Greenhouse Gas Mitigation Typology Issues Paper
Tidal Wetlands Restoration

Prepared for

California Climate Action Registry

Prepared by

Philip Williams & Associates, Ltd. *and*
Science Applications International Corporation

February 4, 2009

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1. INTRODUCTION

Over the last two centuries, atmospheric greenhouse gas (GHG) concentrations, particularly carbon dioxide (CO_2), have risen markedly, contributing to global warming and climate change, and creating interest in sequestering (storing) carbon in land and biomass. Tidal wetlands present an opportunity for carbon sequestration and GHG offsets by virtue of their potential for wetlands creation, restoration, enhancement, and avoided loss.

1.1 REPORT OBJECTIVES

This report addresses issues related to developing a GHG offsets quantification methodology and performance standard for tidal wetlands in the United States. The foci of the report are questions related to additionality, performance standards, permanence, GHG quantification, market interest and other issues related to developing a GHG offsets methodology as part of the California Climate Action Registry (CCAR) offsets program. Another focus will be on the emerging guidance on quantifying sequestration rates, and the related uncertainties with the existing approaches. Two or three representative example states (including California) are used to investigate the options for setting performance standards, and other issues.

No prior offsets program has looked at tidal wetlands as a GHG offsets option, and no prior work has been done to examine methods for quantifying sequestration and determining additionality for this type of project. Because of the absence of earlier work in this area, we begin the report with a background section (Chapter 2), which provides general information on wetlands, relevant GHGs, and GHG quantification methods. This chapter also includes a discussion of possible tidal wetlands classifications that could be used for GHG accounting when establishing the baseline and tracking project emissions and sequestration.

Based on the background information, Chapter 3 then goes on to discuss the specific issues related to creating an offsets methodology for tidal wetlands. It starts with an outline of the specific types of wetlands projects that could be eligible for projects including wetlands creation, restoration, enhancement, and avoided loss. The chapter also summarizes relevant federal and state regulations targeting wetlands conservation and analyses how these could be addressed under the regulatory additionality screen, even though most wetlands targets and polices are not being successful at meeting their stated goals.

Wetlands are somewhat unique for offsets projects because federal and state agencies have a large role in their regulation and management, and actually own much of the land that could be used for tidal wetlands projects. It must therefore be determined how to establish a methodology that determines what is beyond "business-as-usual" activities of the public sector, in addition to that of the private sector. We discuss this issue in a section on the development of a performance standard for tidal wetlands along with a summary of available datasets that can be used for analyzing common and better-than-average practices concerning tidal wetlands. The current datasets are not comprehensive enough to provide adequate information for setting performance standards for the relevant categories of tidal wetlands projects. Instead, we outline a framework for how performance standards could be developed and the additional research and datasets that would have to be developed to support the implementation of such a framework. This discussion is then followed by an analysis of methods for quantifying baseline emissions, potential reduction opportunities, issues to consider in setting the GHG boundary, ownership, permanence, scientific uncertainty, and methods for identifying and establishing leakage.

Finally, in Chapter 4, we summarize our findings and outline the various research questions that would have to be addressed in order to establish an offsets methodology for tidal wetlands.

1.2 DEFINITIONS

1.2.1 Wetlands

There are many definitions of a wetland from various scientific and legal perspectives. Perhaps the most commonly used is that by Cowardin *et al.*, 1979:

> *Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually or near the surface or the land is covered by shallow water. Wetlands must have one or more of the following three attributes: 1) at least periodically, the land supports predominantly hydrophytes[salt tolerant plants]; 2) the substrate is predominantly undrained hydric soil; and 3) the substrate is saturated and covered with water or covered by water at some time during the growing season of each year*.

1.2.2 Tidal Wetlands

Tidal wetlands might be defined as:

> *Freshwater, brackish or marine vegetated or unvegetated systems subject to periodic flooding by tides on a lunar basis or by raised tidal waters associated with winds or run-off.*

Tidal wetlands are classified by the amount of water cover at high and low tides and the type of vegetation. Some legal definitions of tidal wetlands include shallow open water habitat to a depth of -2m below low water.

2. GHG EMISSIONS AND CARBON SEQUESTRATION IN WETLANDS

2.1 OVERVIEW

Wetlands act both as a reservoir for carbon, ultimately sequestered from the atmosphere, and producers of methane (CH_4) and nitrous oxide (N_2O) through biogeochemical processes. The capacity of wetlands to provide an offset for anthropogenic GHG emissions will depend upon landscape settings as variations in these determine both the rate of carbon sequestration and GHG production.

2.2 WETLANDS AS CARBON RESERVOIRS

Wetlands accumulate carbon directly from the atmosphere as plants capture CO_2 during photosynthesis, as well as by directly trapping organic matter carried with flooding waters. The bulk of carbon stored within wetlands is derived from below-ground biomass, the accumulation of roots and rhizomes associated with standing above-ground crop of vegetation. Some of the above ground biomass is accumulated within the soil but much is recycled within the estuary.

The living standing crop of vegetation and the build up of roots and rhizomes in near-surface soils create a *standing pool* of carbon in the marsh. Once a steady state is achieved this standing pool will remain constant unless the vegetation changes or the health of the wetland is impacted. Below this standing crop, microbial degradation of organic matter occurs uncompensated by new production. Consequently, below the surface the amount of soil carbon generally diminishes with depth. There is some indication that below a permanent water table this rate of decomposition decreases and long-term sequestration occurs. The depth to this permanent water table may be a few decimeters to meters depending upon tidal range. A fair approximation of this depth would be the local mean tide elevation. In many coastal settings accumulations of organic bearing soils have built up that date back to the mid Holocene (around five thousand years old).

Bridgham et al (2006) collated data to assess the potential storage and flux of carbon within peatlands, freshwater mineral soil wetlands and tidal wetlands, across Alaska, Canada, the conterminous U.S. and Mexico.[1] (Tables 1-3) The analysis used available datasets. The authors highlighted that the classifications used in these datasets fail to distinguish between different types of tidal wetland, the range of which greatly defines their capacity to sequestering carbon and emit GHGs. Table 1 shows the data for the conterminous U.S. and Alaska. Bridgham et al. (2006) indicated that they were 95% certain that the actual areas are within 10-25% of the estimated areas. [2]

[1] Bridgham, S.D., J.P. Megonigal, J.K. Keller, N.B. Bliss, C. Trettin. 2006. The Carbon Balance of North American Wetlands. Wetlands: 26, 889-916.
[2] Ibid

Table 1. Areas of Wetlands (Bridgham et al., 2006)

Wetland Type		Conterminous U.S.(km^2)		Alaska (km^2)	
		Current	Historical	Current	Historical
Peatlands	Permafrost	0	0	89,000	89,000
	Non-permafrost	93,000	111,000	43,000	43,000
Freshwater	Mineral soil	312,000	762,000	556,000	556,000
Estuarine	Tidal marsh*	20,000	22,000	1,400	1,400
	Mangrove	3,000	4,000	0	0
	Mudflat	2,000	3,000	7,000	7,000

*includes salt marsh, brackish marsh, and freshwater tidal wetland (including freshwater forested)

Bridgham et al. estimated soil carbon and plant carbon pools for several broad classes of wetland types across the conterminous U.S. Alaska. Table 2 and Table 3 summarize those estimates. [3]

Table 2. Estimated Soil Carbon and Plant Carbon Pool (mass, Pg) in the Conterminous U.S. for Wetland Classes Defined by Bridgham *et al.* (2006)

Conterminous U.S.	Permafrost peatlands	Non-permafrost peatlands	Freshwater on mineral soil	Tidal marsh	Mangrove	Mudflat	Total
Soil carbon pool size in current wetlands	0	14.0 (51.3)	5.1 (18.7)	0.40 (1.5)	0.061 (0.22)	0.046 (0.17)	19.6 (71.9)
Plant carbon pool size in current wetlands	0	1.5 (5.5)		0.034 (0.12)	0.024 (0.088)	N/A	1.5 (5.5)

Note: Number in parentheses represents Pg CO_2e.

Table 3. Estimated Soil Carbon and Plant Carbon Pool (mass, Pg) in Alaska for Wetland Classes Defined by Bridgham *et al.* (2006)

Alaska	Permafrost peatlands	Non-permafrost peatlands	Freshwater on mineral soil	Tidal marsh	Mangrove	Mudflat	Total
Soil carbon pool size in current wetlands	9.3 (34.1)	6.2 (22.7)	26.0 (95.3)	0.025 (0.092)	0	0.13 (0.48)	41.7 (152.9)
Plant carbon pool size in current wetlands	0.4 (1.47)		1.1 (4.03)	0.002 (0.0073)	0	N/A	1.5 (5.5)

Note: Number in parentheses represents Pg CO_2e.

[3] Ibid

Bridgham et al. estimated that the conterminous U.S. and Alaskan wetlands have current soil carbon pools of 19.6 and 41.7 Pg C (71.9, 152.9 Pg CO_2e), respectively, equating to 12% of the global soil carbon pool in current wetlands. [4] Plant carbon pools are significantly less with 1.5 Pg C (5.5 Pg CO_2e) estimated for both the conterminous U.S. and Alaska, equating to 19% of the global plant carbon pool in current wetlands. These carbon pools are dominated by peatlands in the conterminous U.S and by freshwater wetlands on mineral soil in Alaska.

The capacity of coastal wetlands to accumulate carbon has been the focus of several review studies. Gathering together data from 154 marshes, mainly from the United States, but also from overseas, Chmura *et al.* estimated that salt marshes and mangroves accumulated, on average 150-250 gC m^{-2} yr^{-1} (550-916.7 g CO_2e m^{-2} yr^{-1}) , though the range varied over an order of magnitude. [5] In a similar summary assessment, Duarte *et al.*, (2005) reviewed the contribution of vegetated and unvegetated coastal wetlands to carbon sinks in coastal areas and estimated that salt marshes, mangroves and sea grass areas store 151, 139 and 83 gC m^{-2} yr^{-1} (553.7, 509.7, 304.3 g CO_2e m^{-2} yr^{-1}), respectively; while unvegetated areas of estuaries (mudflats) and the open continental shelf accumulate 45 and 17 gC m^{-2} yr^{-1} (165, 62.3 g CO_2e m^{-2} yr^{-1}) (Table 4). [6]

[4] *Ibid*
[5] Chmura, G.L., S.C. Anisfield, D.R. Cahoon, J.C. Lynch. 2003. Global carbon sequestration in tidal, saline wetland soils. Global Biogeochemical Cycles: 1111, doi:10.1029/2002GB001917.
[6] Duarte CM, Middelburg JJ, Caraco N. 2005. Major Role of Marine Vegetation on the Oceanic Carbon Cycle. Biogeosciences 2:1-8.

Table 4. Estimates of Organic Carbon Burial Rates in Coastal Systems (Duarte *et al.*, 2005)

Component		Area 10^{12} m^2	g C m^{-2} y^{-1}	Tg y^{-1}	N	Tg y^{-1} M.B.	Notes
Vegetated habitats							
	Mangroves	0.2	139.0	23.6	27	17.0	1
	Salt Marsh	0.4	151.0	60.4	96	70.0	2
	Seagrass	0.3	83.0	27.4	5	44.0	3
Total vegetated habitats				111.4		131.0	
Depositional areas							
	Estuaries	1.8	45.0	81.0	24		4
	Shelf	26.6	17.0	45.2	15		5
Total coastal burial				237.6			
	% vegetated habitats			46.9			
Deep sea burial				6.0			6
Total oceanic burial				243.6			
	% vegetated habitats			45.7			

Notes: 1) Area covered from Valieia *et al.*, (2001)[7], organic burial data from Chmura *et al.*, (2003)[8]; 2) Area covered from Woodwell *et al.*, (1973)[9], organic burial from Chmura *et al.*, (2003) [10]; 3) Area covered calculated from original extent of seagrass and reported fraction relative long-term decline rates.[11,12], Organic burial data from Garcia *et al.* 2002[13], Romero *et al.* 1994[14], Mateo et al, 1997[15]; 1995, and Barron *et al.*, 2004[16]; 4) Area covered by Costanza *et al.*, (1997)[17], organic burial data from Heip *et al.*, (1995)[18] and Widdows *et al.* (2004)[19]; 5) Area covered from Costanza *et al.*, (1997)[20] assuming that depositional area covers 10% of the shelf area, organic burial from Middelburg *et al.* (1997a)[21] and; 6) Berner (1982)[22]. M.B: Mass balance approach, this is the former method for estimating carbon content of ocean sediments but did not account for updated carbon content estimated derived from soil analysis– provided for comparison of change.

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[7] Valiela I, Bowen J, York J. 2001. Mangrove forests: one of the world's threatened major tropical environments. Bioscience 21:807-815.
[8] Chmura, G.L., S.C. Anisfield, D.R. Cahoon, J.C. Lynch. 2003. Global carbon sequestration in tidal, saline wetland soils. Global Biogeochemical Cycles: 1111, doi:10.1029/2002GB001917.
[9] Woodwell G, Rich P, Mall CSA. 1973. Carbon in estuaries. In: Woodwell GM, Pecan EV, editors. Carbon and the Biosphere: United States Atomic Energy Commission.
[10] Chmura, G.L., S.C. Anisfield, D.R. Cahoon, J.C. Lynch. 2003. Global carbon sequestration in tidal, saline wetland soils. Global Biogeochemical Cycles: 1111, doi:10.1029/2002GB001917.
[11] Green E, Short F. 2003. World Atlas of Seagrasses: California University Press.
[12] Duarte CM, Middelburg JJ, Caraco N. 2005. Major Role of Marine Vegetation on the Oceanic Carbon Cycle. Biogeosciences 2:1-8.
[13] Garcia E, Duarte C, Middelburg JJ. 2002. Carbon and nutrient deposition in the Mediterranean seagrass (Posidonia oceanica). Limnology and Oceanography 47:23-32.
[14] Romero J, Perez M, Mateo M, Sala E. 1994. The below-ground organs of the Mediterranean seagrass Posidonia oceanica as a biogeochemical sink. Aquatic Botany 47:13-19.
[15] Mateo M, Romero J, Perez M, Littler M, Littler D. 1997. Dynamics of millenary organic deposits resulting from the growth of the Mediterranean seagrass Posidonia oceanica. Estuarine, Coastal, and Shelf Science 44:103-110.
[16] Barron C, Marba N, Terrados J, Kennedy H, Duarte CM. 2004. Community metabolism and carbon budget along a gradient of seagress (Cymodocea nodosa) colonization. Limnology and Oceanography 49(5):1642-1651.
[17] Costanza R, d'Arge R, De Groot R, Fraber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill R, Paruelo J and others. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253-260.
[18] Heip CHR, Goosen N, Herman PMJ, Kromkamp J, Middelburg JJ, Soetaert K. 1995. Production and consumption of biological particles in temperate tidal estuaries. Oceanography Marine Biology Annual Review 33:1-150.
[19] Widdows J, Blauw A, Heip CHR, Herman PMJ, Lucas CH, Middelburg JJ, Schmidt S, Brinsley MD, Twisk F, Verbeek H. 2004. Role of physical and biological processes in sediment dynamics (sedimentation, erosion and mixing) of a tidal flat in Westerschelde estuary, S.W. Netherlands. Marine Ecology-Progress Series 274:41-56.
[20] Costanza R, d'Arge R, De Groot R, Fraber S, Grasso M, Hannon B, Limburg K, Naeem S, O'Neill R, Paruelo J and others. 1997. The value of the world's ecosystem services and natural capital. Nature 387:253-260.
[21] Middelburg JJ, Soetaert K, Herman PMJ. 1997. Empirical relationships for use in global diagenetic models. Deep Sea Research I 44:327-344.
[22] Berner RA. 1982. Burial of organic carbon and pyrite sulfur in the modern ocean; its geochemical and environmental significance. American Journal of Science 282:451-473.

Carbon accumulation estimates range over two orders of magnitude, which reflect interactions between climate, vegetation type, salinity (a primary control of vegetation type), and soil type (capacity to store carbon in soils). Moving from the saline environment to freshwater tidal wetlands there is potential to accumulate over 500 gC m^{-2} yr^{-1} (1,833 g CO_2e m^{-2} yr^{-1}), perhaps over 1000 gC m^{-2} yr^{-1} (3,667 g CO_2e m^{-2} yr^{-1}) on long-term restoration projects.[23,24] It appears from the literature that organic matter accumulation is limited by salinity and has a maximum threshold; freshwater wetlands are able to accrete at rates greater than sea level rise, until an elevation threshold relative to water elevations is reached. For this reason restoring freshwater wetlands potentially offer higher capacity to store carbon than restoring saline wetlands.

Freshwater tidal marshes are prolific accumulators of carbon, storing in excess of 500 gC m^{-2} yr^{-1} (1,833 g CO_2e m^{-2} yr^{-1}). Managed wetlands (built on subsided former marsh areas) have through water management practices demonstrated the capacity to raise marsh surface at rates far in excess of rates of sea level rise. Now in its 10th year of monitoring a USGS study in the Sacramento-San Joaquin Delta has documented marsh surface accumulation of over 5 cm $yr.^{-1}$ [25] With an average soil carbon content of about 0.2 gC cm^{-3} such accretion rates would equate to an accumulation of about 1,000 gC m^{-2} yr^{-1} (3,667 g CO_2e m^{-2} yr^{-1}).

Brackish wetlands are likely an intermediary between saline and freshwater wetlands. Because of the mix with saline water their storage potential will thus fall somewhere in the range between freshwater and saline wetlands.

Estuarine scrub / shrub and forested wetlands were once common features of the landscape at the margin of estuaries. Less work has been done to characterize the soil carbon storage potential, though one estimate by Yu *et al.* (2006), suggests the storage potential could be in comparable range to salt marsh.[26]

2.3 RELEVANT GREENHOUSE GASES

Developing a carbon budget for tidal wetlands requires that we not only consider carbon sequestration potential but also account for the release of CO_2, CH_4 and N_2O, which are byproducts of organic decomposition by bacteria in wetland soils. Table 5 summarizes the overall the global atmospheric contribution of GHGs to radiative forcing that recycle through wetland biogeochemical pathways.

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[23] Feijtel TC, Delaune RD, Patrick WH. 1985. Carbon Flow in Coastal Louisiana. Marine Ecology-Progress Series 24(3):255-260.
[24] Miller R, Fram M, Fujii R, Wheeler G. 2008. Subsidence reversal in a re-established wetland in the Sacremento-San Joaquin Delta, California, USA. San Francisco Estuary & Watersheed Science. : Available from: http://repositories.cdlib.org/jmie/sfews/vol6/iss3/art1.
[25] *Ibid*
[26] Yu KW, Faulkner SP, Patrick WH. 2006. Redox potential characterization and soil greenhouse gas concentration across a hydrological gradient in a Gulf coast forest. Chemosphere 62(6):905-914.

Table 5. Greenhouse Gases Emitted from Wetlands (Forster *et al.*, 2001[27])

Gas	Current (1998) Amount by Volume	Global Warming Potential	Percent increase Since 1750	Radiative forcing (W/m²)
Carbon dioxide, CO_2	365 ppm	1	31%	1.46
Methane, CH_4	1,745 ppb	25	150%	0.48
Nitrous Oxide, N_2O	314 ppb	310	16%	0.15

2.4 TIDAL WETLANDS AS ACTIVE GHG SINKS OR SOURCES

All tidal marshes are generally net sinks for atmospheric CO_2 through burial of organic matter in sediment. Some portion of this carbon is recycled and consequently emitted as CO_2 to the water column and directly to the atmosphere at low tide.[28]

CH_4 formation occurs in low salinity or non-saline environments and requires strictly anaerobic conditions. Methane production is generally intense in brackish and freshwater tidal flats and marshes because of the high organic matter content of the soils at anoxic depths. Methane production decreases by two orders of magnitude as salinity increases due to the availability of sulfate, which in anoxic sediments feeds sulfate-reducing bacteria that outcompete methanogenic bacteria.

In many wetlands some of the methane produced in subsurface soils is oxidized and denatured as it diffuses to the atmosphere through the oxygenated soil surface.[29] In freshwater and brackish marshes (vegetated by tule, common reed, and sedge) this pathway is short-cut by a route through deep soils and by air passages in the plant to the atmosphere.[30] Forested wetlands that are flooded for parts of the year produce less CH_4 than fully tidal marshes because of the periods of prolonged drying and lowered water table. Such systems may even be net sinks for CH_4.

N_2O in oceanic environments is mainly formed as a byproduct during nitrification (the breakdown of ammonia to nitrate and nitrite) and as an intermediate during denitrification

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[27] Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland, 2007: Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[28] Abril G, Borges AV. 2004. Carbon Dioxide and Methane Emissions from Estuaries. In: Tremblay A, Varfalvy L, Roehm C, Garneau M, editors. Green House Emissions: Fluxes and Processes, Hydroelectric Reservoirs and Natural Environments New York: Springer.

[29] Megonigal JP, Schlesinger WH. 2002. Methane-limited methanotrophy in tidal freshwater swamps. Global Biogeochemical Cycles 16(4).

[30] Van Der Nat, F.J., J.J. Middelburg. 2000. Methane emission from tidal freshwater marshes. Biogeochemistry: 49, 103-121.

(conversion of nitrate to nitrous oxide and nitrogen).[31] Both nitrification and denitrification are microbial processes that can happen in the water column and in sediments, mediated by bacteria living in low oxygen environments. Ammonia and nitrate are natural constituents in estuarine waters but are now found at heightened levels in wetlands due to agriculture and other anthropogenic sources such as air pollution.

While estuaries overall are very effective systems for the recycling of nitrogen, the capacity of estuaries to do so has been degraded by the loss of tidal wetlands.[32] Denitrification is not confined to intertidal sediment but continues in organic bearing continental shelf sediments beyond the estuary. As a consequence, while restored wetlands do contribute to the production of small amounts of N_2O, this compound would be produced elsewhere in the estuarine or on the adjacent continental shelf, even without the presence of the wetland. As a result, the presence of the N_2O precursor compounds and their associated emissions would likely remain unchanged regardless of whether the wetlands are there or not. However, further research is required to confirm this.

Overall, tidal wetlands are a net sink for carbon even though they release a percentage of that as CO_2 to the atmosphere or in particulate or dissolved form to the estuary. In brackish and freshwater tidal systems, large amounts of CH_4 are released, which from a GHG mitigation perspective may exceed their carbon sequestration value. Tidal wetlands also contribute a small amount of N_2O production, but this is a function of nitrogen pollution in coastal areas, and these emissions would most likely occur regardless of the presence of the wetland.

2.4.1 Carbon Flux of All Wetlands

Bridgham *et al.* (2006) estimated that the current wetlands of the conterminous U.S. and Alaska are net carbon sinks of 9.5 and 13.3 Tg C yr^{-1} (34.8, 48.8 Tg CO_2e m^{-2} yr^{-1}), respectively (total 22.8 Tg yr^{-1}, 83.6 Tg CO_2e m^{-2} yr^{-1}), and emit methane to the atmosphere at rates of 3.1 Tg CH_4 yr^{-1} and 1.7 Tg CH_4 yr^{-1} (11.4, 6.2 Tg CO_2e m^{-2} yr^{-1}), respectively (total 4.8 Tg CH_4 yr^{-1}, 17.6 Tg CO_2e m^{-2} yr^{-1}).[33] Though the error bars are large, the Bridgham *et al.* study finds wetlands overall to have a net negative GHG offset balance. However, when looking only at saline tidal marsh, mangroves and mudflats, the low CH_4 emissions and relatively high carbon sequestration potential resulted in these specific wetlands having a positive GHG offset balance.

2.4.2 Carbon Sequestration and Soil Chemistry

Microbial activity in freshwater wetland soils transforms considerable amounts of CO_2 into CH_4, which is then released into the atmosphere. In contrast to freshwater wetlands, tidal saline

[31] Bange HW. 2006. Nitrous oxide and methane in European coastal waters. Estuarine Coastal and Shelf Science 70:361-374.
[32] Jickells T. 1998. Nutrient Biogeochemistry of the Coastal Zone. Science 271(5374):217-222.
[33] Bridgham, S.D., J.P. Megonigal, J.K. Keller, N.B. Bliss, C. Trettin. 2006. The Carbon Balance of North American Wetlands. Wetlands: 26, 889-916.

marshes release negligible amounts of CH_4 to the atmosphere, due to the presence of abundant sulfate which inhibits CH_4 production. As CH_4 has a greenhouse warming potential greater than CO_2, each unit of carbon sequestered in tidal saline marshes will have a greater impact than freshwater wetlands in reducing greenhouse warming.

2.4.3 Carbon Sequestration and Sedimentation

Sediment deposition enhances carbon sequestration by burying organic matter. The nature of the sediment influences the rate at which buried organic material breaks down. Relatively 'sandy' sediments have a higher permeability than more 'muddy' sediments. With higher soil permeability the flow of water, as well as the potential for desiccation, provides conditions for organic oxidation and release of carbon; i.e., lesser carbon sequestration will occur. Therefore, carbon sequestration will be regionally variable depending upon the nature of sediments that are building tidal wetlands.

2.4.4 Carbon Sequestration and Wetland Drainage

Historically, many tidal wetlands in the U.S. have been drained for other uses, principally agriculture and urban development. The direct impact of ditching and drainage is the lowering of the water level, which results in oxidation of organic matter in soil and the release of CO_2 to the atmosphere. Hence, former wetlands that are currently drained for agricultural use are losing their historically stored carbon.

In natural tidal wetlands it is likely, but not scientifically quantified, that the depth of the water table influences carbon sequestration potential. Wetlands in microtidal settings, such as the Gulf Coast, potentially offer a higher percentage of carbon within soils than relatively well drained marshes in coastal areas with high tidal ranges.

2.4.5 Sequestration over Time

Wetlands restoration projects typically follow an evolutionary trajectory from an unvegetated or partially vegetated state to a fully vegetated state. Thus, over time, the capacity of wetlands to sequester carbon evolves at a rate dependant upon the time it takes to achieve a fully vegetated wetland. There is some indication that once wetlands have achieved a fully vegetated state (often less that 10 years after the pioneering vegetation establishes) that carbon accumulation rates are equivalent to that of natural reference marshes.[34,35] In a subsided site with limited sediment

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[34] Craft C, Megonigal P, Broome S, Stevenson J, Freese R, Cornell J, Zheng L, Sacco J. 2003. The Pace of Ecosystem Development of Constructed Spartina Alterniflora Marshes. Ecological Applications 13(5):1417-1432.

[35] Cornell JA, Craft CB, Megonigal JP. 2007. Ecosystem gas exchange across a created salt marsh chronosequence. Wetlands 27(2):240-250.

supply it may take several decades, if at all, to build mudflat areas to elevations where vegetation will begin to colonize.

2.5 CARBON SEQUESTRATION AND CLIMATE CHANGE

Climate change will likely affect the process of carbon sequestration in tidal wetlands, but the impacts are difficult to predict. Climate change scenarios predict warming, changes in precipitation, and water levels (tidal and groundwater), which could affect the carbon cycle in wetlands. Increased CO_2 in the atmosphere will result in higher temperatures and increased plant growth in most wetlands, but also increased decomposition rates in wetland soils, increasing CH_4 emissions.[36]

The primary impact of climate change on tidal wetlands will relate to their capacity to respond to sea level rise. Freshwater tidal marshes consisting of tule reeds (but potentially also common reed) have been found to be resilient to rising water levels with the capacity to build marsh vertically at a rate of several centimeters per year.[37] As long as freshwater marshes are maintained in a low salinity environment (<0.5 ppt) they have the capacity to build under relatively high rates of sea level rise.

Saline and brackish marshes depend on a supply of mineral sediment to maintain accretion rates. It appears that in these marshes, carbon production is relatively constant in healthy marshes but that the contribution of organic matter to marsh building is sufficient to balance only 1-2 mm of sea level rise, at most. As a consequence these marshes may be subject to decay and breakdown if the mineral supply is insufficient to balance sea level rise, and / or lateral erosion as deepening waters adjacent to intertidal areas allow larger waves to attack the marsh edge. Examples exist around the US of marsh breakdown including around 100 km^2 of marsh loss per year in the Mississippi Delta[38], the loss of vegetated wetlands in Elkhorn Slough[39,40], as well as loss of marshes in Chesapeake Bay. By contrast, examples exist of coastal areas with a relatively high sediment yield, including Southern California.

With respect to tidal saline wetlands, climate change is important because of changes in wetland area with potential accelerated sea-level rise, and the subsequent changes in sequestration

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[36] Megonigal JP, Schlesinger WH. 2002. Methane-limited methanotrophy in tidal freshwater swamps. Global Biogeochemical Cycles 16(4).
[37] Miller R, Fram M, Fujii R, Wheeler G. 2008. Subsidence reversal in a re-established wetland in the Sacremento-San Joaquin Delta, California, USA. San Francisco Estuary & Watersheed Science. : Available from: http://repositories.cdlib.org/jmie/sfews/vol6/iss3/art1
[38] Day JW, Jr., Boesch DF, Clairain EJ, Kemp GP, Laska SB, Mitsch WJ, Orth K, Mashriqui H, Reed DJ, Shabman L and others. 2007. Restoration of the Mississippi Delta: Lessons from Hurricanes Katrina and Rita. p 1679-1684.
[39] Van Dyke E, Wasson K. 2005. Historical Ecology of a Central California Estuary: 150 Years of Habitat Change. Estuaries 28(2):173-189.
[40] PWA, Associates HH, Nature n, Thornton E, Monismith S. 2008. Elkhorn Slough Tidal Wetland Project: Hydrodynamic modelings and morphologic projections of large-scale restoration actions. Prepared for The Elkhorn Slough Tidal Wetlands Project.

capacity associated with any change in area. If tidal saline wetlands are able to maintain their elevation with accelerated sea-level rise, then the capacity of carbon sequestration will be sustained. However, if sediment supply to the wetland and organic matter accumulation cannot maintain the elevation of the wetland relative to sea-level rise, there is the potential for the wetland to drown. The soil surface is submerged and the wetland edge may erode releasing stored carbon. Also, tidal saline wetlands may expand inland over former terrestrial land which has a lower sequestration capacity than the wetlands. To avoid future loss of wetlands from GHG offsets projects, it would be important to specify certain long-term management practices at tidal saline wetlands to ensure they will be sustained over time.

2.6 RELEVANT TIDAL WETLAND TYPES AND AREAS

As outlined above, the ability of a tidal wetland to store carbon and emit GHGs depends on its type and size, vegetation, the depth of wetland soils, and water table elevations, amongst other factors. In order to persist, the surface elevations of all tidal wetlands must increase with rising sea level. With prolific ability to build marshes through accumulation of organic material, freshwater tidal marshes have intrinsic capacity to rise in elevation along with water table elevations. Marshes in saline settings do not have this capacity and are dependant upon a supply of mineral sediment to assist in the marsh building process. A further distinction defined by salinity is the capacity of wetlands to emit GHGs. While all wetlands recycle N_2O, wetlands in fully saline environments release minimal amounts of CH_4, but with decreasing salinity up-estuary the emission of methane by wetlands increase to significant levels.

Several wetland classification schemes have been published, of which the most commonly referred to were developed by Cowardin et al, (1979).[41] Such schemes have been used to develop databases that quantify habitat distribution at a given time or track habitat gain and loss across time intervals.[42] These widely established classification schemes are not, in their current form, useful for characterizing the carbon budget for tidal wetlands as they do not distinguish clearly between tidal wetlands across the tidal salinity gradient. Interestingly, a classification and inventory developed by Shaw *et al.*, (1956) for the purposes of mapping wetlands of value of wildfowl and other wildlife, distinguishes between several classes of saline and freshwater wetlands by water depth and frequency of flooding.[43] This water classification appears suitable for classifying tidal wetlands of interest for developing quantification and monitoring methods, though have more classes than are required.

[41] Cowardin, L.M., V. Carter, F.C. Golet, E.T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. U. S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Jamestown, ND: Northern Prairie Wildlife Research Center Home Page. http://www.npwrc.usgs.gov/resource/1998/classwet/classwet.htm (Version 04DEC98).
[42] Dahl T. 2006. Status and trends of wetlands in the conterminous United States 1998 to 2004. Washington, D.C.: U.S. Department of the Interior. Fish and Wildlife Service. 112 p.
[43] Shaw S, Fredine C. 1956. Wetlands of the United States. U.S. Fish and Wildlife Service. 67 p.

Building on the various wetlands and GHG accounting issues outlined above, the following provides our recommendation for the minimum number of classes of tidal wetlands that should be used for developing quantification and monitoring guidance. Each wetland is distinguished in terms of varying capacity to both store carbon and emit GHGs. Each class may vary in terms of ecology between regions of the United States but will be broadly comparable in terms of types of vegetation, carbon sequestration potential and rates of GHG production. At this time, however, there are no established sequestration rates or emission factors for these classifications – similar to those developed for the forestry sector in the Reforestation/Afforestation Project Carbon On-Line Estimator (RAPCOE) tool.

2.6.1 Tidal Wetland Classes (temperate latitudes)

The following simplified tidal wetland classes are found across non-subtropical coastal areas of the United States.

- **Mudflats**: Intertidal unvegetated saline wetlands between the elevation of low tide and mean tide (the approximate elevation at which vegetation colonizes).

- **Salt marshes**: Vegetated marshes found in saline (30-50 ppt) high intertidal areas found primarily in estuarine, lagoons, and delta settings. Typical vegetation – cordgrass (*Spartina* sp.) and pickleweed (*Sarcocornia* sp.).

- **Brackish tidal marshes**: Vegetated marshes found in low salinity (0.5-30 ppt) high intertidal areas, such as estuaries, lagoons and deltas, or in the transitional areas between saline and freshwater settings. Typical vegetation – sedge (*Carex.* sp), bulrush (*Bolboschoenus* sp.).

- **Freshwater tidal marshes**: Vegetated marshes found in high intertidal areas estuaries, lagoons and deltas where salinities are below 0.5 ppt. Typical vegetation – tule (*Schoenoplectus* sp.), reed (*Phragmites* sp.).

- **Estuarine scrub/shrub or forest**: Typically found at the head of estuaries and coastal plains but also on natural channel levees where salinities fall below 0.5 ppt. The hydrology is typically defined by seasonal flooding by high river flow or wind-driven tidal elevations. Typical vegetation – Cyprus (*Cypressus* sp.), willow (*Salix* sp), grasses.

2.6.2 Tidal Wetland Classes (subtropical and tropical latitudes)

- **Mangrove**: Vegetated marshes found in low and high intertidal saline areas found primarily in estuarine, lagoons, and delta settings. Typical vegetation – mangrove (Genus: *Rhizophora* and *Avicennia*).

2.6.3 Other Datasets and National Classification Schemes

Two national-level wetlands classifications and datasets provide information on wetland types, uses, and trends, each of which relies on their own geospatial wetland databases and interpretations of high resolution images. This includes the U.S. Geological Survey's (USGS) National Land Cover Database (NLCD)[44] and the U.S. Fish and Wildlife Service's National Wetland Inventory (NWI).[45] These databases provide the area of different types of wetlands, but their classifications do not match the categories we proposed above. They also do not enable tracking of tidal wetlands separate from other wetlands. The datasets can be used to determine overall trends in wetlands changes, but should not be used for detailed comparison of data across years, since there are potentially significant uncertainties related to the different data points. NLCD only provides 2 data points (ca. 1992 and 2001) and can be somewhat imprecise in the actual wetland boundaries because of variations in water levels between acquisition dates. NWI is based on mostly older data and is generally considered to miss a large fraction (perhaps 30% or more) of wetlands that were actually present at the time of the survey. None of the datasets distinguish between publicly and privately held land and they do not provide information on management practices and functionality of the inventoried wetlands.

2.6.4 Carbon Flux of Proposed Tidal Wetlands Classes

The Bridgham *et al.* (2006) analysis did not sub-divide tidal wetlands into saline and freshwater components.[46] Table 6 provides an estimate of the net carbon balance for tidal wetlands based upon the classification proposed above. Overall, all wetland classes are potentially net sinks for carbon. The carbon budget for mudflats, salt marshes and forested and scrub shrub wetlands appears to be clear cut. While brackish and freshwater tidal wetlands offer potential to sequester greater amounts of carbon than saline wetlands, the substantially greater levels of methane production may reduce or negate the carbon sequestration value over the 100-year time frame. Further science is required to develop carbon budgets for brackish and freshwater tidal wetlands.

There is potential that as part of long-term restoration of drained, subsided freshwater tidal marsh, water management on freshwater wetlands or other management activities could reduce methane emissions and, given the very high carbon accumulations within soils, create a very substantial GHG offset. U.S.G.S. field studies in the Sacramento San-Joaquin Delta suggest that in managed wetlands created to rebuild deeply subsided areas of former freshwater a positive GHG offset (possibly as high as 2000 $gCO_2e\ m^{-2}\ yr^{-1}$) can be achieved through soil water management[47]

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[44] USGS. 2008. National Land Cover Database. United States Geological Survey. http://www.mrlc.gov/

[45] FWS. 2008. National Wetlands Inventory. U.S. Fish and Wildlife Service. http://www.fws.gov/wetlands/data/index.html

[46] Bridgham, S.D., J.P. Megonigal, J.K. Keller, N.B. Bliss, C. Trettin. 2006. The Carbon Balance of North American Wetlands. Wetlands: 26, 889-916.

[47] (R. Miller, Pers. comms.).

Table 6. Summary of Carbon Sequestration and Methane Production Across the Salinity Interface

Wetland Type	Carbon Sequestration Potential ($gC\ m^{-2}\ yr^{-1}$, $gCO_2e\ m^{-2}\ yr^{-1}$)	Methane Production Potential ($gCH_4\ m^{-2}\ yr^{-1}$, $gCO_2e\ m^{-2}\ yr^{-1}$)	Net Balance
Mudflat (saline)	Low (<50, 184)	Low (<2, 50)	Low C sequestration
Salt Marsh	High (50-250, 184-917)	Low (<2, 50)	High C sequestration
Mangrove	High (50-250, 184-917)	Low – High	Depends on salinity
Brackish Tidal Marsh	High (250-450, 183.3-1650)	High (5-100, 125-2,500)	Unclear[48]
Freshwater Tidal Marsh	Very High (500-1000, 1,833-3700)	High - Very High (40-100+, 1,000-2,500+)	Unclear – potential very high C sequestration[49]
Estuarine Forest	High (100-250, 366.7-916.7)	Low (<10, 250)	High C sequestration

Note: 1gC ≡ 3.67 gCO_2e; 1gCH_4 ≡ 25 gCO_2e

2.7 METHODS FOR MEASURING AND MONITORING GHGS IN WETLANDS

There are three different types of measurements that must be undertaken to quantify the net GHG flux of a wetland: the carbon content of the soil, the carbon content of the biomass, and the flux of GHGs between the wetland surface and the atmosphere over time. Measuring the soil carbon content within a wetland project is important for quantifying the actual amount of carbon found belowground. These measurements can be useful for establishing the baseline amount of carbon associated with a particular wetland before restoration or enhancement. Measuring GHG fluxes between the wetland surface and the atmosphere allows for the daily, monthly, seasonal, and yearly GHG consumption and emission rates to be determined. This data is useful in quantifying the amount of GHG consumed and emitted compared to the baseline in a wetland over time. Measuring the carbon found in the aboveground biomass is also important, especially on a seasonal scale as plant growth consumes and the subsequent decomposition emits GHGs throughout a year.

The following section will focus on different methods used to measure the net GHG flux of a wetland, including a description of the method, the potential the method has to quantify one or more of the necessary GHG measurements, and the issues associated with each method. As will be shown, there is uncertainty related to all the described methods and there is no established

48 Too few studies to draw firm conclusions. Potentially CH_4 emissions brackish wetlands may negate carbon sequestration within soils. Further research required.

49 Too few studies to draw firm conclusions. Potentially CH_4 emissions from freshwater tidal wetlands may partially or fully negate carbon sequestration within soils.

method or combination of methods for quantifying GHG flux and storage. In general, measurements should be taken throughout one year to capture seasonal differences in water, storage, and emissions levels.

2.7.1 Core Samples

Determining the carbon content of the soil within a wetland requires collection and transport of soil samples. No standard approach has yet been developed for quantifying the carbon content of wetland soils, and in particular an approach that can reflect the heterogeneity of the carbon content that is typically found throughout a wetland. However, well established procedures do exist for individual core collection and analysis which could be applied to the analysis of soils.[50]

Core collection commonly involves insertion of a pipe (plastic or stainless steel, diameter no less than 100 mm) into a soil. Compaction of the soil during pipe insertion is a concern and difference in surface elevation between inside the pipe and outside should be specified. If necessary, in dense marsh soils, short lengths of pipe should be inserted into the wetlands, which are dug around before the next length of pipe is inserted to minimize compaction.[51,52] The pipe should be sealed and the core stored refrigerated if sampling is to occur upon return to the laboratory, or frozen if stored for any length of time.

Soil carbon content has been measured by soil scientists and engineers for many years. As a rapid proxy measurement, loss on ignition (LOI) by controlled burning of a dried soil provides a close correlation to actual carbon content.[53] LOI determination is a simple, inexpensive and precise procedure that can be carried out on multiple samples simultaneously, and requires only a muffle furnace, drying oven, and balance. The procedure is normally undertaken by an accredited testing laboratory, though is widely undertaken within research laboratories. Standard methods for determining LOI are described by the American Society for Testing Materials (ASDM-D 2974-87, Standard test methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils).

One of the benefits of this method is that the actual carbon content of the wetland soil is obtained. This can be useful to establish the baseline carbon content of a wetland before an offsets project commences. However, this method ignores aboveground biomass and would have to be repeated

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[50] Turner R, Swenson E, Milan C. 2000. Organic and inorganic contributions to vertical accretion in salt marsh sediments. In: Weinstein M, Kreeger DA, editors. Concepts and Controversies in Tidal Marsh Ecology. p 583-595.

[51] Crooks S. 1999. A Mechanism for the Formation of Overconsolidated Horizons Within Estuarine Floodplain Alluvium: Implications for the Interpretation of Holocene Sea-Level Curves. Floodplains: Interdisciplinary Approaches 163:197-215.

[52] Crooks S., Pye K. 2000. Sedimentological Controls on the Erosion and Morphology of Saltmarshes: Implications for Flood Defence and Habitat Recreation. Coastal and Estuarine Environments: Sedimentology, Geomorphology, and Geoarchaeology 175:207-222.

[53] Konen M, Jacobs P, Burras C, Talaga B, Mason J. 2002. Equations for predicting soil organic carbon using loss-on-ignition for North Central U.S. soils. Soil Science Society of America Journal 66:1878-1881.

often to get a seasonal and yearly GHG concentration change. Additionally, hourly or daily GHG fluxes would not be possible to measure using this method.

2.7.2 Closed Chamber Method

The closed chamber method involves placing a chamber over a selection of the wetland surface and measuring decreases in CO_2 concentration or increases in CH_4 and N_2O concentrations over time. This method cannot directly measure the carbon content of the vegetation covering the wetland or the carbon content of the soil below the chamber, only the fluxes of GHG between the surface of the wetland and the atmosphere. This method is one of the more established for measuring GHGs from wetlands, so there is a much better understanding of how it works and more efforts have been made to refine it.

There are some limitations related to the closed chamber technique. The actual placement of a chamber over a plant or the soil may produce biases and errors due to the small spatial extent of measurements, the high spatial variability of the GHG emission from the soil, and the chamber creating conditions over the plants that may incorrectly represent the typical conditions.[54,55] The presence of the chamber can also cause variations in the heat and water balances of the surrounding soil and changes in the local pressure, wind currents, and GHG concentrations. This method does not harm any of the vegetation surrounding the measurement site, but does require expensive equipment.[56] Magenheimer *et al.* (1996) also determined that this measurement method does not include the flux of gases that occur during tides and emissions that can occur when water drains from the marsh to the creek.[57]

Even though there are some uncertainties surrounding this method of quantifying GHG flux of a wetland, there are some benefits to this method, including the fact that the chambers used to measure GHG flux can be placed anywhere within the wetland and can be used to obtain short term (hours or days) or longer term (seasonal, yearly) flux measurements.

2.7.3 Eddy Covariance Technique

The eddy covariance (EC) technique can directly measure the net exchange of CO_2 and CH_4 between a wetland (or any vegetated surface) and the atmosphere. In a few cases, this technique

54 Streever, W.J., A.J. Genders, M.A. Cole. 1998. A closed chamber CO2 flux method for estimating marsh productivity. Aquatic Biology: 62, 33-44.
55 Baldocchi, D.D. 2002. Assessing the Eddy Covariance Technique for Evaluation the Carbon Balance of Ecosystems. Global Change Biology: Invited Review. Available at: http://nature.berkeley.edu/biometlab/pdf/global%20change%20biology%20review%20on%20carbon%20dioxide%20fluxes%20baldocchi.pdf
56 Streever, W.J., A.J. Genders, M.A. Cole. 1998. A closed chamber CO2 flux method for estimating marsh productivity. Aquatic Biology: 62, 33-44.
57 Magenheimer, J.F., T.R. Moore, G.L. Chmura, R.J. Daoust. 1996. Methane and Carbon Dioxide Flux from a Macrotidal Salt Marsh, Bay of Fundy, New Brunswick. Esuaries: 19, 139-145.

has been used for measuring N_2O over grasslands and peatlands, and could thus also be used for tidal wetlands.

The EC method uses measuring equipment secured to a tower to obtain wind measurements. Equations are then used that relate the measured fluctuation of the vertical wind velocity with the CO_2 or CH_4 mixing ratio to obtain the flux of each GHG. Like the closed chamber technique, the EC technique cannot measure soil carbon content or biomass carbon content, only the exchange of GHG between the wetland and the atmosphere over time.

The EC technique has limitations as well. The correct interpretation of the EC measurements is limited to areas over flat terrain, with steady environmental conditions, and where the underlying vegetation stretches upwind for some distance.[58] Due to these specific condition requirements, the typical EC study is able to obtain usable data for 65-75% of the year. Bonneville *et al.* (2008) found that this method could be improved upon by including the carbon contained in belowground biomass.[59] Multi-year studies would be needed to determine long-term trends related to varying climatic and seasonal conditions. Currently, the Oak Ridge National Laboratory has been collecting and maintaining an online database, FLUXNET, of flux tower studies that use the EC technique to measure CO_2, water vapor, and energy balances between the atmosphere and different land covers, including permanent wetlands.[60] However, one of the biggest limitations of this technique is its lack of being able to measure some GHG emissions associated with tidal movements.[61]

One of the benefits of the EC technique is that it does not disturb the vegetation found within the wetland, obtains a spatially-averaged GHG flux over a large area (200-800 m), and can be used to obtain a long-term record of GHG flux.[62]

2.7.4 Water Samples

Water samples can be taken from the wetland's surface waters to determine GHG concentrations and fluxes. Ferron *et al.* (2007) used this methodology to quantify the GHG exchange between a creek and the atmosphere.[63] One hundred ml samples were taken once every hour at 1 m depth

[58] Baldocchi, D.D. 2002. Assessing the Eddy Covariance Technique for Evaluation the Carbon Balance of Ecosystems. Global Change Biology: Invited Review. Available at: http://nature.berkeley.edu/biometlab/pdf/global%20change%20biology%20review%20on%20carbon%20dioxide%20fluxes%20baldocchi.pdf

[59] Bonneville, M.C., I.B. Strachan, E.R. Humphreys, N.T. Roulet. 2008. Net ecosystem CO_2 exchange in a temperate cattail marsh in relation to biophysical properties. Agricultural and Forest Meteorology: 148, 69-81.

[60] ORNL. 2007. FLUXNET. Oak Ridge National Laboratory, National Aeronautics and Space Administration. Available at: http://www.fluxnet.ornl.gov/fluxnet/index.cfm

[61] Yan, Y., B. Zhao, J. Chen, H. Guo, Y, Gu, Q. Wu, B. Li. 2008. Closing the carbon budget of estuarine wetlands with tower-based measurements and MODIS time series. Global Change Biology: 14, 1-13.

[62] CCP. 2008. The Eddy Covariance Technique. Canadian Carbon Program, Fluxnet Canada. http://www.fluxnet-canada.ca/home.php?page=data_tec&setLang=en

[63] Ferron, S., T. Ortega, A. Gomez-Parra, J.M. Forja. 2007. Seasonal study of dissolved CH4, CO2, and N20 in a shallow tidal system of the bay of Cadiz (SW Spain). Journal of Marine Systems: 66, 244-257.

over one tidal cycle (approximately 13 h). Dissolved concentrations of CO_2, CH_4, and N_2O were determined by measuring the concentrations in the head space of the water sample. Fluxes of these gases between the water surface and the atmosphere were measured using the dissolved gas concentrations within each sample and the gas transfer velocity for each GHG. Although this approach can determine the concentration and flux of multiple GHGs, varying environmental conditions found within different coastal systems may contribute to the gas transfer velocity in different ways, causing variability in results between sites. There are also inherent differences in all of the possible measurement techniques which can provide variability. One of the main limitations is the fact that this method depends on the presence of water to take measurements, whereas some wetlands may contain land that is only periodically flooded. This method also does not take into account soil carbon content or biomass carbon content.

2.7.5 Remote Sensing

Remote sensing (analyzing satellite imagery) has only recently been used for quantifying emissions from wetlands and may prove useful for quantifying emissions. However, further testing is necessary to determine the usefulness of this approach. In the most comprehensive study to date, Yan *et al.* (2008) determined the gross ecosystem exchange (GEE) for carbon within an estuarine wetland from:

1) Net ecosystem exchange (NEE) measurements obtained from EC equipment;

2) Estimating gross primary productivity (GPP) from remote sensing products such as MODIS (Moderate Resolution Imaging Spectrometer); and

3) Using equations relating primary productivity to various fluxes of CO_2 and CH_4 ($24GEE = GPP + F_{lateral} + F_{CH4} + F_{other}$).[64] The study did not look at N_2O measurements.

The University of New Hampshire provided the MODIS product which allowed Yan *et al.* (2008) to obtain GPP factor data from a 500 meter pixel surrounding the center of the flux towers. By comparing the two methods for obtaining carbon flux, Yan *et al.* (2008) identified several issues related to quantifying emissions/storage in wetlands. In particular, estimating carbon in these ecosystems is difficult since waves from the ocean carry a considerable amount of dissolved and organic material carbon and methane that cannot be measured by conventional EC techniques.

A benefit by combining a GHG flux method with remote sensing is that both the sequestration and emission of GHGs is captured, as well as the carbon found in aboveground biomass. However, neither of these techniques is able to capture the soil carbon content.

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[64] Yan, Y., B. Zhao, J. Chen, H. Guo, Y, Gu, Q. Wu, B. Li. 2008. Closing the carbon budget of estuarine wetlands with tower-based measurements and MODIS time series. Global Change Biology: 14, 1-13.

2.7.6 Modeling

Saarnio *et al.* (2008) developed a method to model CH_4 emissions from various types of wetlands covering Europe.[65] Geospatial databases were used to estimate areas of mires, freshwater marshes, saltwater marshes, small lakes, large lakes and rivers while a literature review provided methane release factors from each of the wetland types.

Several uncertainties are associated with this study, mainly from estimating the area of each wetland type (partially due to the classification system of the databases) and the internal variability found within each type of wetland. A more robust estimation of methane emissions from all types of wetlands should include long-term CH_4 fluxes, associated environmental factors that control these fluxes, and more detailed mapping. However, the authors did not define what they meant by 'long-term,' so it is unclear if they mean annually or even longer. Current factors that affect CH_4 emissions from wetlands include the water level depth, temperature, aerenchymal plant species density, the primary productivity rate, total phosphorus, dissolved organic carbon, and CH_4 concentrations. Future factors could include land use change as well as biosphere and atmospheric pollution.

Researchers at McGill University have also developed a comprehensive model that simulated carbon exchanges in northern peatlands but this model cannot be explicitly used on tidal wetlands.[66] Once more studies have been undertaken that focus on GHG flux within tidal wetlands, researchers will hopefully be able to develop robust models that simulate the net GHG flux that occurs within these ecosystems.

2.7.7 Portable Mass Spectrometer

Other researchers and organizations have been developing methods and technologies that would help to quantify GHG emission and sequestration rates associated with wetlands. MIT researchers have developed a prototype self-contained battery-operated portable mass spectrometer that can measure methane concentrations without disturbing the environment.[67] Since only a prototype has been developed, the widespread use of this technology has not yet occurred, so any benefits or limitations associated with this method have not been determined. However, research and development of portable technologies that can measure GHG fluxes should continue.

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[65] Saarnio, S., W. Winiwarter, J. Leitao. 2008. Methane release from wetlands and watercourses in Europe. Atmospheric Environment: Article in Press.
[66] St.-Hilaire, F., J. Wu, N.T. Roulet, S. Frolking, P.M. Lafleur, E.R. Humphreys, V. Aroa. 2008. McGill Wetland Model: evaluation of a peatland carbon simulator developed for global assessments. Biogeosciences Discussions: 5, 1689-1725.
[67] MIT. 2008. Focus on Biogeochemistry of the Greenhouse Gases and Reflective Aerosols. Massachusetts Institute of Technology Center for Global Change Science. Available at: http://web.mit.edu/cgcs/www/ghgs.html

2.7.8 Biomass Carbon Content

While none of the methods described above are able to measure biomass carbon content from tidal wetlands, methods such as the peak standing crop method, the Milner-Hughes method, Smalley's method, and the Wiegert-Evans method could be used to calculate this carbon source.[68] These methods require plant harvesting to determine the amount of aboveground biomass. Biomass methods in general do not require expensive equipment to measure carbon content and each of these methods can produce consistent results, although these results may vary between the different methods.[69]

2.7.9 Summary

There are many methods for measuring GHG fluxes within wetlands. Two of the most predominant methods to measure these fluxes include the closed-chamber method and the eddy covariance (EC) technique. Other methods that have been employed and/or are being developed include the use of water samples, remote sensing, modeling, and analyzing core samples. In relation to quantifying GHG flux for offsets, many aspects concerning the different measurement methods need to be considered, including:

1. The closed-chamber method has been proven to be able to quantify gas exchanges for three relevant GHGs over many different wetland surfaces, while other methods are more limited or are less tested;

2. All of the methods require expertise and involve considerable costs to properly quantify GHG flux prior to and during the project time period;

3. All measurements should be taken over the course of a year to capture seasonal variation;

4. The forestry offsets protocol relies on the physical, periodic measurement of carbon uptake within a forest project, but also allows models to be used to predict future carbon uptake. Similar models do not yet exist specifically for tidal wetlands, so the development of such a model would be ideal; and

5. Even though each of these methods has benefits and limitations, multiple methods can be used during the lifetime of the project in order to obtain the most robust GHG flux measurements. For example, the core sampling technique and a standing biomass method can be used to obtain a baseline amount of carbon within the wetland area. The closed chamber method can then be used to determine how GHG flux of a wetland changes over time compared with the baseline. Core and biomass sampling can also be done

68 Streever, W.J., A.J. Genders, M.A. Cole. 1998. A closed chamber CO2 flux method for estimating marsh productivity. Aquatic Biology: 62, 33-44.
69 Streever, W.J., A.J. Genders, M.A. Cole. 1998. A closed chamber CO2 flux method for estimating marsh productivity. Aquatic Biology: 62, 33-44.

periodically over the lifetime of the project to make sure any changes in the soil or aboveground biomass carbon content not picked up by the closed chamber method is taken into account.

3. ISSUES RELATED TO DEVELOPING AN OFFSETS METHODOLOGY FOR WETLANDS

This chapter discusses issues directly related to developing a GHG offsets methodology for tidal wetlands. This includes describing possible project types, addressing regulatory additionality, recommending performance standards for each project type, as well as discussion other GHG accounting, leakage, and permanence issues.

3.1 OFFSETS PROJECT TYPES WITHIN WETLANDS CATEGORY

The development of a performance standard for tidal wetlands depends on the specific type of activity being considered. CCAR's recently updated forestry method defines several distinct offsets types, including forest conservation, conservation-based management, and reforestation projects. We suggest the following types of tidal wetlands projects that could be considered for offsets:

Wetland Creation: Converting land from a non-wetland (either dry land or unvegetated water) to a wetland at lands where there was previously no wetland in existence.[70]

Wetlands creation rarely involves artificial placement of sediments as this is costly and would have to be repeated over time to sustain the wetland. Creation, over all, is not favored as an approach to wetland building because it may not be sustainable without substantial support such as continued addition of sediments. The most likely sustainable location in the landscape to build a wetland is where one once existed (i.e., restoration).

Wetland Restoration: *Actions taken in a converted or degraded natural wetland that result in the reestablishment of ecological processes, functions, and biotic/abiotic linkages and lead to a persistent, resilient system integrated within*.[71] There are many examples of restoration projects, particularly associated with mitigation through the Clean Water Act. Typically, tidal wetland restoration projects involve pre-grading the agricultural surface and breach of the outboard levee to let sediments naturally build tidal wetlands.[72]

[70] IWWR. 2003. An Introduction and User's Guide to Wetland Restoration, Creation, and Enhancement. Interagency Workgroup on Wetland Restoration: National Oceanic and Atmospheric Administration, Environmental Protection Agency, Army Corp of Engineers, Fish and Wildlife Service, and Natural Resources Conservation Service. http://www.epa.gov/owow/wetlands/pdf/restdocfinal.pdf
[71] IWWR. 2003. An Introduction and User's Guide to Wetland Restoration, Creation, and Enhancement. Interagency Workgroup on Wetland Restoration: National Oceanic and Atmospheric Administration, Environmental Protection Agency, Army Corp of Engineers, Fish and Wildlife Service, and Natural Resources Conservation Service. http://www.epa.gov/owow/wetlands/pdf/restdocfinal.pdf
[72] PWA, Faber P. 2004. Design guidelines for tidal wetland restoration in San Francisco Bay. Prepared for: The Bay Institute. 83 p.

Restoration rarely involves artificial placement of sediments as this is costly and would have to be repeated over time to sustain the wetland.

Wetland Enhancement: Increasing one or more of the functions performed by an existing wetland beyond what currently or previously existed in the wetland. [73] Several examples of enhancement techniques exist that could increase the amount of carbon stored within a wetland. These include:

1. **Sediment placement to attain a vegetated surface elevation**. In locations with relatively low sediment availability wave energy can prevent mudflats converting to vegetated marsh. Addition of sediment could facilitate this transition creating a sustainable marsh.

   Potential challenges include: 1) possibility that the carbon footprint of sediment transport and placement may offset some or all of the carbon that will be stored by the project; 2) the marsh may be unsustainable without regular sediment management.

2. **Sediment placement to maintain a vegetated marsh**. Coastal areas are loosing their wetlands because of sea level rise and / or historic engineering impacts. These losses are not captured within carbon accounting (i.e., no agency has taken responsibility for mitigating their loss). Sediment could be placed to maintain vegetated marshes. (Examples Chesapeake Bay, Elkhorn Slough, Mississippi Delta, Jamaica Bay).

   Potential challenges include: 1) possibility that the carbon footprint of sediment transport and placement may offset some or all of the carbon that will be stored by the project; 2) the marsh may be unsustainable without regular sediment management.

3. **Sediment placement to convert a shallow tidal basin to a vegetated tidal marsh.** Similar to (1) but involving the modification of an estuary form from a system that is naturally dominated by mudflat with little vegetated marsh to a form that is naturally dominated by vegetated marsh with little mudflat. Could be self -sustaining in the long-term if sufficient sediment is made available to maintain marsh accretion. This approach is untested but theoretically possible.

   Potential challenges include: 1) those listed above; 2) may also conflict with existing conservation management plans and regulations.

[73] IWWR. 2003. An Introduction and User's Guide to Wetland Restoration, Creation, and Enhancement. Interagency Workgroup on Wetland Restoration: National Oceanic and Atmospheric Administration, Environmental Protection Agency, Army Corp of Engineers, Fish and Wildlife Service, and Natural Resources Conservation Service. http://www.epa.gov/owow/wetlands/pdf/restdocfinal.pdf

4. **Freshwater tidal wetlands (FWTW) long-term restoration, water management**. Restoration of deeply subsided freshwater tidal wetlands may require active management for many decades before organic soils have built up to natural marsh plain elevations. During this time there may be potential to manage water levels to reduce soil methane emissions. This approach is untested, but could be included in the DWR/USGS experiment in the Sacramento-San Joaquin Delta.

5. **FWTW long-term restoration, vegetation management.** There are a few scientific studies that indicate that potential methane emissions from common reed (and likely tule) can be reduced by cutting the vegetation. The implications for carbon sequestration and best management practices for mowed reed utilization would need to be developed before this method should be used for offsets. This approach is untested.

6. **FWTW long-term restoration, water chemistry management.** A number of scientific studies suggest that supplying a source of iron (III) oxide to freshwater marshes may reduce methane production. Though offering potential to lower the GHG emissions of restoring wetlands the GHG impacts of producing and delivering the iron (III) oxide would need to be accounted for. This approach is untested.

7. **FWTW site grading.** FWTWs produce large mounts of methane within soils, while forested and scrub schrub wetlands may offer some methane oxidation capacity. The following restoration enhancements might be tested for use in offsets activities: site graded to maximize connectivity between marsh plain and forested edge, inclusion of sands to enhance soil permeability and oxygen penetration; cutting of channels with vegetated berms to encourage oxygenation of soil waters by transfer through forested soils to open channels. This approach is untested.

These approaches for enhancing carbon storage are untested or involve fairly new techniques so common practices have not yet been developed, and the potential for storage is unknown. Given the potential for substantial carbon sequestration on subsided islands in the Sacramento-San Joaquin Delta it is recommended that all possible approaches to reducing GHG emissions be examined.

Avoided Wetlands Loss: This activity would involve conserving a wetland that would otherwise be converted to a non-wetland use based on historical land conversion rates. An example would be actively supplying sediment to sediment-deficient salt marshes in the Mississippi Delta, Elkhorn Slough or Chesapeake Bay where wetland areas are declining, or prevent a wetland from being converted to agriculture, recreational, or urban uses.

3.2 ADDITIONALITY

This subsection discusses additionality issues related to tidal wetlands projects, including regulations affecting this type of project and any barriers that may influence tidal wetlands as a project activity.

3.2.2 Regulatory Additionality

CCAR uses a regulatory test to screen out non-additional projects, whereby projects required by existing state or federal regulations are prohibited from applying for offsets credits. However, wetlands face a somewhat unique situation compared with other US-based offsets types because the targets and mandates regulating this sector are not being fully enforced. This raises the question of whether the regulatory screen should be enforced as strictly as with other offsets types, or whether a different kind of test should be used to factor in those projects that may be additional even though they could be argued to fall under an existing regulation or mandate to protect wetlands.

The following outlines relevant existing and emerging regulations that affect wetlands at the federal and state level. These include legal requirements to protect wetlands, non-binding targets and mandates for wetlands protection, and funding programs to encourage restoration and enhancement. We conclude this section with an analysis of the extent to which these regulations have been successful in protecting or restoring wetlands, and/or avoiding their loss.

At the national level, the protection of wetlands fall under several jurisdictions, including the U.S. Environmental Protection Agency (EPA), U.S. Fish and Wildlife Service (FWS), The National Oceanic and Atmospheric Administration (NOAA), the U.S. Army Corps of Engineers (Corps), and the Natural Resources Conservation Service (NRCS-USDA).[74] In addition, there are several state and local agencies that regulate and/or manage the use and protection of wetlands. Because of the potential involvement of all of these parties, guidance and regulations for wetlands restoration and management are sometimes implemented differently across different states and localities.

The U.S. EPA Clean Water Act (CWA) is the only federal regulation that has a specific legally binding requirement that wetlands must be protected, including penalties if this requirement is not being met. According to the CWA, a facility that impacts a wetland area must create or restore a similar area at another site through compensatory mitigation (See Section 3.2.2.1). No other federal or state policies for wetlands include such legal requirements. Instead, they set goals for the area of wetlands that should be conserved or restored during a specific time period and/or provide funding for the conservation or restoration of wetlands. These regulations and goals are described below.

[74] NOAA. 2008. Wetland Policy and Guidance. NOAA Office of Habitat Conservation , Habitat Protection Division. http://www.nmfs.noaa.gov/habitat/habitatprotection/wetlands/index3.htm

3.2.2.1 Summary of Regulations and Policies

Federal Regulations and Policies

The only legally binding federal regulations covering wetland loss or restoration is found in the CWA which states that "no net loss" of wetlands can occur. Section 404 of the CWA requires any facility that impacts wetlands to obtain a federal permit and create or restore a similar type of wetland at a different location. On average, about 47,000 acres of wetland mitigation is undertaken each year under this regulation to compensate for about 21,000 acres of permitted wetland losses.[75] Because of the legally binding mitigation system, it would be easy to require that all projects undertaken for the purpose of meeting mitigation requirements under the CWA should be excluded from offsets credits.

As outlined in Table 7, there are several other federal initiatives and regulations that may result in wetlands projection or restoration. For example, under the Endangered Species Act, wetlands must be conserved if an animal listed under this Act inhabits a particular wetland habitat. Protection under the Endangered Species Act are legally binding, so wetlands conserved under this Act should also be excluded under the regulatory additionality screen for the offsets types of wetlands creation, restoration, and avoided loss. One example of wetland creation through the Endangered Species Act is the Delta Smelt recovery project in the Sacramento Delta region. The U.S. Fish and Wildlife Service determined that the Sacramento Division of Water Resources' (DWR) Central Valley Project and State Water Projects have a negative effect on the endangered Delta Smelt by adversely modifying its critical habitat. Because of this finding, DWR must create or restore at least 8,000 acres of intertidal and associated subtidal habitat in the Sacramento Delta and Suisun Marsh. Therefore, wetlands created under the ESA should be excluded from offsets eligibility.[76]

In 2004, President Bush announced a new wetlands initiative that calls for restoring or creating at least one million acres of wetlands, improving or enhancing at least one million acres of wetlands, and protecting at least one million acres of wetlands.[77] However, these goals only consider gross creation and restoration and do not account for any wetland loss that occurs.[78] Table 7 lists several other federal policies that affect wetland restoration or conservation, most of which involves funding for conservation and/or restoration. Since these policies do not include

[75] Kihslinger, R.L. 2008. Success of Wetland Mitigation Projects. Environmental Law Institute, National Wetlands Newsletter: 30.
[76] Sacramento Fish & Wildlife Service. 2008. Delta Smelt Recovery. U.S. Fish and Wildlife Service. http://www.fws.gov/sacramento/es/delta_smelt.htm.
[77] Council Environmental Quality. 2008. Conserving America's Wetlands 2008: Four Years of Partnering Resulted in Accomplishing the President's Goal. Executive Office of the President of the United States. http://www.whitehouse.gov/ceq/wetlands/2008/introduction.html
[78] Council Environmental Quality. 2008. Conserving America's Wetlands 2008: Four Years of Partnering Resulted in Accomplishing the President's Goal. Executive Office of the President of the United States. http://www.whitehouse.gov/ceq/wetlands/2008/exec-summary.html

specific wetlands projects and in some cases involves voluntary participation in funding programs, it is less clear whether such projects should be excluded under the regulatory screen.

Wetlands protection under the US Farm Bill is unique, since the bill does not specifically require farmers to protect wetlands on their land, but penalizes farmers who fill or destroy any wetlands. Under the Bill, federal farm programs benefits are withheld from farmers who convert their wetlands for commodity production but there no mandatory requirement that they *must* protect the wetlands. As such, protections under the farm bill fall somewhere in the middle between mandated regulations that should be excluded under the regulatory additionality screen and voluntary measures/incentives that typically aren't excluded.

Table 7. U.S. Federal Regulations Affecting Wetlands

Federal Policy or Program	Type	Description
EPA Clean Water Act	Legally binding regulation (specific to wetlands)	Section 404 contains a compensatory mitigation program where 'no net loss' of wetlands can occur based on area.[79] Facilities that reduce wetlands in one area, must mitigate this by restoring wetlands somewhere else. This can be done through third parties through what is known as "mitigation banking."
White House Wetland Initiative	Goal	Calls for the restoration or creation of at least one million acres of wetlands, improving or enhancing at least one million acres of wetlands, and protecting at least one million acres of wetlands.[80]
The Farm Bill	Conservation/Restoration Fund	Four programs include the conservation of wetlands. The bill also includes a "swampbuster" provision which withholds Federal farm program benefits to farmers who convert or fill wetlands found on their farmland for use in commodity production until that wetland is mitigated.[81,82]
Endangered Species Act (ESA)	Regulation (dependent on the animal's habitat)	Provides a program for the conservation of threatened and endangered plants and animals and the habitats in which they are found (can include wetlands).[83]

[79] EPA. Wetland Regulatory Authority. U.S. Environmental Protection Agency. http://www.epa.gov/owow/wetlands/pdf/reg_authority_pr.pdf

[80] Council Environmental Quality. 2008. Conserving America's Wetlands 2008: Four Years of Partnering Resulted in Accomplishing the President's Goal. Executive Office of the President of the United States. http://www.whitehouse.gov/ceq/wetlands/2008/introduction.html

[81] Hires, B. 2008. The Final 2008 Farm Bill- A Retrospective and Briefing. Center for Native Ecosystems. http://www.nativeecosystems.org/critterthink/archive/2008/06/03/the-2008-farm-bill-a-retrospective-and-briefing

[82] NRCS. 2008. Wetland Conservation Provisions (Swampbuster). U.S. Department of Agriculture, Natural Resources Conservation Service. http://www.nrcs.usda.gov/programs/compliance/WCindex.html

[83] EPA. 2007. Wetlands: Laws, Regulations, Treaties. U.S. Environmental Protection Agency. http://www.epa.gov/owow/wetlands/laws/

Federal Policy or Program	Type	Description
Transportation Equity Act for the 21st Century (TEA-21)	Conservation/Restoration Fund	Authorizes funding to improve the Nation's transportation infrastructure, enhance economic growth and protect the environment, including opportunities to improve water quality and restore wetlands.[84]
Water Resources Development Act	Research & Conservation/Restoration Fund	Calls for studies related to wetland restoration to determine if funding and implementation is warranted. Provides technical, planning, and design assistance to non-federal parties to carry out watershed projects, including wetlands restoration.[85]
Coastal Wetlands Planning, Protection and Restoration Act	Conservation/Restoration Fund	Engages the Fish and Wildlife Service in interagency wetlands restoration and conservation planning in Louisiana and expands the administration of Federal grants to acquire, restore, and enhance wetlands within coastal states.[86]
North American Wetlands Conservation Act	Conservation/Restoration Fund	Provides funding for the implementation of the North American Waterfowl Management Plan and the Tripartite Agreement on wetlands between Canada, U.S. and Mexico; NAWCA projects often involve partnerships of state and local governments and nongovernmental and private organizations seeking to acquire wetland habitat. These acquisitions may be incorporated into the FWS National Wildlife Refuge System or into a state's protected area system, or they may be included in holdings protected by a nonprofit conservation organization (e.g., The Nature Conservancy).[87]
National Estuary Program (NEP)	Conservation/Restoration Fund	Local stakeholders work together at one of 28 NEP sites across the country. Each community develops and implements a comprehensive conservation and management plan that addresses specific actions that would help conserve the estuary.[88]
National Wildlife Refuge System (Migratory Bird Conservation Fund Program)	Conservation/Restoration Fund	Buys wetlands from sellers in order to protect waterfowl species and other migratory birds' habitat. Many projects include land obtained in the Prairie Pothole region in the Upper Midwest and northern Great Plains area of the Central Flyway.[89]

[84] EPA. 2007. Wetlands: Laws, Regulations, Treaties. U.S. Environmental Protection Agency. http://www.epa.gov/owow/wetlands/laws/

[85] FWS. 2008. Digest of Federal Resource Laws of Interest to the U.S. Fish and Wildlife Service: Water Resources Development Act of 1996. U.S. Fish and Wildlife Service. http://www.fws.gov/laws/lawsdigest/wat1996.html

[86] FWS. 2008. Digest of Federal Resource Laws of Interest to the U.S. Fish and Wildlife Service: Coastal Wetlands Planning, Protection and Restoration Act. U.S. Fish and Wildlife Service. http://www.fws.gov/laws/lawsdigest/coaswet.html

[87] FWS. 2008. Digest of Federal Resource Laws of Interest to the U.S. Fish and Wildlife Service: North American Wetlands Conservation Act. U.S. Fish and Wildlife Service. http://www.fws.gov/laws/lawsdigest/nawcact.html

[88] Council Environmental Quality. 2008. Conserving America's Wetlands 2008: Four Years of Partnering Resulted in Accomplishing the President's Goal: Accomplishments. Executive Office of the President of the United States. http://www.whitehouse.gov/ceq/wetlands/2008/accomplishments.html

[89] Council Environmental Quality. 2008. Conserving America's Wetlands 2008: Four Years of Partnering Resulted in Accomplishing the President's Goal: Accomplishments. Executive Office of the President of the United States. http://www.whitehouse.gov/ceq/wetlands/2008/accomplishments.html

State Regulations and Policies

Each state has the authority to adopt state-specific regulations or permitting systems. Section 401 under the CWA gives states authority to approve, condition, or deny a federal permit or license based on the state's review. The majority of states use Section 401 requirements as the primary or the sole regulatory mechanism to regulate their wetlands.[90] Some states have adopted state laws or regulations that require permits for activities in wetlands and other bodies of water. For example, California and seven other states have adopted regulatory programs for coastal or tidal wetlands only, while fifteen other states have adopted regulatory programs for freshwater and coastal or tidal wetlands.[91] In addition to regulations, many states have adopted separate wetland conservation and/or restoration goals. Examples of these are described in Table 8.

There are also protection goals for specific wetland areas. For example, the US Fish and Wildlife Service issued a Comprehensive Conservation Plan (CCP) for the Chesapeake Marshlands National Wildlife Refuge Complex, which includes the Blackwater, Martin, and Susquehanna National Wildlife Refuges. This plan sets a target of restoring the wetlands to 1930's levels. However, this is not a law or an otherwise legally binding document. Rather, it is an outline for activities that the refuge plans to do if (and only if) they can find the resources. Since the refuge has not yet established the necessary funding to make this goal happen, a larger restoration project would not be business-as-usual for the refuge.

Table 8. State Wetland Restoration Goals

State	Goal
Arkansas	Achieve no-net-loss with a long term net gain of wetland function and value in each region
California	Ensure a no-net-loss and achieve a long term net gain in the quantity, quality, and permanence of wetland acreage and values
Colorado	Protect 100,000 acres of biologically significant wetlands and associated uplands for wetland-dependent species by 2005
Delaware	Restore 1,500 acres and enhance 1,500 acres of wetlands in the Chesapeake Bay watershed by 2010
Maryland	Restore 60,000 acres of wetlands
Michigan	Restore 50,000 acres of wetlands (1% of historic losses) by 2010 while in the long term restore 50,000 acres of wetlands (10% of historic losses)

[90] Environmental Law Institute. 2008. State Wetland Protection: Status, Trends & Model Approaches.
[91] *Ibid*

State	Goal
Minnesota	Maintain and restore the quality and diversity and increase the overall quantity of wetlands in the state
Montana	No net loss of the remaining wetland base in terms of quantity and quality, and conserve, restore, enhance, and create wetlands where feasible to increase the wetland resource base
Ohio	Restore 5,000 acres of wetlands between 2001 and 2010
Oregon	No net loss of freshwater wetlands and a net gain of 250 acres per year of estuarine wetlands
Pennsylvania	No net loss and net gain
Rhode Island	No net loss of wetlands
Tennessee	Restore 70,000 acres of wetlands by 2000
Virginia	Restore 10,000 acres of wetlands by 2010
Source: Environmental Law Institute. 2008. State Wetland Protection: Status, Trends & Model Approaches.	

None of the goals outlined in Table 8 are legally binding, but in some cases, such as California, the state provides significant funding for meeting their wetlands protection goals, mostly on public lands. This creates challenges when determining which type of mandates and funding programs to include/exclude from the regulatory additionality test.

For example, in California the state has raised funds for purchasing land and restoring wetlands on these through the issuance of state bonds. If this funding program was excluded from the regulatory additionality screen and all restoration projects were considered additional (as long as they weren't implemented to meet CWA requirements) it is possible that the state would simply stop its activities to protect wetlands and instead leave it to the offsets market to fund such activities. Thus, some baseline activities would end up getting offsets credits.

However, the state government is short of funds to restore wetlands at all the lands it has set aside for this purpose, so the state government cannot undertake all the activities intended by its conservation goals. A regulatory screen that denied offsets credits to all projects on public lands in California would thus erroneously screen out some truly additional projects. The problem is that it may be difficult to distinguish between projects undertaken as part of normal state-funded restoration practices and those undertaken for offsets purposes, unless past tidal wetlands practices by the government in California is examined.

3.2.2.2 Status of Restoration and Conservation Goals

In spite of the CWA requirements and the long list of federal- and state-level wetlands protection measures, wetlands acreage and functionality has declined in most areas of the country. This includes those areas protected under the CWA mitigation banking system.

Even though Section 404 of the CWA requires compensatory mitigation of all impacted wetlands in order to achieve the national "no net loss" goal, this program might actually have lead to a net loss of wetlands. This is because many of the mitigation projects undertaken under Section 404 do not restore and maintain wetlands according to the same functionality and size as the original wetlands they were intended to replace. Kihslinger (2008) from the Environmental Law Institute reports that on the high end, the compensatory mitigation program may cause an 80% loss in wetland area and function.[92] The National Resource Council found that between 24-30% of the required mitigation from section 404 permits is not implemented.[93] Another study found that on average, just over 20% of all mitigation sites met various ecological equivalency and function tests when compared to the wetlands that were lost.[94] At the state level, a study in California found that only about half of the mitigation sites in the state actually met their required area.[95]

Similarly, individual states are having trouble meeting their wetlands conservation goals. Oregon, for example, established a goal of no-net-loss of freshwater wetlands and a net gain of 250 acres per year of estuarine wetlands. However, state government reports show that around two-thirds of Oregon's estuarine wetlands were converted to other land uses by the end of the 20th century, and that while a goal of reversing this trend has been set by the State, little progress was made by 2006.[96] Other states show similar declines in wetland area, but there is no comprehensive dataset that track wetlands for all states in the United States, so we can only provide anecdotal information at this point.

3.2.2.3 Barriers to Meeting Restoration and Conservation Requirements and Goals

There are many barriers that inhibit or prevent the restoration of wetlands, whether the purpose of the restoration is to comply with regulations or a state conservation goal. These barriers are described below:

Lack of monitoring and oversight: Even though the CWA requires compensatory mitigation of any impacted wetlands, the success of these projects has been questionable. One major reason for this is the lack of monitoring and oversight at the state level. Wetland mitigation projects are

[92] Kihslinger, R.L. 2008. Success of Wetland Mitigation Projects. Environmental Law Institute, National Wetlands Newsletter: 30.
[93] *Ibid*
[94] *Ibid*
[95] *Ibid*
[96] Oregon.gov. 2008.Orgeon Progress Board: Benchmark. http://benchmarks.oregon.gov/Quan/BMReporting/default.aspx#cdc4e3cf-25a8-41c5-ae5f-290ac825acd4

being completed with acreage and function less than what is required and the implementation of permits are going unchecked. One study found that less than 10% of permit files evaluated in Pennsylvania contained the required monitoring permits.[97] The U.S. Government Accountability Office found that the Army Corps of Engineers Districts do not provide sufficient oversight to determine the status of all required compensatory mitigation projects. [98] Additionally, indirect wetland loss due to processes accelerated by anthropogenic activities is often not accounted for.[99] For example, dredging can cause erosion of adjacent wetlands by increasing wave climate, modify estuarine hydraulics or create sediment sinks that draw sediment from adjacent area. Similarly, coastal development can cause a decrease in the amount of sediment supplied to nearby wetlands, putting these wetlands at risk of drowning and erosion.

Cost of restoration: The high cost of wetlands restoration makes it difficult to fund projects, and there is strong competition for limited existing resources. The cost of restoring a wetland can range from around $2,000 per ha ($4,900 per acre) for a low complexity project, while higher complexity projects could cost over $25,000 per ha ($61,800 per acre), including design and permitting costs but excluding land purchase costs. [100,101] Costs of restoration increase considerably if projects require flood levee construction to protect adjacent properties, or fill removal/ sediment placement to achieve wetland elevations. Local jurisdictions often find it difficult to meet non-federal, cost-share requirements via local funds. As a result, there is strong competition for state, local and NGO wetland restoration grants. In some cases, federal and state caps on conservation grants are much lower than what's required to fund a restoration project, thus limiting the amount of wetland restoration. [102]

Coastal population increase: Development and associated sprawl decreases land available for wetland restoration and hinders conservation at existing resources. Also, several states are competing for access to existing freshwater due to increases in state population and development. This could lead to reduced freshwater flow into coastal wetlands. [103]

US Army Corps of Engineers provisions under the Water Resources Development Act: Provisions under sections 1135 (Project Modifications to Improve the Environment), 206 (Aquatic Ecosystem Restoration), and 204 (Environmental Restoration Projects in Connection with Dredging) require the Corps to fund restoration activities. However, in some cases this

[97] Kihslinger, R.L. 2008. Success of Wetland Mitigation Projects. Environmental Law Institute, National Wetlands Newsletter: 30.
[98] *Ibid*
[99] Gulf of Mexico Alliance. 2005. Restoration of Coastal Wetlands/Estuarine Ecosystems. White Paper. Version 8.
[100] EPA. 2008. Polluted Runoff (Nonpoint Source Pollution) Management Measure for Restoration of Wetland and Riparian Areas. U.S. Environmental Protection Agency. http://www.epa.gov/nps/MMGI/Chapter7/ch7-2b.html
[101] Gulf of Mexico Alliance. 2005. Restoration of Coastal Wetlands/Estuarine Ecosystems. White Paper. Version 8.
[102] *Ibid*
[103] *Ibid*

mandate actually violates state constitutional or contracting guidelines because of the way it is supposed to be implemented. Section 204 requires the Corps to choose the cheapest method for the disposal of dredged material and restricts the distance dredged material can be transported. These restrictions decrease the potential for wetland restoration in many areas and limit the beneficial use of dredged material. States also have a difficult time meeting Corps wetland restoration requirements due to the different District boundaries used by the Corps and the varied interpretation of Corps regulations within each state. [104]

State property taxes: In some states, property taxes provide disincentives for conserving wetlands. Wisconsin passed legislation in 1995 that bases the value of agricultural land on production value instead of development value in order to help preserve farmland and rural economies. As a result, property taxes for all lands classified as "agricultural" declined and created a fairly big difference in property taxes per acre between agricultural land and adjacent conservation land. Therefore, no incentive really exists for farmers to take land out of agricultural production and place it in conservation due to the increased property taxes on the different land types. [105]

Weak infrastructure for monitoring and tracking: Several states have weak infrastructure for tracking wetlands and related protection activities. Maryland has reported issues in the establishment of tracking and reporting systems associated with wetland restoration. Issues include: whether to count wetlands created to meet mitigation requirements, wetland enhancement projects, wetlands associated with storm water management facilities and other certain categories of wetlands, and lack of coordination with federal agencies. [106]

Public perception of wetlands: In some cases, there may be a lack of public understanding of the benefits of protecting wetlands which may inhibit wetland restoration. First, many private landowners lack access to educational programs concerning the value of wetland, water conservation, and available incentives to implement conservation strategies. [107] Some members of the general public may also have a negative perception of wetlands thinking that wetlands attract mosquitoes and rodents, contain certain hazards, or are unattractive.[108] Landowners may believe that existing regulatory processes are complex, do not provide final decisions, or that there is a disconnect between various levels of government agencies.[109] Finally, developers may believe

[104] *Ibid*
[105] WWA. 2008. WWA Seeks Property Tax Reform for Wetland Landowners. Wisconsin Wetlands Association. http://www.wisconsinwetlands.org/taxes.htm
[106] Fitzsimmons, E.M. 2000. State of Maryland Wetlands Restoration Steering Committee 2000 Report. Maryland, Department of the Environment. http://www.mde.state.md.us/Programs/WaterPrograms/Wetlands_Waterways/about_wetlands/report.asp
[107] Gulf of Mexico Alliance. 2005. Restoration of Coastal Wetlands/Estuarine Ecosystems. White Paper. Version 8.
[108] Fitzsimmons, E.M. 2000. State of Maryland Wetlands Restoration Steering Committee 2000 Report. Maryland, Department of the Environment. http://www.mde.state.md.us/Programs/WaterPrograms/Wetlands_Waterways/about_wetlands/report.asp
[109] *Ibid*

that land development is a proper trade-off for implementing wetland restoration projects. [110]All of these factors can contribute towards reducing wetlands size and functionality.

Competition between various conservation and restoration activity types: Various incentives might exist for one particular area to be restored as a forest, wetland, or other land cover type.[111] As a result, a wetlands restoration or enhancement may not always be the option that's being implemented.

3.2.2.4 Recommendations for Developing a Regulatory Test

Traditional CCAR regulatory tests used for offset projects exclude all projects that were created to fulfill a regulatory requirement. The general failure of the many federal regulations and state policies/goals make it difficult to implement this test for tidal wetlands. Not only does each state have different policies for creating new wetlands under the CWA or different restoration goals, but each state has varying success in satisfying these regulations and goals. Even the federal governments' CWA mitigation banking program is not being fully implemented.

At a minimum the regulatory test should exclude all restoration projects implemented to come into compliance with the CWA mitigation program and the Endangered Species Act. However, an offset program would not be possible if the regulatory test also excluded all public or private tidal projects implemented to meet the federal and state level goals listed above, since all projects could potentially be excluded until the goals were met.

The following should be considered when establishing a regulatory test for tidal wetlands projects:

- Each of the four wetland offset project types listed in 2.6.4 may be affected differently by the regulations outlined above. As outlined in Table 8, many states have restoration goals, but few have creation, enhancement (specific to carbon sequestration) or avoided wetland loss goals. So for those project types, a regulatory test based on federal and state restoration goals would not be a problem since there are few regulations/policies related to these activities. However, since wetlands restoration may provide the largest potential source for tidal wetlands offsets, it's important not to create a screen that excludes projects in this sector that are truly additional.

- Enhancement of wetlands above what is required on the CWA permit could possibly count as an offsets activity, if it increases the wetland's ability to store CO_2 or reduce the CH_4 emitted. In that case, the offsets method should clearly outline which type of enhancements would be acceptable. This outline could build on the activities listed in Section 3.1, but further research

[110] *Ibid*
[111] *Ibid*

may be necessary to clearly understand the potential reduction opportunities and storage enhancements that would fit under this category.

- Another regulatory issue that will have to be discussed is whether farmers who receive subsidies through the Farm Bill for wetland restoration or conservation should be able to develop offsets for restoration or avoided wetlands lost. Participation in the farm bill program is voluntary, although if farmers do not participate they are excluded from other selected Farm Bill benefits. In the past, CCAR has not excluded voluntary activities from its offsets program. However, the Farm Bill program is somewhat different as there is a clean incentive for protecting the wetland.

- Rather than using a regulatory test that excludes all projects undertaken to meet federal and state restoration/conservation goals, a regulatory test whereby the percent share of the goal is subtracted from the credits generated from the restoration project may be warranted. Since each state has set a different restoration goal and may provide public funding towards these goals, any offset project developed with public funding could be discounted at a rate proportional to the state restoration goal. For example, if a state has established a goal of restoring 25% of its wetlands by 2020, a project developed with public funds specifically for wetland restoration could then be required to discount its overall generated credits by 25%. If a state has a goal to protect a certain amount of acres, the discount could be based on the percent share that these acres represent of the total wetland area of the state. If a state has a 'no net loss' goal, or a vague restoration goal without public funding specifically for wetland restoration, projects would not have to subtract any credits. The development of a spreadsheet tool (along the lines of the spreadsheet tool for forestry offsets projects used by CCAR and the EPA Climate Leaders offsets programs) that provides the established discount rate for each state would be useful if this approach is used. It would be necessary to update this tool on a regular basis (preferably annually), since states may change their wetlands goals periodically.

- Many of the state and federal goals outlined above are being upheld by states, and it is the state governments that are taking leadership in making sure they are being met. This is the case in California where the state government has been purchasing lands for wetlands restoration and protection. If the states are the drivers in meeting the goals, it may not be fair to hold private landowners responsible for activities implemented mostly at the state level. In the case that a discount rate for state goals is used, it could be required that only projects at public lands need to apply this rate. However, determining whether this should be the case would require further analysis of the ownership (public versus private) of restoration projects at the state level. This would be a fairly large undertaking since there are no national-level data sets examining this. Instead, a state-by-state analysis of trends in wetland types by ownership would be necessary.

3.3 PERFORMANCE STANDARD DEVELOPMENT

Tidal wetlands do not easily lend themselves to a standardized performance standard, either nationally (in all of the conterminous U.S. and Alaska) or statewide. The main reason for this conclusion is the significant public involvement in the protection and restoration of wetlands at both the state and federal level, which raises the question of why the offsets market should provide funds for helping public agencies meet the conservation goals that they are otherwise responsible for. In particular, it is important to develop an offsets method that prevents public agencies from reducing available resources for wetlands protection. Currently, there is no national dataset showing public versus private ownership wetlands. It is therefore difficult to determine how great the potential is for crediting offsets projects at state or federal lands.

Other challenges include the range of processes operating in tidal wetlands across local and regional scales. These include different substrates (organic, mud, sand, etc), salinity conditions (a range from marine to freshwater), and geographic area (salt marsh versus mangrove), each of which would have a different emissions performances. Regulations and restoration goals also vary geographically and in terms of success. Data availability for all aspects needed in a performance standard is limited. These issues are described below in more detail.

3.3.1 Approach

For tidal wetlands projects, we considered using a common practice approach for developing a performance standard. However, this approach requires the availability of good data on wetlands practices for each of the four types of tidal wetlands projects (creation, restoration, enhancement, and avoided loss). Specifically, we looked for datasets that would show background trends in wetlands loss, restoration, and enhancement to see if there was a way to develop regional "background" wetlands trends similar to those used for CCAR's forestry offsets protocol. These background wetlands trends could then be used to represent "business-as-usual" for wetlands, and the specific rate could then be subtracted from the credits granted to wetlands projects.

Datasets on Wetlands Trends

As outlined in Section 2.6.3 above there are two national-level datasets that can be used to show wetlands areas, both at the national and state level. However, these geospatial datasets do not provide yearly trends; instead they provide data for series of time intervals. Table 9, taken from the NWI Status and Trends of Wetlands in the Conterminous United States[112], show changes in the area of all wetland types while Table 10[113] and Table 11[114] show changes in estuarine and marine wetlands only.

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[112] Dahl, T.E. 2006. Status and trends of wetlands in the conterminous United States 1998 to 2004. U.S. Department of the Interior; Fish and Wildlife Service, Washington, D.C. 112 pp.
[113] Dahl, T.E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 82 pp.

As described in Table 9, intertidal wetlands decreased by about 0.5% during 1998 to 2004. However, other types of wetland areas increased during this period, thereby offsetting the loss of intertidal wetlands. Combined, all wetlands grew by 2% while all wetlands and deepwater habitats grew by 0.3%.

This data can be used to analyze overall wetland area trends for some tidal wetlands. However, the NWI does not support comparison along our proposed tidal wetlands classifications and project types, and would not show trends for individual states. Moreover, there are significant uncertainties related to the surveys conducted by NWI. The data may be as much as 30% off.

Table 9. Change in Wetland Area for Selected Wetland and Deepwater Categories, 1998 to 2004 (thousands of acres)

Wetland/Deepwater Category	Estimated Area, 1998	Estimated Area, 2004	Change, 1998-2004	Change (In Percent)
Marine	130.4 (20.2)	128.6 (20.5)	-1/9 (68.7)	-1.4
Estuarine Intertidal Non-Vegetated	594.1 (10.7)	600.0 (10.3)	5.9*	1
Estuarine Intertidal Vegetated	4,604.2 (4.0)	4,571.7 (4.0)	-32.4 (32.7)	-0.7
All Intertidal Wetlands	**5,328.7 (3.8)**	**5300.3 (3.8)**	**-28.4 (48.6)**	**-0.5**
Freshwater Non-Vegetated	5,918.7 (3.7)	6,633.9 (3.5)	715.3 (12.8)	12.1
Freshwater Ponds	5,534.3 (3.7)	6,229.6 (3.5)	695.4 (13.1)	12.6
Freshwater Vegetated	96,414.9 (3.0)	95,819.8 (3.0)	-495.1 (35.0)	-0.5
Freshwater Emergent	26,289.6 (8.0)	26,147.0 (8.0)	-142.6*	-0.5
Freshwater Forested	51,483.1 (2.8)	52,031.4 (2.8)	548.2 (56.1)	1.1
Freshwater Shrub	18,542.2 (4.1)	17,641.4 (4.3)	-900.8 (34.2)	-4.9
All Freshwater Wetlands	**102,233.6 (2.9)**	**102,453.8 (2.8)**	**220.2 (77.3)**	**0.2**
All Wetlands	**107,562.3 (2.7)**	**107,754.0 (2.7)**	**191.8 (89.1)**	**0.2**
Deepwater Habitats				
Lacustrine	16,610.5 (10.4)	16,773.4 (10.2)	162.9 (76.2)	1
Riverine	6,765.5 (9.1)	6,813.3 (9.1)	47.7 (68.8)	0.7

[114] Dahl, T.E. 2006. Status and trends of wetlands in the conterminous United States 1998 to 2004. U.S. Department of the Interior; Fish and Wildlife Service, Washington, D.C. 112 pp.

Wetland/Deepwater Category	Estimated Area, 1998	Estimated Area, 2004	Change, 1998-2004	Change (In Percent)
Estuarine Subtidal	17,680 (2.2)	17,717.8 (2.2)	37.3 (40.8)	0.2
All Deepwater Habitats	**41,046 (4.6)**	**41,304.5 (4.5)**	**247.9 (51.7)**	**0.6**
All Wetlands and Deepwater Habitats	**148,618.8 (2.4)**	**149,058.5 (2.4)**	**439.7 (31.3)**	**0.3**

The coefficient of variation (CV) for each entry (expressed as a percentage) is given in parentheses
* Statistically unreliable

Source: Dahl, T.E. 2006. Status and trends of wetlands in the conterminous United States 1998 to 2004. U.S. Department of the Interior; Fish and Wildlife Service, Washington, D.C. 112 pp.

Table 10. Changes to Estuarine and Marine Wetlands in the Conterminous United States, 1986-1997 (thousands of acres)

Wetland Category	Estimated Area, 1986	Estimated Area, 1997	Gain or Loss, 1986-1997	Area (as Percent) of All Intertidal Wetland, 1997
Marine Intertidal	133.1 (19.6)	130.9 (19.9)	-2.2 (88.5)	2.5
Estuarine Unconsolidated Shore	551.3 (10.9)	550.8 (10.8)	-0.5*	10.3
Estuarine Aquatic Bed	29.1 (27.1)	29.3 (26.9)	0.2*	0.6
Marine and Estuarine Intertidal Non Vegetated	580.4 (10.7)	580.1 (10.6)	-0.3*	13.4
Estuarine Emergent	3,956.9 (4.1)	3,942.4 (4.1)	-14.5 (49.2)	74
Estuarine Shrub	666.2 (12.6)	672.8 (12.6)	6.6 (76.5)	12.6
Estuarine Intertidal Vegetated	4623.1 (4.0)	4,615.2 (4.0)	-7.9 (75.1)	86.6
Estuarine Subtidal	17,637.6 (2.2)	17,663.9 (2.2)	26.3 (95.6)	-

The coefficient of variation (CV) for each entry (expressed as a percentage) is given in parentheses
* Statistically unreliable.
Source: Dahl, T.E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 82 pp

Table 11. Changes to Estuarine and Marine Wetlands in the Conterminous United States, 1998 to 2004 (thousands of acres)

Wetland Category	Estimated Area, 1998	Estimated Area, 2004	Gain or Loss, 1998-2004	Area (as Percent) of All Intertidal Wetland, 2004
Marine Intertidal	130.4 (20.2)	128.6 (20.5)	-1.9 (68.7)	2.4
Estuarine Unconsolidated Shore	563.2 (10.8)	567.5 (10.4)	4.3*	10.7
Estuarine Aquatic Bed	30.8 (27.1)	32.4 (26.0)	1.6 (63.6)	0.6

Wetland Category	Estimated Area, 1998	Estimated Area, 2004	Gain or Loss, 1998-2004	Area (as Percent) of All Intertidal Wetland, 2004
Marine and Estuarine Intertidal Non Vegetated	724.5 (9.8)	728.5 (9.5)	4.0*	13.7
Estuarine Emergent	3,922.8 (4.2)	3,889.5 (4.2)	-33.2 (31.8)	73.4
Estuarine Shrub	681.4 (12.5)	682.2 (12.5)	0.8*	12.9
Estuarine Intertidal Vegetated	4,604.2 (4.0)	4,571.7 (4.0)	-32.4 (32.6)	86.3
Estuarine Subtidal	17,680 (2.2)	17,717.8 (2.2)	37.8 (40.8)	-

The coefficient of variation (CV) for each entry (expressed as a percentage) is given in parentheses * Statistically unreliable

Source: Dahl, T.E. 2006. Status and trends of wetlands in the conterminous United States 1998 to 2004. U.S. Department of the Interior; Fish and Wildlife Service, Washington, D.C. 112 pp.

A central database could not be found that contained ownership of wetlands. However, either the NLCD or NWI data could be overlaid with local, state, or regional land ownership data in order to combine wetland type with ownership.

Datasets on historical land conversion rates

Data exists that shows historical land conversion trends from different types of wetlands to agricultural and urban land, and vice-versa. Table 12 contains historical wetland trends from 1954-1992 released by the Economic Research Service and the U.S. Department of Agriculture (USDA) in 1998.[115] Table 13 and Table 14 then show more recent and specific trends of agriculture, urban, and upland rural development conversion to saltwater wetland, and vice-versa.[116, 117] The studies define "urban" as land that is comprised of areas of intensive use in which much of the land is covered by structures (high building density) while "Upland Rural" land includes developments that occur in sparse rural and suburban settings outside distinct urban cities and towns. [118]

The trends outlined in these tables are not available for tidal wetlands only, or for the wetland project types/classifications that we propose to be adopted. Instead, a generalization based on these trends would have to be made, or additional research would be necessary to establish these rates according to our proposed project types/classifications.

[115] Heimlich, R.E., K. D. Wiebe, R. Claassen, D. Gadsby, R. M. House. 1998. Wetlands and Agriculture: Private Interests and Public Benefits. Agricultural Economics Report No. (AER765).
[116] Dahl, T.E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 82 pp.
[117] Dahl, T.E. 2006. Status and trends of wetlands in the conterminous United States 1998 to 2004. U.S. Department of the Interior; Fish and Wildlife Service, Washington, D.C. 112 pp.
[118] *Ibid*

Table 12 shows that, overall, 79,000 acres of wetlands were converted to other land uses between 1982 and 1992. The rate of wetlands conversion was even greater in earlier years (1954-1974 and 1974-1982).

Table 12. Historical Wetland Conversion Area in the Conterminous United States (Thousand Acres/Year)

	1954-74		1974-82		1982-92	
Wetlands converted to:	**thousand acres/year**	**percent**	**thousand acres/year**	**percent**	**Thousand acres/year**	**percent**
Agriculture	593	81	235	53	31	20
Urban Development	54	8	14	3	89	57
Other	35	5	168	38	16	10
Deepwater	48	6	29	6	20	13
Total	730	100	446	100	156	100
Converted to wetlands from:						
Agriculture	248	91	82	53	42	54
Urban Development	0	0	0	0	1	2
Other	0	0	53	34	29	38
Deepwater	25	9	20	13	5	6
Total	272	100	156	100	77	100
Net Change in wetlands						
Agriculture	435	95	153	53	-11	-14
Urban Development	0	0	14	5	87	110
Other	0	0	115	40	-12	-16
Deepwater	23	5	9	2	15	20
Total	458	100	290	100	79	100

Source: Heimlich, R.E., K. D. Wiebe, R. Claassen, D. Gadsby, R. M. House. 1998. Wetlands and Agriculture: Private Interests and Public Benefits. Agricultural Economics Report No. (AER765).

Whereas Table 12, above, shows conversions of all wetland areas in the United States, Tables 13 and 14 show conversions of saltwater wetlands only. The acreage converted is therefore much smaller than the numbers discussed in Table 12. In general the two tables indicate that more developed lands are being converted to saltwater wetlands than are being converted from developed lands to saltwater wetlands. However, these tables do not give a complete picture of potential changes and conversions in saltwater wetlands as they do not capture conversions within and among different types of wetlands and do not account for loss of wetlands due to sea level rise or internal breakdown of marshes.

Table 13. Historical Wetland Conversion Area in the Conterminous United States, Saltwater Wetlands Converted to Developed Areas (Acres)

	1986-1997			1998-2004		
	Agriculture	**Urban**	**Upland Rural Development**	**Agriculture**	**Urban**	**Upland Rural Development**
Marine Subtidal						
Marine Intertidal						
Estuarine Subtidal	131 (62)	214 (53)	222 (86)	30 (51)	1604 (66)	56 (84)
Estuarine Aquatic Bed				19 (104)		
Estuarine Emergents	285 (55)			155 (104)	74 (73)	
Estuarine Forested Shrub						
Estuarine Unconsolidated Shore		221 (78)	41 (96)			

Number in parentheses represents the percentage coefficient variation for that estimate
Shaded areas represent no change
Sources: Dahl, T.E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997. U.S.Department of the Interior, Fish and Wildlife Service, Washington, D.C. 82 pp,
Dahl, T.E. 2006. Status and trends of wetlands in the conterminous United States 1998 to 2004. U.S. Department of the Interior; Fish and Wildlife Service, Washington, D.C. 112 pp.

Table 14. Historical Wetland Conversion Area in the Conterminous United States, Developed Areas Converted to Saltwater Wetlands (Acres)

	1986-1997			1998-2004		
	Agriculture	**Urban**	**Upland Rural Development**	**Agriculture**	**Urban**	**Upland Rural Development**
Marine Subtidal						
Marine Intertidal			24 (98)			17 (94)
Estuarine Subtidal	14 (96)	228 (56)	300 (62)		1511 (68)	3 (95)
Estuarine Aquatic Bed						
Estuarine Emergents	7 (96)	1596 (46)	857 (55)		1489 (54)	94 (50)

	1986-1997			1998-2004		
	Agriculture	Urban	Upland Rural Development	Agriculture	Urban	Upland Rural Development
Estuarine Forested Shrub	442 (70)	864 (51)	909 (57)		67 (58)	330 (85)
Estuarine Unconsolidated Shore		245 (58)	231 (93)		47 (75)	72 (84)

Number in parentheses represents the percentage coefficient variation for that estimate
Shaded areas represent no change
Sources: Dahl, T.E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. 82 pp,
Dahl, T.E. 2006. Status and trends of wetlands in the conterminous United States 1998 to 2004. U.S. Department of the Interior; Fish and Wildlife Service, Washington, D.C. 112 pp.

Creation of more sophisticated datasets

In addition to the national level datasets, a few states have created unique and enhanced datasets based on the requirements of a particular state or organization. States such as Maryland, Montana, and North Carolina, have combined the NWI and NLCD datasets with other localized data to create their own state-specific wetland classifications. The North Carolina Division of Coastal Management (NCDCM) has created a particularly advanced dataset, which includes two sets of geospatial data describing the state's wetlands. This includes a summary of wetland type and acreage and an overview of lands that have the potential to be restored and enhanced. However, the dataset is only for one year and, therefore, does not allow comparison over time.

NCDCM created the following wetland type classification by integrating satellite imagery (from LandSat), soils, hydrography, and the National Wetland Inventory (NWI) data:

TIDAL WETLANDS
- Salt/Brackish Marsh
- Freshwater Marsh
- Estuarine Shrub Scrub
- Estuarine Forest

NON-TIDAL WETLANDS
- Pocosin
- Bottomland Hardwood
- Riverine Swamp Forest
- Depressional Swamp Forest
- Hardwood Flat
- Pine Flat

- Managed Pineland
- Maritime Swamp Forest
- Headwater Swamp

OTHER WETLANDS
- Human Impacted

The NCDCM tidal wetlands classification is similar to the categories for tidal wetlands proposed in Section 2.6.4, except our proposal also includes mudflats, brackish tidal wetlands and mangrove. However, this dataset illustrates that by combining different datasets already in existence, the classifications we propose for offset projects could potentially be created nationwide.

By combining this wetland type data with NRCS soil, land use/land cover and hydrography data, NCDCM was also able to create maps of potential wetland restoration sites. These potential sites represent former wetland areas that have been altered from their natural condition to the extent that the site no longer meets the vegetative, hydrologic, and/or soil conditions required to be classified as jurisdictional wetlands in North Carolina. Hydric soils that (1) used to possess wetland characteristics (restoration sites) or (2) are wetlands, but have been degraded or converted to a different wetland type than what was there in the past were categorized into the type of wetland plant community they most likely would be able to support once restored or enhanced.

North Carolina is clearly a leader in creating and maintaining geospatial wetland data. While some states have maps of wetland extents, many of them do not distinguish between tidal and non-tidal wetlands and certainly do not have areas of potential wetland restoration and enhancement. However, the NCDCM dataset does not represent the complete dataset that is needed for wetland offset projects. Public or private ownership is not distinguished, and data from different time periods is not available to determine trends throughout time.

3.3.2 Summary and Recommendations

Distinct performance standards should be developed for each of the four project types. Possible approaches are discussed below:

1. **Wetland creation:** In the NWI's Status reports, the amount of developed land (agricultural, urban, and upland urban development) converted to wetlands (and vice-versa) over two different time periods is available. The data in Tables 13 and 14 shows that overall more saltwater wetlands are being created from developed land than being converted to developed land, although there is some variation in the conversion rate among individual land/wetland types. However, the NWI's latest trend analysis described

in Table 9 shows that an overall net loss of intertidal wetlands occurred between 1998 and 2004. Some of the differences in the trend data result from the use of different classification systems in each of the tables.

Due to the high variance associated with wetlands conversion rates it would still be difficult to establish what is common practice regarding the creation of wetlands. More data and research is needed to better illustrate changes in all wetlands types using the proposed categories listed in Section 2.6.1. Even so, the latest NWI demonstrates that at the aggregate level it is not common practice to create tidal wetlands. Most tidal wetland creation projects would therefore be additional once they have passed the regulatory test.

The 'background' wetland creation/loss rate presented in the NWI dataset could be used as a performance standard to establish the 'business as usual' conversion rate from other land to tidal wetlands. Using this approach, a 'created' tidal wetland would pass the performance standard, simply by subtracting the background rate of wetlands creation from the acreage protected by the project. This approach would be similar to that adopted in the forestry protocol, except that in this case a national dataset would be used rather than forestry rates for individual states and regions.

The optimal approach would be to develop a dataset that shows conversion rates at the state and regional level and which distinguishes these by public and private lands and by our proposed tidal wetlands classifications. This would enable development of performance standards for both private and public sector projects and would take into account any variation in wetlands trends among states. For example, the state of California has been very active in purchasing land for future wetlands restoration and may therefore have a higher 'background' creation trend than other states.

2. **Wetland Restoration:** Table 10 and Table 11 show an overall decline in most of the tidal wetlands categories tracked by the NWI. As a result, a similar approach could be used as outlined for wetland creation, whereby the background net conversion rates of wetland area gains or losses could be used in the development of a performance standard to establish the 'business as usual' rate. Similarly, because of the problems associated with the NWI data, we recommend building a more comprehensive dataset that tracks wetland trends according to tidal wetlands classifications and individual states and land ownership.

3. **Wetland enhancement:** There are no data sources (at the national or state level) that clearly describe any trends in wetland enhancement. Therefore, it is impossible to determine a 'business as usual' or 'better than average' performance standard for this type of wetland project using established sources. However, none of the enhancement activities outlined in Section 3.1 have been tested in practice because wetlands owners have not focused on carbon sequestration in the past. Rather they would focus on

restoring wetlands to their original functionality and/or ensuring that these were sustainable over time.

Because the carbon storage activities listed in Section 3.1 are not currently being put into practice in tidal wetlands, they should clearly pass any performance standard test. Because there is no data that describes typical wetlands management practices, a "technology" or "activity" approach might be preferential to use for this type of offsets, whereby an outline would be created in advance that describes which type of enhancement activities would qualify as additional.

4. **Avoided wetland loss:** As indicated in the sections above, tidal wetlands in the United State are declining both in area and functionality. One area of particular concern is the Mississippi Delta. This indicates that there would also be room for an offsets category for projects that avoid the loss of tidal wetlands.

   For this category, we suggest developing a similar performance standard to the one that was developed for avoided conversion forestry projects in the recently updated CCAR forest protocol. This would include taking into account:

   - The immediate threat of conversion to the project site by demonstrating the wetland project site would be converted to another use within five years of project initiation; or
   - The conversion risk of the wetland project site by analyzing the likelihood of conversion based on economic, geographic, and political factors.

3.4 BASELINE QUANTIFICATION

The baseline for any offset project is often described as the 'business as usual' case, or the amount of GHGs that would be emitted if the project was not developed. In the case of a tidal wetlands offset project, the baseline would be the net amount of GHGs the land would have sequestered in the absence of any wetland creation, restoration, enhancement, or loss avoided.

3.4.1 Tidal Wetland Classification

Quantifying sequestration rates for the baseline condition poses a challenge similar to that for developing a performance standard since wetlands vary considerably, not only across the U.S. and inter-regionally, but also intra-regionally.

Potentially, it is possible to divide the coast into a series of regions within which the carbon sequestration and GHG emissions can be quantified for a standard series of wetland classes. In this issues paper we suggest a minimum of six classes of wetlands that should be assessed.

Although these wetland classes differ in ecology across the U.S., they are each broadly comparable in terms of carbon sequestration and GHG emission within identified regions.

Because these wetlands classes are based upon simple but clearly identifiable vegetation types we anticipate that it would be possible to use satellite or aerial remote sensing to quantify the distribution of these wetlands. This information could be included within a GIS database to provide sequestration rates for each region and classification. This database could then also support prioritization of restoration areas and predictions of likely carbon sequestration potential.

3.4.2 Sampling Methodology

As described in Section 2.7, simple standard laboratory methods exist for quantifying the amount of organic matter within soils. However, protocols for sampling a marsh surface have not been developed to describe the average carbon content of marsh soils across a landscape in a statistically representative way.

Field based methodologies also exist to quantify GHG emissions from vegetation and soils in tidal wetlands. These approaches are laborious. However, there is some potential that remote sensing approaches may come on line that will provide a spatial description of GHG emissions[119]; further testing and ground-truthing is required.

3.4.3 Predicting Wetland Evolution

By and large, freshwater and saline wetland restoration projects follow broadly predictable geomorphic[120] and ecological / biogeochemical evolutionary trajectories[121,122], which allow at least a first order estimation of carbon sequestration over the timeframe of the project. Such projections support a scoping assessment to help prioritize sites for restoration. Per section 3.4.1, a considerable amount of further quantification is required to provide a basis for attaching a refined net carbon sequestration value to these trajectories and monitoring will be required during the project to track verified progress.

Figure 1a,b. provides an example of numerical model simulations of mudflat accretion into a vegetated tidal wetland. In the model, change in bed elevation is defined by sediment supply rate (determined by ambient suspended sediment concentrations and duration of flooding by tides), contributions of organic matter, compaction of the soils and rate of sea level rise. Figure 1 a and b

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119 Yan, Y., B. Zhao, J. Chen, H. Guo, Y, Gu, Q. Wu, B. Li. 2008. Closing the carbon budget of estuarine wetlands with tower-based measurements and MODIS time series. Global Change Biology: 14, 1-13.

120 Orr M, Crooks S, Williams PB. 2003. Will Restored Tidal Marshes Be Sustainable? San Francisco Estuary and Watershed Science 1(1).

121 Craft C, Megonigal P, Broome S, Stevenson J, Freese R, Cornell J, Zheng L, Sacco J. 2003. The Pace of Ecosystem Development of Constructed Spartina Alterniflora Marshes. Ecological Applications 13(5):1417-1432.

122 Cornell JA, Craft CB, Megonigal JP. 2007. Ecosystem gas exchange across a created salt marsh chronosequence. Wetlands 27(2):240-250.

shows how the timeframe for a restored mudflat to built up to salt marsh elevations depends upon the starting elevation of the flooded surface and the availability of mineral sediment. In this simplified example a restoration of an agricultural field (former salt marsh) that has subsided some 8 feet below natural marshplain elevations will take less than 5 years (available sediment in water column > 350 mg L^{-1}) to more than 45 years (available sediment in water column, 100 mg L^{-1}). Under such conditions we might infer that the net carbon sequestration potential of the site would be similar to that on mudflats in the region, and once vegetation has begun to colonize that within 5-10 years the net sequestration potential is comparable with reference salt marshes.

It should be noted that there are many reasons why a restoring wetland would not follow a trajectory such as the one outlined in the above example. Therefore, these projections should only be undertaken with appropriate inclusion of expert judgment and recognition that evolutionary trajectories can vary from simplified assessments, based upon local conditions.

3.4.4 Selecting Baselines for the Four Tidal Wetland Project Categories

Offsets projects that involve wetlands restoration, enhancement, and avoided loss should all use a baseline based on the sequestration and GHG flux of the existing wetland being referred to. However, in the case of 'wetlands creation,' the baseline should consist of the sequestration rate and GHG flux of the land that is being converted to a wetland. CCAR's forestry protocol provides accounting guidance for how to establish baselines for such lands. These methods could easily be adapted to a wetlands protocol.

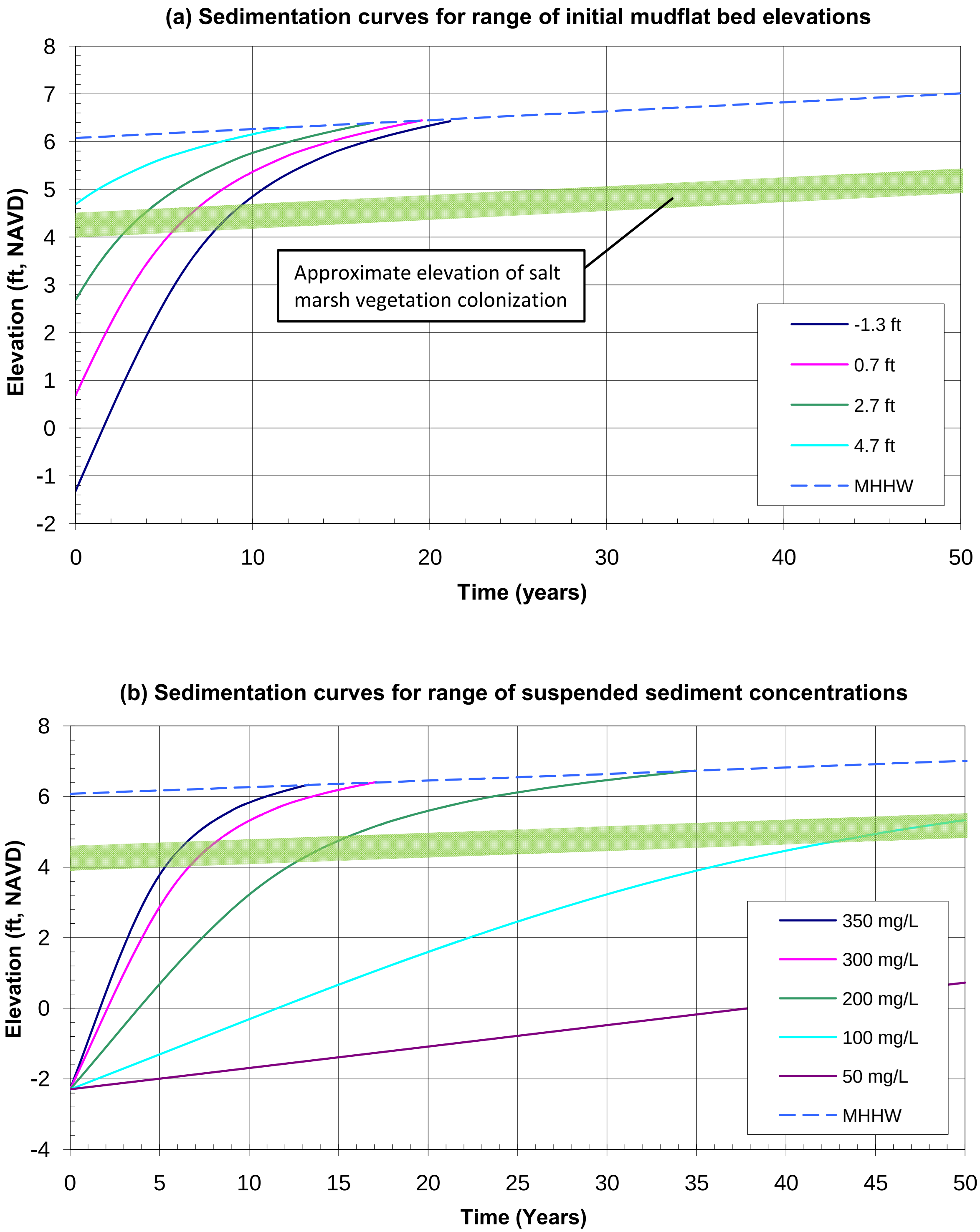
3.5 POTENTIAL REDUCTION OPPORTUNITY

3.5.1 Wetland Creation and Restoration

The extent of tidal wetlands creation and restoration potential across the USA is not known, but with some effort could be quantified. For example, as mentioned the state of North Carolina has already established a GIS database that outlines land areas where wetlands could be created or restored.

We do know that extensive areas of tidal wetlands have been leveed over the past 150-250 years, some of which is in non-urban use and suitable for restoration. For example, California has lost 95% of its tidal wetlands, and New England has lost 37%, on average.[123] Not all of these leveed former wetlands would be restorable because of complicating factors such as onsite infrastructure, flood protection requirements for adjacent lands, and poor connectivity to shoreline.

[123] Bromberg KD, Bertness MD. 2005. Reconstructing New England salt marsh losses using historical maps. Estuaries 28(6):823-832.



Notes: (a) Ambient sediment concentration of 250 mg/L
(a) and (b) Mean monthly tide from Petaluma River Entrance rate of sea level rise = 5.67 mm/yr. Tide range approximately 6.1 ft, MLLW = 0.0 ft NAVD, MHHW = 6.1 ft NAVD.

Source: MARSH98 Sedimentation Model

figure 1

Tidal Wetland Carbon Sequestration

Predicted Sedimentation Curves

PWA Ref# 1957

PWA

J:\1957_CCAR_Tidal_Wetlands_Issue_Paper\Report\Figures\Hamilton Marsh 98 Results REVISED.xlsx

A first order estimation of the area of land available for creation or restoration can be derived from calculations of the floodplain area of coastal states. The Federal Emergency Management Agency has calculated the coastal floodplain area that would flood under a 100 coastal flood event for 1990 (Table 15).[124] This area includes many but not all urban and most agricultural areas on low-lying former marshes as well as upland transitional areas that would be subject to flooding. The current 100 year floodplain is approximately 50,500 km^2 for all coastal regions of the United States. Most of this area is contained in the coastal states from the Mid-Atlantic region to the Gulf of Mexico region. The west coast, Alaska and Hawaii, together count for no more that 5% of the total coastal floodplain.

Table 15. Area of the 100-year Coastal Floodplain (FEMA, 1991)

Region	Floodplain Area in 1990 (km^2)	States included
New England	3,035	Maine, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York
Mid-Atlantic	11,673	New Jersey, Delaware, Maryland, Virginia, North Carolina
Mesotidal Coast	5,778	South Georgia, Georgia
Atlantic Coast Florida	2,300	Eastern Florida and Keys
Gulf Coast Florida	7,734	Western Florida, Alabama, Mississippi
Deltaic Coast	9,567	Louisiana
Texas	8,159	Texas
California/ Hawaii	1,352	California, Hawaii
Alaska	894	Alaska
National total	50,492	

As a very first cut estimate – if we make the unvalidated assumption that up to 10% of the total floodplain area nationally is suitable for tidal wetland restoration – there may be an opportunity to restore up to 5,500 km^2 of tidal wetlands across the United States. Making an assumption that all this area is created or restored and assuming an average range of carbon sequestration of 50 – 150 gC m^{-2} yr^{-1}, then the total potential carbon sequestration is around 0.2 – 0.8 TgC yr^{-1} (0.73-2.9 $TgCO_2e$ yr^{-1}), within restored marsh soils[125].

[124] FEMA. 1991. Projected Impact of Relative Sea Level Rise on the National Flood Insurance Program. Published by Federal Emergency Management Agency, Federal Insurance Adminstration.
[125] Estimate assumes near GHG emissions of saline wetlands near zero, GHG emission from freshwater tidal wetlands reduce net carbon sequestration to that similar to salt marsh and does not account for sequestration of existing agricultural land. The estimate does not include the carbon storage within standing crop Estimate is very sensitive to total available and net sequestration potential of freshwater tidal wetlands.

Wetland creation and/or restoration potential will primarily be restricted to agricultural land not greatly partitioned by urban sprawl. It might be expected that states like North Carolina, South Carolina, Georgia, and Mississippi might have greater potential for restoration than urbanized states, such as New Jersey, Virginia and California.

An example of one potential but unverified 'hot spot' for reduction opportunities is restoration of freshwater tidal wetlands in the Sacramento - San Joaquin Delta. Levee construction and agricultural drainage has, over the past 150 years, oxidized organic rich soils that extended over 180,000 ha of former wetlands, creating a volume below sea level of around 2.5 billion cubic meters. Ongoing studies have shown the potential to raise freshwater marsh elevations at a rate of more than 5 cm per year, under managed conditions.[126] If such rates of marsh build up could be sustained then marsh accumulation could sequester around 1000 gC m^{-2} yr^{1} (3,667 gCO_2e m^{-2} yr^{-1}). An unaddressed question is the degree to which this carbon sequestration potential is offset by CH_4 emissions. Data collected over a 6 year period at an experimental site by the USGS suggest that carbon sequestration values may outweigh GHG emissions, providing a positive net carbon offset. Depending upon water management positive GHG offsets of between around 0 to 2000 CO_2 m^{-2} yr^{-1} have been recorded in managed vegetated marshes, while open water area emit up to 2000 CO_2 m^{-2} yr^{-1} [127]. These results are very promising and indicate the potential for considerable GHG offsets though restoration of freshwater tidal wetlands.

3.5.2 Wetland Enhancement

Wetland enhancements fall into one of two categories, those which:

1. Accelerate the rate of site evolution to vegetated wetland from unvegetated wetland; and
2. Reduce GHG emissions of managed wetlands.

Augmentation of natural sedimentation with placement of clean sediment may be used to accelerate salt marsh development from mudflats. Such approaches have occasionally been used to provide an environmentally beneficial reuse of dredge material. Such approaches are presently uncommon, for a number of reasons including cost comparisons with standard dredge material disposal options. The potential benefits of accelerating the rate of vegetated marsh establishment by actively adding sediment may or may not be positive from a carbon accounting perspective. Energy is required to collect, transport and deliver sediment to the restoration site, which may outweigh the carbon sequestration value of accelerating the rate of marsh evolution.

Water management approaches, including periodically lowering the water table to quell methanogenesis or vegetation 'harvesting' approaches to reduce the transfer of methane from the

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[126] Miller R, Fram M, Fujii R, Wheeler G. 2008. Subsidenc`e reversal in a re-established wetland in the Sacramento-San Joaquin Delta, California, USA. San Francisco Estuary & Watersheed Science. : Available from: http://repositories.cdlib.org/jmie/sfews/vol6/iss3/art1

[127] R. Miller, pers. comm.

soil to the atmosphere[128] in managed, restoring freshwater tidal wetlands may offer potential to reduce GHG emissions and shift the net carbon balance to positive. Such approaches have yet to be fully tested in the field.

3.5.3 Avoided Wetland Loss

In a US Fish and Wildlife status report on the extent of wetland in the conterminous United States[129], it was estimated that of the 2.1 million ha of marine and estuarine wetlands that existed in 1998, 86 % consisted of vegetated saline and brackish wetlands. By 2004 the area of vegetated tidal wetlands had declined by 13,450 ha while unvegetated wetlands gained by 1,620 ha. The average rate of loss was about 2,240 ha yr^{-1}. This rate of loss was consistent with the rates of salt marsh loss recorded between 1986 and 1997.[130] Development accounted for about 700 ha of loss (3% of total) but most losses were due to erosion and occurred mainly in Louisiana. Despite numerous restoration projects undertaken as part of the Coastal Wetlands Planning, Protection and Restoration Act of 1990 the rate of estuarine wetland loss has remained constant since the mid 1980's. An EPA study cites several interrelated factors likely contributing to loss of vegetated wetlands in Louisiana[131], including:

- sediment deficiency;
- canals and artificially created waterways;
- wave erosion;
- land subsidence; and
- salt water intrusion caused by mash disintegration.

The diversion of sediment that once spilled across flooding river banks across wetlands, and now confined to leveed channels until expulsion to deep Gulf waters is a primary reason for marsh loss.[132]

There is potential to use sediment applications to reverse or halt the loss of some salt marsh areas. In Louisiana degraded, subsided wetland marsh test sites are being raised with mud slurry and showing promising results of returning vegetation.[133] The potential benefits of preventing marsh loss likely extend beyond just avoiding a decline in carbon accumulation by plants. Once a degraded marsh loses its vegetation cover and converts to mudflat the rate of erosion increases.

[128] Van Der Nat, F.J., J.J. Middelburg. 2000. Methane emission from tidal freshwater marshes. Biogeochemistry: 49, 103-121.
[129] Dahl, T.E. 2006. Status and trends of wetlands in the conterminous United States 1998 to 2004. U.S. Department of the Interior; Fish and Wildlife Service, Washington, D.C. 112 pp.
[130] Dahl, T.E. 2000. Status and trends of wetlands in the conterminous United States 1986 to 1997. U.S.Department of the Interior, Fish and Wildlife Service, Washington, D.C. 82 pp
[131] Day JW, Jr., Boesch DF, Clairain EJ, Kemp GP, Laska SB, Mitsch WJ, Orth K, Mashriqui H, Reed DJ, Shabman L and others. 2007. Restoration of the Mississippi Delta: Lessons from Hurricanes Katrina and Rita. p 1679-1684.
[132] *Ibid.*
[133] Schrift A. 2006. Salt marsh restoration with sediment-sluffy amendments following a drought-induced large-scale disturbance. Baton Rouge: Louisiana State University. 54 p.

At this point many years of past marsh accumulation can be remobilized by wave erosion and released in to circulation.

The following thought exercise illustrates the comparative implications of marsh erosion to a marsh carbon budget. Let us assume that decline of vegetated salt marsh in Louisiana of about 100 km^2 yr^{-1} or 1,000 ha yr^{-1} equates to a loss of about 1.5 GgC yr^{-1} (5.5 $GgCO_2e$ yr^{-1}) in ongoing sequestration potential (assuming that average salt marsh carbon sequestration in the delta is 200 gC m^{-2} yr^{-1} (733.3 gCO_2e yr^{-1}) and that created mudflat is 0.5 gC m^{-2} yr^{-1} (1.8 gCO_2e yr^{-1})). However, if we take into account an very rough estimation for soil erosion under waves, say the top 50 cm (average soil carbon content of 0.15 Mg C m^{-2} (0.55 Mg CO_2e m^{-2}), then each loss of 100 km^2 of tidal marsh could be releasing around 7.5TgC (27.5 Tg CO_2e). This quantity alone is an order or magnitude greater than the total annual sequestration potential were 10% of all of existing coastal floodplains restored to saline tidal wetlands. The error in the estimation of carbon released by erosion could have a range of 100% or more.

Freshwater tidal wetlands are less sensitive to mineral sediment supply but highly sensitive to water management. Drained wetlands in the Sacramento – San Joaquin Delta are subsiding around 2 cm per year through oxidation or organic soils. Over an area of 180,000 ha this loss equates to release of some 4 TgC yr^{-1} (14.7 Tg CO_2e) (carbon content 0.2 g /g dry wt of soil).

3.6 PROJECT BOUNDARY

To define a physical boundary is difficult when dealing with dynamic biological and geomorphic systems, especially if they are subject to migration with climate change. Tidal wetlands are defined by their relationship to tidal hydrology. The most landward boundary can be approximated by an infrequent high tide flood event. One such boundary is the 100 year elevation as defined by the Federal Emergency Management Agency. The seaward boundary is defuse.

The boundary of the actual restoration project is less defuse as it will usually take place on well-defined parcels of land ownership.

We explore two main areas to define the physical project boundary for tidal wetland restoration, and two further areas are discussed with respect to the GHG sources and sinks that need to be assessed to determine net change in emissions attributed to tidal wetland restoration.

3.6.1 Expansion of the Tidal Wetland with Sea-level Rise

The natural response of tidal wetlands is to migrate landward as sea level rises. As a consequence the outboard margin of the project will erode and new marsh will be built on the landward boundary. This process occurs slowly and at a rate which depends upon the rate of sea level rise and the slope of the local topography.

3.6.2 Nitrate Pollution from Adjacent Agricultural Land

The potential increase in N_2O production as a result of the new wetland may offset much of the sequestration achieved by the restoration and should be addressed in the offset project boundary.

Nitrate pollution from agriculture, urban and industrial sources, is the direct cause of N_2O production within tidal wetlands. Increased pollutant loading leads to a direct increase in N_2O production. Estuaries and adjacent nearshore regions of the continental shelf are areas of intense nitrogen recycling. While most of this nitrogen is recycled before reaching the open ocean the sea ward boundary of nitrogen recycling is defuse and variable.

In this paper we suggest that N_2O production should not be accounted from within the wetlands restoration project as production of this gas would occur elsewhere in the estuary or adjacent continental shelf even if the project were not built.

3.6.3 Allochthonous Carbon Deposition

This involves the deposition of carbon in the restored tidal wetland from sources external to the project. The potential increase in carbon storage has to be reconciled with the replacement of carbon in the source area, and any differences in decomposition rates between wetland and the source.

Our recommendation is to disregard this in the offsets methodology by concentrating on quantifying the carbon that is sequestered within the soils. There is a lot of carbon flux within estuaries, some of it derived from rivers, some from marsh vegetated and eroding soils. If we consider all of that a mobile pool but only quantify that which is buried, it should be sufficient. But this is probably an area that deserves feedback from other experts.

3.6.4 GHG Accounting Boundary

The GHG accounting boundary should include carbon sequestered within the wetlands boundary as well as any CO_2 and CH_4 emitted through flux. N_2O emissions emitted through flux should likely be omitted from the boundary, since it is usually insignificant and because it would typically be emitted even if the wetland were not there. However, this is an area that may want warrant further research.

In addition, the GHG boundary should include any GHG emissions from fuels used for transporting and placing sediments within the wetlands. Relevant gases would include CO_2, CH_4 and N_2O from the combustion of fossil fuels. Any fossil fuel combustion related to creating/restoring the wetland (such as removing levees) should also be included in the GHG accounting boundary.

3.7 OWNERSHIP

3.7.1 Landside Wetland Restoration

Land ownership on the landward side of flood protection levees is usually well defined. Restoration projects are commonly undertaken on former agricultural land that was once under private ownership. It is not uncommon, particularly in California for wetland restoration projects to be facilitated by State Organizations (such as the California State Coastal Conservancy) and non profit organizations (e.g., Marin Audubon Society, Trust for Public Land) to purchase parcels of land for wetland restoration and once the project is complete deed those lands to an agency (such as the California Department of Fish & Game) for future management. Ownership of offset credits should be readily determinable.

3.7.2 Waterside Wetland Restoration

Land ownership on the waterside of levees is more complicated than the landward side. Tidal wetlands may be owned by a range of private entities or public agencies but because of the dynamic nature of wetland systems (with shifting channels and mobile edges) ownership disputes are not uncommon.

3.8 LEAKAGE

Leakage refers to a situation in which a carbon sequestration activity (e.g., wetland restoration) on one piece of land triggers an activity outside the project boundary, which counteracts (whole or in part) the carbon effects of the initial activity. World Resources Institute (WRI) further defines this type of leakage as a 'secondary effect.' Alternatively, WRI defines 'primary effects' as "the intended changes in GHG emissions or removals associated with a GHG source or sink caused by the project activity,[134]" in other words, the GHG flux resulting from the presence of a wetland.

Two common secondary effects include activity-shifting leakage and market leakage. Activity-shifting leakage occurs when activities inside the physical project boundary is moved to a location outside the project boundary, directly resulting from the project's activities. Market leakage occurs when the project activity affects an established market for goods and causes the substitution or replacement of that good elsewhere, causing GHG emissions that offset or mitigate the project's GHG reductions. We describe two leakage effects related to restoration of wetlands, issues related to their quantification, and potential mitigation strategies.

[134] Greenhalgh, S., F. Daviet, E. Weninger. YEAR. The Greenhouse Gas Protocol: The Land Use, Land-Use Change, and Forestry Guidance for GHG Project Accounting. http://pdf.wri.org/lulucf_guidance.pdf

3.8.1 Drainage of Land Elsewhere due to Agricultural Demand

Market leakage could occur if agricultural lands removed by wetland creation or restoration increase the demand for agricultural products. This demand might then cause pressure for drainage or disturbance of wetlands elsewhere, into agricultural land. This would also apply to a case where a wetland area is set aside for preservation, resulting in a different piece of land being cleared instead. It is also conceivable that some forestland or grassland could be cut to create new agricultural land to replace the land that has been given up for wetland restoration.

Little data is available to quantify the interaction between wetland creation and restoration from agricultural or degraded land and the subsequent market pressures to develop land for agricultural. A study by Murray *et al.* (2002) has been referenced in multiple offset protocols as a source for leakage values that can be applied to forest offset projects. In this study, regional leakage values were based on obtained by modeling land transfers between the agricultural and forestry sectors over time.[135] Similar modeling could be completed to determine leakage values associated with the conversion of wetlands to agriculture land and the economic factors affecting this interplay.

It is also difficult to assess the risk of leakage due to limited trend availability. However, if wetland restoration is concentrated on lands of marginal agricultural use, this risk would be lowered.

3.8.2 Changes in Sediment Supply to Wetlands Elsewhere

Wetland restoration could also cause activity-shifting leakage. Restoration of a functioning wetland that can sequester carbon relies on capturing sediment to allow the surface to rise to elevations where vegetation can colonize. This sediment demand creates a new sediment sink, which could reduce sediment supply to other vegetated wetlands, leading to their erosion, and potential leakage. In order to quantify this possible sediment loss at other wetland locations, project managers could use a sediment budget analysis. Recharging the wetland with mud to replenish lost sediment could also be used as a sediment management method to mitigate for the erosion.

3.9 PERMANENCE

Restored tidal wetlands would probably be a comparatively resilient stock of carbon because of their high sedimentation rates and low decomposition rates. Many tidal wetland sequences are relatively thick and store large amounts of carbon. With continued rise in sea-level, and an adequate sediment supply, restored tidal wetlands would continue to function and sequester relatively large amounts of carbon, with low risk of reversal. However, if sea-level rise exceeds

[135] Murray, B.C., B.A. McCarl., H.C. Lee. 2002. Estimating Leakage from Forest Carbon Sequestration Programs. RTI International. http://www.rti.org/pubs/rtipaper_02_06.pdf

sediment accumulation, the wetland will drown and its carbon sequestration potential will be reduced. In addition, erosion of the wetland may lead to a potential reversal from a sink to a source, as carbon stored in the wetland sediments is released to general circulation.

The storage potential of tidal wetland systems and their potential response to sea-level rise varies around the U.S. Both are poorly quantified. Sifting through the data suggests that, for example, restoring tidal wetlands in the Mississippi Delta has the potential for effective accumulation of carbon because of regional climatic and hydrologic conditions. However, these tidal wetlands are potentially highly sensitive and vulnerable to sea-level rise. By contrast, wetlands in regions of the country with a higher tidal range (e.g., California, Maine, Washington) will likely recycle a high proportion of their carbon inventory before a portion reaches permanent storage, but these wetlands are potentially more resilient to sea-level rise, and so offer more permanent long-term storage potential.

Though saline wetlands will erode at the seaward margin as sea level rises they will remain healthy as long as there is space on the landward side to migrate.

In locations such as the Sacramento-San Joaquin Delta freshwater wetland were sustainable for more that five thousand year. Once restored, freshwater tidal wetlands will have the potential to be highly resilient to high rates of sea level rise.

3.10 SCIENTIFIC UNCERTAINTY

Three critical scientific information gaps exist: wetland gas exchange rates (including CO_2, CH_4, and N_2O), wetland interactions with the surrounding landscape (specifically carbon budgets), and carbon accumulation rates in the soil and litter column of wetlands. For example, because the tiny traces of methane gas from microbes are hard to measure, very few data are available on methane releases from wetlands.

3.10.1 Carbon Capture Farming in the Sacramento-San Joaquin Delta

In California's Sacramento-San Joaquin Delta a project is being developed by the USGS, the California Department of Water Resources (DWR), and the University of California, Davis, called 'carbon-capture' farming. The project is assessing the carbon sequestration efficiency of growing tules and cattails in wetlands created on abandoned farmland on islands in the Delta, and in the process rebuild the Delta soil elevations. CH_4 emissions are being monitored but have yet to be reported.

3.11 OTHER POSITIVE/NEGATIVE ENVIRONMENTAL IMPACTS

3.11.1 Positive Impacts

Tidal wetland restoration offers opportunities for significant co-benefits. Besides reducing emissions, projects would increase ecosystem values such as wildlife habitat, protection for rare and endangered plants and animals, water quality and flood protection. Wetlands are recognized internationally as habitats with high biodiversity value. They also have important functions in water regulation and purification, and tidal wetlands can help to alleviate the impacts of storm surges. Wetland restoration and improved management of wetlands feature highly in climate change adaptation strategies.

3.11.2 Negative Impacts

Restoration would in most cases involve a change in land use. Restoring wetlands currently used for agricultural purposes could lead to reduction of food production.

Evidence exists that shows increased land conversion to tidal wetlands could cause an increase in bioaccumulation of mercury within local food webs. [136] Tidal wetlands provide an environment that allows inorganic mercury in sediments to transform through methylation into a new molecule that is toxic to fish, wildlife, and humans. The area with potentially the biggest methylation problem is the estuaries of northern California. Here, large quantities of mercury entered the river and coastal system.

3.12 MARKET INTEREST

Similar to other market mechanisms, project developers will most likely take on wetland restoration projects if they can sell the resulting carbon offsets at a price that is greater than the project costs. Conversely, GHG emitters will most likely buy carbon offsets if the price is less than the cost associated with reducing their emissions, or buying allowances in a mandatory market. With the potential to store a lot of carbon, offsets derived from wetland creation, restoration, enhancement, or from avoided wetland loss could become profitable to varying degrees for both private and public landowners.

Private landowners: One of the main market drivers that would influence private landowners to develop wetland offset projects is profit. However, project developers would need to consider multiple cost factors during project development. As seen in Figure 2, gross profits from wetland offset projects vary greatly depending on the size of the project, the amount of CO_2 sequestered, the amount of CH_4 emitted (CO_2 equivalent sequestration), and the price of carbon. This figure represents estimated total gross profit after the wetland has been sequestering carbon for 20 years,

[136] Brown, L.R. 2003. A Summary of the San Francisco Tidal Wetlands Restoration Series. San Francisco Estuary and Watershed Science: Vol. 1, Issue 1, Article 6

and does not include the actual cost of restoration. By converting estimated restoration costs reported by the EPA in 1990 into 2007 dollars, low complexity restoration projects would cost around \$2,000 per ha, while higher complexity restoration projects could cost around \$25,000 per ha.[137]

Non-profits and land trust organizations who historically have bought, conserved, and/or restored wetlands for their significant ecological value may have additional motives if they could also sell carbon offsets from that land. Researchers associated with private institutions might also be interested in being able to study the GHG flux associated with wetland restoration while at the same time producing offsets that could help fund additional research.

Restored salt marsh will, depending upon location, sequester between 100 and 200 gC $m^2 yr^{-1}$ (3.7 and 7.3 $tC0_2e$ ha yr^{-1}). For the simplest level of restoration (e.g. one without flood protection and fill removal requirements or complex design and permitting; and elevations suitable for vegetation colonization within 4 years), excluding land purchase costs and assuming \$25 per tCO_2e, a restoration project could be cash flow positive within 12-25 years. For more complex designs, the period over which the project would become cash flow positive would be correspondingly extended.

Carbon sequestration potential for freshwater tidal marshes is higher that for salt marshes, possibly ten times so, around 1000 gC $m^{-2}yr^{-1}$. Though very few studies have been undertaken in freshwater tidal wetlands the results of the U.S.G.S. in a managed restoration site offers considerable encouragement that it would be possible to sequester large quantities of carbon (20 $tC0_2e$ ha yr^{-1}, including accounting for CH_4 emissions), and correspondingly the potential for economic return is much higher.

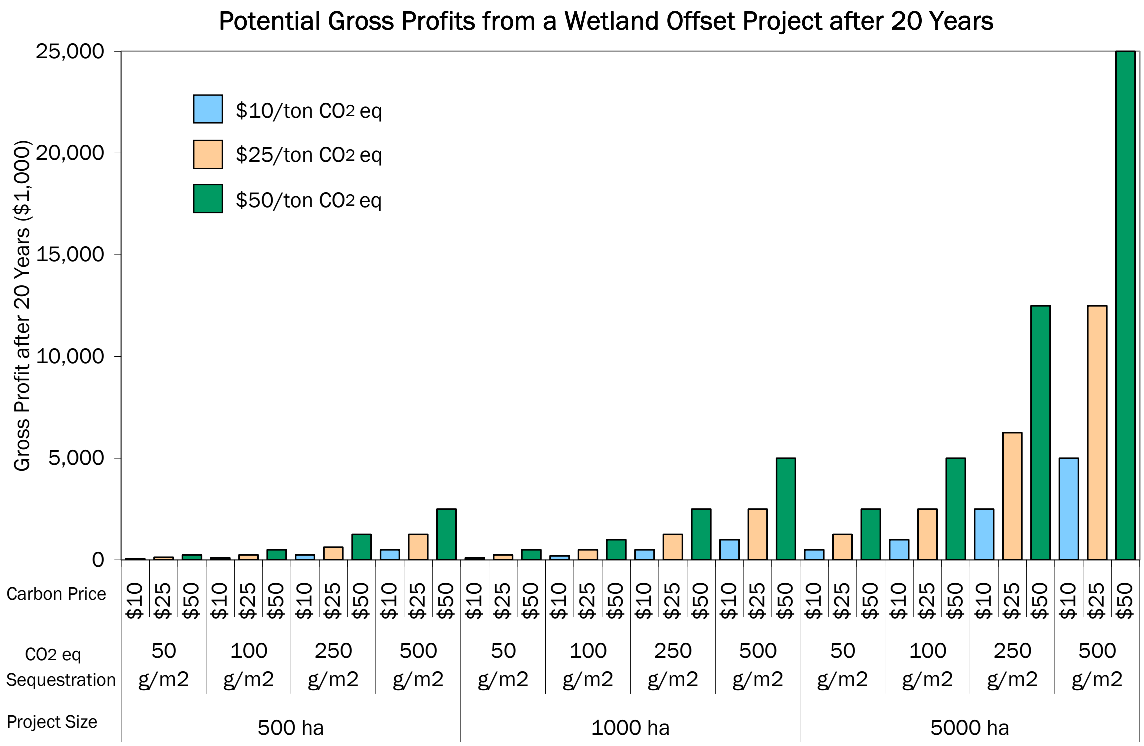
Currently, agricultural land use on former freshwater tidal wetlands in the Sacramento-San Joaquin Delta are releasing very large quantities of carbon dioxide (estimated to be around 13Mt CO_2e yr^{-1}, equivalent to around 3% of California's total annual emissions), and unaccounted levels of GHG emissions associated with nitrogen pollution (N_2O production). Reducing or reversing these GHG emissions could have considerable immediate GHG offset potential for the State of California. Similar assessments should be undertaken in other regions of the country that have drained freshwater tidal wetlands (e.g. Louisiana and Florida).

Public landowners: Local, state, or federal government agencies may be driven to develop these projects in order to satisfy a wetland restoration goal. However, in the past, state and local governments have been consistently short of funding and other resources to meet these restoration goals. The possibility of securing additional funds through the offsets market would be a great help to these agencies, most likely at the state level. This is the case in California and in

[137] EPA. 2008. Polluted Runoff (Nonpoint Source Pollution) Management Measure for Restoration of Wetland and Riparian Areas. U.S. Environmental Protection Agency. http://www.epa.gov/nps/MMGI/Chapter7/ch7-2b.html

Maryland, for example, where research groups and state representatives have approached both the EPA Climate Leaders Program, the Regional Greenhouse Gas Initiative and the California Climate Action Registry to explore the opportunities for advancing the development of an offsets methodology for wetlands. The Maryland Power Plant Research Program is involved in a pilot project to examine the carbon sequestration potential in a sample plot in the Blackwater Wildlife Refuge, and is very keen to expand this project to a wider area in the Refuge, in case funding were available. Lawmakers are aware that by restoring coastal wetlands they may also help the state adapt to expected sea level rise.

Figure 2. Potential Offsets Profits



4. CONCLUSIONS

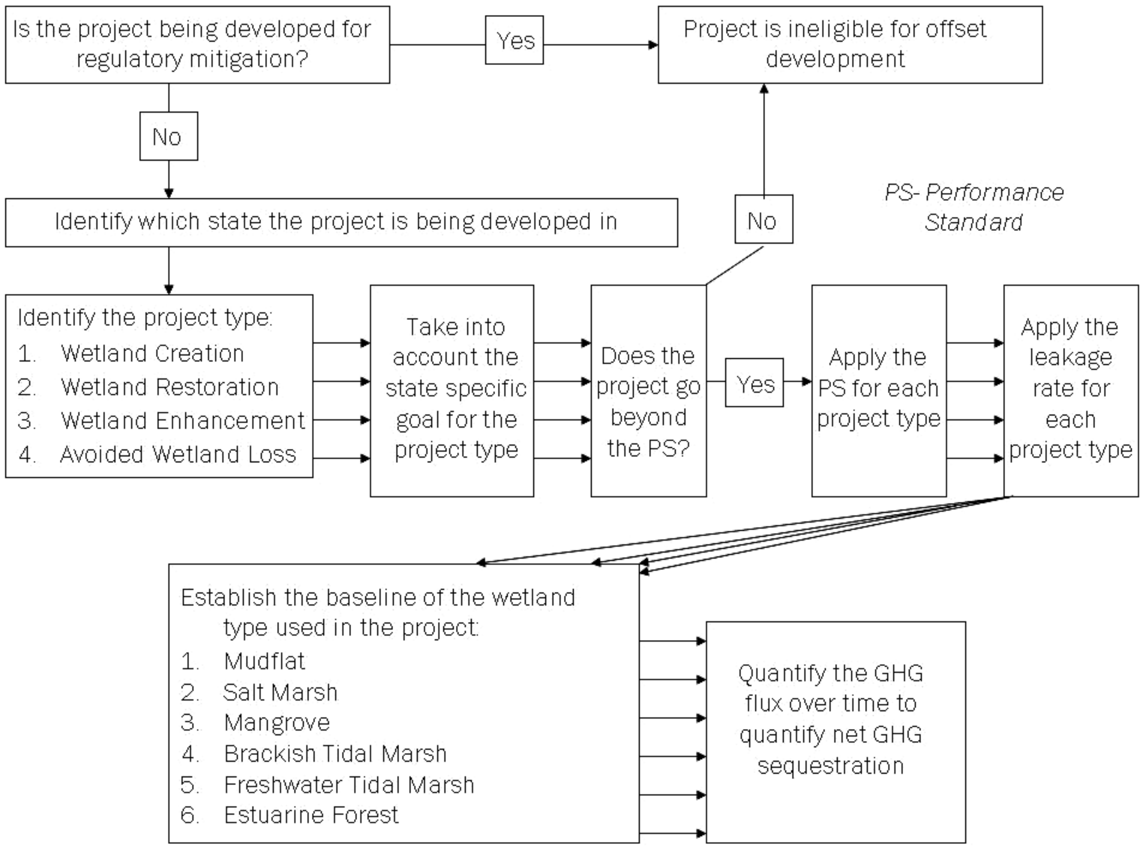
As illustrated throughout this report very little prior work has been done to examine methods for quantifying carbon sequestration and GHG flux and determining additionality for tidal wetlands offsets. Because of the absence of earlier work in this area, there are still many uncertainties related to developing an offsets methodology for this project type including an absence of good datasets on wetlands practices and trends as well as a lack of established accounting guidance and emission factors/sequestration rates for relevant tidal wetlands classifications.

Wetlands are somewhat unique for offsets projects because federal and state agencies have a large role in their regulation and management, and actually own much of the land that could be used for tidal wetlands projects. It must therefore be determined how to establish a methodology that determines what is beyond "business-as-usual" activities of the public sector, in addition to that of the private sector.

The current datasets are not comprehensive enough to provide adequate information for setting performance standards for the relevant categories of tidal wetlands projects. Instead, this report outlines a framework for how performance standards could be developed and the additional research and datasets that would have to be developed to support the implementation of such a framework. Figure 3 describes this possible methodology framework for offsets developed through tidal wetland projects. As illustrated in the Figure, before a project developer can consider developing carbon offsets for any wetland project, it must be confirmed that the project is not being completed to comply with the CWA or other federal or state regulations. Depending on the project type, a state-specific creation, restoration, or enhancement goal may have to be taken into account. If the project then goes beyond the set performance standard, a leakage factor can be applied to take into account any secondary GHG emissions associated with the project. Finally, one or more wetland types might be present within one wetlands project. The GHG flux will have to be measured over time to quantify the net GHG sequestered above each wetland type's baseline.

However, as discussed in the report, for each step of this framework, additional data and GHG accounting guidance would have to be developed in order to support the development of specific regulatory additionality test, performance thresholds, and GHG sequestration rates for individual tidal wetlands classifications.

Figure 3. Suggested Framework for a Tidal Wetland Offsets Methodology



4.1 NEXT STEPS

In order to develop an offsets protocol for wetland projects, we suggest the following actions be completed:

- Review and refine the wetland classification scheme suggested in this report.
- Map wetland ownership data by state.
- Map distribution of wetlands by classification and state across a series of years, to determine trends in wetlands practices. To expedite the development of more knowledge in this area, it may be useful to immediately begin researching areas with high offsets potential such as the Chesapeake Bay Watershed, California estuaries, and the Mississippi Delta.
- Define biogeomorphic regions in which wetland classes and physical processes can be grouped (e.g., for California, possible biogeomorphic regions may be Northern California Estuaries, San Francisco estuary, and Central / Southern Californian estuaries. On the Gulf Coast, the Mississippi Delta may be considered a single biogeomorphic unit).
- Develop standardized approaches for measuring C storage and GHG's emissions.

- Define carbon budget for wetlands classes per biogeomorphic region.
- Confirm validity of removing N_2O from wetland GHG mitigation accounting.
- Determine whether states and federal agencies are eligible to provide GHG offsets.
- Develop the science to quantify GHG emissions from freshwater tidal wetlands.
- Develop geomorphic predictions of coastal wetland response to sea level rise.
- Explore options for setting the boundary for wetlands offsets projects. For example, in this paper we consider drawing the boundary to include be whole estuary. However, is this appropriate if other restoration activities are being introduced within the estuary?

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