



Waquoit Bay National Estuarine Research Reserve Greenhouse Gas Calculator for Land-holding Entities

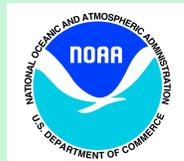
Instruction Manual



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2012



Acknowledgements

These instructions are meant to be used in conjunction with the *Greenhouse Gas calculator for Land-holding Entities*: <http://www.waquoitbayreserve.org/index.aspx>

Attribution: For publication of analyses resulting from use of this calculator, we request that the following attribution be included: Xie, Y. and A. Leschen, Waquoit Bay National Estuarine Research Reserve. 2012. Greenhouse Gas calculator for land-holding entities. www.waquoitbayreserve.org.

Background: In 2012 the Waquoit Bay National Estuarine Research Reserve undertook an analysis of the Reserve's Greenhouse Gas "footprint." Results were interesting enough that we felt other land-holding entities might want to conduct a similar analysis. We therefore developed this blank "calculator" and instructions for other Reserve, parks, etc. to use. Please let us know if you find it useful, or have additions or edits to suggest. Below is the Executive Summary of the Waquoit Bay NERR analysis.

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Executive Summary

Climate Change has become one of the most pressing issues facing coastal communities. In response, the National Estuarine Research Reserve (NERR) System is implementing the Climate Change Initiative designed to help NERRs and their communities understand, mitigate, and adapt to changing conditions. In addition, the Governor of Massachusetts issued an Executive Order 484, “Leading By Example—Clean Energy And Efficient Buildings,” which in 2002 charged Massachusetts state agencies with reducing greenhouse gas emissions from building use by 25% by 2012. In response to these directives, Waquoit Bay NERR on Cape Cod, MA undertook a Greenhouse Gas (GHG) Analysis of its facilities and operations, including both emissions due to the burning of fossil fuel, and sequestration by land in its possession. The goal of the analysis was several fold: to quantify the savings in energy from the numerous efficiency measures implemented at the Reserve, to understand the contribution of each activity to the Reserve’s total “carbon footprint” so as to enable strategic targeting of reductions, to understand whether carbon stored by managed lands offset carbon produced by activities, and to produce blank a greenhouse gas calculator that could be transferred to other Reserves and parks so they can produce the same analysis.

The Reserve has instituted a number of energy saving measures in the last 8 years, and effects are observable in the data. Reductions in GHG production from building use, totaling 27%*, were realized on three levels: technical (and out of the Reserve’s control - i.e. the power company switched to a more efficient fuel for electricity generation); institutional - ie WBNERR installed more efficient lighting and heating systems, insulation, etc.; and individual - i.e. staff turned off computers and fans when not in use. When vehicle use and staff commutes were factored in, the reduction in emissions was 20%. Surprisingly, staff commutes were highest or second highest contributor of in GHG production over several years, above building heating and/or electricity usage. Sequestration rates of habitats owned and managed by the Reserve were 100 times production rates, emphasizing the importance of land conservation and restoration as climate change mitigation tools for the NERRS, parks, land trusts, municipalities, and private citizens. Of the ecosystems found at Waquoit Bay NERR, forests and salt marshes are by far the most effective at storing carbon. This information can help the Reserve and others prioritize land acquisition and restoration projects, prioritize funding and draw attention to efforts to mitigate contributions to climate change. In addition to this report, a blank GHG calculator with coefficients, extensive references, and an instruction manual are available for downloading at www.waquoitbayreserve.org.

*(exceeding the target of 25% Executive Order 484)

Instructions for Using the GHG Calculator

The accompanying calculator is designed so that, in most cases, easily obtainable data specific to an organization can be entered in the spreadsheet, and the calculator will do the rest. Since we could not cover all types of vehicles and habitat, references available on the web are provided which should make the necessary information accessible to anyone with an internet connection. Enter the data in the tan areas on the individual tabs of the spreadsheet as instructed below, starting with *Building Fuel Usage*. Using the coefficients provided in the light blue areas, the calculator will compute kg CO₂e (scroll to the right to see these values). These coefficients can be updated or targeted to an organization's specific circumstances if necessary using references found in the Appendix. Based on data entered in the individual tabs, values in the *Result Overview* and *Brief Analysis* tabs will automatically be calculated.

While the calculator does much of the work, it can still be time-consuming to collect all the energy bills, vehicle records, etc. At Waquoit Bay Reserve we enlisted the help of interns and volunteers for this task. Others may want to consider this approach so that the analysis gets the focused attention it requires.

1. Building Fuel Usage (natural gas and #2 heating oil)

To calculate GHG emission attributed to building fuel usage:

- a) Obtain natural gas and heating oil records from provider for annual usage of natural gas and/or heating oil for each building. (Heating oil in the US is #2 oil – coefficients in the attached calculator are for this fuel.)
- b) Convert the units of the data obtained in step (a) into the unit of *Btu*. Converters are available, for example, on [EIA](http://www.eia.gov/kids/energy.cfm?page=about_energy_conversion_calculator-basics) website, http://www.eia.gov/kids/energy.cfm?page=about_energy_conversion_calculator-basics
- c) Enter the converted data into the appropriate tan area in the *Building Fuel Usage* tab. Make sure the data for each building are included. If only one type of fuel is used, simply leave the other column blank. The calculator will automatically present the GHG emissions of each building, as well as the total amount of fuel emissions from all buildings.

2. Building Electricity Usage

To calculate GHG emissions attributed to building electricity usage:

- a) Obtain annual electricity usage for each building from provider or company records.
- b) Identify the sub-region that the organization belongs to according to The Emissions & Generation Resource Integrated Database (eGRID)¹ because the GHG emission factor differs by sub-region.
- c) Check the EPA's website and obtain updated GHG emission factors of electricity generation. (This step will be necessary to calculate the GHG emission of electricity in the years after 2011.) For the details of this step, see *Building Electricity Usage* in Appendix.
- d) Enter the converted data into the tan area in the *Building Electricity* tab. Make sure the data of each building are included. The calculator will automatically compute the GHG emissions of each building, as well as a total amount from all buildings.

¹ http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2012_eGRID_subregions.jpg

3. Gasoline Usage

3.1 GHG Emission from Corporate Vehicles

To calculate GHG emissions attributed to corporate vehicles:

- a) Determine the miles driven annually for each vehicle from vehicle logs, maintenance records, etc.
- b) Obtain miles per gallon gasoline (MPG) for each vehicle through relevant documents or websites.
- c) Determine the CH₄ and N₂O emission factors for each vehicle by:
 - Obtaining the year of the vehicle,
 - Determining the control technology with Table A-100 in Annex 3 in 2012 U.S. Greenhouse Gas Inventory Report²,
 - Referring to Table A-103 in Annex 3 to find out CH₄ and N₂O emission factors (in the unit of g CH₄ (or N₂O) /mile) for the vehicle with this control technology.
- d) Enter relevant data into appropriate tan input area in the *Gasoline Usage* tab. Make sure the data for each vehicle are included. The calculator will automatically present the GHG emissions of each vehicle.

3.2 GHG Emission Related to Other Gasoline Usage (such as boat engines or lawnmowers)

To calculate GHG emissions attributed to other sources:

- a) If usage records are available, enter these data directly under the column of *Other Gasoline Usage*. Then the calculator will show the GHG emission under the column of *Other Sources*.
- b) If relevant records are not available:
 - Obtain total annual gasoline usage through relevant invoices (most convenient if gas is obtained from a state pump or other centralized source)
 - Enter these data under the column of *Total Gasoline Usage*. Then the calculator will automatically estimate the amount of gasoline used by other sources by subtracting gasoline usage of corporate vehicles from total gasoline usage, and show relevant GHG emissions under the column of *Other Sources*.

4. Staff Commutes

To calculate GHG emissions attributed to staff commutes:

- a) Determine the daily one-way distance of each staff member's commute through interviews.
- b) Obtain MPG of each staff member's vehicle through interviews and relevant websites.
- c) Enter these data into appropriate "Input Area" in the *Staff Commute* tab. The calculator will automatically compute the GHG emissions of each staff member's commute, as well as a total amount.

² <http://www.epa.gov/climatechange/emissions/downloads12/US-GHG-Inventory-2012-Annex-3-additional-Source-or-Sink-Categories.pdf>

5. Business Travel

To calculate GHG emissions attributed to business travel (generally consists of the following five modes of transport: private car, airplane, bus/shuttle, taxi and train):

- a) Determine the annual mileage for each of these five approaches through relevant records (typically invoices on staff travel reimbursement forms).
 - For terrestrial travel, some records may directly show the mileage; otherwise online mapping programs (Google map, MapQuest) can be used to determine distances travelled.
 - For flights, if relevant records do not show total distance travelled, some websites (such as www.expedia.com) can be referenced to determine the distance.
 - Double the distances for round trips where appropriate.
- b) Enter these data into appropriate tan input area in the *Business Travel* tab. The calculator will automatically present the GHG emissions of each transport mode, as well as a total amount.

6. Wastewater Disposal

To calculate GHG emissions attributed to wastewater disposal:

- a) Obtain annual water usage for each building from the organization's water provider – usually the town (generally, it is assumed that the amount of wastewater generated equals the amount of water supply).
- b) Identify whether wastewater is disposed of through a septic system or publicly owned wastewater treatment facility. In the attached calculator, the default method is septic system.
- c) If the organization uses a septic system, enter data obtained in step (a) into appropriate "Input Area" in the spreadsheet of *Wastewater*. The calculator will automatically give the GHG emission of each building, as well as a total amount. If wastewater is disposed of through sewers, change the coefficient in Columns F in the *Wastewater* tab to: 0.000238³.

7. Solid Waste Disposal

7.1 Unrecycled Solid Waste

To calculate GHG emission attributed to unrecycled solid waste (generally, it is assumed that the component of solid waste generated by an organization is mixed MSW, or Municipal Solid Waste):

- a) Find out the annual amount of solid waste it generates through
 - Contacting the solid waste collector, or
 - Estimation (when the collector lacks such data) — the volume of MSW each time the company comes to collect this MSW (approximation), the density of MSW (90.64kg/cubic yard⁴ for uncompacted MSW), and the number of times that the company comes to collect MSW in one year.
- b) Determine whether the organization's solid waste collector uses a landfill or combustion to dispose of MSW. In the attached calculator, the default method is combustion. If the method is landfill, change the coefficients in Column D to 0.12⁵.
- c) Enter data into appropriate "Input Area" under the column of *Unrecycled Solid Waste* in the spreadsheet of *Solid Waste*. Then the calculator will automatically present relevant GHG emissions, which can become negative if the disposal method is combustion.

³See *Wastewater Disposal* Session in *Appendix*

⁴ http://www.deq.state.ms.us/MDEQ.nsf/page/Recycling_MaterialDensityandVolumeConversion?OpenDocument

⁵ *Exhibit 8-6, Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks*, 3rd edition (2006), <http://www.epa.gov/climatechange/wycd/waste/downloads/fullreport.pdf>

7.2 Recycled Solid Waste

To calculate GHG emission attributed to recycled solid waste (generally the major materials the organization recycles are office paper and PET bottles; this calculator only considers them):

- a) Estimate the annual amount of solid waste recycled through determining the volume of paper/bottles at the time of collection, the density of paper/bottles, and the number of times in a year that they are collected.
 - In this calculator, the default density of office paper is 800kg/m³⁽⁶⁾; density of PET bottle is 1400kg/m³.⁽⁷⁾
 - Sometimes the paper/bottles are loosely placed and the air spaces are considerable in containers. To adjust for the air spaces, this calculator introduces vacancy adjustment factors: paper is 0.5; PET bottles is 0.014⁸ – they can be changed where necessary, if, for example compaction is provided.
- b) Enter data into appropriate “Input Area” under the column of *Recycled Solid Waste* in the spreadsheet of *Solid Waste*. The calculator will automatically give relevant GHG emissions, which can be negative.

8. Paper Usage

To calculate GHG emission attributed to office paper usage:

- a) Determine the annual purchased weight of office paper (including printing paper and paper pads) for each type of recycling percentage (in this calculator, the default types of recycling percentage include 100%, 30% and 0%) through relevant documents and websites.
- b) Enter data into appropriate “Input Area” in the spreadsheet of *Paper Usage*. Then the calculator will show the total amount of GHG emission from paper usage. If the organization purchases office paper with any other recycling percentage, its GHG emission factor can be found on the Environmental Paper Network website⁸.

⁶<http://en.wikipedia.org/wiki/Paper>

⁷ http://en.wikipedia.org/wiki/Polyethylene_terephthalate

⁸ A 500ml PET bottle merely weighs 10g, while 500cm³ PET weigh 700g, http://www.factsonpet.com/Articles/Facts%20on%20PET%20Flyer_June18%20PRINT.pdf

⁹<http://calculator.environmentalpaper.org/home>

9. Carbon Sequestration

If the organization possesses a large amount of land, such as forest, freshwater wetlands, and salt marshes, carbon sequestration capacity can be estimated; otherwise this session can be skipped.

To calculate GHG sequestration:

- a) Determine the areal extent (acreage) of each type of natural habitat through relevant documents, such as the organization's GIS files. If this information is not available it may be possible to obtain rough estimates through satellite maps (e.g. Google maps).
- b) Enter these data into the appropriate tan input area in the *C Sequestration* tab. The calculator will show the GHG sequestration of each type of natural habitat, as well as the total amount.
 - In this calculator, the default types of natural habitats include: beach/dune, salt marsh, freshwater wetland, pine/oak forest and residential/developed regions. If the organization possesses any other natural habitats, it needs to determine the GHG sequestration factors through reviewing relevant scientific articles.
 - In this calculator, all GHG sequestration factors match the climate around Waquoit Bay, which is located in Falmouth, MA. If the climate of the organization's location is significantly different from that in Falmouth, the organization may need to determine proper GHG sequestration factors through reviewing relevant scientific articles. The selected tables can be found in the Appendix in case original articles are not accessible.
 - Useful articles relevant to GHG sequestration factors may include (these tables are included under #9 in the Appendix for the convenience of users who do not have access to these articles through a database):
 - i. *Table 3*, CO₂ balance of boreal, temperate, and tropical forests derived from a global database. S. Luysaert et al. *Global Change Biology* (2007). [LINK](#)
 - ii. *Table 3*, Major role of marine vegetation on the oceanic carbon cycle. C. M. Duarte, J. J. Middelburg, and N. Caraco. *Biogeosciences* (2005) [LINK](#)
 - iii. *Table 5*, Comparing carbon sequestration in temperate freshwater wetland communities. Blanca Bernal and William J. Mitsch. *Global Change Biology* (2012) [LINK](#)
 - iv. *Table 3*, Carbon sequestration in temperate grassland ecosystems and the influence of management, climate and elevated CO₂. M.B. Jones and Alison Deonnelly. *Phytologist* (2004). [LINK](#)

10. Brief analysis

Under the Brief Analysis tab, the calculator provides two additional capabilities:

- Conversion of GHG emissions into units that may be more meaningful to people – tree equivalents
- Ability to calculate a “per staff” emission value.

Appendix (Derivations of Coefficients)

1. Building Fuel Usage (natural gas and #2 heating oil)

The calculator contains coefficients derived as follows:

EPA has a complete table to show CO₂ emission factors ranging from 1995 to 2010 for diverse fuel types, including natural gas, distillate fuel oil #2 and motor gasoline¹⁰. The unit of these factors is *Tg Carbon/Qbtu*. For convenience, units have been converted into *kg CO₂/Mbtu* (1Tg Carbon/Qbtu=3.667 kg CO₂/Mbtu) in the calculator.

For CH₄ and N₂O emissions from stationary combustion, EPA provides a table to show their emission factors by fuel type and sector. Generally, organizations belong to the residential end-use sector. The CH₄ emission factors for natural gas and heating oil are 5g/GJ and 10g/GJ, respectively; the N₂O emission factors for natural gas and #2 heating oil are 0.1g/GJ and 0.6g/GJ, respectively¹¹. For convenience, the units of these factors have been converted into *kg/Mbtu* (1g/GJ=0.001055kg/MBtu) in the calculator.

2. Building Electricity Usage

Greenhouse gas emission factors can be found in eGRID files. Usually EPA updates eGRID files every two or three years; as a result, the emission factors in certain years have to be substituted by those in other years as approximations. For example, one can only find the emission factors for three years (2005, 2007 and 2009) from eGRID; therefore, 2005 emission factors are used to calculate 2006 GHG emission, 2007 emission factors are used to calculate 2008 GHG emission, and 2009 emission factors are used to calculate 2010 and 2011 GHG emissions.

EPA will probably update the eGRID file in 2013, which will likely include the emission factors for the year of 2011. Therefore, if the organization needs to calculate its GHG emission from electricity usage in the years after 2011, referring to a newer version of eGRID can generate a more accurate result.

The tables showing GHG Annual Output Emission Rates in eGRID files have two columns: *annual total output emission rates* and *annual non-baseload output emission rates*. According to EPA, “annual total output emission rates for greenhouse gases (GHGs) can be used as default factors for estimating GHG emissions from electricity use when developing a carbon footprint or emission inventory.” Therefore, *annual total output emission rates* should be used when calculating GHG emission. CO₂, CH₄ and N₂O emission rates for electricity purchased in the following years are given below:

- 2005: 927.68 lbs./MWh, 86.49 lbs./GWh and 17.01 lbs./GWh, respectively¹², or **0.424 kg CO₂e/kWh**.
- 2007: 827.95 lbs./MWh, 76.98 lbs./GWh and 15.20 lbs./GWh, respectively¹³, or **0.378 kg CO₂e/kWh**.
- 2009: 728.41 lbs./MWh, 75.68 lbs./GWh and 13.86 lbs./GWh, respectively¹⁴, or **0.333 kg CO₂e/kWh**.

¹⁰ See *Annex 2, Table A-37*, 2012 U.S. Greenhouse Gas Inventory Report. <http://www.epa.gov/climatechange/emissions/downloads12/US-GHG-Inventory-2012-Annex-2-emissions-from-Fossil-Fuel-Combustion.pdf>

¹¹ See *Annex 3, Table A-83*, 2012 U.S. Greenhouse Gas Inventory Report, <http://www.epa.gov/climatechange/emissions/downloads12/US-GHG-Inventory-2012-Annex-3-additional-Source-or-Sink-Categories.pdf>

¹² eGRID2007 Version 1.1 Year 2005 GHG Annual Output Emission Rates, http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2007V1_1_year05_GHGOutputRates.pdf

¹³ eGRID2010 Version 1.1 Year 2007 GHG Annual Output Emission Rates, http://www.epa.gov/cleanenergy/documents/egridzips/eGRID2010V1_1_year07_GHGOutputRates.pdf

¹⁴ eGRID2012 Version 1.1 Year 2009 GHG Annual Output Emission Rates, http://epa.gov/cleanenergy/documents/egridzips/eGRID2012V1_0_year09_GHGOutputRates.pdf

3. Gasoline Usage

In the 2012 U.S. Greenhouse Gas Inventory Report, the EPA shows CO₂ emission factors ranging from 1995 to 2010 for motor gasoline¹⁵. Relevant unit is *Tg Carbon/Qbtu*. In addition, according to the EPA, the average heat content per gallon of gasoline is 0.125 Mbtu/gallon¹⁶. Therefore, 1Tg Carbon/Qbtu= 3.667kg CO₂/Mbtu= 0.458kg CO₂/gallon. For convenience, the original units (*Tg Carbon/Qbtu*) of all coefficients obtained from 2012 U.S. Greenhouse Gas Inventory Report have been converted into *kg CO₂/gallon* (gasoline) in the calculator.

4. Staff Commutes

The coefficients come from the columns of *CO₂ Emission Factor* in the session of *Gasoline Usage*, and Table 1 of *Optional Emissions From Commuting, Business Travel and Product Transport*¹⁷.

5. Business Travel

Since specific types of vehicles (buses, taxis) used are rarely known, national averages are used as approximations. The EPA has a series of estimations regarding national average emissions for different vehicles and modes of transportation¹⁸. Intercity Rail is chosen as the typical Rail System Type, Long Haul (longer than 700 miles) is chosen as the typical Airline Travel Distance. The EPA does not provide emission factors for taxis; however, here the default factor of taxi is regarded as the same factor of a private car. The following GHG factors are provided for convenience:

- Private cars: 0.364 kg CO₂/mile, 0.031g CH₄/mile and 0.032 g N₂O/mile, or **0.375 kg CO₂e/mile**.
- Airplanes: 0.185 kg CO₂/mile, 0.0104 g CH₄/mile and 0.0085 g N₂O/mile, or **0.188 kg CO₂e/mile**.
- Buses: 0.107 kg CO₂/mile, 0.0006 g CH₄/mile and 0.0005 g N₂O/mile, or **0.107 kg CO₂e/mile**.
- Taxis: **0.375 kg CO₂e/mile**.
- Trains: 0.185 kg CO₂/mile, 0.002g CH₄/mile and 0.001 g N₂O/mile, or **0.185 kg CO₂e/mile**.

6. Wastewater Disposal

According to the EPA¹⁹, disposing of wastewater with septic systems emits both CH₄ and N₂O. EPA estimates that about 100 gallons of wastewater per capita flow into publicly owned treatment works everyday, which accounts for 80% of US wastewater generation per capita. Therefore, wastewater generation per capita equals to 125 gallon/person/day.

For septic systems, the EPA estimates the CH₄ emission factor is 10.7g CH₄/person/day. Therefore, CH₄ emission factor per gallon wastewater equals to 8.56×10⁻³kg CH₄/gallon.

In order to estimate N₂O emission, the first step is to estimate the amount of N existing in wastewater. According to EPA, US protein consumption per capita equals 32.4kg protein/person/year = 0.0887kg protein/person/day. (This consumption occurred in 2008, but protein consumption per capita changed little in recent years, future GHG trackers may just refer to the US Census Bureau for latest data every five years.) Therefore, N consumption per capita equals 0.0887kg protein/person/day*0.16kg N/kg protein = 0.0142kg N/person/day.

¹⁵ Annex 2, Table A-37, 2012 U.S. Greenhouse Gas Inventory Report, <http://www.epa.gov/climatechange/emissions/downloads12/US-GHG-Inventory-2012-Annex-2-Emissions-from-Fossil-Fuel-Combustion.pdf>

¹⁶ <http://www.epa.gov/cleanenergy/energy-resources/refs.html>

¹⁷ http://www.epa.gov/climateleadership/documents/resources/commute_travel_product.pdf

¹⁸ Table 1-4, Optional Emissions From Commuting, Business Travel and Product Transport, http://www.epa.gov/climateleadership/documents/resources/commute_travel_product.pdf

¹⁹ 8.2 Wastewater Treatment, 2012 U.S. Greenhouse Gas Inventory Report, <http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2012-Chapter-8-Waste.pdf>

Assuming all consumed N is emitted through wastewater, therefore, N concentration in one gallon of wastewater equals $0.0142\text{kg N/person/day} / 125 \text{ gallon/person/day} = 0.000114\text{kg N/gallon}$. Since septic systems do not treat N, all sewage is emitted into the aquatic environment via groundwater without removing N. The EPA suggests a default emission rate of $0.005\text{kg N}_2\text{O-N/kg sewage-N}$ produced. Therefore, N_2O emission factor per gallon wastewater equals to $5.7 \times 10^{-7}\text{kg N}_2\text{O/gallon}$.

After converting CH_4 emission factor and N_2O emission factor into CO_2e unit, the GHG emission factor for wastewater disposal with septic system is $8.56 \times 10^{-5} \times 21 + 5.7 \times 10^{-7} \times 310 = \mathbf{0.002\text{kg CO}_2\text{e/gallon}}$.

If wastewater is disposed of through sewers, national average levels of CH_4 and N_2O emission factors of wastewater disposal are used as approximations, because such factors vary depending on the methods that publicly owned treatment works use to dispose of wastewater. For example, Aerobic Systems, Anaerobic Systems, Anaerobic Digesters have different factors relevant to CH_4 emission factor, and whether the centralized wastewater treatment plant conducts nitrification/denitrification determines the N_2O emission factor. Lacking relevant information, national average levels are used as substitution.

According to the EPA, publicly owned treatment works emit $2.7 \text{ Tg CO}_2\text{e}^{20}$ annually for $100 \text{ gallon/person/day} \times 311 \text{ million people} \times 365 \text{ days/year}$, which means $2.38 \times 10^{-4}\text{kg CH}_4/\text{gallon}$. Unfortunately, in terms of N_2O , EPA does not provide annual emissions from septic systems. However, theoretically, centralized wastewater treatment plants using nitrification/denitrification emit less N_2O during operation because this process removes N from sewage through transforming it into N_2 . Therefore, using the coefficient already existing in this calculator will generate a conservative estimate of N_2O emission caused by wastewater disposal, and this coefficient is used to calculate N_2O emission, whichever the disposal method is used.

Therefore, if disposing of wastewater with publicly owned treatment works, the GHG emission factor is $2.38 \times 10^{-4} \times 21 + 5.7 \times 10^{-7} \times 310 = \mathbf{0.005\text{kg CO}_2\text{e/gallon}}$.

7. Solid Waste Disposal

7.1 Unrecycled Solid Waste

According to the EPA²¹, the GHG emission factor of the disposal of MSW with the method of combustion is $-0.03 \text{ MTCE}^{22}/\text{Ton}$, or $\mathbf{-0.03\text{kg CO}_2\text{e/kg MSW}}$.

7.2 Recycled Solid Waste

According to the EPA²³, the GHG emission factor for recycling (office) paper is $-0.78 \text{ MTCE}/\text{Ton}$, or $\mathbf{-0.78 \text{ kg CO}_2\text{e/kg paper}}$; the factor for recycling PET (bottle) is $-0.42 \text{ MTCE}/\text{Ton}$, or $\mathbf{-0.42 \text{ kg CO}_2\text{e/kg PET}}$.

8. Paper Usage

The GHG emission factor of paper varies, depending on the recycling percentage. The recycling percentages of the office paper in this calculator include 100%, 30% and 0%. Their GHG emission factors are $\mathbf{1.70, 2.62}$ and $\mathbf{3.01 \text{ lbs. CO}_2\text{e/lbs. paper}}$, respectively²⁴.

²⁰ Table 8-9, 8.2 Wastewater Treatment, 2012 U.S. Greenhouse Gas Inventory Report, <http://www.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2012-Chapter-8-Waste.pdf>

²¹ Exhibit 8-5, Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks, 3rd edition (2006), <http://www.epa.gov/climatechange/wycd/waste/downloads/fullreport.pdf>

²² Metric Tons Carbon Equivalent

²³ Exhibit 8-3, Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks, 3rd edition (2006), <http://www.epa.gov/climatechange/wycd/waste/downloads/fullreport.pdf>

²⁴ Environmental Paper Network, <http://calculator.environmentalpaper.org/home>

9. Carbon Sequestration

Beach/dunes lack notable capacity to sequester CO₂; as a result, it is assumed that **no CO₂ is sequestered in this region.** (Grasses may grow occasionally somewhere in this region. However, the proportion is quite small. Besides, the capacity of grasses to sequester CO₂ is weak compared to other ecosystems discussed below. Therefore, their sequestrations are ignored.)

Note: Sequestration capacities may not be available for your exact region or circumstance. In these cases, global average levels of carbon sequestration capacities can be used as approximations, as they were here.

Also, carbon sequestration capacity discussed below refers to Net Ecosystem Production (NEP) discussed in relevant literature. According to Johnsen et al. (2001), “carbon sequestered by forests is the difference between carbon gained by photosynthesis and carbon released by respiration of all the components of the ecosystem; this overall carbon gain or loss is called net ecosystem productivity (NEP).”¹⁶

However, other researchers suggest that carbon sequestration capacity and NEP are different due to non-respiratory CO₂ losses and non-CO₂ losses. Luyssaert et al. (2007) provide an equation showing the connection between net ecosystem carbon balance (NECB) and NEP:

“NECB= NEP- non-respiratory CO₂ losses – non-CO₂ losses+ import from bordering ecosystems”

In this equation, non-respiratory CO₂ losses refer to “all or part of the carbon that has been built up over the years by the accumulation of the annual NEP can leave the ecosystem and eventually return to the atmosphere as non-respiratory CO₂ fluxes by forest fires, harvests and/or erosion.”¹⁷

Similarly, Randerson et al. (2002) argue that “a robust definition of NEP should be based on a full ecosystem mass balance and include non-CO₂ and non-respiratory components of the C flux and clearly defined temporal and spatial boundaries. Defined in this way, NEP provides an unambiguous measure of change in C storage...”¹⁸

However, because of the difficulties in determining non-respiratory CO₂ losses and non-CO₂ losses, usually researchers use NEP as the approximation of carbon sequestration capacity. In addition, for the forests in the Waquoit Bay Reserve, the only thing we know about the non-respiratory CO₂ losses and non-CO₂ losses is that controlled burns will occasional occur in forests here to avoid catastrophic fires. Without further information, NEP is the only reasonable value to estimate carbon sequestration of these forests.

Current research going on at Waquoit Bay Reserve will further refine estimates of GHG sequestration in **salt marshes** for this region, and develop modeled values for other regions. Those data should be available by 2014. In the meantime values from Duarte et al. (2005) are used: 1585g Carbon/m²/year²⁵, or **6414.3kg Carbon/acre/year**. Bernal and Mitsch (2012) reviewed and compared carbon sequestration capacities for **freshwater wetlands** located in temperate regions. This article does not discuss freshwater wetlands in Massachusetts. However, the freshwater wetlands in Waquoit Bay are most similar to Buttonbush swamp (202g Carbon/m²/year) and Cattail marsh (210g Carbon/m²/year)²⁶ in Ohio among all wetlands listed in this article. Therefore, an averaged number (206g Carbon/m²/year, or **833.7kg Carbon/acre/year**) from these two factors is used in calculation.

²⁵ Table 3, Major role of marine vegetation on the oceanic carbon cycle. C. M. Duarte, J. J. Middelburg, and N. Caraco. Biogeosciences, 2, 1–8, 2005

²⁶ Table 5, Comparing carbon sequestration in temperate freshwater wetland communities. Blanca Bernal and William J. Mitsch. Global Change Biology (2012) 18, 1636–1647

Luyssaert et al. (2007) provide a series of carbon sequestration capacities for different types of **forests**, ranging from boreal humid evergreen to tropical humid evergreen. Deciduous trees dominate in Waquoit Bay’s forest (temperate humid). Therefore, the factor interval $311 \pm 38\text{g Carbon/m}^2/\text{year}$ ²⁷ is used in estimating the sequestered amount of mixed pine/oak forest in Waquoit Bay. In addition, considering the existence of evergreen trees (about 20-30% in Waquoit Bay), the largest possible number in this interval, or $349\text{ g Carbon/m}^2/\text{year}$ (**1412.4 kg Carbon/acre/year**), is chosen as the factor.

Finally, for **residential/developed regions**, the carbon sequestration capacity of grassland (lawn) is used. According to Jones and Donnelly (2004), in cool temperate regions, the carbon sequestration capacity of grassland is $0.27\text{t Carbon/hectare/year}$ ²⁸, or **109.3kg Carbon/acre/year**.

The following tables, from which these figures are obtained, are included for users with habitat types other than those used as defaults in the calculator. The values can be substituted on the calculator.

Habitat	NEP, g C m ⁻² y ⁻¹	plus/minus
Mangroves ^a	221	
Salt marsh ^a	1585	
Forests ^b		
Boreal humid evergreen	131	79
Boreal semi-arid evergreen	40	30
Boreal semi-arid deciduous	178	
Temperate humid evergreen	398	42
Temperate humid deciduous	311	38
Temperate semi-arid evergreen	133	37
Mediterranean warm evergreen	380	73
Tropical humid evergreen	403	102

^a Duarte, C. M. J. J. Middleburg, and N. Caraco. 2005. Major role of marine vegetation on the oceanic carbon cycle. *Biogeosciences* 2: 1-8.

^b S . Luyssaert et al. 2007. *Global Change Biology* 13, 2509–2537.

²⁷ Table 3, CO₂ balance of boreal, temperate, and tropical forests derived from a global database. S. Luyssaert et al. *Global Change Biology* (2007) 13, 2509-2537

²⁸ Table 3, Carbon sequestration in temperate grassland ecosystems and the influence of management, climate and elevated CO₂. M.B. Jones and Alison Donnelly. *New Phytologist*, 2004, Vol 164 Issue 3

Table 5: Comparison of carbon sequestration rates of freshwater wetlands located in temperate regions reported in the literature. Carbon sequestration rates estimated in this study are included in each appropriate wetland type. All studies except those with an asterisk (*) used ^{13}C s and/or ^{210}Pb to determine carbon sequestration rates

Wetland site	Carbon sequestration rate (g m ⁻² yr ⁻¹)	References
<i>Isolated, depressional, and/or forested wetlands</i>		
Dismal swamp, Virginia	105	Craft <i>et al.</i> (2008)
Cypress swamp, Florida	122	Craft <i>et al.</i> (2008)
Pocosin, North Carolina	127	Bridgham & Richardson (1993)
Okefernokee peat swamp, Georgia	25-82	Schlesinger (1978)*, Craft <i>et al.</i> (2008)
Peat meadow, Netherlands	280	Hendriks <i>et al.</i> (2007)*
Danube floodplain, Austria	180	Zehetner <i>et al.</i> (2009)
Cypress-gum floodplain, Georgia	107	Craft & Casey (2000)
Upper St. Johns floodplain, Florida	117-244	Brenner <i>et al.</i> (2001)
Pin oak swamp, Ohio	473	This study
Buttonbush swamp, Ohio	202	This study
Cattail marsh, Ohio	210	This study
<i>Riverine and/or flow-through wetlands</i>		
Cattail marsh, nutrient enriched, Florida	264	Reddy <i>et al.</i> (1993)
Cattail-sawgrass marsh, Florida	104-167	Reddy <i>et al.</i> (1993), Craft & Richardson (1993)
Sawgrass marsh, Florida	124	Reddy <i>et al.</i> (1993)
Grass-sedge marsh, Georgia	56	Craft & Casey (2000)
Reed-bulrush marsh, Oregon	116	Graham <i>et al.</i> (2005)
Reed marsh, Denmark	504	Brix <i>et al.</i> (2001)*
Arum arrow marsh, Virginia	97	Whiting & Chanton (2001)*
Anderson rule marsh, California	106-155	Kim (2003)
Everglades, Florida	99-190	Craft & Richardson (1993)
Reed-bulrush marsh, Ohio	105	This Study
Cutgrass mudflat, Ohio	112	This Study
Water lotus marsh, Ohio	160	This Study

From: Bernal, B. and W.J. Mitsch. 2011. Comparing carbon sequestration in temperate freshwater wetland communities. *Global Change Biology* 18: 1636-1647.