C-LOCK: AN ONLINE SYSTEM FOR QUANTIFYING AND MARKETING FARMLAND CARBON SEQUESTRATION SERVICES

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ABSTRACT

We have developed an integrated web interface, database and biogeochemical modeling system (C-Lock) to allow landowners to quantify, certify, pool and market carbon emission reduction credits (CERCs) resulting from changes in land management. The goal is to provide scientifically defensible, standardized and transparent measurement, monitoring and verification services that minimize transaction costs and maximize prices paid to landowners. We present an overview of the system and preliminary estimates from a pilot CERC trade in process on the Cheyenne River Sioux Reservation in South Dakota. C-Lock's initial focus has been on agricultural soil carbon sequestration due to reduced tillage or land set-aside; however, a forest carbon accounting module is under development.

Keywords: CENTURY, emissions offsets, greenhouse gases, soil carbon.

INTRODUCTION

With the entry into force of the Kyoto Protocol and a growing number of state-level greenhouse gas (GHG) reduction and mitigation initiatives, industrial emitters are attempting limit their future exposure to litigation and possible regulatory penalties by investing in low-cost mitigation strategies that include the purchase of emissions offsets. Terrestrial sequestration options, including carbon sequestration in soils and biomass, presently comprise the most cost-effective medium-term mitigation strategy. However, the market for carbon emissions offsets generated through carbon sequestration in soils and biomass is constrained by perceived uncertainties in the quantification, certification, and permanence of such offsets, as well as by anticipated high transaction, measurement, monitoring and verification (MMV) costs.

We have developed a web-based system called C-Lock (patent pending), which is intended to reduce transaction and MMV costs and thereby improve the market viability of soil sequestration offsets. The system allows individual landowners to register their land, to quantify actual and potential changes in soil carbon stocks due to management changes, and aggregate their specific credits with those of other landowners to create a generic pool of certified, marketable offsets. The offsets are credible because they are generated using robust, scientifically defensible and transparent methods of data collection and modeling and a conservative certification procedure to convert raw estimates of accrued soil carbon into carbon emission reduction credits (CERCs). A more detailed technical description of the system is provided by Zimmerman et al. (2005).

C-Lock facilitates low-cost monitoring and verification because it doesn't depend on field-level sampling or monitoring of individual sequestration projects. A rigorous uncertainty analysis provides well-defined confidence bounds consistent with EPA and IPCC guidelines for defining uncertainty. These features help to minimize transaction costs and increase the value of soil carbon sequestration for landowners.

As a proof-of-concept and field test of C-Lock's credit estimation, aggregation and marketing capabilities, we are developing a pilot trade including tribal and private farmlands on the Cheyenne River Sioux Reservation in central South Dakota. The goal of the project is to assemble a package of at least 100,000 $MTCO_2$-e (metric tons carbon dioxide equivalent) CERCs, which will be auctioned or offered to an industrial buyer.

OVERVIEW OF THE C-LOCK SYSTEM

C-lock is comprised of 4 linked components: a web interface, a client database, a GIS database and the CENTURY soil carbon model (Parton et al. 1987; 1993). The databases are linked using Perl and Unix shell scripts, which process the data to prepare input parameter files for CENTURY. The uncertainty analysis procedure resamples the input data, reruns CENTURY and produces output distribution statistics that are used to construct confidence bounds for the CERC estimates delivered to the client.

The CENTURY Model

CENTURY has been used to simulate soil C and N dynamics in a wide range of ecosystems, although it has been most extensively validated in temperate grasslands and semi-arid croplands (NREL 2000). It is comprised of three major submodels: (1) a biophysical model that generates hydrologic and temperature driver variables; (2) a crop production model of below- and aboveground vegetative processes; and (3) a soil organic matter model that estimates carbon (C) and nitrogen (N) fluxes among eight soil and litter organic matter pools. CENTURY 4.0 operates by default on a monthly timestep. Event scheduling is done with default (pre-defined) and user-defined management schedule files. CENTURY will simulate C, N, phosphorous (P), and sulfur (S) dynamics, although in the C-Lock framework we are presently simulating only C.

Input variables are organized into a suite of ASCII-format parameter files that include monthly mean maximum and minimum temperature, total precipitation, soil texture, atmospheric and soil N inputs, plant growth parameters and lignin content, and initial soil C and nutrient levels. Because no specific model validation or parameterization has been performed for South Dakota, in most cases we have use default parameter files (developed by Colorado State University) appropriate to our regional crop and tillage systems. However, some parameter customization has resulted from initial model testing. The system is amenable to ongoing parameter refinement as new research and validation data become available.

For each modeled field, CENTURY is run for a 3000-year initialization period, assuming, in South Dakota, undisturbed grassland, in order to obtain a stable baseline level of soil C. An initial “plowdown” event is imposed to signal the beginning of agriculture around 1900. Management regimes are client-selected (see below) or based on default crop and tillage approaches derived from historical agricultural data for that climate zone.

Client Database

Clients accesses C-Lock via a secure web interface that allows them to create a private account associated with a parcel label and a set of spatial coordinates, which they can enter themselves or obtain via a mapserver link. Management information supplied by the client is compiled in a secure database, which is accessible exclusively by the registered client, authorized database administrators, and (possibly) third-party certifiers. The client is allowed to select generalized management options for five defined time blocks from 1900-1989 via drop-down menus, but thereafter they must specify annual crop and management parameters that include crop type, tillage times and equipment, fertilizer and irrigation regimes, and grazing schedules. The client may also specify a future date to which they would like to estimate carbon sequestration. At present the management parameters specified by the client for the 1990-1999 period are recycled to create future scenarios.

The use of generalized management schedules prior to 1990 merits some explanation. Although accurate determination of absolute soil organic carbon (SOC) stocks for a site requires detailed site information and land use history, the estimation of relative SOC stock changes does not. We have found that a general history capturing the relative amounts of time that land has been cropped, grazed or undisturbed is adequate to place the site within a general scale of SOC depletion. Our evaluations in South Dakota have indicated that subsequent to 80 or 90 years of agriculture, SOC levels are depleted by about 50 percent relative to the pre-agricultural baseline. Given a threshold level of depletion, trends of SOC recovery in the wake of a management change are not highly sensitive to the initial SOC stock (C. Peng, manuscript in preparation), although they are sensitive to current crop and management parameters. Therefore, prior to 1990 a limited suite of standard management options was found adequate to estimate a “pre-Kyoto” reference soil carbon stock.

When all the required data for a field have been completed, the client “submits” the field to C-Lock's automated processing system, which creates the database entries, initiates the modeling process, and ultimately delivers to the client a set of field-specifc CERC estimates on decade timesteps over their specified modeling period.

GIS Databases

C-Lock supplements client management data from a GIS-linked database of climate data (which includes mean monthly temperature and precipitation) and soil texture parameters.

Monthly-timestep temperature and precipitation data since 1900 have been compiled from the National Climatic Data Center (NCDC 2005) Cooperative Station Network data set, which includes about 160 stations in South Dakota. Missing data records for individual climate stations have been replaced by averages from the applicable climate division (hereafter: climate zone, of which there are 9 in South Dakota). Although nearest-station climate records may not exactly represent precipitation and temperature patterns for a given site, CENTURY's use of monthly (total precipitation, minimum/maximum temperature) data minimizes its sensitivity to local variations that might be important in a daily-timestep setting.

Mean climate statistics are applied to the initialization run, while actual nearest-station climate data are applied from 1900 to the present. To extend the simulation beyond the present, we use CENTURY’s stochastic climate-generation algorithms, which are driven by precipitation statistics for the applicable climate zone (mean, skewness, kurtosis). Stochastic climate scenarios use stochastic precipitation but only monthly mean temperatures.

Soil texture data for the selected site are provided based on (preferably) 1:24,000 SSURGO or 1:250,000 STATSGO (NRCS 2005a;b) soil coverages. Nearly all South Dakota counties are now included in the SSURGO database. For each record in the aggregated database we caculated a thickness-weighted texture triad (sand:silt:clay); area-weighted averages of soil layers (to 20 cm) were used to assign texture values to each soil polygon. Polygons were gridded to a 30-m resolution for each county. A similar grid was developed for soil bulk density, derived from soil texture. These data are used to generate a polygon with area-weighted average texture and bulk density for each client-defined field.

We assign default land use and crop management histories to climate zones based on national sources of historical agricultural data (USDA 2004; NASS 2005) as well as on a survey of South Dakota agricultural extension agents. These data have been aggregated to a climate zone level, so that the generalized management data for historical time blocks are selected based on the climate zone within which the client parcel is located.

The client-specific and general management data, climate and soil parameters are filtered though a set of scripts that create customized parameter and event-schedule files for the CENTURY model.

Uncertainty Estimation

Modeled estimates of soil organic carbon (SOC) changes are inevitably fraught with uncertainty, which arises from a range of sources. Mapped estimates of soil characteristics may not apply to specific points, nearest-station climate data may be inaccurate, or land-use history may be misspecified. There is also uncertainty in the built-in parameter values that CENTURY applies to soils or crops. In order to account for these factors, estimated CERCs are based not on a single CENTURY run but a large number (typically about 200) of iterations. Input parameters related to soil, cultivation impacts, irrigation, and fertilizer or organic matter additions are varied within specified ranges using a Monte Carlo randomized sampling routine. This approach is similar to that used in the GEMS ensemble simulation environment (Kerr et al. 2003), in which frequency distributions for geographic variables are derived from spatial datasets. However, frequency distributions for nonspatial variables, such as tillage impacts, are based on empirical data and expert advice. Past and future climate are generated using CENTURY’s stochastic climate algorithms.

The distribution of Monte Carlo output values allows us to define a statistical (e.g., 95%) confidence interval for estimated credits. In practice, the large N (200 iterations) of the uncertainty estimation procedure results in such narrow (e.g. 2-3% of the mean) confidence bounds that we will likely set a higher standard, such as a 99% confidence interval, for CERC certification. Typically soil sampling errors of less than 5% of the mean are only achieved using a very large number of samples.

Determining Additionality

An important advantage of the model-based approach is that it can ensure that the additionality criterion for carbon offset projects is met. Most conventional offset or emissions reduction projects use a simple historical mean emissions rate as the emissions baseline, although at present considerable ambiguity remains regarding appropriate baseline determinations for terrestrial (soil or biomass) emissions offset projects. We have conducted preliminary analyses that suggest that the use of a baseline mean emissions rate is likely to bias our calculated CERCs. For example, unusually favorable or unfavorable growing conditions during the baseline period would result in unrealistically high or low mean rates of atmospheric C uptake by crops.

Therefore, in order to factor out all non-anthropogenic effects on soil C dynamics, we run the client-defined scenario in parallel with a baseline or business-as-usual (BAU) scenario. Through 1989 the client and BAU scenarios are identical; beginning in 1990 the client scenario conforms to the management parameters specified for each year by the client, while the BAU scenario simply recycles the management option selected by the client for the 1982-1989 time period. Thus, rather than establishing a baseline emissions rate C-Lock establishes a baseline management scenario. The client and BAU scenarios are both subjected to Monte Carlo analyses, as described above, using exactly identical randomized weather and parameter files. Consequently any difference in soil C between the two scenarios should be due exclusively to management effects. CERCs are then derived from the cumulative modeled difference in soil C stocks between the two scenarios (Figure 1).

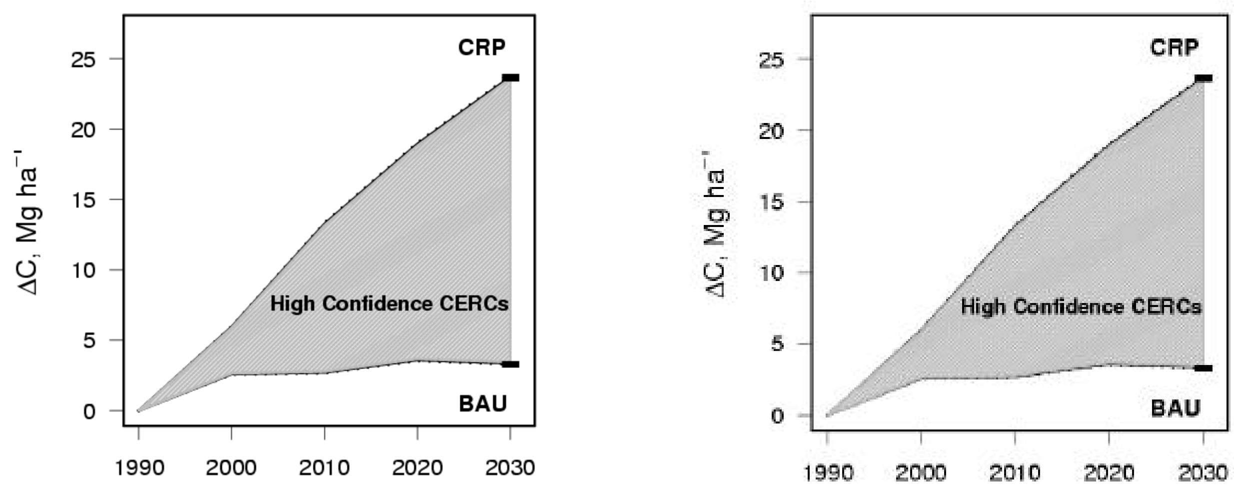

Figure 1. Schematic representation of how Monte Carlo simulation results will be used to estimate and certify certainty pools of CERCs. Values on the Y axis are the total C, extrapolated by decade increments from T_0 to T_{40}. Solid lines represent the mean predicted C values for each scenario, while the flanking dotted lines delimit the 95% confidence ranges.

The actual marketable CERCs are constrained by the 95% confidence intervals for the Monte Carlo output ranges. Estimated credits that fall between the lower 95% confidence bound of the client-defined scenarion (“CRP” in Figure 1) and the upper 95% confidence bound of the BAU scenario are defined as certified or high-confidence CERCs, while the residual credits that fall within the outer 95% confidence bounds of the two ranges are retained in a pool of reserve CERCs, to serve as a buffer against producer shortfalls.

C-LOCK PILOT CHEYENNE RIVER SIOUX RESERVATION TRADE

No accounting or marketing method will gain wide acceptance without a real-world demonstration of its utility. In October 2004 SDSMT received a grant from the USDA to develop a pilot trade based on land use changes within the Cheyenne River Sioux (CRS) Reservation. The springboard for this trade is a contract developed by a group of businessmen and ranchers associated with the tribe, incorporated as AB Resources.

The AB Resources contract commits tribal land managers and tribal land lessees to maintaining conservation practices, which will generate sequestration credits validated between 2003-2008. These practices include, for example, a mandated 20% reduction in grazing intensity on up to 362,700 hectares (ha) (896,000 acres (ac)) of tribal tribal rangelands. In addition, approximately 25% of the 8,000 ha (20,000 ac) of farmland on the reservation are under some type of reduced or conservation tillage, and up to 19,000 ha (47,000 ac) were enrolled in the Conservation Reserve Program (CRP) prior to 1998. Constraints related to constitutionally determined tribal land lease limits resulted in the withdrawal of most of this land from the CRP at that time; however, it is likely that some or most of the previously enrolled land has not been returned to tillage agriculture. The estimates provided below assume that only 121 ha (300 ac) of CRP land will be eligible to generate credits.

As a testbed application, the CRS trade has the advantage of involving large tracts of land managed by a single entity (the tribe), with good historical management records. C-Lock's spatial databases are complete for South Dakota, so that modeling the effect of land use changes can be done quite rapidly once the management data have been entered. We are currently in the process of locating and compiling tribal lease and land management records for entry into the C-Lock database.

Our goal is to compile a trading unit of at least 100,000 $MTCO_2$-e of sequestered carbon. We conducted a preliminary analysis of potential sequestration and income by applying some estimates of likely C sequestration in north-central South Dakota farmlands derived through CENTURY modeling of an actual parcel. Based on modeling results, we can expect about 1.8 $MTCO_2$-e ha^{-1} yr^{-1} sequestered under CRP, 1.1 $MTCO_2$-e ha^{-1} under no-till cropland management, and about 0.4 $MTCO_2$-e ha^{-1} through a significant reduction in grazing on rangeland (from “heavy” to “light” in terms of CENTURY parameters).

Although at present we do not have exact numbers for the proportion of cropland on the reservation on which no-till management is practiced, the CTIC provides county-level data for conservation tillage rates, however, and the overall no-till adoption rate for the two counties included in the reservation is 27%. Therefore only about 2170 ha (5300 ac) of reservation cropland would be generating credits. These, in combination with 121 ha (300 ac) of CRP land, would store a cumulative 15,670 $MTCO_2$-e between 2003-08, and would not approach 100,000 $MTCO_2$-e before 2012. If tribal rangelands are included, however, the cumulative sequestration and storage would exceed 400,000 $MTCO_2$-e by 2005. This is because, even though the incremental sequestration rate on rangelands is likely to be quite low, there is a very large potentially eligible land base.

An important obstacle to overcome in developing this trade is the current consensus that the uncertainties inherent in determining net rangeland carbon sequestration rates render it impractical to use rangelands as emissions offsets. There are two major issues in this regard: first, that verification of real management changes is difficult due to the lack of good records for open rangelands, and secondly that it is impractical to determine the impact of livestock numbers and management on emissions of non-CO_2 GHGs, primarily methane (CH_4) and nitrous oxide (N_2O), which are emitted as a result of ruminant digestive processes and manure decomposition. In the first case, the use of tribal leased rangeland units, which have been under a centralized management and record-keeping system for several decades, provides a unique advantage in determining both the BAU and changes in management. With respect to the second issue, the EPA has developed default emission factors for livestock-related GHG emissions, based on population sizes and predominant manure management methods. More detailed information for the development of livestock enteric emission estimates has been published in the new draft Voluntary Greenhouse Gas Reporting guidelines (USDOE 2005). Finally, we are investigating opportunities for using remote sensing of rangeland productivity and condition to determine baselines and to monitor and verify rangeland management projects. In the current instance, we believe it will be possible to develop reasonable (order-of-magnitude) estimates of livestock-related GHG emissions by using tribal rangeland records and the applicable parcel-specific grazing regulations. These estimates can be used to modulate our reported values of marketable soil CERCs.

It is worth observing that as yet the federal government has produced no unambiguous guidance with respect to accounting or certification standards to be applied to terrestrial sequestration offsets, with the result that each contract has been an idiosyncratic event, with prices and contract terms determined on an *ad hoc* basis. Accounting standards for afforestation and reforestation projects are more advanced, thanks to their inclusion in the Kyoto Clean Development Mechanism, and to efforts by organizations such as Winrock International and the World Resources Institute to develop widely applicable guidelines. In addition, the California Climate Action Registry has produced a protocol for forest sector carbon accounting that will likely serve as a blueprint for similar programs in other states (CCAR 2004). No comparable standards are yet available for agricultural soil carbon sequestration, pending the release of final guidelines associated with the Department of Energy's Voluntary Reporting of Greenhouse Gases (1605(b)) Program (EIA 2005). In the event, the few sales to date of soil-based sequestration offsets, such as the contract developed between GEMCo, a Canadian consortium, and a group of Iowa farmers (Blank 2003), as well as the lease agreement between Entergy Corp. and the Pacific Northwest Direct Seed Association (Entergy 2002), have not been constrained by enterprisewide or “whole-farm” accounting requirements.

Contracting

Our picture of the most viable type of contract for soil sequestration is based on the concept of expiring credits or temporary certified emissions reductions (tCERs), which are becoming the accepted format for land-use, land-use change and forestry (LULUCF)-derived credits within the Kyoto flexibility mechanism framework (Bode and Jung 2004). However, we would further refine this idea by paying a premium for new or additional sequestration, while simultaneously providing an incentive to keep that carbon in the ground. For example, the current year's estimated SOC stock change would be credited at a premium value, while carbon sequestered in past years would be credited at some fraction thereof. With appropriate pricing, the producers would benefit from a modest but significant annual income stream, while the buyers would save money by paying lower rates than they would for permanent credits, and in annual increments that reduce the impact on the corporate bottom line.

As an illustration related to the CRST trade, assuming a total of 15,670 $MTCO_2$-e estimated C storage between 2003-2008, a buyer paying full price up front for 2008-vintage credits (2006-vintage credits were $1.65 per $MTCO_2$-e on the Chicago Climate Exchange as of 9 March 2005) would pay $7,052.

On the other hand, a lease arrangement between 2003-2008, wherein the buyer paid 50% of market rate for current-year credits and 25% of market rate for stored carbon, would see the buyer paying out a total of $7,933 by 2008, but only $6,499 in NPV terms, assuming a 5% discount rate.

The ultimate arrangement will be contingent on the willingness of the eventual credit buyer to consider various leasing alternatives.

The CRST pilot trade is based on a large block of land, which will facilitate data compilation. Since individual land managers should not have to personally register their leased parcels, this trade will serve largely as a test application of the credit estimation, verification and marketing methodology.

Monitoring and Verification

C-Lock incorporates at least three levels of verification. At a minimum, all data entered by the client are screened using built-in quality control limits that will flag and possibly reject unrealistic values for critical management parameters. A secondary level entails the verification of current and past management using tribal and Farm Service Agency (FSA) agricultural management records, supplemented by limited ground truthing by tribal range managers and agricultural agents. Finally, we have also arranged for third-party certification of C-Lock's data management, modeling and certification procedures.

Although we do not consider it necessary or cost-effective to conduct field-level monitoring that includes periodic soil sampling, the management database will be updated every other year, and credits re-estimated using actual management and weather data. This will ensure that the contract stipulations are being met, and provide feedback to land managers regarding the impact of their management approaches.

Remote sensing of land management and land condition, mainly through satellite photography, is another MMV method that we are actively investigating for future applications.

THE C-LOCK ENTERPRISE

Although C-Lock is the product of an academic research and development effort, the long-term goal is to develop it into a self-sustaining business proposition. With this in mind, SDSMT is in the process of establishing an independent company, which will pursue business opportunities in South Dakota and beyond in partnership with AB Resources.

In order to extend the applicability of the system, we are currently evaluating optimal approaches for adding a forest-sequestration module that will allow us to similarly package and market generic credits generated by afforestation or riparian planting projects. This will involve accounting for both biomass and soil carbon.

Ultimately the system will be available to any landowner who can document changes in his land management that result in additional sequestered carbon in soils or biomass, provided that the climate, soils and management databases are in place for his area. We are also extending the geographic scope of the package by compiling soil and climate databases for Montana, Idaho, and Wyoming. This effort was made possible by our participation in the Big Sky Regional Carbon Sequestration Partnership, based in Bozeman, MT.

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