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The Viability of Creating Wetlands for the Sale of Carbon Offsets

LeRoy T. Hansen

This analysis estimates the profitability of restoring wetlands for the sale of carbon offsets. Results indicate that about 7% to 12% of the recently restored grassed wetlands of the prairie pothole and high plains regions and 20% to 35% of the forested wetlands of the Mississippi alluvial valley and Gulf-Atlantic coastal flats regions could have carbon offset values that exceed the cost of restoring the wetland and the opportunity cost of moving the land out of agricultural production. Given the uncertainties, the analysis applies conservative estimates of wetlands' costs, offset prices, and wetlands' effects on greenhouse gases.

Key words: carbon markets, carbon sequestration, offsets, wetland restoration

Introduction

Wetland ecosystems are among the most productive in the world. The availability of water, soil, and nutrients leads to rapid plant growth, providing food and habitat for a large number of aquatic and terrestrial species. Among other things, wetland ecosystems support the fisheries industry and recreational fishing by providing habitat for fry; wetland ecosystems offer wildlife-viewing and hunting opportunities; many endangered species depend on wetlands; and wetlands reduce flood risks and remove nutrients from waters (Tiner, 2003). Earlier studies have estimated the values of many wetland services—e.g., flood protection (Costanza et al., 2008), waterfowl hunting (Cooper and Loomis, 1993), bird watching (Signorello, 1999), existence values (Thompson and Young, 1992), preservation values (Whitten and Bennett, 2005), and aquifer recharge (Farber, 1996), to name but a few. Although valued by society, the public nature of ecosystem services, their dispersed benefits, and the difficulties involved in linking beneficiaries to providers have historically limited economic incentives to the private sector for restoring and preserving wetlands (Ribaudo et al., 2008).

The public's interest in wetland ecosystem services has been strong enough to motivate non-governmental organizations (NGOs) and federal, state, and local governments to preserve and restore wetlands. Perhaps the most significant wetland restoration and conservation effort is the U.S. Department of Agriculture's (USDA's) Wetland Reserve Program (WRP). The WRP is a voluntary land retirement program that enrolls agricultural lands which were once wetlands and restores the wetland acreage. As of October 2008, over 2 million acres have been enrolled in the WRP (USDA, 2008). A unique attribute of the WRP is that the USDA holds permanent easements on 80% and 30-year easements on 15% of all WRP contracts. It is the permanence of the WRP acreage, coupled with the fact that some wetland ecosystem

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services need decades to recover, which will allow the WRP to restore more ecosystem services than other existing wetland conservation programs. The USDA's Conservation Reserve Program (CRP), another cropland retirement program, has increased wetland acreage by paying landowners to retire farmed wetlands. Unlike the WRP, however, most CRP contracts are for 10 years, and thus do not provide long-term carbon sequestration benefits. The CRP provides little funding for wetland restoration.

Another policy approach for restoring and protecting wetlands is to create markets for wetland services. Despite their public nature, markets have developed for some environmental goods. Through eco-labeling, the consumer is able to purchase food items with the assurance they were produced without agri-chemicals. In the United States, SO_2 emission trading allows firms that exceed emission caps to purchase credits from others whose emissions fall below these caps. In many areas, landowners can sell access to their lands for wildlife viewing or hunting. More recently, carbon offset markets have emerged.

In the United States, the most significant and long-lived clearinghouse for carbon trading is the Chicago Climate Exchange (CCX). The CCX is a voluntary cap and trade organization accepting memberships from the United States, Canada, and Mexico, and carbon offset projects from these three countries as well as Brazil. Member firms agree to reduce their carbon emissions, either by taking measures to reduce their own emissions or by purchasing carbon offsets from qualified projects. Farmers can sell carbon offsets on the CCX. Such offsets are produced by adopting conservation practices that sequester carbon or reduce emissions of greenhouse gases (GHGs). The CCX sets the standards linking agricultural practices to the quantity of offsets produced. The CCX accepts carbon offsets from agriculture even though the quantity and permanence of carbon sequestration on agricultural soils is less certain than for other types of emission reductions (Zeuli and Skees, 2000). Agricultural lands restored to wetlands also sequester carbon. Recent studies indicate that one acre of a newly restored wetland can sequester more than 1.5 metric tons (mt) of carbon a year in its earlier years (Euliss et al., 2006). Currently, the CCX does not accept carbon offsets associated with wetlands.

The objective of this analysis is to estimate the potential profitability of restoring wetlands on agricultural lands for the sale of carbon offsets. Profitability is based on the capitalized values of income and cost. Expected income is based on expected offset prices and carbon sequestration rates. Offset prices are taken from market data and a variety of recent economic analyses. Estimates of wetlands' carbon sequestration rates are taken from recent analyses of forested and grassed (non-woody vegetative cover) wetlands. WRP contract data are used to estimate wetland restoration and preservation costs.

Results indicate that, for grassed wetlands, 7% to 12% of the contracts have per acre carbon offset values exceeding costs. The economic potential of forested wetlands is slightly better, with approximately 20% to 35% of the contracts having per acre values that exceed costs. Based on these results, a minority of farmland owners might find it profitable to restore wetlands for the sale of carbon offsets. Given the uncertainties involved, these results should be viewed as indicative—but the approach developed here can be refined as better information becomes available.

Greenhouse Gases

The public's concern about global warming has spawned research on carbon sequestration by wetlands. All analyses conclude that newly restored wetlands sequester atmospheric carbon,

yet wetlands' net effect on global warming potential (GWP) is uncertain. While wetlands sequester carbon and hence reduce carbon dioxide or CO_2, they release other GHGs, primarily methane (CH_4) and nitrous oxide (N_2O). A wetland's release of relatively small amounts of CH_4 and N_2O can more than offset the GWP of the CO_2 it removes. The Intergovernmental Panel on Climate Change (IPCC) has adopted the measure of carbon equivalent to express the global warming potential of greenhouse gases. A carbon equivalent (CO_2e) expresses the GWP of greenhouse gases in terms of the amount of carbon dioxide that has the same impact on global warming. The index is calibrated across a 100-year time horizon. The 100-year GWP of one ton of CO_2 is indexed at 1. Methane has a GWP 21 times that of CO_2, and N_2O has a GWP 310 times that of CO_2 (Reilly and Richards, 1993).

It is important to note that the GWP index has several weaknesses (Godal, 2003). First, the index does not account for GHG concentrations. As the concentration of a GHG increases, its marginal effect on GWP increases. Further, because concentrations of GHGs are projected to continue to increase, the GWP index will become less reliable and understate changes in GWP (Godal).

A second weakness of the GWP index is its failure to account for the effect of timing of GWP impacts—i.e., there is no discounting of future impacts (Reilly, 1992; Hammitt et al., 1996). Most of the GWP of CH_4 occurs in the first 12–15 years after its release, while the GWP of CO_2 remains strong, though diminished, after 100 years (IPCC, 1990). With discounting, a GWP index for CH_4 would be greater than 21.

Reilly and Richards (1993) proposed an index based on GHG damages. Their proposed index would embody changes in GWP due to changes in GHG concentrations and would capture differences in the time-distribution of damages. Work in this area continues, with most efforts attempting to better capture the social damages of marginal changes in GHG emissions (Hammitt et al., 1996; Tol, 1999; Manne and Richels, 2001). At this time, analyses of GHG effects continue to apply the GWP index (Godal, 2003). Accordingly, the GWP index is also applied here.

The Price of Carbon Offsets

The carbon offset prices used in this investigation are developed or taken from three different sources. First, offset prices observed on the CCX are used. Second, offset prices are equated to the marginal social costs of CO_2e, generated in a recent analysis that estimated a socially optimal GHG control policy. Third, offset prices generated in analyses of recently proposed GHG cap and trade legislation are used.

Values Based on Market Prices

When the CCX first began, demand for offsets was driven by the private sector's interest in reducing its carbon footprint. In more recent years, the governments of Illinois and New Mexico have become members of the CCX (see http://www.chicagoclimatex.com/content.jsf?Id=64). These state governments accept the full responsibilities and are given the same trading rights as other CCX members. In joining the CCX, members make a legally binding commitment to reduce and/or offset their greenhouse gas emissions to 6% below their 1998–2001 average. Members can purchase credits from other members—members produce credits by reducing emissions beyond their agreed-upon cap—and by purchasing offsets from emissions reduction and carbon sequestration projects. Some farm-related eligible projects

supply offsets by reducing agricultural CH_4 releases and increasing the carbon stored in agricultural and rangeland soils. Since its inception in 1997, the CCX has traded almost 24 million metric tons of CO_2e.

In July 2007, the price of a CO_2e averaged $3.25 per metric ton (mt), whereas carbon offsets in the European Union's Emissions Trading Scheme (EU ETS) (a Kyoto program) traded at $30.60 per mt (Ecosystem Marketplace, 2007). The difference may be due to the fact that most transactions on the CCX are voluntary, while those on the EU ETS are not. It is important to note that agricultural soil sinks are not recognized as a source of carbon offsets by the EU ETS.

The July 2007 CCX price is used in this analysis (table 1). The CCX provides what is probably a very conservative estimate of society's willingness to pay for reductions in GHG emissions for two reasons. First, the demand driving CCX prices does not include everyone who benefits. Specifically, most people will enjoy the benefits of reduced GHGs without having to pay a price. This "free-rider" problem is common when there is private provision of a public good. Second, future carbon prices may be much higher because of mandatory cap and trade programs that are starting to come on line at the regional level, and the likelihood of a national carbon cap and trade program. In this investigation, the "observed" price remains at $3.25 per mt through 2030 (table 1).

Values Based on Estimates of Social Costs and Benefits

The social cost of GHG impacts is a function of the broad range of physical impacts (GHG effects on climate, climate change impacts on ecosystems, food production, flooding, etc.) and the values society places on these impacts. The benefit of a reduction in GHG emissions is the subsequent reduction in social cost. But reductions in GHG emissions come at a cost. For example, the cost for electricity can rise as the industry moves toward carbon-free energy sources. An optimal policy for control of GHG emissions equates the marginal benefit of reducing impacts of climate change to the marginal cost of reducing emissions.

A number of studies have estimated the costs and benefits of controlling GHG emissions. Results reported by Nordhaus (2007), Tol (2006), and Mendelsohn (2006) are generally consistent. Nordhaus uses the Dynamic Integrated Model of Climate and the Economy (DICE) to estimate a socially optimal rate of GHG emissions control if, prior to 2015, public actions were to impose a carbon tax (or an equivalent emissions cap) that equates marginal social costs to marginal benefits (the benefit of reduced emissions). Under what Nordhaus considers the most probable conditions, offset prices are estimated to be $9.90 per mt CO_2e in 2015, and rise at 2.5% annually to $14.40 by 2030, while emissions increase about 1% per year (table 1).[1] We use these values in our analysis.

Stern et al. (2006) report much higher estimates of GHGs' social costs. This report gained much attention from the press and was highly criticized by economists, particularly because its results suggest there is a strong need for extreme and extensive actions to optimally control damages from GHGs. Damages are reported to be $91.50 per mt of CO_2e and, if the world takes no actions, climate change impacts will be equivalent to a 5% reduction in the standard of living of future generations.

The very different and controversial findings of Stern et al. (2006) are largely attributed to the use of a 0.5% discount rate (Nordhaus, 2007). Stern et al. argue that higher discount rates

[1] All dollar amounts are reported in 2007 $.

Table 1. Observed and Estimated CO_2e Prices

Price Scenario	$/Metric Ton of Carbon[a] 2015	2030	δ
Observed[b]	3.25	3.25	0
Nordhaus (2007)	9.90	14.40	2.5%
Lieberman-Warner Bill (S.2191)[c]	21.40	61.40	7%
Bingaman-Specter Bill (S.1766)[d]	9.20	26.40	7%

[a] Amounts are in 2007 $.
[b] The CCX reported prices and those reported by the U.S. Department of Energy (USDoE) have been converted from dollars per mt of CO_2e to dollars per mt of OC-C.
[c] Source: USDoE (2008b) reports prices for 2020 and 2030, and applies a 7% rate of price increase. The reported 2015 price reflects a 7% rate of increase.
[d] Source: USDoE (2008a) reports prices for 2020 and 2030, and applies a 5% rate of price increase. The reported 2015 price reflects a 5% rate of increase.

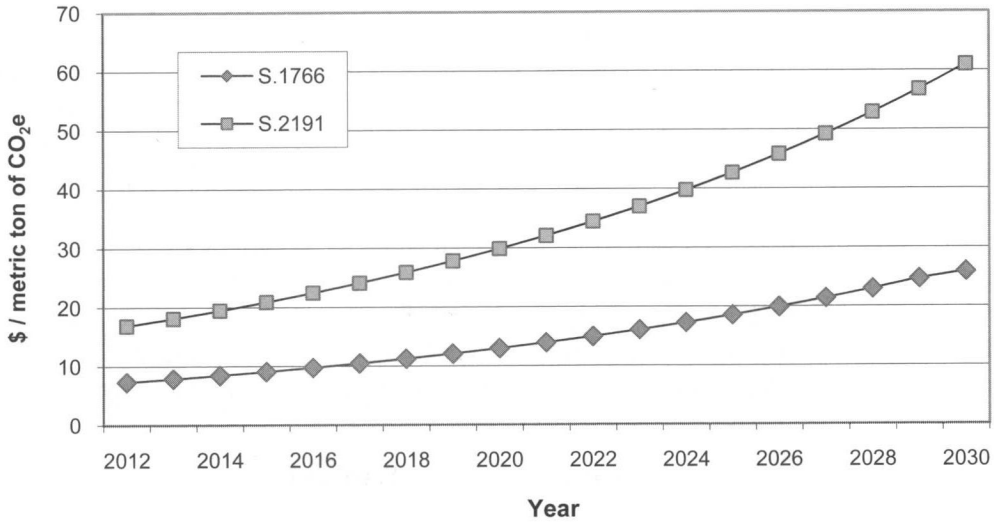
discourage resource conservation, thereby shortchanging future generations. But a 0.5% rate is not in line with the conventional belief that future consumption opportunities can be maximized only when capital resources are allocated in the present so as to maximize future net returns. This condition holds whether resources are used to expand production or reduce GHG emissions (Nordhaus).

A more extreme view is taken by Baer and Spash (2008). They argue that available and future social cost estimates are of little, if any, value because they are not likely to embody purely scientific measures of the physical effects and economic values of GHG impacts. Although many of the more recent analyses (e.g., Nordhaus, 2007; Tol, 2006; and Mendelsohn, 2006) do address major socioeconomic issues, such as intergenerational issues, risks and uncertainty, extreme events, and distributional equity, Baer and Spash contend these studies side-step the associated controversy by assigning scalar values to the representative variables. In our view, however, the Nordhaus estimates are of value because they provide a measure based on the information available. We believe Baer and Spash are implicitly arguing that using no estimate is better than using estimates which come with uncertainties.

Baer and Spash (2008) also argue that the political community is not likely to shape policy around economic efficiency, but instead will select portions of economic studies appearing to justify their political goals. Yet, there is strong evidence to suggest the political community does consider results of economic analyses. For example, early versions of GHG cap and trade legislation proposed that emission allowances be given to utilities—with the intent of achieving smaller changes in energy prices for consumers. However, economic analyses have shown why giving away allowances will have no significant price effect—i.e., allowance prices will not affect consumer prices—and, as a result, more recent cap and trade legislation proposes some portion of allowances be sold.

Values Based on Cap and Trade Legislation

Two of the competing 2007 U.S. Senate bills limiting GHG emissions were the Low-Carbon Economy Act of 2007 (S.1766) or the Bingaman-Specter Bill, and the Climate Security Act of 2007 (S.2191) or the Lieberman-Warner Bill. Both proposed caps on GHG emissions and allowed purchases of carbon offsets. The more constraining was the Lieberman-Warner Bill,



Data Source: U.S. Department of Energy, Energy Information Administration (2008) [http://www.eia.doe.gov/oiaf/servicerpt/s2191/excel/s1766_08.xls].

Figure 1. Department of Energy estimates of CO_2e prices under the Bingaman-Specter Low-Carbon Economy Act (S.1766) and the Lieberman-Warner Climate Security Act (S.2191)

where CO_2e emissions were to drop from 6 billion metric tons (bmt) in 2012 to 4.0 bmt in 2030. Alternatively, under the Bingaman-Specter Bill, CO_2e emissions were to drop to 5.0 bmt in 2030. Due to the greater constraint on emissions, carbon estimates of offset prices are higher under the Lieberman-Warner Bill.

The U.S. Department of Energy (USDoE, 2008a,b) and the U.S. Environmental Protection Agency (USEPA, 2008a,b) have estimated economic impacts of both bills. The impact analyses rely on multiple assumptions related to, among other things, technological change, consumer demand elasticity, and domestic and international growth. These assumptions are especially important when estimating the trajectory of the economy with no emission constraints because the sizes of the economic impacts of cap and trade legislation reflect deviations from the baseline trajectory (USDoE). Both the DoE and EPA estimations consider multiple scenarios. We use these agencies' results and do not detail or attempt to evaluate their analyses and supporting assumptions.

The DoE analyses project CO_2e offset prices of $17.50 per mt in 2012 (and $21.40 in 2015) rising to $61.40 in 2030 under the Lieberman-Warner Bill and, under the Bingaman-Specter Bill, $9.20 per mt in 2015 rising to $26.40 in 2030 (USDoE, 2008a,b) (figure 1 and table 1). Both studies employ the DoE Energy Information Administration's National Energy Modeling System. Both studies allow cap and trade market participants to bank allowances and, consequently, prices rise at a 7% annual rate. (An allowance permits the release of one ton of CO_2e. GHG emissions are capped by a cap on allowances.)

By comparison, the EPA analyses project CO_2e offset prices of $29.90 per mt in 2015 rising to $62.90 by 2030 under the Lieberman-Warner Bill and, under the Bingaman-Specter Bill, $12.20 per mt in 2015 rising to $25.80 in 2030 (USEPA, 2008a,b). The EPA used both the Applied Dynamic Analysis of the Global Economy (ADAGE) (Ross, 2007) and the Inter-temporal General Equilibrium Model (IGEM) (Goettle et al., 2007). The ADAGE results are

reported here because they are the more conservative estimates. EPA analyses also permit allowance banking. The EPA price estimates increase 5% each year.

While the DoE and EPA analyses provide similar results, the DoE price estimates are more conservative, and hence are used here. Offset prices based on cap and trade legislation exceed the Nordhaus (2007) estimates (table 1). This difference suggests that, if the Nordhaus estimates represent socially optimal tradeoffs, then both of the proposed cap and trade bills are too stringent on GHG control.

Note, the offset prices reported here are in dollars per metric ton of CO_2e. The value of sequestering a ton of carbon is 3.67 times the offset price. For example, an offset price of \$1.00 per mt of CO_2e is equivalent to a sequestration price of \$3.67 per mt of carbon. As reflected by these price differences, when one ton of carbon is sequestered, 3.67 tons of CO_2 (e.g., one ton of carbon plus 2.67 tons of oxygen) are removed from the atmosphere.

Carbon Sequestration by Wetlands

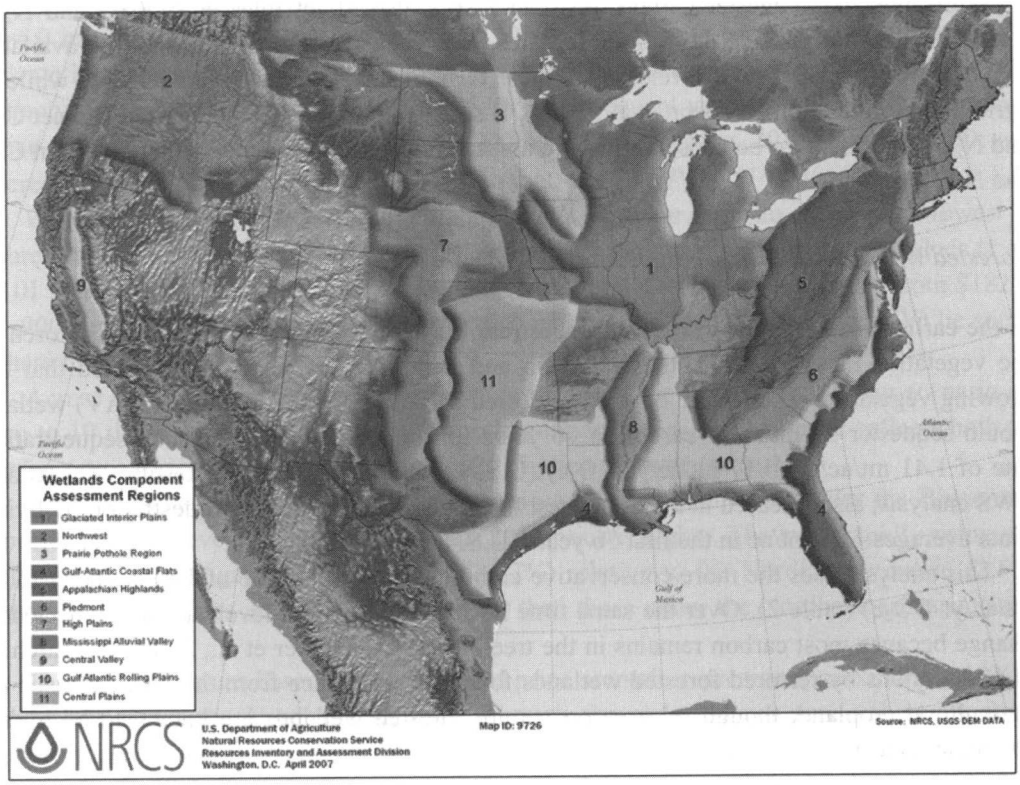
While wetlands are known to sequester atmospheric carbon in soils and plants, they also release CH_4 and N_2O. Consequently, the net GHG effect of wetlands is uncertain. In an evaluation of the GHG effects of North American wetlands, Bridgham et al. (2006) found no conclusive evidence that wetlands significantly alter the stock of GHGs. Rather, they conclude much of the uncertainty is due to a lack of detail on releases of CH_4 and N_2O by wetlands. Bridgham et al. also found evidence supporting the belief that new wetlands have higher carbon sequestration rates and lower rates of CH_4 and N_2O releases than mature wetlands. The authors also note that different kinds of wetlands have different GHG effects.

The most extensive research on the GHG effects of newly restored wetlands has focused on the grassed prairie pothole wetlands of the Dakotas, Minnesota, and Iowa, and the forested Mississippi alluvial valley wetlands of Mississippi, Louisiana, Arkansas, and Tennessee (figure 2). The estimated GHG impacts reported by these studies are applied in this analysis.

Grassed Wetlands: The Prairie Potholes

Euliss et al. (2006) estimate that the carbon held in the living biota of restored prairie pothole wetlands (PPWs) reaches its maximum at 2.86 metric tons per acre (mt/ac) in five years. Also in the first five years, the carbon content in the upper-level soil (the top 15 cm) increases 4.94 mt/ac as soil carbon moves from normal dryland to normal wetland levels. Taken together, carbon sequestration by a restored PPW averages 1.56 mt/ac/yr (or a 5.72 mt/ac/yr reduction in CO_2e) in the first five years (table 2). Euliss et al. also estimate that, in subsequent years, wetlands sequester 0.34 mt/ac/yr of carbon (1.25 mt/ac/yr CO_2e).

Gleason, Laubhan, and Euliss (2008) estimate that, after 10 years, the carbon in restored PPWs' standing vegetation reaches 2.02 mt/ac—which is about 0.84 mt/ac less than reported by Euliss et al. (2006). In the upper soil levels, Gleason et al. (2005) estimate carbon storage increases by 9.11 mt/ac, or approximately 2.5 mt/ac greater than the Euliss et al. values. Comparing their 10-year totals, the Gleason, Laubhan, and Euliss (2008) and Gleason et al. (2005) estimates indicate that restored wetlands sequester about 1.6 mt/ac more carbon than estimated by Euliss et al. Because they are slightly lower and they also account for variations in the sequestration rate across the 10-year horizon, the Euliss et al. estimates are applied here.



Source: USDA, National Resources Conservation Service (April 2007) [http://www.nrcs.usda.gov/technical/nri/ceap/images/ceap_wetlands_map.gif].

Figure 2. Wetland regions of the contiguous 48 states

Table 2. Carbon Sequestration Rates and CO_2e Removal Rates by Type of Wetland

		Reduction in CO_2e	
Wetland Regions [a]	Wetland Type	First 5 Years (mt/ac/yr)	6 to 70 Years (mt/ac/yr)
PPW, HP	Grassed wetlands	5.72	1.25
MAV, CF	Forested wetlands	5.17	5.17
RP	40% grassed, 60% forested	5.39	3.59
CV	50% grassed, 50% forested	5.45	3.21

[a] PPW = prairie pothole wetlands, HP = high plains, MAV = Mississippi alluvial valley, CF = coastal flats, RP = rolling plains, and CV = central valley.

While they do sequester carbon, restored PPWs also affect releases of CH_4 and N_2O. Research does not provide definitive estimates. However, the limited data that are available suggest newly restored PPWs' releases of these GHGs may be below levels released while in agricultural production (Gleason et al., 2005). If so, a restored PPW will decrease the net CH_4 and N_2O emissions. To be conservative, we assume restored PPWs have no net effect on CH_4 and N_2O emissions.

Forested Wetlands: The Mississippi Alluvial Valley

In the earlier years, nearly all carbon sequestration by restored forested wetlands is stored in the vegetative mass. In 2005, the U.S. Fish and Wildlife Service (FWS) reported that the growing vegetation on one acre of newly restored Mississippi alluvial valley (MAV) wetland would sequester 99 mt/ac of carbon in 70 years for an average annual carbon sequestration rate of 1.41 mt/ac/yr (5.17 mt/ac/yr CO_2e) (U.S. FWS, 2005a; table 2). Results of a second FWS analysis, also released in 2005, suggest the annual rate of carbon sequestration by living biota averages 1.77 mt/ac in the first 70 years (U.S. FWS, 2005b).

This analysis uses the more conservative carbon sequestration rate of 1.41 mt/ac/yr (5.17 mt/ac/yr CO_2e) (table 2). Over the same time horizon, soil carbon levels are not expected to change because most carbon remains in the tree biomass (Faulkner et al., 2008). Research of N_2O emissions by restored forested wetlands found no difference from the level released on agricultural cropland, though releases on mature forested wetlands are known to be higher (Faulkner et al.).

Analyses of Other Wetlands

In order to value the income potential of wetlands in regions other than the PPW and MAV, such as the high plains (HP), coastal flats (CF), rolling plains (RP), and central valley (CV) (figure 2), we assume all grassed (forested) wetlands have the same per acre sequestration rate—i.e., the sequestration rate of grassed wetlands of the HP (forested wetlands of the CF) equals the rate of PPWs (MAV). Rates of the RP and CV wetlands are weighted averages of the PPWs and MAV rates where the weights are based on the portion of grassed and forested wetland acres (table 2). The assumed carbon sequestration rates of the HP, CF, RP, and CV are meant to provide a perspective of the values wetlands could have. Yet, keep in mind, actual sequestration rates might be quite different than what are assumed here.

Values of Restored Wetlands

Wetland carbon sequestration values are based on offset price estimates from 2015 to 2030. We do, however, test the sensitivity of results to longer time horizons.

Although restored wetlands can provide other benefits, the focus here is on wetlands' carbon sequestration values. A wetland's carbon sequestration value is the discounted present value of future credit sales, which depends on future offset prices (P_t), sequestration rates (C_t) across the relevant time horizon (T), and the appropriate discount rate (r). More specifically:

$$Wetland_value = \sum_{t=0}^{T} P_t C_t (1+r)^{-t},$$

where *Wetland_value* is the discounted present value of future credit sales, t is the time period ($t = 0$ in year 2015). The discount rate of 5.5% applied here is often applied in analyses of private investments (Nordhaus, 2007). As an example, consider a PPW where C_t equals 5.72 mt/ac/yr CO_2e for the first five years, and 1.25 in subsequent years; and, under the Nordhaus price scenario, in the year 2015, P_0 = \$9.90/mt CO_2e. In years 2016 through 2030, as t increases from 1 to 15, $P_t = \$9.90 * (1.025)^t$ so that, in 2030, $P_{30} = \$14.40$/mt CO_2e.

Within any one price scenario, the highest *Wetland_value* estimate exceeds the lowest by more than 75%. The grassed wetlands (PPW and HP) have the lowest per acre values (from \$101 to \$990 per acre), the forested wetlands (MAV and CF) have the highest (from \$182 to \$1,900 per acre), and the values of the mixed forest/grassed wetlands (RP and CV) lie somewhere in between (table 3).

Across all four price scenarios, the per acre values of the Lieberman-Warner scenario are two to 10 times the per acre values of other scenarios (table 3). This result reflects both the higher rate of price increase and the higher 2015 price estimate (table 1).

Per acre values under the Nordhaus scenario are lower than those under the Bingaman-Specter scenario, even though the Nordhaus 2015 price is higher. The more rapidly rising offset price in the Bingaman-Specter scenario (7%) relative to the Nordhaus scenario (2.5%) leaves wetland values as much as 27% higher than those under the Nordhaus scenario (table 3).

The per acre values based on the observed price scenario represent approximately 60% of the values under the Nordhaus scenario. Though the observed per acre values are more conservative, we apply values based on the Nordhaus analysis. We chose not to use the observed price for two important reasons. First, there is no projection as to how, or whether, observed prices might change over time. We could assume that price does not change over time, but there is no support for this assumption—in all GHG impact analyses, damages from a marginal increase in CO_2e increase over time. Second, as discussed earlier, observed prices are likely to underestimate the social value of a reduction in GHGs.

The Nordhaus offset price estimates are more conservative than those based on cap and trade bill analyses, and so we use these estimates in much of the subsequent investigation. Still, we also examine the market implications of offset prices taken from the cap and trade bill analyses.

Estimates reported in table 4 provide a perspective of the sensitivity of results. First, the per acre value estimates are more sensitive to a 15-year increase in the time horizon than a one-percentage-point change in the discount rate, especially for forest lands—due to their higher sequestration rates in the latter years. A discount rate of 4.5% (6.5%) increases (decreases) the value of grassed wetlands by 5% and forested wetlands by 15%. Extending the time horizon to 2045 increases the per acre value of grassed wetlands by \$40, or 15%, and forested wetlands by \$300, or 45%.

Costs of Restoring and Preserving Wetlands

A landowner who wishes to convert cropland to a wetland will face several costs, with the more significant likely to be the net opportunity cost of the land and wetland restoration or creation costs. The net opportunity cost is measured by the decrease in the land's value once the wetland is restored and the carbon offsets sold. Agricultural values can be quite high because soils of many drained wetlands are very productive. Also, the land's value

Table 3. Estimated Value of Restored Wetlands Based on Sales of Carbon Offsets by Price Scenario and Wetland Type ($/acre)

Price Scenario	PPW, HP (grassed)	MAV, CF (forested)	RP (40% grassed, 60% forested)	CV (50% grassed, 60% forested)
Observed	101	182	150	141
Nordhaus (2007)	368	627	523	498
Lieberman-Warner Bill (S.2191)	990	1,900	1,540	1,450
Bingaman-Specter Bill (S.1766)	419	798	646	608

Note: Amounts are in 2007 $.

Table 4. Sensitivity of the Per Acre Estimates to the Discount Rate and Time Horizon Based on Nordhaus Price Scenario ($/acre)

Wetland Regions[a]	$T = 15$, $r = 5.5$	$T = 15$, $r = 4.5$	$T = 15$, $r = 6.5$	$T = 30$, $r = 5.5$
PPW, HP	368	383	353	461
MAV, CF	627	670	588	938
RP	523	560	492	688
CV	498	520	458	617

Note: Amounts are in 2007 $.

[a] PPW = prairie pothole wetlands, HP = high plains, MAV = Mississippi alluvial valley, CF = coastal flats, RP = rolling plains, and CV = central valley.

can be high if there is a potential for urban development, but tend to be lower when lands are susceptible to flooding. After the wetland is restored, the value of the land can be substantially reduced (hence, net opportunity costs are high), especially if the owner faces wetland maintenance costs.

Restoration costs vary. In some instances, there may be no restoration costs—the lands revert to natural wetland conditions once the land is left undisturbed. However, restoration costs rise as the need to restore land structure and wetland vegetation increases.

The wetland cost estimates reported here are based on data from the USDA's Wetland Reserve Program (WRP). The WRP restores wetlands and, in most cases, purchases permanent and 30-year easements on the restored lands. While there might be several ways to structure agreements between landowners and those who purchase wetland carbon offsets, we assume the agreement structure is similar to that established by the WRP. Principally, the property owner maintains ownership of the land, can use the wetland as long as its health is not affected, and can sell the land as long as the buyer accepts preexisting contractual agreements. By design, each WRP easement payment is to equal the land's net opportunity cost, and so is directly applicable for this analysis.

In addition to the easement payment, the WRP contract data include restoration cost, which is applicable here. The data also include contract size and other, generally smaller, costs:

Table 5. Wetland Costs and Potential Values of Carbon Sequestered Based on Nordhaus Price Scenario ($/acre)

Wetland Regions[a]	Wetlands' Carbon Value	Cost 50th Percentile	Cost 25th Percentile	Cost 75th Percentile	Cost ≤ Benefit
PPW	368	1,160	545	1,953	12.6
HP	368	1,081	729	1,456	6.9
MAV	627	803	328	1,074	35.0
CF	627	1,030	696	1,658	21.0
RP	523	792	585	1,088	17.0
CV	498	1,907	1,437	2,289	5.4

Note: Amounts are in 2007 $.

[a] PPW = prairie pothole wetlands, HP = high plains, MAV = Mississippi alluvial valley, CF = coastal flats, RP = rolling plains, and CV = central valley.

surveying, title, appraisal, and closing costs. Landowners who create wetlands for carbon credit sales may face one or more of these and perhaps other costs. To decrease the likelihood of understating costs, we include all WRP costs in this analysis.

Other than the Central Valley (CV) of California where WRP easement costs are especially high, median per acre costs of WRP easements fall within a range of $792 to $1,160 (table 5). But, within each region, easement costs vary considerably. While somewhat smaller in the CV, per acre costs at the 75th percentile are two to three times the costs at the 25th percentile.

Wetlands' Costs and Carbon Values

Across all six regions, wetlands' median per acre costs exceed per acre carbon sequestration values (based on the Nordhaus estimates). But results differ across regions. Because of its high per acre costs, over 94% of the Central Valley's WRP contracts cost more than the estimated carbon value (table 5).

Exclusive of the CV, regions with grassed wetlands (PPW and HP) have higher easement costs and lower carbon sequestration values than other regions (table 5). Few contracts—less than 13%—have per acre values exceeding costs. Even with the much higher offset price estimates associated with the Lieberman-Warner Climate Security Act (S.2191) (table 3), costs of more than 50% of all contracts would exceed wetlands' per acre carbon sequestration values.

The forested wetlands of the MAV and CF have the lowest median costs and highest carbon sequestration benefit estimates (table 5). Yet median costs are still 28% to 64% higher than the per acre values. Moreover, nearly 65% (79%) of the MAV (CF) easement contracts have per acre costs that exceed their values (table 5). Still, with the much higher offset price associated with S.2191 (table 3), per acre carbon sequestration values of wetlands exceed costs for over 75% of all MAV and CF wetland contracts.

Together, these results suggest that, in most areas, creating wetlands for carbon offset production and sales is not likely to be economically viable for most landowners, especially for nonforested wetlands. Nevertheless, if landowners were able to sell other wetland services—

such as water quality benefits, mitigation banking credits, or hunting rights—in combination with carbon offsets, then creating wetlands might be profitable.

However, if cap and trade legislation with a cap as tight as that proposed in the Lieberman-Warner Bill is signed into law, the market price of carbon offsets, and subsequently the per acre values of newly created wetlands, could be more than double the values reported in table 5. Consequently, nearly half of the converted MAV and CV wetlands would yield carbon benefit values that exceed costs.

Conclusions

The objective of this analysis was to estimate the potential profitability of converting agricultural lands to wetlands for the sale of carbon offsets. To do so, we first estimated the income potential of restored wetlands based on possible offset prices and carbon sequestration rates. Offset prices were taken from market data and a variety of recent economic analyses. Estimates of wetlands' carbon sequestration rates were taken from recent analyses of forested and grassed wetlands. Using the USDA's Wetland Reserve Program (WRP) contract data, we estimated the direct and indirect costs landowners are likely to face when restoring and preserving wetlands.

Results suggest that the economic potential of restoring wetlands for the sale of carbon offsets is limited. Over 87% of the grassed wetlands' contracts have costs exceeding their carbon sequestration value. The economic potential of forested wetlands is better—around 21%–35% of the contracts have per acre carbon value estimates that exceed costs. However, should cap and trade legislation with emission caps as tight as the Lieberman-Warner Climate Security Act (S.2191) be signed into law, many farmland owners in the MAV and similar areas could see wetland creation for the sale of carbon offsets as a viable economic option. When considering the extent to which markets might encourage wetland restoration, one must keep in mind that wetlands provide other potentially marketable benefits.

The wetland cost and carbon sequestration values reported here provide an illustrative perspective and should not be viewed as conclusive. They are based on what are probably conservative measures of carbon values and sequestration rates. The variances of these estimates are not known and are likely to be fairly large.

In concluding, we note four major caveats concerning this analysis. First, the social costs of GHGs are unknown. We applied Nordhaus estimates of social costs because they tend to be more conservative. We also considered DoE carbon price estimates generated in analyses of two recently proposed cap and trade bills.

Second, the effect of restored wetlands on GHGs remains uncertain. The rates we applied to the PPW and MAV wetlands are reported in recent published research, but DoE analysts point to the need for additional research. More importantly, the sequestration rates applied to regions other than the PPW and MAV are built on our assumptions—not on analyses. The assumptions provide only a very rough estimate of these wetlands' carbon sequestration values.

Third, the wetlands' GHG effects applied here do not account for variations in carbon sequestration across wetlands within the same region. Within each region, there are differences in climate, flood patterns, and other factors impacting wetlands' GHG effects. Clearly, the restored wetlands with higher carbon sequestration rates will generate more revenue.

Fourth, the WRP cost data are historical. Per acre costs may increase, especially if conservation programs have been restoring the least-cost wetlands first. Furthermore, the WRP per

acre cost estimates are based on total contract acreage, which includes both upland and wetland acreage. Thus, the per acre costs might be underestimated.

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