Factor or Practice	Description	Potential GHG Effect
Wetland management practices	Depth of water	Depth of water affects GHG removal and emissions and vegetation
Wetland management practices	Flow through or limited or zero outflow	May affect CH_4 emissions
Wetland vegetation	Variation in species	May affect GHG removals
Wetland vegetation	Planted seedlings, seeded, colonization or natural recruitment	Affects time required for vegetative cover, CH_4 emissions and GHG removal.
Wetland vegetation	Open water areas	Minimal GHG removal, CH_4 emissions
Wetland spatial variability	Location relative water circulation	May affect GHG removals and GHG emissions
Wetland age		May affect GHG removal rates
Soil chemical composition – soil organic matter content	For baseline conditions	Soil organic matter is key determinant of baseline GHG emissions on organic soils
Soil hydrology	Depth to groundwater, oxidation-reduction conditions	Depth to groundwater is an important determinant of baseline GHG emissions on organic soils
Agricultural land use	Crop type	Affects baseline GHG emissions and removals

It will usually be sufficient to stratify according to soil organic matter content, agricultural land use (i.e., field crops, hay and grain crops, pasture, etc.), fertilizer use, soil chemical and physical properties (e.g., redox conditions, temperature) and average depth to groundwater as these are the primary factors that affect GHG emissions for baseline conditions.

The stratification for *ex-ante* estimations shall be based on the content of the project monitoring plan. The stratification for *ex-post* estimations shall be based on the actual implementation of the project monitoring plan. If natural or anthropogenic impacts (e.g., levee breaks and flooding) or other factors (e.g., altered hydrology or water management) add variability in the vegetation of the project area, then the stratification shall be revised accordingly. Project Proponents may use remotely sensed data acquired close to the time of project commencement and/or the occurrence of natural or anthropogenic impacts for *ex-ante* and *ex-post* stratification.

Step 4. Baseline Carbon Stock Changes and Emissions

The baseline scenario consists of the most likely emissions and removals in the absence of project implementation for the projected life of the project (Table 7). The baseline net GHG emissions shall be estimated using methodology described in this section and the methods module (MM-W/R) or using biogeochemical models. For *ex-ante* calculation of baseline net GHG emissions, the Project Proponents shall provide estimates of the site-specific values for the appropriate parameters used in the calculations and/or model estimates. Peer-reviewed biogeochemical models can be used as per the model module. Project Proponents shall retain a conservative approach in making these *ex-ante* estimates.

Table 7. Baseline emissions sources included in the project boundary. Nitrous oxide and methane are considered optional (see Framework Module, WR-MF)

Source	Gas
Soil emissions due to fertilizer application	N2O
Soil emissions due oxidation of organic soils	N2O, CO2, CH4
Emissions resulting from Fossil Fuel Combustion	, CO2,

The cumulative total carbon stock change for the baseline agricultural scenario when the project activity will include managed wetlands or rice;

$$\Delta C_{BSL\ Ag\ W/RC} = \Delta GHG_{BSL\ Ag\ W/RC} + T_{pp} * E_{FFC} \qquad (4)$$

Where:

$\Delta GHG_{BSL\ Ag\ W/RC}$ is the cumulative net emissions due to oxidation of organic soils as shown in the Methods Module (MM-W/R) and determined using eddy covariance, subsidence measurements or biogeochemical models in metric tons CO2-e ;

T_{pp} is the period of time which corresponds to the reporting period in years and;

E_{FFC} is the annual emissions of fossil fuels in in metric tons CO2-e.

It is assumed that the soil carbon pool is decreasing via oxidation, and emissions and carbon stock changes are accounted for by $\Delta GHG_{BSL\ Ag\ W/RC\ L}$ in the above equation. For calculation of fossil fuel combustion see the module "estimation of emissions from fossil fuel combustion" (E-FFC).

The net baseline GHG emissions due to organic soil oxidation from the project area shall be estimated from direct measurement of gaseous fluxes using the eddy covariance technique, subsidence measurements, by modeling or equivalent method or determined based on an acceptable proxy, data from peer-reviewed literature or approved parameters or a combination of gaseous flux and subsidence measurements.

Step 5. Monitoring requirements for baseline renewal

A Crediting Period for all projects using this methodology is 40 years, during which the baseline scenario is fixed. In order to renew the crediting period the Project Proponents must:

- Re-submit the GHG Project Plan in compliance with then-current GHG Program standards and criteria;
- Re-evaluate the project baseline;
- Demonstrate additionality against then-current regulations and performance standards;
- Use GHG program-approved baseline methods, emission factors, tools, models and methodologies in effect at the time of Crediting Period renewal;
- Undergo validation by an approved validation/verification body.

PARAMETERS ORIGINATING IN OTHER MODULES

Data /parameter:	$\Delta GHG_{BSL\ Ag\ W/RC}$
Data unit:	t CO_2-e
Used in equations:	4
Description:	Cumulative total of the change in carbon emissions of the baseline scenario
Module parameter originates in:	M-M-W/RC
Any comment:	

Data /parameter:	$\Delta C_{BSL\ Ag\ W/RC}$
Data unit:	t CO_2-e
Used in equations:	4
Description:	Cumulative total of the carbon stock changes of soils for the baseline scenario
Module parameter originates in:	M-M-W/RC
Any comment:	

Data /parameter:	ΔGHG_{FFC}
Data unit:	t CO_2-e
Used in equations:	4
Description:	Cumulative total of GHG emissions as a result of fossil fuel combustion in the baseline scenario
Module parameter originates in:	E-FFC
Any comment:	Only included if significant

Wetland Restoration and Rice Methodological Module - Estimation of baseline greenhouse gas emissions and carbon stock changes for seasonal wetlands (BL-SW)

I. SCOPE, BACKGROUND, APPLICABILITY AND PARAMETERS

Scope

This module allows for estimating carbon stock changes and GHG emissions for seasonal wetlands used for waterfowl hunting or non-managed seasonal wetlands in the baseline case where the project activity will include hydrologic management and infrastructural modification for managed and permanently flooded wetland construction and rice cultivation.

Applicability

The module is applicable for estimating baseline GHG emissions and carbon stock changes for project areas planned for wetland construction or rice cultivation. These land use changes will occur due to some combination of hydrologic management changes and infrastructural modification with assisted natural regeneration, and seeding. Infrastructural modification includes drainage modification and earth moving. The following conditions must be met to apply this module.

Project activities shall meet the applicability conditions in the methodology framework (WR-MF) listed under wetland restoration and construction and rice cultivation (section E. Applicability Conditions in WR-MF). All wetland restoration, construction and rice cultivation activities involving changes in hydrologic management and modification shall occur in compliance with all applicable local, state and federal environmental regulations.

This module is always mandatory when the project activity will include hydrologic management and infrastructural modification for wetland construction and restoration and rice cultivation on lands where there are seasonal wetlands and organic soils or highly organic mineral soils[69]. Seasonal wetlands include areas in the Delta and San Francisco Estuary that may be used for attracting and breeding waterfowl for hunting such as duck clubs (Table 8).

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[69] As mapped in the Delta by Deverel, Steven J; & Leighton, David A. (2010). Historic, Recent, and Future Subsidence, Sacramento-San Joaquin Delta, California, USA. San Francisco Estuary and Watershed Science, 8(2). jmie_sfews_11016. http://escholarship.org/uc/item/7xd4x0xw
In Suisun Marsh and San Francisco Estuary, the Delta Risk Management Project documents provide a map of soil organic matter in Suisun Marsh
http://www.water.ca.gov/floodsafe/fessro/levees/drms/docs/Subsidence_TM.pdf

Table 8. Examples of eligible seasonal wetlands

Seasonal Wetland Type	Examples	Comments
Managed seasonal wetlands or organic soils	Suisun Marsh seasonal wetlands used for attracting and breeding waterfowl for hunting. There are also seasonal wetlands used for hunting in the Delta.	Most of the land within Suisun Marsh (85%) consists of diked wetlands which are flooded most of the year and are drained from mid-July through mid- September[70].
Unmanaged seasonal wetlands on organic soils in the Delta	Many areas of the central Delta where elevations are less than -2 m have become too wet to farm and are now seasonal wetlands.[71]	These areas likely continue to subside and emit carbon dioxide although there are no measurements.

Parameters

This module provides procedures to determine the following parameter:

Parameter	SI Unit	Description
$\Delta C_{BSL\_SW\ W/RC}$	t CO_2-e	Cumulative total carbon stock changes and greenhouse gas emissions for the seasonal wetlands baseline scenario

II. PROCEDURE

This module proceeds in five steps:

- Step 1: Identification of baseline scenario and performance standard evaluation.
- Step 2: Establishment and documentation of the project boundary
- Step 3: Baseline stratification
- Step 4: Baseline GHG emissions and carbon stock changes
- Step 5: Monitoring requirements for baseline renewal

Step 1. Identification of the baseline scenario and performance standard evaluation.

Project Proponents must identify the most plausible and credible baseline scenario describing that would have occurred in absence of the Project Activities. Under this module, the baseline scenario must be limited to seasonal wetlands. The geographical coordinates of the boundaries of each project area must be unambiguously defined and provided to the Validation/Verification Body (VVB) in shapefile format.

[70] Steven Chappell, November 2006, Suisun Marsh Resource Conservation District, personal communication
Rubissow Okamoto, Ariel, Wong, Kathleen, 2011, Natural History of San Francisco Bay, University of California Press
Map on p. 189 shows the large area of managed habitat in Suisun Marsh.

[71] Deverel, Steven J., Lucero, Christina, Bachand, Sandra, 2015, Evolution of arability and land use, Sacramento-San Joaquin Delta, California, submitted to San Francisco and Estuary Science

Performance Standard Evaluation

Emission reductions achieved by rice cultivation or wetland management must exceed those likely to occur in a conservative business-as-usual scenario and are subject to a practice-based performance standard. Practice base performance standard requirements are detailed in the Wetland-Rice Methodology Framework Module (WR-MF, section II, Step 3).

Step 2. Establishment and documentation of the project boundary

The project GHG boundary describes the carbon pools that will be included or excluded from GHG accounting as defined in the WR-MF Step 2). It shall be demonstrated that each discrete parcel of land to be included in the boundary is eligible for wetland or rice project activity. For the baseline case, the GHG boundary includes primarily emissions due to oxidation and loss of soil organic carbon. Hydrologic management and infrastructural modification practices in seasonal wetlands may result in GHG emissions that may need to be accounted for. These include emissions associated with earth moving and vegetation control if determined to be significant. Exclusion of carbon pools and emission sources is allowed subject to considerations of conservativeness and significance testing. Pools or sources can be neglected (i.e., counted as zero) if application of the tool T-SIG indicates that the source is insignificant, i.e. the source represents less than 3% of the *ex-ante* calculation of GHG emission reductions/removal enhancements. If monitoring of baseline and project emissions determines that an emission source(s) initially included in the GHG assessment boundary is insignificant using the tool T-SIG, monitoring may cease.

Step 3. Baseline stratification

Stratification is a standard procedure to decrease overall variability of carbon stock estimates by grouping data taken from environments with similar characteristics. When estimating baseline carbon stocks, several strata can be assessed. If the project activity area is not homogeneous, stratification should be carried out to improve the accuracy and precision of carbon stock estimates. Different stratifications may be required for the baseline and project scenarios, especially if there will be a change in hydrology, in order to achieve optimal accuracy and precision of the estimates of net GHG benefit. For estimation of baseline net GHG removals or emissions, or estimation of project net GHG benefit, strata should be defined based on parameters that affect GHG removals or emissions and/or are factors that influence measurement of changes in biomass stocks. Potential stratification factors are listed in Table 9.

Table 9. Factors and practices that can be used for stratification and their effects on GHG emissions and removals.

Stratification Factor or Practice	Description	Potential GHG Effect
Wetland management practices	Depth of water	Depth of water affects GHG removal and emissions and vegetation
Wetland management practices	Flow through or limited or zero outflow	May affect CH_4 emissions
Wetland vegetation	Variation in species	May affect GHG removals
Wetland vegetation	Planted seedlings, seeded, colonize or natural recruitment	Affects time required for vegetative cover, CH_4 emissions and GHG removal.
Wetland vegetation	Open water areas	Minimal GHG removal, GHG emissions
Wetland spatial variability	Location relative water circulation	May affect GHG removals and GHG emissions
Wetland age		May affect GHG removal rates
Soil chemical composition – soil organic matter content	For baseline conditions	Soil organic matter is key determinant of baseline GHG emissions on organic soils
Soil hydrology	Depth to groundwater, oxidation-reduction conditions	Depth to groundwater is an important determinant of baseline GHG emissions on organic soils

For baseline net GHG emissions, it will usually be sufficient to stratify according to soil organic matter content, vegetation, soil chemical and physical properties (e.g., redox conditions, temperature) and surface-water depth as these are the primary factors that affect GHG emissions.

For actual baseline emissions, the stratification for *ex-ante* estimations shall be based on the project monitoring plan. The stratification for *ex post* estimations shall be based on the actual implementation of the project monitoring plan. If natural or anthropogenic impacts (e.g., levee breaks and flooding) or other factors (e.g. altered hydrology or water management) add variability in the vegetation of the project area, then the stratification shall be revised accordingly. The Project Proponents may use remotely sensed data acquired close to the time of project commencement and/or the occurrence of natural or anthropogenic impacts for *ex-ante* and *ex-post* stratification.

Step 4. Baseline Emissions and Carbon Stock Changes

The baseline scenario consists of the most likely emissions and removals in the absence of project implementation (Table 10). The baseline net GHG emissions shall be estimated using methodology described in this section and the methods module (MM – W/R) or using biogeochemical models. For *ex-ante* calculation of baseline net GHG emissions, the Project Proponents shall provide estimates of the site-specific values for the appropriate parameters used in the calculations and/or model estimates. Biogeochemical models documented in the peer-reviewed literature can be used as per the model module. Project Proponents shall retain a conservative approach in making these *ex-ante* estimates.

Table 10. Baseline emissions sources included in the project boundary. Nitrous oxide and methane are considered optional (see Framework Module)

Source	Gas
Soil emissions due to fertilizer application	N2O
Soil emissions due oxidation of organic soils	N2O, CO2, CH4
Emissions resulting from Fossil Fuel Combustion	CO2,

The cumulative total carbon stock change for the baseline seasonal wetlands scenario when the project activity will include managed wetlands or rice;

$$\Delta C_{BSL\ SW\ W/RC} = \Delta GHG_{BSL\ SW\ W/RC} + T_{pp} * E_{FFC} \qquad (5)$$

Where:

$\Delta GHG_{BSL\ SW\ W/RC}$ is the cumulative net emissions due to oxidation of organic soils as shown in equations 2 and 7 in the Methods Module (MM-W/R) and determined using eddy covariance, subsidence measurements or biogeochemical models (in metric tons CO2-e) ;

T_{pp} is the period of time which corresponds to the reporting period in years and;

E_{FFC} is the annual emissions of fossil fuels in in metric tons CO2-e.

It is assumed that the soil carbon pool is decreasing via oxidation and emissions are accounted for by $\Delta GHG_{BSL\ SW\ W/RC\ L}$ in the above equation. For calculation of fossil fuel combustion see the module "estimation of emissions from fossil fuel combustion" E-FFC.

The net baseline GHG emissions due to organic soil oxidation from the project area shall be estimated from direct measurement of gaseous fluxes using the eddy covariance technique, subsidence measurements, by modeling or equivalent method or determined based on an acceptable proxy, data from peer-reviewed literature or approved parameters or a combination of gaseous flux and subsidence measurements.

Step 5. Monitoring requirements for baseline renewal

A Crediting Period for a project is a predetermined length of time for which the baseline scenario is applicable. This period of time is used for carbon quantification of offsets generated relative to its baseline. In order to renew the Crediting Periods the Project Proponents must:

- Re-submit the GHG Project Plan in compliance with then-current GHG Program standards and criteria
- Re-evaluate the project baseline
- Demonstrate additionality against then-current regulations and performance standard data
- Use GHG program-approved baseline methods, emission factors, tools, and methodologies in effect at the time of Crediting Period renewal
- Undergo validation by an approved validation/verification body

PARAMETERS ORIGINATING IN OTHER MODULES

Data /parameter:	$\Delta GHG_{BSL\ SW\ W/RC}$
Data unit:	t CO_2-e
Used in equations:	5
Description:	Cumulative total of the change in carbon emissions of the baseline scenario
Module parameter originates in:	MM-W/RC
Any comment:	

Data /parameter:	$\Delta C_{BSL\ SW\ W/RC}$
Data unit:	t CO_2-e
Used in equations:	5
Description:	Cumulative total of the carbon stock changes of soils for the baseline scenario
Module parameter originates in:	MM-W/RC
Any comment:	

Data /parameter:	ΔGHG_{FFC}
Data unit:	t CO_2-e
Used in equations:	5
Description:	Cumulative total of GHG emissions as a result of fossil fuel combustion in the baseline scenario
Module parameter originates in:	E-FFC
Any comment:	Only included if significant

Wetland Restoration and Rice Methodological Module - Estimation of baseline greenhouse gas emissions and carbon stock changes for open water (BL OW W)

I. SCOPE, BACKGROUND, APPLICABILITY AND PARAMETERS

Scope

This module provides guidance for estimating carbon stock changes and GHG emissions for open water in the baseline case when the project activity will include hydrologic management and infrastructural modification for tidal wetlands construction and restoration in the San Francisco Estuary. This module also provides guidance for demonstrating that the project area meets the definition of open water and estimating GHG emissions and removals for baseline conditions.

Applicability

The module is applicable for estimating baseline carbon stock changes and GHG emissions for project areas planned for tidal wetland construction and restoration. This module is always mandatory when the project activity includes hydrologic management and infrastructural modification for tidal wetlands including tidal marshes and eelgrass meadows. These land use changes will occur due to some combination of hydrologic management changes and infrastructural modification with assisted natural regeneration, and seeding. Infrastructural modification includes earth moving, berm and levee construction, drainage modification and application of dredge materials. The following conditions must be met to apply this module.

Project activities shall meet the applicability conditions in the methodology framework listed under tidal wetland construction and restoration. All wetland construction activities involving changes in hydrologic management shall occur in compliance with applicable local, state and federal environmental regulations. The Project Proponents shall provide attestations and/or evidence (e.g., permits or permit applications) of environmental compliance to ACR at the time of GHG Project Plan submission, and to the validation/verification body at the time of validation. Any changes to the project's environmental compliance status shall be reported to ACR.

Parameters

This module provides procedures to determine the following parameter:

Parameter	SI Unit	Description
$\Delta C_{BSL\_OW\ W/RC}$	t CO_2-e	Cumulative carbon stock changes and greenhouse gas emissions for the open water baseline scenario

II. PROCEDURE

This module proceeds in five steps:

- Step 1: Identification of baseline scenario and determination of additionality
- Step 2: Establishment and documentation of the project boundary
- Step 3: Baseline stratification
- Step 4: Baseline GHG emissions and carbon stock changes
- Step 5: Monitoring requirements for baseline renewal

Step 1. Identification of the baseline scenario and physical boundaries and determination of additionality

Project Proponents must identify the most plausible and credible baseline scenario describing what would have occurred in absence of the Project Activities. Under this module, the baseline scenario must be limited to open water and tidal wetlands. The geographical coordinates of the boundaries of each project area must be unambiguously defined and provided to the Validation/Verification Body (VVB) in shapefile format.

Performance Standard Evaluation

Emission reductions and carbon stock changes achieved by a wetland project must exceed those likely to occur in a conservative business-as-usual scenario and are subject to a practice-based performance standard. Practice base performance standard requirements are detailed in the Wetland-Rice Methodology Framework Module (WR-MF).

Step 2. Project GHG boundary

The project GHG boundary describes the carbon pools that will be included or excluded from GHG accounting as defined in the WR-MF. It shall be demonstrated that each discrete parcel of land to be included in the boundary is eligible for project activity. For the open-water/tidal wetland baseline case, emissions will occur due to fossil fuel combustion during dredging operations, infrastructural modification, earth moving and construction. These emissions must be accounted for if they are determined to be significant. Methane ebullition may also occur. Emissions shall be estimated based on site/project specific data, an acceptable proxy, reference sample plots or field monitoring of similar sites, peer-reviewed literature, approved local parameters and model estimates.

Allochthonous carbon may enter the open water area from outside source which may contribute to carbon accumulation at the site. However, for purposes of this methodology, carbon from outside sources is not counted in determination of baseline GHG emissions or removals. Only autochthonous processes are to be considered in the determination of the GHG baseline removals or emissions.

The Project Proponents using emission values from the literature or non-site data must make conservative estimates to determine the baseline GHG emissions. Exclusion of carbon pools and emission sources is allowed subject to considerations of conservativeness and significance testing. This may be accomplished by using peer-reviewed literature, reference sample plots or field monitoring of similar sites, approved local or national parameters, the most recent default emission factors provided by IPCC, government reports and models. Pools or sources may be excluded if exclusion will tend to underestimate net project GHG emission reductions or removal enhancements relative to the baseline.

Pools or sources can be neglected (i.e., counted as zero) if application of the tool T-SIG (http://unfccc.int/home/items/2783.php) indicates that the source is insignificant, i.e. the source represents less than 3% of the *ex-ante* calculation of GHG emission reductions/removal enhancements. If monitoring of baseline and project emissions indicate that an emission source(s) initially included in the GHG assessment boundary is insignificant using the tool T-SIG, monitoring may cease.

Step 3. Baseline stratification

Stratification is a standard procedure to decrease overall variability of carbon stock estimates by grouping data taken from environments with similar characteristics. When estimating baseline carbon stocks, several strata can be assessed. If the project activity area is not homogeneous, stratification should be carried out to improve the accuracy and precision of carbon stock estimates. Different stratifications may be required for the baseline and project scenarios, especially if there will be a change in hydrology, in order to achieve optimal accuracy and precision of the estimates of net GHG benefit. For estimation of baseline net GHG emissions, strata should be defined based on parameters that affect GHG emissions. These may include:

- Elevation and depth of open water
- Water quality (e.g. salinity, nutrient inputs, distance from source, etc.)

For baseline conditions, it will usually be sufficient to stratify according to soil organic matter content, vegetation, soil chemical and physical properties (e.g. redox conditions, temperature) and surface-water depth as these are the primary factors that affect GHG emissions. The Framework Module (W/R-MF) provides examples and factors for stratification. The stratification for *ex-ante* estimations shall be based on the project monitoring plan. The stratification for *ex post* estimations shall be based on the actual implementation of the project monitoring plan. If natural or anthropogenic impacts (e.g., levee breaks and flooding) or other factors (e.g. altered hydrology or water management) add variability in the vegetation of the project area, then the stratification shall be revised accordingly. Project Proponents may use remotely sensed data acquired close to the time of project commencement and/or the occurrence of natural or anthropogenic impacts for *ex-ante* and *ex-post* stratification.

Step 4. Baseline Carbon Stock Changes and Emissions

The baseline scenario consists of the emissions immediately prior to tidal wetland construction. Baseline emissions include GHG emissions within the project boundary within the year prior to site preparation, or the most likely emissions in the absence of the project activity (Table 11). The baseline net GHG emissions may be estimated using methodology described in this section and the methods module (MM-W/R). When applying these methods for the *ex-ante* calculation of baseline net GHG removals or emissions, the Project Proponents shall provide estimates of the site-specific values for the appropriate parameters. The Project Proponents shall retain a conservative approach in making these *ex-ante* estimates.

Table 11. Baseline emissions sources included in the project boundary. Nitrous oxide and methane are considered optional (see Framework Module, WR-MF)

Source	Gas
Emissions due oxidation of organic matter	N2O, CO2, CH4
Emissions resulting from Fossil Fuel Combustion	CO2,

Net Baseline emissions and cumulative carbon stock changes are estimated using the following equations.

The net carbon stock changes in the baseline are equal to the soil organic carbon stock minus the baseline greenhouse gas emissions including the combustion of fossil fuels if determined to be significant. Project Proponents may elect to assume carbon stock changes in the baseline are nil and go to step 5.

Baseline stock changes, $\Delta C_{bsl,}$ may be estimated using the following equation.

$$\Delta C_{bsl\_Ow\ W/r} = (\Delta C_{SOC} - NBE) * T_{pp} \quad (6)$$

$$NBE = GHG_{BSL\_Ow\ W/r} + GHG_{BSL\ FF,E} \quad (7)$$

Where::

NBE is the net baseline annual greenhouse gas emissions in metric tons of CO_2 equivalent (t CO_2-e) per year;

T_{pp} is the time period in years;

GHG $C_{bsl\_Ow\ W/r}$ is the annual net emissions of (t CO_2-e yr^{-1}) of N_2O, CO_2,, CH_4 due to the oxidation of organic matter (t CO_2-e);

$GHG_{BSL\ FF,E}$ is the GHG emissions as a result of fossil fuel combustion within the project boundary in the baseline (t CO_2-e yr^{-1});

ΔC_{SOC} is the annual change in carbon stocks for the baseline condition (t CO_2-e);

T_{pp} is the pre-project period of time which corresponds to the reporting period in years.

If deemed significant based on *ex-ante* estimates, the baseline GHG emissions due to organic matter oxidation from the project area may be estimated from direct measurement of gaseous fluxes prior to project activity using eddy covariance technique or by modeling or equivalent method or determined based on an acceptable proxy, data from peer-reviewed literature or approved parameters.

Estimation of emissions from fossil fuel combustion shall be estimated as described in the emissions module (E-FFC). The total baseline emission is the sum of the product of NBE and the area of each stratum for all strata in the project area (tCO_2-e yr^{-1}).

Step 5. Monitoring requirements for baseline renewal

A Crediting Period for a project is a predetermined length of time for which the baseline scenario is applicable. This period of time is used for carbon quantification of offsets generated relative to its baseline. In order to renew the Crediting Periods the Project Proponents must:

- Re-submit the GHG Project Plan in compliance with then-current GHG Program standards and criteria
- Re-evaluate the project baseline
- Demonstrate additionality against then-current regulations and performance standard data
- Use GHG program-approved baseline methods, emission factors, tools, and methodologies in effect at the time of Crediting Period renewal
- Undergo validation by an approved validation/verification body

PARAMETERS ORIGINATING IN OTHER MODULES

Data /parameter:	$\Delta GHG_{\_Ow\ W/r}$
Data unit:	t CO_2-e
Used in equations:	7
Description:	Cumulative total of the change in carbon emissions of the baseline scenario
Module parameter originates in:	MM – R/C
Any comment:	

Data /parameter:	ΔC_{SOC}
Data unit:	t CO_2-e
Used in equations:	7
Description:	Cumulative total of the carbon stock changes of soils for the baseline scenario
Module parameter originates in:	MM – R/C

Any comment:	

Data /parameter:	ΔGHG_{FFC}
Data unit:	t CO_2-e
Used in equations:	7
Description:	Cumulative total of GHG emissions as a result of fossil fuel combustion in the baseline scenario
Module parameter originates in:	E-FFC
Any comment:	

Project modules

Wetland Restoration and Rice Methodological Module - Estimation of project carbon stock changes and greenhouse gas emissions for managed wetlands (PS-MW)

I. SCOPE, BACKGROUND, APPLICABILITY AND PARAMETERS

Scope

This module provides guidance for estimating *ex-ante* and *ex-post* carbon stock enhancements and greenhouse gas (GHG) emissions related to managed non-tidal wetlands when the project activity includes hydrologic management, infrastructural modification, and plantings or natural plant regeneration.

Applicability

This module is always mandatory when the project activity includes hydrologic management, infrastructural modification and plantings or natural plant regeneration for construction of managed non-tidal wetlands that occur in the Sacramento-San Joaquin Delta and San Francisco Estuary. Infrastructural modification includes drainage modification and earth moving.

Project activities shall meet the applicability conditions in the methodology framework (WR-MF). All wetland construction activities involving hydrologic management shall occur in compliance with all applicable local, state and federal environmental regulations. The Project Proponent shall provide attestations and/or evidence (e.g. permits or permit applications) of environmental compliance to ACR at the time of GHG Project Plan submission, and to the validation/verification body at the time of validation. Any changes to the project's regulatory compliance status shall be reported to ACR.

Parameters

This module produces the following parameter.

Parameter	SI Unit	Description
$\Delta C_{actual\text{-}MW}$	tCO_2-e	Cumulative total carbon stock changes and greenhouse gas emissions under the managed wetlands project scenario

II. PROCEDURE

The methodology proceeds in 8 steps outlined and described in the Framework Methodology. This module provides guidance for the following 5 steps.

1. Project boundaries and stratification
2. Monitoring project implementation
3. Project GHG Emissions

4. Project carbon stock changes
5. Estimation of project emission reductions or enhanced removals

Step 1. Project boundaries and stratification

Guidance for definition of geographic and temporal boundaries is provided in the Framework Module (WR-MF). The Project Proponent must provide a detailed description of the geographic boundaries for project activities. Note that the project activities may occur on more than one discrete area of land, but each area must meet the project eligibility requirements. This methodology allows for "Programmatic Aggregated Projects", meaning that it is allowed to add new wetland areas to an existing Project after the start of the crediting period as long as all the applicability criteria are met for each new area.

The Project Proponent serving as aggregator for a Program of Activities (PoA) shall complete a GHG Project Plan covering the entire PoA as well as the first Cohort of Project Participants. The GHG Project Plan shall define the project boundary and baseline criteria encompassing the initial Cohort of fields, producers or facilities, and should be written broadly enough to encompass new Cohorts anticipated to be added in the future. The GHG Project Plan will specify project boundaries (geographic, temporal, and the GHG assessment boundary), a baseline scenario, and a monitoring/verification plan for the entire PoA, i.e. for the initial and future Cohorts.

A PoA may be created at the time of registering the first Cohort of fields, producers or facilities. Cohorts may be added at any time provided they conform to the project boundaries and baseline criteria established in the initial GHG Project Plan. A PoA will have multiple Start Dates and Crediting Periods, but a single overall baseline scenario and monitoring/verification plan.

The ACR Standard requirements for precision (±10% of the mean at a 90% confidence level) shall be applied at the level of each Cohort for the purposes of monitoring and verification.

Information to delineate the project boundary may include:

- USGS topographic map or property parcel map where the project boundary is recorded for all areas of land. Provide the name of the project area (e.g., compartment number, allotment number
- Local name) and a unique ID for each discrete parcel of land
- Aerial map (e.g. orthorectified aerial photography or georeferenced remote sensing images)
- Geographic coordinates for the project boundary, total land area, and land holder and user rights

A Geographic Information System shapefile is required

The Framework Module (WR-MF) provides guidance for description of the Project GHG Boundary carbon pools and sources that will be included or excluded from GHG accounting. If the project activity area is not homogeneous and where applicable, Project Proponents shall implement stratification to improve the accuracy and precision of carbon stock estimates. Different stratifications may be required for the baseline and project scenarios due to changes in hydrology. For estimation of *ex-ante* carbon stocks, strata should be defined based on factors and processes that affect GHG sequestration or emissions and/or that are key variables for the methods used to measure changes in carbon stocks.

In the GHG Project Plan, Project Proponents shall present an *ex-ante* stratification of the project area or justify the absence of stratification. Stratification for *ex-ante* estimations shall be based on the Project Management Plan. Aerial or satellite imagery used to delineate strata shall be verified in the field. The *ex-ante* defined number and boundaries of the strata may change during the crediting period (*ex-post*). The *ex-post* stratification shall be updated if natural or anthropogenic impacts or other factors add variability to the carbon stock changes or emissions of the project area. Table 12 provides typical factors and practices that can be used for stratification.

Table 12. Factors and practices that can be used for stratification and their effects on GHG emissions and removals.

Stratification Factor or Practice	Description	Potential GHG Effect
Wetland management practices	Depth of water and land surface elevation	Depth of water affects GHG removal and emissions and vegetation
Wetland management practices	Flow through or limited or zero outflow	May affect CH_4 emissions
Wetland vegetation	Variation in species	May affect GHG removals
Wetland vegetation	Planted seedlings, seeded, colonize or natural recruitment	Affects time required for vegetative cover, CH_4 emissions and GHG removal.
Wetland vegetation	Open water areas	Minimal GHG removal, GHG emissions
Wetland spatial variability	Location relative water circulation	May affect GHG removals and GHG emissions
Wetland age		May affect GHG removal rates
Soil chemical composition – soil organic matter content	For baseline conditions	Soil organic matter is key determinant of baseline GHG emissions on organic soils
Soil hydrology	Depth to groundwater, oxidation-reduction conditions	Depth to groundwater is an important determinant of baseline GHG emissions on organic soils
Agricultural land use	Crops or seasonal wetlands	Affects baseline GHG emissions and removals

Step 2. Monitoring Project Implementation

As described in Methodology Framework (MF-W/R), Project Proponents shall include a single monitoring plan in the Project Plan that includes description of baseline and project monitoring and estimation of carbon stock changes. Information shall be provided in the monitoring plan (as part of the GHG Project Plan), to document that:

a. The geographic position of the project boundary is recorded for all areas of land;
b. The geographic coordinates of the project boundary (and any stratification inside the boundary) are established, recorded, and archived;
c. Commonly accepted principles of wetland management are implemented;
d. Standard operating procedures (SOPs) and quality control / quality assurance (QA/QC) procedures for field data collection and data management are applied;
e. Use or adaptation of relevant practices already applied in managed wetland monitoring, or available from published relevant materials are implemented;
f. The monitoring plan, together with a record of implemented practices and monitoring during the project, shall be available for validation and verification.

Step 3. Project GHG Emissions

Greenhouse-gas emissions shall be estimated using methodology described in the methods module (MM-W/R). The methods module (MM-W/RC) provides the appropriate methods for measuring and estimating emissions for project and baseline activities. Possible baseline activities include agriculture and seasonal wetlands. The methods listed in the MM-W/R module may be used alone or in tandem with the other methods listed. For emissions measurements for managed non-tidal wetland project activities, chamber and eddy covariance methods are appropriate. The methods module provides guidance for quality assurance and control precautions and recommendations for chamber and eddy covariance techniques. Emissions can be estimated using appropriate peer-reviewed proxy measurements or estimates for similar situations in which case the environmental setting for the estimates shall be detailed. Also, there shall be an in-depth demonstration of conservatism and applicability. Biogeochemical models documented in the peer-reviewed literature that are calibrated and validated for the project area and demonstrably similar project conditions can be used for estimating GHG emissions.

Proponents shall provide transparent calculations for the parameters or data used for modeling or calculations during the crediting period. Parameter estimates shall be based on measured data or existing published data where appropriate and can be demonstrated as applicable. In addition, Project Proponents must be conservative. If different values for a parameter used in models or calculations are equally plausible, a value that does not lead to over-estimation of net GHG emission reductions must be selected and its use documented. If project activities include moving sediments, fossil fuel combustion emissions must be quantified during project activities using methods described in module E-FFC if determined to be significant using module T-SIG. An *Ex-Ante* estimate shall be made of fuel consumption based on projected fuel usage.

Step 4. Project carbon stock changes

Methods are described in the methods module (MM-W/R) for calculating above- and below-ground biomass and soil organic carbon stock changes. Acceptable methods include eddy covariance and soil coring. For use of the mean in estimating carbon stock changes, the 90% statistical confidence interval (CI) for estimated values of carbon stock changes can be no more than +/-10% of the mean estimated amount of the combined carbon stock change across all strata[72]. If the data does not meet the targeted uncertainty criteria described in the Framework Module (W/R-FM) using equations in the Uncertainty Module (X-UNC), then the reportable GHG reductions shall be calculated as per equation 2 in the Framework Module (W/R-FM).

A 5-year monitoring and reporting frequency is considered adequate for the determination of changes in soil carbon stocks. Specifically, coring for measurements of carbon stock changes can be conducted every five years after project inception and placement of feldspar markers. If eddy covariance measurements are used to estimate carbon stock changes, continual monitoring shall occur from project inception unless another method is selected (such as a calibrated biogeochemical modeling). Project Proponents shall demonstrate that the spatial and temporal monitoring frequency adequately reflects reported and credited changes. Peer-reviewed biogeochemical models developed and calibrated for project conditions shall be used to simulate project carbon stock changes and GHG emissions at 5-year

[72] For calculating pooled confidence interval of carbon pools across strata, see equations in Barry D. Shiver, *Sampling Techniques for Forest Resource Inventory (John Wiley & Sons, Inc, 1996)*

intervals.

Pertinent concepts and assumptions

1. Above- and below-ground biomass of wetland vegetation and litter contribute to the soil organic carbon (SOC) pool in wetlands.
2. Net increases in the SOC pool as the result of biomass contributions shall be estimated using methods described in the methods module (MM-W/R).
3. Project Proponents shall not double count carbon stock changes in above- and below-ground biomass and the SOC pool.
4. Emissions shall be measured in the field under project conditions or may be quantified by an acceptable proxy, reference sample plots, or field monitoring of similar sites, using approved local or national parameters, peer-reviewed biogeochemical models or demonstrably applicable peer-reviewed literature.
5. Project Proponents using non-project specific values must use conservative estimates.

Step 5. Estimation of Project Emission Reductions or Enhancement Removals

The actual net GHG removals by sinks shall be estimated using the equations in this section. When applying these equations for the *ex-ante* calculation of actual net GHG removals by sinks, Project Proponents shall provide estimates of the values of those parameters that are not available before the start of the crediting period and commencement of monitoring activities. Project Proponents should retain a conservative approach in making these estimates.

$$\Delta C_{ACTUAL\_MW} = \Delta C_p - \Delta GHG_p - E_{FC,i,t} \quad (8)$$

where:

ΔC_{ACTUAL_MW}	Cumulative total of carbon stock changes and greenhouse gas emissions under the project scenario; t CO_2-e
ΔC_p	Cumulative total of carbon stock changes under the project scenario; t CO_2-e (CP-S)
ΔGHG_p	Cumulative total of the changes in GHG emissions as a result of implementation of the project activity*;* t CO_2-e (MM-R/W).
$E_{FC,i,t}$	Cumulative total emission from fossil fuel combustion in stratum *i;* t CO_2-e (E-FFC).[73]

Note: In this methodology, equation 8 is used to estimate actual cumulative net GHG removals for the period of time elapsed since the last verification period.

[73] Include in equation if project activities include moving sediment and fossil fuel combustion emissions have been determined to be significant using module T-SIG.

Parameters for which Guidance Originates in other Modules

Parameter	ΔC_p
Units	Metric tons carbon dioxide equivalents (t CO2-e)
Equation	8
Description	Cumulative total of carbon stock changes under the project scenario up to time *t*
Module	Methods Module (MM-W/R)
Comment	Relevant information shall be included in the GHG Project Plan

Parameter	ΔGHG_p
Units	t CO2-e
Equation	8
Description	Cumulative total of the changes in GHG emissions as a result of implementation of the project activity up to time *t*
Module	Methods Module (MM-W/R)
Comment	Relevant information shall be included in the GHG Project Plan

Parameter	$E_{FC,i,t}$
Units	t CO2-e
Equation	8
Description	Emission from fossil fuel combustion in stratum *i*
Module	E-FCC
Comment	Relevant information shall be included in the GHG Project Plan

Wetland Restoration and Rice Methodological Module - Estimation of Project Carbon Stock Changes and Greenhouse Gas Emissions for Tidal Wetlands with in the San Francisco Bay Estuary (PS -TW)

I. SCOPE, APPLICABILITY AND PARAMETERS

Scope

This module provides guidance for estimating *ex-ante* and *ex-post* carbon stock enhancement and greenhouse gas (GHG) emissions related to tidal wetlands construction and restoration in the San Francisco Estuary when the project activity includes hydrologic management and infrastructural modification.

Applicability

This module is always mandatory for use with tidal wetlands when the project activity includes hydrologic management and infrastructural modification with plantings, natural plant recruitment, or seeding. Tidal wetland restoration includes tidal marshes and Eelgrass meadows in the San Francisco Estuary. Hydrologic management and infrastructural modification activities include levee breaching and construction, earth moving, levee construction and other activities related to re-introducing tidal action and application of dredged material. This module is not applicable where application of nitrogen fertilizer(s) such as chemical fertilizer or manure, occurs in the project area during the project period.

Project activities shall meet the applicability conditions in the methodology framework (W/R-MF). All wetland construction activities involving hydrologic management and infrastructural modification shall occur in compliance with applicable local, state and federal environmental regulations. The Project Proponent shall provide attestations and/or evidence (e.g. permits or permit applications) of environmental compliance to ACR at the time of GHG Project Plan submission, and to the validation/verification body at the time of validation. Any changes to the project's environmental compliance status shall be reported to ACR.

Parameters

This module produces the following parameter.

Parameter	SI Unit	Description
ΔC_{actual_TW}	Metric tons carbon dioxide equivalents (t CO2-e)	Cumulative total of carbon stock changes and greenhouse gas emissions for the project scenario.

II. PROCEDURE

The methodology proceeds in 8 steps outlined and described in the Framework Methodology. This module provides guidance for the following 5 steps.

1. Project boundaries and stratification
2. Monitoring project implementation
3. Project GHG Emissions
4. Project carbon stock changes
5. Estimation of project emission reductions or enhanced removals

Step 1. Project boundaries and stratification

Guidance for definition of geographic and temporal boundaries is provided in the Framework Module (WR-MF). The Project Proponent must provide a detailed description of the geographic boundaries for project activities. Note that the project activities may occur on more than one discrete area of land, but each area must meet the project eligibility requirements. This methodology allows for "Programmatic Aggregated Projects", meaning that it is allowed to add new wetland areas to an existing Project after the start of the crediting period as long as all the applicability criteria are met for each new area.

The Project Proponent serving as aggregator for a Program of Activities (PoA) shall complete a GHG Project Plan covering the entire PoA as well as the first Cohort of Project Participants. The GHG Project Plan shall define the project boundary and baseline criteria encompassing the initial Cohort of fields, producers or facilities, and should be written broadly enough to encompass new Cohorts anticipated to be added in the future. The GHG Project Plan will specify project boundaries (geographic, temporal, and the GHG assessment boundary), a baseline scenario, and a monitoring/verification plan for the entire PoA, i.e. for the initial and future Cohorts.

A PoA may be created at the time of registering the first Cohort of fields, producers or facilities. Cohorts may be added at any time provided they conform to the project boundaries and baseline criteria established in the initial GHG Project Plan. A PoA will have multiple Start Dates and Crediting Periods, but a single overall baseline scenario and monitoring/verification plan.

The ACR Standard requirements for precision (±10% of the mean at a 90% confidence level) shall be applied at the level of each Cohort for the purposes of monitoring and verification.

Information to delineate the project boundary may include:

- USGS topographic map or property parcel map where the project boundary is recorded for all areas of land. Provide the name of the project area (e.g., compartment number, allotment number;
- Local name and a unique ID for each discrete parcel of land;
- Aerial map (e.g. orthorectified aerial photography or georeferenced remote sensing images);
- Geographic coordinates for the project boundary, total land area, and land holder and user rights;
- A GIS shapefile is required.

If the project activity area is not homogeneous and where applicable, Project Proponents shall stratify to improve the accuracy and precision of carbon stock estimates. Different stratifications may be required for the baseline and project scenarios due to changes in hydrology. Strata must be identified using spatial data (e.g. maps, GIS, classified imagery). Strata must be spatially discrete and stratum areas must be known. Areas of individual strata must sum to the total project area. For estimation of *ex-ante* carbon stocks, strata should be defined based on parameters that affect GHG sequestration or emissions and/or that are key variables for the methods used to measure changes in carbon stocks. Potential strata criteria are as follows.

a. Wetland elevation
b. Vegetation type and species, such as eelgrass meadows
c. Age class
d. Water quality (e.g. salinity, nutrient inputs, distance from source, etc.). See discussion below for relevance to methane (CH_4) emissions
e. Hydrology (e.g. wetland water depth, depth of eelgrass meadow)
f. Soil type (e.g. organic or mineral soils)

Tidal wetlands may also be stratified according to salinity with relevance for CH_4 emissions. It is generally understood that wetlands exposed to high concentrations of sulfate (an anion present in seawater) emit CH_4 at relatively low rates due to low rates of CH_4 production. The presence of sulfate in tidal marsh soils allows sulfate-reducing bacteria to outcompete methanogens for energy sources, consequently inhibiting CH_4 production[74]. However, sulfate can be reduced to sulfide in marsh soils and thus the inhibitory effect of marine-derived saline water can be affected by site-specific conditions that allow CH_4 production to persist if sulfate availability is limited by diffusion or oxidation-reduction conditions[75]. Moreover, temporal and spatial variation in sources and sinks for sulfate and CH_4 can create conditions where both processes can coexist[76]. Therefore, estimates of CH_4 emissions and corresponding stratification may require direct measurements or conservative estimates as described in Step 3 below.

Established strata may be merged if reasons for their establishment have disappeared or have proven irrelevant to key variables for estimating net GHG emission reductions or removals. In the GHG Project Plan, Project Proponents shall present an *ex-ante* stratification of the project area or justify the absence of stratification. Stratification for *ex-ante* estimations shall be based on the Project Management Plan. Aerial or satellite imagery used to delineate strata shall be verified in the field. The *ex-ante* defined number and boundaries of the strata may change during the crediting period (*ex-post*). The *ex-post* stratification shall be updated if natural or anthropogenic impacts or other factors add variability to the carbon stock changes or emissions of the project area.

[74] Poffenbarger, Hanna J. Needelman, Brian A. & Megonigal, J. Patrick, 2011, Salinity Influence on Methane Emissions from Tidal Marshes, Wetlands, 31:831-842.

[75] E.g. Megonigal JP, Hines ME, Visscher PT (2004) Anaerobic metabolism: linkages to trace gases and aerobic processes. In: Schlesinger WH (ed) Biogeochemistry. Elsevier-Pergamon, Oxford, pp 317–424
Weston NB, Vile MA, Neubauer SC, Velinsky DJ (2011) Accelerated microbial organic matter mineralization following salt-water intrusion into tidal freshwater marsh soils. Biogeochemistry 102:135–151

[76] See footnote 1

Eelgrass Meadows

Seagrasses which include Eelgrass (*Zostera marinas)* are among the planet's most effective natural ecosystems for sequestering (capturing and storing) carbon However, there is limited data and quantifying and modelling the GHG removal capacity is critical for successfully managing Eelgrass ecosystems to maintain their substantial abatement potential[77]. Given the tendency of eelgrasses to respond differently under different light and depth regimes, projects may differentiate between eelgrass meadow sections that occur at different depths given discrete - or relatively abrupt - bathymetric and substrate changes. For Eelgrass meadow restoration projects in areas with existing Eelgrass meadows, Project Proponents must quantify the percentage of natural meadow expansion that can be attributed to the restoration effort. Existing meadows are not eligible for inclusion in calculations of project emissions, even in cases where the restored meadow influences carbon emission rates in existing meadows.

New beds that result from natural expansion must be contiguous with restored meadow plots to be included in project accounting unless Project Proponents can demonstrate that non-contiguous meadow patches originated from restored meadow seeds. This may be done through genetic testing or estimated as a percentage of new meadow in non-contiguous plots observed no less than four years after the project start date[78]. This percentage must not exceed the proportion of restored meadow area relative to the total Eelgrass meadow areal extent and Project Proponents must demonstrate the feasibility of current-borne seed dispersal from the restored meadow. In cases where a restored meadow coalesces with an existing meadow(s), Project Proponents must delineate the line at which the two meadows joined. Project proponents may use either aerial observations showing meadow extent or direct field observations.

Step 2. Monitoring Project Implementation

As described in Methodology Framework (WR-MF), Project Proponents shall include a single monitoring plan in the Project Plan that includes description of baseline and project monitoring and estimation of carbon stock changes and emissions. Information shall be provided in the monitoring plan (as part of the GHG Project Plan), to document that:

a. The geographic position of the project boundary is recorded for all areas of land;
b. The geographic coordinates of the project boundary (and any stratification inside the boundary) are established, recorded, and archived;
c. Commonly accepted principles of wetland management are implemented;
d. Standard operating procedures (SOPs) and quality control / quality assurance (QA/QC) procedures for field data collection and data management are applied;
e. Use or adaptation of relevant practices already applied in managed wetland monitoring, or available from published relevant materials are implemented;
f. The monitoring plan, together with a record of implemented practices and monitoring during the project, shall be available for validation and verification.

[77] P.I. Macreadie, M.E. Baird, S.M. Trevathan-Tackett, A.W.D. Larkum, P.J. Ralph, 2014, Quantifying and modelling the carbon sequestration capacity of seagrass meadows – A critical assessment, Marine Pollution Bulletin, 82, 430 - 439

[78] McGlathery, KL, LK Reynolds, LW Cole, RJ Orth, SR Marion, A Schwarzchild. 2012. Recovery trajectories during state change from bare sediment to eelgrass dominance. *Marine Ecology Progress Series* 448: 209-221.

Step 3. Project GHG Emissions

Greenhouse-gas emissions shall be estimated using methodology described in the methods module (MM-W/R) which provides the appropriate methods for measuring and estimating emissions for project and baseline activities (use baseline modules BL OW W or BL SW W). The methods listed the Methods Module may be used alone or in tandem with the other methods listed. For emissions measurements for tidal wetland project activities, chamber and eddy covariance methods are appropriate. The methods module provides guidance, and quality assurance and control precautions and recommendations for chamber and eddy covariance techniques. Emissions can be estimated using appropriate proxy measurements or estimates for similar situations documented in the peer-reviewed literature. In this case, the environmental setting for the estimates shall be detailed. Also, there shall be a comprehensive demonstration of conservatism and applicability. Peer-reviewed biogeochemical models that are calibrated and validated for the project area or demonstrably similar project conditions can be used for estimating GHG emissions.

As discussed above, CH_4 fluxes are generally influenced by salinity that can affect stratification. Methane emissions can be measured using methods described in the Methods Module. These methods can be used to directly determine and characterize the spatial and temporal variability resultant from topography, temperature, vegetation and water levels. Alternatively, a conservative estimate of CH_4 emissions requires measurement in the stratum where emissions are likely to be the largest. That is, chamber or eddy covariance measurements shall be conducted at times and places in which CH_4 emissions are expected to be the highest based on expert judgment, datasets or literature. These are likely to be wettest strata that support emergent vegetation, but may include stagnant pools of water. If eddy flux towers are used for the conservative approach, they will be placed so that the footprint lies in the stratum with the highest CH_4 emissions for 50% of the time.

Where a default factor approach is used based on salinity, the salinity average or low value shall be measured in shallow pore water or soil salinity within 30 cm of land surface using acceptable technology or analytical determination of total dissolved solids. Sulfate concentrations shall also be determined when salinity is measured using standard analytical methods at a certified laboratory. The salinity average shall be calculated from measurements during periods of peak CH_4 emissions. When the number of measurements is fewer than monthly for one year, the minimum salinity value shall be used. The salinity of the floodwater source may be used as a proxy for salinity in pore water provided there is regular hydrologic exchange between the source and the wetland (i.e. the source floods the wetland at least on 20% of the time during high tides).

The default factor[79] may be used with caution (see exceptions below) where the salinity average or salinity minimum is greater than 18 parts per thousand. Thus the estimated default CH_4 flux:

$$fGHG_{TW,i} = 0.0045 \text{ t } CH_4 \text{ acre}^{-1} \text{ yr}^{-1} \qquad (9)$$

Where $fGHG_{TW,i}$ is the annual rate of CH_4 emissions from the project area in stratum i.

The default factor shall not be used where oxidation-reduction conditions or sulfate concentrations are

[79] Poffenbarger, Hanna J. Needelman, Brian A. & Megonigal, J. Patrick, 2011, Salinity Influence on Methane Emissions from Tidal Marshes, Wetlands, 31:831-842.

such that CH_4 production may not be inhibited. For example, Winfrey and Ward[80] demonstrated greatly increased CH_4 pore-water concentrations with decreasing sulfate to chloride ratios in intertidal sediments below 0.01. Morris and Riley[81] reported a sulfate chloride ratio of 0.14 +/- 0.00023 for the world's oceans. .

Specific applicability conditions follow for the use of the default factor:

1. The default factor shall not be used when sulfate/chloride ratios are less 0.01;
2. In intertidal areas where there are likely sulfate to chloride ratios near or below 0.01, CH_4 fluxes shall be measured using methods described in the Methods Module (MM-R/C);
3. Methane flux measurements shall be used to characterize the spatial and temporal variability caused by topography, temperature, vegetation and water levels or conservatively estimated based on direct measurements taken at times and places in which CH_4 emissions are expected to be the highest based on expert judgment, datasets or literature

Project proponents may also estimate GHG emissions using locally calibrated and peer-reviewed biogeochemical models as per guidance in the biogeochemical modeling methods module and the framework module (WR-MF). Proponents shall provide transparent calculations for the parameters or data used for modeling during the crediting period. Parameter estimates shall be based on measured data or existing published data where appropriate and can be demonstrated as applicable. In addition, Project Proponents must be conservative. If different values for a parameter used in models or calculations are equally plausible, a value that does not lead to over-estimation of net GHG emission reductions must be selected and its use documented. Emissions of N_2O may be conservatively set to zero for Eelgrass meadows.

If project activities include moving sediments, fossil fuel combustion emissions must be quantified during project activities using methods described in module E-FFC if determined to be significant using module T-SIG. An *Ex-Ante* estimate shall be made of fuel consumption based on projected fuel usage.

Step 4. Project Carbon Stock Changes

Methods are described in the methods module (MM-R/C) for calculating above- and belowground biomass and soil organic carbon stock changes. Acceptable methods for estimating soil carbon stock changes include eddy covariance and soil coring as described in the methods module (MM-R/C). For use of the mean value or replicate measurements in time and space in estimating carbon stock changes, guidance in the uncertainty (X-UNC) and framework (WR-MF) modules .

A 5-year monitoring and reporting interval is considered adequate for the determination of changes in soil carbon stocks. Specifically, coring for measurements of carbon stock changes shall be conducted every five years after project inception and placement of feldspar markers or sediment pins where opening of the project area would wash feldspar markers away due to tidal influence. Sediment pins are pounded into the ground to refusal and sediment accretion is measured against the pin's height[82].

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[80] Winfrey, M.R. and Ward, D.M., 1983, Substrates for Sulfate Reduction and Methane Production in Intertidal Sediments, Applied and Environmental Microbiology, January, 193-199

[81] Morris, A.W. and Riley, J.P., 1966, The bromide/chorinity and sulphate.chlorinity ratio in sea water, Deep Sea Research and Oceanographic Abstracts, August, 699 – 705.

[82] *US Geological Survey. 2012. Sediment pin standard operating procedures. Unpublished protocols. USGS, Western Ecological*

If eddy covariance measurements are used to estimate carbon stock changes, continual monitoring shall occur from project inception until such time as biogeochemical models can effectively predict carbon stock changes. As per guidance in the methods module aqueous carbon fluxes shall be accounted for when eddy covariance methods are used for estimating soil carbon stock changes. Project Proponents shall demonstrate that the spatial and temporal monitoring frequency adequately reflects reported and credited changes. Biogeochemical models developed and calibrated for project conditions shall be used to simulate cumulative project carbon stock changes and GHG emissions at 5-year intervals.

Pertinent concepts and assumptions

1. Above- and belowground biomass of wetland vegetation and litter contribute to the soil organic carbon (SOC) pool in wetlands. Measurement of these biomass contributions to the wetland can only be used as inputs for biogeochemical models and will not be double counted with changes in the SOC pool for estimating carbon sequestration.
2. Net increases in the SOC pool as the result of biomass contributions shall be estimated using methods described in the Methods Module (MM-W/R).
3. Project Proponents using non-project specific values must demonstrate use of conservative estimates.

Step 5. Estimation of Project Emission Reductions and GHG Removals

Equations and methods for project emissions and carbon stock changes are provided in the Methods Module (MM-R/C) and summarized here. The framework module provides equations for calculating net carbon stock change. The project carbon stock change shall be estimated using the equations in this section. In applying these equations *ex-ante*, Project Proponents shall provide estimates before the start of the crediting period and monitoring activities. Project Proponents shall utilize a conservative approach in making these estimates. The net carbon stock change when using soil coring is estimated as follows.

$$\Delta C_{actual\_TW} = \Delta C_p - \Delta GHG_p - E_{FFC} \qquad (10)$$

where:

ΔC_{actual_TW} is the cumulative total of carbon stock changes and greenhouse gas emissions; t CO_2-e;

ΔC_p is the cumulative total of carbon stock changes under the project scenario; t CO_2-e;

ΔGHG_p is the cumulative total of the changes in GHG emissions as a result of implementation; t CO_2-e;

E_{FFC} is the cumulative emissions of fossil fuels in in metric tons CO2-e.

Where allochthonous soil organic carbon (soil organic carbon originating outside the project boundary and being deposited in the project area) accumulates on the project site in the project scenario, the following procedure is provided for a compensation factor, D_{cf}.

Research Center, San Francisco Bay Estuary Field Station, Vallejo, CA.
http://www.tidalmarshmonitoring.org/pdf/USGS-WERC-Sediment-Pin-SOP.pdf

$$D_{cf} = \Delta C_{p\ i} \times (\%C_{alloch} / 100) \qquad (11)$$

where:

D_{cf}	is the deduction to account for the percentage of the carbon stock that is derived from allochthonous soil organic carbon (t CO_2-e)
ΔC_p	ΔC_p is the *c*umulative total of carbon stock changes under the project scenario; t CO_2-e
$\%C_{alloch}$	is percentage of carbon stock derived from allochthonous soil organic carbon; %
i	1, 2, 3 … strata

D_{cf} may be conservatively set to zero for the baseline.

Parameters for which Guidance Originates in other Modules

Parameter	ΔC_p
Units	Metric tons carbon dioxide equivalents (t CO2-e)
Equation	10
Description	Cumulative total of carbon stock changes under the project scenario up to time *t*
Module	Methods Module (MM-W/R)
Comment	Relevant information shall be included in the GHG Project Plan

Parameter	ΔGHG_p
Units	t CO2-e
Equation	10
Description	Cumulative total of the changes in GHG emissions as a result of implementation of the project activity up to time *t*
Module	Methods Module (MM-W/R)
Comment	Relevant information shall be included in the GHG Project Plan

Wetland Restoration and Rice Methodological Module - Estimation of project carbon stock changes and greenhouse gas emissions for rice cultivation (PS RC W/RC)

I. SCOPE, APPLICABILITY AND PARAMETERS

Scope

This module provides methods for estimating *ex-ante* and *ex-post* carbon stock enhancement greenhouse gas (GHG) emissions related to rice cultivation (RC) when the project activity includes hydrologic management and infrastructural modification on subsided lands in the Sacramento-San Joaquin Delta.

Applicability

This module is always mandatory when the project activity includes rice cultivation on organic and highly organic mineral soils in the Sacramento-San Joaquin Delta. The module is applicable for estimating project GHG emissions and carbon-stock changes for project areas planned for rice cultivation where drained agriculture is the primary baseline activity as discussed in the agricultural baseline module (BL-Ag). The rice cultivation project activity includes a combination of hydrologic management changes with planting and infrastructural modification. Infrastructural modification includes drainage modification and earth moving.

Project activities shall meet the applicability conditions provided in the methodology framework. Rice shall remain flooded during the growing season at depths ranging from not less than 4 inches up to 1 foot. All rice cultivation activities involving hydrologic management shall occur in compliance with applicable local, state and federal environmental regulations. Straw burning and removal are not allowed. Baseline drained agricultural activities as described in the agricultural baseline module (BL-Ag) shall be in place during 5 years prior to beginning rice cultivation. The Project Proponent shall provide attestations and/or evidence (e.g., permits or permit applications) of environmental compliance to the verification body at each verification. Any changes to the project's environmental compliance status that occurs between verifications shall be reported to ACR.

Parameters

This module produces the following parameters:

Parameter	SI Unit	Description
ΔC_{actual_RC}	t CO_2-e	Cumulative total carbon stock changes and greenhouse gas emissions under the project scenario; metric tons CO_2-e

II. PROCEDURE

The methodology proceeds in 8 steps outlined and described in the Framework Methodology. This module provides guidance for the following 5 steps.

1. Project boundaries and stratification
2. Monitoring Plan
3. Monitoring and estimation of emissions
4. Monitoring and estimation of carbon stock changes
5. Estimation of project emission reductions or enhanced removals

Step 1. Project boundaries and stratification

The geographic boundaries of a rice project are fixed (*ex-ante*) and may change over the Crediting Period (40 years). This methodology allows for “Programmatic Aggregated Projects”, meaning that it is allowed to add new rice fields areas to an existing Project after the start of the crediting period as long as all the applicability criteria are met for each new rice field.

The Project Proponent serving as aggregator for a Program of Activities (PoA) shall complete a GHG Project Plan covering the entire PoA as well as the first Cohort of Project Participants. The GHG Project Plan shall define the project boundary and baseline criteria encompassing the initial Cohort of fields, producers or facilities, and should be written broadly enough to encompass new Cohorts anticipated to be added in the future. The GHG Project Plan will specify project boundaries (geographic, temporal, and the GHG assessment boundary), a baseline scenario, and a monitoring/verification plan for the entire PoA, i.e. for the initial and future Cohorts.

A PoA may be created at the time of registering the first Cohort of fields, producers or facilities. Cohorts may be added at any time provided they conform to the project boundaries and baseline criteria established in the initial GHG Project Plan. A PoA will have multiple Start Dates and Crediting Periods, but a single overall baseline scenario and monitoring/verification plan. The ACR Standard requirements for precision (±10% of the mean at a 90% confidence level) shall be applied at the level of each Cohort for the purposes of monitoring and verification.

If the project activity area is not homogeneous (and where applicable), proponents shall implement stratification to improve the accuracy and precision of carbon stock estimates. Different stratifications may be required for the baseline and project scenarios, especially if there was a change in hydrologic conditions. For estimation of *ex-ante* carbon stocks, strata should be defined based on parameters that affect GHG removal or emissions and/or that are key variables for the methods used to measure changes in carbon stocks. The key factors affecting GHG emissions are fertilization and soil organic carbon concentrations. Potential strata criteria are described in Table 13.

Table 13. Factors and practices that can be used for stratification and their effects on GHG emissions and removals.

Stratification Factor or Practice	Description	Potential GHG Effect
Rice water- management practices	Depth of water	Depth of water affects GHG removal and emissions and vegetation
Rice water management practices	Flow through or limited or zero outflow	May affect GHG emissions
Rice cultivar	Time for maturity varies among cultivars	Affects length of growing season which affects GHG removals and emissions
Soil chemical composition – soil organic matter content	For baseline conditions	Soil organic matter is key determinant of baseline GHG emissions on organic soils
Soil hydrology	Depth to groundwater, oxidation-reduction conditions	Depth to groundwater is and important determinant of baseline GHG emissions on organic soils
Agricultural land use	Baseline crops or seasonal wetlands	Affects baseline GHG emissions and removals
Fertilization rates and timing	Optimum fertilization rates vary for different organic matter[83].	Nitrous oxide emissions affected by rates and timing[84].

In the GHG Project Plan, the Project Proponents shall present an *ex-ante* stratification of the project area or justify the absence of stratification. Stratification for *ex-ante* estimations shall be based on the Project Management Plan. Aerial photography or satellite imagery used to delineate strata shall be verified in the field. The *ex-ante* defined number and boundaries of the strata may change during the crediting period (*ex-post*). The *ex-post* stratification shall be updated if natural or anthropogenic impacts or other factors add variability to the growth pattern or emissions of the project area.

Step 2. Monitoring Plan

As described in the Methodology Framework, Project Proponents shall include a single monitoring plan in the Project Plan that includes a description of baseline and project monitoring and estimation of carbon stock changes. Information shall be provided in the monitoring plan (as part of the Project Plan), to establish that:

a. The geographic position of the project boundary is recorded for all areas of land;
b. The geographic coordinates of the project boundary (and any stratification inside the boundary)

[83] Matthew B. Espe, Emilie Kirk, Chris van Kessel, William H. Horwath , and Bruce A. Linquist, 2015, Indigenous nitrogen supply of rice is predicted by soil organic carbon, Soil Sci. Soc. Am. J, Accepted, posted 12/23/2014. doi:10.2136/sssaj2014.08.0328
[84] Ye, R. and Horwath, W.R.,2014 Influence of variable soil C on CH_4 and N_2O emissions from rice fields 2013-2014. Presentation at UC Davis

are established, recorded, and archived;

c. Commonly accepted principles of rice cultivation for minimizing GHG emissions in the Delta are implemented as described in the Appendix;
d. Standard operating procedures (SOPs) and quality control / quality assurance (QA/QC) procedures for field data collection and data management are implemented;
e. The monitoring plan, together with a record of implemented practices and monitoring during the project, shall be available for validation and verification.

Step 3. Project GHG Emissions

GHG emissions shall be estimated using the methodology described in this section and the Methods Module (MM-W/R) which provides the appropriate methods for measuring and estimating emissions for project and baseline activities. The methods listed in the methods module may be used alone or in tandem with the other methods listed. For emissions measurements for rice cultivation project activities, chamber and eddy covariance methods are appropriate. Monitoring shall occur during the entire calendar year. The emission module provides guidance for quality assurance and control precautions and recommendations for chamber and eddy covariance techniques. Emissions can be estimated using appropriate proxy measurements or estimates for similar situations if proxy measurements are used, the environmental setting relevance and scientific validity shall be detailed. Also, there shall be a demonstration of conservatism. Peer-reviewed biogeochemical models that are calibrated and validated for the project area and demonstrably similar project conditions can be used for estimating GHG emissions.

Project Proponents shall provide transparent calculations or estimates for the parameters that are monitored or used for calculations or modeling during the crediting period. These estimates shall be based on measured data or existing published data where appropriate. In addition, Project Proponents shall apply the principle of conservativeness. If different values for a parameter are equally plausible, a value that does not lead to demonstrable overestimation of net GHG emission reductions must be selected. If project activities include moving sediments, fossil fuel combustion emissions must be quantified during project activities using methods described in module E-FFC if determined to be significant using the T-SIG tool. An *Ex-Ante* estimate shall be made of fuel consumption based on projected fuel usage.

Step 4. Estimation and Monitoring of Project Carbon Stock Changes

Methods can be found in the Methods Module (MM-W/R) for calculating above-and belowground biomass and soil organic carbon stock changes. Acceptable monitoring methods include eddy covariance, remote sensing techniques and biogeochemical models. If eddy covariance techniques are used, the carbon of the harvested biomass must be accounted for as described in the methods module. The 90% statistical confidence interval (CI) for estimated values of carbon stock changes can be no more than +/-10% of the mean estimated amount of the combined carbon stock change across all strata[85]. If the Project Proponents cannot meet the targeted +/-10% of the mean at 90% confidence, then the reportable amount for calculation of offsets shall be adjusted as per the Framework Module (W/R-FM) A 5-year monitoring and reporting frequency is considered adequate for the determination of changes

[85]For calculating pooled confidence interval of carbon pools across strata, see equations in Barry D. Shiver, *Sampling Techniques for Forest Resource Inventory (John Wiley & Sons, Inc, 1996)*

in soil carbon stocks. The Project Proponents shall demonstrate that the spatial and temporal monitoring frequency adequately reflects and supports reported and credited changes.

Pertinent concepts and assumptions

1. Above-and belowground biomass of rice vegetation and litter contribute to the soil organic carbon (SOC) pool. As discussed in the methods modules, monitoring of biomass and soil organic carbon stock changes shall not be used to double count GHG removal or carbon sequestration.
2. The mass of carbon in the harvested grain shall be counted in the carbon stock change estimates. The mass of carbon in the seed may also be counted.
3. Net increases and/or avoided losses in the soil-organic-carbon pool as the result of rice cultivation shall be estimated using methods described in the Methods Module (MM-W/R).
4. Emissions shall be measured in the field under project conditions or may be quantified by an acceptable proxy, reference sample plots, or field monitoring of similar sites, using approved local or national parameters, peer-reviewed biogeochemical models or peer-reviewed literature.
5. Project Proponents using non-project specific values must use conservative estimates and demonstrate applicability.

Step 5. Estimation of Project Emission Reductions

This section describes calculation of $\Delta C_{Actual\text{-}RC}$ (cumulative total of the carbon stock changes and GHG emissions under the project scenario in tons CO_2-e). The actual net GHG removals by sinks shall be estimated using the equations in this section. When applying these equations for the *ex-ante* calculation of actual net GHG removals by sinks, Project Proponents shall provide estimates of the values of those parameters that are not available before the start of the crediting period and commencement of monitoring activities. Project Proponents should retain a conservative approach in making these estimates.

The net carbon stock change is estimated using the following general equation.

$$\Delta C_{actual\_TW} = \Delta C_p - \Delta GHG_p - E_{FFC} \qquad (12)$$

where:

ΔC_{ACTUAL_RC}	Cumulative total of carbon stock changes and greenhouse gas emissions under the project scenario; t CO_2-e
ΔC_p	Cumulative total of carbon stock changes under the project scenario; t CO_2-e (MM-W/R)
ΔGHG_{RC}	Cumulative total of the changes in GHG emissions as a result of implementation of the project activity; t CO_2-e (MM-W/R).
$E_{FC,i,t}$	Emission from fossil fuel combustion in stratum *i*; t CO_2-e (E-FFC).[86]

Equations for project emissions and carbon stock changes are provided in the Methods Module (MM-W/R). In applying these equations *ex-ante*, Project Proponents shall provide estimates before the start

[86] Only include in equation if project activities include moving sediment and fossil fuel combustion emissions have been determined to be significant using module T-SIG.

of the crediting period and monitoring activities using peer-reviewed literature (see Appendix) or biogeochemical models calibrated for project soil, climate and hydrologic conditions. Project Proponents should retain a conservative approach in making these estimates.

Nitrous oxide and CH_4 emissions (equation 3) can be measured using static chamber methods described in the Methods Module (MM-W/R). Alternatively, Table 14 can be used to estimate the N_2O emissions for rice cultivation for varying soil organic carbon content and fertilization rates in the Sacramento-San Joaquin Delta. Where fertilization rates are intermediate between 0 and 71 pounds N/acre, the project proponent can either conservatively use the high emissions estimate or estimate an emissions rate as a proportion of the rate for 71 pounds N per acre. For example for 5% soil carbon and a fertilization rate of 35 pounds N per acre, a project proponent may estimate the annual nitrous oxide emission rate at 0.25 tCO_2-e per acre (0.25 = 0.34 – ((0.34 - 0.16)/(71/35))).

Table 14. Annual nitrous oxide emissions estimates for varying soil organic carbon content and fertilizer application rates (0 and 71 lbs N per acre)[87].

Rate: 71 lbs N per acre

Soil carbon content (%)	Annual N_2O emission (t CO_2-e/acre-year)	Standard error
5	0.34	0.03
6	0.28	0.02
7	0.22	0.02
8	0.15	0.01
9	0.09	0.01
10	0.03	0.02
11	0.04	0.03
12	0.05	0.04
13	0.07	0.05
14	0.08	0.06
15	0.09	0.06
16	0.10	0.07
17	0.11	0.08
18	0.13	0.09
19	0.14	0.05
20	0.15	0.05
21	0.11	0.04
22	0.07	0.02
23	0.02	0.01
24	-0.02	0.01
25	-0.06	0.11

[87] Ye, R. and Horwath, W.R.,2014 Influence of variable soil C on CH_4 and N_2O emissions from rice fields 2013-2014. Presentation at UC Davis.

Rate: 0 lbs N per acre

Soil carbon content (%)	Annual N_2O emission (tCO_2-e/acre-year)	Standard error
5	0.16	0.09
6	0.13	0.08
7	0.11	0.06
8	0.08	0.05
9	0.06	0.03
10	0.03	0.02
11	0.04	0.02
12	0.04	0.02
13	0.05	0.03
14	0.05	0.03
15	0.06	0.03
16	0.07	0.04
17	0.07	0.04
18	0.08	0.04
19	0.08	0.05
20	0.09	0.04
21	0.07	0.03
22	0.05	0.02
23	0.04	0.02
24	0.02	0.01
25	0.00	0.04

Parameters for which Guidance Originates in other Modules

Parameter	ΔGHG_p
Units	t CO2-e
Equation	12
Description	Cumulative total of the changes in GHG emissions as a result of implementation of the project activity up to time *t*
Module	MM-W/R
Comment	Relevant information shall be included in the GHG Project Plan

Parameter	E_{FFC}
Units	t CO2-e
Equation	12
Description	Emission from fossil fuel combustion
Module	E-FCC
Comment	Relevant information shall be included in the GHG Project Plan

Recommended Best Management Practices for Rice in the Delta

Based on data collection efforts during 2008 – 2014, the following best management practices are indicated for rice production the western delta.

- To minimize loads of organic carbon and methyl mercury to Delta surface water bodies, strategies should be developed that promote recycling and reuse of island and rice- field drainage water. These strategies will include use of rice drainage water for irrigation of other crops and wetlands, irrigation with water from other crops and recycling of rice drainage water.
- Maintenance of high water levels in rice drainage ditches will minimize seepage from rice fields and reduce water application needs.
- Drain water quality and flow monitoring will aid in managing on-island and off-island constituent loads.
- Concomitant with recycling and reuse is the need to assess and manage soil and irrigation-water salinity. Rice is a salt sensitive crop and the reported threshold for the soil saturation extract salinity for yield declines in rice is 3,000 μS/cm[88]. For continued rice production, salt leaching will be required where soil salinity approaches this value.
- Crop nitrogen needs vary depending on nitrogen contribution from soil organic matter[89]. To maximize nitrogen availability to the crop and minimize nitrous oxide emissions, fertilizer should be applied about a month after planting immediately prior to flooding.
- Results presented here for Twitchell Island indicate less than 72 pounds nitrogen per acre are required and high yields were obtained with no addition of nitrogen. Soil nitrogen levels should be used to determine fertilizer requirements.

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[88]Maas, E.W., 1990, Crop Salt Tolerance in Tanji, K.K. (ed.) Agricultural Salinity Assessment and Management, American Society of Civil Engineers, New York

[89] Espe et al. 2015, see footnote 1

Methods and Model modules

Methodological Module for Estimation of Carbon Stock Changes and Emissions for Wetland and Rice Cultivation Projects in the San Francisco Estuary and Sacramento-San Joaquin Delta (MM-W/R)

Scope

This module provides direction for *ex-ante* estimation of soil carbon-stock changes and emissions for baseline and project conditions and data collection for inputs to biogeochemical models. Module X-UNC presents guidance for estimating uncertainty. Baseline conditions are discussed in modules BL Ag W/RC and BL SW W and BL OW W. Project conditions are discussed in PS-MW, PS-TW and PS-RC.

Applicability

This module is applicable for baseline conditions and project activities that include managed and tidal wetlands and rice cultivation in the San Francisco Estuary and Sacramento-San Joaquin Delta. The Framework Module (WR-MF) describes the applicable conditions and relevant project activities for the use of the methodology. If eddy covariance is used for project conditions, aqueous carbon losses from the wetland or contributions to the wetland must also be accounted for. Biogeochemical models documented in the peer-reviewed literature that are calibrated and validated for the project area can be used for estimating carbon stock changes for baseline and project conditions. The biogeochemical model module provides guidance for use of biogeochemical models for estimating project carbon stock changes and GHG emissions.

Parameters and Estimation Methods

Table 15. Parameters, description and estimation methods.

Table 15a. Carbon stock changes

Parameter symbol	SI Unit	Description	Estimation methods
ΔC_{BSL}	Metric tons CO_2-e (tCO_2-e)	Cumulative total of carbon stock changes for the baseline scenario	Biogeochemical modeling, eddy-covariance, subsidence measurements
ΔC_{P}	t CO_2-e	Cumulative total of carbon stock changes for the project scenario	Eddy-covariance, modeling, soil core collection and analysis using feldspar markers and tidal pins

Table 15b. Emissions

Parameter symbol	SI Unit	Description	Estimation methods
ΔGHG_{BSL}	Metric tons CO_2 - e (tCO_2-e)	Cumulative GHG emissions for the baseline scenario	Chamber measurements, biogeochemical modeling, eddy-covariance measurements, subsidence measurements
ΔGHG_{P}	Metric tons CO_2 - e (tCO_2-e)	Cumulative GHG emissions due to project activities	Chamber measurements, biogeochemical modeling, eddy-covariance measurements
ΔGHG_{ff}	Metric tons CO_2-e (tCO_2-e)	Cumulative GHG emissions due to consumption of fossil fuel	Module E-FFC-WR (http://americancarbonregistry.org/carbon-accounting/restoration-of-degraded-deltaic-wetlands-of-the-mississippi-delta), provides guidance for fossil fuel emissions estimates.

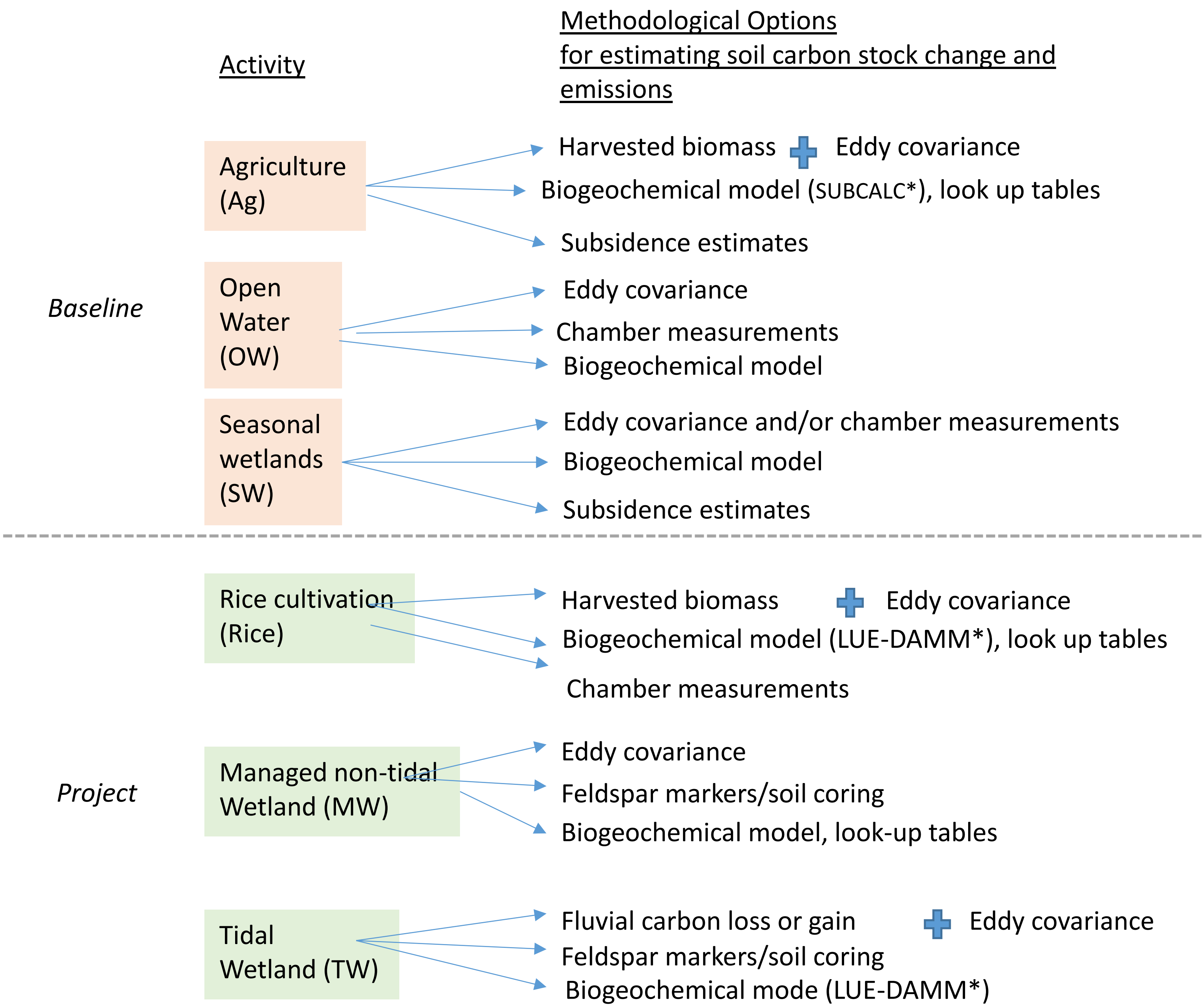

Figure 5. Relation of project and baseline activities to methods for determination of GHG emissions and soil carbon stock changes.

*** LUE-DAMM and SUBCALC models are described in the MODEL module.**

This module also provides guidance for determination of the following parameters which are inputs for biogeochemical models for project conditions. These parameters can be estimated using appropriate measurements documented in the peer-reviewed literature or estimates for similar situations in which case the environmental setting for the estimates shall be detailed. If proxy measurements are used, documentation of similar climate, soil chemical and hydrologic conditions and vegetation must be provided. Also, there shall be a documentation of conservatism and that there is not double counting of sequestered carbon through documentation of monitoring and modeling inputs and results. (See Framework Module for explanation of double counting and relevant carbon pools.)

Table 16. Parameters used in biogeochemical models, description and estimation methods.

Parameter	SI Unit	Description	Estimation methods
$\Delta C_{ag\ biomass\ P}$	Metric tons CO_2-e (t CO_2-e)	Cumulative above-ground non-woody biomass carbon stock changes for project	Allometric equations, leaf area index, digital photography, destructive methods
$\Delta C_{bg\ biomass\ P}$	t CO_2-e	Cumulative below-ground biomass carbon stock changes for project	Multiplication of accumulated above-ground biomass times published root:/shoot ratio, destructive methods
$\Delta C_{litter\ P}$	t CO_2-e	Litter carbon stock changes	Direct measurements using decomposition bags or indirect estimates from isotopic technique and/or modeled estimates based on environmental controls
$\Delta C_{cr\ BSL}$	t CO_2-e	Crop residue remaining in field for baseline conditions	Destructive methods for harvest and determination of carbon content of biomass.

Methods

Figure 5 and Table 16 show the appropriate methods for both the project and baseline activities. The methods listed in column 4 can be used alone or in tandem with the other methods listed. For the agricultural and seasonal-wetland baseline carbon stock changes, subsidence estimates and eddy covariance methods are appropriate. If eddy covariance is used to estimate carbon losses for the agricultural baseline, the harvested biomass must also be estimated. For the open water baseline, measurements of baseline soil carbon stock changes and emissions are not required. Soil carbon stock changes for project activities can be estimated using eddy covariance or soil coring and feldspar markers or sediment pins. If eddy covariance is used for project conditions, aqueous carbon losses from the wetland or contributions to the wetland must also be accounted for. Soil carbon stock changes can be estimated using appropriate peer-reviewed proxy measurements or estimates for settings with similar soil, hydrologic, climatic and vegetation conditions. The environmental setting for the proxy estimates shall be detailed. Also, there shall be a demonstration of conservatism. The number of sampling plots should ensure that they adequately represent the area being measured by following guidance in the T-PLOTS module.

Eddy Covariance

The eddy covariance (EC) technique[90] estimates fluxes of GHGs by relying on the concurrent determination and statistical analysis of vertical atmospheric velocity and the atmospheric concentration of the GHG (e.g. CO_2, CH_4, N_2O) of interest. These two values (GHG concentration and vertical atmospheric velocity) are multiplied to obtain a flux. Carbon dioxide and CH_4 can be measured at the field scales of tens of acres using this method. The eddy covariance method is capable of measuring gaseous fluxes directly and for extended periods to times in a quasi-continuous manner. This approach is allowed for estimating carbon stock changes and emissions for baseline and project conditions. Soil carbon stock changes can be quantified by measuring the net ecosystem carbon exchange.

Solar radiation provides the source of energy that drives CO_2 assimilation. It sets the upper limit for photosynthesis, respiration, evaporation and canopy leaf area, which are related to one another[91]. Carbon dioxide is respired as the result of decomposition. Decomposition of the soil organic pools results in release of CO_2, CH_4, dissolved organic carbon, N_2O and N_2. Eddy covariance measurements provide an effective way to determine the net exchange of CO_2 for a variety of ecosystems[7] and have been used to measure baseline[92] and project[9] carbon stock changes on Delta organic and highly organic mineral soils.

For agricultural baseline conditions (e.g. corn) on organic soils, CO_2 assimilation occurs as the result of plant photosynthetic uptake during the growing season and the crop is a net GHG remover during this time. During the non-crop period, oxidation of organic matter results in a net GHG emission. However, CO_2 assimilation into the harvested grain is removed and results in an overall annual GHG emission for the cropped system under drained conditions. In contrast, for a permanently flooded wetland and to a lesser extent, rice, flooding the soil during the warmest time of the year greatly reduces GHG emissions due to oxidation of soil organic matter and there is net CO_2 assimilation into the wetland vegetation resulting in a net GHG removal.

Several researchers have used eddy covariance to measure the carbon budget for agricultural, marsh and forest ecosystems. Hatala et al.[93] determined the rates of carbon stock changes in rice and a pasture on an organic soil in the Sacramento-San Joaquin Delta. Their rates of carbon capture in rice were slightly lower than those from a riparian cottonwood stand about 50 km east of their site where

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[90] Baldocchi DD, Hicks BB, Meyers TP (1988) Measuring biosphere–atmosphere exchanges of biologically related gases with micrometeorological methods. *Ecology* **69**, 1331–1340.

[91] Brinson MM, Lugo AE, Brown S (1981) Primary Productivity, Decomposition and Consumer Activity in Fresh-Water Wetlands. *Annual Review of Ecology and Systematics* **12**, 123-161.

Kim J, Verma SB, Billesbach DP (1999) Seasonal variation in methane emission from a temperate Phragmites-dominated marsh: effect of growth stage and plant-mediated transport. *Global Change Biol* **5**, 433-440.

Running, S.W., Baldocchi, D.D., Turner, D.P., Gower, S.T., Bakwin, P.S., Hibbard, K.A. (1999) A global terrestrial monitoring network integrating tower fluxes, flask sampling. Ecosystem modeling and EOS satellite data. *Remote Sens. Environ*. **70** (1), 108–127.

[92] Teh YA, Silver WL, Sonnentag O, Detto M, Kelly M, Baldocchi DD (2011) Large greenhouse gas emissions from a temperate peatland pasture. *Ecosystems* **14**, 311–325.

[93] Hatala JA, Detto M, Sonnentag O, Deverel SJ, Verfaillie J, Baldocchi DD (2012) Greenhouse gas (CO2, CH4, H2O) fluxes from drained and flooded agricultural peatlands in the Sacramento-San Joaquin Delta. *Agriculture, Ecosystems and Environment* **150**,1-18.

Kochendorfer et al.[94] measured a net carbon removal using eddy covariance. The magnitude of CO_2 uptake at the Hatala et al. rice paddy was well below that from a restored marsh in southern California, where net carbon captured measured with eddy covariance varied between 6.8 and 18.5 tons CO_2 per acre during an eight-year study[95], higher than historical rates of accumulation in disturbed ecosystems of the same region[96] . Hollinger at al.[97] used continuous eddy-covariance carbon flux measurements from 1997 to 2002 to evaluate the carbon budget for a maize and soybean rotation agricultural ecosystem. Their results indicated and net carbon sequestration of 7 and 0.5 metric tons CO_2 per acre per year for maize and soybean on mineral soils, respectively. However, these authors did not account for N_2O emissions.

Applicability Conditions for Use of Eddy Covariance for Estimation of Carbon Stock Changes and Emissions

The following applicability conditions apply to the use of eddy covariance.

1. Stratification and eddy covariance footprint. The area of land which is included in the eddy covariance flux measurements or footprint of the eddy covariance measurement shall be quantified during the monitoring period and shall be shown to adequately represent the hydrologic, water quality and soil conditions and land- and water-management practices for the stratum. (Stratification is a standard procedure to decrease overall variability of carbon stock estimates by grouping data taken from environments with similar characteristics (e.g., vegetation type; age class; hydrology; elevation. More detail about stratification is provided in the Framework Module (MF-W/R). For example, for baseline conditions, the agricultural crop and water- and land-management practices within the eddy covariance footprint shall be the same as for the entire stratum. Also, for baseline conditions, the average soil organic matter content within the eddy-covariance footprint shall not vary more than 20 % relative to the average soil organic matter content within the stratum.
2. Adjacent land uses. To avoid influences of adjacent land uses, the eddy covariance footprint shall be entirely within the stratum that includes project or baseline land uses.
3. Monitoring period. The monitoring period using eddy covariance techniques shall be sufficient to quantify annual variations in carbon stock changes and to enable the use of biogeochemical models. The Project Proponents shall demonstrate that annual values for carbon stock changes for baseline are representative. At least one year of monitoring is required for baseline conditions. The counterfactual baseline scenario shall be developed for the entire life of the project using site-specific data and/or data and models documented in the peer-reviewed. For project conditions, continuous monitoring is required throughout the life of the project unless the use of biogeochemical models calibrated with the eddy covariance data are shown to adequately predict emissions and carbon stock changes. At this point, eddy covariance measurements can be terminated.

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[94] Kochendorfer J, Castillo EG, Haas E, Oechel WC, Paw UKT (2011) Net ecosystem exchange, evapotranspiration and canopy conductance in a riparian forest. *Agric.Forest Meteorol*. **151**, 544–553.

[95] Rocha AV, Goulden ML (2008) Large interannual CO_2 and energy exchange variability in a freshwater marsh under consistent environmental conditions. *J. Geophys. Res. Biogeosci*. **113**, G03026

[96] Canuel EA, Lerberg EJ, Dickhut RM, Kuehl SA, Bianchi TS, Wakeham SG (2009) Changes in sediment and organic carbon accumulation in a highly disturbed ecosystem: the Sacramento-San Joaquin River Delta (California, USA). *Mar. Pollut. Bull*. **59**, 154–163.

[97] Hollinger SE, Bernacchil CJ, Myers TP (2005) Carbon budget of mature no-till ecosystem in North Central Region of the United States, *Agricultural and Forest Meterology*, **130**, 59–69.

Quality Control and Quality Assurance Precautions

Table 17. Quality Control/Assurance for Eddy Covariance Measurements

Quality Control/Assurance Topic	Considerations	Procedures
Temporal variability and frequency of measurements	GHG and energy fluxes shall be measured at each site with the EC method[1] using parameters determined to be adequate for accurate eddy covariance measurements in peat soils and wetlands[2-4]. Carbon accumulation rates shall be compared with measurements reported for natural and disturbed ecosystems in the region[12].	Standard eddy covariance practice as described in the literature cited above shall be employed to measure the covariance between turbulence and C fluxes at 10 Hz intervals (every 0.1 s). These data shall be used to calculate half-hourly fluxes for net ecosystem exchange.
Filtering and removal of spurious data	Eddy covariance data typically contain gaps and artificial spikes.	The sampling rate and averaging interval will allow for a 5 Hz cut-off for the cospectra between turbulence and carbon fluxes. After computing the fluxes, flux values with anomalously high and low friction velocity (u^* > 1.2 m s−1 and $\|uw\| < 0.02$)[9] shall be filtered to constrain the analysis to periods where the air near the sensors was well-mixed. The random instrumental noise in each half-hour fluxes shall be assessed using bootstrapping technique[9]. Fluxes from wind directions outside of the footprint of the target land-use type shall be excluded from the dataset. For baseline and project conditions, missing data shall be treated conservatively so as to not overestimate the GHG benefit. Filtering software may be used to remove artificial spikes, which shall be greater than six standard deviations of the mean[3], within a one-minute window and diagnostic instrument values that corresponded with bad readings, which are often correlated with rain or fog events. Typically, no less than 10% of the original flux data is excluded through this procedure[9]. The Project Proponents shall justify a conservative application of any larger percentages. The bootstrap technique will evaluate the covariances to calculate the standard deviation of calculated fluxes across the bootstrapped covariances.

Equations for Baseline and Project Conditions

$$\Delta GHG = T * [\sum_{i=1}^{n}(E_{CO_2,i} + E_{CH_4,i} + E_{N_2O,i}) + \sum_{i=1}^{n} Cgr_i \ + E_{aq,}] \qquad (13)$$

Where ΔGHG represents cumulative net emissions in metric tons (tCO_2-e) of CO_2 and CH_4 during the reporting period and:

$E_{CO_2,i}$ is the annual net emission of CO_2 (tCO_2-e);

$E_{CH_4,i}$ is the annual net emission of CH_4 (tCO_2-e);

$E_{N_2O,i}$ is the annual net emission of N_2O (tCO_2-e) ;

i refers to the stratum within the project boundary;

n is the total number of strata within the project boundary;

E_{aq} is the annual net aqueous loss of carbon in drainage water (tCO_2-e);

T is the period of time which corresponds to the reporting period in years

Cgr_i is the harvested or removed grain or biomass for crop in stratum i (tCO_2-e).

The net aqueous loss of dissolved and particulate organic carbon can be calculated by subtracting the aqueous carbon input from the aqueous carbon export. Specifically,

$$E_{aq} = \left(Q_{export} \times [TOC] - Q_{import} \times [TOC]\right) \qquad (14)$$

Because eddy covariance measures the net ecosystem exchange,

$$\Delta GHG = \Delta C \qquad (15)$$

Where ΔC is the cumulative carbon stock change.

Chamber Measurements

For project and baseline conditions, gaseous fluxes of CO_2, CH_4 and N_2O from wetland surfaces and open water for project or for baseline conditions can be measured using the static chamber method[98 99]. Measurements should ensure that temporal variations are accounted for, or be measured during the time of greatest anticipated flux in order to conservatively estimate net GHG emission reductions/removal enhancements. For agricultural baseline conditions, the chamber methods described in Livingston and Hutchinson[100], Mosier[101] and Rolston[102] are applicable. Chambers described in Lindau are appropriate for project conditions.[103, 104,105,106]

Temperature inside the chamber shall be monitored. Gas must be mixed so that a concentration gradient does not occur. Mixing is normally accomplished by diffusion in small chambers, but a small fan may be required to ensure mixing in larger chambers. Gas samples are taken with plastic syringe and stainless steel hypodermic needles. Samples shall be collected at minimum at least three times to allow to allow a linear buildup of the concentration of the gas being measured) after chamber top placement. The overpressure created will ensure that atmospheric gases will not contaminate the sample gases. Silicone sealant is used to seal the injection hole in the rubber septum. The CH_4, CO_2, or N_2O concentrations of the gas samples can be measured on a gas chromatograph (GC). The flux of gases from the soil or wetland surface is calculated from the data obtained from the GC and can be then estimated using the equation[1]:

$$f(gas) = \frac{V\Delta C}{A\Delta t} \qquad (16)$$

where:

f is the GHG gas flux (g gas m^{-2} s^{-1})

V is the volume of chamber headspace (m^3 gas volume)

A is the soil surface area (m^2) and

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[98] Livingston, G.P. and G.L. Hutchinson, 1995. Enclosure-based Measurement of Trace Gas Exchange: Application and Sources of Error. P. 14-51 In: P.A. Matson and R.C. Harris (eds.) Biogenic Trace Gases: Measuring Emissions from Soil and Water. Blackwell Science Ltd., London.

[99] Klinger, L.F., Zimmerman, P.R., Greenberg, J.P., Heidt, L.E., and Guenther, A.B., 1994. Carbon Trace Gas Fluxes Along a Successional Gradient in the Hudson Bay Lowland. J. Geophys. Res. 99 (D1):1469–1494

[100] ibid

[101] Hutchinson, G. L., and A. R. Mosier, Improved soil cover method for field measurement of nitrous oxide fluxes, *Soil Sci. Soc. Am. J.*, *45*, 311–316, 1981

[102] Rolston, D. E., Gas flux, in *Methods of Soil Analysis*, *Part 1*, *Agron.Monogr*., vol. 9, edited by A. Klute, pp. 1103–1119, Am. Soc. of Agron. and Soil Sci. Soc. of Am., Madison, Wis., 1986

[103] Lindau, C.W., and R.D. DeLaune. 1991. Dinitrogen and nitrous oxide emission and entrapment in *Spartina alterniflora* saltmarsh soils following addition of N-15 labelled ammonium and nitrate. Estuarine Coastal Shelf Sci. 32:161–173. doi:10.1016/0272-7714(91)90012-Z

[104] Miller, R.L., Hastings, L., Fujii, R., 2000. Hydrologic treatments affect gaseous carbon loss from organic soils, Twitchell Island, California, October 1995-December 1997. U.S. Dept. of the Interior, U.S. Geological Survey, Sacramento, Calif.

[105] Majumdar, D., 2013. Biogeochemistry of N_2O Uptake and Consumption in Submerged Soils and Rice Fields and Implications in Climate Change. Critical Reviews in Environmental Science and Technology 43, 2653-2684.

[106]Linquist, B.A., Adviento-Borbe, M.A., Pittelkow, C.M., van Kessel, C., van Groenigen, K.J., 2012b. Fertilizer management practices and greenhouse gas emissions from rice systems: A quantitative review and analysis. Field Crops Research 135, 10-21.

$\Delta C/\Delta t$ the change in gas concentration (g/m^3s^{-1}) per unit of time within the chamber

Locations of measurements shall be determined by known spatial variability and the required level of certainty. Chamber measurements shall account for heterogeneous landscapes within strata as described in baseline and project modules. If present, baseline chamber measurements shall be conducted within upland and lowland areas, and drainage ditches[107]. Spatially weighted up-scaling methods are recommended for estimating annual GHG budgets across heterogeneous landscapes[15]. Flux measurements shall be taken multiple times during the year for estimating seasonal or annual flux and temporal and spatial replication is important to reduce uncertainty.

Special care must be taken when estimating N_2O emissions using chambers. Fertilization and re-wetting events are especially important for N_2O budgets, where a single pulse event can account for >50% of the annual N_2O budget[108]. Therefore, in order to accurately estimate N_2O emissions using manual chambers, deployment must include fertilization, irrigation and precipitation events. These pulse events can encompass several days (1-30 days) and therefore must be evaluated at an appropriate time scale. Estimations of annual N_2O budgets from chamber measurements must account for the amount and frequency of fertilization, irrigation, and precipitation events in addition to lower-level N_2O emission rates that occur outside pulse events.

The following applicability conditions apply to the use of chambers.

1. Stratification. The distribution of chamber measurement shall be shown to adequately represent the hydrologic, water quality and soil conditions and land- and water-management practices for the stratum.
2. Monitoring period. The monitoring period using chamber measurements shall be sufficient to quantify possible annual variations in emissions. The Project Proponents shall demonstrate that annual values for emissions for baseline are representative. At least one year of monitoring is required for baseline conditions. For project conditions, monitoring is required throughout the life of the project unless the use of biogeochemical models calibrated with site data are shown to adequately predict emissions. At this point, chamber measurements may be terminated.
3. N_2O emissions can be conservatively ignored in permanently flooded wetland conditions. Under permanently flooded soil conditions, N_2O is mostly consumed during denitrification and converted to N_2[109].
4. When measuring N_2O emissions using chambers, deployment must include fertilization, irrigation and precipitation events.
5. Monitoring must occur for baseline establishment and renewal. For project conditions, the monitoring frequency shall occur at least every 5 years for one year. Baseline field monitoring should be conducted seasonally for one year to determine the seasonal effects on greenhouse gas fluxes, or measurements can be made during the period of peak emissions (e.g., summer or

[107] Teh, Y.A., Silver, W.L., Sonnentag, O., Detto, M., Kelly, M., Baldocchi, D.D., 2011. Large greenhouse gas emissions from a temperate peatland pasture. Ecosystems 14, 311–325.
These authors demonstrated that drainage ditches can account for <5% of the land area and contribute more than 84% of CH_4 emissions and 37% of ecosystem GWP in a Delta peat-land pasture.

[108] Wagner-Riddle C, Thurtell G, Kidd G, Beauchamp E, Sweetman R (1997) Estimates of nitrous oxide emissions from agricultural fields over 28 months. *Canadian Journal of Soil Science,* **77**, 135-144.

[109] Butterbach-Bahl K, Baggs EM, Dannenmann M, Kiese R, Zechmeister-Boltenstern S (2013) Nitrous oxide emissions from soils: how well do we understand the processes and their controls? *Philosophical Transactions of the Royal Society B: Biological Sciences,* **368**, 20130122.

fertilization events). Livingston and Hutchinson[110] and Crill et al.[111] provide guidance for minimizing measurement and flux estimation error in chamber measurements. Also, it is important to account for microsites and spatial variability as discussed above.

Quality Control and Quality Assurance Precautions for Chamber Measurements

Quality assurance and control measures for chamber measurements are listed and discussed in Table 18.

Table 18. Quality Control/Assurance for Chamber Measurements

Quality Control/Assurance Topic	Considerations	Precautions and safeguards	Reference footnote
Temperature	Ambient temperature should be preserved within the chamber. Solar heating of the enclosure surface can rapidly lead to increasing chamber temperatures	Minimize deployment times, use shading of opaque materials, monitor chamber temperature	21
Deployment - development of a disturbance free seal	Leakage can occur in unsaturated-zone soils especially during high winds.	Use weighted skirts around chambers and /or baffled, double-walled enclosures. Avoid high winds. Estimate leakage with a tracer gas	21, 22
Deployment – surface compaction	Artificial gradients and mass inflow can be induced by surface compaction from foot traffic. Water-saturated soils are particularly susceptible.	Use of designated walkways, remote gas withdrawal from chambers.	21
Deployment – vegetative disturbance	Disturbance of vegetation can affect exchange processes under study and influence plant mediated gas transport	Avoid cutting roots or severing stems and leaves	21
Field sample handling and processing	Sample container leakage and accuracy	Analyze gas samples within a few hours, analyze standards frequently	21
Laboratory analysis	Potential for analytical error	Follow acceptable analytical protocol for trace gas analysis	21

[110] Livingston, G.P. and G.L. Hutchinson, 1995. Enclosure-based Measurement of Trace Gas Exchange: Application and Sources of Error. P. 14-51 In: P.A. Matson and R.C. Harris (eds.) Biogenic Trace Gases: Measuring Emissions from Soil and Water. Blackwell Science Ltd., London.

[111] Crill, P.M., Butler, J.H., Cooper, D.J., and Novelli, P.C., 1995, Standard analytical methods for measuring trace gases in the environment In: P.A. Matson and R.C. Harris (eds.) Biogenic Trace Gases: Measuring Emissions from Soil and Water. Blackwell Science Ltd., London

Flux estimation	Time for concentration change measurements, chamber dimensions	Minimize sources of variability in sampling handling and analysis using maximum possible measurement period and number of independent samples. Two samples are insufficient. Determine chamber volume precisely.	21
Spatial variability and stratification	Previous measurements in Delta rangelands have demonstrated substantial spatial variability.	Locations of measurements shall be determined by known spatial variability and the required level of certainty. Chamber measurements must account for heterogeneous landscapes. Spatially-weighted up-scaling methods are recommended for estimating annual GHG budgets across heterogeneous landscapes	

Equations

Cumulative GHG emissions for baseline (ΔGHG_{BSL})

Where chambers are used to estimate cumulative GHG emissions shall be estimated using the following equation.

$$\Delta GHG_{BSL} = \left(\frac{1}{n}\sum_{t=1}^{n} fGHG_{BSL,t}\right) \times T_{pp} \times CF \qquad (17)$$

where:

ΔGHG_{BSL} is the cumulative GHG emissions for the baseline scenario; metric tons CO_2-e;

$fGHG_{P,t}$ is the rate of GHG emissions from the project area at monitoring event t prior to project activity (tCO_2-e)

T_{pp} is the reporting period for pre-project monitoring (years)

n is the number of baseline monitoring events

t *represents the* monitoring event

CF is the factor for converting from the measurement time scale to the time scale of T_{pp}.

The flux of greenhouse gases from the project area under baseline conditions at time t is:

$$fGHG_{BSL,t} = \sum_{i=1}^{n} fGHG_{CH_4\_BSL,i,t} \cdot GWP_{CH_4} + \sum_{i=1}^{n} fGHG_{N_2O\_BSL,i,t} \cdot GWP_{N_2O} \qquad (18)$$

where:

$fGHG_{BSL,t}$ is the rate of GHG emissions from the project area at monitoring event t prior to project activity, measured using chambers (tCO_2-e);

$fGHG_{CH_4\_BSL,i,t}$ is the rate CH_4 emissions from the project area in stratum i at monitoring event t (tCO_2-e)

GWP_{CH_4} is the global warming potential for CH_4 (= 21 per ACR Standard) (tCO_2-e)

$fGHG_{N_2O\_BSL,i,t}$ is the rate of N_2O emissions from the project area in stratum i at monitoring event t (tCO_2-e)

GWP_{N_2O} is the global warming potential for N_2O (= 310 per ACR Standard) (tCO_2-e)

n is the number of strata in the project scenario

i represents the strata in the project scenario and

t represents the monitoring event

Cumulative GHG emissions for the project scenario ($\Delta \boldsymbol{GHG_p}$)

Where chambers are used, total project GHG emissions should be extrapolated from average instantaneous measurements using the following equation:

$$\Delta GHG_P = \left(\frac{1}{n} \sum_{t=1}^{n} fGHG_{P,t} \right) \times T_p \times CF \qquad (19)$$

where:

ΔGHG_P is the cumulative GHG emissions for the project scenario (tCO_2-e);

$fGHG_{P,t}$ is the rate of GHG emissions from the project area at monitoring event t, measured using chambers (tCO_2-e);

n is the number of monitoring events;

t represents the monitoring event and

CF is the factor for converting from the measurement time scale to years (the time scale of T_p)

T_p is the period of time which corresponds to the project reporting period in years.

The flux of greenhouse gases from the project area under baseline conditions at time t is:

$$fGHG_{P,t} = \sum_{i=1}^{n} fGHG_{CH_4\_i,t} \cdot GWP_{CH_4} + \sum_{i=1}^{n} fGHG_{N_2O\_i,t} \cdot GWP_{N_2O} + \sum_{i=1}^{n} fGHG_{CO_2\_i,t} \qquad (20)$$

where:

$fGHG_{P,t}$ is the rate of GHG emissions from the project area at monitoring event t, measured using chambers (tCO_2-e);

$fGHG_{CH_4\_i,t}$ is the rate of CH_4 emissions from the project area in stratum i at monitoring event t (tCO_2-e);

GWP_{CH_4} is the global warming potential for CH_4 (= 21 per ACR Standard) (tCO_2-e);

$fGHG_{N_2O\_i,t}$ is the rate of N_2O emissions from the project area in stratum i at monitoring event t (tCO_2-e);

GWP_{N_2O} is the global warming potential for N_2O (=310 per ACR Standard) (tCO_2-e)$fGHG_{CO_2\_i,t}$ is the rate of project CO_2 emissions from the project area in stratum i at monitoring event t (tCO_2-e);

n is the number of strata in the project scenario;

i represents the strata in the project scenario and

t represents the monitoring event.

Harvested Grain and Biomass

The carbon in harvested grain and biomass represents an essential part of the net ecosystem exchange for baseline agricultural and rice project conditions when determined by eddy covariance (Equation 13). Harvested grain or biomass is determined by 1) collection of grain or biomass in representative plots within the stratum and 2) determination of the carbon and moisture content on the collected material using literature and laboratory analysis of the material and 3) estimation of total carbon removed in grain and/or biomass for the stratum. Alternatively, the Project Proponent may obtain information from the farmer about the weight of the harvested grain and/or biomass and use literature values and laboratory-determined values for the carbon and moisture content of the harvested grain and/or biomass to estimate Cgr_i, the carbon dioxide harvested or removed grain or biomass for the crop in stratum i (tCO_2-e) (Equation 1). The moisture content of the harvested material shall be determined at harvest. Methods described in Karlra[112] and McGeehan and Neeler[113] are applicable for determination of moisture content and carbon content.

Applicability Conditions

1. Stratification. The distribution of determination of Cgr_i shall be shown to adequately represent the hydrologic, water quality and soil conditions and land- and water-management practices for the stratum.
2. Monitoring. Annual estimates of Cgr_i are sufficient. For multiple harvests (such as for hay or grain crops), the annual estimate shall equal the sum of all harvests.
3. Monitoring must occur for baseline establishment and renewal. For project conditions, the monitoring frequency shall occur at least every 5 years over a period of one year.
4. The Project Proponent shall demonstrate using maps and photographs that yield plots are representative of the entire stratum.

Quality Assurance Measures

1. Where yield plots are used, plots shall be replicated three times within each stratum and the entire plot shall be harvested.
2. The average yield and standard deviation from the three replicate plots shall be used in uncertainty calculations in the uncertainty module (X-UNC).

Equations

For agricultural baseline conditions and rice project conditions, carbon removal in harvested biomass shall be estimated using the following equation[114]:

$$C_{gr} = W \times fC \times Y \qquad (21)$$

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[112] Karlra, Yash P. (ed.), 1998, Handbook of Reference Methods for Plant Analysis, CRC Press

[113] McGeehan, S.L. and D.V. Naylor. 1988. Automated instrumental analysis of carbon and nitrogen in plant and soil samples. *Commun. Soil Sci. Plant Anal.* 19:493-505.

[114] e.g. Steven E. Hollinger a,*, Carl J. Bernacchi a,1, Tilden P. Meyers, 2005, Carbon budget of mature no-till ecosystem in North Central Region of the United States, Agricultural and Forest Meteorology 130 (2005) 59–69

where:

C_{gr} = Carbon removal in harvested biomass in metric tons (tCO_2-e per unit area).

W is the moisture content expressed as a fraction ;

fC is the fraction of carbon in the grain or biomass[115] and;

Y is the yield in tons per unit area.

The use of equations 1 and 9 assumes that 100% of the harvested biomass is eventually consumed and oxidized to CO_2 and CH_4 which is released back into the atmosphere.

Aqueous Carbon Loads

For baseline and project conditions, aqueous carbon loads ($E_{aq,}$) represent part of the overall carbon budget as determined by eddy covariance (Equation 13). Aqueous carbon can enter and exit the project area to and from adjacent channels as dissolved and particulate organic carbon. The total organic carbon (TOC) concentration is equal to the sum of particulate and dissolved organic carbon. Loads are equal to the water flow times the concentration of total organic carbon in the water. The project Proponent shall utilize peer-reviewed methods for determining concentrations, flow and loads in tidal l[116] [117] and non-tidal[118] systems. For flow measurements, methods include manual flow and acoustic velocity meters. Methods for total dissolved organic carbon determination in drain-water samples are described in Deverel et al.[119]

Specifically, for non-tidal managed wetlands, subsurface and surface drainage flow can be measured and calculated continuously using traditional flow measurements using manually operated flow meters and tracking stage at a control device such as a weir with a water level recorder. Dissolved and particulate organic carbon concentrations shall be determined at intervals that adequately represent the temporal variability but not less than bimonthly. Alternatively, flow can be measured using continuous recording acoustic Doppler technology. For tidal systems, a similar approach can be used except that flow is bidirectional depending on tidal influences.

Applicability Conditions

1. Stratification. The determination of $E_{aq,}$ shall be shown to adequately represent the hydrologic, water quality and soil conditions and land- and water-management practices for the stratum.

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[115] Loomis, R.S., Conner, D.J., 1992. Crop Ecology: Productivity and Management in Agricultural Systems. Cambridge Univ. Press, New York, NY, 538 pp.

[116] Ganju NK, Schoellhamer DH, Bergamaschi ABA (2005) Suspended Sediment Fluxes in a Tidal Wetland: Measurement, Controlling Factors, and Error *Analysis Estuaries* **28**(6), 812–822

[117] Bergamaschi BA, Fleck JA, Downing BD, Boss E, Pellerin B, Ganju NK, Schoellhamer DH, Byington AA, Heim WA, Stephenson M, and Fujii R, (2011) Methyl mercury dynamics in a tidal wetland quantified using in situ optical measurements*, Limnol. Oceanogr*., **56**(4), 2011, 1355–1371

[118] e.g. Deverel, Steven J., David A. Leighton and Mark R. Finlay. Processes Affecting Agricultural Drainwater Quality and Organic Carbon Loads in California's Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science. Vol. 5, Issue 2 [May 2007]. Article 2. http://repositories.cdlib.org/jmie/sfews/vol5iss2/art2

[119] ibid

2. Monitoring. Measurements shall adequately represent the temporal variability in concentrations and loads.
3. For non-tidal systems, the temporal variability is determined by hydrologic management and season variability. Monthly measurements are generally sufficient to characterize the temporal variability.
4. Tidal fluxes of dissolved and particulate organic carbon shall be estimated or measured at a time scale that allow determination of the net annual loss or gain of organic carbon to or from the wetland.

Quality Assurance

The uncertainty in manual flow measurements shall be determined as per guidance in Sauer and Meyer[120] and incorporated in into the uncertainty equations in the uncertainty module (X-UNC). Uncertainty in acoustic velocity measurements shall be evaluated using information described in Laenen and Curtis[121]. Analytical uncertainty for dissolved organic carbon shall be determined using field duplicate and blank samples and laboratory QA/QC samples and shall be incorporated into the flow measurement uncertainty.

Equations

See equation 14.

Subsidence Measurements for Estimating Baseline Soil Carbon Stock Changes and Emissions

Subsidence is caused by the oxidation of organic soils[122]. As organic soils are drained for agricultural use and exposed to oxygen, they oxidize and disappear. Subsidence is estimated as the difference between elevations at two points in time. For the baseline scenario, subsidence measurements can be converted to carbon stock changes using methods described in Couwenberg and Hooijer[123] and here. Couwenberg and Hooijer described a simple approach to determining total net carbon loss from subsidence records.

If subsidence measurements are used, it is assumed that the soil carbon pool is decreasing via oxidation, and emissions are accounted for by ΔGHG using equation shown below. Where there are elevation measurements in organic or highly organic mineral soils, at two or more points in time, the difference in elevation and soil carbon density can be used to estimate historic baseline emissions by multiplying the elevation change by the soil carbon density. Soil carbon density is equal to the soil carbon content multiplied by the soil bulk density. Data for soil organic matter content for Delta and San Francisco

[120] Sauer, V.B. and R.W. Meyer. 1992. Determination of error in individual discharge measurements. Open-File Report 92-144. U.S. Geological Survey.
[121] Laenan, Antoniua and Curtis, R.E., Accuracy of acoustic velocity metering systems for measurements of low velocity in open channels, US Geological Survey Water Resources Investigation Report 89-4090.
[122] Deverel S.J. and Leighton D.A., 2010, Historic, Recent, and Future Subsidence, Sacramento-San Joaquin Delta, California, USA. San Francisco Estuary and Watershed Science 8(2). http://www.escholarship.org/uc/item/7xd4x0xw
[123] Couwenberg J, Hooijer A (2013) Towards robust subsidence-based soil carbon emission factors for peat soils in south-east Asia, with special reference to oil palm plantations, *Mires and Peat*, **12**, 1–13.

Estuary soils is described in Callaway et al.[124] Deverel and Leighton[125] and Drexler et al.[126]. Soil carbon content is equal to 50% of the soil organic matter content. Drexler et al. provided data for soil bulk density for eight Delta islands.

Applicability Conditions

1. Locations of measurements shall be determined by strata, known spatial variability and the required level of certainty as per guidance in the T-PLOT module. The determination of ΔGHG_{BSL} (Equation 7) shall be shown to adequately represent the hydrologic, water quality and soil conditions and land- and water-management practices for the stratum.
2. Project Proponents shall be conservative in estimating the depth of subsidence from elevation measurement differences by calculating the minimum possible difference between elevations measured at two points in time.
3. All elevation measurements for subsidence calculations shall be referenced to stable benchmarks.
4. Project Proponents shall insure and document the consistent use of vertical datums for elevations measured during different years.
5. Project Proponents shall use conservative values for soil organic carbon and bulk density values that result in conservative estimates for subsidence.

Quality Control and Quality Assurance

Uncertainty in subsidence estimates stem from 1) elevation measurements and 2) soil carbon and bulk density determinations. For elevation measurements, uncertainty is dependent on methods used which shall be documented and incorporated into uncertainty calculations in the uncertainty module (X-UNC). For example, Deverel and Leighton determined elevations at locations on Bacon Island in 2006 where elevations were measured by University of California researchers in 1978. The vertical closure error for the 1978 survey with traditional surveying equipment was 0.07 m. For the 2006 survey which utilized real time kinematic, static and fast-static Global Positioning System measurements vertical closure error was 0.002 m. Therefore, the conservatively estimated subsidence at any point along the survey route followed in 1978 and 2006 is equal to the elevation determined in 1978 minus the closure error minus the 2006 elevation plus the closure error. Table 19 shows an example calculation. Elevation errors in topographic-map elevations range from about 0.3 to 1 m.

[124] Callaway, John C., Borgnis, Evyan L. Turner, R. Eugene & Milan, Charles S., 2012, Carbon Sequestration and Sediment Accretion in San Francisco Bay Tidal Wetlands, Estuaries and Coasts, (2012) 35:1163–1181

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

[126] Drexler JZ, de Fontaine CS, Deverel SJ. 2009. The legacy of wetland drainage on the remaining peat in the Sacramento–San Joaquin Delta, California, USA.Wetlands 29:372–386.

Table 19. Example subsidence calculation for point 44027 on Figure 2 in Deverel and Leighton.

Year	Elevation (m)	Closure Error (m)	Depth of Subsidence (m)
1978	-3.98	0.07	
2006	-5.26	0.002	1.21 ((-3.98 – 0.07)-(-5.26+0.002)

Data presented in Drexler et al.[127] provide ranges of estimates for organic matter content and bulk density for eight Delta islands.

Equations

If measured by determining the depth of subsidence over a known period of time, ΔGHG_{BSL} represents the cumulative net emissions (tCO_2-e) due to the oxidation of organic soils as estimated by the depth of subsidence using the following equation

$$\Delta GHG_{BSL} = \frac{44}{12} \times \sum_{i=1}^{n} (S_i \times BD_i \times FC_i \times A_i) \qquad (22)$$

where:

S is the depth of land subsidence in meters;

BD is the dry bulk density of the peat in metric tons per cubic meter

FC is the carbon content of the peat on a dry weight basis expressed as a fraction;

44/12 is the ratio of molecular weights of CO_2 to carbon; dimensionless.;

A is the area of the stratum in square meters;

i refers to the stratum within the project boundary and;

n is the total number of strata within the project boundary.

Because the subsidence estimate represents the GHG emission due to organic carbon loss

$$\Delta GHG_{BSL} = \Delta C_{BSL} \qquad (23)$$

Soil Coring

Carbon stock changes in the soil carbon pool in managed non-tidal wetlands and tidal wetlands can be measured in soil cores by determining the carbon accumulated above feldspar markers or sediment pins

[127] ibid

pounded into the ground to refusal[128] placed at the start of project activities. The material located above the feldspar marker or sediment pin/sediment interface shall be analyzed for total carbon or organic matter content and bulk density. Any compaction that occurs should be measured and accounted for. The change in carbon stocks in soil cores shall be determined by quantifying the carbon density above a marker horizon defined by a feldspar marker.

Feldspar markers should be placed at the start of the project activity. Feldspar marker horizons are prepared by spreading a thin aqueous slurry (~1 cm) layer of feldspar clay on the wetland[129] surface. Soil carbon content can be determined using elemental analysis using a CHN analyzer[130] or estimated from the loss-on-ignition method[131] (LOI). Results throughout the Sacramento-San Joaquin Delta and San Francisco Estuary[132] [133] [134] demonstrate a statistically significant relation between soil carbon content and LOI. These regression relations yield similar results for determination of soil organic carbon from LOI and can be used to calculate the carbon content of the harvested cores on a mass carbon per mass of soil basis. Alternatively, a relationship can be established between loss on ignition of organic matter and organic carbon content by determining both and conducting simple regression analysis. Then the organic carbon content can be estimated using the cheaper/simpler analysis of LOI.

To estimate carbon density in mass per unit volume, multiply the carbon content times the bulk density. The bulk density shall be determined using methods reported in Calloway et al.[135] and Blake and Hartge[136].

Specific steps for core collection:

Step 1. Collect soil core samples and measure the depth of the feldspar marker or measure the sediment accumulated at the sediment pin and collect a soil core sample to the depth of accumulated sediment. See quality assurance section below for discussion of compaction and compaction avoidance.

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[128] US Geological Survey. 2012. Sediment pin standard operating procedures. Unpublished protocols. USGS, Western Ecological Research Center, San Francisco Bay Estuary Field Station, Vallejo, CA. http://www.tidalmarshmonitoring.org/pdf/USGS-WERC-Sediment-Pin-SOP.pdf

[129] Cahoon, D. R. and R. E. Turner, 1989. Accretion and Canal Impacts in a Rapidly Subsiding Wetland. Feldspar marker horizon technique. Estuaries 12: 260-268.

[130] Nelson, D.W. and Sommers, L.E., 1982, Total carbon, organic carbon, and organic matter *in (*Page, A.L., ed.) Methods of Soil Analysis, American Society of Agronomy, Madison, WI

[131] Ball,D.F. 1964. Loss-on-ignition as an estimate of organic matter and organic carbon in non-calcareous soils. Journal of Soil Science 15: 84–92. Craft, C.B., E.D. Seneca, and S.W. Broome. 1991. Loss on ignition and Kjeldahl digestion for estimating organic carbon and total nitrogen in estuarine marsh soils: calibration with dry combustion. Estuaries 14: 175–179.

[132] Drexler JZ, de Fontaine CS, Deverel SJ. 2009a. The legacy of wetland drainage on the peat resource in the Sacramento-San Joaquin Delta, California, USA. Wetlands 29:372–386

[133] Callaway, J.C., Borgin, E.L., Turner, R. Eugene, Milan, Charles Sl, 2012, Carbon Sequestration and Sediment Accretion in San Francisco Bay Tidal Wetlands, Estuaries and Coasts (2012) 35:1163–1181

[134] Craft, C.B., E.D. Seneca, and S.W. Broome. 1991. Loss on ignition and Kjeldahl digestion for estimating organic carbon and total nitrogen
in estuarine marsh soils: calibration with dry combustion. Estuaries 14: 175–179.

[135] John C. Callaway & Evyan L. Borgnis, R. Eugene Turner & Charles S. Milan, 2012, Carbon Sequestration and Sediment Accretion in San Francisco Bay Tidal Wetlands, Estuaries and Coasts (2012) 35:1163–1181

[136] Blake, G.R. and Hartge, K.H., 1986, Bulk density in Klute, Arnold (ed). Methods of Soil Analysis, Physical and Mineralogical Methods, American Society of Agronomy, Madison, WI

Step 2. Aggregate samples from plots as per guidance provided in the uncertainty module for estimating the number of samples and uncertainty.

Step 3. For bulk density analysis, a single core shall be collected next to the core collected for determination of soil carbon content. Bulk density shall be determined as per methodology described in Blake and Hartge. Soil samples need to be thoroughly dried until their weight no longer changes and then the weight of each section needs to be divided by the volume.

Step 4. The mass of carbon per unit volume is calculated by determining the product of the carbon concentration and bulk density (g/cm^3).

Applicability Conditions

Locations of measurements shall be determined by strata, known spatial variability and the required level of certainty as outlined in the T-PLOT module. The determination of ΔC_p (Equation 9) shall be shown to adequately represent the hydrologic, water quality and soil conditions and land- and water-management practices for the stratum.

Quality Control and Quality Assurance

The primary quality control/quality considerations are related to 1) accurate depth of the core and 2) spatial variability in determinations of ΔC_p. Compaction during core collection is estimated by measuring the difference in elevation inside and outside of the coring tube to the nearest millimeter. Example coring devices include McAuley[137], Livingstone[138] or Hargis[139] coring devices that allow cores to be taken with minimal or no compaction. Strata and known spatial variability, shall determine the number of samples and the required level of certainty as described in the T-PLOT tool.

If inorganic carbon is present in soil samples, there may be interference in the determination of soil organic carbon. Total inorganic carbon can be determined and subtracted from the organic carbon determination.

Equations

Where soil coring is used to estimate cumulative carbon stock changes in t CO_2-e,

$$\Delta C_p = (\frac{1}{N} * \sum_{i=1}^{n} (D_i * CD_i)) \qquad (24)$$

Where:

[137] Bricker-Urso S, Nixon SW, Cochran JK, Hirschberg DJ, Hunt C (1989) Accretion Rates and Sediment Accumulation in Rhode Island Salt Marshes. *Estuaries* **12**, 300 ‐ 317.
[138] Wright Jr HE (1991) Coring tips. Journal of Paleolimnology **6**:37–49.
[139] Hargis TG, Twilley RR (1994) Improved coring device for measuring soil bulk density in a Louisiana deltaic marsh. Journal of Sedimentary Research Section A: *Sedimentary Petrology and Processes* **64**, 681–683.

$D_{i,}$ is the depth of the soil accumulated above a feldspar maker;
$CD_{i,}$ is the carbon density of the soil accumulated above a feldspar maker (product of the soil carbon content on a weight basis and soil bulk density);
N is the number of cores collected with stratum i.

In this case, CH_4 emissions are measured using chambers or eddy covariance as described above.

Methods used for inputs to biogeochemical models

The methods described in this section shall be used solely to determine inputs to biogeochemical models. The Project Proponents shall demonstrate that atmospheric carbon removal by above- and below-ground biomass is not additive in the overall carbon stock change calculation.

Above- and Below Ground Biomass and Litter Decomposition for Use in Biogeochemical Modeling

Rates of carbon accumulation in above- and below-ground biomass can be measured using direct measurements (allometric determinations and harvesting) and indirect methods, which include use of remote sensing techniques. Litter decomposition can be estimated using traditional litterbags, isotopic analysis and modeling.

Estimating Above- and Below Ground Biomass Using Allometric and Destructive Methods

The mean carbon stock in aboveground and below-ground biomass per unit area is estimated based on field measurements of the wetland plants in fixed area plots using allometric equations and destructive methods such as those described in Miller and Fujii[140] (Table 20). The number and size of plots shall ensure adequate representation of the area being measured by utilizing guidance provided in the module T-PLOTS. The allometric method can be used to estimate aboveground biomass by using equations that express aboveground biomass as a function of plant height and diameter. Miller and Fujii used extensive destructive biomass harvest to determine parameters in allometric equations for the predominant species (*Typha and Schoenoplectus spp)* in managed non-tidal wetlands in the Sacramento-San Joaquin Delta. The following table provides the equations from Miller and Fujii.

[140] Miller, Robin L. and Fujii, Roger, 2010, Plant community, primary productivity, and environmental conditions following wetland re-establishment in the Sacramento-San Joaquin Delta, California, Wetlands Ecol Manage (2010) 18:1–16

Table 20. Allometric equations for above ground biomass estimates expressed in grams of biomass per square meter).

Species	SI Unit	Equation
Schoenoplectus acutus	Biomass weight in grams per square meter	$\log_{10} weight = (0.5028 * \ln height) + (0.3471 * \ln diameter) - 1.7654$ $r^2 = 0.924$
Schoenoplectus acutus	Biomass weight in grams per square meter using only height	$\log_{10} weight = (0.7947 * \ln height) - 3.2177$ $r^2 = 0.824$
Typha. Species	Plant biomass weight in grams per square meter	$\log_{10} weight = -2.188 + (0.601 * \ln height) + (0.2128 * \ln diameter) + (0.2721 * \ln leaf\ number) - 0.484$ $r^2 = 0.9$

Miller and Fujii reported root biomass measurements and root:shoot ratios ranging from 0.6 ± 0.2 to 1.7 ± 0.4 for *Schoenoplectus acutus* and 0.7 ± 0.1 to 1.0 ± 0.3 for *Typha sp*. Values varied seasonally and with water depth. Average values for both species were not significantly different; 0.9 ± 0.1 for *Schoenoplectus acutus* and 0.8 ± 0.1 for *Typha sp.* For the purposes of this methodology for constructed wetland activities where these species are present, these values are appropriate for multiplication times the above-ground biomass weight. Destructive methods such as those described in Miller and Fujii can also be used to determine root biomass.

Estimating Above- and Below Ground Biomass Using Remote Sensing Methods

Spectral information from remotely sensed imagery can be used to estimate above-ground biomass. This spectral information can be used to not only estimate above-ground biomass but the fraction of photosynthetically active material driving photosynthesis as well as the timing and duration of the growing season.

Phenocam

Phenocams are digital cameras that are automated to record images of canopy cover throughout the year. These images can then be processed to calculate a greenness index (GI) which can be empirically related to above-ground leaf area index (LAI) based on field measurements where LAI is defined as half the total developed area of green leaves per unit ground surface area) LAI can be directly measured using destructive field sampling or measured using a LAI sensor such as the LAI-2200C Plant Canopy Analyzer (LI-COR, Lincoln, NE, USA)[141]. Measurements must be collected three times per month during the growing season. LAI can be used to estimate gross primary productivity for project conditions (managed and tidal wetlands and rice) which is an input to biogeochemical models.

Satellite images

Satellite-derived LAI products give information across large spatial scales (e.g. 1km for MODIS) with

[141] Sonnentag, O., et al. (2011) Tracking the structural and functional development of a perennial pepperweed (Lepidium latifolium L.) infestation using a multi-year archive of webcam imagery and eddy covariance measurements. Agricultural and Forest Meteorology 151

fairly high temporal resolution (e.g. 8-16 days for MODIS). The drawbacks to this method include poor small-scale resolution associated with high uncertainty at the field scale as well as data gaps associated with cloud cover[142]. Satellite-derived LAI products are therefore ideal for projects encompassing large spatial scales (multiple square kilometers) and may need to be supplemented with direct measurements.

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[142] Garrigues, S., *et al.* (2008) Validation and intercomparison of global Leaf Area Index products derived from remote sensing data. *Journal of Geophysical Research: Biogeosciences* 113, G02028

Litter Decomposition

Litter decomposition represents a large term in the global carbon budget, playing a critical role in regulating soil carbon dynamics across multiple scales of space and time[143]. To accurately predict litter carbon stock changes, litter decomposition rates (k) must be measured or estimated for project conditions. Litterbags are the most widely used method for direct k calculations and have been used and replicated around the world for decades[144] and can be used within this methodology. The analysis of natural abundances of ^{13}C isotopes[145] as well as labeling experiments with isotopically enriched litter[146] are also effective ways to estimate litter carbon stock changes over time. Laboratory microcosm studies show large discrepancy in relation to field litterbag and isotopic studies and shall not be used. Modeled decomposition rates on the long-term inter-site decomposition experiment team (LIDET)[147] can be used to provide conservative estimates of decomposition.

Predicting root decomposition at wetland sites is greatly improved by estimating decomposition rates of wetland roots separately from all other litter. The LIDET databases can be used to generate conservative root decomposition estimates. The same methods shall be employed to estimate k values under baseline and project conditions. If models are used, they shall be constrained by main drivers of decomposition, such as geographic factors (latitude and altitude), climatic factors (temperature, precipitation, evapotranspiration) and litter quality (C:N ratios, lignin content) and calibrated using data for the project or demonstrably equivalent conditions.

[143] Zhang D, Hui D, Luo Y, Zhou G (2008) Rates of litter decomposition in terrestrial ecosystems: global patterns and controlling factors. *Journal of plant ecology*, 2, 85-93

[144] Olson JS (1963) Energy stores and the balance of producers and decomposers in ecological systems. Ecology 44:322–31.

[145] Silva LCR, Corrêa RS, Doane TA, Pereira EIP, Horwath WR. (2013) Unprecedented carbon accumulation in mined soils: the synergistic effect of resource input and plant species invasion *Ecological Applications* 23 (6), 1345-1356 2013

[146] Qiao Y, Miao M, Silva LCR, Horwath WR (2014) Understory species regulate litter decomposition and accumulation of C and N in forest soils: A long-term dual-isotope experiment *Forest Ecology and Management*

[147] Bonan GB, Hartman MD, Parton WJ, Wieder WR (2013) Evaluating litter decomposition in earth system models with long-term litterbag experiments: an example using the Community Land Model version 4 (CLM4). *Glob Chang Biol* **19**(3):957-74.

Wetland Restoration and Rice Methodological Module-Biogeochemical Model Module (Model –W/R)

Scope

This module allows for the *ex-ante* and *ex-post* estimation of greenhouse gas (GHG) removals and emissions reductions for wetlands (W) in the project scenario.

For project conditions, this module uses a validated process-based biogeochemical model, the Peatland Arrhenius Michaelis-Menten model (PAMM), that can be used for *ex-ante* estimation of t-CO_2 and CH_4 exchange from wetlands in the Sacramento-San Joaquin Delta. This model has been calibrated and validated using a multi-year data set collected in a 14-acre mature restored wetland on Twitchell Island. Future updates to this model, including calibrations to restored wetlands of different ages (1-17yr) and a rice paddy, will be made publically available.

For baseline conditions, the SUBCALC model (Deverel and Leighton, 2010) may be used to estimate baseline CO_2 emissions. SUBCALC simulates microbial oxidation or agricultural organic soils using Michaelis–Menten kinetics. Parameters for the model Michaelis–Menten equations were developed from field data (Deverel and Rojstaczer, 1996). Inputs for the model are described in Deverel and Leighton and include soil organic matter content, average soil annual temperature at 30 cm, depth to groundwater, soil bulk density. We plan to integrate the SUBCALC and PAMM models for predicting both CO_2 and CH_4 from diverse land use types in the Delta.

Applicability Conditions

The following conditions must be met for this module to be used:

1. For project areas that are converted to flooded conditions, separate model simulations must be run for baseline and project conditions.
2. The participating wetlands shall be in the Delta area of organic soils where the models have been successfully calibrated.
3. The model described here is applicable to fully vegetated wetlands.
4. Wetlands or strata with open water require separate validation.
5. Net aqueous loss of carbon must be negligible or estimated using other methods (see methods module (MM-W/R). Sites with significant import and/or export of dissolved forms of carbon (such as tidal wetlands) are not appropriate sites for employing the LUE-DAMM.
6. For each model run, appropriate input parameter files must be available to the auditor.

<u>Parameters</u>

Parameter	SI Unit	Description
$\Delta C_{baseline}$	t CO_2-e	Cumulative total of carbon stock changes and GHG emissions for the baseline scenario

ΔC_{actual}	t CO_2-e	Cumulative total of carbon stock changes and greenhouse gas emissions for the project scenario

Project Model Description

The PAMM model requires leaf area index (LAI), meteorological data, initial soil organic carbon content (SOC), and water table height. See Data and Parameters Monitored section for description and requirement for each input.

Model calibration and validation

In order to use this model in systems in which it has not been calibrated such as rice fields in the Sacramento Valley, it needs to be calibrated and validated using at least 2 years of semi-continuous ecosystem exchange data of CO_2 and CH_4. Other model input variables will also need to be recorded during this time. Two years is the minimum in order have sufficient data for both parameterization and validation (recommended 70% data used for parameterization and 30% for validation). Model calibration and validation do not need to be conducted within project bounds but must be conducted in and documented for a similarly managed system with similar soil qualities and climate conditions.

Table 21. Project emissions sources included in the project boundary

Source	**Gas**
Net GHG emissions due to C uptake, ecosystem respiration and methanogenesis	CO_2, CH_4

Quantification of Project Emissions and Carbon Stock Changes

Project emissions of CO_2 and CH_4 may be estimated using the PAMM model, which must be run separately for each wetland site, strata or cohort. Flux rates derived from the PAMM model, net ecosystem exchange of CO_2 (NEE; g CO_2 acre^{-1} day^{-1}) and net ecosystem exchange of CH_4 (R_{CH4}; g CH_4 acre^{-1} day^{-1}) will be used to derive annual sums of CO_2 and CH_4 for each project year and project site:

$$[CO_2]_{project,y,i} = \sum_{t=1} NEE_{project,t} * n \qquad (25)$$

$$[CH_4]_{project,y,i} = \sum_{t=1} R_{CH_4 project,t} * n \qquad (26)$$

Where:

$[CO_2]_{project,y,i}$ = cumulative project net CO_2 ecosystem exchange (*NEE*) from wetland stratum *i* over reporting time period which may vary from 0.5 to 2 years

$[CH_4]_{project,y,i}$ = cumulative project net CH_4 ecosystem exchange (R_{CH4}) from wetland stratum *i* over reporting time period which may vary from 0.5 to 2 years

$NEE_{project,t}$ = project net CO_2 ecosystem exchange flux rate (g CO_2 $acre^{-1}$ day^{-1}) at time *t* for wetland stratum *i*

$R_{CH4project,t}$ = project net CH_4 ecosystem exchange flux rate (g CH_4 $acre^{-1}$ day^{-1}) at time *t* for wetland stratum *i*

n = area in wetland stratum *i*

Project annual net GHG exchanges for each year and site are then used to calculate total project net emissions:

$$\Delta C_{actual} = \frac{44}{12} * [CO_2]_{project,y,i} + 25 * \frac{16}{12} * [CH_4]_{project,y,i} \quad (27)$$

Where:

ΔC_{actual} = Cumulative total of carbon stock changes and greenhouse gas emissions for the

project scenario wetland site in tCO_2-e

$[CO_2]_{project,y,i}$ = cumulative project net CO_2 ecosystem exchange (*NEE*) from wetland stratum *i* over reporting time period which may vary from 0.5 to 2 years

$[CH_4]_{project,y,i}$ = cumulative project net CH_4 ecosystem exchange (R_{CH4}) from wetland stratum *i* over reporting time period which may vary from 0.5 to 2 years

44/12 Ratio of molecular weight of CO_2 to carbon; dimensionless

16/12 Ratio of molecular weight of CH_4 to carbon; dimensionless

Following the IPCC Fifth Assessment Report[i], 25 is the Global Warming Potential for methane on a 100-yr timescale.

Calculation of Emission Reductions

The GHG emission reductions for year *y* (ER_y) are calculated as difference between baseline and project carbon stock changes as defined in the Framework Module.

Project Model description: The Peatland Arrhenius Michaelis-Menten model (PAMM)

I. CO_2 ecosystem PAMM model

In order to predict net ecosystem exchange of CO_2 (NEE) both gross primary productivity (GPP) and ecosystem respiration (R_{eco}) need to be simulated:

$$NEE = GPP + R_{eco} \qquad (28)$$

To predict GPP, we employ a simple and widely-used light use efficiency model called the LUE model (Monteith, 1977):

$$GPP = PAR * \varepsilon * fPAR(LAI) * f(T) \qquad (29)$$

where GPP is a function of available photosynthetically active radiation (*PAR*), plant light use efficiency (*ε*), the fraction of PAR absorbed by canopy (*fPAR*) which is a function of leaf area index (*LAI*), and a temperature function (*f(T)*). The light use efficiency and temperature function are calibrated to each ecosystem, as these vary among plant species (Yuan *et al.*, 2007). The temperature function assumes photosynthesis increases exponentially with temperature until it reaches an optimum (e.g. 25°C), above which photosynthesis is inhibited:

$$f(T_k) = 1 * \left(\frac{H_d * exp\left(\frac{H_a\left(T_k - T_{opt}\right)}{T_k * R * T_{opt}}\right)}{H_d - H_a(1 - exp\left(\frac{H_d\left(T_k - T_{opt}\right)}{T_k * R * T_{opt}}\right)} \right) \qquad (30)$$

where R is the universal gas constant, T_k is air temperature, H_a is the rate of exponential increase below the optimum temperature, and H_d is the rate of decrease above the optimum temperature(Medlyn *et al.*, 2002). From these equations, photosynthetic rates are computed every 30 min and up-scaled to the ecosystem using LAI.

Ecosystem respiration (R_{eco}) is the total CO_2 respired by both plants and soil. In order to predict R_{eco} we employ a simple respiration model based on enzyme kinetics which was adapted from the Dual Arrhenius Michaelis-Menten kinetics (DAMM) model (Davidson *et al.*, 2012). This model assumes R_{eco} is a function of the size and availability of 2 soil C pools, temperature, and water table height (WT). The 2 soil carbon pools are regulated by initial soil carbon conditions (i.e. soil organic carbon (SOC)) and recently-fixed photosynthetic C, which is predicted using GPP. According to enzyme kinetics, respiration increases exponentially with temperature. Water table and soil moisture influence the availability of oxygen in the soil, an important substrate for aerobic respiration. Specifically, R_{eco} is predicted using an Arrhenius equation paired with Michaelis-Menten equations to address substrate availability of 2 C pools:

$$R_{eco} = \left(\frac{Vmax_{SOC} * [C_{SOC}]}{kM_{SOC} + [C_{SOC}]} + \frac{Vmax_{labile} * [C_{labile}]}{kM_{labile} + [C_{labile}]}\right) * f(WT) \qquad (31)$$

where R_{eco} is the total respiration rate for the given ecosystem (µmol CO_2 m^{-2} s^{-1}), V_{max} (µmol CO_2 m^{-2} s^{-1}) is the maximum rate of enzyme kinetics for the respective C pools when substrate concentrations are not limiting (where labile refers to recently-fixed photosynthetic C and soil organic carbon (SOC) refers to older more recalcitrant forms of C), C is the soil C content for the respective C pools (µmol C m^{-2}), and kM is the half-saturation concentration for the respective substrates (µmol C m^{-2}). Under flooded conditions, soil respiration is inhibited due to depleted O_2. Soil CO_2 emission rates under anaerobic conditions have been previously reported to decrease by 32-65% (Wright & Reddy, 2001) due to the use of alternative electron acceptors, and were recently reported to be reduced by 50% in a Delta rangeland site (McNicol & Silver, 2014). Therefore the water table function (*f(WT)*) describes elevated rates of respiration when the water table falls below the soil surface due to introduction of O_2 to the soil.

C pool sizes are dynamic. For example, both pools are reduced in response to respiration rates. The SOC pool is enhanced at the end of the year when vegetation senesces and contributes to the SOC pool, estimated as a function of LAI. The labile pool is a function of *GPP* (explained above). Initial SOC conditions for the simulated region is another driver for model simulation and must be sampled at the beginning of the project (5-10 soil profile samples to assess average SOC in the top 1m of soil; see tables 1-3 for complete list of drivers, parameters and state variables).

Following the Arrhenius function, V_{max_x} is the maximum rate of enzyme reaction for each soil C pool (i.e. SOC and labile soil C):

$$V_{max_x} = a_x * e^{-Ea_x/RT} \tag{32}$$

where V_{max_x} is predicted using the pre-exponential factor (a_x), the activation energy of the enzymatic reaction with the substrate (Ea_x), air temperature (T) and the universal gas constant (R).

II. CH_4 ecosystem PAMM model

In order to predict net CH_4 emissions, both methane oxidation and production need to be simulated. Again, we employ a simple model based on enzyme kinetics where CH_4 production is a function of the size and availability of 2 soil C pools, temperature, and water table height, and CH_4 oxidation is a function of the availability of CH_4, temperature, and water table height. Both processes are predicted to increase exponentially with temperature. However, high water table conditions enhance CH_4 production and limit oxidation and low water table heights inhibit CH_4 production and increase oxidation. Two transport pathways are also modeled, plant–mediated CH_4 transport and hydrodynamic CH_4 flux. Both of these transport pathways are dependent on water table height and concentration gradients of CH_4 between the water and atmosphere. Plant-mediated transport is also a function of GPP.

The biogeochemical model for CH_4 production and oxidation is based on the DAMM model foundation. Similarly to the R_{eco} DAMM model, CH_4 production is predicted using an Arrhenius equation paired with Michaelis-Menten equations estimating the concentration of 2 C substrates at the enzyme reaction site:

$$R_{CH4} = \frac{Vmax_{labile} * [C_{labile}]}{kM_{labile} + [C_{labile}]} * \frac{Vmax_{SOC} * [C_{SOC}]}{kM_{SOC} + [C_{SOC}]} * f(WT) \tag{33}$$

To account for the inhibition of CH_4 production by the presence of O_2, an O_2 effect parameter is applied when the water table falls below the soil surface.

Similarly, CH_4 oxidation follows the DAMM model foundation, where there is only 1 substrate pool: CH_4:

$$O_{CH4} = \frac{Vmax_{CH4} * [CH_4]}{kM_{CH4} + [CH_4]} * f(WT) \tag{34}$$

To account for the inhibition of CH_4 oxidation when the water table is above the soil surface, and O_2 effect parameter is applied when the water table is above the soil surface.

Hydrodynamic flux is predicted using the Poindexter model, which was parameterized and validated at the same mature wetland site as the model described here (Poindexter *et al. submitted*). This predicts transfer of CH_4 stored in the water directly to the atmosphere given the concentration gradient between CH_4 in water and CH_4 in the atmosphere as well as a gas transfer velocity:

$$F_{hydro} = k * \left([CH4_{water}] - [CH4_{surface}]\right) \qquad (35)$$

Where k is the gas transfer velocity through the water (m d^{-1}). Concentrations of CH_4 in the water or soil ($[CH_{4water}]$; µmol m^{-3}) are modeled based on production and oxidation rates of CH_4. After accounting for methane solubility in water, dissolved concentrations of methane at the surface ($[CH_{4surface}]$; µmol m^{-3}) are so small they are assumed to be zero.

Plant-mediated flux is predicted following the Dynamic Land Ecosystem Model (DLEM) (Tian *et al.*, 2010). This predicts plant-mediated transport of CH_4 given the concentration gradient between CH_4 in water and CH_4 in the atmosphere as well as plant transport efficiency and plant activity:

$$F_{plant} = V_{plant} * ([CH4_{water}] - [CH4_{atm}]) * \frac{GPP}{GPP_{max}} \qquad (36)$$

Where V_{plant} is the gas transfer velocity through plants (m d^{-1}). Concentrations of CH_4 in the water or soil ($[CH_{4water}]$; µmol m^{-3}) are modeled based on production and oxidation rates of CH_4. After accounting for methane solubility in water, dissolved concentrations of methane at the surface ($[CH_{4atm}]$; µmol m^{-3}) are so small compared to concentrations in water, we assume this is zero. Plant activity is assessed using GPP, where the most plant transport is expected to occur when GPP is at its highest point.

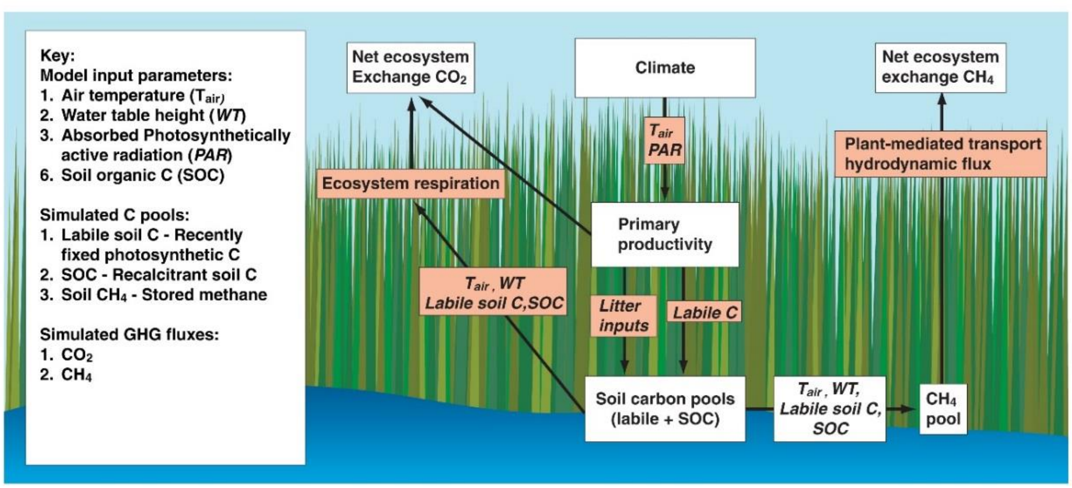

Figure 6. Conceptual diagram of input parameters and simulated C pools and GHG fluxes predicted using the PAMM model in the Delta.

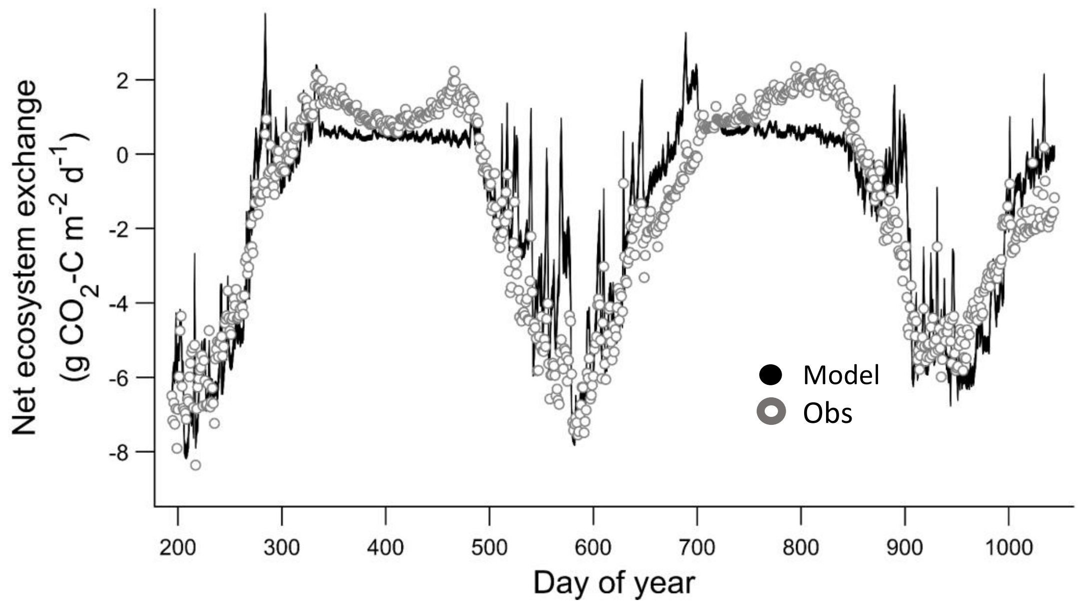

Figure 7. PAMM modeled and observed net ecosystem exchange of CO2 (g CO2-C m-2 d-1) above a mature wetland (West Pond pilot wetland) on Twitchell Island. Data begin on July 12, 2012 and end on November 10, 2014

Approximately 70% of observed data were used to parameterize the model (July 12, 2012-September 22, 2013), and 30% were used for model validation (September 23, 2013- November 10, 2014). Modeled fluxes are shown in black with 95% confidence intervals. PAMM model simulations explained 90% of the variation in observed fluxes. Observed and modeled cumulative CO_2 budgets for the validation period were very similar (Obs: -458g CO_2-C m^{-2}; Mod: -413 ± 65 g CO_2-C m^{-2}).

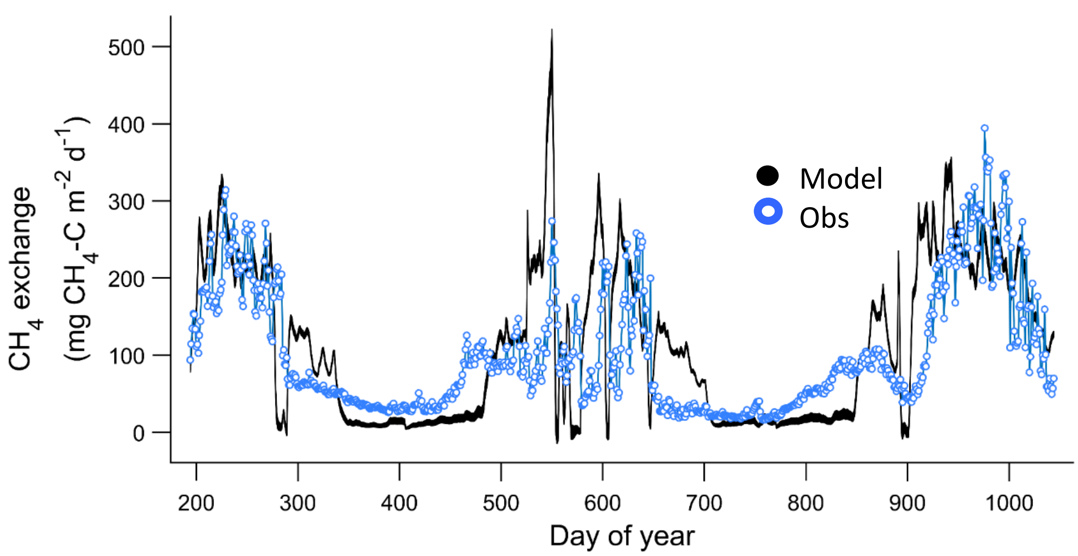

Figure 8. PAMM modeled and observed net ecosystem exchange of CH4 (mg CH4 -C m-2 d-1) above a mature wetland (West Pond pilot wetland) on Twitchell Island.

Data begin on July 12, 2012 and end on November 10, 2014. Approximately 70% of observed data were used to parameterize the model (July 12, 2012-September 22, 2013), and 30% were used for model validation (September 23, 2013- November 10, 2014). Modeled fluxes are shown in black with 95% confidence intervals. PAMM model simulations explained 50% of the variation in observed fluxes. Observed and modeled cumulative CH4 budgets for the validation period were very similar (Obs: 33g CH4 -C m-2; Mod: 37± 2 g CH4 -C m-^{2}).

Data and Parameters Monitored

Data Unit / Parameter	Meteorological data
Description	Air temperature and in-coming radiation
Units	Degree Celsius and µmol radiation m^{-2} s^{-1}
Data source	California Irrigation Management Information System (CIMIS) website (http://wwwcimis.water.ca.gov/cimis/data.jsp)
Description of measurement methods and procedures to be applied	
Frequency of monitoring/recording	30 min
QA/QC procedures	
Verification requirements	
Comments	

Data Unit / Parameter	Initial soil organic carbon
Description	Amount of existing soil organic carbon at beginning of project
Units	g C m^{-3} soil
Data source	Soil survey data (NRCS SSURGO) or direct sampling (5-10 soil profile samples averaged across top 1m soil; replicate spatially as needed)
Description of measurement methods and procedures to be applied	If data from NRCS SSURGO is used, the uncertainty in the spatial resolution of soils properties (including soil organic matter) must be accounted for in model inputs.
Frequency of monitoring/recording	Once at beginning of project
QA/QC procedures	
Verification requirements	
Comments	

Data Unit / Parameter	Water table height
Description	Distance from surface of soil to water table—for project conditions

Units	cm
Data source	Direct or automated measurement
Description of measurement methods and procedures to be applied	Measure by hand distance of water height to soil surface or install pressure transducer to continuously monitor water table height (such as Campbell Scientific CS451-L)
Frequency of monitoring/recording	Daily-weekly
QA/QC procedures	
Verification requirements	
Comments	

Data Unit / Parameter	Leaf area index
Description	One-sided green leaf area per ground surface area
Units	m^2 leaf area m^{-2} ground area
Data source	Destructive field sampling, LAI sensor (e.g. LAI-2200C Plant Canopy Analyzer), or remote sensing
Description of measurement methods and procedures to be applied	Destructive sampling: remove all leaves in a known surface area (e.g.40cm x 40cm), measure leaf area of all removed leaves. Repeat across landscape (ideally 5 measurements per plant cover type). LAI sensor: collect 10 measurements along a transect through each plant cover type Remote sensing: Phenocams, or digital cameras that are automated to record images of canopy cover throughout the year, can be used to calculate a greenness index (GI) which can be empirically related to LAI based on field measurements (Richardson *et al.*, 2009, Ryu *et al.*, 2012, Sonnentag *et al.*, 2011). Other forms of remote sensing may also be available such as satellite images provided by MODIS.
Frequency of monitoring/recording	Measurements must be collected frequently during the growing season (2x per month); monthly measurements during the non-growing seasons are also required
QA/QC procedures	See methods module (MM-W/R)
Verification requirements	
Comments	

Table 22. Photosynthesis PAMM model parameters, descriptions and values

Parameters, state variables, and driver variables	Description	Value
Parameters		
ε	Light use efficiency (g C m^{-2} MJ^{-1})	0.9
H_a	Activation energy for photosynthesis	30
H_d	Inhibition of photosynthesis at high temperatures	100
R	Universal gas constant	0.00831
T_{opt}	Optimum temp for photosynthesis	25ºC
State variables		
NEE	Net ecosystem exchange CO_2 (µmol m^{-2} s^{-1})	
GPP	Gross ecosystem primary productivity (µmol m^{-2} s^{-1})	
Driver variables		
Air temperature	ºC	
PAR	Photosynthetically active radiation (µmol m^{-2} s^{-1})	
LAI	Leaf area index	

Table 23. Respiration PAMM model parameters, descriptions and values

Parameters, state variables, and driver variables	Description	Value
Parameters		
kM_{labile}	Michaelis-Menten constant for labile C	6.5*10^5
kM_{SOC}	Michaelis-Menten constant for SOC	1.5*10^8
α_{labile}	Pre-exponential factor for labile C	7.7*10^6
α_{SOC}	Pre-exponential factor for SOC	4.5*10^5
Ea_{labile}	Activation energy for	32.7

	labile C	
Ea_{SOC}	Activation energy for SOC	27.6
C_{SOC}	Initial SOC pool	89mol C m-2
State variables		
R_{eco}	Ecosystem respiration (μmol m^{-2} s^{-1})	
C_{SOC}	SOC pool	
Driver variables		
Air Temp	ºC	
PAR	Photosynthetically active radiation (μmol m^{-2} s^{-1})	
WT	Water table height	
GPP	Gross ecosystem primary productivity (μmol m^{-2} s^{-1})	

Table 24. CH_4 PAMM model parameters, descriptions and values

Parameters, state variables, and driver variables	Description	Value
Parameters		
kM_{labile}	Michaelis-Menten constant for labile C	3000 μmol m^{-3}
kM_{SOC}	Michaelis-Menten constant for SOC	3000 μmol m^{-3}
kM_{CH4}	Michaelis-Menten constant for CH_4 oxidation	3000 μmol m^{-3}
α_{labile}	Pre-exponential factor for labile C	$4*10^{14}$ μmol m^{-3} s^{-1}
α_{SOC}	Pre-exponential factor for SOC	$5*10^{12}$ μmol m^{-3} s^{-1}
a_{CH4}	Pre-exponential factor for CH_4 oxidation	$3*10^{13}$ μmol m^{-3} s^{-1}
Ea_{labile}	Activation energy for labile C	85 kJ mol^{-1}
Ea_{SOC}	Activation energy for SOC	80 kJ mol^{-1}
Ea_{CH4}	Activation energy for CH_4 oxidation	80 kJ mol^{-1}
C_{SOC}	Initial SOC pool	*measured*
$V_{\mathbf{plant}}$	Plant transfer velocity (Kettunen et al. 2003)	0.6 m d^{-1}
k	Gas transfer velocity (Poindexter et al. submitted)	0.03 m d^{-1}
State variables		
R_{CH4}	CH_4 production (μmol m^{-2} d^{-1})	
O_{CH4}	CH_4 oxidation (μmol m^{-2} d^{-1})	

N_{CH4}	Net CH_4 emission (µmol m^{-2} d^{-1})
C_{CH4}	Soil CH_4 pool
Driver variables	
Air Temp	ºC
PAR	Photosynthetically active radiation (µmol m^{-2} s^{-1})
WT	Water table height
GPP	Gross ecosystem primary productivity (µmol m^{-2} s^{-1})

Tools

Methodological Module Tool for estimation of uncertainty for wetland construction and restoration and rice cultivation in the Sacramento-San Joaquin Delta and San Francisco Estuary (X-UNC)

SCOPE, APPLICABILITY AND PARAMETERS

Scope

This module provides guidance for calculating uncertainty for estimation of emissions and GHG removals from wetland construction and restoration activities and rice cultivation activities implemented in the Sacramento-San Joaquin Delta and San Francisco Estuary where water quality ranges from fresh to saline conditions.

Applicability

This module is mandatory and provides guidance for the calculation of the following sources of uncertainty:

- Baseline and project emissions
- Baseline and project changes in soil carbon stocks

Where an uncertainty value is not known or cannot be accurately calculated, a Project Proponents shall justify that it is using an indisputably conservative value for carbon stock changes or emissions and an uncertainty of 0% may be used for this component.

Parameters

This module provides procedures to determine the following parameters:

Parameter	**Description**
UNC	Total project uncertainty (%)
$Uncertainty_{BSL,SS,i}$	Percentage uncertainty of the combined carbon stocks and greenhouse gas sources for the uncertainty baseline case in stratum *i*
$Uncertainty_{P,SS,i}$	Percentage uncertainty of the combined carbon stocks and greenhouse gas sources for the project scenario case in stratum *i*

Either as default values given in IPCC Guidelines for greenhouse gas (GHG) inventories[148] good practice

[148]Eggleston S, Buendia L, Miwa K, Ngara T, Tanabe K (2006) IPCC Guidelines for National Greenhouse Gas Inventories

for land use[149], expert judgment[150], or estimates based on sound sampling design and statistical analysis shall provide the basis for uncertainty calculations. Uncertainties arising from the measurement and monitoring of carbon pools and the changes in carbon pools shall always be quantified. Indisputably conservative estimates can also be used instead of uncertainties in which case the uncertainty is assumed to be zero. However, this section provides a procedure to combine uncertainty information and conservative estimates resulting in an overall project scenario uncertainty.

To calculate total project uncertainty the following equation shall be applied:

$$\text{Total Project } UNC = \sqrt{{UNC_{BSL}}^2 + {UNC_P}^2} \qquad (37)$$

where

UNC = Total project uncertainty (%)

UNC_{BSL} = Baseline uncertainty (%)

UNC_P = Project uncertainty (%)

The allowable uncertainty under this methodology is ±10% of the mean carbon stock change at the 90% confidence level. Where this precision level is met, no deduction shall result for uncertainty. Where uncertainty exceeds 10% of the mean carbon stock change, the deduction shall be equal to the amount that the uncertainty exceeds the allowable level, as indicated in the Framework Module (WR ‐ MF).

ESTIMATION OF BASELINE UNCERTAINTY

It is important that the process of project planning consider uncertainty. *A priori* estimations of statistical power[151] can be used to ensure proper spatiotemporal replication[152] and determine procedures, such as stratification and allocation of resources to allow the number of measurement plots to reduce uncertainty. It is good practice to consider uncertainty at an early stage to identify the data sources with the highest risk to allow the opportunity to conduct further work to improve representativeness and optimize project practices over time. Estimation of uncertainty for pools and emissions sources for each measurement pool requires calculation of both the mean and the 90% confidence interval. In all cases, uncertainty should be expressed at the 90% confidence interval as a percentage of the mean.

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[149]Penman J, Gytarsky M, Hiraishi T, Krug T, Kruger D, Pipatti R, Buendia L, et al. (2003) IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry

[150]Justification should be supplied for all values and parameters measured or derived from expert judgment.

[151]Park, H. M. 2010. Hypothesis testing and statistical power of a test. Technical Working Paper. University Information Technology Services (UITS) Center for Statistical and Mathematical Computing, Indiana University. http://www.indiana.edu/~statmath/stat/all/power/power.pdf

[152]Silva LCR, Corrêa RS, Doane TA, Pereira EIP, Horwath WR (2013) Unprecedented carbon accumulation in mined soils: the synergistic effect of resource input and plant species invasion. Ecological Applications 23:1345–1356

The uncertainty in the baseline scenario is defined as the square root of the summed errors in each of the carbon pools listed in the framework module. For modeled results, the uncertainty in the input inventory data and model structural uncertainty shall be considered as discussed below. The total baseline uncertainty in each pool can be weighted by the size of the pool so that projects may reasonably target a lower precision level for pools that comprise only a small proportion of the total stock as follows:

$$Uncertainty_{BSL,SS,i} = \frac{\sqrt{(U_{BSL,SS1,i} * E_{BSL,SS1,i})^2 + (U_{BSL,SS2,i} * E_{BSL,SS2,i})^2 + \cdots + (U_{BSL,SSn,i} * E_{BSL,SSn,i})^2}}{E_{BSL,SS1,i} + E_{BSL,SS2,i} + \cdots + E_{BSL,SSn,i}} \quad (38)$$

where

$Uncertainty_{BSL,SS,i}$	Is the percentage uncertainty of the combined carbon stocks and greenhouse sources for the baseline case in stratum *i* (%)
$U_{BSL,SS,i}$	Is the percentage uncertainty (expressed as 90% confidence interval as a percentage of the mean where appropriate) of carbon stocks and greenhouse gas sources for the baseline case in stratum *i* (1,2…n) represent different car pools and/or GHG sources) (%)
$E_{BSL,SS,i}$	Is the carbon stock change in stratum *i* (1,2…n represent different carbon pools and/or GHG sources) for the baseline case (tCO_2-e)
i	1, 2, 3 … *M* strata

ESTIMATION OF PROJECT UNCERTAINTY

As with baseline uncertainty, it is important that the process of project planning consider uncertainty. Procedures including stratification and the allocation of sufficient number of measurement locations can help minimize uncertainty. It is good practice to consider uncertainty at an early stage to identify the data sources with the highest risk to allow the opportunity to conduct further work to diminish uncertainty. Estimation of uncertainty for pools and emissions sources for each measurement pool requires calculation of both the mean and the 90% confidence interval. In all cases, uncertainty should be expressed at the 90% confidence interval as a percentage of the mean. The uncertainty in the project scenario should be defined as the square root of the summed errors in each of the carbon pools. For modeled results, follow guidelines discussed below. The errors in each pool can be weighted by the size of the pool so that projects may reasonably target a lower precision level for pools that comprise only a small proportion of the total stock as follows:

$$Uncertainty_{P,SS,i} = \frac{\sqrt{(U_{P,SS1,i} * E_{P,SS1,i})^2 + (U_{P,SS2,i} * E_{P,SS2,i})^2 + \cdots + (U_{P,SSn,i} * E_{P,SSn,i})^2}}{E_{P,SS1,i} + E_{P,SS2,i} + \cdots + E_{P,SSn,i}} \quad (39)$$

where

$Uncertainty_{P,SS,i}$ is the percentage uncertainty of the combined carbon stock

$U_{P,SS,i}$ is the percentage uncertainty (expressed at the 90% confidence interval) as a percentage of the mean where appropriate, of carbon stock changes for the project scenario case in stratum *i.*

$E_{P,SS,i}$ is the carbon stock change in stratum *i* for the project carbon pools 1, 2, 3 … *M* strata

ESTIMATING UNCERTAINTY ASSOCIATED WITH EDDY COVARIANCE MEASUREMENTS

When calculating uncertainty associated with using eddy covariance to estimate emission reductions, this protocol requires project proponents to account for random measurement error and error associated with gap-filling procedures used to calculate annual sums. Systematic bias error is also discussed here but can be conservatively excluded from uncertainty deductions if quality assurance and quality control measures are appropriately followed as discussed in the emissions and carbon-stock methods modules (E-E and CP-S).

Random measurement error

Random measurement error can create substantial noise or scatter in the data and can occur due to spectral filtering effects, turbulent transport, instrumentation, and footprint issues[153]. Errors can be reduced by using high sampling rates (at least 1Hz; ideally 10Hz), measuring continuously during each project year, measuring gas concentration and wind speed high enough above the vegetation, minimizing separation between sensors (<20cm), and minimizing flow distortion in the sensor array and mast[154].

Two general approaches are allowed for estimating the random error (ε_{random}),. A project proponent may use a documented and validated empirical model demonstrated to be an accurate predictor of the observed eddy covariance data. The residual between observed and modeled fluxes can give an estimate of error as long as model error is shown to be minimal[155]. The project proponent may also use a daily-differencing approach where data points collected under the same environmental conditions in successive days (x_1, x_2) are compared and the random measurement error is estimated as the standard deviation of the differences between x_1 and x_2[156,157]. This method can be used in combination with Monte Carlo methods to estimate the 90% confidence interval due to random error in gap-filled net ecosystem exchange at the annual time step[9,11]. It is important to note that random error associated with eddy covariance measurements typically follows a double-exponential (Laplace) distribution and not the normal (Gaussian) distribution, therefore maximum likelihood estimation techniques should be used to estimate random error confidence intervals as opposed to least squares optimization with

[153] Richardson, A.D. et al., 2012. Eddy covariance: a practical guide to measurement and data analysis. Springer.
[154] Massman, W.J., 2000. A simple method for estimating frequency response corrections for eddy covariance systems. Agricultural and Forest Meteorology, 104(3): 185-198.
[155] Richardson, A.D. and Hollinger, D.Y., 2005. Statistical modeling of ecosystem respiration using eddy covariance data: maximum likelihood parameter estimation, and Monte Carlo simulation of model and parameter uncertainty, applied to three simple models. Agricultural and Forest Meteorology, 131(3): 191-208.
[156] Liu, M. et al., 2009. Uncertainty analysis of CO2 flux components in subtropical evergreen coniferous plantation. Science in China Series D: Earth Sciences, 52(2): 257-268.
[157] Richardson, A.D. et al., 2006. A multi-site analysis of random error in tower-based measurements of carbon and energy fluxes. Agricultural and Forest Meteorology, 136(1): 1-18.

requires normally distributed error and constant variance[10,11]. Alternatively, the project proponent may also use peer-reviewed methods for estimating the random error in eddy-covariance methods.

Estimations of random and gap-filling errors over long time scales

To estimate uncertainty of annual sums for emissions and carbon stock changes associated with gap-filling using eddy covariance, project proponents shall use accepted and peer-reviewed methodologies. Monte Carlo or resampling techniques are recommended. System failure and data filtering can lead to gaps in the data which need to be filled in order to calculate annual sums. Most sites experience 35% data loss[158] If more than 60% of eddy covariance data need to be gap filled, uncertainty in measurements and annual sums are excessively high and alternate measurement methods for measuring emissions and carbon stock changes must be used. There are several approaches for filling data gaps[159]. Generally, the longer the time scale of integration the smaller the uncertainty due to larger sample sizes and the dampening of outliers[10,160]. Resampling techniques allowing accounting for uncertainties associated with gap-filling.

Project proponents may use the bootstrap resampling technique for estimating error associated with gap-filled annual sums ($\varepsilon_{gapfill}$) he or other appropriate peer-reviewed method. In this method, artificial datasets (of 1000-10000 data points) are created from the observed data using Monte-Carlo techniques[9]. Models used for filling gaps are then applied to those data sets. These datasets are used to calculate annual values and the variation across those data is used to estimate a 90% confidence interval around the annual carbon stock changes or GHG emissions[161].

Random measurement error and gap-filling error are calculated using the root-sum-square method[162] and collectively constitute the total eddy covariance uncertainty expressed as a 90% confidence interval around the annual sum, U_{EC}.

$$U_{EC} = \sqrt{\varepsilon_{random}{}^2 + \varepsilon_{gapfill}{}^2} \quad (40)$$

Where $\varepsilon_{gapfill}$ is the 90% confidence interval associated with gap-filled annual sums and ε_{random} is the 90% confidence interval of the total random measurement uncertainty described above.

Systematic measurement error

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[158] Eva Falge, Dennis Baldocchi, Richard Olson, Peter Anthoni, Marc Aubinet, Christian Bernhofer, George Burba, Reinhart Ceulemans, Robert Clement, Han Dolman, Andre Grainer, Thomas Grunwald, David Hollinger, Niels-Otto Jensen, Gabriel Katul, Petri Keronen, Andrew Kowalski, Chun Ta Lai, Beverly E. Law,Tilden Meyers, Jon Moncrieff, Eddy Moors, J. William Munger, Kim Pilegaard, Ullar Rannik, Corinna Rebmann, Andrew E. Suyker, John Tenhunen, Kevin Tu, Shashi Verma, Timo Vesala, Kell Wilson, and Steve Wofsy, 2001, Gap filling strategies for defensible annual sums of net ecosystem exchange, Agricultural and Forest Meteorology, 107 (2001) 43–69

[159] Moffat, A.M. et al., 2007. Comprehensive comparison of gap-filling techniques for eddy covariance net carbon fluxes. Agricultural and Forest Meteorology, 147(3): 209-232.

[160] Moncrieff, J., Malhi, Y. and Leuning, R., 1996. The propagation of errors in long‐term measurements of land‐atmosphere fluxes of carbon and water. Global change biology, 2(3): 231-240.

[161] Hirano, T. et al., 2012. Effects of disturbances on the carbon balance of tropical peat swamp forests. Global Change Biology, 18(11): 3410-3422. Also Lui et al. 2009 (footnote 10)

[162] See footnote 10

Systematic measurement errors create a constant bias in the data. These errors do not need to be deducted from emission reductions using eddy covariance techniques if they are appropriately avoided or corrected for as per guidelines in the emissions and carbon-stock modules. Systematic errors or biases in the data can be avoided by calibrating instruments properly and meeting assumptions of the eddy covariance technique such as requirements of flat homogeneous terrain and ample turbulence. These errors are also related to advection, drainage effects, storage[163] and roving flux footprints[164] Previous work in the Delta has demonstrated flux footprint issues can create large errors eddy flux measurements[165]. Other systematic biases can be avoided by correcting for high-frequency losses and density fluctuations associated with long tube lengths in closed path systems. For further discussion of systematic errors associated with eddy covariance measurements and how to avoid and correct for them see Richardson et al[166] and the methods module.

Estimating uncertainty in biogeochemical modeling

When using process-based biogeochemical models to estimate emission reductions, this protocol requires project proponents to account for model structural error and error associated with data inputs. The uncertainty associated with model inputs and model structural uncertainty shall be incorporated into equations 2 and 3.

Error associated with data inputs

Project proponents shall estimate random measurement and sampling error associated with data inputs for biogeochemical models[167,168]. Where measurements are replicated in time and space within strata, pools and locations, sampling error can be calculated using the standard error of the mean value of the replicate measurements. For example, initial measurements of soil organic carbon must be replicated across strata. Those measurements will be averaged and the standard error of the mean is used to estimate the spatial uncertainty in soil organic carbon measurements. The estimated uncertainty shall be incorporated into the model uncertainty estimate.

To estimate random measurement error, measurements shall be replicated in the same location during the same timeframe. For example, if LAI is measured using a LAI-2200C Plant Canopy Analyzer (LI-COR, Lincoln, NE, USA), the variance across measurements replicated in the same location can be used to calculate the random error associated with LAI data. Random measurement and sampling errors together comprise the total error associated with each data input. The percent error associated with data inputs (U_{inputs}) is estimated by taking the product of the random and sample errors. Errors are expressed as 90% confidence intervals.

[163] Aubinet, M. et al., 2005. Comparing CO2 storage and advection conditions at night at different CARBOEUROFLUX sites. Boundary-Layer Meteorol, 116(1): 63-93.
[164] Ibid and Göckede, M., Markkanen, T., Hasager, C.B. and Foken, T., 2006. Update of a footprint-based approach for the characterisation of complex measurement sites. Boundary-Layer Meteorol, 118(3): 635-655.
[165] Baldocchi, D. et al., 2012. The challenges of measuring methane fluxes and concentrations over a peatland pasture. Agricultural and Forest Meteorology, 153(0): 177-187.
[166] See footnote 7
[167] Keenan, T.F., Carbone, M.S., Reichstein, M. and Richardson, A.D., 2011. The model–data fusion pitfall: assuming certainty in an uncertain world. Oecologia, 167(3): 587-597, Richardson, A.D. et al., 2010. Estimating parameters of a forest ecosystem C model with measurements of stocks and fluxes as joint constraints. Ibid., 164(1): 25-40.
[168] Richardson, A.D. et al., 2010. Estimating parameters of a forest ecosystem C model with measurements of stocks and fluxes as joint constraints. Oecologia, 164(1): 25-40.

$$U_{inputs} = \prod_i(\sigma_{random_i} + \sigma_{sample_i}) \quad (41)$$

where

σ_{random_i} is the 90% confidence interval associated with measurements of model inputs in stratum *i*

σ_{sample_i} is the 90% confidence interval associated with sample collection in stratum *i*

Meteorological drivers for the model such as air temperature and available light do not add significant error to the model estimations of emissions and therefore do not need to be deducted from emission reductions[13].

Model Structural Error

Model structure uncertainty (U_{struct}) shall be estimated by validation of the model against a year of data that is independent from the data used to calibrate the model. A minimum of 1 year of data will be used for estimates of uncertainty[13]. There are numerous ways of estimating model output uncertainty such as bootstrapping methods discussed above. In addition a χ2 statistic can be used to determine the uncertainty of the model output[12]. Project proponents shall document appropriate peer reviewed methods and parameters for calculating model uncertainty. As new data and updated model versions become available model structural uncertainty shall be re-evaluated.

Uncertainty deductions to emission reductions

Model uncertainty must be calculated for each year when the carbon stock changes and emissions are estimated. Model estimated uncertainty deductions to emission reductions shall be calculated as follows:

$$ER_{corr} = \sqrt{U_{inputs}^2 + U_{struct}^2} \quad (42)$$

where

ER_{corr} Total model uncertainty expressed as a 90% confidence interval around the annual sum (tCO_2e)

U_{inputs} Total uncertainty from model inputs expressed as a 90% confidence interval (tCO_2e)

U_{struct} Model structure uncertainty expressed as a 90% confidence interval (tCO_2e)

DATA AND PARAMETERS MONITORED

Data /parameter:	$E_{BSL,SS}$
Data unit:	tCO_2e
Used in equations:	38
Description	Carbon stock (e.g. soil organic carbon, and emissions if determined significant) in the baseline case.

Source of data:	The terms denoting significant carbon stocks or GHG emissions from baseline modules used to calculate emission reductions
Measurement procedures (if any):	
Monitoring frequency:	The monitoring must occur within five years before the start of the project activity and when the baseline is revisited.
Quality Assurance / Quality Control	
Any comment:	Baseline stocks and sources are estimated ex-ante for each baseline period.

Data /parameter:	$E_{P,SS}$
Data unit:	t CO_2e
Used in equations:	39
Description	Description: Carbon stock (e.g. soil organic carbon, and emissions if determined significant) in the project case.
Source of data:	The terms denoting significant carbon stocks, or GHG emissions used to calculate net emission reductions from the following relevant modules
Measurement procedures (if any):	
Monitoring frequency:	Monitoring frequency may range from 5 to 20 years and can be fixed to coincide with the crediting period.
Quality Assurance / Quality Control	
Any comment:	The ex-ante estimation shall be derived directly from the estimations originating in the relevant modules:

Data /parameter:	$U_{BSL,SS}$
Data unit:	%
Used in equations:	38
Description	Percentage uncertainty (expressed as 90% confidence interval as a percentage of the mean where appropriate) for carbon stocks and greenhouse gas sources in the baseline case in stratum *i* (1,2…n represent different carbon pools and/or GHG sources)
Source of data:	Calculations arising from field measurement data.
Measurement procedures (if any):	Uncertainty in pools derived from field measurement with 90% confidence interval calculated as the standard error of the averaged plot measurements in each stratum multiplied by the t value for the 90% confidence level. For emission sources and wetland loss conservative parameters should be used sufficient to allow the uncertainty to be set as zero.
Monitoring frequency:	The monitoring must occur within five years before the start of the project activity and when the baseline is revisited.
Quality Assurance / Quality Control	
Any comment:	Baseline stocks and sources are estimated ex-ante for each baseline period.

Data /parameter:	$U_{P,SS}$
Data unit:	%
Used in equations:	38
Description	Percentage uncertainty (expressed as 90% confidence interval as a percentage of the mean where appropriate) for carbon stocks and greenhouse gas sources in the baseline case in stratum *i* (1,2…n represent different carbon pools and/or GHG sources)
Source of data:	Calculations arising from field measurement data.
Measurement procedures (if any):	Uncertainty in pools derived from field measurement with 90% confidence interval calculated as the standard error of the averaged plot measurements in each stratum multiplied by the t value for the 90% confidence level. For emission sources and wetland loss conservative parameters should be used sufficient to allow the uncertainty to be set as zero.
Monitoring frequency:	Monitoring frequency may range from 5 to 20 years and can be fixed to coincide with the crediting period.
Quality Assurance / Quality Control	
Any comment:	*Ex-ante* the uncertainty in the with-project carbon stocks and sources shall be equal to the calculated baseline uncertainty

Methodological Module Tool for estimation of non-permanence risk for wetland construction and restoration and rice cultivation in the Sacramento-San Joaquin Delta and San Francisco Estuary

The currently acceptable non-permanence risk tool is the VCS AFOLU Non-Permanence Risk Tool which can be found at

http://www.v-c-s.org/sites/v-c-s.org/files/AFOLU%20Non-Permanence%20Risk%20Tool,%20v3.2.pdf

Methodological Module Tool for significance testing for wetland construction and restoration and rice cultivation in the Sacramento-San Joaquin Delta and San Francisco Estuary

The currently acceptable significance testing tool is the Clean Development Mechanism (CDM) tool for testing significance of GHG emissions which can be found at:

http://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-04-v1.pdf/history_view

Methodological Module Tool for the calculation of the number of sample plots for measurements for wetland construction and restoration and rice cultivation in the Sacramento-San Joaquin Delta and San Francisco Estuary

The currently acceptable tool is the Clean Development Mechanism (CDM) tool for calculation of the number of sample plots for measurements which can be found at:

http://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-03-v2.1.0.pdf/history_view

Appendix A

Global Warming Potential Leakage Evaluation for Replacement of Traditional Agriculture by Wetlands and Rice in the Sacramento-San Joaquin Delta

Introduction and Background

Leakage is an increase in the global warming potential (GWP) (i.e. changes in greenhouse emissions or removals) outside the project boundaries that occurs because of the project action. The American Carbon Registry (ACR) requires Project Proponents to assess, account for, and mitigate for leakage above de-minimis levels. Project Proponents must deduct leakage that reduces the GWP benefit of a project in excess of the applicable threshold specified in the methodology.

Activity-shifting leakage occurs when the land uses resulting in baseline emissions that operated in the project area before the project start date are relocated to another area outside of the project boundary. Such market-effects leakage is transmitted through market forces: a supply reduction can result in an upward pressure on price that may incentivize increased production and shifts in cropping patterns elsewhere. The change in the GWP as the result of these market-effects leakage shall be accounted for in the net project greenhouse gas removals. For the activities included in this methodology, the market-effects leakage would result from replacement of crops currently grown in the Sacramento-San Joaquin Delta (Delta) by wetlands and rice.

We herein present a leakage analysis for replacement of traditional crops in the Delta with wetlands and rice. First an economic analysis was conducted to determine how crop acreages statewide would be affected by Delta land conversion. Next we estimated the change in GWP as the result of this crop-area change.

Methodology

Economic Analysis

ERA Economics (see ERA technical memorandum below) used the Statewide Agricultural Production (SWAP) model[169] to quantify market leakage. The purpose of this analysis was to evaluate the potential "leakage" effects for four Delta land-use-change scenarios. For the purposes of this analysis, market leakage is defined as the shift in agricultural production to other regions of California as a result of land

[169] Richard E. Howitt, Josue Medellin-Azuara, Duncan MacEwan, and Jay R. Lund. (2012). Calibrating Disaggregate Economic Models of Agricultural Production and Water Management. Environmental Modeling and Software. 38, 244-258.

changes in the Delta. Land use change from traditional crops to wetlands and rice in the model has been imposed as an exogenous policy constraint in the model.

The SWAP model is a regional agricultural production and economic optimization model that simulates decisions by farmers across 93 percent of agricultural land in California (over 6 million acres). It is the most current in a series of California agricultural production models originally developed by researchers at the University of California at Davis in collaboration with the California Department of Water Resources. The SWAP model, and its predecessor the Central Valley Production Model (CVPM), have been used for numerous policy analyses and impact studies over the past 15 years, including the economic implications of Delta conveyance options[170] and has been subject to peer-review[171] .

For this analysis, the 27 Central Valley SWAP model regions were aggregated into 4 regions; Sacramento Valley, Delta, San Joaquin River, and Tulare Lake Basin. Additional SWAP model regions along the central coast and southern California were not included in the analysis because these regions are decoupled from the Central Valley market. The 20 standard crop groups modeled in SWAP were aggregated into 7 groups; trees and vineyards, irrigated pasture, rice, miscellaneous field crops (including corn, forage and other field crops), vegetables, and cotton.

The SWAP model was used to estimate crop acreage changes for the following alternatives in which land-use changes were simulated to occur by 2030; conversion of traditional field crops and pasture to wetlands or rice. There is no option for implementing wetlands in the SWAP model so it was assumed that fallow land would adequately represent wetlands. Field crops and pasture predominate in areas where there are oxidizing organic soils that contribute to baseline carbon dioxide emissions.

1. No Action Alternative (NAA).
2. Remove 35,000 acres of field crops from the Delta and leave the land fallow.
3. Remove 35,000 acres of field crops from the Delta and convert those acres to rice.
4. Remove 10,000 acres of irrigated pasture from the Delta and leave the land fallow.
5. Remove 10,000 acres of irrigated pasture from the Delta and convert those acres to rice.

Calculation of Changes in Greenhouse Gas Emissions and Removals

To estimate GWP changes, we used the results of statewide modeling and field experiments for over 40 crops.[172] We aggregated the GWP into the 7 groups used in the SWAP analysis and estimated GWP on a per acre basis. We used the estimated GWP in tons of carbon dioxide per acre per year multiplied times the non-Delta acreage changes for the crop groups to estimate the potential GWP leakage for each scenario. Table A1 shows the net emissions (positive values) and removals (negative values) and associated standard error for the crop groups.

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[170] Duncan MacEwan and Stephen Hatchett. (2012). Statewide Agricultural Production Model Update and Application to Federal Feasibility Analysis. Prepared for United States Department of the Interior, Bureau of Reclamation Mid-Pacific Region. 104 pp.

[171] See footnote 169

[172] Li, Changsheng, Six J., Horwath W.R., Salas W., 2014, Calibrating, Validating, and Implementing Process Models for California Agriculture Greenhouse Gas Emissions, Final Report to the Air Resources Board. February 27, 2014.

Table A1. Greenhouse gas emissions (+) and removals (-) for crop groups

Crop group	Tons carbon dioxide equivalents per acre per year	Standard Error
1. Trees and vines	-0.7	0.05
2. Pasture	0.2	4.1
3. Rice	4.8	3.9
4. Field crops (corn, safflower, sorghum, sunflower)	-2.4	0.2
5. Miscellaneous Field Crops (small grains, dry beans, alfalfa, hay)	-4.2	0.3
6. Vegetable Crops	1.9	0.2
7. Cotton	2.8	3.7

Results and Discussion

Economic Analysis

No Action Alternative

The 2030 No Action Alternative provides the baseline against which alternative simulations were compared. Table A2 shows the land use by region and crop group.

Table A2. No Action Alternative (2030) Land Use, thousands of acres

Region	Trees and Vines	Pasture	Rice	Field	Other Field/Forage	Vegetables	Cotton
Sacramento	611	73	575	124	203	142	2
Delta	48	10	5	152	97	54	0
San Joaquin	603	25	11	382	192	202	60
Tulare	1,280	23	0	561	533	353	205
Total	2,541	131	590	1,219	1,026	752	268

Alternatives

The predominant crops in the Central Delta where wetlands and rice would likely be implemented to mitigate subsidence and provide a greenhouse removal benefit are field crops (primarily corn) and pasture. Thus, the alternative simulations replaced these crops with wetlands and rice. Table A3 shows the statewide acreage changes for the alternatives.

2- Retire 35,000 Acres Field Crops and Convert to Wetlands

In alternative 2, 35,000 acres of field crops (corn, safflower, and "other field crops") are converted to wetlands. The statewide change in the total agricultural footprint is slightly less than 35,000 acres, indicating limited crop substitution to other regions as farmers adjust crop mix in response to changing relative prices. Most of the acreage change occurs in the Delta.

3 – Retire 35,000 Acres Field Crops and Convert to Rice

Alternative 3 is the same as alternative 2 except the 35,000 acres is converted entirely to rice. The estimated statewide decrease in the total agricultural footprint is estimated to be less than 20,000 acres. There is a simulated decrease in rice acreage in the Sacramento Valley, the primary rice producing area in the state.

4 – Retire 10,000 Acres Irrigated Pasture and Convert to Wetlands

In alternative 4, 10,000 acres of pasture are removed from the Delta and that land is converted to wetlands. Statewide, net acreage changed by approximately the same amount.

5 – Retire 10,000 Acres Irrigated Pasture and Convert to Rice

Alternative 5 is the same as alternative 4 except the pasture acreage is converted entirely to rice. The estimated statewide change in the total agricultural footprint is estimated to be less than 1,000 acres. The primary land-use change would occur in the Delta where rice replaces pasture. Some acreage is simulated to go out of rice production in the Sacramento Valley.

Table A3. Changes by region and crop group for alternatives relative the NAA.

Scenario	Region	Trees and Vines	Pasture	Rice	Field	Other Field/Forage	Vegetables	Cotton
A2 Field Crops to Wetlands	**Sacramento**	-9	-178	-5	920	-247	-49	-1
	Delta	-522	5,119	6	-35,992	-2,948	-662	0
	San Joaquin	-106	-72	-2	853	-359	-51	-45
	Tulare	-101	-498	0	1,422	-384	-36	-96
A2 Total Net Change	**-34,043**	**-738**	**4371**	**-1**	**-32,797**	**-3,938**	**-798**	**-142**
A3 Field Crops to Rice	**Sacramento**	2,414	557	-2,919	914	583	124	55
	Delta	-257	-10,071	35,000	-35,000	-11,029	-449	0
	San Joaquin	-447	-59	-111	630	133	-53	-49
	Tulare	-276	-364	0	664	172	-66	-201
A3 Total Net Change	**-20,105**	**1,434**	**-9,937**	**31,970**	**-32,792**	**-10,141**	**-444**	**-195**
A4 Pasture to Wetlands	**Sacramento**	-11	110	11	14	-77	-2	0
	Delta	-54	-10,000	71	-1,768	1,732	19	0
	San Joaquin	31	60	3	79	-118	-1	1
	Tulare	24	114	0	62	-148	10	42
A4 Total Net Change	**-9,796**	**-10**	**-9,716**	**85**	**-1,613**	**1,389**	**26**	**43**
A5 Pasture to Rice	**Sacramento**	883	298	-936	-11	186	56	18
	Delta	4	-10,000	10,000	60	378	11	0
	San Joaquin	-73	48	-26	52	12	1	-1
	Tulare	-33	78	0	-23	1	2	3
A5 Total Net Change	**988**	**781**	**-9,576**	**9,038**	**78**	**577**	**70**	**20**

Greenhouse Gas Analysis Results

Alternatives

2- Retire 35,000 Acres of Field Crops and Convert to Wetlands

We estimated the GHG effect of changes in crop acreage outside the Delta on the GWP (Table 4). Due to simulated changes in price, supply and demand, the SWAP model estimated a total change of 5,431 acres for the non-Delta region. For each crop group, the change in acreage was multiplied by the emissions or removals listed in Table 1 to result in a net removal of 4,198 tons carbon dioxide equivalents per year relative to the NAA (Table A4). For comparison, estimated median baseline emissions in the Delta are about 7 tons carbon dioxide equivalents per acre per year[173] due to the oxidation of organic soils. Therefore, for the 35,000 acres of field crops in the Delta the estimated baseline emission is about 245,000 tons carbon dioxide equivalents per year. The estimated standard error associated with the GWP is relatively large as there is substantial variability within crop groups and spatial and temporal variability associated with the modeled and measured values. Considering the total standard error (the sum of absolute values for individual crop groups) results in a range of GWP change relative to the NAA of -8,790 to 395 tons carbon dioxide equivalents per year.

Table A4. Change in acreage and greenhouse gas emissions due to conversion to wetlands in Alternative 2.

	Trees and Vines	Pasture	Rice	Field	Other Field/Forage	Vegetables	Cotton	Total
Non-Delta acreage change	-215	-748	-7	3,195	-990	-135	-141	5,431
Non-Delta GWP change (tons carbon dioxide equivalents per year)	151	-150	-35	-7,667	4156	-257	-396	-4,198
Estimated GWP Standard Error	11	3067	29	639	297	27	524	4593

3- Retire 35,000 Acres of Field Crops and Convert to Rice

For the alternative, the SWAP model estimated a total non-Delta acreage change of 8,152 acres (Table A5). For each crop group, the change in acreage was multiplied by the emissions or removals listed in Table 1 to result in a net GWP change of -25,270 tons carbon dioxide equivalents per year relative to the NAA. A key reason for the large net removal is the decrease in non-Delta rice acreage which was multiplied by the estimated per acre emissions of 4.8 tons carbon dioxide equivalents per acre per year on mineral soils in California (Table A1). Similar to Alternative 2 and for comparison, the estimated baseline emission for the 35,000 acres of field crops in the Delta is about 245,000 tons carbon dioxide equivalents per year. Considering the total standard error (the sum of absolute values for individual crop groups) results in a range of GWP change relative to the NAA of -39,156 to -11,383 tons carbon dioxide equivalents per year.

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

Table A5. Change in acreage and GWP due to conversion to rice in Alternative 3.

	Trees and Vines	Pasture	Rice	Field	Other Field/Forage	Vegetables	Cotton	Total
Non-Delta acreage change	1,691	134	-3,031	2,208	888	5	-195	8,152
Non-Delta GWP change (tons carbon dioxide equivalents)	-1183	27	-14,547	-5299	-3,730	10	-547	-25,270
Estimated GWP Standard Error	85	551	11,819	442	266	1	723	13,886

4- Retire 10,000 Acres of Pasture and Convert to Wetlands

For this alternative, the SWAP model estimated a total non-Delta acreage change of 1,269 acres. For each crop group, the change in acreage was multiplied by the emissions or removals listed in Table 1 to result in a net GWP change of 1,296 tons carbon dioxide equivalents per year relative to the NAA (Table A6). For comparison, estimated median baseline emissions in the Delta are about 7 tons carbon dioxide equivalents per acre per year. Therefore, for the 10,000 acres of pasture in the Delta, the estimated baseline emission is about 70,000 tons carbon dioxide equivalents per year. The estimated change in the GWP is less than 2% of the estimated baseline emission. Considering the total standard error (the sum of absolute values for individual crop groups) results in a range of GWP change relative to the NAA of -221 to 2,813 tons carbon dioxide equivalents per year or a maximum of 4% of baseline emissions.

Table A6. Change in acreage and annual greenhouse gas emissions due to conversion to wetlands in Scenario 4.

	Trees and Vines	Pasture	Rice	Field	Other Field/Forage	Vegetables	Cotton	Total
Non-Delta acreage change	43	284	14	155	-343	6	43	890
Non-Delta GWP change (tons carbon dioxide equivalents)	-30	57	69	-373	1441	12	121	1,296
Estimated GWP Standard Error	2	1164	56	31	103	1	160	1,517

5 - Retire 10,000 Acres of Pasture and Convert to Rice

For this alternative, the SWAP model estimated a total non-Delta acreage change of 2,460 acres. For each crop group, the change in acreage was multiplied by the emissions or removals listed in Table A1 to result in a net GWP change of -5,788 tons carbon dioxide equivalents per year relative to the NAA. The decrease in rice acreage outside the Delta represents the majority of the change in the GWP. Similar to Alternative 4 and for comparison, the estimated baseline emission for the 10,000 acres of pasture in the Delta is about 70,000 tons carbon dioxide equivalents per year. Considering the total standard error (the sum of absolute values for individual crop groups) results in a range of GWP change relative to the NAA of -11,465 to -111 tons carbon dioxide equivalents per year.

Table A7. Change in acreage and annual greenhouse gas emissions due to conversion to wetlands in Scenario 5.

	Trees and Vines	Pasture	Rice	Field	Other Field/Forage	Vegetables	Cotton	Total
Non-Delta acreage change	777	424	-962	18	199	60	20	2,460
Non-Delta GWP change (tons carbon dioxide equivalents)	-544	85	-4619	-44	-835	114	55	-5,788
Estimated GWP Standard Error	39	1737	3753	4	60	12	73	5,677

Summary and Conclusions

Holistic economic and GWP analysis of likely land-use changes in California due to implementation of rice and wetlands in the Delta provides useful and insightful information about potential market-based leakage. For 4 scenarios in which we simulated the changes in agricultural acreages resultant from conversion of traditional crops to wetlands and rice in the Delta, estimated GWP changes were insignificant relative to the no-action alternative and baseline emissions or there was a net GWP benefit. The following bullets summarize our results.

- Retirement of 35,000 acres of field crops and conversion to wetlands resulted in a non-Delta GWP change of -4,198 tons carbon dioxide equivalents per year. The baseline emissions associated with field crops is about 245,000 tons carbon dioxide equivalents per year.
- Retirement of 35,000 acres of field crops and conversion to rice resulted in a non-Delta GWP change of -25,270 tons carbon dioxide equivalents per year. The baseline emissions associated with field crops is about 245,000 tons carbon dioxide equivalents per year. A key reason for the large net removal is the decrease in non-Delta rice acreage which when was then multiplied by the estimated per acre emissions of 4.8 tons carbon dioxide equivalents per acre per year on mineral soils in California.

- Retirement of 10,000 acres of pasture and conversion to wetlands resulted in a non-Delta GWP change of 1,296 tons carbon dioxide equivalents per year. The baseline emissions associated with pasture is about 70,000 tons carbon dioxide equivalents per year.
- Retirement of 10,000 acres of pasture and conversion to rice result in a net GWP change of -5,788 tons carbon dioxide equivalents per year relative to the NAA. For comparison, the estimated baseline emission for the 10,000 acres of pasture in the Delta is about 70,000 tons carbon dioxide equivalents per year
- We estimated uncertainty by using the standard error associated with the GWP estimates. In all alternatives except for alternative 4, the range of GWP changes was insignificant (3% or less) relative to baseline emissions.
- Where rice acreage increases in the Delta, our results indicate a net statewide GWP benefit due to the decrease in rice acreage in non-Delta areas where there are large GHG emissions on mineral soils.

ERA Economic Analysis Technical Memorandum

Prepared by: Duncan MacEwan, ERA Economics

Prepared for: Steve Deverel, HydroFocus

August 12, 2014

This technical memorandum briefly describes the methods, results, and limitations of an economic analysis of land use change in the Sacramento-San Joaquin Delta (Delta) using the Statewide Agricultural Production (SWAP) model. The purpose of this analysis was to evaluate the potential "leakage" effects from four (4) Delta land use policies. Leakage is a term used to describe the offset of carbon (or other) policy benefits caused by a shift in economic activity to another region. For the purposes of this analysis, leakage is defined as the shift in agricultural production to other regions of California as a result of land retirement policies in the Delta.

It is important to note that changes in land use resulting from environmental (e.g. carbon) policy, and the partial offsetting effects of leakage, are clearly driven by the economics of the crops being produced. An effective Delta land use policy must alter the relative profitability of crops, considering conditions in domestic and international export markets, in order to incentivize growers to shift production systems or retire land. In this analysis no attempt has been made to model land use change as an endogenous outcome of some incentive structure. Instead land use change has been imposed as an exogenous policy constraint. It follows that this study should be viewed as a partial equilibrium analysis of Delta land use policy which is mandated and therefore decoupled entirely from economics, holding all other factors constant. The estimated leakage represents one outcome resulting from a series of critically important simplifying assumptions. In practice, a significant incentive structure would need to be in place to affect the type and scale of land use conversion considered in this analysis.

More careful general equilibrium and sensitivity analysis should be performed prior to drawing any policy conclusions from the results summarized in this technical memorandum.

Analytic Approach

The SWAP model is a regional agricultural production and economic optimization model that simulates the decisions of farmers across 93 percent of agricultural land in California. It is the most current in a series of California agricultural production models, originally developed by researchers at the University of California at Davis in collaboration with the California Department of Water Resources with additional funding provided by the United States Bureau of Reclamation. The SWAP model has been subject to peer-review (Howitt et al. 2012). The SWAP model, and its predecessor the Central Valley Production Model (CVPM), have been used for numerous policy analyses and impact studies over the past 15 years, including the impacts of the Central Valley Project Improvement Act, Upper San Joaquin Basin Storage Investigation, the SWP drought impact analysis, and the economic implications of Delta conveyance options (MacEwan and Hatchett 2012).

The SWAP model was used to estimate the following scenarios (alternatives):

1. No Action Alternative (NAA)
2. Remove 35,000 acres of field crops from the Delta and leave the land fallow
3. Remove 35,000 acres of field crops from the Delta and convert those acres to rice
4. Remove 10,000 acres of irrigated pasture from the Delta and leave the land fallow
5. Remove 10,000 acres of irrigated pasture from the Delta and convert those acres to rice

Key Assumptions

Field crops for this analysis were defined as safflower, sudan grass and other miscellaneous field crops, and corn. Year 2030 was assumed for the level of development. Other key assumptions include:

1. Crop demand: linear shift based on changes in real income and population. No attempt was made to model international export markets, it was assumed that California maintains a constant export share in the international market.
2. Real electricity cost: held constant.
3. Other inputs real cost: held constant.
4. Technological change: not modeled.
5. Climate effects (changes in crop yield and ET): not modeled.
6. Surface water deliveries: CVP, SWP, and local supplies were held constant.
7. Groundwater depth and installed capacity: held constant.
8. Urban development (ag-urban land conversion): not modeled.

Results

The impact of an alternative is defined as the difference between the NAA and that alternative. This analysis holds all other factors constant, given the assumptions described above, to estimate the shift in statewide crop production in response to each policy alternative.

The 27 Central Valley SWAP model regions were aggregated into 4 regions including the Sacramento Valley, Delta, San Joaquin River, and Tulare Lake Basin. Additional SWAP model regions along the central coast and southern California were not included in the analysis because these regions are generally decoupled from the Central Valley market. The 20 standard crop groups modeled in SWAP were aggregated into 7 groups: trees and vineyards, irrigated pasture, rice, miscellaneous field crops including corn, forage and other field crops, vegetables, and cotton.

The accompanying Excel workbook summarizes the results. This section provides a brief summary of the findings.

No Action Alternative

The 2030 NAA provides the baseline against which the future policy runs are compared. Agricultural land use is expected to contract slightly by 2030, by around 6.5 million irrigated acres (~5%) statewide, including a contraction to 367,000 acres in the Delta. This is consistent with the recent trends in California toward more intensive tree and specialty crop production on a smaller land footprint. Climate change, international markets, relative energy costs, and resource conditions such as surface and groundwater availability will affect the 2030 NAA, but were held constant in this analysis.

Irrigated pasture in the Delta is estimated to decrease from approximately 14,000 acres to 10,000 acres.

No Action Alternative (2030) Land Use, thousands of acres

Region	Trees and Vines	Pasture	Rice	Field	Other Field/Forage	Vegetables	Cotton
Sacramento	611	73	575	124	203	142	2
Delta	48	10	5	152	97	54	0
San Joaquin	603	25	11	382	192	202	60
Tulare	1,280	23	0	561	533	353	205

Alternative 2 – Retire 35,000 Acres Field Crops

In alternative 2, 35,000 acres of field crops (corn, safflower, and "other field crops") are removed from the Delta and the land is left fallow. The statewide change in the total irrigated footprint is slightly less than 35,000 acres, indicating limited crop substitution to other regions as farmers adjust crop mix in response to changing relative prices.

Alternative 2 (2030) Land Use, thousands of acres

Region	Trees and Vines	Pasture	Rice	Field	Other Field/Forage	Vegetables	Cotton
Sacramento	611	73	575	125	203	142	2
Delta	47	15	5	116	94	54	0
San Joaquin	603	25	11	383	192	202	60
Tulare	1,280	23	0	563	533	353	205

Alternative 3 – Retire 35,000 Acres Field Crops and Convert to Rice

Alternative 3 is the same as alternative 2 except the acreage is converted entirely to rice. This analysis assumed that land use conversion is exogenously mandated. The statewide decrease in the total irrigated footprint is estimated to be less than 20,000 acres.

Alternative 3 (2030) Land Use, thousands of acres

Region	Trees and Vines	Pasture	Rice	Field	Other Field/Forage	Vegetables	Cotton
Sacramento	613	73	572	125	204	143	3
Delta	48	0	40	117	86	54	0
San Joaquin	603	25	10	383	192	202	60
Tulare	1,280	23	0	562	534	353	205

Alternative 4 – Retire 10,000 Acres Irrigated Pasture

In alternative 4, 10,000 acres of irrigated pasture are removed from the Delta and that land is left fallow. Statewide irrigated acreage decreases by approximately the same amount.

Alternative 4 (2030) Land Use, thousands of acres

Region	Trees and Vines	Pasture	Rice	Field	Other Field/Forage	Vegetables	Cotton
Sacramento	611	73	575	124	203	142	2
Delta	48	0	5	150	99	54	0
San Joaquin	603	25	11	382	192	202	60
Tulare	1,280	23	0	561	533	353	205

Alternative 5 – Retire 13,800 Acres Irrigated Pasture and Convert to Rice

Alternative 5 is the same as alternative 4 except the acreage is converted entirely to rice. It is important to note, again, that this analysis assumed that land use conversion is exogenously mandated. The statewide total irrigated area is estimated to increase by just over 1,000 acres.

Alternative 5 (2030) Land Use

Region	Trees and Vines	Pasture	Rice	Field	Other Field/Forage	Vegetables	Cotton
Sacramento	611	73	574	124	204	143	3
Delta	48	0	15	152	98	54	0
San Joaquin	603	25	11	382	192	202	60
Tulare	1,280	23	0	561	533	353	205

The leakage analysis is primarily concerned with the change in crop mix and shift in production to other regions of California. The leakage effect is fundamentally driven by basic supply and demand principles of economics. When the production of a crop(s) decreases in response to Delta land use policy, all else constant, the price of that crop(s) will increase. As the price of that crop(s) increases this will change the relative profitability of crops in all other regions in the state, and in response, growers may switch production systems and change the statewide crop mix. The magnitude of this effect is driven by a number of factors including domestic and international market conditions, the relative supply and demand elasticities of all crops, and cross-price elasticities. In addition, there are intensive margin (for example, input use per acre) adjustments to production that affect the magnitude of leakage.

The following subsections briefly describe the results of the leakage analysis and summarize key trends.

Alternative 2

A total of 35,992 acres of corn, other field, and safflower crops (35,000 attributed to the policy and 992 attributed to market adjustment) are removed from the Delta. 35,000 acres of land is left fallow and the total irrigated acreage in the Delta decreases by the same amount.

The decrease in Delta field crop production increases the statewide price for field crops, causing an additional 3,200 acres to be planted in the Sacramento, San Joaquin and Tulare Basin areas of the Central Valley. The additional acreage in other regions comes from a small shift in the crop mix, meaning a decrease in the acreage of some other crops. For example, growers in the Tulare Lake Basin plant 500 fewer acres of irrigated pasture and substitute toward other field crops.

Alternative 3

35,000 acres of field crops removed from the Delta are converted to rice.

The increased rice production in the Delta puts downward pressure on rice prices and rice production decreases, primarily in the Sacramento Valley. In response to the decreased rice production, the Sacramento Valley production shifts to other crops including deciduous and forage crops. This causes a change in the market price of those crops and production decreases in other regions and the market reaches a new equilibrium.

Alternative 4

A total of 10,000 acres of irrigated pasture are removed from the Delta and the land is left fallow.

Fallowing 10,000 acres of pasture has a small statewide price effect and other regions slightly increase production. There is a correspondingly small shift in the crop mix to accommodate the increase in pasture acreage in these regions.

Alternative 5

10,000 acres of irrigated pasture are removed from the Delta and converted to rice.

Similar to alternative 3, the increased rice production in the Delta puts downward pressure on rice prices and rice production decreases, primarily in the Sacramento Valley. The Sacramento Valley production adjusts and shifts to other crops including deciduous, pasture and other forage crops. This causes a change in the market price of those crops and production adjusts in other regions until the market reaches a new equilibrium.

Change in Irrigated Acreage from NAA								
Scenario	**Region**	**Trees and Vines**	**Pasture**	**Rice**	**Field**	**Other Field/Forage**	**Vegetables**	**Cotton**
A2 Fallow Field	**Sacramento**	-9	-178	-5	920	-247	-49	-1
	Delta	-522	5,119	6	-35,992	-2,948	-662	0
	San Joaquin	-106	-72	-2	853	-359	-51	-45
	Tulare	-101	-498	0	1,422	-384	-36	-96
A3 Field to Rice	**Sacramento**	2,414	557	-2,919	914	583	124	55
	Delta	-257	-10,071	35,000	-35,000	-11,029	-449	0
	San Joaquin	-447	-59	-111	630	133	-53	-49
	Tulare	-276	-364	0	664	172	-66	-201
A4 Fallow Pasture	**Sacramento**	-11	110	11	14	-77	-2	0
	Delta	-54	-10,000	71	-1,768	1,732	19	0
	San Joaquin	31	60	3	79	-118	-1	1
	Tulare	24	114	0	62	-148	10	42
A5 Pasture to Rice	**Sacramento**	883	298	-936	-11	186	56	18
	Delta	4	-10,000	10,000	60	378	11	0
	San Joaquin	-73	48	-26	52	12	1	-1
	Tulare	-33	78	0	-23	1	2	3

Limitations

There are several important limitations of this analysis. First, the standard caveats to any analysis using SWAP or other economic optimization models apply.

The SWAP model is an optimization model that makes the best (most profitable) adjustments to water supply and other changes. Constraints can be imposed to simulate restrictions on how much adjustment is possible or how fast the adjustment can realistically occur. Nevertheless, an optimization model can tend to over-adjust and minimize costs associated with detrimental changes or, similarly, maximize benefits associated with positive changes.

The SWAP model does not explicitly account for the dynamic nature of agricultural production; it provides a point-in-time comparison between two conditions. This is consistent with the way most economic and environmental impact analysis is conducted, but it can obscure sometimes important adjustment costs.

The SWAP model also does not explicitly incorporate risk or risk preferences (e.g., risk aversion) into its objective function. Risk and variability are handled in two ways. First, the calibration procedure for SWAP is designed to reproduce observed crop mix, so to the extent that crop mix incorporates risk spreading and risk aversion, the starting, calibrated SWAP base condition will also. Second, variability in water delivery, prices, yields, or other parameters can be evaluated by running the model over a sequence of conditions or over a set of conditions that characterize a distribution, such as a set of water year types.

In addition, there are several important limitations to the current analysis stemming from the assumptions.

The analysis assumes a single statewide supply and demand elasticity for all crops. Further analysis should consider the different types of rice and geographic differences in elasticities. Additionally, the key supply elasticity used in the SWAP model is the acreage response elasticity, which means that other dimensions of supply response are not explicitly calibrated in the model.

California's export share to international markets has been assumed to remain constant. Sensitivity analysis of Asian export markets and production in other mediterranean climate regions should be considered.

Finally, this analysis did not attempt to model infrastructure capacity to support rice production, including mills and crop insurance. Future analysis should consider the capacity to support rice production in the Delta and third-party (indirect and induced) impacts.

SWAP Model References

Richard E. Howitt, Josue Medellin-Azuara, Duncan MacEwan, and Jay R. Lund. (2012). Calibrating Disaggregate Economic Models of Agricultural Production and Water Management. *Environmental Modeling and Software*. 38, 244-258.

Duncan MacEwan and Stephen Hatchett. (2012). Statewide Agricultural Production Model Update and Application to Federal Feasibility Analysis. *Prepared for United States Department of the Interior, Bureau of Reclamation Mid-Pacific Region*. 104 pp.

Appendix B. Responses to comments provided by The Nature Conservancy, US Geological Survey and Environmental Defense Fund

Responses are in italics, bold and black.

General

Comment

Check if uncertainty can be met with current data from delta managed wetlands

Response
Using the Miller and others soil core and SET data from 1997 – 2006 for the west pond results in an uncertainty of about 10% at the 90% confidence level. According to equation 2 in the Framework, this would result in no discount of the cumulative total net GHG emission reduction. I think the west pond probably would represent the variability in a typical stratum with similar water management. The east pond is more variable with an uncertainty of about 25% which result in a discount of about 35% in equation 2. The east pond had deeper water levels and a mixture of open water and vegetated areas and therefore could have likely represented multiple strata.

Validate model against soil core data (averaged over longer period)

Language requiring this is included in the Framework module.

Sea level rise is still missing as a C-sea driver- check if you can link your model with other physical models (e.g. Morris, MEM) to capture the SLR-driven volume accretion

Additional language has been included in the Framework module that incentivizes project proponents to consider SLR.

Use tables to describe strata for both baseline and project

Tables describing strata have been included in the framework, baseline and project modules.

Try for more explicit guidance on DOC/DIC load tracking

Additional clarifying language has been added.

If you are not using the Miller chamber gas flux or the Anderson Eddy Covariance (EC) data in the model (2002-present), they could be used as independent validation of flux rates

We are using Baldocchi lab group Eddy Covariance data for model validation (70% for model parameterization; 30% for validation). The Anderson EC data have not been made available to us for validation purposes, as Anderson needs to publish before sharing. In addition, I believe those data were not collected in conjunction with water table height, which is a critical input for the model. The

Miller chamber data will not be a good dataset for validation since the model and data work at significantly different temporal and spatial scales.

Clarify some of the bigger differences between using EC flux in a harvested crop (rice) v a permanent wetland.

This language has been inserted into the methods module.

For agricultural baseline conditions (e.g. corn) on organic soils, CO_2 assimilation occurs as the result of plant photosynthetic uptake during the growing season and the crop is a net GHG remover during this time. During the non-crop period, oxidation of organic matter results in a net GHG emission. However, CO_2 assimilation into the harvested grain is removed and results in an overall GHG emission for the cropped system under drained conditions. In contrast, for a permanently flooded wetland and to a lesser extent, rice, flooding the soil during the warmest time of the year greatly reduces GHG emissions due to oxidation of soil organic matter and there is CO_2 assimilation into the wetland and rice vegetation resulting in a net GHG removal.

Look for model sensitivity in specific subsets rather than just overall CO2 budget driven primarily by photosynthesis during the summer (is winter and/or nighttime respiration properly captured? does the model work well at all scales? daily, seasonally, yearly? what are the most sensitive drivers (initial SOC?)? what does that tell us about whether it will be validated 40 years out)

The model is being thoroughly evaluated. Model evaluation includes assessment of sensitivity to different parameters and inputs. Evaluation is not only conducted at the annual scale but also at the daily scale. In the years to come, the model will be compared with data collected in the Delta in order to 1) maintain validation and 2) expand the model to more diverse systems.

I expect ARB to want much more standardization of the protocols so results are more consistent and easily verifiable from a regulatory perspective. This may be a tension with ACR approach for voluntary market

Agreed. The methodology will likely undergo revision before submittal to and acceptance by ARB.

Overall, I think the protocol as written is a pretty good draft (includes lots of biogeochemistry across the range of project types) that would be enough to give a methodology validator plenty to chew on. Of course, the more work done now, the better (and smoother and cheaper) the validation process will go. Some requirements seemed fairly broad (ex.: for ag baseline, there's a long list of options for stratification, and not much guidance or parameters). Project developers (and also project auditors) may want more narrowly defined requirements and guidance – which will reduce the amount of subjective judgment needed for project validation, and basically gives the auditor less room to question a project's validity. The methodology validation process probably will help address some of this.

Some additional clarifying language has been added to the Framework and Project and Baseline modules to provide specifics for stratification.

Applicability condition - compliance with applicable laws and regs: we recently ran into concerns over impacts on delta smelt resulting from any project that required pumping water out of waterways and on to islands (which would then be subject to ESA review process, incidental take permit, etc.). To avoid this, the methodology may want to exclude / prohibit pumping out of waterways onto islands. I suspect that many/most islands would not require pumping on to the island (merely the cessation of pumping water *off* the island) as a part of a carbon project. Let me know if you want more background on this.

Good point. Language has been included in the Framework Module that specifically requires project proponents to mitigate through use of fish screens or other methods to avoid impact to fish populations.

Rice project module: interesting that they've included aggregation

Aggregation is allowed by ACR and can be used for all project activities.

Additionality: I'm not familiar with ACR's exact requirements on this, but the performance standard for tidal wetlands seems a bit more tenuous than the other 2 project types; the methodology notes that these projects are already taking place at a large scale… For our (VCS) wetlands meth, we used the activity penetration method to demonstrate that project activities were not common practice; VCS would count projects as additional only until the practice reached 5% of the regions covered by the methodology. If that approach were applied here, the rice and non-tidal project types would qualify, but the tidal projects would not…

ACR and ARB (see rice methodology for non-organic soils) have accepted the use of the performance standard in a less specific way than it is specified for this methodology.

Methods for estimating carbon stock changes and emissions: overall, the methods seem pretty comprehensive.

Framework

Geographies could be specified after going through each landuse baseline scenario. The geographical designations are examples, but it doesn't seem like a baseline scenario is exclusive to a geography and may be confusing to a project proponent. I would suggest keeping baselines based on the land use described in Table 1. Also, if not all of the Table 1. components are addressed, there should be an overall explanation of why.

In response to other reviewers' comments, we included examples for land uses but these are not intended to be all inclusive. Language has been added to clariy.

I thought the [rice] yields were low. Just checking.

Rice yields on the Twitchell Island pilot project have been relatively low for a variety of management-related factors. However, the agronomic yield trial results are consistent with Sacramento Valley yields and other areas in the Delta range from 8,000 to 10,000 pounds per acre. Yields on other islands are consistent with Sacramento Valley yields

It would be helpful to know which baselines can undertake which projects in an easy to read image. Or even a table/explanation

For example, something simple upfront like:

Baseline 1 => Project types 1 and 2

Baseline 2 => Project types 2 and 3

Baseline 3 => Project type 3

Baseline 4 => Project types 1 and 3

It might be a rethinking of Table 1 and Figure 4.

Figure 4 tries to capture this, but it is a bit confusing with the multiple arrows and is later on.

Text has been added to the applicability conditions section in an attempt to clarify what baseline conditions correspond to.

Net Ecosystem Productivity not defined. I would want to know the impact of root exudates, litter production, and plant turnover- i.e. explain the importance of this, or re-write the sentence to show how Net Ecosystem productivity is used.

Net Ecosystem Production is defined as the difference between gross primary production and respiration and represents the amount of carbon available for storage. The point of the sentence is to reference the concept that increased NEP is associated with increased amounts of root exudates, litter production and plant turnover.

We also want to make sure that we aren't confusing growers who might be using the rice protocol to reduce methane emissions. (in reference to net GHG benefit of rice on Delta organic soils)

Note that the baseline for rice is always traditional Delta agriculture on organic soils. Language has been changed in an attempt to clarify.

In reference to the following statement

"The methodology assumes the Project Proponent has or engages the necessary expertise and requires that the activities implemented under this methodology comply with all applicable regulations."

I like this statement- in the future, there will need to be additional (or references to) sources for individuals who want to access these types of experts, as well as more of a statement that these practices require significant active management and knowledge.

Comment noted

Relative to use of soil coring

Yes, but where included – I couldn't find it. Important validation of model related to measurement of soil organic matter.

Soil coring is specified in the methods module for determining changes in soil organic matter. Language in framework module now specifies the need for validation using soil organic matter measurement.

Referring to Figure 4, I would move a version of this figure up. Also, Baselines need to be determined before project is implemented, so I would switch baseline to the left.

We elected to leave the figure as is and add more language to explain.

Calculation of uncertainty Important part! Suggest compare with IPCC Wetlands Supplement approach

The approach presented in the Uncertainty Module is consistent with the algebraic combination of uncertainty approach presented in the IPCC (2013 Wetlands Supplement) document.

Figure 2 (should be Figure 1) could benefit from being upgraded and, as is, is a bit confusing regarding CH_4. Usually, there is high CH_4 when there is an anaerobic environment, not when there is oxidation of soils. I think the document would benefit greatly from a full discussion and explanation of how CO_2 and CH_4 emissions arise from both agricultural and wetland soils and what types of changes or disturbances give rise to increases or decreases in gaseous carbon fluxes. The emission of N_2O also needs a full explanation.

Figure numbering changed and narrative has been added to explain Note that in figure 1, CH_4 is shown as being emitted from tidal marsh (upper panel) not from the lower panel which shows the aerobic environment.

Figure 3 needs to be updated to 2015. The caption mentions 7000 years, but ~6800 is closer to the truth (see Drexler et al. 2007).

Caption changed to 6800 years.

Top of page 5: "baseline CO_2e emissions range from 2 to 18 metric tons CO_2e per acre (per year needs to be added).

Corrected. Thank you.

Under "San Francisco Estuary", bottom of page: "This oxidation results in emission of CO_2, CH_4, and possibly N_2O." This sentence needs to be explained better.

More explanation has been added.

Page 6 first para: "There have been no baseline measurements or estimates of GHG in the Suisun Marsh or northern SF Bay Area". Frank Anderson is currently measuring GHG fluxes in Rush Ranch, located in Suisun Marsh.

Mention of Frank's measurements have been added.

Under "Open Water". Last word of paragraph: removals of what?

Removals refers to GHG removals

Sentence now reads

Also, there can be large primary productivity and respiration rates in these open water areas thus demonstrating the potential for baseline GHG emissions and removals.

footnote 15 . Assuming an organic soil bulk density of 0.3 g cm-3 (seems quite high for peat—is this an amalgamation of mineral and organic soils?) and 50% organic carbon (that is an incredibly high estimate for organic carbon content, even for peat), this volume of 5800 acre feet translates to about 2.6 million tons of CO2. Seems like an overestimate to me.

Good catch. It should be 50% organic matter (25% organic carbon). This results in about 2.0 million tons. Using a lower bulk density (0.2) results in 1.3 million tons. Corrected in the footnote.

In describing the Twitchell Demo project, which pond are you describing when you say that carbon sequestration ranged from 2-14 tons or are you including both?

Yes, both ponds. Now, clarified in the text.

Figure 3 should be part of a more in-depth discussion of carbon cycling processes. This would also benefit the section under Tidal Wetlands in SF Estuary and CA Coast on page 8.

A more in-depth discussion has been added.

Please change Dexler to Drexler. Also the citation should be Drexler 2011.

Another good catch. The misspelling has been corrected. Thanks.

Sources of Information. It would be good to spell out these abbreviations so that they are clear for all and provide citations.

Clarification has been added.

Table 1. I could not find definitions for "CP-S/EE, E-FFC. What is a "counterfactual scenario?"

These refer to the methods modules. More explanation has been added as follows.

The counterfactual scenario provides a forecast of the likely stream of emissions or removals to occur if the Project Proponent does not implement the project, i.e., the "business as usual" case. It also reflects the sum of the changes in carbon stocks (and where significant, N_2O and CH_4 emissions) in the carbon pools within the project boundary that would occur in the absence of the Project Activity, where the land would remain degraded or continue to subside in the absence of the project activity.

Under ineligible management activities, what about adding diversion of water flows?

Diversion of water is necessary for impounded marshes.

Development of a monitoring plan. How many years should a site be monitored?

Monitoring and estimation of GHG removals and will occur during the life of the project. A sentence has been added.

Temporal boundaries. It is difficult to understand how projects dating back to 2000 can be eligible to receive offsets retroactively. This needs to be explained much better.

The criteria are a demonstration of intentional GHG mitigation and documented carbon stock changes to the satisfaction of third party auditors. Some additional language has been added.

Carbon Pools and Sources. A much more comprehensive explanation is required concerning what constitutes double counting and when pools or sources may be excluded. As written, this could be a loophole that might be abused.

More explanation has been included.

Table 3. The text "baseline" and "project" needs to be much bigger to avoid confusion to the reader.

Font size changed to 18 for better visibility.

The optional status for CH4, N2O for baseline needs to be better explained. How would you know the change in these emissions after the project if they weren't measured before?

For baseline conditions, the primary GHG of interest is CO2 and this is the largest contributor to GHG emissions. A project proponent can therefore conservatively include only this GHG in the determination of GHG emissions for the baseline. It is a conservative estimate of the GHG emissions which is counted as avoided emissions when the project is implemented. Or, the project proponent can invest more to determine CH4 and N2O to increase the magnitude of the avoided emission.

CH4 may only be excluded if salinity is > 18 ppt.

As explained in the tidal wetlands module and as per Poffneburger et al., there are minimal CH4 emissions where salinities exceed 18 ppt. However, sulfate must also be determined to assess the potential for CH4 emissions where there is sulfate reduction.

Why is N2O optional for lands other than rice?

The literature indicates that N2O emissions are insignificant in wetlands in flooded but previously non-flooded organic soils. Citations have been added. Therefore, determination is optional except for rice where there is fertilizer application and there are known emissions of N2O.

What about other previously fertilized lands?

See response above for baseline conditions.

Under Leakage, first paragraph. This paragraph is really hard to understand due to lots of jargon.

We simplified the language and provided more explanation.

What about leakage in other areas besides the Delta?

It can be reasonably assumed that market forces will only operate where lands are currently in agriculture. This language has been added:

"Project Proponent muse insure and verify that the project activity will not result in a reduction of wetland restoration activities, GHG removals or increase wetland loss outside of the project boundary. "

Monitoring plans. What time period should a monitoring plan cover? EPA has some guidance on this. Invasive plant species can pose significant problems after 5+ years, so long-term monitoring is important.

The module now states that monitoring shall occur for the life of the project for a minimum of 40 years.

Is there any concern about the ultimate ecological value of wetlands that are restored for carbon benefits? Are there any requirements for minimum ecological value of restored wetlands, such as habitat value for sensitive species?

The methodology does not allow for activities that diminish the ecological value of project or non-project lands and prohibits the planting of non-native species.

"greenhouse described" is a typo.

Corrected to read greenhouse gas emissions. Thank you.

Under "Use of Models". Must be peer-reviewed. This is a pretty general term. I think a better requirement would be "models must be in the peer-reviewed primary literature in the form of journal articles or book chapters."

Text changed as follows.

Models must be described in the peer reviewed literature

Relative to the monitoring plan. We will want to see how realistic these requirements are- how time consuming. Are these normal questions and activities that won't take significant additional time?

Comment noted. There are economies of scale and efficiency issues to be considered relative to the development of the monitoring plan. The use of validated models and values from the peer-reviewed literature and reference sites can reduce project costs as can aggregation.

Top of page 26, second sentence ends with "political". ?

Political refers to external risk factors in the sentence. "External risk factors include land tenure, community engagement and political"

Sentence changed to

"External risk factors include possible changes in land tenure, community engagement and political forces"

Risk Assessment: why only 40 years for project term, when radiative forcing calculations for emitted gases are usually estimated for 100 years of time?

The methodology was written for the voluntary market which currently uses a minimum of 40 years within the American Carbon Registry. For the compliance market it will likely increase to 100 years.

Agricultural Baseline

So no biomass or crops are included here – what about tree crops (almond/pear)?

Tree and vine crops are generally limited to non-organic soils in the Delta. Verbiage has been added to reflect this. Further, the project proponent must account for GHG emissions and removals that affect the determination of net baseline emissions.

Managed Wetlands

This is module with the highest potential for implementation. As with the others, tables that illustrate the range of management options (water depth, flowthrough, planted v colonized,) would be helpful to user in stratifying potential sites/management (described in strata but table would be better).

Table added

I don't think the aboveground biomass contributes directly to longterm SOC. This may be an issue in review.

Hmm. Aboveground biomass contributes to litter which contributes to SOC right? Possible discussion point.

Baseline Open Water

The main things missing here is discussion of :

Some subsided lands are sinks or sources depending on conditions outside project boundaries. For example:

Allochtonous v autochtonous (OW is below sea level and thus will fill up – do you get credit for the C that arrives and fills your site? What if that C is highly labile and your system turns into a source of C? Who takes ownership of those fluxes?

Added to OW module:
Allochthonous carbon may enter the open water area from outside source which may contribute to carbon accumulation at the site. However, for purposes of this methodology, carbon from outside sources is not counted in determination of baseline GHG emissions or removals. Only autochthonous processes are to be considered in the determination of the GHG baseline removals or emissions.

I was looking for this more clearly stated. Perhaps again a list of dominant landuses in delta

e.g. breached delta islands (liberty, franks tract), salt ponds, other subsided lands?

Addressed with more background information in Framework module and a table has been added to Framework module to address comment.

Rice

Good but a lot of details missing. The inclusion of biomass/harvest issues in the EC flux work separates rice from wetlands –that does not come across here as a module difference. Appendix could use better descriptions/citations

More detail added to the module to help clarify.

Perhaps include incentive for N2O data collection, in order to validate the model used, as it is very new and N fluxes so dominant that they could swamp CO2eq budget.

I am confused by this comment. Nitrous oxide emissions are relatively low for rice in most cases. I am not sure what an incentive would look like as nitrous oxide emissions are part of the overall GHG budget.

Seasonal Wetlands

This one may be hard to implement so a good walkthrough, on the background uncertainties, may be important prior to review.

There are many ways to be seasonal within the delta. Perhaps a table of dominant land types and flooding regimes to illustrate the different seasonality and hydroperiods considered here. There are big differences in the fate of soil C and DOC.

Table added to provide more information about example types of eligible seasonal wetlands.

Big differences from Suisun out to Cosumnes River

Clarification to limit applicability to organic soils and highly organic mineral soils has been included.

Leakage

This is well done for agricultural leakage by market forces. The other leakage issue, for tidal wetlands, is the effect of a project on neighboring lands through flooding, or in the case of other tidal marhses, reduced tidal prism or effects of "stealing sediment". There are interactions that I think will be brought up in review.

We define leakage is an increase in in greenhouse emissions outside the project boundaries that occurs because of the project action. In the framework module, we now specify that the project activity will not result in a reduction of wetland restoration activities or increase wetland loss outside of the project boundary.

Tidal wetlands

The strata and concept are layed out well but the Methods Module may need more attention to tidal hydrology, and the unique issues of input/output, sedimentation, C source allocation, interannual variability and extreme event responses due to drivers way outside project bounds.

More background information relative to sea level rise, tidal hydrology, inputs/outputs, carbon and temporal variability have been added to the Framework module.

I'm looking forward to seeing this module applied in a site that is already well known (reference site), to see if it can be validated. The historic N pool in ag land, btw, may be important problem for N2O flux.

Just an FYI, that IPCC 2013 has only accounting for replanting seagrass, with default emission factor of -43 g/m2 y. Very small flux and accounting only for projected soil C accumulation.

Verbiage has been added to emphasize the need data collection for quantifying carbon sequestration rates in Eelgrass.

Need to also measure sulfate at least once across site to validate the salinity/sulfate relationship.

The requirement for sulfate monitoring has been added to the tidal wetlands module.

Uncertainty

If its possible to make this a 1-tailed distribution (conservative approach), results would be more likely to meet the threshold.

This should be possible. The module does not specify that the data should be treated as normally distributed or how confidence intervals should be calculated.

Methods Module

"Equattions" typo.

Good catch. Thanks.

under "Methods". The descriptions included here are not very detailed, which could lead to misinterpretation and loopholes.

There is substantial detail provided in cited references, method descriptions and quality assurance tables. Because there is variability in project practices and types, we are reluctant to be more prescriptive. As specified in the Framework Module, the methodology is not intended to provide explicit direction; the Project Proponent is required to engage the necessary expertise to implement the required activities. The project proponent is required to document methods and quality assurance and control results and substantiate GHG removal estimates.

If the measurement period is 40 years, how are the soil carbon stock changes going to be measured throughout the period. In the beginning there will be great changes in both carbon fluxes and soil development. How exactly will total carbon stocks be estimated through time?

Project proponents are required to report the cumulative carbon stock changes during the reporting period. Certainly during the reporting period, carbon stock changes will vary but the bottom line is the cumulative change. As discussed in the methods section, cumulative carbon stock changes can be measured using eddy covariance and soil coring.

The text under footprint needs further details and clarification.

Text has been added to define the footprint.

One year of monitoring for baseline conditions seems inadequate to me as emissions could vary a lot just due to weather conditions.

The project proponent is required to monitor baseline conditions for at least one year and project baseline emissions for the life of the project and justify the estimates and make them conservative. The baseline emissions are part of the estimate for baseline conditions which shall be projected into the future. Given that the primary factors affecting for baseline emissions are soil carbon content, soil temperature and depth to groundwater, we do not expect substantial climate-related inter-annual variability for baseline conditions (see for example, Hatala et al. 2012).

"Standard" eddy covariance practices need to be defined.

Changed to read "Standard eddy covariance practice as described in the literature cited".

Because the term “stratum” is used throughout these documents, it wouldn’t hurt to reiterate the meaning in each of the documents.

Explanation added

N2O is present in the equation but its measurement has yet to be described.

Equation refers to Eddy Covariance which can be used measure N2O emissions as now stated.

“The eddy covariance (EC) technique[174] estimates fluxes of GHGs by relying on the concurrent determination and statistical analysis of vertical atmospheric velocity and the atmospheric concentration of the GHG (e.g. CO_2, CH_4, N_2O) of interest

The description of parameters for equation 5 contains both C and N (see last line on page before footnotes) and is confusing.

The ΔC refers to the change in gas concentration not carbon. N2O was included as an example gas. The sentence now reads as follows.

“ΔC/Δt the change in gas concentration per unit of time (g/m^3s^{-1}) within the chamber .”

“N20 emissions can be conservatively ignored in permanently flooded wetland conditions”. After what period of time?

Since fertilization and wastewater effluent are not allowed in wetlands under this methodology, nitrous oxide emissions are not expected to occur once the soil is flooded. The emissions of N2O from rewetted organic soils are controlled by the quantity of N available for nitrification and denitrification, and the availability of the oxygen required for these chemical reactions. Oxygen availability is limited as the water table depth decreases which will cause N2O emissions to decrease rapidly, and fall practically to zero when the soil is saturated (e.g. Couwenberg et al., 2011, IPCC, 2013 cited in the revised module).

Please include units for each parameter in equation Under the parameters, did you mean to say Equation 1 or Equation 6 in the last sentence before “Aqueous Carbon Loads”?

Both

“Quality Assurance”: Aren’t all manual measurements done in all systems subject to error and uncertainty?

***Good* point. Sentence deleted.**

“Data presented in Drexler et al. (2009) provide ranges of estimates for organic matter content and bulk density for eight islands throughout the Delta”. Better not to exaggerate.

[174] Baldocchi DD, Hicks BB, Meyers TP (1988) Measuring biosphere–atmosphere exchanges of biologically related gases with micrometeorological methods. *Ecology* **69**, 1331–1340.

Text changed.

Soil organic carbon content can be analyzed with a CHN analyzer. A relationship can be established between loss on ignition of organic matter and organic carbon content by analyzing both and conducting simple regression analysis. Then the organic C content can be estimated using the cheaper/simpler analysis of LOI.

This is now offered as an alternative in the methods module.

"Specific steps for core collection". No description is included regarding how to coring should be done and what depth of cores are recommended. This needs to be added, with a bit of text describing how compaction needs to be avoided and how it can be determined.

The methodology states that core samples should be collected to the depth of the feldspar marker or to the depth accumulated at the sediment pin. The methodology assumes that qualified professionals will be conducting the coring.

It would be good to move the text on corers that is found on page 22 to this part of the document.

Reference is made to this text in the specific steps section.

Bulk density determination doesn't need a reference per se. Soil sections (2 cm) for a full core need to be thoroughly dried until their weight no longer changes and then the weight of each section needs to be divided by the volume.

Text added to reflect this method.

Something needs to be said about the possibility of carbonates being in soil samples and how this possibility needs to either be eliminated (by analyzing for carbonates) or accounted for by subtracting out soil carbonate carbon.

Text has been added to reflect the interference of inorganic carbon.

Model Module

Overall comments:

- What metrics need validation over 2 years? Subsets of data? Day/night? Seasonal?

  Not clear about what is meant here.

- Sensitivity to the different drivers should be used for projection?

  Stayed tuned for the answer to this question. As the model is published during the next few months, the publication will provide more information about sensitivity.

- Ec based approach likely an over estimate if not calibrated to soil stocks.

  The data for the Twitchell west pond indicate the opposite. This is however an important point that we will investigate further.

- Empirical focus good for delta, not immediately applicable to bay or coastal wetlands

Agreed. We chose to focus on the system with the most potential.

- DOC/DIC import/export not accounted for in fluxes

We see the DOC/DIC import/export as additive to the model and estimated separately from site specific data.

General comment –The different methods for project and baseline is odd. If they cannot be coupled, then a flow chart or decision tree showing how the model decision is coupled would help.

We intend to couple them in the future. However, for now, there is a diagram in the Framework module that provides guidance for use of baseline and project models.

in reference to methanogenesis

Need to model emission or Net Methane Production (methanogenesis – oxidation)

A section has been added that describes the methane ecosystem model.

in reference to aerobic respiration

Assumes aerobic respiration, when anaerobic through profile –fermentation additionally a source of acetate for methanogenesis, but not linked in model

We assumed this pathway to be negligible

In reference to initial SOC conditions "Profile? Which depth – Bulk".

Sentence now reads as follows.

Initial SOC conditions for the simulated region is another driver for model simulation and must be sampled at the beginning of the project (5-10 soil profile samples) to assess average SOC in the top 1 m of soil; see tables 1-3 for complete list of drivers, parameters and state variables).

Model assumes bulk soil diffusion of CO2 rather than radial oxygen loss or other oxidation pathways

We agree that this needs further looking into.

SSURGO is not very spatially relevant within large soil series and/or after changes in landuse (e.g. past oxidation). I didn't see this called out in the uncertainty module.—

Model input uncertainty is discussed in the Uncertainty Module and should apply to this.

Wow, maybe a smaller plot suggestion? The overall leaf area perhaps could be 16 m2, but that's a lot of scanning,

Size has been reduced