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memorandum

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subject Addendum to the Tampa Bay Blue Carbon Assessment, Summary of Findings Report

This memorandum elaborates on the technical details that went into the greenhouse gas (GHG) analysis described in the June 2016 Tampa Bay Blue Carbon Assessment (TBBCA), Summary of Findings Report. Specifically, this memo summarizes the analysis that went into the results presented in Table 14 of the final report.

1. Introduction and Summary of TBBCA Results

In the TBBCA, a GHG accounting framework was developed to quantify future changes in GHG fluxes due to sea-level rise and different coastal management strategies. Changes in CO_2 and methane (CH_4) fluxes[1] were estimated over time as habitats are projected to evolve as a result of sea-level rise. The framework used locally and/or regionally appropriate values or estimates of aboveground biomass ("biomass"), soil carbon sequestration rates, and methane emission rates for each habitat type to estimate GHG fluxes based on land use changes. The values for biomass, soil carbon sequestration, and methane emissions were derived from both literature values and field data from Tampa Bay (see following section; Tomasko et al. 2015, Moyer et al. 2016, Gonneea 2016).

The framework was used to evaluate changes in GHG fluxes for historic and future habitat areas, as well as for restoration projects implemented in Tampa Bay in the last 10 years. Historic and recent habitat estimates were based on data from TBEP and Southwest Florida Water Management District (SWFWMD) Land Use and Land Cover datasets, and from the reporting of restoration projects through the Government Performance and Results Act (GPRA). Future habitat areas were projected using the Habitat Evolution Model[2].

Primary goals of the place-based National Estuary Programs (NEPs) located throughout the U.S. are to restore and protect our estuaries and coastal habitats. Both sustaining existing habitats and creating or restoring future habitats are critical to healthy estuaries. Thus, understanding ecosystem services such as carbon storage associated with existing habitats and underlying soils (and what could be lost if these habitats are not sustained)

1 A GHG flux is the combination of emissions and removals of GHGs.
2 To improve predictions of habitat responses to sea-level rise, ESA developed a geographic information system (GIS)-based habitat evolution model specific to Tampa Bay as part of the overall study (Sheehan et al. 2016).

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as well as estimated future carbon sequestration and GHG services provided are critical. The TBBCA report found that based on the HEM results, existing Tampa Bay coastal habitat soil stocks contain approximately 71M tonnes CO_2 equivalent. Modeled future scenarios (taking into account various sea level rise scenarios and how acreage of habitat types would change) estimate an additional net of 2M tonnes GHG sequestered. Together, existing stocks plus modeled future habitat extents provide between 73M and 74M tonnes of CO_2 equivalent stored by 2100, the equivalent CO_2 emissions of approximately 15.5 million fossil-fueled vehicles for one year (EPA, 2016).

The HEM runs give some insight into potential management strategies that maintain carbon sequestration. Table 14 of the final report is presented below as part of Table 2. Combinations of two accretion rates (1.6-3.75 or 3.0-5.0 mm/yr, based upon habitat) and two rates of sea level rise (60 or 130 cm from 1992-2100) were examined with the model. Runs showed increased sedimentation resulted in more wetland habitats and more carbon sequestration, especially with higher rates of sea-level rise. Management strategies that focus on allowing more sediment from the watershed (e.g. preventing new impoundments) to reach the wetlands or supplementing wetland sediment losses in the future would help sustain the habitats and continue carbon sequestration for longer. Additionally, results showed that allowing wetlands to migrate into "soft" development (e.g., agricultural areas near the coast) would buffer potential habitat losses and increase carbon sequestration. Coastal managers can use the HEM results to prioritize areas for restoration. Even greater benefits could be gained by identifying "harder" developed areas that would be highly susceptible to future inundation, and target these areas for restoration activities as well. Further, reduced future sea-level rise will allow habitats to be preserved longer and sequester more carbon. Strategies that reduce emissions to limit climate change will have a positive effect on Tampa Bay habitats and their ability to sequester carbon in the future.

2. Previous GHG Emissions Calculations

The calculations that were used to reach the results in Table 2 are presented in this section by column. Most of the information provided below is presented in the tables and appendices to the TBBCA. For example, Table 7 of the report provides all of the sequestration and emissions factors used in the calculations (Table 1), Appendix B presents the equations that were used, and Appendix I presents the habitat acreages resulting from the HEM.

2.1 Loss in Biomass by 2100 (2100-2007)

This column of the table represents the change of the carbon stock stored in the vegetation within all of the habitats. As sea level rises, habitats convert to lower elevation habitats (e.g. high salt marsh evolves to mangrove habitat) and some habitats drown out. When this happens, some of the carbon stored in the biomass is incorporated into the soils, but much of it is released to the atmosphere.

The loss of biomass was calculated in three steps:

1. Biomass was calculated for each habitat category (e.g. upland forest, freshwater marsh, subtidal, or seagrass) and at each time step (i.e. 2007 and 2100).

   To calculate biomass for each habitat category, Equation 1 from TBBCA Appendix B was used:

$$ST_A = CF * AB_A * A * \frac{MW_{CO_2}}{MW_C}$$

TABLE 1 (TABLE 7 IN TBBCA)
ABOVEGROUND BIOMASS, REDUCTIONS FACTORS, AND EMISSIONS FACTORS

		Biomass Stock		Carbon Conversion		Existing Soil Carbon Sequestered		Soil Carbon Sequestration		Methane Emissions	
Habitat		**Biomass Stock (tonnes DM/ha)**	**Reference/Assumptions**	**% Carbon in Dry Matter**	**Reference/Assumptions**	**Soil Carbon (tonnes C/ha)**	**Reference/Assumptions**	**C Removal Rate (tonnes C/ha/yr.)**	**Reference/Assumptions**	**CH4 Emission Rate kg CH4 /ha/yr.**	**Reference/Assumptions**
	Cropland and Pastureland	2.6	IPCC 2006 V4 Chapter 5 -Table 5.9 (for tropical, moist)	0.45	IPCC 2014 Chapter 4 - Table 4.2	54.5	Mulkey et al. 2008 (Table 12)	0.09	Kroodsma and Field 2006 value for non-rice annual cropland	0	Assumed
Agriculture	Tree Crops	2.6	IPCC 2006 V4 Chapter 5 -Table 5.9 (for tropical, moist)	0.45	IPCC 2014 Chapter 4 - Table 4.3	54.5	Mulkey et al. 2008 (Table 12)	0.26	Kroodsma and Field 2006 value for orchard	0	Assumed
	Vineyards	2.6	IPCC 2006 V4 Chapter 5 -Table 5.9 (for tropical, moist)	0.45	IPCC 2014 Chapter 4 - Table 4.4	54.5	Mulkey et al. 2008 (Table 12)	0.24	Kroodsma and Field 2006 value for vineyards	0	Assumed
Developed	Low Intensity	0.8	Assume half the stock of grassland	0.45	IPCC 2014 Chapter 4 - Table 4.5	27.25	Assume half the stock of grassland	0.045	Assume half the sequestration of grassland	0	Assumed
	Mid/High Intensity	0	Assumed	0.45	IPCC 2014 Chapter 4 - Table 4.6	0	Assumed	0	Assumed	0	Assumed
	Grassland/Herbaceous / Open Land	6.2	IPCC 2006 V4 Chapter 6 – p. 6.29 & Table 6.4 (for tropical, moist)	0.45	IPCC 2014 Chapter 4 - Table 4.7	54.5	Mulkey et al. 2008 (Table 12)	0.09	Kroodsma and Field 2006 value for non-rice annual cropland	0	Assumed
Rangeland	Shrub and Brushland	41	Hobbs and Mooney 1986, biomass for 3 to 6 year-old shrubs, assume 80% cover	0.45	IPCC 2014 Chapter 4 - Table 4.8	54.5	Mulkey et al. 2008 (Table 12)	0.24	Kroodsma and Field 2006 value for vineyards, which are similarly woody	0	Assumed
	Upland Forest	220	IPCC 2006 V4 Chapter 4 - Table 4.7 (for subtropical humid)	0.45	IPCC 2014 Chapter 4 - Table 4.9	54.5	Mulkey et al. 2008 (Table 12)	0	Assumed	0	Assumed
Upland Forest	Tree Plantations	140	IPCC 2006 V4 Chapter 4 - Table 4.12 (for subtropical humid)	0.45	IPCC 2014 Chapter 4 - Table 4.10	54.5	Mulkey et al. 2008 (Table 12)	0	Assumed	0	Assumed
	Freshwater Swamp	136.6	Assumed same as mangroves	0.45	IPCC 2014 Chapter 4 - Table 4.11	54.5	Mulkey et al. 2008 (Table 12)	1.50	Assumed same as mangroves	193.7	
	Mangrove	136.6 ± 14.8	Moyer et al. 2016 (includes DOM)	0.44	Ew et al. 2006, Bouillon et al. 2008 as cited in Moyer et al. 2016	144.9 ± 49.5	Moyer et al. 2016	1.50 ± 0.59	Gonneea 2016 (1950-present)	14.95	Average of Bartlett et al. 1989, and Harriss et al. 1988
	Salt Marsh	26.2 ± 19.6	Moyer et al. 2016	0.45	Howard et al. 2014 as cited in Moyer et al. 2016	60.8 ± 70	Moyer et al. 2016	1.6 ± 69.9	Moyer et al. 2016 (restoration sites only)	0	Assumed
Wetlands	Salt Barren	5.1 ± 2.7	Moyer et al. 2016	0.45	Howard et al. 2014 as cited in Moyer et al. 2016	18.6 ± 3.7	Moyer et al. 2016	0.32	Assume 20% of salt marsh	0	Assumed
	Freshwater Marsh	26.2	Assumed same as salt marsh	0.45	IPCC 2014 Chapter 4 - Table 4.11	54.5	Mulkey et al. 2008 (Table 12)	1.6	Assumed same as salt marsh	193.7	IPCC 2013 Table 4.14
	Brackish (*Juncus*) Marsh	26.2	Assumed same as salt marsh	0.45	Howard et al. 2014 as cited in Moyer et al. 2016	54.5	Mulkey et al. 2008 (Table 12)	0.71 ± 0.28	Gonneea 2016 (1950-present)	775	Average of Whiting and Chanton 2001
	Open Freshwater	0	Assumed	0.45	IPCC 2014 Chapter 4 - Table 4.10	0	Assumed	0	Assumed	193.7	IPCC 2013 Table 4.14
Beach	Dune	6.2	Assumed same as grassland	0.45	IPCC 2014 Chapter 4 - Table 4.10	0	Assumed	0	Assumed	0	Assumed
	Subtidal	0	Assumed	0.45	IPCC 2014 Chapter 4 - Table 4.11	0	Assumed	0	Assumed	0	Assumed
Subtidal	Seagrass	6.18	Average of Zieman and Wetzel 1980	0.35	Fourqurean et al. 2012	108	IPCC 2014 Chap 4 - Table 4.11	0.64 or 2.19	See Section 3.3.2	0	Assumed

DM = Dry Matter. This is converted to Carbon Stock (in tonnes C/ha) by multiplying by the assumed % Carbon in the next column.

Where:

Variable	Represents	Unit	Value
ST_A	Aboveground carbon stock	tonnes CO_2	Calculated
CF	Carbon fraction of dry matter	n/a	Column 5 in Table 1
AB_A	Aboveground biomass, per area	tonnes dry matter/ha	Column 3 in Table 1
A	Habitat area	ha	Last 5 columns of TBBCA Appendix I
MW_{CO2}	Molecular weight of carbon dioxide	g/mol	44
MW_C	Molecular weight of carbon	g/mol	12

2. Total biomass for each time step was calculated by summing all of the habitat categories.

3. The loss of biomass was calculated between 2100 and 2007 by subtracting the initial biomass from the final biomass.

These steps were repeated for each run to provide the results shown in the second column of Table 1.

2.2 Change in Soil Carbon Stock by 2100 (2100-2007)

This column of the table represents the increase in soil carbon between 2007 and 2100. As vegetation dies, some of the carbon accumulates in the soil, especially in wetlands. Additionally, vegetation has roots, which contribute to belowground biomass in varying degrees (grasses have low belowground biomass, while mangroves have high belowground biomass). This carbon stock changes over time based on the habitat type.

The change in soil carbon was calculated in four steps:

1. The amount of soil carbon accumulated between time steps was calculated with Equation 2b in TBBCA Appendix B:

$$ST_{B,t} = ST_{B,t-1} + \frac{A_{t-1} + A_t}{2} * SS * (t - (t-1)) * \frac{MW_{CO_2}}{MW_C}$$

Where:

Variable	Represents	Unit	Value
$ST_{B,t}$	Belowground/soil carbon stock @ time = t	tonnes CO_2	Calculated
$ST_{B,t-1}$	Belowground/soil carbon stock @ the time step before t (t = t-1)	tonnes CO_2	0 for 2007, calculated for next time steps
A_t	Habitat area @ time = t	ha	Appropriate column for time = t from the last 5 columns of TBBCA Appendix I
A_{t-1}	Habitat area @ the time step before t	ha	Appropriate column for time = t from the last 5 columns of TBBCA Appendix I
SS	Soil carbon sequestration rate, per area	tonnes C/ha/yr	Column 9 in Table 1
t	Time	yr	2007, 2025, 2050, 2075, or 2100

MW_{CO2}	Molecular weight of carbon dioxide	g/mol	44
MW_C	Molecular weight of carbon	g/mol	12

2. Total biomass for each time step was calculated by summing all of the habitat categories.

3. This analysis assumed that 60% of the soil carbon is released back to the atmosphere through erosion when habitats convert to subtidal as a conservative estimate. Since the HEM did not give results showing which habitats converted to which other habitats (just total acreage of each habitat type at each time step), it was assumed that an increase in seagrass meant a conversion of some other habitat to subtidal. So if there was an increase in seagrass habitat from the previous time step, erosion was included. Also, because the habitat type that is converted to seagrass was unknown and the amount of time that habitat was accumulating sediment was unknown, it was assumed to be mangrove habitat for one year to be conservative on the carbon loss (since mangroves store large amounts of carbon). The equation used was:

$$ST_{emitted} = E * A_{restored\ to\ seagrass} * SS_{mangroves} * 1\ year * \frac{MW_{CO_2}}{MW_C}$$

Where:

Variable	Represents	Unit	Value
$ST_{emitted}$	Belowground/soil carbon stock released to atmosphere	tonnes CO_2	Calculated
E	Percent of carbon released to atmosphere due to erosion	n/a	0.6
$A_{restored\ to\ seagrass}$	Habitat area of seagrass restored from previous time step	ha	Last 5 columns of TBBCA Appendix I for seagrass row
$SS_{mangroves}$	Soil carbon sequestration rate, per area for mangroves	tonnes C/ha/yr	1.50 (Column 9 in Table 1)
MW_{CO2}	Molecular weight of carbon dioxide	g/mol	44
MW_C	Molecular weight of carbon	g/mol	12

4. The change in soil carbon was calculated between 2100 and 2007 by subtracting the initial soil carbon (2007) from the final soil carbon (2100) and adding in the results from Step 3 to account for the loss of soil carbon due to erosion.

These steps were repeated for each run to provide the results shown in the third column of Table 1.

2.3 Cumulative Carbon Sequestered by 2100

The cumulative carbon sequestered by 2100 includes the existing soil stock in 2007, the soil stock accumulated between 2007 and 2100, and the biomass carbon stock. This was calculated in three steps:

1. The existing soil carbon stock in 2007 was calculated for each habitat type with a version of Equation 2a in TBBCA Appendix B:

$$ST_B = SS_0 * A * \frac{MW_{CO_2}}{MW_C}$$

Where:

Variable	Represents	Unit	Value
ST_B	Belowground/soil carbon stock	tonnes CO_2	Calculated
SS_0	Soil carbon already sequestered @ t = 0, per area	tonnes C/ha	Column 7 in Table 1
A	Habitat area	ha	Last 5 columns of TBBCA Appendix I
MW_{CO2}	Molecular weight of carbon dioxide	g/mol	44
MW_C	Molecular weight of carbon	g/mol	12

2. The soil carbon stock for each habitat type was then added together.

3. The existing soil stock in 2007 was added to the soil stock accumulated between 2007 and 2100 (Section 2.2 and third column in Table 1) and the biomass carbon stock in 2100 (Section 2.1).

These steps were repeated for each run to provide the results shown in the fourth column of Table 1.

2.4 Methane Emissions between 2007 and 2100

This column represents the methane emissions that are produced when microorganisms in wet, poorly aerated soils, such as in freshwater marshes, decompose organic matter. High salinities reduce this methane production, so salt marsh is assumed to have negligible emissions (Poffenbarger et al. 2011).

The methane emissions were calculated using three steps:

1. A version of Equation 5 in TBBCA Appendix B was used to calculate the emissions for each habitat type between each time step (e.g., between 2007 and 2025):

$$E_{CH4} = \frac{A_{t-1} + A_t}{2} * ER * (t - (t-1)) * \frac{tonnes\ CH4}{kg\ CH4} * \ GWP$$

Where:

Variable	Represents	Unit	Value
E_{CH4}	Methane emissions	tonnes CO_2	Calculated
A_t	Habitat area @ time = t	ha	Appropriate column for time = t from the last 5 columns of TBBCA Appendix I
A_{t-1}	Habitat area @ the time step before t	ha	Appropriate column for time = t from the last 5 columns of TBBCA Appendix I
ER	Methane emission rate	kg CH_4/ha/yr	Column 11 in Table 1
t	Time	yr	2007, 2025, 2050, 2075, or 2100

tonnes CH4 / kg CH4	Unit conversion	tonnes/kg	0.001
GWP	Global Warming Potential	tonnes CO_2/ tonnes CH_4	28

2. The cumulative methane emissions were calculated by summing the emissions for all of the habitat categories.

3. The methane emissions were calculated between 2100 and 2007 by adding the emissions for each time step (e.g. 2007 to 2025 plus 2025 to 2050).

These steps were repeated for each run to provide the results shown in the fifth column of Table 1.

2.5 Net GHG Sequestered by 2100

The net GHG sequestered by 2100 includes the existing 2007 soil stock, the soil stock accumulated between 2007 and 2100, the biomass carbon stock in 2100, and the methane emissions between 2007 and 2100. This was calculated by adding the cumulative carbon sequestered (Section 2.3 and column D of Table 2) to the methane emissions (Section 2.4 and column E of Table 1).

3 Updated Results Table

An updated results table is presented in Table 2.

Basic Calculations for Table 2:

- Columns A, B, C, and E calculated as explained
- Column D = Column A + Column B + Column C
- Column F = Column D + Column E
- Column G = Column D + Column E - Column B = Column F – Column B

TABLE 2
GHG EMISSIONS BY HEM RUN - REVISED

Scenario (Run)	A. Loss in Biomass by 2100 (2100-2007) (tonnes CO_2 equiv.)	B. Existing Soil Carbon Stock in 2007 (tonnes CO_2 equiv.)	C. Accumulation of Carbon in Soil Stock by 2100 (2100-2007) (tonnes CO_2 equiv.)	D. Cumulative Carbon Sequestered by 2100 (tonnes CO_2 equiv.)	E. Methane Emissions from 2007 to 2100 (tonnes CO_2 equiv.)	F. Cumulative Net GHG Sequestered by 2100 (tonnes CO_2 equiv.)	G. Net GHG Sequestered between 2007 and 2100 (tonnes CO_2 equiv.)
Run 1-low slr, low accretion	-161,042	71,936,887	30,682,234	102,458,079	-28,302,683	74,155,397	2,218,509
Run 2-low slr, high accretion	-157,558	71,936,887	30,719,337	102,498,667	-28,391,168	74,107,499	2,170,611
Run 3-high slr, low accretion	-1,535,591	71,936,887	29,997,627	100,398,923	-26,983,877	73,415,046	1,478,159
Run 4-high slr, high accretion	-352,169	71,936,887	30,697,049	102,281,768	-27,964,916	74,316,851	2,379,964
Run 5-high slr, low accretion, marshes allowed to migrate	-1,373,153	71,936,887	30,019,445	100,583,179	-27,023,918	73,559,261	1,622,374

SLR = sea-level rise
Positive values indicate sequestration while negative numbers indicate emissions.

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