Delta Wetlands Project
Greenhouse Gas Analysis

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August 2007

Jones & Stokes. 2007. Delta Wetlands Project Greenhouse
Gas Analysis. August. (J&S 00487.07.) Sacramento, CA.

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Acronyms and Abbreviations

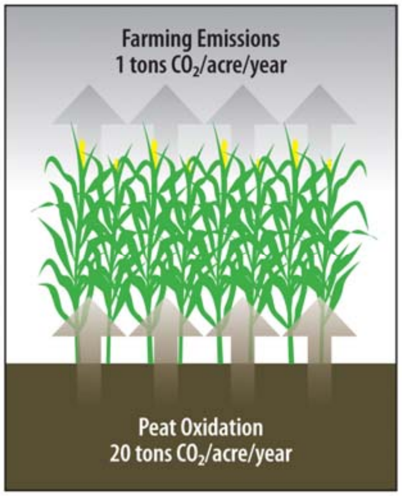
AB	Assembly Bill
af	acre-feet
CH4	methane
CO2	carbon dioxide
Delta	Sacramento–San Joaquin River Delta
GHG	greenhouse gas
GWP	global warming potential
IPCC	Intergovernmental Panel on Climate Change
kWh	kilowatt hour
Msl	mean sea level
N_2O	nitrous oxide
SF_6	sulfur hexafluoride

Executive Summary

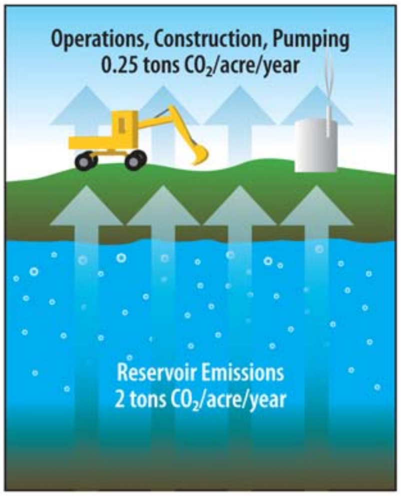
The construction and operation of the Delta Wetlands reservoir project would reduce total CO_2 emissions by 150,000 tons per year, equivalent to removing 30,000 cars from California's roads.

The reduction in CO_2 emissions resulting from flooding two Delta islands (8,000 acres of peat soils) is much greater than the CO_2 emissions caused by the construction and operation of the reservoirs, and overwhelms greenhouse gas (GHG) comparisons with other surface water storage projects. Analysis of existing information makes it clear that no other storage project can match the large net carbon benefit associated with the Delta Wetlands Project.

The Delta Wetlands Project contracted with Jones & Stokes to evaluate the carbon footprint of its project. This request followed recent reports that suggested a net increases in CO_2 emissions from surface water reservoirs. The request was to evaluate CO_2 impacts of the Delta Wetlands Project reservoir islands specifically, and in relation to the other storage projects being evaluated by CALFED. The study evaluated the CO_2 emissions of existing conditions, reservoir construction, and reservoir operations. Carbon impacts of reservoir operations consisted of electrical power consumption (or generation) and decomposition of reservoir peat sediments.



EXISTING CONDITIONS



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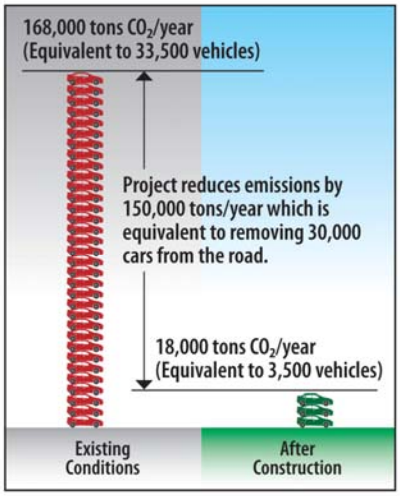

COMPARISON

Flooding the peat soils of Bacon Island and Webb Tract and eliminating agricultural production (equipment and fertilizers) will reduce CO_2 emissions by 150,000 tons/year. Cultivation of the Delta peat soils produces a substantial amount of CO_2 emissions (20 ton of CO_2 per acre) that would be reduced by an estimated 90% to about 2 tons of CO_2 per acre when the islands are flooded for water storage.

Reservoir construction will generate an estimated 50,000 tons of CO_2 (1,000 tons per year over a 50-year project life). Consumption of electrical energy for pumping will generate 750 tons of CO_2 per year, and decomposition of the submerged peat soils will generate an estimated 16,000 tons of CO_2 per year.

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Introduction

This report describes the general effects that changes in land use in the Sacramento–San Joaquin River Delta (Delta) region may have on greenhouse gas (GHG) emissions. The conversion of Delta peat soil land from agricultural uses into reservoir storage or wetlands will be compared in terms of GHG carbon dioxide (CO_2) equivalents.

This study is restricted to GHG emissions associated with CO_2, methane (CH_4), and nitrous oxide (N_2O). These three gasses constitute approximately 99% of the worldwide GHG budget. GHG emission estimates are based on emission factors listed in peer-reviewed literature, government reports, and Intergovernmental Panel on Climate Change (IPCC) publications.

The major GHG emissions from the Delta region are associated with the oxidation of peat soil organic matter that produces CO_2 and methane. Agricultural crops such as corn and alfalfa remove some CO_2 gas from the atmosphere (photosynthesis), with some portion of this carbon returning to the soil as organic matter and some of the carbon removed as food product, which subsequently are consumed and respired as animal waste or as human food (i.e., as milk or beef, chicken, and pork products). Fertilizers must be added to the peat soils for maximum crop production, and mechanized agriculture requires substantial energy use for tilling and harvesting. Most of the carbon in crop production therefore is not sequestered from the atmosphere for longer than a year. GHG emissions from reservoir construction and operations also are considered briefly in this analysis.

Carbon Dioxide Emission Equivalents

California Assembly Bill (AB) 32 (2006) defines the following GHG: CO_2, CH_4, N_20, sulfur hexafluoride (SF_6), hydrofluorocarbons, and perfluorocarbons (AB-32 2006). Each of these gas molecules absorbs radiation to a differing extent, so a normalization scheme is required to compare the effect of each gas on climate change.

The most commonly accepted method to compare GHG emissions is the global warming potential (GWP) (IPCC 2001). The IPCC defines the GWP of various GHG emissions on a normalized scale that recasts all GHG emissions in terms of CO_2 equivalents. One must select a time horizon to convert GHG emissions to equivalent CO_2 emissions to account for chemical reactivity and lifetime differences among various GHG species.

The standard time horizon for climate change analysis is 100 years. The 100-year time horizon is used to ensure consistency with state and worldwide GHG emission inventories. The assumed atmospheric lifetimes and GWP of various GHG species are listed in Table 1. Note that CO_2 (the reference gas for all GHG calculations) has an estimated atmospheric lifetime of 50 to 200 years.

Table 1. Global Warming Potentials and Atmospheric Lifetimes

GHG Greenhouse Gas Species	Atmospheric Lifetime (years)	Global Warming Potential for Various Time Horizons		
		20 years	100 years	500 years
Carbon dioxide (CO_2)	50–200		1	
Methane (CH_4)	12±3	62	21	7
Nitrous oxide (N_2O)	120	275	310	156

Source: IPCC Climate Change 2001.

Carbon Cycle Conversion Factors

Comparison of the estimated carbon equivalents for the Delta Wetlands Project requires some basic conversion factors for land area and mass flux rates. Many of the carbon emission measurements are made and reported as a daily rate of grams of carbon per square meter (g-C/m^2/day). There are 10,000 square meters in a hectare, and a hectare is 2.47 acres. CO_2 equivalents are often expressed as kg-CO_2 per hectare per year. An emission rate of 1,000 kg-CO_2/ha-yr is equivalent to 0.445 tons/ac-year. Each kg of peat soil carbon that is oxidized will release 3.67 kg of CO_2 to the atmosphere. There are 2.2 pound in a kilogram, and 1,000 kg (metric ton) is about 1.1 tons.

The organic content of peat soil generally is expressed as a percentage that is determined by loss on ignition, the difference between dry soil and furnace (burned) soil. The carbon fraction of the organic content is assumed to be 40%. Therefore for each kg of soil organic matter oxidized, about 0.4 kg of carbon will be oxidized, and about 1.44 kg of CO_2 gas will be released. The Delta peat soil organic content varies widely from less than 5% to more than 80%. An average organic content of 50% is assumed for these initial calculations. The density of the organic material within the soil is needed when comparing a subsidence rate (cm of soil oxidized per year) to a carbon oxidation rate (kg of organic material per square meter oxidized per year). A peat soil bulk density of about 120 kg/m^3 (12% water density) is assumed for these initial calculations.

Project-Related Greenhouse Gas Emissions

The current land use on the Delta Wetlands project islands is primarily corn production for livestock. The water storage project considered in this analysis would strengthen the earthen levees, provide intake and discharge facilities, and armor the inside of the reservoir islands (Jones & Stokes 1995). In addition to the direct emissions associated with construction, the conversion of land use from agriculture to reservoir storage would result in different GHG emissions from the project area. An overview of estimated GHG emissions associated with agricultural and water storage land uses is presented below.

Peat Soil Oxidation

The causes of subsidence in the Delta have been an active research area for several years. Peat soil lands in the Delta are subsiding significantly with estimated subsidence rate between 0.2 and 2.5 inches per year that is a result primarily of oxidation of the peat soil (Deverel and Rojstaczer 1996). It is assumed that the soil is oxidized continuously when not submerged and that the agricultural oxidation rate would be reduced by 90% if converted to reservoirs or wetlands. The methodology used to determine the CO_2 emissions from peat soil oxidation is based on the following assumptions:

1. Land surface subsidence of the peat soil in the project area averages 1.0 inch/year [0.025 m/year]
2. The primary cause of subsidence is the oxidation of the peat soil (Deverel and Rojstaczer 1996).
3. The dry weight (bulk density) of the peat soil is 7.4 pounds per cubic foot [118.5 kg/m^3].
4. The carbon content of the organic component of the soil is 40%.
5. Peat soil oxidation will be reduced by 90% when the land use is converted to reservoirs and wetland habitat.

Combining these assumptions, one can calculate the yearly CO_2 emissions associated with peat soil on a per hectare basis.

$$CO2_{SOd} = SR \times \rho \times CC \times MWC \times UCF$$

$$CO2_{SOd} = 0.025 \times 118.5 \times 0.4 \times 44/12 \times 10{,}000$$

$$CO2_{SOd} = 43{,}450\left[\frac{kg\ CO2}{ha - year}\right]$$

$$CO2_{SOr} = SR \times \rho \times CC \times MWC \times UCF \times RR$$

$$CO2_{SOr} = 39{,}105\left[\frac{kg\ CO2}{ha - year}\right]$$

Where:

$CO2_{SOd}$ is the CO_2 emission rate from peat soil oxidation in dry conditions (kg CO_2/ha-yr), and

$CO2_{SOr}$ is the reduction in CO_2 emissions associated with the conversion of Delta land into reservoirs (kg CO_2/ha-yr)

SR is the subsidence rate (0.025 m/year)

ρ is the density of the peat (118.5 kg/m^3)

CC is the carbon content of the soil (0.4 unitless)

MWC is the molecular weight conversion from C to CO_2 (44/12 mass CO_2/C)

UCF unit conversion factor (10,000 m^2/ha)

RR is the estimated percent reduction in oxidation for land converted to reservoir usage (0.9 unitless)

Based on these assumptions, GHG emissions are currently about 44,000 kg CO_2/ha-yr (equivalent to about 20 tons of CO_2/acre-year) and would be reduced by about 40,000 kg CO_2/ha-yr [18 tons of CO_2/acre-year]. There are approximately 8,000 acres of peat soils (3,240 ha) that could be converted from agricultural uses to reservoirs with the proposed project. The oxidation is currently releasing about 160,000 tons of CO_2 per year from these 8,000 acres. The assumed peat soil oxidation emissions once submerged would be about 16,000 tons of CO_2 per year. The proposed Delta Wetlands habitat islands contain another 8,000 acres of peat soils. Additional reductions in CO_2 emissions from peat soil oxidation are likely because some of these agricultural peat soils will be converted to ponds, permanent wetlands, seasonal wetlands, and other habitat uses.

Agricultural Production

The land being considered for conversion to In-Delta reservoirs currently is used for agricultural production. Agricultural land affects the GHG budget by carbon uptake (photosynthesis of organic carbon from atmospheric CO_2), fertilization, and farming machinery use (tailpipe emissions). The existing corn crop produces about 40,000 kg /ha-yr of biomass (40% carbon), which is equivalent to a carbon dioxide uptake of about 60,000 kg CO_2 /ha-yr (27 tons of CO_2/acre-year). However, this CO_2 uptake is not considered a GHG credit, because all of this carbon will be returned to the atmosphere through microbial decomposition and animal respiration.

Estimates of carbon emissions from agricultural usage are derived from a 20-year experiment conducted to determine the carbon cycle of land used for corn production based on changes in fertilizer loading rates and tillage methods (West 2003). In this study, CO_2 emissions from farming inputs and production of corn and soil/flora carbon sequestration rates were determined. Table 2 lists the CO_2 emissions from inputs to corn production based on this study. To convert carbon emissions to CO_2 emissions, it is necessary to multiply all fluxes by 3.67 (44/12). It is assumed that farming practices for corn are suitably similar to the production of other crops that the GHG estimates provided here can be generalized to all crops produced in the region. West estimates that the total annual CO_2 emissions for all farming operations totaled between 750 and 1,850 kg of CO_2 per hectare (0.3 to 0.8 ton of CO_2/acre), depending on tilling and fertilization practices. For comparison, an active adult human (2,800 calories/day) will produce about 400 kg of CO_2 per year (0.45 tons) from normal metabolism (digestion and respiration).

N_20 emissions from croplands are less understood than the carbon cycle. Generation of N_2O in soil occurs from nitrification and denitrification, two major microbial pathways of soil nitrogen transformation, as well as from the chemical process of chemodenitrification. Generally, denitrification is considered to be the most important N_2O source in agricultural soils (Johnson 2005). In one study, growing season N_2O emissions in a reduced-tillage cornfield ranged from 3.5 to 6.3 kg N ha^{-1} $year^{-1}$ (equivalent to 3,400 to 6,150 kg CO_2 ha^{-1} $year^{-1}$) which was considerably higher than from nearby tilled plots (Johnson 2005). It is assumed that N_20 emissions from corn cultivation in the Delta area are similar to tilled-corn emissions, about 500 kg CO_2 ha^{-1} $year^{-1}$ (0.225 ton CO_2/acre-year). Conversion of the agricultural lands to reservoir or wetlands would eliminate this source of GHG. Because the cropland is in an oxidizing environment, methane emissions from corn production are likely to be small in comparison to CO_2 emissions.

Table 2. Carbon Dioxide Emissions from Inputs to Corn Crops

N Applied (kg N ha^{-1} yr^{-1}): Production inputs	Conventional Till				No-Till			
	0	84	168	336	0	84	168	336
	Carbon flux to the atmosphere (kg C ha^{-1} yr^{-1})							
Plow	26.75	26.75	26.75	26.75	0.00	0.00	0.00	0.00
Disk (twice)	17.44	17.44	17.44	17.44	0.00	0.00	0.00	0.00
Planting (corn)[a]	6.79	6.79	6.79	6.79	6.79	6.79	6.79	6.79
Seed (corn)[b]	22.26	22.26	22.26	22.26	22.26	22.26	22.26	22.26
Harvest (corn)	16.47	16.47	16.47	16.47	16.47	16.47	16.47	16.47
Broadcast planting (rye)[c]	2.46	2.46	2.46	2.46	2.46	2.46	2.46	2.46
Seed (rye)[d]	33.09	33.09	33.09	33.09	33.09	33.09	33.09	33.09
Herbicide application	2.54	2.54	2.54	2.54	2.54	2.54	2.54	2.54
Herbicide[e]	17.12	17.12	17.12	17.12	17.12	17.12	17.12	17.12
Fertilizer application	8.03[i]	12.35	12.35	12.35	8.03[i]	12.35	12.35	12.35
Nitrogen (N)	0.00	72.03	144.07	288.13	0.00	72.03	144.07	288.13
Potassium (K)[f]	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
Lime application[g]	1.85	1.85	1.85	1.85	1.85	1.85	1.85	1.85
Lime[h]	45.65	45.65	45.65	45.65	45.65	45.65	45.65	45.65
Total CO_2 emissions	209.45	285.80	357.84	501.90	165.26	241.61	313.65	457.71

Source: West 2003.

[a] Based on agricultural inputs detailed by Frye and Blevins (1997) and Ismail et al. (1994), Blevins et al. (1983). Fields were not cultivated after planting, and there are no data for application of pesticides or fungicides. Soils were naturally high in P, and we do not show emissions for the one initial year of P application. Conversion of agricultural inputs to CO_2 emissions is based on data circa 1995 (West and Marland 2002a [in press]).

[b] Application rate of corn seed was estimated to be 21 kg ha^{-1} yr^{-1}, based on establishment of 50,000 plants ha^{-1}, 95% germination, 5% mortality, and a 1,000 kernel weight of 380 g (Miller and McLelland 2000).

[c] Rye was planted as a winter cover crop. Broadcast planting for the rye cover crop assumes 1.4 L ha^{-1} (72 MJ ha^{-1}) of diesel (Bowers 1992) and 42 MJ ha^{-1} embodied in the manufacture, transport, and repair of machinery (West and Maryland 2002a [in press]).

[d] Application rate of rye seed was 188 kg ha^{-1} yr^{-1}. Cost of rye seed was assumed to be \$0.42 kg^{-1} (Windham 1999).

[e] Average application rate of 3.64 kg ha^{-1} yr^{-1} consists of 0.28 and 3.36 kg ha^{-1} yr^{-1} of paraquot and simazine, respectively.

[f] Average application rate of 62 kg K ha^{-1} yr^{-1} consists of 42 kg K ha^{-1} yr^{-1} in 1970 and 100 kg K ha^{-1} yr^{-1}, 1978–1989. A high K application rate was used to minimize the effects of K as a confounding variable in the experiment.

[g] Carbon emissions from lime application were normalized by the number of years that lime was applied (3 out of 20 years; [West and Marland 2002a (in press) and W. W. Frye pers. comm. 2000]).

[h] Lime was applied at a rate of 6.7 and 11.2 Mg ha in 1973 and 1975, respectively, and an estimated 9 Mg ha^{-1} in 1983. Lime is assumed to be 95% $CaCO_3$.

[i] For the plots where nitrogen was not applied, carbon emissions from fertilizer application were normalized by the number of years that K was applied (13 out of 20 years; West and Marland [2002a] [in press] and W. W. Frye [pers. comm. 2000]).

Reservoir Construction

GHG emissions associated with the construction of a traditional reservoir are attributable primarily to tailpipe emissions from construction vehicles and emissions associated with the production and use of cement/concrete. Tailpipe emissions are a function of project design, heavy-duty vehicle usage, and construction equipment control technology. Concrete emissions are primarily functions of cement production methods (mining, heating, plant efficiency) and delivery (shipping/transport) of concrete from production facilities to job sites. The GHG emissions from construction activity can be generally estimated from the diesel fuel used for construction. A typical diesel emission factor is about 20 pounds of CO_2 emissions emitted per gallon diesel fuel used (CSE 2007). Excavating and moving 20 cubic yards (typical earth-moving equipment) is estimated to require about 5 gallons of diesel fuel and would generate about 100 pounds of CO_2.

Based on the DWR In-Delta Storage Program evaluation (DWR 2006a), the estimated earthwork quantities for embankment fill were about 20 million cubic yards for the two reservoir islands (on-site borrow). This is expected to produce about 50,000 tons of CO_2. This is a one-time production that will occur during construction. Assuming a project life of 50 years, the constructions emissions are equivalent to 1,000 tons of CO_2 per year.

Reservoir Operations

The principal source of GHG emissions from off-stream reservoir operation is associated with electricity used to pump water into storage. The project's estimated water storage volume was estimated to be about 200,000 acre-feet (af) (DWR 2006a). The In-Delta reservoirs considered in this study generally would be filled by gravity, but pumping would be needed to fill the reservoirs to a maximum water elevation of about 5 feet above mean sea level (msl). In comparison, about half of the project storage will require pumping, with an assumed pumping head of 7.5 feet (includes head losses through the pumping facilities. The electrical power required each year to fill the reservoirs can be estimated, based on the potential energy required to lift an acre-foot of water (unit conversion is conveniently about 1):

> Energy (kilowatt hour [kWh]) = water volume (af) x head (feet) / pump efficiency

For an efficiency of 0.75 and a head of 10 feet with a volume of 100,000 af, the required energy is about 1.33 million kWh. This can be converted to CO_2 equivalents by assuming that each kWh produced from coal, oil, or natural gas will generate about 1.5 pounds of CO_2. The annual pumping energy for the Delta Wetlands reservoirs (about 1 GWh) therefore would generate about 1,000 tons of CO_2 per year.

Reservoir Emissions While Storing Water

Several studies have been conducted recently that investigate the GHG emissions associated with the decay of organic materials beneath reservoirs (Cole 2007; Matthews 2005; Soumis et al. 2004). In the Matthews study, CO_2 emission factors were determined, by modeling, to range from 1,500 to 2,500 kg CO_2 ha^{-1} $year^{-1}$ while CH_4 emissions ranged from 100 to 1,000 kg CO_2 ha^{-1} $year^{-1}$. GHG emissions from reservoirs are a function of air/gas transfer rates from open water bodies, and volatilization of gasses from water passing through hydraulic machinery. However, the decay of organic material beneath a reservoir should be considered a net GHG emission only if it is greater than the decay of this organic material from the watershed without the reservoir.

A field study conducted by Soumis et al., determined CO_2 and CH_4 emissions from six reservoirs in the western United States. These measurements are consistent with Matthews's study and provide an order of magnitude understanding of the GHG emissions associated with reservoirs. The prevailing literature indicates that wetland areas are likely to be a net sink of GHG because the accumulation of organic materials in the wetland sediment is greater than the decay of organic materials. The assumption that the existing peat oxidation rate would be reduced by 90% to a value of about 10% of the existing oxidation of 1 inch per year would be equivalent to about 4,000 kg CO_2 ha^{-1} $year^{-1}$, which is greater than the maximum reservoir emission rates for both CO_2 and CH_4 combined based on the Matthews study. Given the large organic content of Delta Wetlands soils, the CO_2 and CH_4 emission rates from the proposed Delta Wetlands reservoirs may be greater than those analyzed in previous reservoir studies.

Comparison with Alternative Reservoirs

The two major sources of CO_2 emissions from an off-stream reservoir are construction (earth-moving) and operations (pumping). Emissions from the reservoir sediments are expected to be lower than the reservoir measurements described in the Matthews study (about 1,000 kg CO_2 ha^{-1} $year^{-1}$) because the inflow of watershed debris will be limited. As an example of an alternative off-stream reservoir, the Sites Reservoir construction and operations are generally described in the DWR preliminary feasibility study (DWR 2006b). The main dam and 10 saddle dams would require an estimated 25 million cubic yards of earth to be moved. This is similar to the fill needed for the Delta Wetlands Reservoir project (20 million cubic yards), but because the distance moved (and elevation change) likely will be greater for the Sites Reservoir, the energy use per cubic yard of fill moved for that project is estimated to be about twice the Delta Wetlands construction. It is assumed that 10 cubic yards of earthwork for the Sites Reservoir will consume five gallons of diesel, which would result in the generation of about 125,000 tons of CO_2 from heavy equipment diesel fuel use during construction. Equally distributed over the first 50 years of the project, construction emissions are approximately 2,500 tons of CO_2/year.

An average of 500,000 af of water would be delivered from the Tehama-Colusa Canal and stored in the proposed Sites Reservoir. A pumping plant with an average head (lift) of about 250 feet will pump this water from the canal elevation (200 feet) to storage in the reservoir (elevation of about 450 feet). The pumps will be pump-turbine units to allow most of the pumping energy to be recaptured as hydropower generation. The assumed efficiency of pump-turbine facilities (95% turbine, 75% pumping) will recapture all but about 20% of the pumping energy. Therefore the energy requirements for storing water in the Sites Reservoir can be estimated as:

Energy (kWh) = Water volume (af) x head (feet) x 0.2/pump efficiency

Although the Sites Reservoir would have an average yield of about 500,000 af with a maximum storage of more than 1 million af, the energy required to store 200,000 af of water with an average head of 250 feet would be approximately 13 million kWh, which corresponds to about 10,000 tons of CO_2/year.

The construction and operation CO_2 emissions for the Delta Wetlands reservoirs would be approximately 1,750 tons of CO_2/year, whereas the Sites Reservoir emissions would be about 11,500 tons of CO_2/year (normalized for 200,000 af, 40% of the Sites Reservoir yield). Thus, for equal volumes of water, the proposed Sites Reservoir would use approximately five times more energy and emit about five times more GHG than would the proposed Delta Wetlands reservoirs.

The enlarged Los Vaqueros Reservoir likely would involve a smaller volume of excavation and earth-moving during construction than Sites Reservoir, but would have a greater pumping head (more than 500 feet) compared to Sites Reservoir. The GHG emissions required to pump and store 200,000 af of water in the enlarged Los Vaqueros Reservoir would be about twice the emissions required to store water in Sites Reservoir and about 10 times the emissions required to store water in the proposed Delta Wetlands reservoirs. The comparison of these off-stream reservoirs is summarized in Table 3.

Table 3. Comparison of CO2 Emissions from Pumping and Storing 200,000 af in Alternative Reservoirs

	Delta Wetlands	Enlarged Los Vaqueros	Sites	Enlarged Shasta	Temperance Flats
Existing emissions	168,000 tons/yr	None assumed	None assumed	None assumed	None assumed
Construction emissions	50,000 tons (1,000 tons/yr)	75,000 tons (1,500 tons/yr)	125,000 tons (2,500 tons/yr)	1,000 tons/yr assumed	2,500 tons/yr assumed
Pumping emissions (for 200,000 af of water)	1,000 tons/yr	20,000 tons/yr	10,000 tons/yr	-11,000 tons/yr (reduced) from new hydropower	17,000 tons/yr from lost hydropower
Reservoir sediment emissions	16,000 tons/yr (8,000 acres)	None assumed	None assumed	None assumed	None assumed
Total emissions for reservoir	18,000 tons/yr	21, 500 tons/yr	12,500 tons/yr	-10,000 tons/yr (reduction)	19,500 tons/yr
Net emissions	–150,000 tons/yr (reduction)	+21,500 tons/yr (increase)	+12, 500 tons/yr (increase)	-10,000 tons/yr (reduction)	+19,500 tons/yr (increase)

Two other reservoirs are being considered in the CALFED surface storage program—an enlarged Shasta Reservoir and an enlarged Millerton Reservoir (Friant Dam) or a new reservoir on the San Joaquin River above Millerton Reservoir. Some preliminary information on these alternative projects is available from Bureau of Reclamation documents (Reclamation 2004, 2005). The earthmoving and concrete estimates (construction emissions) for these projects have not been given, although they are assumed to be similar to the Delta Wetlands, Sites Reservoir, or enlarged Los Vaqueros projects.

The water supply and associated hydropower generation benefits are difficult to estimate because these benefits depend on the hydrology and various assumptions about reservoir operations. Nevertheless, an enlarged Shasta Reservoir (6.5 feet increase) would have an estimated water supply yield of about 75,000 af and produce about 15 GWh of additional hydropower generation each year. This would provide a GHG credit of about 11,000 tons of CO_2 per year.

The enlarged Friant Dam or new reservoir alternatives would interfere with the existing hydropower generation. Raising Friant Dam by more than 25 feet would interfere with the Kerchoff #2 powerhouse, but a larger reservoir is needed to increase the water supply yield. Some San Joaquin Reservoir alternatives include new hydropower facilities to replace those lost, but none of the alternatives would produce more hydropower generation than the existing facilities. The alternative with the least hydropower generation reduction would be the Temperance Flat Dam at San Joaquin River mile 279, between Millerton Reservoir and Kerchoff Dam. This alternative could have a water supply yield of about 125,000 af but would reduce hydropower generation by about 23 GWh per year. The replacement of this power would result in GHG emissions of about 17,000 tons of CO_2 per year.

Summary Analysis

Based on the emission factors discussed above, the change in GHG emissions associated with converting 8,000 acres (3,240 ha) of peat soil from agricultural use to reservoir storage was examined. For this analysis it was assumed that existing agriculture farming practices result in 1,500 kg CO_2 ha^{-1} $year^{-1}$ from CO_2-related emissions and that an additional 500 kg CO_2 ha^{-1} $year^{-1}$ are emitted from N_2O emissions for a total of 2,000 kg CO_2 ha^{-1} $year^{-1}$ of GHG emissions from farming practices. It is assumed that existing CO_2 emissions from peat soil oxidation are 44,000 kg CO_2 ha^{-1} $year^{-1}$ based on a subsidence rate of 1.0 inch/year. The total GHG emissions from the project area for existing conditions are approximately 46,000 kg CO_2 ha^{-1} $year^{-1}$, with over 95% of GHG emissions emanating from peat soil oxidation. The total annual emissions of CO_2 are therefore about 168,000 tons.

If the project area were converted to reservoir storage, it is assumed that the inundated peat soils would emit about 4,000 kg CO_2 ha^{-1} $year^{-1}$ as combined CO_2 and CH_4 emissions (16,000 tons/yr). GHG emissions from water pumping are estimated to be 750 tons of CO_2 $year^{-1}$. GHG emissions from construction activities are estimated to be 1,000 tons of CO_2 $year^{-1}$. The total GHG emissions from the project area after conversion to reservoir storage would be approximately 18,000 tons of CO_2 $year^{-1}$. This would be a reduction of about 150,000 tons of CO_2 per year.

The GHG reduction benefits associated with this project can be compared to removing an equivalent number of passenger vehicles from the road. For these calculations it is assumed that a passenger car averages 10,000 miles per year with a fuel efficiency of 20 miles per gallon. EPA estimates that, for each gallon of gas, about 20 pounds of CO_2 will be emitted (EPA 2007). Thus, a typical car emits 10,000 pounds or about 5 tons of CO_2 per year. Based on these values and a subsidence rate of 1.0 inch/year, the conversion of 8,000 acres of Delta peat soil to reservoir storage is equivalent to removing approximately 30,000 vehicles from the road. Because there are about 24 million cars and trucks in California, this is equivalent to about 0.1% of the emissions from California motor vehicles.

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