Conversion to Native Grasslands Offset Project Protocol Framework

Prepared for:

Delta Waterfowl Foundation
Winnipeg, Manitoba

Norfolk ALUS
Simcoe,Ontario

March, 2011

Montreal
1097, rue St-Alexandre,
#201, Montréal (Qc.)
Canada H2Z 1P8
Teléfono: +1 (514) 787-1724
montreal@ecoressources.com

Québec
825, rue Raoul-Jobin
Québec (Québec)
Canada G1N 1S6
Teléfono: +1 (418) 780-0158
quebec@ecoressources.com

Vancouver
1763, East 3rd Ave.
Vancouver (B.C.)
Canada V5N 1H3
Teléfono: +1 (604) 688-1245
vancouver@ecoressources.com

Lima
Av. República de Panáma 6084
Oficina 302, San Antonio-
Miraflores, Lima (18) Perú
Teléfono: +51 (1) 446-6531
lima@ecoressources.com

Table of Contents

1. EXECUTIVE SUMMARY

1.1. Introduction

Grasslands management strategies (including conversion of croplands to grasslands, avoided conversion of grasslands and improved grasslands management) on a worldwide basis have received significant attention as a GHG reduction strategy (Internationally – Hendrickson 2003; Conant 2010; Canada - McConkey et al 1999; Australia - Russell and Williams 1982 and Gifford et al 1992; New Zealand - Tate et al 1997; Portugal - Teixeira et al 2008; and U.S. - Conant et al 2001 and Eagle et al 2010). The objective of this project is to identify, research and describe technical requirements and issues for a quantification and monitoring protocol focused on conversion of croplands to native or natural grasslands offset projects in southern Ontario.

The framework focuses on the likely quantification and monitoring requirements and issues for conversion to grasslands offset projects in the Norfolk County area of southern Ontario but its concepts have general applicability for native grasslands conversion offset projects in other parts of North America. The research is not directed at developing a protocol for one particular offset system. However, the Ontario Government is developing a cap and trade system that is consistent with its participation in the Western Climate Initiative (WCI) and agricultural offset projects are one of the WCI's designated acceptable offset categories so WCI system design expectations and directions are referenced in this framework. As well, there is ongoing interest from larger corporations in acquiring offsets from terrestrial carbon offset projects that help sustain natural ecosystems. North American located projects that use Voluntary Carbon Standard (VCS) approved methodologies and registration or Climate Action Reserve (CAR) protocols and registration are particularly favoured by these voluntary market buyers so the general requirements of each of these offset programs are also referenced in this framework.

This discussion of the strengths and weaknesses of each of the various options for addressing scientific knowledge and protocol technical and methodological issues provides a future native grasslands protocol development process with a pathway to filling any knowledge gaps.

The framework is divided into two sections: the first presents the North American state of the science on soil organic carbon sequestration and GHG flux in native grasslands and the second section presents the issues and options for addressing each key element of a conversion to grasslands offset protocol.

1.2. State of Science

The success of an offset project depends on accurate quantification of its GHG emissions and removals through direct measurement of GHG flows within the boundaries of the offset project or estimation using indirect methods or a combination of the two. While GHG measurement techniques and technologies for soils and plant ecosystems are available and precise, they are expensive and often time consuming to implement, hence alternative but accurate estimation approaches have to be applied to assist in the estimation of the GHG emission reduction achieved by converting lands from cropping systems to native or natural grasslands.

These estimation approaches fall into two categories. The first one is the use of sequestration or emission factors or co-efficients calculated, mainly, from results of experiments involving direct measurement of carbon and GHGs. The other approach is to use computer process models that calculate key growth, yield, carbon and $N:N_2O$ parameters for plant and soil systems. Although these estimation methods are not as accurate as direct measurement of GHG flows they are much more cost effective to implement, can be structured to offer acceptable levels of accuracy and are based on direct measurement of GHG flows, albeit not measurement undertaken for the offset project. There are numerous examples in protocols, for terrestrial carbon offset projects, in well established offset systems or programs, such as the Climate Action Reserve (CAR), Alberta Offset System, and Voluntary Carbon Standard (VCS), where project proponents are allowed to use either co-efficients and/or computer process models to help quantify the GHG reduction.

A combination of estimation with computer process models and a modest level of direct measurement to help calibrate the models with local conditions appears to offer a suitable combination of quantification accuracy and cost effectiveness for this offset project type.

1.2.1. Grasslands Carbon Sequestration

Within a grasslands system there is a GHG flux cycle consisting of: CO_2 fixation in the above-ground shoots through photosynthesis; release of CO_2 and CH_4 emissions from the above-ground dead litter; transfer of carbon from dead plant matter into the soil organic matter (SOM); carbon released through exudation from growing roots into the SOM; fixation of atmospheric nitrogen and nitrogen in inorganic (fertilizers) and organic (plant litter and manures) forms by soil microbes; and release of N_2O emissions from the soil and denitrified nitrate. The largest amount of long-term storage of carbon occurs in the SOM.

The following table shows estimated annual changes in soil organic carbon (SOC) resulting conversion of annual cropping systems to perennial grasses. All of the estimates demonstrate the positive annual increase resulting from planting grasses.

TABLE 1-1: COMPARISON OF ESTIMATES OF SOC SEQUESTRATION RATES FOR CONVERSION OF ANNUAL CROPPING SYSTEMS TO PERENNIAL GRASSES

Location	Activity	Change rate (Mg C/ha/yr)	Reference
East Central Canada	Conversion to perennial cropping	0.74	VandenBygaart 2008
East Central Canada	Conversion to perennial grasses	2.14	IPCC based calculation reported in VandenBygaart 2008
La Pocatiere, QC	Corn to alfalfa	0.6	Angers 1992
Harrow, ON	Corn to grass	1.07	Gregorich et al 2001
Temperate U.S.	Conversion to grasslands	0.67	CCX 2009
U.S. Average	Conversion to natural grasslands	0.68	Eagle et al 2010

The co-efficient of 2.14 Mg C/ha/yr is based on the IPCC Tier 1 calculation methodology and is clearly larger than the SOC change rate estimate of 0.74 Mg C/ha/yr for Central Canada calculated for the Canadian National Inventory Report (NIR) using the CENTURY plant-soil model. The NIR modeling and the IPCC-based calculation predict that total carbon change will be similar however, 38.2 and 42.8 Mg C/ha, respectively (VandenBygaart et al 2008). The NIR model-based estimation shows sequestration occurring at a lower annual rate over a longer time period than the higher annual rate and shorter 20 year total time period assumed under the IPCC Tier 1 methodology. A SOC stock change of 37.6 Mg C/ha measured over 35 years (1.07 Mg C/ha/yr) is an example of a longer time frame empirical result and comes from Gregorich et al (2001).

In eastern Canada, empirical research results from Harrow (and also Elora and Woodslee) indicate that SOC changes are higher when converting a given annual cropland (e.g. corn) to a perennial grass (e.g. bluegrass) rather than alfalfa or legume crops. However, the number of research data points is small for eastern Canada.

The meta-analysis estimate of 0.68 Mg C/ha/yr for conversion to natural grasslands from Eagle et al is mainly based on croplands converted back to natural landscape or “set-asides” within the U.S. federal government’s Conservation Reserve Program (CRP). It is worth noting that this average SOC change rate for conversion to natural grasslands (0.68 Mg C/ha/yr)) is in the range of the Canadian values for natural grasslands (0.43-0.94 Mg C/ha/yr) and similar to the default factor of 0.67 Mg C/ha/yr used in the CCX conversion to grassland protocol and the CENTURY model estimated co-efficient of 0.74 Mg C/ha/yr for Central Canada prepared for the NIR.

1.3. Key Protocol Elements[1]

A protocol provides rules and guidance for quantification and monitoring of the GHG reduction resulting from the conversion of marginal croplands to native grasslands.

This section of the report is divided into seven key topics that are either critical protocol elements or directly related to fulfilling well-established criteria underlying high quality offsets. Verification and crediting are not protocol elements *per se*, but several protocol elements will be designed based on verification and crediting features (e.g. monitoring procedures or crediting period). The seven topics are as follows:

- Offset project boundary
- Estimation, measurement and monitoring
- Baselines and additionality
- Leakage
- Permanence and risk of reversal management
- Verification
- Crediting

This work was guided by best available practices in protocol preparation, including the directions and guidance of the ISO 14064-2 standard. It also draws from the knowledge and experience of those who have been involved in preparing and developing offset protocols, standards and projects in the terrestrial carbon sector.

1.3.1. Offset project boundary

In an offset project (or in any carbon balance exercise), the boundary is delineated by the sources, sinks and reservoirs (SSRs) that are controlled by an offset project operator and affected by and related to an offset project. The emission reductions of an offset project represent the balance of the carbon exchanges between the carbon reservoirs (also called “pools”). An examination of the carbon budget of a reservoir can provide information about whether the reservoir is functioning as a source or sink for CO_2. Once the SSRs are completely defined, the boundary of the project activity is also defined and only direct reductions occurring within this boundary will be eligible for crediting.

Soil organic matter pool (SOM) must be an included or required pool in a grasslands conversion protocol as it accounts for the majority of annual GHG change according to the scientific literature review [2] (Follett et al 2001; Parton et al 2001). Below-

[1] The material in the executive summary only covers introductory material in regard to each protocol element. Please see the report text for the material on how current and in development protocols address these topics, and the issues and options for addressing the topics within a conversion to native grasslands protocol.
[2] Pers. Comm. A. VandenBygaart 2011-02-07

ground biomass is recommended to be designated as an optional pool. Live above-ground herbaceous (non-woody) biomass and dead litter biomass should be designated as excluded carbon pools.

North American protocols generally adhere to the principles and structure in the ISO 14064-2 protocol standard for identifying and classifying SSRs that compose the offset project boundary.

1.3.2. Estimation, measurement and monitoring

Quantification and monitoring procedures are fundamental to a grassland protocol in order to assure the accuracy and conservativeness of estimates of baseline and project emissions and removals. There is a wide range of methods available for estimation, measurement and monitoring and they can be generally classified as direct measurement (field sampling and analysis) or indirect estimation (computer modeling and default values).

Field measurement includes taking periodic soil samples to estimate soil carbon stocks over time and directly measuring emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) gases in the field (e.g. using gas chambers that capture and analyze gas samples).

With certain offset systems (e.g. Alberta Offset System) the use of standard default factors have been widely accepted to estimated SOC change due to changes in agricultural management practices.

The Canadian and U.S. National GHG inventory processes use the CENTURY plant-soil model to quantify SOC and N_2O change arising from agricultural land use changes. Largely relying on biogeochemical computer models has emerged as a key basis for estimating *ex ante* and *ex post* project reductions for terrestrial carbon offset projects because of the sophistication, peer-reviewed science and measurement cost effectiveness of these models.

A typical approach with high quality terrestrial protocols is to require a certain level of field sampling in combination with modeling. An option is to require periodic field measurements during a project in order to improve the model's local calibration. Use of field specific data and measurements (NPP, shoot to root ratios, and soil characteristics) to calibrate models improves the accuracy of their estimates of SOC, under-ground biomass carbon and N_2O emissions.

1.3.3. Baselines and additionality

The baseline scenario is a quantitative representation of what would have happened in the project's absence. The baseline is intrinsically hypothetical and the difference between this hypothetical scenario and the actual scenario (project) represents the reductions or removals that could be credited as offsets. The baseline scenario is intimately linked with the concept of additionality, since a project is deemed "additional" when the project emission reductions are incremental to those that would have occurred under the baseline scenario. An offset protocol must describe how to develop appropriate baselines and assess additionality.

There may already be a certain proportion of marginal lands in a region that have been converted in recent times to perennial grasses. Where there is a smaller level of penetration and grasslands conversion is not viewed as common practice then the practice could be viewed as additional.[3] If the penetration level is fairly high, a level that would have to be stated in the protocol, then a discount factor could be applied to the amount of offsets received by each project based on the level of conversion in the region.

A grasslands protocol performance standard could be defined as a percentage of the croplands area involving native grasslands areas. In this case the additional changes in management or land-use are rewarded and landowners who took early action but want to convert more marginal farmlands to grasslands are not excluded.

1.3.4. Leakage

Leakage typically refers to GHG emissions that are shifted from a project area to an area outside of the offset project boundary as a result of project activities thereby partially or completely cancelling the GHG benefits generated by the project. These emissions are not taken into account as "project emissions" and this is why they have to be accounted for as "leakage" and deducted from the calculated baseline emissions in order to obtain the net emission reductions.

A grassland management project involving grazing reduction could involve a shift in grazing activity to another grassland area under the control of the proponent (internal leakage) or another area outside of the project boundary (external leakage). Leakage can be addressed through adequate project design (e.g. incorporating project activities that reduce pressure on other lands) and any resulting leakage must be accounted for and considered as project emissions.

For conversion to grassland projects, it can be assumed *ex ante* that no activity-shifting leakage will occur, especially for smaller-scale projects (e.g. ≤ 10,000 ha). Lands retired from cropland to grassland are marginally productive, which reduce considerably the risk of leakage compared to more productive lands. As stated in CCX and VCS grassland protocols, documentation could be required of a project proponent to prove that no internal leakage is occurring at the moment of verification.

[3] Subject to meeting a protocol's other additionality conditions

1.3.5. Permanence and risk of reversal management

Agricultural offset protocols must contemplate procedures to provide adequate assurance that carbon credits will be valid given that grasslands are ecosystems susceptible to natural and human disturbances.

Permanence risks are unique to terrestrial carbon offset projects as well as carbon capture and storage projects. Agricultural protocols must therefore include provisions and methodologies for assessing and managing carbon storage reversal risks. Several issues have been identified as needing attention in addressing reversal risks, including:

- Assessing and measuring risk of reversal
- Managing risk of reversal
- Liability for reversal
- Replacement of credited offsets when a project's carbon storage is intentionally or unintentionally reversed
- Due diligence required to ensure that the program authority does not bear disproportionate risk
- Monitoring of intentional and unintentional reversals during the crediting and post-crediting periods

An option that could represent a good balance between environmental integrity and economic efficiency is a "risk-based" approach to managing reversals and permanence issues. A risk-based approach is commonly used in insuring other products and processes (e.g. automobiles, houses and health from fire, flood, hurricanes, etc.). Statistical estimates of risk, based on historical data or prediction tools are used to devise actuarial tables and risk premiums. Similar techniques have already been considered for offset projects (e.g. CAR). This approach is much more project specific and does not penalize low-risk projects, however its implementation is more costly since it requires the recollection of large sets of historical data and/or the use of actuarial models.

The most common protocol option is to consider repayment by project owners for intentional reversals. Change in grasslands management requirements and practices may be readily identifiable as "intentional" but the change however may actually be caused by natural factors. The simplest way to address the matter is to clearly pre-define each category into verifiable distinctions.

Another option to overcome difficulties associated with estimating reversal risks and assigning liability for reversals is to issue "partial credit" for stored carbon based on the length of time it is deemed to be stored. For example, one tonne of CO_2 stored for 20 year would receive 20/100ths of a credit. This approach does away with treating reversals as a liability thereby enhancing project attractiveness for both investors and project developers. An issue however is that it is not obvious how storing 1,000 tonnes of CO_2 for ten years (after which the CO_2 is emitted) may be equivalent to permanently reducing 100 tonnes of CO_2 emissions.

Due to the biological process length behind the carbon sequestration dynamics in grasslands, a lengthy monitoring period of carbon stocks is needed for such project-based offsets in order to be considered as permanent and fully fungible with projects that generate reductions that are clearly permanent. A WCI compliant protocol would have to use a term of 100 years.

1.3.6. *Verification*

Once the project activity is implemented and effectively reducing emissions, the emission reductions (or removals) initially claimed by the project participants must be verified by a third party in order to generate offset credits. Among all the different existing offset systems, the verification process tends to have more or less the same features although the requirements and criteria for accreditation of the third party and the verification procedures may vary slightly. The verification is carried out by an independent accredited third-party.

The verification of grassland conversion and management practices can be a combination of site visits and desk audits conducted by the verifier that incorporates simple visual checks.

For most offset project types, a verification event is required every year however the situation differs for agriculture and forestry projects where annual change in a project reduction may be relatively small and occur non-linearly. The length of the interval between two verifications should not affect the accuracy and robustness of the reduction claims, as long as the interval is not excessively long and major changes in carbon stocks (e.g. after natural disturbances occur) are properly monitored and reported to the offset's system authority when they occur. Allowing for the proponent to choose the periodicity of verification may be an attractive option since it allows the proponent to tailor the costs associated with verification to the project budget.

1.3.7. *Crediting*

Once the emission reductions are recognized by a given standard or offset system, "credits" are issued to the project participants (1 credit for 1 tonne of CO_2e). In existing compliance-based and most voluntary offset schemes, the credit issuance is *ex post*, i.e. after the verification of carbon reduction activities.

The crediting period of a grassland project should be based on the "sequestration duration" of the project, ie. how long the project can sequester incremental amounts of carbon before reaching a steady state[4]. Dormaar and Smoliak (1985) and

[4] When SOM associated sequestration and CO_2 emissions are roughly equal on an annual basis and there is very little or no incremental additions to storage of SOC.

McConnell and Quinn (1988) each reported that it took 50 plus years for cropland converted to native grasslands to approach the SOC levels of native rangeland.

An option that allows for changing circumstances in the baseline is to use renewable crediting; in this instance allowing for multiple crediting periods. The WCI offset design allows for a maximum crediting period of 100 years, which could incorporate for 25 year crediting periods.

2. Introduction

Grasslands management strategies (including conversion of croplands to grasslands, avoided conversion of grasslands and improved grasslands management), on a worldwide basis have received significant attention as a GHG reduction strategy (Internationally – Hendrickson 2003; Conant 2010; Canada - McConkey et al 1999; Australia - Russell and Williams 1982 and Gifford et al 1992; New Zealand - Tate et al 1997; Portugal - Teixeira et al 2008; and U.S. - Conant et al 2001 and Eagle et al 2010). The objective of this project is to identify, research and describe technical requirements and issues for a quantification and monitoring protocol focused on conversion of croplands to native or natural grasslands offset projects in southern Ontario.

The direct sponsors of this protocol framework project are Norfolk ALUS and Delta Waterfowl Foundation. The latter is a Winnipeg headquartered non-profit organization primarily focused on supporting research into Canadian and U.S. wetlands ecosystems. The former is a southern Ontario farm producer supported organization focused on promoting and implementing Alternative Land Use Services (ALUS) of marginal agricultural lands. The Ontario Ministries of Environment and of Agriculture, Food and Rural Affairs participated through their representation on the project's steering committee. Funding for the project was cost shared by The W. Garfield Weston Foundation and Environment Canada.

The framework focuses on the likely quantification and monitoring requirements and issues for conversion to grasslands offset projects in the Norfolk County area of southern Ontario but its concepts have general applicability for native grasslands conversion offset projects. The research is not directed at developing a protocol for one particular offset system. However, the Ontario Government is developing a cap and trade system that is consistent with its participation in the Western Climate Initiative (WCI) and agricultural offset projects are one of the WCI's designated acceptable offset categories so WCI system design expectations and directions[5] are referenced in this framework.[6] As well, there is ongoing interest from larger corporations in acquiring offsets from terrestrial carbon offset projects that help sustain natural ecosystems. North American located projects that use Voluntary Carbon Standard (VCS) approved methodologies and registration or Climate Action Reserve (CAR) protocols and registration are particularly favoured by these voluntary market buyers so the general requirements of each of these offset programs are also referenced in this framework.

---

[5] See http://www.westernclimateinitiative.org/component/remository/func-startdown/277/

[6] The WCI's *Offset System Essential Elements Final Recommendations Paper* states that only protocols that have been approved within the WCI's protocol review process can be used to create that can be used for compliance in a partner's (such as Ontario) cap and trade system. See pg 1 of this document.

The project's research is guided by current best practices and builds on the knowledge and learnings of scientists researching various aspects of grasslands ecosystems and management and business and government entities that have worked on various aspects of terrestrial carbon offset projects. In the course of research and writing this document its authors communicated with a total of 45 scientists, researchers and consultants and reviewed approximately 140 reports and peer-reviewed articles.

The framework is divided into two sections: the first presents the North American state of scientific understanding on matters pertaining to GHG flux in native grasslands that are relevant to offset project quantification and the second presents the issues associated with and options for addressing each key element of a conversion to grasslands offset protocol.

3. STATE OF SCIENCE ON GRASSLANDS GHG SEQUESTRATION AND EMISSIONS

3.1. Introduction

3.1.1. Purpose

This section focuses on the availability and quality of suitable information and data that could be used to help quantify the GHG reduction of an offset project featuring conversion of croplands to native or natural grasslands in southern Ontario.[7]

The success of an offset project depends on an accurate and conservative[8] quantification of its GHG emissions and removals within the boundaries of the offset project. Techniques for estimating GHG emissions and removals can be divided into two broad categories, direct measurement and indirect estimation. While techniques and technologies for directly measuring carbon storage and GHG fluxes in soils and plant ecosystems are available and often precise in terms of estimation accuracy, they are expensive and often time consuming to implement, and in the case of eddy covariance, require specialized scientific expertise[9], hence indirect estimation approaches have been considered as an option for estimating the GHG emission reduction achieved by agricultural land use management changes.

The direct measurement approaches are the following (Janzen et al 2006).

- Soil core sampling – involves carefully collecting many samples of soil cores across a project area to achieve desired statistical accuracy targets for results. Soil samples are air-dried, passed through a fine sieve and dry combusted prior to laboratory analysis. This approach is used to estimate carbon storage in soils [10] but does not offer an overall way of determining GHG flux.

[7] This protocol framework focuses on grasslands that would be left in a natural state, possibly used as a conservation buffer, but not used as an extensively or intensively managed pasture for grazing livestock or intensively managed as a bioenergy feedstock. If the grasslands are managed for grazing or bioenergy purposes then the SSRs associated with these activities should be included in the project's offset boundary.
[8] Within the context of quantifying carbon offset projects the concept of conservativeness has a specific meaning that comes from the direction in Section 4.3.7 of the ISO 14064-2 standard that a project proponent should use conservative assumptions, values and procedures to ensure that GHG emission reductions or removal enhancements are not overestimated.
[9] See pg 27 of Goldenfum June 2009
[10] Another technique for quantifying root biomass and carbon is to insert minirhizotron tubes and use video cameras and specialized software to record and analyze root length and decomposition (Stewart and Frank 2008)

- Gas chambers – is a field level sampling technique for capturing samples of GHGs, including CO_2, N_2O and CH_4, in order to estimate their fluxes.[11]
- Eddy covariance towers – is a micro-metereological technique that measures and calculates fluxes of GHGs in the atmosphere at or near the ground level.

The indirect estimation approaches fall into two categories. The first one is the use of sequestration or emission default factors mainly calculated from results of experiments involving direct measurement of GHGs or soil and biomass carbon. The other approach is the use of biogeochemical computer models that calculate key biomass growth, carbon, CH_4 and N:N_2O parameters for plant and soil systems. Although these estimation methods are not as accurate as direct measurement techniques they are much more cost effective to implement, can be structured to offer acceptable levels of accuracy for offset programs and incorporate results of experiments that use direct measurement of soil and biomass carbon and GHGs. There are numerous examples in protocols for terrestrial carbon offset projects in well established offset systems or programs, such as the Climate Action Reserve (CAR), Alberta Offset System, and Voluntary Carbon Standard (VCS), where project proponents are allowed to use either default factors and/or computer process models to help quantify the project GHG reduction.

3.1.2. Grasslands GHG change

The primary offset project type of interest for this project is the conversion of lands used for cropping systems into natural or native grasslands in southern Ontario. The tallgrass prairie systems covered large parts of the Canadian and U.S. prairies, and parts of southern Ontario prior to the migrations in the early 1800s of European settlers who converted much of them to annual cropping systems (Janzens et al 2008).

The baseline or business-as-usual condition is use of offset project lands for annual crops, such as corn, rye, barley, soybeans and tobacco. Offset project proponents would convert these annual cropping systems to native perennial grass systems, especially tallgrass prairie systems composed of a diversity of species such as Indiangrass, Switchgrass and Big Bluestem. They are classed in the C-4 grass photosynthetic group, more commonly called warm season grasses.

Recognition of the relative importance of this strategy (and its converse, avoided conversion of native grasslands to croplands or uses) to help mitigate climate change is the research of the Intergovernmental Panel on Climate Change (IPCC)[12] and Canadian and U.S. government groups on quantifying agricultural land use management changes for national GHG inventories.

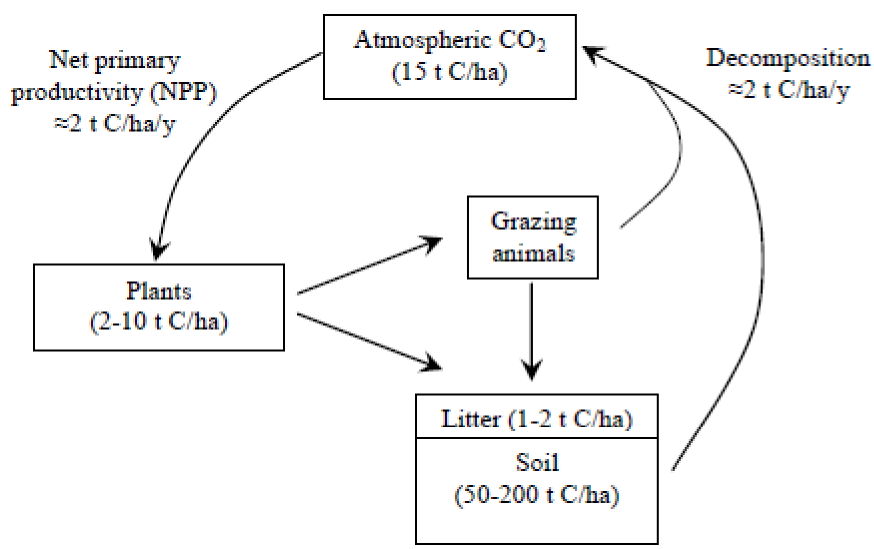
[11] Ambient clean air samples are also collected to approximate time zero concentration of each gas.
[12] IPCC is the leading international organization studying climate change and was established by the UN Environmental Programme (UNEP) and the World Meteorological Organization (WMO).

An estimated 89% of the global mitigation potential in agriculture is through the accumulation of carbon in the soil (Smith P. et al 2008). Dr. Andrew MacDougall, a research scientist at the University of Guelph, compares a prairie swath to an iceberg, 90% of the activity is below ground, primarily in the soil organic matter (SOM) pool.[13]

Within a grasslands system there is a GHG flux cycle consisting of: CO_2 fixation in the above-ground shoots through photosynthesis; release of CO_2 and CH_4 emissions from the above-ground dead litter; transfer of carbon from dead plant matter into the SOM; carbon released through exudation from growing roots into the SOM; fixation of atmospheric nitrogen and nitrogen in inorganic (fertilizers) and organic (plant litter and manures) forms by soil microbes; and release of N_2O emissions from the soil and denitrified nitrate..

The largest amount of long-term storage of carbon occurs in the SOM as shown in the illustrative figure below. This example shows the approximate annual CO_2 flux on a per hectare basis arising from grassland use of atmospheric CO_2 and CO_2 emissions from decompostition (mainly from the dead litter) and the per hectare carbon storage in above- and below-ground plant biomass and the soil.

FIGURE 3-1: GRASSLAND CO_2 FLUX AND STORAGE [14]



Grassland soils gain organic matter and its associated carbon through growth, death and decomposition of the above- and below-ground biomass of grass plants. Figure 3-2 on the next page is a simplified illustration of the carbon cycle for native

[13] See http://www.uoguelph.ca/news/2010/08/prof_turns_soyb.html
[14] Source: Bremer December 2008, see pg 1

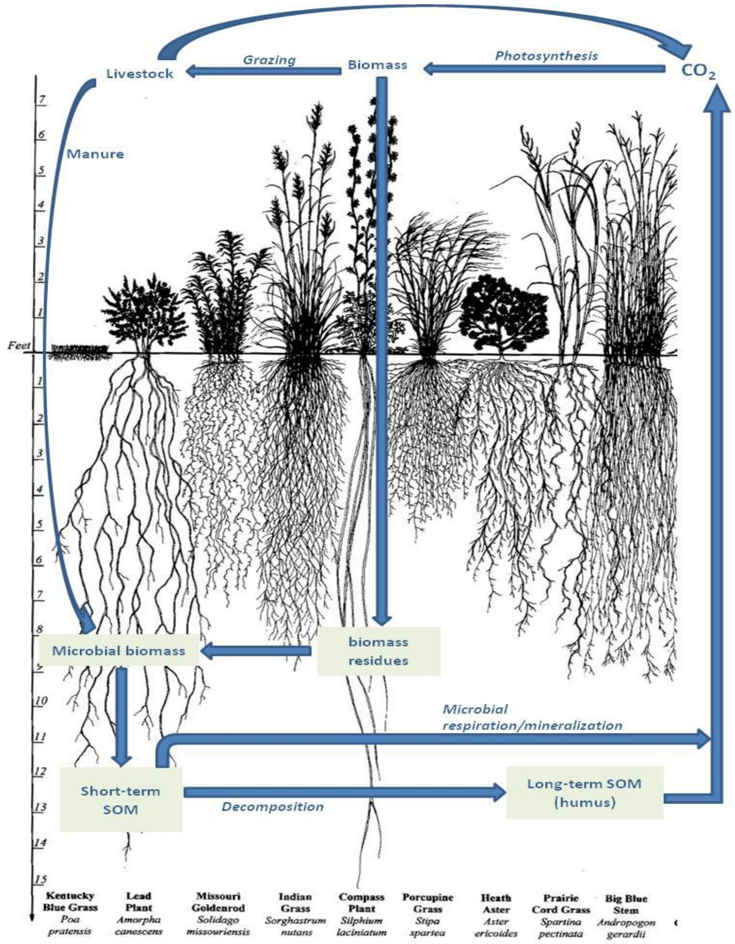
grasslands.[15] Through photosynthesis, the grassland cover captures atmospheric CO_2. The carbon is fixed in the herbaceous above-ground biomass (plant shoots, stems, leaves) and the below-ground biomass (roots and shoots). Ultimately, the volume in these biomass pools represents the difference between the fixation of atmospheric carbon (input) and the death and decomposition of plant biomass (output).

As shown in the figure, the biomass residues then decompose in the soil and a portion of the carbon initially fixed in the biomass ends up in the soil organic matter. This is called Soil Organic Carbon (SOC). If the grasslands are used for grazing then there can also be forage wastage during grazing and manure deposition, which will also partly convert into SOC and emit methane (CH_4), another GHG.

It is generally accepted that within a year up to 50% of the biomass carbon (both roots and above-ground biomass) dies, decomposes and results as residues in the SOC pool (Follett et al 2001). The above-ground herbaceous biomass dies each autumn and regenerates each spring in temperate perennial grasslands and their root systems also have a rapid turnover but on a longer time scale, an estimated 55% of temperate grassland root biomass turns over annually (Gill and Jackson 2000; Gill et al 2002). Thus, the size of the SOC pool for any given state of the plant-soil system represents the difference between input of the fixed biomass carbon from decomposed plant residues and other organic carbon sources (such as manure) and output as oxidative decomposition of SOM (Follett et al 2001).

[15] This figure shows images of the following grass varieties: Kentucky Blue Grass, Lead Plant, Missouri Goldenrod, Indian Grass, Compass Plant, Porcupine Grass, Heath Aster, Prairie Cord Grass, Big Blue Stem.

FIGURE 3-2: SCHEMA OF A GRASSLAND CARBON CYCLE[16]



Many factors typically affect the carbon uptake of grassland ecosystems, including: growing season length, rainfall, temperature, soil type, grass species and diversity and grazing-induced shifts in species composition and production. Soil organic carbon is generally low where microbial activity[17] is high (such as in warm and humid ecosystems), while enhanced SOC levels are observed where microbial activity is low but where sunlight, nutrients and water are abundant.

Grasslands SOC can decrease due to disturbance factors, such as fire, drought, disease or excessive forage consumption by grazing. Several management practices have also been demonstrated to increase SOC or reduce carbon losses, including fertilization, irrigation, intensive grazing management and planting forage grasses and legumes.

[16] Illustration provided by Heidi Natura of the Conservation Research Institute - http://www.cdfinc.com/Conservation_Research_Institute

17 The activity of microscopic organisms that are responsible for the decay of dead material.

Apart from the enhanced soil carbon sequestration, the conversion of croplands to grasslands also provides numerous co-benefits such as wildlife habitat, improved soil structure, enhanced water quality or increased biodiversity. For example, introduction of conservation buffers into croplands reduce water and sediment run-off by an estimated average of 45% (Arora et al 2010). Because conversion to grasslands often comes at the expense of lost agricultural productivity, this offset project type is usually focused on less productive agricultural lands, where the offset revenues provide sufficient incentive to induce land owners to finance the conversion to grasslands and absorb any foregone agricultural revenues.

3.1.3. Grassland offset project carbon pools

The offset project (or GHG assessment) boundary is delineated by the sources, sinks or reservoirs (SSRs) that are affected by an offset project and ultimately controlled by an offset project operator. Only direct GHG reductions and removals that occur within the offset project boundary are eligible for crediting with an offset. In general, North American protocols adhere to the principles and structure in the ISO 14064-2 protocol standard for identifying and classifying SSRs that compose the offset project boundary.[18]

Conversion of croplands to grasslands can result in both net emissions (*from sources*) or net removals or sequestration of CO_2 in biomass (below-ground and above-ground) and soil carbon pools (or reservoirs). When carbon content reaches a steady-state in a given pool, and this steady-state is maintained on the long-term, it is considered a *reservoir* and its carbon is considered to be sequestered "permanently", although subject to reversal from human sources (tilling of soil for example) or natural disturbance (a wildfire is an example). Grasslands SOC and forests are considered to be important reservoirs and act as GHG sinks when they are not subject to major reversals of their carbon storage.

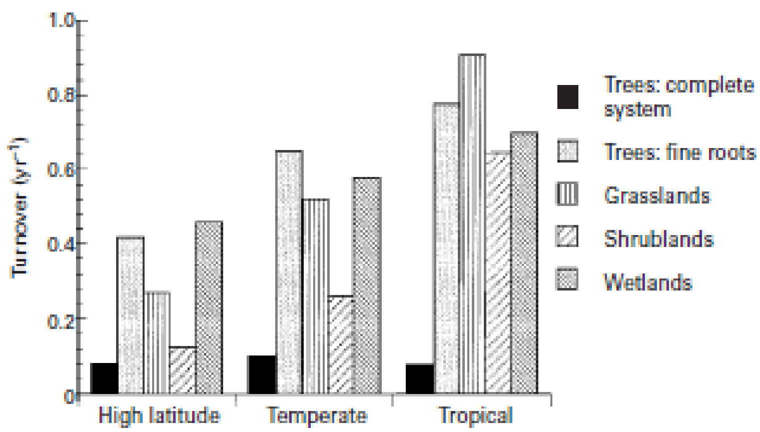
From a carbon offset project accounting perspective, the focus is on the science associated with the measurement or estimation of GHG emissions and sequestration for the selected SSRs in the offset project boundary.

Above-ground herbaceous biomass is a relatively small, transient carbon pool compared to soils (Conant 2010). It is all living, typically, herbaceous biomass above the grassland soil and generally represents only 1% of the total grassland carbon pools (Burke et al 1997). It is a transitory carbon pool with a very rapid turn-over rate (every 1-2 years). The changes in biomass carbon stock from conversion to grassland result from the removal of existing vegetation and replacement with grassland vegetation. A protocol for a conversion to grasslands offset project would not likely require the quantification of this pool.

[18] See Section 4.6 for a more in-depth presentation on the offset project boundary of a conversion to grasslands offset project.

Although between 24% and 87% of the Net Primary Production (NPP) of temperate grasslands is estimated as being accounted for in its below-ground biomass (Sims and Singh 1978), it is also estimated to account for only 11% of the total carbon pool of a grassland system (Burke et al 1997) and has a fast turn-over rate (Stewart and Frank 2008; Gill and Jackson 2000).[19] A meta-analysis of published studies that contained data on turnover of grassland roots calculated an annual turnover rate of 55% (Gill and Jackson 2000). This fast turnover of the root systems of temperate grasslands is attributed to the fineness of their roots and several studies have shown that root diameter is directly correlated with root lifespan (Lauenroth and Gill 2003). A bar chart showing estimated annual root turnover rates by climatic zone and vegetation type is shown below.

FIGURE 3-3: ANNUAL ROOT TURNOVER BY CLIMATE ZONE AND VEGETATION CATEGORY [20]



According to Dr. Rattan Lal[21], below-ground biomass of grasslands is viewed as a transient pool due to very short turn-over rates. Following decomposition, a part of the below-ground biomass carbon ends up in the soil organic matter (SOM) pool and "this is why the SOM pool is considered as an "integrative" pool", he says.[22]

Although C3-C4 grasses have deeper roots than annual crops, root production in grasses declines sharply with increasing depth (Steinaker and Wilson 2008)[23]. Around 85% of root production is concentrated in the first 30 cm of the soil (which is the most common default sampling depth). As well, annual SOC change with grasses

[19] A study of a 3-year long experiment published in 1945 also examined root turnover in temperate grasslands and reported a much lower rate of turnover (Weaver and Zink 1945). This experiment however is based on older research technologies whereas the much more recent research results use more sophisticated research technologies.
[20] Source: Gill and Jackson 2000
[21] Professor in the School of Environment and Natural Resources of Ohio State University
[22] Pers. Comm. R. Lal, 2011-01-19
[23] Steinaker and Wilson's research was undertaken east of Regina (SK), where the native grassland is dominated by Stipa comata (Spear Grass), Agropyron spp.(wheatgrass), Koeleria macrantha (Crested hair-grass), Poa spp. (bluegrass) and Selaginella densa (Lesser Spikemoss).

appears to decrease with greater depth, reaching a modest level beyond the 30 cm depth level (Liebig et al 2010).

SOM is the most significant pool for a conversion to grasslands offset project, both in terms of its relative amount of carbon storage but also in terms of the duration or permanence of its storage. Carbon fractions of the SOM have much longer residence times (200-1,000 years), compared to plant biomass therefore changes in these fractions have the largest effects on the capacity of grassland ecosystems to sequester carbon on a long-term basis (Reeder et al 2001; Canadell et al 1996). In the context of an offset protocol, the long-term carbon sequestration in the SOM pool contributes to mitigate the risk of non-permanence, as opposed to above-ground biomass or below-ground fine roots, which both are subject to unintentional reversals and short turnover time frames. The Canadian and U.S. national GHG inventory processes quantify only SOC change and not above or below-ground biomass change for grassland land use change.

Soil organic matter includes organic carbon in mineral and organic soils to a specified depth (IPCC 2006). Live fine roots (of less than 2 mm diameter) are included with soil organic matter where they cannot be distinguished from it empirically. Soil organic carbon is the carbon stored within the SOM pool.

In some grassland systems there will be long-lived trees so an offset system that incorporated the planting of them would create three reservoirs, one based on the SOC, another based on below-ground biomass of grasses and the other in the above- and below-ground biomass of the long-lived trees.

3.1.4. Reduced N_2O emissions

N_2O is an important GHG having 310 times the Global Warming Potential (GWP) of CO_2. The N_2O:N flux in agricultural and grassland systems is a small but important part of their total GHG flux.

Nitrogen is a primary plant nutrient and in a grasslands ecosystem almost all is organically bound but only about 3% exists as part of the living plant as the remainder is a component of SOM (Bellows 2001). Nitrogen becomes available for the growth of grasses and crops through the natural plant process of nitrogen fixation, nitrogen fertilizer applications, manure application and mineralization of organic matter in the soil.

Since N_2O emissions from grassland soils are a minor GHG source compared to N_2O emissions from croplands, a conversion to grasslands project will result in lower N_2O emissions than the business-as-usual cropping system.. They are higher for croplands as a result of the use of nitrogen rich materials, nitrogen fertilizers and animal manure, the decomposition of crop residues and the tillage of soils (Rochette et al 2008). There is a normal nitrogen cycle and human actions, such as conversion of grasslands to croplands, and, of most importance in North America, the application of N inputs on farmlands and N fixation of crops, are the cause of 70% of N_2O emissions into the atmosphere (Mosier 1994).

3.1.5. Sources of quantification information and data

In this document we present information on the results of empirical science research into SOC sequestration and N_2O emissions that occur as a result of converting croplands to grasslands. These empirical results are first presented because they are some of the main pieces of scientific research that are the basis of construction of default emission/sequestration factors and SOC and plant production computer models.

The following sections of this report are divided as follows to present the state of science that can possibly facilitate the quantification of conversion to natural grasslands offset projects in southern Ontario.

- Empirical science research results for Canada and the U.S.
- Default emission/sequestration factors
- Canadian National Greenhouse Gas Inventory co-efficients
- Soil-plant computer models
- Underway research in Canada on grasslands sequestration and GHG flux

3.2. **Empirical science research**

3.2.1. Canadian research on SOC impact of conversion to grasslands

It is now widely recognized that perennial vegetation enhances carbon sequestration in soils compared to annual crops. This phenomenon is explained by several mechanisms. First of all, soils of grassland systems are not ploughed as are many annual crop systems, thereby reducing the mineralization of the organic matter. The above and below-ground perennial biomass is renewed over relatively short time frames, allowing the accumulation of soil organic matter. Year after year, the organic carbon is therefore prevented from oxidation or microbiological decomposition, and thus a larger portion is ultimately stored in the soil layers. Furthermore, C-4 grasses generally have deep, extensive root systems which help prevent erosion and therefore enhance the permanence of carbon storage in soils.

Dr. William Deen, research scientist at the University of Guelph, recommends a shift to a more diverse rotation that includes high-biomass crops, perennials and legumes. "Our data clearly demonstrate that if you want to alter soil carbon, the best way to do it is not by altering your tillage system, but by altering your rotation"[24]. For instance, a corn/soybean/wheat rotation will not retain as much soil carbon as a corn/soybean/wheat/red clover rotation. Other practices involving perennials, such

[24] see http://www.topcropmanager.com/content/view/4240/

as conversion to pasture utilizing cultivated forages and hay[25] and native grasslands, has also been shown to increase SOC stocks in southern Ontario.

There have been several research undertakings in Canada evaluating the SOC implications of converting croplands to different types of C-3 grasses. The research on C-4 grasses consists of fewer endeavors, however. The research on grasses whether, C-3 or C-4 grasses, has mainly occurred in Alberta and Saskatchewan, and few took place in central Canada. There is underway research on C-4 grasses in Ontario but the focus is on their bioenergy applications. One long-term tallgrass prairie research project got underway in 2010 at the University of Guelph and another is in the planning stages at the University of Western Ontario.

A recent SOC measurement project by VandenBygaart et al involved the sampling of 27 Long-Term Agroecosystem Experiments (LTAE) across Canada (2010). Seven LTAEs were sampled comparing perennial grass cover to annual cropping and it was found that SOC stocks[26] were 9.0 Mg[27] C/ha higher under perennial cropping after an average of 16.9 years, which gives an average SOC stock change (sequestration) factor of 0.6 Mg C/ha/yr.[28]

Table 3-1 summarizes SOC change factors for conversion of croplands to grasslands in central Canada and Canadian prairie locations.[29] The table's sequestration results range from 0 to 1.40 Mg C/ha/yr and cover a range of species of legumes or grasses - such as Crested Wheatgrass, Bromegrass or Kentucky Bluegrass, but all are C-3 (cool season) grasses.

[25] Generally alfalfa grass mixture cut
[26] in the 0−30 cm layer, which is a typical depth for sampling in grassland SOC experiments
[27] Mg is a megagram or a tonne (t)
[28] Sequestration or stock change rates are almost always reported as annual averages in the peer-reviewed science literature. However the sequestration occurs at a non-linear rate over time.
[29] The data was sourced from peer-reviewed science journals.

TABLE 3-1: CANADIAN EMPIRICAL RESEARCH ON SOIL CARBON CHANGE (SOC) FOR CONVERSION FROM ANNUAL CROPS TO PERENNIAL COVER OR INCLUSION OF PERENNIAL SPECIES IN ROTATIONS

Location	Activity	Change rate (Mg C/ha/yr)	Reference
Harrow, ON	Cont. corn vs. continuous grass (Poa Pratensis L.)	1.07	Gregorich et al 2001 Sourced from VandenBygaart 2008
Woodslee, ON	Continuous corn vs. Legumes in rotation	0.40	Gregorich et al 2001 sourced from VandenBygaart 2003
Elora, ON	Corn vs. Alfalfa	0.32	VandenBygaart et al 2010
Elora, ON	Continuous corn vs. Legumes in rotation	0.22	Yang and Kay 2001 from VandenBygaart 2003
La Pocatière, QC	Corn vs. Alfalfa	0.60	Angers 1992
Lethbridge, AB	Wheat vs. Crested wheatgrass	0.23	VandenBygaart et al 2010
Three Hills, AB	Annuals vs. Bromegrass	0.93	VandenBygaart et al 2010
Three Hills, AB	Annuals vs. Bromegrass/alfalfa	0.79	VandenBygaart et al 2010
Onefour, AB	Fallow-Wheat vs undisturbed native grass (*Stipa-Bouteloua*)[30]	0.6	Wang et al 2010[31]
Lethbridge, AB	Fallow-Wheat vs undisturbed native grass (*Stipa-Bouteloua-Agropyron*)[32]	0.9	Wang et al 2010
Swift Current, SK	Fallow-Wheat vs native grassland	0.5	Iwassa and Schellenberg 2005
East-Central, SK	Wheat rotation vs native grass (*Bouteloua-Agropyron*)	0.6-0.8[33]	Mensah et al 2003
Scott, SK	Wheat vs. Bromegrass (Bromus inermis Leyss)/alfalfa	1.40	Malhi et al 2003

[30] Experiment based on conversion of grassland to wheat cropping system
[31] Willms et al reported SOC change results of other long-term experiments in this article that were in the same range as the figures presented in this table.
[32] Experiment based on conversion of grassland to wheat cropping system
[33] 12 sites

Bow Island, AB	Fallow-wheat rotation vs Crested Wheat Grass (Agropyron cristatun L.)	0.50	Bremer et al 2002
Swift Current, AB	Fallow-wheat-wheat rotation vs. Crestedwheat grass	0.14	Campbell et al 2000
Breton, AB	Annual crop vs. Legumes in rotation	0.16	Grant et al 2001
Lethbridge, AB	Annual crops vs. hay in rotation	0.16	Bremer et al 1995
Swift Current, SK	Annual crop vs. Legumes in rotation	0.05	Campbell and Zentner 1993
Indian Head, SK	Annual crops vs. hay in rotation	0.18-0.20	Campbell et al 1991a
Melfort, SK	Annual crops vs. hay in rotation	0-0.17	Campbell et al 1991b
Canadian prairies	Seeded grasslands and legumes	0.06-0.08	Lynch et al 2005

Smith et al (2001) measured the carbon sequestration change for cropland conversion to permanent grass (C-3) cover by Canadian soil group, soil texture and crop rotations. Other soil management practices were also researched and conversion to grasses showed the highest carbon sequestration rates compared to no-till, removal of all fallows and fertilization practices. Soils of southern Ontario are dominantly luvisolic (gray brown luvisol), gleysolic (humic gleysol) and slightly brunisolic (melanic brunisol) in the north part of southern Ontario. Soils of Norfolk County are predominantly luvisolic (gray brown luvisol)[34] and their annual sequestration rate was estimated as 0.503 Mg C/ha/yr.

TABLE 3-2: SOIL CARBON CHANGE (MG C/HA/YR) FOR CONVERSION TO GRASSLANDS BY VARIOUS SOIL GROUPS, SOIL TEXTURES, AND CROP ROTATIONS

Soil Type	Crop rotation[35]	Texture	Mg C/ha/yr	Average
Gray Brown Luvisol	MMBB	Sandy loam	0.439	**0.503**
		Loam	0.589	
		Clay Loam	0.731	
	MMHB	Sandy loam	0.379	
		Loam	0.387	

[34] National Atlas of Canada - http://atlas.nrcan.gc.ca/site/english/maps/archives/4thedition/environment/land/041_42

[35] W – wheat, F – summer fallow, C – canola, B – barley, H – hay, M – maize

		Clay Loam	0.491	
Gleysolic	MMBB	Sandy loam	0.387	**0.432**
		Loam	0.524	
		Clay Loam	0.625	
	BBHHH	Sandy loam	0.379	
		Loam	0.322	
		Clay Loam	0.355	
		Loam	1.121	
		Clay Loam	0.944	
	BBHHH	Sandy loam	0.406	
		Loam	0.458	
		Clay Loam	0.505	
Gray Luvisol	CWWB	Sandy loam	0.352	**0.383**
		Loam	0.535	
		Clay Loam	0.6	
	BBHHH	Sandy loam	0.229	
		Loam	0.27	
		Clay Loam	0.311	

Although sequestration in these peer-reviewed studies is reported as a total figure along with the duration in years of the experiment and/or an average annual sequestration rate for the experiment period, sequestration occurs non-linearly over time in SOM. The rate is higher at the outset and slows as the carbon in the SOM reaches a steady state.

The capacity of soil to continue storing organic carbon is limited. Soil sequestration rates typically decrease non-linearly over time and reach a steady state. Burke et al (1995), Dormaar and Smoliak (1985) and McConnell and Quinn (1988) each reported that it took 50 plus years for the SOC of cropland converted to native grasslands to approach the level of native rangeland. By comparison other agricultural land use management changes appear to have shorter time periods before reaching a steady state. Enhanced grassland management strategies, such as irrigation, resulted in an average duration of 33 years before a steady state was reached in another experiment (West and Six 2006). This experiment did not include change in land use cover to perennial grasses. This experiment reported an average duration of 21 years before a steady state was reached in no till soil projects.

Of most interest to this project is conversion of croplands to natural or native C-4 grasses. There are few instances of empirical research on sequestration associated with C-4 grasses in Canada. The ones that have occurred to date were located in western Canada. The sequestration research results ranged from 0 to 0.94 Mg C/ha/yr as shown in Table 3-3.

TABLE 3-3: SOIL CARBON CHANGE FOR CONVERSION FROM ANNUAL CROPLANDS TO NATURAL GRASSLANDS

Location	Activity	Change rate (Mg C/ha/yr)	Reference
Lethbridge, AB	Wheat vs. Native grass	0.62	VandenBygaart et al 2010
Lethbridge, AB	Fallow-wheat rotation vs. Reseeded native grass	0.94	Bremer et al 1994
Bow Island, AB	Wheat vs. Native grass	0.43	VandenBygaart et al 2010
SK (12 sites)	Wheat-based rotations vs. Restored grasslands	0.60-0.80	Mensah et al 2003
Melfort, SK	Fallow wheat rotation vs. 12 yr restored grass	0	Wu et al 2003

The introduction of C3 and C4 grasses is known to increase the SOC sequestration rates compared to those for annual cropland, but the difference in SOC change between C-3 grasses and C-4 native grasses is not well researched. There are conflicting results where literature studies directly compare C-3 and C-4 grasses on SOC storage. A Saskatchewan study showed a SOC level that was 25% higher with C-4 native grasses than C-3 grasses (Christian and Wilson 1999). Tilman et al also reported higher SOC levels for C-4 grasses than C-3 grasses (2006). A couple of other studies from the U.S. came up with results that C-3 grasses had similar or higher SOC levels, however (Cahill et al 2009; Conant et al 2001).

According to MacDougall and Wilson, the cause of these conflicting results is attributed to difficulties in quantifying root production, such as shallow sampling, incomplete recovery of root, and short term rhizotron studies (in press). MacDougall and Wilson showed that compared to C-4 native vegetation, the C-3 grasses can double root productivity but this does not lead to substantive differences in SOC due to differences in root characteristics between C-3 and C-4 species, including more young white tissue, much higher mortality and lower C:N ratios.

The understanding of root dynamics is viewed as an important gap in terrestrial carbon research (MacDougall and Wilson in press; Chapin et al 2009). This gap is well illustrated by the relatively few studies of root production and C storage (MacDougall and Wilson in press). Contrary to expectation, carbon storage is frequently inconsistent with root production as increased root production typically increases its decomposition, and as a result there is no net change in storage (Steinbeiss et al 2008).

3.2.2. US research on Grassland SOC

The U.S. empirical research on SOC change associated with conversion of annual croplands to perennial natural grasslands or legumes or pastures demonstrated similar SOC change rates to the Canadian results. Table 3-4 shows that SOC change rates reported in the U.S. research ranged from -0.18 to 1.17 Mg C/ha/yr; the range of results was 0 to 1.40 Mg C/ha/yr for the Canadian experiments.

TABLE 3-4: SOIL CARBON CHANGE FOR CONVERSION FROM CROPLAND TO PERENNIAL CROP/PASTURE[36]

Location	Activity	Change rate (Mg C/ha/yr)	Reference
US (South Dakota)	Interseed native rangeland with legume	4 yrs: 1.17 14 yrs: 0.67 36 yrs: 0.33	Mortensen et al 2004
US (North Dakota)	Cropland seeded with wheatgrass	0.05	Liebig et al 2010
Texas	Tilled row crops to pasture	-0.18 - 0.82	Martens et al 2005
South Dakota	Cultivation to improved pasture	0.21	White et al 1976
Georgia Piedmont	Grazed vs. hayed bermudagrass	0.43	Franzluebbers et al 2000
Southeastern US	Conventionally tilled cropland convert to perennial pasture	0.73 - 0.95	Franzluebbers 2010
U.S., review	Cropland to pasture	0.4-1.2	Lal 2003
Review of 42 global studies	Conversion of cropland to pasture	1.01	Conant et al 2001

An extensive area of croplands has been taken out of production and converted to "conservation buffers" through the U.S. Conservation Reserve Program (CRP).[37] This area has been planted mainly with grasses for the purpose of reducing erosion, reducing nutrients leakage into waterways, and for wildlife habitat protection. These buffer strips (filter strips, conservation buffers, field borders, contour buffer strips) range in width from 6 to 30 m (Eagle et al 2010).

The potential of set-aside lands to sequester carbon can vary greatly from one piece of land to another since SOC change rates depend on site specific factors, such as

[36] These experimental results were summarized in Eagle et al 2010, Tables 26 and 27
[37] http://www.nrcs.usda.gov/programs/crp/

soil, vegetation, former land use and climate. This land-use change has led to enhanced carbon sequestration as shown in Table 3-5 and provided several co-benefits, such as wildlife habitat, erosion prevention, water quality protection, and aesthetics (Bruce et al 1999; Sperow et al 2003).

TABLE 3-5: SOIL CARBON CHANGE FACTORS FOR CONVERSION TO NATURAL GRASSLANDS[38]

Location	Activity	Change rate (Mg C/ha/yr)	Reference
U.S.	Conservation buffers (CRP)	0.82	Bruce et al 1999
14 sites in 9 states across the historic grasslands region in the central U.S.	Conservation buffers (CRP)	0.60 - 0.90	Follett 2001
Illinois, Indiana, Iowa, Kentucky, Michigan, Missouri, Minnesota, Ohio, Pennsylvania, Tennessee, West Virginia and Wisconsin	Conversion of cropland to grassland	-0.04 - 1.18	Johnson et al 2005
U.S.	Conservation buffers (CRP)	0.25 - 1.09	Lal et al 1999
Georgia	Unharvested land	0.04 - 0.11	Franzluebbers and Stuedemann 2009
U.S.	Conservation buffers (Wetland Reserve Program)	0.19 - 0.70	Lal et al 2003
Wyoming, semi-arid grassland	Cultivation to seeded grass	0	Robles and Burke 1998
Colorado short grass steppes	Cultivation to abandoned field	0.03	Burke and Coffin 1995
U.S. (CRP)	Cropland to grassland	0.61 - 1.28	Murray et al 2005
Colorado and Kansas	Cultivated soils to perennial grass cover	0.9-1.6	McPherson et al 2006
Wyoming	Cropland to ungrazed pasture	-0.125 – 0.81	Reeder et al 1998

38 These experimental results were summarized in Eagle et al 2010, Tables 27 and 28

U.S.	Conversion of all highly erodible land to perennial grass set-aside	0.41	Sperow et al 2003

3.2.3. Improved management of established grassland

While practices such as the use of perennial plants in rotations and the conversion to grasslands can result in greater storage of SOC compared to annual cropping systems, the improved management of already established native grasslands, pastures and rangelands can also lead to additional carbon storage. With established grasslands, good management practices can lead to increased soil carbon by eliminating disturbances to the soil (e.g. reduced grazing pressure) and by increasing primary production (Conant et al 2001). Several management techniques are known to increase forage production for livestock, which have the potential to increase SOM and thus leading to enhanced soil carbon sequestration rates. These improved management practices includes fertilization (Follett et al 2001), irrigation (Martens et al 2005), intensive grazing management (Follett and Reed 2010), and sowing of favorable forage grasses and legumes (Conant et al 2001).

3.3. **IPCC default sequestration/emission factors**

The IPCC has three broad approaches, or tiers, for GHG quantification, named Tier 1, Tier 2 and Tier 3, which are organized on the basis of their methodological complexity and data-demands. For Tier 1 and Tier 2, simple formulas are used to calculate default SOC change factors that are climate zone and region specific, respectively. The data for the IPCC stock change factors were computed through a meta-analysis of a global dataset of experimental studies. Calculations can be undertaken for three types of practices; fertilization, irrigation and sowing legumes or grass species (IPCC 2006).

The calculated SOC default factor for conversion to managed grasslands that would be applicable to eastern Ontario is 2.3 Mg C/ha/yr.[39] This figure is much higher than the empirical results from Canada reported in Section 3.3. The difference arises because the IPCC factors are based on a mathematical aggregation of studies from around the globe, and although the data is dis-aggregated by climate zone and soils, the factors are not specific to Canada.

The Tier 1 calculation for conversion from annual to managed grassland in Ontario (eastern Canada) is a four step process as follows:

i. IPCC value for the starting point croplands is found in Table 2.3 of the IPCC Guidelines (2006) and is 95 t C/ha for high activity clay such as luvisols.

[39] Author's calculation

ii. Grasslands stock change factors FLU, FMG and FI[40] are found in Table 6.2 and are respectively: 1.0, 1.14 and 1.0 for conditions representing improved grassland in Ontario.

iii. Croplands stock change factors FLU, FMG and FI are found in Table 5.5 and are respectively: 0.69, 1.15 and 0.92 for conditions representing an Ontario annual cropland, full till and with low organic input.

iv. Input of these Tier I default values in the IPCC equations:

$$SOC_0 = 95 \times 1.0 \times 1.14 \times 1.0 = 108.3 \text{ t C/ha}$$

$$SOC_{(0-T)} = 95 \times 0.69 \times 1.0 \times 0.92 = 60.306 \text{ t C/ha}$$

Hence:

$$\Delta C = \frac{SOC_0 - SOC_{(0-T)}}{20\ years} = \frac{108.3 - 60.306}{20} = 2.3 \frac{\text{t C}}{\text{ha}}/\text{yr}$$

As well, a SOC co-efficient for a conversion from an annual cropland to a perennial crop[41] can be calculated with the IPCC data and Tier 1 methodology. The land-use factor (F_{LU}) for perennial crops is the same as for grasslands (1.0) but the management factor (F_{MG}) is 1.15 instead of 1.14, and the organic input factor (F_I) is 0.92 instead of 1.0.

$$SOC_0 = 95 \times 1.0 \times 1.15 \times 0.92 = 100.51 \text{ t C/ha}$$

Hence:

$$\Delta C = \frac{SOC_0 - SOC_{(0-T)}}{20\ years} = \frac{100.51 - 60.306}{20} = 2.01 \frac{\text{tC}}{\text{ha}}/\text{yr}$$

The Tier 2 approach uses similar IPCC equations but requires more country-specific and region-specific parameters that better account for geographic differences in temperature, management, soils and other activity-specific conditions.

The Tier 3 methodology uses computer process models and detailed soil carbon inventory measurements as the basis for estimating annual stock changes. A Tier 3 approach may also be developed using a measurement-based approach in which a monitoring network is sampled periodically to estimate SOC stock changes.

---

40 FLU – stock change factor for land use; FMG – stock change factor for management regime; FI – stock change factor for input of organic matter

41 VandenBygaart et al 2008 also estimated the SOC change attributed to a conversion to perennial crop based on the IPCC Tier 1 equation and similar results were shown (2.14 versus 2.01/2.3 Mg C/ha/yr). The small difference may be due to the regional averaging of factors, for instance SOC_{REF} for all eastern Canada.

The Government of Canada uses a Tier 3 methodology to help provide estimates of soil carbon change for Canada's National Greenhouse Gas Inventory Report.

3.4. SOC change factors estimated for Canada's National Greenhouse Gas Inventory Report

Agriculture and Agri-Food Canada developed and maintains the National Carbon and Greenhouse Gas Accounting and Verification System (NCGAVS).[42] Research scientists from Agriculture and Agri-Food Canada use the CENTURY plant-soil model to develop data for NCGAVS, which is used for GHG inventory reporting on Canada's agricultural lands to the United National Framework Convention on Climate Change (UNFCCC) (Janzens et al 2008; VandenBygaart 2008). This modeling helps prepare a Tier 3 estimate of soil carbon stock change for each of four land management changes (LMC).[43]

- Change in area of perennial crops
- Change in area of annual crops
- Change in tillage practice
- Change in area of summer fallow

To estimate carbon emissions or removals associated with each of these land management changes, an SOC stock change factor specific to each combination of Soil Landscapes of Canada (SLC) polygon (the analysis unit) and management change is multiplied by the area of the geographical location subject to change. The factor is the average rate of SOC change per year and per unit of area of LMC[44]. The Canadian SOC change factors are calculated with the CENTURY plant-soil model.[45]

From the CENTURY model calculation, the regional SOC change factor for the East Central region of Canada (Ontario and Quebec) is 0.74 Mg C/ha/yr for conversion of croplands to grasslands (mainly C-3 grasses). The range of calculated sequestration rates across Canada is 0.46 to 0.77 Mg C/ha/yr and reflects the different regional soils and climatic conditions. The following table lists the SOC change factors from the CENTURY modeling carried out by Agriculture and Agri-food Canada to prepare estimates for the Canadian national GHG inventory report.

---

42 See http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1288966652091&lang=eng#l1

43 The U.S. Government also uses the CENTURY model to prepare estimates for its national GHG inventory.

44 Derived from key management practices and management changes data of the Census of Agriculture. A 10-year crop-and-tillage system (CTS) is then constructed for each analysis unit (SLC) and census year, using data from the Census of Agriculture. The CTS is parameterized by seven crops and crop types (grain, oilseeds, pulses, alfalfa, root crops, perennial crops and summer fallow) and three tillage practices.

45 Described in Section 3.10

TABLE 3-6: CANADIAN GHG INVENTORY SOC CHANGE FACTORS BY ZONE FOR CONVERSION TO PERENNIALS [46]

Canadian Zone	Mean Annual SOC Linear Co-efficient (Mg C/ha/yr)
East Central[47]	0.74
East Atlantic	0.77
Parkland	0.55
Semi-arid prairies	0.56
West	0.46

3.5. Conversion to grasslands offset protocols

There are offset systems or programs that have developed or approved quantification protocols for terrestrial carbon project types. Most of these have been focused on forestry project types, such as afforestation, improved forest management, reforestation and avoided conversion. Few terrestrial carbon protocols have been developed for agricultural offset projects to date. The lack of interest has been due to the unwillingness of the main compliance market, the European Union Emissions Trading System (EU ETS) to accept offset credits from agricultural land-based projects. Interest in these types of offset projects is rapidly picking up in North America however because the Western Climate Initiative (WCI) has decided to allow the use of offset credits from agricultural land-based projects to help meet compliance obligations in the emission trading systems of its partner jurisdictions, which includes, California, Ontario, Quebec and British Columbia.

As mentioned in Section 3.2 offset protocols must specify allowable methods for quantifying an annual project reduction from the project type to which the protocol applies. The following sections summarize how the few approved agricultural land use protocols specify the quantification of soil carbon sequestration (or removal enhancements). There is only one approved protocol focused on grasslands conversion so the quantification approaches for offset projects focused on conversion from conventional soil tillage practices to reduced or no till practices are also cited.

[46] Source: National Inventory Report 1990-2008, Table A3-35 (p.135)
[47] Ontario and Quebec

Soil Carbon Sequestration Offset project Protocol – Chicago Climate Exchange (CCX)

This agricultural soil carbon protocol has been active since 2004, and CCX claims that approximately 20 million acres on 12,000 farms were enrolled in its program.[48] The protocol covers activities converting cropland to grassland (annual to perennial crops) and conventional tillage to conservation tillage practices (such as no till and slot tillage). In terms of project take-up, the latter has been overwhelmingly the main focus of activity, not conversion to grasslands. CCX uses the same quantification approach for both offset project types, a CCX-designated SOC change factor that was created through professional evaluation of empirical research. If project proponents adhere to a simple practice standard then they can calculate their offsets by multiplying the standard SOC change factor by the number of acres subject to the new practice (CCX 2009).

The CCX's SOC change factors for conversion to grasslands are 0.67 Mg C/ha/yr for most of the US and 0.27 Mg C/ha/yr for hot-dry areas such as California or Arizona.[49]

Alberta Offset System[50]

Canada's Alberta Province has two approved agricultural protocols: (i) Quantification Protocol for Tillage System Management, (ii) Quantification Protocol for Agricultural Nitrous Oxide Emissions Reductions. It does not have a conversion to grasslands protocol but is examining the technical requirements for implementing a protocol on conversion of annual croplands to perennial forages. The Alberta working group is considering usage of SOC factors from the National Carbon and Greenhouse Gas Accounting and Verification System (NCGAVS), which were developed with the CENTURY plant-soil model.[51]

The Alberta conservation tillage protocol uses a similar practice performance standard framework as the CCX protocol but it draws its SOC change factors from a Tier 3 quantification source.

Ducks Unlimited

Ducks Unlimited (DU) has developed an offset project called "Avoided Grassland Conversion Project in the Prairie Pothole Region"[52]. It has submitted this project to the Climate, Community and Biodiversity Alliance (CCBA), headquartered in Arlington, Virginia, for approval under its offset standard, which is focused on

[48] Its new owners decided in late 2010 to wind down its operations, including its offset program.
[49] See page 61 of CCX 2009, the factors are given in t per acre per year and have been converted here to Mg C/ha/yr for ease of comparison in this report.
[50] http://www.carbonoffsetsolutions.ca
[51] Pers. Comm., S. Nolan, December 29, 2010
[52] http://www.climate-standards.org/projects/files/20090323_du_agc_ccba_final_for_release.pdf

community and biodiversity benefits of voluntary offset projects. This is not a quantification protocol or standard. However it does require quantification of a project consistent with the ISO 14064-2 Standard.

Ducks Unlimited submitted a project report that includes quantification of the project's enhanced sequestration, based on IPCC SOC factors (Ducks Unlimited et al March 2009). The SOC factors range from 0.5 to 1.475 Mg C/ha/yr, depending on the climate zone of the Prairie Pothole region (cool-moist dry and cool-moist temperate, respectively).

In December 2010, VCS announced its intention to incorporate an avoided grasslands conversion category into their Agriculture, Forestry, and Other Land Uses (AFOLU) guidelines. Once this process is completed, Ducks Unlimited intends to submit a methodology to VCS for approval and to quantify its project reductions using this new VCS approved methodology.[53]

VCS – Voluntary Carbon Standard[54]

The VCS has developed requirements for a new AFOLU category covering the Avoided Conversion of Ecosystems (ACE), specifically non-forested areas such as grasslands. Eligible ACE activities are those that reduce net GHG emissions by reducing or avoiding the conversion of non-forested, native or natural ecosystems to other land uses with lower carbon densities. It has not approved any approved agricultural land use change methodologies (protocols) to date but several are at various stages in its double approval process and are listed in the following table, along with their GHG quantification approaches.

[53] Pers. Comm.. R. Dell, January, 2011

[54] As of March 1, this organization will be formally known as Verified Carbon Standard.

TABLE 3-7: VCS AGRICULTURAL LAND MANAGEMENT METHODOLOGIES

VCS Methodology or scoping document	Quantification Basis	Status
ALM Adoption of Sustainable Grassland Management through Adjustment of Fire and Grazing	IPCC Tier 3 soil methodology-based modeling of project soil C sequestration. Periodic sampling and analysis of actual soil C flux must occur within 3-10 years of project implementation.	VCS first assessment
Quantifying N2O Emissions Reductions in US Agricultural Crops through N Fertilizer Rate Reduction	Peer-reviewed science (one article already published (Miller et al 2010, see above), two more in press. IPCC guidelines, supplemented with empirical field data in Tier 2.	VCS first assessment
VCS SALM	Requires use of 'accepted' computer process models to estimate changes in carbon stocks.	VCS first assessment
Agricultural Land Management Improved Grassland Management	Peer reviewed computer process models (e.g. RothC or CENTURY model) that have been field tested on soils within the geographic region Must include land management practice as an input parameter Must be designed to account for time since clearing from natural vegetation Must be able to predict differences in SOC at the scale of project activity	Open for Public Comment

3.6. Comparison of SOC sequestration data

The following table shows estimated annual changes in soil organic carbon (SOC) resulting conversion of annual cropping systems to perennial grasses. All of the estimates taken from several different sources demonstrate the positive annual increase resulting from planting grasses in Canada and the U.S.

TABLE 1-1: COMPARISON OF ESTIMATES OF SOC SEQUESTRATION RATES FOR CONVERSION OF ANNUAL CROPPING SYSTEMS TO PERENNIAL GRASSES

Location	Activity	Change rate (Mg C/ha/yr)	Reference
East Central Canada	Conversion to perennial cropping	0.74	VandeBygaart 2008
East Central Canada	Conversion to perennial grasses	2.14	IPCC based calculation reported in VandenBygaart

			2008
La Pocatiere, QC	Corn to alfalfa	0.6	Angers 1992
Harrow, ON	Corn to grass	1.07	Gregorich et al 2001
Temperate U.S.	Conversion to grasslands	0.67	CCX 2009
U.S. Average	Conversion to natural grasslands	0.68	Eagle et al 2010

The co-efficient of 2.14 Mg C/ha/yr based on the IPCC Tier 1 calculation methodology is clearly larger than the SOC change rate estimate of 0.74 Mg C/ha/yr for Central Canada calculated for the Canadian National Inventory Report (NIR) using the CENTURY plant-soil model. The NIR modeling and the IPCC-based calculation predicts that total carbon change will be similar however, 38.2 and 42.8 Mg C/ha, respectively (VandenBygaart et al 2008). The NIR model-based estimation shows sequestration occurring at a lower annual rate over a longer time period than the higher annual rate and shorter 20 year total time period assumed under the IPCC Tier 1 methodology. A SOC stock change of 37.6 Mg C/ha measured over 35 years (1.07 Mg C/ha/yr) is an example of a longer time frame empirical result and comes from Gregorich et al (2001).

In Eastern Canada, empirical research results from Harrow (and also Elora and Woodslee) indicate that SOC changes are higher when converting a given annual cropland (e.g. corn) to a perennial grass (e.g. bluegrass) rather than alfalfa or legume crops. However, the number of research data points is small for eastern Canada.

The meta-analysis estimate of 0.68 Mg C/ha/yr for conversion to natural grasslands from Eagle et al is mainly based on croplands converted back to natural landscape or "set-asides". Those figures come from all across U.S. and many are from the Conservation Reserve Program (CRP). The set-asides capacity to sequester carbon depends on their size, vegetation, former land use (e.g. monoculture or rotations), and structure; hence it is difficult to generalize.

It is worth noting that the average SOC change rate for conversion to natural grasslands (0.68 Mg C/ha/yr)) is in the range of the Canadian values for natural grasslands (0.43-0.94 Mg C/ha/yr) and similar to the CCX figure for conversion to grassland (0.67 Mg C/ha/yr) and the CENTURY model estimated co-efficient of 0.74 Mg C/ha/yr for Central Canada prepared for the NIR.

3.7. N_2O emissions

The N_2O emission reduction can be significant when converting an annual cropland to grasslands. Full accounting of GHG flux of the baseline and project scenarios must therefore include sources of N_2O emissions for an accurate quantification of an offset project. The N_2O emission reduction is a result of the following:

- grasslands can reduce N_2O emissions by capturing N_2O before it reaches the surface or groundwater and is denitrified off-site; and
- grass systems generally need no or much less fertilization than cropping systems.

Stehfest and Bouwman's global model of N_2O emissions shows grassland emissions were 0.16 Mg CO_2e/ha/yr less than those of cereal crops (2006). Various other researchers have concluded that N_2O emissions from grasslands are much lower than from annual croplands (Grant et al 2004; Machefert et al 2002; Smith et al 2008).[55] Other studies have also showed there is no significant difference in terms of N_2O emissions between grasses and legumes. Although legume crops typically have much higher soil mineral N concentrations compared to grasses, the N_2O emissions of legume crops are similar to grasses (Eagle et al 2010; Rochette et al 2008).

Recent Canadian research (Smith et al 2010) used the DNDC soil model to estimate GHG emissions for several changes in agricultural management, including conversion of crop rotations to permanent cover, for six ecodistricts in Canada. The model outputs were compared with the Tier 2 N_2O emission factors for agricultural land use changes from the National Carbon and Greenhouse Gas Accounting and Verification System (NCGAVS). The estimated reduction in N_2O emissions from converting croplands to grasslands in Ecodistricts 546 and 559 are 3.47 kg N_2O/ha/yr and 1.81 kg N_2O/ha/yr, respectively. These ecodistricts are located in the ecozone of the mixwood plains corresponding to southern Ontario. Ecodistrict 559 is situated on the south shore of Lake Simcoe and characterized by gray brown luvisol soils.[56]

The next table shows estimated N_2O reductions which range from 1.47 to 3.47 kg N_2O/ha/yr based on the DNDC model estimates and then from 0.96 to 3.27 kg N_2O/ha/yr for the National Inventory Report estimates. The estimates in the national inventory are based on a Tier 2 estimation approach (Rochette et al 2008).[57]

[55] Measurement results for N_2O are highly variable over space and time (Smith et al 2010; Rochette et al 2008; Janzen et al 2006).
[56] There are 83 ecodistricts in the province of Ontario. These ecodistricts are uniquely numbered.
[57] The DNDC modeling's N_2O estimations were consistently higher than the NIR's Tier 2 estimates.

TABLE 3-9: ESTIMATED N_2O REDUCTIONS FOR CONVERSION TO PERENNIAL COVER FROM DNDC MODELING AND NATIONAL INVENTORY REPORT ESTIMATES[58]

Ecodistrict	Rotation	DNDC estimate for N_2O emission reduction (kg/ha/yr)	NIR estimate for N_2O emission reduction (kg/ha/yr)
546	Corn	3.47	3.27
546	Soybean-Alfalfa	2.02	0.96
546	Barley-Alfalfa	3.16	1.01
559	Corn-Barley	1.81	2.01
559	Soybean	1.47	1.15
559	Barley-Alfalfa	1.72	1.02
Average kg N_2O/ha/yr		2.28	1.57
Average Mg CO_2e/ha/yr		0.71	0.49

3.8. GHG Change

A measure of the total annual GHG change associated with soils when croplands are converted to grasslands is the annual SOC change plus the annual N_2O emissions change. Smith et al estimated this total change for certain agricultural areas in Canada using the DNDC model (2010). The average annual reduction of soil-based GHGs from conversion to grasses in two southern Ontario ecodistricts based on this DNDC modeling was 3.10 Mg CO_2e/ha/yr. The comparable result from modeling undertaken for the NIR was similar, 3.37 Mg CO_2e/ha/yr. The latter is based on CENTURY modeling for SOC and a Tier 2 estimate for N_2O emissions.

The main source of GHG reduction in this example is enhanced sequestration in the soils; reduced N_2O emissions accounted for only about 15-20% of the total reduction. The following table presents the results from these two modeling experiments for conversion of lands from several different cropping systems to perennial grass cover.

[58] Source: Smith et al 2010

TABLE 3-10: ESTIMATED TOTAL GHG EMISSION CHANGE FACTORS FOR CONVERSION TO PERENNIAL COVER BASED ON DNDC MODELING AND CENTURY MODELING/TIER 2 ESTIMATES FOR THE NIR[59]

Ecodistrict	Rotation	DNDC (Mg CO_2e/ha/yr)	NIR (Mg CO_2e /ha/yr)
546	Corn	3.59	4.20
546	Soybean-Alfalfa	2.78	3.07
546	Barley-Alfalfa	3.29	3.09
559	Corn-Barley	3.20	3.58
559	Soybean	2.69	3.16
559	Barley-Alfalfa	3.05	3.10
Average Mg CO_2e/ha/yr		3.10	3.37

The carbon change in underground biomass between a cropland baseline and grassland project could possibly be included in an estimation of overall GHG change within an offset project. However, the period of underground biomass-based sequestration gain associated with the project would effectively be completed in a period of a few years.[60] This period would depend on the species and local growing conditions but is likely in the range of 2-4 years. For example, switchgrass grown in southern Ontario climatic conditions reaches its maximum production in its 3rd growing season (Samson et al 2007).

The biomass of the root system and its associated stored carbon would likely stay roughly in balance after the initial short growth period as there would be growth and death of the root system thereafter on a perennial basis barring partial or complete destruction of the grass plants through either a natural or anthropogenic event.

The biomass and associated carbon of root biomass of plant species is typically estimated indirectly by using shoot to root ratios and measurements of peak above-ground biomass. These shoot to root ratios have been developed across a wide variety of crop and grass plants in a range of North American growing locations. Bolinder estimated shoot to root ratios for major grass species of eastern Canada in the 1st and 2nd production year based upon direct measurements of root biomass and peak above-ground standing biomass (2002).

59 Source: Smith et al 2010
60 As stated in Section 3.1.3, the contribution of the root system to annual SOC sequestration continues over time through root exudation and death.

These ratios also show the large amount of biomass located in the root systems of grasses compared to crop plants and the larger amount of biomass in the root systems of C-4 grasses compared to C-3 grasses. The estimated shoot to root ratios for each of switchgrass and reed canarygrass was 0.54 in the 2nd production year and 0.87 and 0.83 for alfalfa and red clover, respectively. Winter wheat, barley and corn grown in eastern Canada have reported shoot to root ratios of 7.0, 2.0, and 5.3 (Bolinder et al 1997; Bolinder et al 1999). This data on shoot to root ratios can be combined with the data on above-ground biomass being developed through the bioenergy focused research in Ontario on switchgrass and other C-4 grasses currently underway or concluding to produce a southern Ontario specific estimate of below-ground biomass and carbon for native grasslands. Samson estimated that yields for switchgrass in southern Ontario can be 8-12 tDM per ha (2007), which would result in a rough estimate of carbon in below-ground biomass of 7.4 Mg C/ha.[61]

3.9. Modeling soil and plant biomass carbon sequestration and N_2O emission changes

Introduction

With requirements for national and corporate GHG emission inventories,[62] emerging markets in offset credits, and climate change public policy demands, terrestrial carbon estimation techniques have been developed that range from back-of-the-envelope calculations to sophisticated computer models. The range of methods is helpful because it allows a tool to be selected that fits a project's estimation precision, scheduling, and budget.

Use of computer models for estimating GHG change associated with forest lands has become well established in both national inventories and offset protocols. The Canadian Forest Service has developed the carbon budget computer model CBM-CFS3 for Canadian GHG quantification efforts and has made an operation-level version publicly available.[63] A user can develop estimates of above- and below-ground carbon in this model by inputting and manipulating stand data (net merchantable volume) produced by a timber supply model such as SELES, FS-SIM, Woodstock, or Atlas. The CBM-CFS3 model is sophisticated, and its proficient operation requires a forester well versed in timber supply analysis. The Climate Action Reserve's Forest Protocol and the BC Government's draft Forest Carbon Offset Protocol both require use of established and approved computer models for certain aspects of forest offset project quantification.

[61] 10tDM of above-ground biomass x 1.85 (root to shoot ratio, 1/0.54)) x 0.4 (ratio of carbon in below-ground biomass)

[62] For example, see the National Inventory Report: Greenhouse Gas Sources And Sinks In Canada, 1990-2006 http://www.ec.gc.ca/pdb/ghg/inventory_report/2006_report/tdm-toc_eng.cfm

[63] http://carbon.cfs.nrcan.gc.ca/SoftwareDownloads_e.html

These process-based models account for the interrelationships for a range of factors (including management practices, soil features, climatic conditions, biogeochemical reactions) so their use results in more accurate estimates than using default factors. These models have also been peer-reviewed in comparison with field measurements to assess their accuracy (Janzen et al 2006).

In this section of the report each of the major computer models that could be used for quantifying the GHG reduction associated with a conversion to grasslands project is given a short overview.[64]

CENTURY - The CENTURY[65] plant-soil model has been the main biogeochemical model used within the scientific research community to derive carbon factors through modeling of soil and plant carbon dynamics. It simulates carbon nutrient for different types of environmental (soil, climate, previous land management) and management (cropping, livestock, manure, grazing) variables. The CENTURY SOC and plant carbon factors have been compared to empirical values of the published literature and have been proven reliable.

The model has been used to simulate the impact of climate change and increased atmospheric CO_2 levels on grasslands around the world (Parton et al 1995) with a detailed analysis for the US Great Plains region (Burke et al 1991; Schimel et al 1990). The effect of improved land use practices on soil carbon storage and plant production has been evaluated for the US Corn Belt (Donigian et al 1995), while Paustian et al (1996) have used CENTURY to evaluate soil carbon storage in the US resulting from the Conservation Reserve Program (CRP).

It was used to estimate the SOC change co-efficients for the Canadian and U.S. national GHG inventories. It has also been used by Canadian research scientists (Desjardins et al 2005; Smith et al 2001) for estimating GHG impacts of modifying agricultural practices.

DAYCENT[66] - is the daily time-step version of the CENTURY biogeochemical model. It simulates exchanges of carbon and nitrogen among the atmosphere, vegetation and soil. Flows of C and N between the different soil organic matter pools are controlled by the size of the pools, carbon/nitrogen ratio and lignin content of material.

DNDC[67] - is a soil biogeochemistry model simulating thermodynamic and reaction kinetic processes of C, N and water driven by the plant and microbial activities in the ecosystems. A relatively complete set of farming management practices are covered by the DNDC such as crop rotation, tillage, residue management, fertilization,

[64] Other models are available, including EPIC and IBIS, but they have shortcomings that make them unlikely candidates for use in offset project quantification.
[65] http://www.nrel.colostate.edu/projects/century5/
[66] http://www.nrel.colostate.edu/projects/daycent/index.html
[67] http://www.dndc.sr.unh.edu/

manure amendment, irrigation, flooding, grazing, etc. These practices have been parameterized in DNDC to regulate their impacts on soil environmental factors (e.g., temperature, moisture, pH, redox potential and substrate concentration gradients). Output parameters are: N_2O, NOx, CH_4, and CO_2.

Researchers have constructed Canadian datasets for Canada to facilitate the application of the model for Canadian conditions (Smith et al 2010).

Introductory Carbon Balance Model (ICBM) - The ICBM model is a family of analytically solved models of soil carbon, nitrogen and microbial biomass dynamics. It has been developed for general use to describe the different soil carbon dynamics with only two state variables and five parameters. According to ICBM specialist Martin Bolinder from Laval University, the ICBM is a good alternative to the CENTURY model since its application is simpler[68] and more versatile, with comparable levels of uncertainty.

RothC - is one of the earliest soil carbon models and was developed at the Rothamsted Research Station in the UK. Like the other models, soil moisture, temperature and clay content control soil organic matter decay. Management practices are categorized into soil management and crop management. The output parameter is soil carbon. It is a more limited model in this regard and has not been applied in Canada as far as the authors are aware although it is being used in Australia as well as in Europe.

COMET-VR[69] – is a web-based application aimed at facilitating an agricultural producer's GHG estimates based on his farm level practices. The application is underlain by CENTURY plant-soil model and estimates soil carbon stock changes, based on a simple set of user inputs (i.e., location, soil attributes, past and current crop rotation and tillage practices) that utilize pull-down menus (Paustian et al 2009). The system is supported by a large database of management choices and a number of other databases of environmental and management factors.

The COMET-Farm system[70] is a web-based, user-friendly, full greenhouse gas accounting system which is designed for comprehensive farm-level analyses. It is similar to the Holos Canadian model. The first version of the system is scheduled for release at the beginning of 2011.

Holos[71] - is a whole-farm modeling software program that estimates GHG emissions based on information entered for individual farms. It can accept 'scenarios', i.e. common packages of Canadian farm management practices. The user selects scenarios that best describe his/her farm and then adds detail to the extent desired.

[68] It is an Excel spreadsheet model
[69] www.cometvr.colostate.edu
[70] Currently under development
[71] Available at http://www4.agr.gc.ca/AAFC-AAC/displayafficher.do?id=1226606460726&lang=eng

Algorithms used in the model are generally based on IPCC factors modified for Canadian conditions.

This model estimates CO_2, N_2O and CH_4 emissions from enteric fermentation and manure management, cropping systems and energy use. Carbon storage and loss from tree plantings and changes in land use and management are also estimated resulting in a whole-farm GHG estimate.

3.10. Underway research on grasslands sequestration

There is increasing research interest in Ontario on the relationships between grassland ecological systems and many climate change matters. The research falls into two broad categories. One focuses on the fundamental science of native grasslands ecology in Ontario and the other is directed at the bioenergy attributes of native grasses in Ontario.

The latter research efforts have been underway for a few years and preliminary results are already being reported. They involve researchers connected with University of Guelph and OMAFRA and funding has come from Ontario Power Generation and Ontario Government ministries.[72] This research has been structured to focus on production issues associated with growing grass crops as a bioenergy feedstock (Samson 2007; Parrish et 2008). These projects have not directly examined matters of interest for offset project quantification, such as SOC change and N_2O emissions, so measurement of these attributes are either not part of these studies or a peripheral element. Since these studies focus on native grasses within Ontario growing conditions their results are of interest from the general point of better understanding the ecology of native grasses in Ontario but not likely of specific interest for obtaining new empirical results for better understanding long-term SOC, under-ground biomass carbon and N_2O flux. A specific exception is a soon to start project (*Evaluation of Perennial Grass Polycultures for Biomass Production and Agri Environmental Sustainability*) mainly focused on the impact of including legumes in native grassland polycultures managed for bioenergy purposes. Its project management would like to monitor and measure SOC and certain GHG fluxes but this aspect of the project has not yet been finalized at the time of this report's publication.

One recently underway, long-term research project through the University of Guelph and another, currently in the planning stage, through the University of Western Ontario will produce new, Ontario specific GHG flux and carbon stock empirical data for native grasslands. However, obtaining empirical results from both is several years in the future.

In addition, several Agriculture and Agri-food Canada research scientists have projects underway on different types of grasslands, including Ontario-based experiments that will add to the body of empirical research results for SOC change

[72] These projects are summarized at http://www.omafra.gov.on.ca/english/engineer/biomass/projects.htm

and N_2O emissions associated with conversion to grasslands and improved management practices for grasslands. There does seem to be Agriculture and Agri-food Canada-based research underway on sequestration and storage of CO_2 in underground biomass of grasslands.

In Appendix II is a summary of the underway research on grasslands in Canada and the U.S. that could possibly yield new empirical research results and understandings of SOC change and/or N_20 emissions associated with C-3 and C-4 grasses.

4. PROTOCOL FRAMEWORK

4.1. Section Purpose

This section provides information on issues and options for addressing the key elements of project reduction quantification and monitoring. It can be used as a guide to help research and draft a conversion to native grasslands offset protocol. The framework is targeted at a Canadian audience, but can help inform non-Canadian offset projects focused on conversion to native grasslands as well.

4.2. Section Structure

This section is divided into seven key topics that are either critical protocol elements or directly related to fulfilling well-established criteria underlying high quality offsets. Verification and crediting are not protocol elements *per se*, but several protocol elements will be designed based on verification and crediting features (e.g. monitoring procedures or crediting period). The seven topics are as follows:

- Offset project boundary
- Estimation, measurement and monitoring
- Baselines and additionality
- Leakage
- Permanence and risk of reversal management
- Verification
- Crediting

Each protocol topic chapter is structured as follows:

i) **Introduction** - Description of the topic's purpose in a protocol
ii) **Situation** - Description of approaches to address the topic in approved or draft terrestrial protocols and offset standards
iii) **Issues -** Description of issues related to the topic, including environmental, financial and institutional considerations in selecting an approach to deal with the element in a conversion to grasslands protocol
iv) **Options** - Description of options that have reasonable currency about how to address the topics and their associated issues. In certain cases includes recommendation about how to address the topic in a conversion to native grasslands protocol.

This work has been guided by best available practices in protocol preparation, including the directions and guidance of the ISO 14064-2 standard. It also draws from the knowledge and experience of those who have been involved in preparing and developing offset protocols, standards and projects in the terrestrial carbon sector.

4.3. Existing or under development protocols

Protocols (or methodologies) are offset development rules approved by the authority overseeing a given standard, initiative or program. The "compliance market" and "voluntary market" are the two broad categories within which offset standard or initiatives have evolved since the Kyoto Protocol's ratification in 2005. The voluntary market includes a wide variety of offset program types established by various non-governmental organizations to help service offset demand by companies wanting to offset their emissions for social responsibility reasons and to acquire offset credits that would likely be eligible for use within compliance systems. The regulated, or "compliance market" directs offsets for use in GHG emissions regulation systems implemented by governments, such as the Government of Alberta's Specified Gas Emitters regulatory system, regional governments, such as the European Union (EU)'s Emissions Trading Scheme (ETS), or multi-state international organizations, such as the United Nations, which implement market-based GHG emissions management programs.

These program authorities, whether operating in the voluntary or compliance markets, authorize the acceptance of a wide variety of offset project types from entities that do not need to comply with GHG emissions limits as a mechanism to incent entities to reduce or sequester GHG emissions beyond their business-as–usual practices. The offset project types are often categorized according to their GHG reduction or sequestration[73] activity such as fuel switching, energy efficiency, landfill gas capture, agriculture practices, land use change, forestry, ozone depleting substances and transportation.

The development of agricultural offset project directions, requirements and guidance has been led to date by non-governmental programs and initiatives, such as ISO's 14064-2 standard, World Resources Institute's *Land Use, Land-Use Change, and Forestry Guidance for GHG Project Accounting*[74] and Voluntary Carbon Standard's *Guidance for Agriculture, Forestry and Other Land Use Projects*[75]. Several offset program organizations are currently developing new protocols for agricultural projects, such as the California-based Climate Action Reserve (CAR)[76] and the Alberta Offset System[77].

Hereafter is an overview of the most relevant agricultural protocols and standards approved or currently under development.

[73] Sometimes referred to as removals enhancement
[74] http://www.wri.org/publication/land-use-land-use-change-and-forestry-guidance-greenhouse-gas-project-accounting
[75] http://www.v-c-s.org/docs/AFOLU%20Guidance%20Document.pdf
[76] http://www.climateactionreserve.org/how/protocols/in-progress/agriculture/
[77]http://carbonoffsetsolutions.climatechangecentral.com/files/microsites/OffsetProtocols/ABProtocolDevelopmentWorkshops/angeland_Technical_Scoping_Document_Mar31_09.pdf

Western Climate Initiative (WCI) – is a partnership of several North American jurisdictions including Ontario that is jointly designing a cap and trade system for regulating GHG emissions, which includes provision for an offset program. Four WCI jurisdictions (Ontario, BC, California and Quebec) are working towards a January 2010 implementation of cap and trade systems in their respective jurisdictions. In July 2010, the WCI released its overarching guidance for the design of offset programs, entitled *Offset System Essential Elements Final Recommendations Paper* and its design for the cap and trade system, entitled *Design for the WCI Regional Program*. The offset design paper features essential criteria to be incorporated into the offset program of each jurisdiction that implements a cap and trade system.

Clean Development Mechanism (CDM) – is the offset flexibility mechanism created under the UNFCCC's auspices and the most influential offset program at the international level. The CDM is based on the following four UNFCCC criteria for an offset project registration:

- additionality of emissions reductions compared to the 'business-as usual' situation;
- no adverse environmental impact;
- consistency with host country sustainable development strategy; and
- emission reductions benefits that are real and measurable.

The CDM has only one approved agricultural methodology[78] (AMS-III.A)[79] and it is directed at offsetting synthetic nitrogen fertilizers by inoculants application in legumes-grass rotation on acidic soils on existing croplands. The CDM has also developed a *Tool for estimation of change in soil organic carbon stocks due to the implementation of A/R CDM project activities*[80], which is mainly based on the IPCC Tier 1 quantification approach and is used to estimate SOC changes associated with afforestation and reforestation activities.

Voluntary Carbon Standard (VCS)[81] – allows the use of three categories of protocols: (i) CDM methodologies, (ii) CAR protocols and (iii) proponent developed protocols that pass through its double validation approval procedure. There are currently no agriculture methodologies approved in its Agriculture and Forestry and Other Land Use (AFOLU) category, all six approved protocols being applicable to forestry or REDD[82] projects.

The following four agricultural protocols are currently in the initial stage of the VCS' methodology approval process: (i) Adoption of Sustainable Agricultural Land Management (SALM), (ii) Quantifying N_2O Emissions Reductions in US Agricultural

78 The CDM uses the term "methodology" rather than "protocol".
79 http://cdm.unfccc.int/methodologies/DB/4OC3QS857382TW21LYYOJLTX3HHQKK
80 http://cdm.unfccc.int/methodologies/ARmethodologies/tools/ar-am-tool-16-v1.pdf/history_view
81 As of March 1st, 2011, the "Voluntary Carbon Standard" will become officially known as the "Verified Carbon Standard"
82 Acronym for « Reducing Emissions from Deforestation and Forest Degradation »

Crops through N Fertilizer Rate Reduction, (iii) ALM Adoption of Sustainable Grassland Management through Adjustment of Fire and Grazing, and (iv) Agricultural Land Management Improved Grassland Management[83]. There are two approved tools that can be applied to help quantify an agricultural project GHG reduction once a protocol is approved: *Tool for the Demonstration and Assessment of Additionality in VCS AFOLU Project Activities* and *Estimation of stocks in the soil organic carbon pool*.

VCS has included three Agricultural Land Management (ALM) categories in its AFOLU guidance: (i) "Improved cropland management activities", (ii) "Improved grassland management activities" and (iii) "Cropland and grassland land-use conversions". Category (ii) and (iii), which respectively involve soil carbon enhancement through improved management practices on established grasslands and conversion of cropland to perennial grasses, fall under this framework scope.[84]

Chicago Climate Exchange (CCX) – has developed an agricultural soil carbon protocol that has been actively used since 2004, and CCX claims that approximately 20 million acres on 12,000 farms have been enrolled in its program.[85] The protocol covers two types of activity: (i) converting cropland to grassland (annual to perennial crops) and (ii) conventional tillage to conservation tillage practices. In terms of project take-up, the latter has been overwhelmingly the main focus of activity. CCX uses the same quantification approach for both offset project types, which consists of multiplying an annual SOC change default factor against the number of acres subject to the project's practice (CCX 2009).

Alberta Offset System– Apart from animal feeding and biogas related protocols, Alberta Province has two approved agricultural protocols: (i) Quantification Protocol for Tillage System Management, (ii) Quantification Protocol for Agricultural Nitrous Oxide Emissions Reductions.

In March 2009, a technical scoping document *Potential for Reductions in Greenhouse Gas Emissions from Native Rangelands in Alberta*[86] concluded that conversion of degraded

[83] The methodology is applicable to improved grassland management projects, which means that it can only be applied on existing grass-dominated lands where baseline grassland management activities result primarily - but not exclusively - in livestock production. There are two carbon pools considered under this protocol: above-ground woody biomass and SOM.

[84] We communicated with two organizations that stated their intent to submit grasslands related methodologies to VCS for approval. One comes from Ducks Unlimited, for a called "Avoided Grassland Conversion Project in the Prairie Pothole Region", which is an avoided grasslands project. A consortium including The Earth Partners and Applied Ecological Services (AES) has developed a "Soil Carbon Quantification Methodology" incorporating ecosystems services such as water, fertility and carbon as a complete package.

[85] In November 2010, the Climate Exchange stated that it would cease trading carbon credits at the end of 2010, although carbon exchanges will still be facilitated. Many of the projects that have been registered on this exchange may migrate to other offset programs if they can meet their eligibility conditions.

[86] Namely, "Potential for Reductions in Greenhouse Gas Emissions from Native Rangelands in Alberta" available at:

cropland to native rangeland or perennial cover could potentially reduce GHG emission due to increased carbon storage. This protocol type is currently being researched by a parallel working group led by Alberta Agriculture and Rural Development.

Climate Action Reserve (CAR) - In 2010 the Climate Action Reserve (CAR) researched several protocol ideas in the agriculture sector. In January 2011, CAR released a Request for Proposals[87] to assist in the development of a Cropland Management Project Protocol (CMPP) and Nutrient Management Project Protocol (NMPP). Through research and workgroups, CAR aims to resolve methodological issues and develop and finalize protocols in these two areas. There will be several eligible activities under the Cropland Management Project Protocol (CMPP), including setting aside annual cropland and converting it into permanent vegetative cover (herbaceous). A protocol is expected to be ready for the CAR board's consideration and final approval in early 2012.

American Carbon Registry (ACR)[88] – is a voluntary GHG registration system operated by Winrock International, Environmental Defense Fund, and Environmental Resources Trust (American non-governmental organizations). ACR allows the use of four categories of protocols: (i) ACR-approved CDM methodologies; (ii) ACR-approved VCS protocols; (iii) ACR-approved EPA Climate Leaders protocols and (iv) proponent developed protocols that pass through ACR's approval procedure. ACR plans to develop in 2011 a "holistic" grassland methodology that would include improved management, restored grasslands, rotational grazing, fertilization, and irrigation.[89] The methodology would be developed by Winrock-ACR and could also be submitted for consideration by the Chinese Panda Standard.[90]

There are three key standard or good practice guidance documents to facilitate the development of terrestrial carbon offset protocols.

- World Resources Institute (WRI) – prepared an influential standard for quantifying terrestrial carbon sequestration projects: *The Land Use, Land-Use Change, and Forestry Guidance for GHG Project Accounting*[91], in 2006. It is to be used in conjunction with this organization's more general offset project accounting protocol.
- International Panel on Climate Change (IPCC) – produced the most recent version of its guidance document on preparing land use-

http://carbonoffsetsolutions.climatechangecentral.com/files/microsites/OffsetProtocols/ABProtocolDevelopmentWorkshops/angeland_Technical_Scoping_Document_Mar31_09.pdf

87 http://www.climateactionreserve.org/how/protocols/in-progress/agriculture/

88 http://www.americancarbonregistry.org

89 Pers. comm. with ACR's Chief Technical Officer Nick Martin, November 2010

90 http://www.pandastandard.org/

91 Available at http://pdf.wri.org/lulucf_guidance.pdf

focused GHG inventories, *Good Practice Guidance, for Land Use, Land-Use Change and Forestry*[92], in 2007.

- International Standards Organization (ISO) – has a protocol standard for project accounting, namely 14064-2[93], which is applicable across offset project types and is widely used in Canada and the U.S. for structuring and drafting offset protocols.

92 Available at http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.html

93 Namely, "Specification with guidance at the project level for quantification, monitoring and reporting of greenhouse gas emission reductions or removal enhancements" available at http://www.iso.org/iso/catalogue_detail?csnumber=38382

4.4. Protocol Requirements

The key protocol elements have been identified based on internationally recognized criteria, standards and terminology common to offset systems. Fundamental commonalities include such criteria for establishing offsets as “real”, “additional”, “permanent” and “verifiable”.[94] Prior to offset project activity implementation, the project proponent must typically select or develop a quantification protocol, *ex ante* quantify the estimated project reduction, describe the project in a Project Document, establish monitoring procedures, and commission a third party validation of the Project Document. Once the project is implemented, the project proponent must monitor the project, quantify the project reduction in compliance with the selected protocol, prepare Project Reports on the project reduction and commission third part verification of the Project Reports.

4.5. Applicable Project Types

A protocol for conversion of land to native or natural grasslands must define applicable project types that can be quantified through its requirements, including a project’s main activities. The main activity is the land-use change when setting aside marginal, annual croplands or rotational crops, and converting this land into native or natural grassland. The established grassland may then be used as pasture or left idle as natural grasslands or a conservation buffer. However the protocol must specify the general activities that will occur on the grasslands with a view to their GHG implications. For example, if the grasslands are going to be used for extensively managed grazing then this activity must be mentioned in the project applicability section of the protocol. The GHG emissions and removals associated with these activities on the grasslands must be included in an offset project’s boundary for quantification and monitoring purposes. The protocol would also likely specify the species or categories (such as C-4 and/or C-3) of grasses that could be planted in the project.

In order to be eligible and to actually sequester optimal and incremental volumes of carbon, grassland management activities should be further defined as either (i) decreasing the proportion of bare soil[95] in the grasslands’ landscape; (ii) decreasing the time bare soil is exposed or (iii) increasing the proportion of perennial grass species above the baseline scenario. Any combination of the aforementioned measures would be eligible.

In this framework, the grasslands established in the project activity do not include woody perennials that would reach the threshold for the national definition of forest. Similarly, both baseline scenarios (cropland or unmanaged grasslands) must comply with the definition provided by the IPCC in “Basis for Consistent Representation of

[94] See PEW Centre’s white paper on high quality offsets for example, http://www.pewclimate.org/publications/whitepaper/ensuring-offset-quality

[95] Bare soil means soil not covered by grass

Land Areas"[96] that specifies that croplands and grasslands are characterized by vegetation that falls below the thresholds used for the forest land category as per national definitions.

4.6. **Offset Project Boundary**

4.6.1. Introduction

In an agricultural offset project, the geographic boundary is the farmland on which the land use change is taking place but for offset project quantification, the boundary is delineated by its sources, sinks and reservoirs (SSRs) that are controlled by an offset project operator and related to and affected by an offset project. The emission reductions of an offset project (or net emissions in the case of an inventory) represent the balance of the carbon exchanges (through sources and sinks) between the carbon reservoirs (also called "pools"). An examination of the carbon budget of a reservoir can provide information about whether the reservoir is functioning as a source or sink for CO_2. Once the SSRs are completely defined, the boundary of the project activity is also defined and only direct reductions occurring within this boundary will be eligible for crediting.

North American offset protocols generally adhere to the principles and structure in the ISO 14064-2 protocol standard for identifying and classifying SSRs that compose the offset project boundary. In Canada, the Ministry of Environment's *Guide for Protocol Developers*[97] suggests a life-cycle assessment to identify relevant SSRs.. Potential SSRs across the life-cycle of activities that take place in the baseline and in the project must be identified within a protocol.

In agreement with the Kyoto Protocol, all carbon pools should be accounted for, including living biomass (above-ground biomass and below-ground biomass), dead organic matter (dead wood and litter) and soil organic matter. Protocol developers, however, are given the flexibility to exclude elements of pools where they can be shown to be negligible or "immaterial" under a protocol's materiality rules.

4.6.2. Situation

Following are short descriptions of the direction that various agricultural protocols, standards or guidance documents give on identifying and selecting carbon pools and GHG sources.

- *UNFCCC/CDM* - defines terrestrial carbon pools as Living Biomass (above- and below-ground biomass), Dead Organic Matter (dead wood and litter), and Soils (SOM).[98]

[96] http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf_files/Chp2/Chp2_Land_Areas.pdf
[97] See http://www.ec.gc.ca/creditscompensatoires-offsets/7CAD67C6-B798-4B69-9648-BD7F1F74B2CB/June10_protocol_eng_COM618_Guide_for_Protocol_Developers_AUG%207.pdf
[98] IPCC 2007 p. 3.15

- *VCS AFOLU Guidance* - lists certain required pools and gives project proponents the discretion to quantify "any significant sources (sinks are optional) of carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) that are reasonably attributable to project activities' (VCS 2008). The VCS also provides guidance regarding materiality: projects emissions (decreases in carbon pools or increases in N_2O/CH_4 emissions) may be neglected if their total volume represents less than 5% of the total emission reductions. The following five pools are considered: (i) above-ground biomass, (ii) below-ground biomass, (iii) dead wood, (iv) litter and (v) soil carbon. Nevertheless, inclusion is optional and therefore a given pool can be omitted if its exclusion leads to conservative estimates of the number of carbon credits generated.

- *VCS Improved Grassland Management (draft)* – is consistent with the VCS AFOLU guidance direction[99], which states that the primary pool of concern for agricultural land management (ALM) under VCS is the soil organic matter (SOM). For this grassland management protocol, above- and below-ground biomass is included but only for woody components (e.g. treed pastures) as opposed to herbaceous species. All other pools (dead-wood, non-woody below-ground, litter, and harvested wood products) are excluded from the project boundary. Emission sources other than those resulting from changes in stocks in carbon pools - such as enteric emissions (CH_4) from cattle grazing, burning of biomass (CH_4, N_2O), combustion of fossil fuels (CO_2) through farm activities and application of nitrogen based fertilizer (N_2O) – are also included.

- *CCX Protocol for Conversion to Grassland* – Controlled GHG sources for grassland conversion projects are those that are part of the planting process and directly attributable to the conversion of cropland to grassland. Only soil sequestration factors are derived from science experts - although it is not clear how the factors were developed – and other carbon pools are implicitly excluded. GHG emissions resulting from the conversion of cropland to grasslands are not expected to qualify as significant and are therefore excluded from the project boundary. CCX does not allow for the crediting of reduced fuel use or other emission reductions that may be occurring; these are therefore excluded from the project boundary.

The project plan for Ducks Unlimited's Avoided Grassland Conversion project stated that its boundary only includes one carbon pool, SOM. It is assumed that no additional non-CO_2 gases occur as a result of the project. Methane emissions

[99] VCS 2008

from cattle grazing are not included in the project boundary since under the baseline scenario the cattle would be taken off the land and placed elsewhere (e.g. other grasslands) hence the emissions from these cattle would continue to exist.

4.6.3. Issues

The selection of SSRs - especially reservoirs (i.e. carbon pools) – has a crucial impact on the carbon storage quantification and therefore the eligible volume for offset crediting. On the one hand, a protocol that makes only certain pools eligible to generate offsets runs the risk of excluding a significant pool (such as woody biomass) and on the other hand other pools are relevant to include in a grassland conversion protocol (e.g. above-ground biomass) because of their temporary feature. The following are key considerations or issues in defining the offset project boundary in a protocol focused on a grasslands conversion offset project.

- ***Protocol flexibility on pool inclusion and exclusion*** - Two broad design streams have emerged in terrestrial carbon protocols and standards about giving direction to proponents on the matter of selecting SSRs. The first one is where the project proponent does not have the flexibility to choose among pools: certain pools are designated as included and others are excluded.[100] The second approach is where certain pools are required to be quantified while the quantification of other pools is left optional or to the discretion of proponents.

- ***Inclusion of below-ground biomass pool*** - The selection of the relevant carbon pools is a major issue that needs to be addressed and that is particularly prominent in the case of a grassland protocol. While it is widely recognized that SOC is the primary, permanent and integrative carbon pool[101] in grasslands carbon sequestration, the relevancy of designating below-ground biomass carbon pools as a required or included pool has not yet been demonstrated.[102] The two

[100] California Air Resources Board for example has followed this approach with its rules for forestry offset projects.

[101] Please refer to section 3.1.3

[102] The carbon change in underground biomass between a cropland baseline and grassland project is not included because the carbon stock in the underground grassland biomass reaches a steady state in a few years rather than accumulating over several decades. For example, switchgrass grown in southern Ontario climatic conditions reaches its maximum production in its 3rd growing season (Samson et al 2007). Troughton observed that the equilibrium between net root growth and root turnover is typically reached after 2-4 years with perennial forages (1957).
IPCC direction for national inventory quantification of land use change recommends inclusion of below-ground biomass pools, see Ch. 6 of IPCC 2006. Canada and the U.S do not include below-ground biomass of grasslands in their inventory estimations however.

main concerns related to this pool are (i) permanence[103] and (ii) materiality[104]. Grassland management activities that include parcels having woody living biomass component (e.g. silvipastures, orchards, agroforestry) need to consider above-ground woody biomass carbon stocks.

4.6.4. Options

The following are the SSRs options defining the project boundary in this grassland conversion protocol framework.

SOM carbon pool

SOM must be an included or required pool in a grasslands conversion protocol as it accounts for the majority of annual GHG change according to the scientific literature review[105] (Follett et al 2001; Parton et al 2001), it is integrative and involves minimal risk of reversal compared to other pools. For instance, VCS AFOLU Guidance states that soil carbon is the "primary pool of concern" for agricultural projects.

Live woody biomass

Live woody biomass should be deemed an included pool where grassland management activities include parcels having woody living biomass components (e.g. silvopastures).

Live above-ground herbaceous (non-woody) biomass and dead litter biomass

Live above-ground herbaceous (non-woody) biomass and dead litter biomass should be designated as excluded carbon pools. They represent an insignificant carbon reserve in terms of the amount of carbon contributed to total stored carbon at any one point in time (Follett et al 2001, Lal 2011[106], Haak 2011[107]). More importantly above-ground biomass has a high turnover rate as there is there is an annual cycle of additions to each of these pools, and associated shift in carbon storage, through death of the above-ground herbaceous biomass, and CO_2 emissions from the decaying litter. There is turnover of carbon between pools, both in terms of transfer of some dead litter carbon eventually into SOM and live above-ground biomass into dead litter, and CO_2 emissions from the

[103] The annual root turnover in temperate climate grasslands was found to be 55% in a meta-analysis (Gill and Jackson 2000). For more discussion on root turnover in temperate climate grasslands see Stewart and Frank 2008 and Section 3.1.3.
[104] The minim materiality threshold for terrestrial carbon pool may vary depending on the standard but is typically set around 5% (e.g. Environment Canada, EU-ETS, UNFCCC-CDM, Alberta Offset System, BC Regulatory System, Western Climate Initiative)
[105] Pers. Comm. A. VandenBygaart 2011-02-07
[106] Pers. Comm. R. Lal 2011-01-19
[107] Pers. Comm. D. Haak 2011-01-10

decaying dead litter. Due to the annual regeneration and temporary nature of the above-ground biomass it is recommended that live above-ground biomass and dead litter be designated as excluded pools.

Below-ground biomass

Below-ground biomass is recommended to be designated as an optional pool. The Canadian and U.S. GHG inventories have chosen to not include this pool in their quantification of agricultural land use changes. There is peer-reviewed research that demonstrates that the root biomass of C-4 grasses is relatively extensive. The stored carbon in the root biomass is still relatively minor to the stored carbon in SOM at the steady state equilibrium level, however. The root biomass grows relatively quickly to almost its maximum within a few years. The sequestration benefit within an offset project quantification occurs within that time period as thereafter death and regeneration will maintain the root biomass at a steady state level subject to climatic conditions, such as droughts. A project proponent could choose to include this pool in the offset boundary and quantify it subject to the quantification approaches and accuracy requirements specified in the protocol.

Emission sources other than those resulting from changes in stocks in carbon pools

Emission sources other than those resulting from changes in stocks in carbon pools such as grazing cattle (CH_4), burning of biomass (CH_4, N_2O), combustion of fossil fuels (CO_2) and nitrogen based fertilizer (N_2O) – should be included sources. The relevant sources for the offset project boundary should be identified through a life cycle assessment (LCA) and considering the relevant life cycle categories as follows: upstream (e.g. production and transportation of fertilizer), on-site (e.g. fertilizer use, tractors) and downstream SSRs (e.g. waste management) before, during and after the project operation (Environment Canada 2008b). Emissions sources may be insignificant – especially in the case of a grassland conversion project – and can be excluded from the boundary as long as the sum of increased emissions falls under the materiality threshold (typically 5% of the total GHG benefits).

Materiality[108]

The materiality threshold convention for most high quality programs is 5%.[109]Optional SSRs have to be tested through models[110], default factors or measurements to assess their materiality prior to including or excluding them.

108 Materiality is a concept that applies to the allowable deviation of an individual or aggregate affect of an error, omission or misrepresentation that results in an overestimation of the project reduction. The matter is one of deliberate omission in the case of excluding a pool.

109 For instance VCS defines the materiality threshold at 5% except for mega projects (more than 1,000,000 tCO_2 per year) where it is 1%.

4.7. **Estimation, Measurement and Monitoring**

4.7.1. Introduction

Quantification and monitoring procedures are fundamental to a grassland protocol in order to assure the accuracy and conservativeness of estimates of baseline and project emissions and removals. There is a wide range of methods available for estimation, measurement and monitoring and they can be generally classified as direct estimation (field sampling and analysis) or indirect (computer modeling, default values).

In considering estimation and measurement approaches, a project proponent should adhere to the following principles as they are based on accepted GHG project accounting and reporting practice:[111]

- Relevance - Use data, methods, criteria and assumptions appropriate to the intended use of the reported information;
- Completeness - Consider all relevant information that may affect the accounting and quantification of a project reduction, and complete all requirements;
- Consistency - Use data, methods, criteria, and assumptions that allow meaningful and valid comparisons;
- Transparency - Provide clear and sufficient information for reviewers to assess the credibility and reliability of GHG reduction claims;
- Accuracy - Reduce uncertainties as much as is practical; and
- Conservativeness **-** Use conservative assumptions, values, and procedures when uncertainty is high, and do not overestimate a project's reduction.

Field measurement includes taking periodic soil samples to estimate soil carbon stocks over time and directly measuring emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) gases in the field (e.g. using gas chambers that capture and analyze gas samples).

Indirect methods are based on relationships between other predictor variables and require modeling. Most methods rely on some form of extrapolation from a small set of samples to the project or regional scale, thus all methods are directly or indirectly based on samples data. This chapter focuses on issues associated with protocol requirements for accurately and economically measuring carbon stocks and carbon changes in soils.

[110] For example using a plant-soil process model like CENTURY

[111] More information about these principles can be found in the WRI/WBCSD GHG Project Protocol, available at http://www.ghgprotocol.org/files/ghg_project_protocol.pdf

4.7.2. Situation

Protocols and standards include prescriptions about required or allowed estimation methods and, in some cases, measurement accuracy and precision targets. Some specify confidence discounts from the estimated reductions or removals when certain estimation accuracy targets are missed (Kollmus et al 2010).

None of the reviewed protocols or standards endorses the use of remote sensing techniques to estimate amount and type of vegetation but there is an overall interest in the development of these techniques because of their likely lower cost.

- *WCI Offset System Essential Elements Final Recommendations Paper* – contains broad guidance on quantification that states quantification methods in a protocol must: "be appropriate to the GHG source or sink; be current at the time of quantification; consider local conditions…; account for uncertainty…; and when uncertainty is above the defined threshold, apply the principle of conservativeness…". A material statement occurs when errors, omissions and misstatements result in a overestimation of the project reduction by 5% (ie. +5%).

- *IPCC 2006 Guidelines for LULUCF* – Many standards and protocols are based on or refer to IPCC Tier estimation methods, which involve progressively higher tier number, data requirements and complexity as tier number increases.[112]

- *VCS AFOLU Guidance* – specifies that measurements must be based on "randomized sampling", using established and reliable methods. The sampling density shall be defined in order to determine statistically significant changes at a 95% confidence level. SOC stock change factors must be based on measurements of SOC stocks to the full depth of affected soil layers, accounting for differences in bulk density as well as organic carbon concentrations. Measurements to estimate project-specific N_2O and CH_4 emissions factors should be based on "scientifically defensible" measurements of sufficient frequency and duration to determine emissions (VCS 2008, page 30)[113]. The proposed direct measurement approach may be used alone or in combination with model estimates (VCS 2008, p.30). VCS refers to IPCC 2006 Guidelines and the three "Tiers" estimation methods.

112 Outlined in Section 3.3
113 See step 6 of the VCS AFOLU Guidance

- *CDM* – The CDM has developed several "tools" that are detailed guidance on to address a particular aspect of protocol application. It has issued a *Tool for estimation of change in soil organic carbon stocks due to the implementation of A/R CDM project activities*. It is directed at quantifying SOC change in afforestation and reforestation offset projects and is not directed for use in agricultural offset projects as the CDM has not adopted agricultural protocols to date. Its quantification prescriptions draw upon the IPCC Tier 1 equations and relative stock change factors as previously described.[114]

- *VCS Improved Grassland Management (draft)* – stipulates use of a modeling approach to determine the SOC stock change in the baseline and project scenarios. However, broad scale models - such as those designed for regional or national inventory – are not accepted since they are not able to predict change at the scale of management activity. The choice of the model is at the project participant's discretion, however the selected model must comply with strict protocol criteria, including:
  - ⇒ be accepted in peer-reviewed scientific publications[115];
  - ⇒ be field tested on soils within the geographic region that includes the project area;
  - ⇒ have an output resolution that can predict differences in SOC at the scale of project activity;
  - ⇒ include land management practice as an input parameter;
  - ⇒ be designed to account for time since clearing from natural vegetation;
  - ⇒ generate forward and backward projections of SOC stocks in the modeled scenario;
  - ⇒ include statistical model outputs such as mean and variance in SOC density in t/ha at time t.

  The protocol includes an *ex post* comparison of SOC model output with SOC values determined by field sampling in the project area. Sampling (at a depth of 30 cm) must be from a minimum of three co-ordinates in sufficient strata identified that cover 80% of the project area. The protocol specifies a minimum of 30 samples across the project area.

- *CCX Protocol for Conversion to Grassland* – GHG estimations are not based on models or measurements, but rather on application of a SOC change default factor derived from professional evaluation of empirical research.

[114] See also section 1.4 for a detailed description of Tier 1 method
[115] The CENTURY model is cited as an example

- *CAR* - has a general policy to require estimation methods that provide 95% confidence that actual carbon stocks are within ± 5% of measured or calculated values (CAR 2010a). Carbon stocks are measured directly or indirectly, i.e. calculated from measurements of parameters from which carbon stocks can be derived. In a scoping paper, CAR has proposed that for crop management offset projects where direct measurements are too costly or infeasible, carbon stocks may be estimated using standard assumptions or models (CAR 2010a).

- *Alberta Offset System* – Through its research for a native grasslands protocol, the Alberta Government is proposing to use Canadian National GHG Inventory default factors. [116][117] This is the same type of quantification approach that is used in the Alberta Offset System's *Quantification Protocol for Tillage System Management*.

4.7.3. Issues

- ***SOC sampling issues*** - Soil carbon stocks can be measured in the field with various methods and extrapolated across the management area.[118] In contrast to renewable energy or industrial gas offset projects, which tend to be discrete and easily monitored, agricultural GHG sources and sinks are relatively small, dispersed over diverse landscapes, and very sensitive to biophysical conditions and soil properties. Moreover, sequestration rates due to practice change are low, although significant over a long period (Haak 2008). Soil C change associated with management change, typically about 0.3-0.7 Mg C/ha/yr, is difficult to detect compared with total soil C, which can be as high as 100 Mg C/ha (Bolinder et al 2006). For these reasons, it is challenging to detect changes in sequestration rates and can cause rates to vary considerably over space and time. For instance, the number of samples required to determine a net change in SOC of around 1 Mg/ha at 90% confidence level is prohibitively high and typically higher than 1,000 samples for gleysolic and brunisolic soils (Vandenbygaart et al 2007).

  SSRs are typically influenced by several unavoidable factors such as seasonal climate variability and natural disturbances (insects,

[116] Pers. Comm. S. Nolan, 2011-01-03

[117] How these are developed was described in Section 3.4.

[118] The most common form of direct measurement is to extract soil samples. The sample is then combusted in a laboratory and analyzed for carbon content. Dry combustion is the most accurate and common technique, but could be relatively expensive[118] relative to the carbon revenues expected from the project. More sophisticated soil analysis methods are available, such as spectral analysis technologies (laser and infrared spectroscopy), but are usually cost-prohibitive (Fynn et al 2009).

precipitations, temperature, etc.). Depending on the project biophysical specific characteristics, these factors may have significant impact on N_2O and CH_4 emissions and even carbon stocks on the long term. Therefore, repeated measurements over time are likely to be necessary, ranging from seasonal sampling (N_2O and CH_4) to yearly sampling (carbon stock changes).

- ***Sampling depth*** - Depth of sampling is an important question and a source of ongoing debate. Deeper sampling is expensive and sometimes difficult to do. There is not sufficient evidence at this time to know whether accounting for deeper soils would result in increases or decreases in measurement of soil carbon changes, and how this might vary with soils and climate. Experts suggests deep soils will likely have a small impact on total carbon changes over shorter time scales and are more likely to have a positive effect than negative (Eagle et al 2010). Thus given conservative accounting principles it would not be necessary to sample deep soils, at least not very frequently, which can be time consuming and expensive. Further research is definitely needed in this area and recommendations may change.

- ***Sampling cost*** - Aside from laboratory analysis costs, many other costs are to be taken into account such as field technician, transport, etc. Table 4-1 is an overview of the costs that may be related to soil sampling. Costs presented are unit costs and total costs will depend on the number of samples needed per hectare.

TABLE 4-1: EXAMPLE OF SAMPLING COSTS [119]

Parameter	Unit cost
Sample Prep.	$6.00
Total organic carbon (SOC)	$18.00
Total inorganic carbon (SIC)	$15.00
Bulk Density	$8.50
Field sampling/reporting	$52.50
Total for SOC	$85.00
Total for SOC and SIC	$100.00
Sample archiving	$10/month

[119] Source: Eagle et al 2010

- ***GHG emissions field measurement*** - Achievement of typically acceptable levels of accuracy for an offset project (such as within ±10% at 95% confidence level) via SOC sampling and gas chamber sampling of GHG emissions will be a significant challenge due to the high variability in storage and emissions over small spatial scales making it difficult to extrapolate results. Another option is a micrometeorological technique, tower flux eddy covariance, that measures GHG flux. However, these instruments are very specialized and expensive and thus not practical for use in an offset project. Field measurement for a grasslands conversion project would have to be adapted into a cost acceptable sampling accuracy framework.

- ***Standard default factors -*** Standard factors are simple and cost-effective to use, however their accuracy depends on how well the input data used in their calculation represents the conditions of the specific projects. Since the estimation of GHG emissions or sequestration in agriculture is very sensitive to the project specific biophysical conditions, factors should be viewed as generalized representations rather than site specific factors. For instance, the default standard deviation is 50% for the stock change factors applicable to grassland management and land-use change (IPCC 2003).

- ***Biogeochemical model accuracy -*** Models can be a good estimation alternative that mitigates the high monitoring costs associated with grasslands projects. However, in order to be accepted and used under an offset protocol, models have to be peer reviewed, validated through a third party assessment and calibrated with region-specific data. While model results tend to improve when estimates are undertaken at large (ecozone/ecoregion) scale (e.g. national GHG inventory report), it is generally recognized that a model's predictive accuracy decreases with scale. In order to improve their accuracy and integrate the cumulated knowledge at the project level, models need to be continuously scaled-down to work at a smaller region level (e.g. ecodistrict, SLCs) and eventually at project scale (Bolinder et al 2007).

4.7.4. Options

The following are options for to address estimation and monitoring requirements, associated with a conversion to grasslands offset protocol.

Direct Measurement

Field sampling and laboratory analysis is likely to be involved directly (as the main estimation technique) or indirectly (in order to help calibrate biogeochemical computer models with key project area data) for agricultural offset projects. Field based measurements are widely perceived as the most accurate and scientifically sound method to obtaining an estimate as close as possible to actual results[120].

Within an agricultural offset project context, field sampling and laboratory analysis has a few shortcomings. One is that there can be a high degree of variability between sample results for a project area because of heterogenous conditions across the area (Conant 2010; VandenBygaart 2007). A key issue is that field sampling and laboratory analysis to determine SOC storage, underground biomass carbon storage and GHG fluxes is a costly endeavour. The cost is in part tied to the spatial variability in key parameters. There are sampling methods that can address some of the issues related to sampling costs and logistics within an offset project, however. Statistical stratification, for instance, consists in subdividing the area to be measured into relatively homogenous (e.g. same soil texture) regions (strata) and may contribute to reduced sampling cost. Another technique is called paired sampling and consists of isolating SOC change from spatial variability through the use of repeated measurements at fixed locations (Lark 2009; Eagle et al 2010).

Other sampling techniques have been discussed and put forward to help address the cost issue associated with a large number of samples. For instance, Vandenbygaart and Kay (2004) designed a sample protocol so as to be able to reposition soil core locations in each successive sampling period across time, thereby achieving spatial control for the cores and reduce the number of samples[121]. This method could be integrated into an offset monitoring and verification procedure.

One option to address the cost issue related to sampling is to facilitate project aggregation or "bundling". Sampling costs per acre will tend to decrease when estimating carbon stocks over larger areas because sampling efficiency will improve as fewer samples per acre will be required to achieve the desired confidence level over the entire area being measured.

SSRs related to other GHGs (N_2O, CH_4, CO_2), are more difficult and costly to measure in the field than carbon stocks. Nevertheless, these can be estimated using general emissions factors, regionally specific models or process-based models that simulate the mechanisms driving changes in carbon storage and flux, and are calibrated to existing field and laboratory data.

[120] Pers.Comm. B. VandenBygaart 2011-01-07 and Pers. Comm. R. Conant 2011-02-08

[121] 30 cores per 9 x 4m plot grid

Standard default factors

With certain offset systems (e.g. Alberta Offset System) the use of standard default factors constructed largely on the basis of the results reported in peer-reviewed articles has been widely accepted for estimating SOC change due to changes in agricultural management practices (such as conversion of croplands to grasslands and switching from a conventional to a no tillage system). In the context of an early stage program, the use of such factors is simpler and their lesser accuracy on a project area basis does not necessarily lead to over-estimation since they can be combined with conservative assumptions in their development and discount factors.

Default factors for reduced N_2O emissions and increased CH_4 emissions associated with grasslands conversion projects could be integrated with SOC default factors to form the basis for a more comprehensive quantification approach.[122]

Although they tend to be the least accurate option for quantifying GHG emissions or sequestration in agriculture projects, it is a typical practice with offset protocols to use factors to estimate minor SSRs, such as fossil fuel emissions associated with operation of farm equipment in the baseline scenario, and to rely on more accurate estimation techniques for the major SSRs.

Modeling[123]

As previously mentioned the Canadian and U.S. National GHG inventory processes use the CENTURY model[124] to quantify SOC and N_2O change arising from agricultural land use changes. However the inventories are carried out at a much larger spatial scale and estimation accuracy requirements are much less demanding than in the case of offset projects where the intrinsic product across all project types is a homogeneous one tonne of CO_2e reduction.

Largely relying on biogeochemical computer models has emerged as a key method to help estimate *ex ante* and *ex post* project reductions for terrestrial carbon offset projects because of their sophistication, peer-reviewed science and cost effectiveness. For example, the draft VCS protocol on Improved

122 A discount on the SOC factors could also be used to account for CH_4 emissions associated with incremental grazing.

123 Section 1.10 described the different peer-reviewed models available and that have been cross-checked with empirical data.

124 The PC standalone version of the CENTURY model and a Windows Help file version of the CENTURY manual can be downloaded from the CENTURY homepage: http://www.nrel.colostate.edu/projects/century/

Grassland Management specified the use of a combination of modeling and soil sampling to estimate SOC change. Use of models has become common in high quality forest offset projects. The draft Forest Carbon Offset protocol issued by the BC Government in November 2010 allows proponents to rely on properly calibrated computer models for estimating project reductions.[125]

The CBM-CFS3 model was developed by the Canadian Forest Service to facilitate quantification of the Canadian GHG inventory and is now designated as an acceptable model in high quality forestry offset protocols. A similar carbon budget model development exercise has not been directed at the Canadian agriculture sector although the CENTURY plant-soil model is integrated into the Holos web-based model created by Agriculture and Agri-Food Canada for estimating GHGs associated with an overall farm operation.

The DNDC is another well known biogeochemical plant-soil model, and it has been parameterized for modeling at the ecodistrict level in Canada (Smith et al 2010).

These protocols that allow the use of models for certain aspects of project quantification are either highly prescriptive in what models that can be used, for example the CAR's Forest Protocol and the BC Government's draft forest protocol, or suggestive about a suitable model, for example the draft Improved Grassland Management methodology currently under consideration within the VCS's approval process.

Estimation uncertainty associated with these models can be quantified and discount factors used to help ensure the conservativeness of the project reduction estimate (Ogle et al 2007).

Following is an explanation of the operation and data requirements of the well established CENTURY plant-soil model and the ICBM soil model, which can be considered for designation as suitable models for helping to quantify a project reduction in a conversion to grasslands protocol.

CENTURY/DAYCENT model

The CENTURY model is a generalized plant-soil ecosystem model that simulates plant production, soil carbon dynamics, soil nutrient dynamics, and soil water and temperature. It allows for the input of local data such as NPP and soil characteristics so its results reflect the combination of a sophisticated process model based on up-to-date science and local climatic, soil and plant information.

[125] See pg 69-73, available at http://www.env.gov.bc.ca/cas/mitigation/pdfs/FCOP_Final-(22nov2010)-for_public_review.pdf

The DAYCENT model is the daily version of the CENTURY which simulates plant-soil systems using a daily time step. The DAYCENT model is capable of simulating detailed daily soil water and temperature dynamics and trace gas fluxes (N_2O) which are not simulated in CENTURY.

The model allows the user the flexibility to choose among several types of events to be simulated as well as their order of magnitude and their duration. Those include for instance fire, tillage, fertilizer added, grazing, type of harvest (if any), irrigation, organic inputs (e.g. manure), etc. This characteristic is particularly useful in an offset project since several management practices may have to be considered that result in GHG changes.

The model includes three main "submodels": the plant production, soil organic matter and the soil water and temperature, as well as three "element submodels": nitrogen, phosphorus, sulfur. The relevant submodels for an offset project are: plant production (covering above and below-ground carbon pool), SOM and nitrogen, described as follows:

- **The plant production submodel** represents a large variety of grassland systems and includes pools for live shoots and roots as well as standing dead plant material above and below-ground. Potential production (g C/m^2) is a function of a genetic maximum defined for each crop. The effect of grazing and fire on the grassland is represented in the model with the major effect of fire being the increase in root to shoot ratio, increase in the C:N ratio of roots and shoots, removal of vegetation and return of nutrients from the fire (Parton et al 2001).

- **The SOM submodel** is based on multiple compartments for SOM. The model includes three soil organic matter pools (active, slow and passive) with different decomposition rates, above and belowground litter pools and a surface microbial pool which is associated with decomposing surface litter. It divides SOC into several pools depending upon turnover rate of SOC. It also takes into account the type of material the carbon is in (plant lignin, microbial material, or soil particulate carbon).

- **The nitrogen submodel** simulates gaseous losses of nitrogen (N_2O) associated with mineralization/nitrification, denitrification and volatilization from harvesting crops are calculated. Losses due to burning, transfer of nitrogen in animal excreta, and soil erosion are also accounted for.

This model takes into account site-specific parameters and those have to be entered (this step is called site parameterization). They include:

- monthly precipitation in centimeters
- monthly mean minimum temperatures in degrees Celsius

- monthly mean maximum temperatures in degrees Celsius
- site latitude and longitude
- percentage sand, silt, and clay in top 20 cm layer of mineral soil
- bulk density of the top 20 cm layer of soil (g/cm^3)
- rooting depth and root distribution of the vegetation (cm)
- C in the soil organic matter in the top 20 cm of soil
- N in the soil organic matter in the top 20 cm of soil

Besides, in order to parameterize the model, other grassland vegetation specific info is required including:

- productivity of vegetation (g C/m^2/year or growing season)
- C:N ratio of aboveground and belowground vegetation
- root to shoot ratio of vegetation
- lignin content of vegetation, aboveground and belowground

CENTURY output variables are grouped in the following eight categories (Parton et al 2001) as summarized below:

TABLE 4-2: CENTURY OUTPUT VARIABLES[126]

Output Category	Description
Water and temperature	Soil water and temperature, precipitation, mean air temperature, decomposition factor.
Soil C	Soil and litter C pools (SOM1, SOM2, SOM3), erosion and deposition.
Grass C	Grass above and below-ground C
Forest C	Forest above and belowground production, NPP.
CO_2	Respiration.
N	All nitrogen output variables, including volatization (N_2O)
P	All phosphorus output variables.
S	All sulfur output variables.

ICBM model

In cases where CENTURY is judged too complex or costly to use (e.g. for small-scale projects), the ICBM model is an alternative to consider. It is an analytically solved, non-linear model of soil carbon, nitrogen and microbial biomass dynamics. It is available online in a single Excel spreadsheet, has been

[126] Source : CENTURY User's Guide and Reference available at : http://www.nrel.colostate.edu/projects/century/userguideframe.htm

widely used by the soil science community and is easy to use.[127] It has been developed for general use to describe the different soil carbon dynamics with only two state variables and five parameters.

As part of ICBM modeling, the user has to source project area or local data on NPP (Net Primary Productivity) of the plant system being modeled, which is then entered into the ICBM spreadsheet in order to help calculate SOC. The use of NPP data is key to the calculation and is used with the S:R ratio (shoot-to-root ratio) of the site specific crop or grasses (Bolinder et al 2006).[128] "The S:R ratio is generally available for the common C3-C4 grasses however its availability would have to be verified for less common, more exotic grass species", Bolinder says[129]. In comparison, CENTURY uses a more complex plant production sub-model that requires more site specific input parameters. It does not rely on easy-to-use default values (such as S:R ratio) to estimate the total carbon input.

According to Bolinder, ICBM would not need to be regionally calibrated if used for an offset project. "The best option would likely be a combination of both default and measured input values: the use of site-specific parameters (e.g. crop production, climate, soils) that can be measured or determined in a short period of time, and use of default values (e.g. S:R ratio) where site or crop-specific data are unavailable", says Bolinder.[130]

Hybrid or integrated modeling and sampling approach

The direct measurement and modeling estimation options (either CENTURY or ICBM) considered above are not mutually exclusive. A typical approach with high quality terrestrial carbon protocols is to require a certain level of field sampling in combination with modeling. An option is to require periodic field measurements only a few times during a project in order to develop project or local area data to improve the model's local calibration (Conant, Ogle Paustian 2010; Conant 2010; De Gryze et al 2009). The cost of direct measurement could be lowered by allowing the use of certain techniques that reduce the number of samples that must be collected and analyzed.

This type of approach would help to balance environmental integrity, economic efficiency and practicality. Even though models tend to offer the best balance between those criteria, use of field data and measurements (NPP, shoot to root

---

[127] Pers. Comm., A. VandenBygaart, 2011-02-07

[128] Bolinder et al (2002) estimated the S:R ratios for the following species of grasses and perennials grown under eastern Canada conditions: bromegrass, switchgrass, Italian ryegrass, esterwolds ryegrass, orchardgrass, canarygrass, timothy, ryegrass, birdsfoot trefoil, fescue, sweet clover, alfalfa and red clover. NPP data for C-4 grasses grown in eastern Canada is available from the scientific literature and will be forthcoming from the Ontario bioenergy research projects cited in Section 3.10.

[129] Pers. Comm. M. Bolinder 2011-02-25

[130] Pers. Comm. M. Bolinder 2010-12-09

ratios, and soil characteristics) from the project area or region to calibrate models improves the accuracy of their estimates of SOC, under-ground biomass carbon and N_2O emissions.

4.8. Baseline Setting and Additionality

4.8.1. Introduction

The baseline scenario is a quantitative representation of what would have happened in the project's absence. The baseline is intrinsically hypothetical and the difference between this hypothetical scenario and the actual scenario (project) represents the reductions or removals that could be credited as offsets.

It is intimately linked with the concept of additionality, since a critical criteria of deeming a project as "additional" is when the project emission reductions are incremental to those that would have occurred under the baseline scenario. An offset protocol must describe how to develop appropriate baselines and assess additionality.

There are two broad approaches to establish a baseline: project-specific and standardized approach. Thus, depending on the protocol and standard, the baseline can be determined via project specific research or through accessing the existing scientific literature. A standardized approach has typically been adopted in land-use change protocols mainly because of its simplicity and typically involves a "practice or activity test", and a default standard of enhanced SOC sequestration based on adoption of the new practice.

There is usually a four part test to determining additionality in project-based protocols: the project (1) must begin operation after a certain start date (2) is legal surplus (ie. not required by current or proposed regulation) (3) must result in a GHG reduction incremental to the baseline (4) offset revenues can be proven to overcome an obstacle (such as inadequate IRR) to project implementation. The financial additionality requirement test is typically not required with protocols or offset programs using performance standard baselines. In this case, the project must exceed or surpass the stated performance standard. Some offset systems also include a common practice test to determine additionality, i.e. the project is not common practice in the region of the project's location.

4.8.2. Situation

Following are short descriptions of the direction that various agricultural protocols, standards or guidance documents give on determining the baseline.

- *WCI Offset System Essential Elements Final Recommendations Paper* – states that "When possible, the baseline shall be set using a sector-specific or activity-specific performance standard which is set in WCI offset protocols based on a regional assessment of project performance or common practice." [131] The performance standard should reflect the

[131] See http://www.westernclimateinitiative.org/component/remository/func-startdown/277/

most stringent legal requirements amongst the WCI jurisdictions.[132] It also states that offsets may be awarded only for projects that are initially commenced on or after January 1, 2007.

- *VCS AFOLU Guidance* - For agriculture projects, VCS guidance suggests that baseline carbon stocks can be determined from measured inventory estimates using approved methodologies and/or activity-based estimation methods (e.g. IPCC 2006), considering current and previous management activities. If activity-based methods are used for projects focused on SOC change, then stock estimates should be determined relative to the computed maximum carbon stocks that occurred in the designated land area within the previous 10 years. Minimum baseline estimates for N_2O and CH_4 emissions should be based on verifiable management records (e.g. fertilizer purchase records, manure production estimates, livestock data) averaged over the 5 years prior to project establishment.

- *VCS Improved Grassland Management (draft)* – This draft methodology defines the baseline as the realistic and credible scenario that could occur on the grassland in the absence of the project activity. When selecting the baseline scenario, the project proponent must use the VCS "Tool for Demonstration and Assessment of Additionality"[133] to describes all possible baseline scenario and assess which of the alternatives (management strategies in this case) shall be excluded from further consideration.[134] The most credible baseline scenario identified must be a scenario of grassland management, since the protocol is designed to implement enhanced grasslands management practices.

- *CCX Protocol for Conversion to Grassland* – The baseline definition and additionality are based on performance criteria. There are two performance criteria that projects must meet to be considered for offset issuance: a regulatory criterion and a common practice criterion. Common practice is defined as per the lands that have completed their contractual requirements under the Conservation Reserve Program (CRP): for these lands, reversion to croplands has been observed to be the most common practice. Therefore, conversion of cropland to grassland and maintenance of the land in a grassland state is deemed to be an uncommon practice in the U.S. The baseline scenario for grassland conversion is the existence of

[132] See pg 11 of the WCI's Offset System Essential Elements Recommendations Paper
[133] Currently the CDM tool available at:
http://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-01-v5.2.pdf

cropland or the conversion of cropland to grasslands under ineligible management practices
.

- *Ducks Unlimited Avoided Grassland Conversion Project Plan* – The DU project document describes its baseline scenario as the conversion into cropland, pushed by the U.S. Government's biofuels policies acting as a driver of grassland conversion into cropland. Statistics are presented to support this assertion and derive annual loss rate. The estimated annual loss rate - 73.1% - is then applied to the Project Properties which are native grasslands converted to croplands over 99 years. Aside from carbon baseline scenario, other baseline scenarios are presented such as biodiversity, soil and water resources baselines.

- *Climate Action Reserve* – is a strong advocate of the use of performance standard baselines and to date has incorporated them into all of its approved protocols. CAR is currently compiling resources that could be used to establish common practice performance standards for cropland management (including conversion of croplands to grasslands). CAR's initial research states that a performance standard could be based on either on emission/sequestration rate thresholds or on practice/technology-based thresholds (CAR 2010a).

  In addition to requiring a performance standard baseline, CAR has restrictions on the earliest eligible start date for projects. The general policy is that for 12 months following the adoption of a new protocol, projects may register as long as their start date is no more than 24 months prior to the date of the protocol's adoption. After the 12-month initial period, only new projects may register (and must do so within 6 months of starting operation).

4.8.3. Issues

- ***Subjectivity in project-based approaches to baseline setting*** - The project-based or "bottom-up" approach, in which the project proponent is given some discretion in baseline setting, involves a high degree of subjectivity, which leads to increased administrative costs and extra delays since a case-by-case evaluation of a project's circumstances is needed. They are administratively more difficult to apply and affect consistency in how additionality determinations are made. The bottom-up approach increases the level of uncertainty related to the eligibility and therefore this uncertainty is transferred to the project developers and investors.

- ***Data requirements of performance standard baselines*** - There is high interest in performance standard approaches for reasons of cost saving, certainty, simplified approach to determining additionality and greater transparency. The recently issued BC Government Offset consultation paper, followed the direction of the WCI design, in stating that "when possible, the baseline should be set using a sector-specific or activity-specific performance standard."[135] Data collection to define a standard can be challenging, however. Even where data are sufficiently available to identify a common practice baseline, it may not always be easy to clearly identify conditions under which a particular practice should be considered additional.

- ***Free riders with activity or practice-based performance standards*** – A criticism of activity or practice-based performance standards is that they are too simple and broad. All entities that adopt the activity or practice are eligible to be awarded credits whether or not they would have done so anyway in the absence of the offset revenue incentive. These are non-additional projects and therefore free riders. A way to address this situation is to discount individual project offsets by the projected percentage amount of offset credits generated by free riding projects. This helps preserve the overall environmental integrity of this group of offset projects.

- **Challenge of incorporating N_2O and CH_4 emissions into performance standards** – The level of N_20 emissions reduction due to a grasslands conversion project will depend on the cropping system that is considered part of the baseline scenario. A conservative N_2O default factor approach could be used to account for N_2O emissions. Similarly if there is increased grazing associated with the new grasslands then a conservative default factor based on the intensity of the grazing could be incorporated into the project quantification.

- ***Additionality and common practice penetration*** - With marginal croplands there may be an economic incentive to plant perennial native grasses and institute extensive grazing practices. There may already be a certain proportion of marginal lands in a region that have been converted in recent time to perennial grasses. Establishing the extent of this practice may be a challenge because of data inavailability. In the performance standard baseline case it also raises the question of what level of penetration should be used to assess

[135] See pg. 11, "Cap and Trade Offsets Regulation under the *Greenhouse Gas Reduction (Cap and Trade) Act* – Consultation Paper", http://www.env.gov.bc.ca/cas/mitigation/ggrcta/pdf/ctor-consultation-paper.pdf

that the grasslands conversion practice is common practice and should possibly not be considered as additional. The problem should not arise with a project-based approach to baseline setting however as the financial additionality test should indicate whether or not a grasslands conversion project is additional. Where there is a smaller level of penetration and grasslands conversion is not viewed as common practice then the practice could be viewed as additional. If the penetration level of the practice in the region is fairly high, a level that would have to be stated in the protocol, then a discount could be applied to the amount of offsets received by each project based on the level of conversion in the region. For example, if 20% of the croplands in a given project boundary are already converted to native grasslands, then only 80% of the land area converted to grasslands would be eligible for crediting. Under this option, only a certain percentage of cropland being converted to grassland could be eligible based on historical, business-as-usual data. In the case of this proposed protocol, it is expected that grazing would either be an ineligible practice or certain conditions would be placed on the intensity of the allowed grazing for an eligible offset project. These limits would remove or diminish the economic incentive associated with grazing and make it unlikely that the project would proceed as a business-as-usual proposition.

4.8.4. Options

The following are the baseline options that ought to be considered for a grassland conversion protocol.

Practice or activity-based performance standard

A grasslands protocol performance standard could be defined on the basis of the activity of converting marginal lands to native grasslands. This is the approach used in the aforementioned CCX protocol and mimics the approach used in soil tillage management protocols. It is easy to apply, and therefore less expensive to structure and quantify however the level of uncertainty about additionality is higher and the market and scientific acceptability may be challenged by some stakeholders. Nevertheless, this option can be combined with a discount factor to adjust for anticipated non-additional projects. It could also be structured to accommodate landowners who took early action but want to convert more marginal farmlands to grasslands. If the protocol was directed at WCI compliance markets then discounts associated with accuracy uncertainty would have to be accommodated.

SOC performance standard

An option is to set a performance standard based on common practice carbon stocks: either on a region's agriculture sector average carbon stock or on the highest SOC change rates. This option depends on the availability and reliability of historical data, since it requires abundant and accurate historical SOC data associated with baseline management practices. Under this option the changes in carbon stocks above the region's sectoral performance standard are rewarded. This approach and the activity-based performance standard approach could also account for the reduced N_2O emissions[136] associated with grasslands conversion projects but specific default factors would have to be constructed for them.

Project-specific baseline

A project-specific projection based approach requiring minimum legal requirements and business-as-usual practices in construction of the baseline. Under this option the changes in carbon stocks are rewarded. It typically involves more quantification and monitoring costs although these incremental costs could be partly offset by the greater offset quality and quantity. It has the advantage of readily accommodating N_2O and CH_4 emissions into project quantification. It is unlikely to be a financially viable option for smaller projects but it has the advantage of avoiding the additionality concerns of an activity-based performance standard and the data development challenges of a SOC performance standard.

Applicability conditions

The protocol's applicability conditions could be written to limit the intensity of allowable grazing on the grasslands of a project. This would diminish the financial viability of converting marginal croplands to grasslands thereby increasing the likelihood that a project that meets this applicability condition is additional.

Aggregation

Risk of crediting non-additional projects typically decreases as broad-scale participation increases and this participation can be encouraged through an aggregation mechanism. Under this approach, projects would only be eligible if they encompassed a large percentage of the landowners within a particular geographic region (similar to the CDM programmatic approach). There are

---

136 And any increased CH_4 emissions if incremental grazing occurs on the new grasslands

logistical challenges to face, but such an approach may help to mitigate the risk of non-additionality.

4.9. **Permanence and Reversal Risk Management**

4.9.1. Introduction

The matter of how to manage the permanence of carbon storage in grasslands biomass and soils within an offset system arises because they are at risk of releasing emissions from their stored carbon due to anthropogenic and natural disturbances.

Although there is continued scientific investigation on the lifetime of CO_2 in the atmosphere, the IPCC uses a 100-year atmospheric lifetime for CO_2 and the Global Warming Potentials of other GHGs are based on this 100-year time frame. This is the minimum time frame that high quality offset systems, such as CAR and BC's offset system, set as the minimum time frame that a GHG reduction of a sequestration-focus offset project must endure. .

Mandating risk management plans that incorporate reversal mitigation tactics and undertakings is one pathway to limiting reversal risk. It is helpful however to develop ways to account and compensate for reversals that occur prior to the minimum 'permanence' time period that an offset project authority sets. Further, in cases where liability falls on the project authority, the latter may want to protect the integrity of the scheme by setting up an arrangement to safeguard against risks. Protocols can include provisions requiring projects to do this in several ways. For example, protocols can require that projects contract for appropriate insurance coverage or simply discount total offsets by a certain percentage or place a certain amount of offsets in a reserve pool or 'buffer' account[137].

The concepts of reversal risk management and mitigation planning, reversal accounting and compensation and offset project monitoring period are directly linked to a common goal of safeguarding the atmospheric benefit created by an offset project and its retired offsets. Many types of offset projects result in immediate and permanent GHG reductions and accompanying atmospheric benefits. An example would be a project that replaces fossil fuel consumption with a zero rated biomass fuel. A lengthy period of monitoring carbon stocks is needed however for terrestrial carbon -based offsets in order for their offsets to be considered as permanent and fully fungible with offsets from fuel switch and other projects that generate reductions that are clearly permanent.

[137] These buffer pools use a portfolio risk mitigation approach whereby all terrestrial carbon offset projects must contribute a percentage of their offset credits based on a reversal risk assessment and the pool will replace stored carbon that is lost through emissions from an unintended reversal. Proponents remain responsible for intended reversals, such as replacing grasslands with crops, and compensating for the reversal with offset credits equal to the reversal's amount of GHG emissions.

4.9.2. Situation

There are several ways of guaranteeing that offset credits earned by native grasslands conversion projects are not affected if something happens to the project. In a few offset programs, terrestrial carbon offset projects have been required to keep a portion of the offsets in "buffer pools", which can be used in case of reversal to replace the invalid credits. Another well know approach is the concept of "expiring credits" (long-term or temporary CERs) which expire after a given period (e.g. 5 years) and have to be re-verified and replaced by fresh credits. That said, new tools (e.g. private insurance) are expected to emerge as the terrestrial carbon offset market matures in order to make reversal risk management less costly and simpler.

- *WCI Offset System Essential Elements Final Recommendations Paper* – uses a 100 year permanency requirement.[138] Proponents are to replace credits when a project's reductions are reversed. This document mentions several of the methods that are used to sustain the atmospheric benefit of projects but included only a broad direction that "Applicable approaches to assuring permanence for a project type will be included in the appropriate WCI offset protocol."[139]

- *Climate Action Reserve (CAR)* – does not consider its forest protocol approach to addressing reversals automatically transposable to agriculture sector (CAR 2010b). In terms of fundamental definition of the permanency time frame, however, CAR is committed to the definition of how long carbon must be stored to fully offset CO_2 emissions, the minimum obligation period is 100 years and starts with issuance of the last credit.[140]

- *Ducks Unlimited Avoided Grassland Conversion Project Plan* – allows for a buffer reserve (equal to 10% of marketable carbon credits) commensurate with the risk related to replacing carbon credits in the event there is an easement violation.

- *VCS tool for AFOLU Non-Permanence Risk Analysis and Buffer Determination* – uses a buffer pool account to address risk of reversal. The percentage of carbon credits to be deposited into the VCS AFOLU Buffer Pool is based on the project's risk assessment by which is derived a risk factor. For instance, risk factors are related to

[138] It states the following "Sequestration projects must be designed so that the net atmospheric effect of their greenhouse gas removal is comparable to the atmospheric effect achieved by non-sequestration projects. The atmospheric effect will be based on the current international standard established by the UNFCCC, which is currently 100 years."
[139] See pg 15 of the *WCI Offset System Essential Elements Final Recommendations Paper*
[140] If the last year in which offset credits are issued is 30 years from the project start then the project must be monitored for another 100 years, a total project term of 130 years. The BC Government in its *Emission Offsets Regulation* imposes a similar requirement.

unproven technologies or practices, land tenure, drought, fire, insects, diseases, etc. The buffer withholding percentages will depend on the averaged risk factors attributed to each project. For grassland conversion and grassland management projects, the buffer withholding can range from 10% (low risk) to 50% (high risk).

- *CDM* – addresses the reversal risks through the issuance of two kinds of CDM certified emission reductions or CERs: temporary certified emissions reductions (tCERs) and long-term certified emission reductions (tCERs). Projects can choose to issue either tCERs (which must be re-issued every five years) or lCERs (which have a 20-year life-span but which must be re-verified at five-year intervals to ensure the carbon stored by the project has not been released). It is noteworthy that the default liability for re-emissions is with the buyer, unless a contract specifying otherwise is done on a private basis.

- *CCX Protocol for Conversion to Grassland* – has put in place a "permanence reserve" and a "soil carbon reserve pool" as precautions against reversals after and during the contract, respectively. Sequestration rates for conversion to grasslands are initially discounted by 10-20% rates in order to create the permanence reserve with actual offsets that have occurred but have never been issued to the Project Owner. The soil carbon reserve pool is built through a 20% discount applied to any project. These offsets remain the property of the project owner and all offsets that remain in the buffer pool are released to the owner after the long-term commitment.

4.9.3. Issues

- **Cost of risk of reversal management -** Measures to ensure permanence and mitigate risk of reversal often represent significant barriers for prospective proponents to developing soil carbon sequestration projects compared with permanent emission reductions projects. Liability and discount factors significantly reduce the attractiveness of these project types.

- ***Permanency time frame -*** A 100+ year project obligation is seen by many proponents as too long of a commitment for them. The VCS and American Carbon Registry have made attempts to balance concerns about the length of an individual proponent's project obligation with the need to address non-permanence risk of reversal.

- ***Differences between forestry and agricultural land use change projects -*** To transpose the forestry approach to addressing risks of reversal is tempting but some distinctions have to be considered between both sectors. A few elements of the forestry protocol/standard approach to managing reversal risks could be transposed in the agricultural sector, for instance the use of a buffer pool and liability assignment essentially based on the distinction between avoidable and unavoidable reversals. However, these elements have to be adapted to the agricultural context. A consideration is that agricultural projects involve shorter management cycles than forest projects and therefore require more flexibility to respond to unexpected circumstances that impact yields as opposed to a forest that stands idle. In addition, agricultural projects often involve land tenure agreements where farmers rent the land on a short-term basis. This last issue is a challenge since the liability for an avoidable reversal (e.g. harvesting) in forestry tends to be assigned to the landowner. In the case of agriculture, the landowner may be completely removed from land management activities and the farmer – who controls management – may not work the same land for a 100-year period. Nevertheless, these issues tend to be less problematic for the case of native grassland conservation areas - which require much less management intervention (if any) and can be left “idle” in a similar fashion to forests.

- ***Intentional reversal -*** Intentional reversals caused by changes in perceived risks and profits have been observed in agricultural programs, especially the CRP (Eagle et al 2010). The driver for intentional reversal is primarily financial, as crop prices rise then there is movement out of the CRP. A similar issue could arise with carbon offset projects unless the consequences of intended reversals were clear and enforced (Smith 2005). Mechanisms have to be put in place to address intentional reversal and to define which situation falls into intentional (avoidable) as opposed to unintentional (unavoidable).[141]

- ***Liability -*** For unintentional reversals, neither project developers nor credit buyers should face liability for any reversals that actually occur. This situation can be handled through a buffer account. As for avoidable reversals – i.e. reversals that are due to intentional activities (e.g. conversion to annual crops), the common practice with forestry offset projects has been to transfer the liability to the project proponent.

[141] A prescribed burn would not be an intentional reversal. It results in immediate emissions from the above-ground biomass but this pool is recommended to be an excluded pool in a conversion to grasslands protocol.

4.9.4. Options

Risk-based approach

An option that could represent a good balance between environmental integrity and economic efficiency is a "risk-based" approach to managing reversals and permanence issues. A risk-based approach is commonly used in insuring other products and processes (e.g. automobiles, houses and health from fire, flood, hurricanes, etc.). Statistical estimates of risk, based on historical data or prediction tools are used to devise actuarial tables and risk premiums. Similar techniques have already been considered for offset projects (e.g. CAR). This approach is much more project specific and does not penalize low-risk projects, however its implementation is more costly since it requires the recollection of large sets of historical data and/or the use of actuarial models.

Clear distinction between intentional and unintentional reversal

The most common protocol option is to consider repayment by project owners for intentional reversals. Change in grasslands management requirements and practices may be readily identifiable as "intentional" but the change however may actually be caused by natural factors. For instance, the invasion of "superweeds" is best managed by periodic tillage (Eagle et al. 2010). Since the superweeds invasion is not caused by any intentional action from the landowner, the tillage could potentially fall into the unintentional category. The simplest way to address the matter is to clearly pre-define each category into verifiable distinctions.

Buffer Pool

Projects are required to contribute credits to a buffer pool according to the expected risk of reversals under this approach. The operator of the buffer pool would have the obligation for a 100 year period to compensate for losses of stored carbon due to unintentional reversals. This approach ensures that unintentional reversals are compensated by retiring credits out of the buffer pool.

The advantages of this approach are that project developers do not face an added cost (aside from required buffer pool contributions), and buyers are able to acquire reversal risk-free credits (i.e. they would not have to replace credits in the case of a reversal). However, the challenge is to estimate the risk and magnitude of reversals over a 100-year time horizon. This is especially true for agricultural systems involving soil carbon, which have short management cycles and may be subject to significant variability depending on the management regime and possible natural perturbations.

Partial crediting

An option to overcome difficulties associated with estimating reversal risks and assigning liability for reversals is to issue "partial credit" for stored carbon based on the length of time it is deemed to be stored. A partial crediting scheme is based on the principle that full crediting for a given tonne of CO_2 is achieved only at the end of the 'permanence' time period (e.g. 100 years). For example, one tonne of CO_2 stored for 20 year would receive 20/100ths of a credit. Full crediting is achieved after the tonne has been effectively stored for 100 years. Under such an arrangement, there would be no penalty if a reversal occurred prior to 100 years.

Partial crediting has many practical advantages. It does away with treating reversals as a liability thereby enhancing project attractiveness for both investors and project developers. The length of the 'permanence' time period is important since it affects the portion of the credit that a proponent receives in the event that the project is abandoned prior to the end of this official time period.

An issue is that it is not obvious how storing 1,000 tonnes of CO_2 for ten years (after which the CO_2 is emitted) may be equivalent to permanently reducing 100 tonnes of CO_2 emissions. Critics of this concept point out that partial crediting and permanence are not equivalent, ie storage of 100 tonnes for 10 years offers a lesser atmospheric benefit than storage of 10 tonnes for more than 100 years.

Liability

Project proponents and buyers can negotiate contracts whereby the buyer assumes the liability for reversals. Under this approach carbon revenues to the project proponent would be significantly below a secondary market price or below prices for projects with no reversal or little reversal risk. In an over-the-counter (OTC) market this option is always available and appears to be more feasible than an exclusive proponent liability arrangement, which could face significant logistical barriers in an agricultural context as mentioned previously.

4.10. **Leakage**

4.10.1. Introduction

Leakage typically refers to GHG emissions that are shifted from a project area to an area outside of the offset project's geographical boundary as a result of project activities thereby partially or completely cancelling the GHG benefits generated by the project. These are sources "affected" by the project. These emissions are not taken into account as "project emissions" and this is why they have to be accounted for as "leakage" and deducted from the calculated baseline emissions in order to obtain the net emission reductions.

Leakage is generally defined as either "market leakage" or "activity-shifting" leakage, both defined as affected by the project. Market leakage refers to increased GHG emissions resulting from substitution of goods lost as a result of project activity. Activity-shifting leakage occurs when activities that would occur within project boundaries under the baseline scenario are displaced outside the project boundary. An example is when a nearby area gains cropping acres because there is market demand for the crops that are displaced because of the grasslands conversion project. The associated fertilizer emissions and fossil fuel emissions of the baseline would not be eliminated, they would be fully or partially re-located to this nearby area of new crop production.

4.10.2. Situation

Following are short descriptions of the direction that various agricultural protocols, standards or guidance documents give on the matter of leakage.

- *WCI Offset System Essential Elements Final Recommendations Paper* – requires a leakage assessment in a protocol but does not specify a specific method, although it states a preference for a quantitative assessment.

- *VCS tool for AFOLU* - For small-scale ALM land set-aside projects (< 10,000 ha), leakage due to displaced activities can be assumed to be zero. Furthermore, VCS considers leakage negligible for projects involving grassland management activities, since the yields are assumed to be maintained. For grassland projects greater than 10,000 hectares and involving land use change, VCS considers the following leakage sources as being potentially significant:
  - ⇒ Reductions in carbon stocks outside the project area due to the displacement of pre-project activities
  - ⇒ Increases in N_2O, CH_4 and production-related fossil CO_2 emissions outside the project area due to the displacement of pre-project activities

⇒ Other emissions of CO_2 from fossil fuel use that are attributable directly to the project but occur outside of project boundaries; for example, the transportation of products from the project that are additional to those accounted for in the baseline.

- *VCS Improved Grassland Management (draft)* – assumes that no activity-shifting leakage will occur. Documentation (e.g. location, area and land use, grazing management plans, etc.) must be provided to prove that no leakage is occurring at the moment of verification. Where activity shifting occurs, then the project is considered not to meet the requirements for verification. Project proponents may optionally choose to submit a methodology deviation with their future verifications to address activity shifting leakage. Displacement of baseline scenario livestock to commercial producers outside the project boundary is defined as market leakage and must be accounted for.

- *Climate Action Reserve* – considers agricultural leakage as a result of shifts in crop production outside of a project's physical boundaries due to project-related yield changes. Leakage risks for a project maintaining constant yields are therefore considered minimal. CAR is contemplating two approaches for leakage accounting in crop management offset projects: project level and system-wide accounting. At the project level, project yields would be monitored and leakage estimated accordingly. At the system-wide level, system-wide leakage would be estimated and default discount factors assigned on a project basis.

- *Ducks Unlimited Avoided Grassland Conversion Project Plan* - Based upon data on the acres of new native grasslands easements, as well as statistics on the "new breaking" acres (i.e. converted to croplands), a statistical relationship would be established between both practices. If the relationship is positive (i.e. there is a positive proportional correlation), then there would be an assumption that leakage occurred. If there is no statistical relationship, then the conclusion would be that there is no leakage.

- *CCX Protocol for Conversion to Grassland* - does not expect grassland conversion projects to result in new or changed activities that increase GHG emissions outside of the project boundary so no project specific leakage assessment is required.

4.10.3. Issues

- **Activity-shifting leakage** – is a risk in the case of cropland conversion projects crop production is displaced to previously uncropped lands (possibly causing soil carbon losses). Similarly, there can be the displacement of nitrogen fertilizer and/or manure additions to existing or new croplands (causing increases in N_2O emissions) to compensate for the loss of agricultural production. Activity-shifting leakage risk is minimal if the services provided by the land are maintained or increased as a result of project activity (e.g. inclusion of perennials). This is obviously not the case of a conversion from annual productive cropland to native grasslands, and therefore leakage risk is significant.

- **Grazing reduction** - Grassland management projects involving a grazing reduction could involve a shift in grazing activity to another grassland area under the control of the proponent (internal leakage which has to be considered as project emissions) or another area outside of the project boundary (external leakage).

- **Econometric techniques** – of estimating leakage using price elasticity can be highly subjective exercises and impose a significant added cost for project development.

4.10.4. Options

No leakage assumption

For conversion to grassland projects, it can be assumed *ex ante* that no activity-shifting leakage will occur, especially for smaller-scale projects (e.g. $\leq$ 10,000 ha). Lands retired from cropland to grassland are marginally productive, which reduce considerably the risk of leakage compared to more productive lands. As stated in CCX and VCS grassland protocols, documentation could be required of a project proponent to prove that no internal leakage is occurring at the moment of verification.

Boundary extension

An approach to account for leakage is to extend the carbon accounting boundary beyond the geographical boundaries of the project. This allows any localized shifting of activity in response to the project to be covered in the project accounting system and not generate unaccounted leakage locally (Fynn et al 2009).

Leakage management zones

Leakage management zones can be used to internalize emissions associated with meeting crop demand. Here a proponent would increase crop production on other lands to accommodate the displacement resulting from conversion to grasslands of other lands. It maintains the agricultural products within areas under the control of project proponents.[142]

Leakage discount factor

The CAR forest protocol uses a discount approach to account for grazing and crop production related leakage in afforestation projects (CAR 2010e). To quantify emissions associated with the shifting of cropland and grazing activities each year, a "leakage" risk percentage (0 to 50%) is determined *ex-ante*. Each year, this percentage is then applied as a discount to the net increase in onsite carbon stocks.

[142] See pg 25 of VCS 2008

4.11. **Verification**

4.11.1. Introduction

Once the project activity is implemented and effectively reducing emissions, the emission reductions (or removals) claimed by a project proponent must be verified by a third party in order to generate offset credits. Across the major offset systems and programs, the verification process tends to have more or less the same features although the requirements and criteria for accreditation of the third party assurance providers and the verification procedures may vary slightly.

The verification is generally carried out by an independent third-party assurance provider whose main task is to ensure that the GHG reductions or removals claimed by the project are real and quantified in compliance with the designated protocol and offset regulation(s). A focus of this exercise is to consider whether the project report is subject to material errors, omissions or misrepresentations. The verifier will review monitoring records and calculations, including any modeling use.

4.11.2. Situation

Following are short descriptions of the direction that various agricultural protocols, standards or guidance documents give on the matter of verification.

- *WCI Offset System Essential Elements Final Recommendations Paper* – requires use of verifiers that are accredited to a standard set by the WCI jurisdiction in which the project is located. It also requires validation of the likely result of a project reduction or sequestration, ie an independent assessment of the quantification stated in the project plan.

- *ISO 14064-3*[143] - provides general guidance (principles and requirements) for third party entity or program conducting or managing the verification process. It is applied to GHG quantification, monitoring and reporting in accordance with ISO 14064-2. ISO 14064-3 specifies requirements for selecting verifiers, establishing the level of assurance, objectives, criteria and scope, determining the validation/verification approach, assessing GHG data, information, information systems and controls, evaluating GHG assertions and preparing validation/verification statements.

- *UNFCCC/CDM* - requires that verification of a LULUCF project reduction occur every five years at minimum, although the first verification can be done at the project developer's convenience. A further requirement is that verification cannot systematically coincide with peaks in carbon stocks.

---

143 Available at http://www.iso.org/iso/fr/catalogue_detail?csnumber=38700

- *VCS AFOLU Guidance* - provides financial incentives to make projects undergo verification every five years at least, by automatically cancelling 50% of the project's buffer if they do not undergo verification. VCS verifiers can only perform validations/verifications within the sectoral scopes for which they are accredited (scope 2 - agricultural land management, covers all ALM projects).

- *Climate Action Reserve* – Its Program Manual summarizes CAR's verification principles, general project accounting guidelines, and its rules and procedures for registering projects and creating offset credits. CAR requires periodic third-party verification in order to review documentation, monitoring data, and procedures used to estimate GHG reductions/removals. The verification entity then submits and publishes a verification report including a negative or positive opinion. AFOLU projects may submit annual monitoring reports instead of annual verification, but may not go longer than six years between verifications.

4.11.3.Issues

- **Desk audits** - The verification of practices can be a combination of site visits and desk audits conducted by the verifier and checked by simple visual checks. These checks can be complemented by the collection of farm records for fertilizer purchase and application, fuel purchase and equipment use and crop yields. However verifying the project quantification may require much more time and expertise. For instance, re-sampling or model validation is likely to involve substantial costs at the project level if the protocol allow for too much project specificity. Site specific quantitative parameters (e.g. assessment of soil organic carbon) may not be appropriate to require as part of verification.

- **Level of assurance** - Reasonable assurance is a level of assurance typically used in public company financial statement audits and incorporates a direct factual statement of the opinion of the verifier about the assertion. Limited assurance is based on identifying problems with an assertion rather than positively confirming the assertion. The verifier issues a statement on not finding problems. The verifier will phrase the assurance statement to say that nothing has come to its attention that causes it to think that the statement in the assertion is not presented fairly in accordance with the relevant criteria. To offer the higher level of assurance of "reasonable", the verifier probes more deeply into the supplied evidence and undertakes additional effort to review files, documents and data than it would if the expected standard was "limited" level of assurance.

A point on which there can be a divergence between offset systems is the level of assurance required of the verifier. High quality offset systems typically require a reasonable level of assurance. Some only require a limited level of assurance, the Alberta Offset System being one.[144]

- **Model use** – Proper application of plant-soil biogeochemical models require a sophisticated understanding of plant and soil ecology and model technical operation. An element of verification where models are allowed to estimate project reductions is to require verifiers to operate the proponent's model to ensure that proponent stated project reduction estimates can be replicated.

4.11.4. Options

Options may include one or a combination of the following:

Proponent chooses verification frequency

For most offset project types, a verification event is required every year however the situation differs for agriculture and forestry projects where annual change in a project reduction may be relatively small and occur non-linearly. The length of the interval between two verifications should not affect the accuracy and robustness of the reduction claims, as long as the interval is not excessively long and major changes in carbon stocks (e.g. after natural disturbances occur) are properly monitored and reported to the offset's system authority when they occur. Allowing for the proponent to choose the periodicity of verification may be an attractive option since it allows the proponent to tailor the costs associated with verification to the project budget.

Reliance on desk audits

Allow for desk audit based verification where annual verification is elected and require an in-field audit only every 5th year.

Truing up

CAR has issued a consultation document for aggregated forest offset projects that features less stringent verification requirements. It allows for a 'truing up'

[144] The Alberta Offset system will require verifications undertaken to a reasonable level of assurance as of January 1, 2012. See pg 7 of Alberta Environment

process for aggregated projects. There is annual crediting of offsets and they are allowed to proceed for 12 years without verification but at that point offset credits from the previous dozen years are adjusted if necessary to reflect the verified results.[145]

[145] See http://www.climateactionreserve.org/wp-content/uploads/2010/04/Reserve_Forest_Project_Aggregation_Proposal.pdf

4.12. **Crediting**

4.12.1. Introduction

Once emission reductions are verified and recognized by a given standard or offset system, "credits" are issued to the project participants (1 offset credit for 1 tonne of CO_2e project reduction). In existing compliance-based and most voluntary offset schemes, the credit issuance is generally *ex post*, i.e. after the verification of carbon reduction activities.

In some offset programs, the term "validation" period is used. It refers to the length of time that a validated project plan can be the basis for an offset project. More than one validation period may be allowed so at the end of a validation period, the project plan must be revised to take account of new circumstances and undergo a third party validation process. The validation period and crediting period are the same in this situation as both pertain to the length of time that offset credits can be earned by the project in question.

A grassland protocol should specify which party will own the credits. Ownership of credits on leased land should be subject to private contracts between the landowner and renter.

4.12.2. Situation

Forest protocols are well established and provide insights about the duration of crediting periods for terrestrial carbon projects.

- *WCI Offset System Essential Elements Final Recommendations Paper* - states that a crediting period for a sequestration project "… may not exceed 25 years before a renewal, and the total crediting period including all renewals may not exceed 100 years for sequestration projects."[146] Projects and their reductions have to be verifiable so only *ex post* crediting is allowed.

- *UNFCCC/CDM* - provides for temporary credits, tCERs for reforestation/afforestation project but they must be replaced at the end of a crediting period by either other temporary credits or conventional credits, i.e. CERs.

- *VCS* – allows a proponent to choose a crediting period of between 20 and 100 years for forestry or agricultural projects.

- *(draft) BC Forest Offset Guide* – follows the *BC Emission Offsets Regulation*, which requires *ex post* recognition of offsets. The maximum crediting

[146] See http://www.westernclimateinitiative.org/component/remository/func-startdown/277/

or validation period for forest carbon projects in this draft guide is listed as 25 years.

- *CCX Protocol for Conversion to Grassland* – used a contract period, which was 5 years (2006-2010) for soil and grassland projects.

- *Alberta Offset System* – The crediting period is 20 years for tillage management offset projects.

- *CARB Forest Protocol* – uses a 25 year crediting period.[147]

4.12.3. Issues

- **Matching crediting period and sequestration period** – The crediting period is the time frame during which a project can receive credits for reducing emissions or increasing removals. Its duration can directly impact the financial viability of a project as a shorter time frame may not allow sufficient time for offset revenues to help recoup project investment costs.

  The crediting period of a grassland project should be based on the "sequestration duration" of the project, ie. how long the project can sequester incremental amounts of carbon before reaching a steady state[148]. Dormaar and Smoliak (1985) and McConnell and Quinn (1988) each reported that it took 50 plus years for cropland converted to native grasslands to approach the SOC levels of native rangeland.

- **Timing of credit allocation** - Due to the long time-frame involved in generating climate benefits in the case of agricultural projects, *ex post* crediting may prove financially challenging for project proponents since high up-front payments will be necessary to absorb project costs until it generates the initial revenues. For some activities, *ex ante* crediting may make some project types more financially viable. However, there is a risk of over-crediting with *ex ante* crediting and the incentive to perform (i.e. sequester as promised) is much weakened.

- **Credit ownership** - An offset project proponent must have legal ownership of the GHG emission removal resulting from the offset project. Establishing clear ownership of the emission reductions generated by an offset project is important prior to registration. In the case of multi-participants project, the credits ownership sharing

[147] The CAR forest protocol uses a 100 year crediting period.
[148] When SOM associated sequestration and CO_2 emissions are roughly equal on an annual basis and there is very little or no incremental additions to storage of SOC.

has to be clearly and legally defined prior to the offset project registration. The offset project proponent will be responsible for all statements and information provided to the entity issuing the offset certificate before the verification of the carbon removal and the issuance of the offset certificates.

4.12.4.Options

Long-term crediting period

An option is *ex post* crediting and a fixed crediting term of between 20[149] to 50 years selected by the proponent. This approach is consistent with that of the VCS but takes account of the period over which carbon sequestration occurs in SOM when marginal farmland is converted to a native grassland. However it is inconsistent with the WCI offset program design which sets a maximum period of 25 years for sequestration projects.

Renewable crediting periods

An option that allows for changing circumstances in the baseline is to use renewable crediting; in this instance allowing for multiple crediting periods. The WCI offset design allows for a maximum crediting period of 100 years, which could incorporate for 25 year crediting periods.

Aggregation

Small, less attractive projects are more likely to be eligible for crediting (more strongly additional) while on the other hand there may be serious financial limitations to verify the project emissions and sequestration rates. One option to address this issue is to allow for project aggregation or "bundling" so monitoring and verification third party costs can be split among several project participants thereby achieving economies of scale. For instance, aggregation is allowed under the CDM Programmatic (PoA) scheme which facilitates the registration of strongly additional small-scale project activities. The activities included under the PoA's umbrella share the quantification and monitoring costs, thereby reducing their risk and making the adhesion to the programme attractive.

[149] The 20 years crediting period is generally considered the minimum acceptable for AFOLU project crediting period for the buffer approach to serve as an effective non-permanence risk mitigation tool (VCS 2008)

4.13. Environmental co-benefits

Through this type of offset project, Norfolk ALUS aims to provide farmers with new economic incentives through a market-based approach to help meet the public demand for environmental ecological services and benefits on private land (Bailey and Reid 2004). Benefits associated with conversion to native grasslands and grassland good management practices include mitigating the greenhouse effect, decreasing risk of water pollution, reduction of erosion, improving wildlife habitat, and helping maintain biodiversity (Follett et al 2001; Conant 2010). Besides, improvements in soil water quality and availability are generally correlated with increased plant productivity (Huston and Marland 2003).

Grasslands also have the potential to provide multiple co-benefits related to climate change adaptation. For instance, risks associated with prolonged drought periods and heavy rains episodes can be partly mitigated by the reduced erosion, increased water infiltration and retention associated with SOM accumulation (Conant 2010).

Potential negative impacts related to grasslands carbon sequestration are minor and mainly attributed to additional organic inputs. For instance the addition of animal manure to the soil can alter plant community composition by modifying competitive interactions between plant species. Uncomposted manure may introduce seeds of invasive species or have a detrimental effect on water quality, depending on factors such as manure concentration and type (Follett et al 2001).

BIBLIOGRAPHY

Alberta Environment. February 2009. *Quantification protocol for tillage system management, Version 1.3*

Alberta Environment. October 2007. *Soil carbon custom coefficient/protocols guidance document, Version 1*

Alberta Environment. January 2011. *Technical guidance for Offset Project Developers, Version 2.0*

Angers, D. A. 1992. *Changes in soil aggregation and organic carbon under corn and alfalfa.* Soil Sci. Soc. Am. J. 56: 1244-1249.

Arora, K., Mickelson, S.K., Helmers, M.J. and Baker, J.L. 2010. *Review of pesticide retention processes occurring in buffer strips receiving agricultural runoff.* Journal of the American Water Resources Association 46(3):618–47.

Bailey, R.O. and Reid, D.J. 2004. *ALUS: The Farmer's Conservation Plan*.

Bellows, B. (2001) *Nutrient Cycling in Pasture*. National Centre for Appropriate Technology.

Boehm, M., Junkins, B., Desjardins, R., Kulshreshtha, S. and Lindwall, W. 2004. *Sink potential of Canadian agricultural soils.* Climatic Change 65:297-314.

Bolinder, M. A., Angers, D. A. and Dubuc, J. P. 1997. *Estimating shoot to root ratios and annual carbon inputs in soils for cereal crops.* Agric. Ecosyst. Environ. 63: 61-66.

Bolinder, M. A., Angers, D. A., Giroux, M. and Laverdière, M.R. 1999. *Estimating C inputs retained as soil organic matter from corn (Zea mays L.).* Plant Soil. 215: 85–91

Bolinder, M., Angers, D., Bélanger, G., Michaud, R. and Laverdière, M. 2002. *Root biomass and shoot to root ratios of perennial forage crops in eastern Canada.* Can. J. Plant Sci. 82: 731–737.

Bolinder, M., Janzen, H., Gregorich, E., Angers, D., and VandenBygaart, A. 2006. *An approach for estimating net primary productivity and annual carbon inputs to soil for common agricultural crops in Canada. Agriculture,* Ecosystems and Environment 118: 29-42.

Bolinder, M.A., Andren, O., Katterer, T., de Jong, R., VandenBygaart, A.J., Angers, D.A., Parent, L-E., Gregorich, E.G. 2007. *Soil carbon dynamics in Canadian Agricultural Ecoregions: Quantifying climatic influence on soil biological activity*. Agriculture, Ecosystems and Environment 122 (2007) 461–470

Bolinder, M. A., Andren, O., Katterer, T. and Parent, L.-E. 2008. *Soil organic carbon sequestration potential for Canadian agricultural ecoregions calculated using the Introductory Carbon Balance Model.* Canadian Journal of Soil Science 88: 451-460.

Bremer, E., Janzen, H. H. and Johnston, A. M. 1994. Sensitivity of total, light fraction and mineralizable organic matter to management practices in a Lethbridge soil. Can. J. Soil Sci. 74: 131_138.

Bremer, E., Ellert, B. H. and Janzen, H. H. 1995. *Total and light-fraction carbon dynamics during four decades after cropping changes.* Soil Sci. Soc. Am. J. 59: 1398-1403.

Bremer, E., Janzen, H. H. and McKenzie, R. H. 2002. *Short-term impact of fallow frequency and perennial grass on soil organic carbon in a Brown Chernozem in southern Alberta.* Can. J. Soil Sci. 82: 481-488.

Bremer, E. December 2008. *Potential of rangelands to sequester carbon in Alberta.* Prepared for Alberta Sustainable Resource Development.

Bruce, J.P., Frome, M., Haites, E., Janzen, H., Lal, R. and Paustian, K. 1999. *Carbon sequestration in soils.* Journal of Soil and Water Conservation 54(1): 382–9.

Burke, I.C., Kittel, T.G.F., Lauenroth, W.K., Snook, P., Yonker, C.M. and Parton, W.J. 1991. *Regional analysis of the Central Great Plains: sensitivity to climate variability.* Bioscience 41:685 692.

Burke, I.C. and Coffin, D.P. 1995. *Soil organic matter recovery in semiarid grasslands: implications for the conservation reserve program.* Ecological Applications 5(3): 793–801.

Burke, I.C., Lauenroth, W.K., and Milchunas, D.G. 1997. *Biogeochemistry of managed grasslands in central North America.* In E.A. Paul, K. Paustian, E.T. Elliott, and C.V. Cole (eds), *Soil Organic Matter in Temperate Agroecosystems: Long-Term Experiments in North America,* CRC Press, Boca Raton, FL, pp. 85-102.

Cahill, K., Kucharik, C., and Foley, J. 2009. *Prairie restoration and carbon sequestration: difficulties quantifying C sources and sinks using a biometric approach.* Ecological Applications, 19(8): 2185–2201.

Campbell, C. A., Biederbeck, V. O., Zentner, R. P. and LaFond, G. P. 1991a. *Effect of crop rotations and cultural practices on soil organic matter, microbial biomass and respiration in a thin Black Chernozem.* Can. J. Soil Sci. 71: 363–376.

Campbell, C. A., Bowren, K. E., Schnitzer, M., Zentner, R. P. and Townley-Smith, L. 1991b. *Effect of crop rotations and fertilization on soil organic matter and some biochemical properties of a thick Black Chernozem.* Can. J. Soil Sci. 71: 377–387.

Campbell, C. A. and Zentner, R. P. 1993. *Soil organic matter as influenced by crop rotations and fertilization*. Soil Sci. Soc. Am. J. 57: 1034–1040.

Canadell, J.G., Pitelka, L.F. and Ingram, J.S.I. 1996. *The effects of elevated CO_2 on plant-soil carbon belowground: A summary and synthesis*. Plant and Soil 187:391-400.

Campbell, C. A., Zentner, R. P., Liang, B.-L., Roloff, G. and Gregorich, E. G. 2000. *Organic C accumulation in soil over 30 years in semiarid southwestern Saskatchewan- Effect of crop rotations and fertilizers*. Can. J. Soil Sci. 80: 179-192.

Chapin, F. S., McFarland, J., McGuire, A.D., Euskirchen, E.S., Ruess, R.W. and Kielland, K. 2009. *The changing global carbon cycle: linking plant-soil carbon dynamics to global consequences.* Journal of Ecology 97:840-850.

Chicago Climate Exchange. 2009. *CCX Offset Project Protocol: Agricultural Best Management Practices – Continuous Conservation Tillage and Conversion to Grassland Soil Carbon Sequestration.*

Christian, J.M. and Wilson, S.D. *Long-Term Ecosystem Impacts of an Introduced Grass in the Northern Great Plains.* Ecology, 80(7), pp. 2397-2407, 1999.

Climate Action Reserve (CAR). 2010a. *Quantification Options for Agriculture Projects*.

Climate Action Reserve (CAR). 2010b. *Options for Managing CO2 Reversals*.

Climate Action Reserve (CAR). 2010c. *Options for Determining the "Additionality" of Agriculture Projects*.

Conant, R.T., Paustian, K. and Elliott, E.T. 2001 *Grassland Management and Conversion into Grassland: Effects on Soil Carbon.* Ecological Applications, 11(2), pp. 343–355.

Conant, R.T., Paustian, K., Del Grosso, S.J. and Parton, W.J. 2005. *Nitrogen pools and fluxes in grassland soils sequestering carbon*. Nutrient Cycling in Agroecosystems 71(3): 239–48.

Conant, R. 2010. *Challenges and opportunities for carbon sequestration in grassland systems - A technical report on grassland management and climate change mitigation.* Food and Agriculture Organization of the United Nations, Rome.

Conant, R., Ogle, S. and Paustian, K. 2010. *Measuring and monitoring soil organic carbon stocks in agricultural lands for climate mitigation.* Front Ecol Environ. Doi:10. 1890/090153.

De Gryze, S., Albarracin, M., Catal-Luque, R., Howitt, R. and Six, J. 2009. *Modeling shows that alternative soil management can decrease greenhouses gases. California Agriculture*. Vol. 63 no.2: 84-92.

Desjardins, R.L, Smith W., Grant B., Campbell C., Janzen H., and Riznek R. 2005. *Management Strategies to Sequester Carbon in Agricultural Soils and to Mitigate Greenhouse Gas Emissions.* Climatic Change 70(1): 283-297.

Donigian, A.S., Metherell, A.K. , Blevins, R.L., Patwardhan, A.S., Chinnaswamy, R.V., Frye, W.W. and Paustian, K. 1995. Application of the CENTURY soil organic matter model to a field site in Lexington, Kentucky. Pages 385-394 in R. Lal, J. Kimball, E.

Dormaar, J.F., and Smoliak, S. 1985. *Recovery of vegetative cover and soil organic matter during revegetation of abandoned farmland in a semiarid climate*. J. of Range Manage. 38:487-491.

Dormaar, J.F., Smoliak, S. and Willims, W. 1990. Soil chemical properties during succession from abandoned cropland to native range. J. of Range Manage. 43(3): 260-265.

Douglas, J.T., and Goss, M.J. 1982. *Stability and organic matter content of surface soil aggregates under different methods of cultivation and in grassland*. Soil & Tillage Res. 2:155-175.

Ducks Unlimited Inc, New Forests Inc., Equator, LLC. 2009. *Ducks Unlimited Avoided Grassland Conversion Project in the Prairie Pothole Region*. Climate, Community, and Biodiversity Alliance Report.

Eagle, A.J, Henry L.R., Olander L.P., Haugen-Kozyra K., Millar N., and Robertson G.P. 2010. *Greenhouse Gas Mitigation Potential of Agricultural Land Management in the United States - A Synthesis of the Literature.* Nicholas Institute for Environmental Policy Solutions, Duke University.

Environment Canada. 2008a. *National Inventory Report: Greenhouse Gas Sources And Sinks In Canada 1990-2006*.

Environment Canada. 2008b. *Canada's Offset System for Greenhouse GasesGuide for Protocol Developers*. Canada Gazette August 9 2008.

Fisher, M. J., Rao, I.M., Ayarza, M.A., Lascano, C.E., Sanz, J.I., Thomas, R.J. and Vera, R.R. 1994. Carbon storage by introduced deep-rooted grasses in the South American savannas. Nature 371:236-238.

Follett, R.F., Kimble, J.M. and Lal, R. 2001, *The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect.* CRC Press, Boca Raton, FL.

Follett, R.F. and Reed, D.A. 2010. *Soil carbon sequestration in grazing lands: Societal benefits and policy implications*. Rangeland Ecology & Management 63(1): 4–15.

Franzluebbers, A.J., Stuedemann, J.A., Schomberg, H.H. and Wilkinson, S.R. 2000. *Soil organic C and N pools under long-term pasture management in the Southern Piedmont USA*. Soil Biology & Biochemistry 32(4): 469–78.

Franzluebbers, A.J. and Stuedemann, J.A. 2009. *Soil-profile organic carbon and total nitrogen during 12 years of pasture management in the Southern Piedmont USA*. Agriculture, Ecosystems & Environment 129(1–3): 28–36.

Franzluebbers, A.J. 2010. *Achieving soil organic carbon sequestration with conservation agricultural systems in the southeastern United States*. Soil Science Society of America Journal 74(2): 347–57.

Fynn, A.J., Alvarez, P., Brown, J.R., George, M.R., Kustin, C., Laca, E.A., Oldfield, J.T., Schohr, Tracy, Neely, C.L., Wong, C.P. 2009. *Soil Carbon Sequestration in U.S. Rangelands - Issues Paper for Protocol Development*. Environmental Defense Fund 2009.

Gebhart, D.L., Johnson, H.B., Mayeux, H.S., and Polley, H.W. 1994. *The CRP increases soil organic carbon*. J. Soil Water Conserv. 49:488-492.

Gifford, R. M., Cheney, N.P., Noble, J.C., Russell, J.S., Wellington, A.B., Zammit, C., and Barson, M.M. 1992. *Australian land use, primary production of vegetation and carbon pools in relation to atmospheric carbon dioxide concentration*. Pages 151–187 in Australia's Renewable Resources: Sustainability and Global Change. IGBP, Canberra, Australia.

Gill R.A. and Jackson R.B. (2000) *Global patterns of root turnover for terrestrial ecosystems*. New Phytol 147:13–31

Gill, R. A., Kelly, R.H., Parton, W.J., Day, K.A., Jackson, R.B., Morgan, J.A., Scurlock, J.M.O., Tieszen, .L.L., Castle, J.V., Ojima, D.S. and Zhang, X.S. 2002. *Using simple environmental variables to estimate below-ground productivity in grasslands*. Global Ecology and Biogeography 11: 79–86.

Goldenfum, J. June 2009. *The UNESCO/IHA measurement specification guidance for evaluating the GHG status of man-made freshwater reservoirs*. UNESCO/IHA Greenhouse Gas (GHG) Research Project.

Grant, R. F., Juma, N. G., Robertson, J. A., Izaurralde, R. C. and McGill, W. B. 2001. *Long-term changes in soil carbon under different fertilizer, manure and rotation: Testing the mathematical model ecosystem with data from the Breton Plots*. Soil Sci. Soc. Am. J. 65: 205–214.

Grant, B., Smith, W.N., Desjardins, R.L., Lemke, R., Li, C., 2004. *Estimated N_2O and CO_2 emissions as influenced by agricultural practices in Canada*. Climatic Change 65, 315–332.

Gregorich, E.G., Drury, C.F. and Baldock, J.A. 2001. *Changes in soil carbon under long-term maize in monoculture and legume-based rotation.* Canadian Journal of Soil Science 81(1): 21–31.

Gregorich, E.G., Rochette, P., VandenBygaart, A.J. and Angers, D.A. 2005. *Greenhouse gas contributions of agricultural soils and potential mitigation practices in Eastern Canada*. Soil & Tillage Research 83(1): 53–72.

Guzman, J. and Al-Kaisi, M. 2010. *Soil Carbon Dynamics and Carbon Budget of Newly Reconstructed Tall-grass Prairies in South Central Iowa.* J. Environ. Qual. 39:136–146.

Haak, D. 2008. Assessment of different quantification approaches and application of multiple practices for a single farm unit. Agriculture and Agri-Food Canada.

Hendrickson, O. 2003. *Influences of global change on carbon sequestration by agricultural and forest soils.* Published on the NRC Research Press Web site at http://er.nrc.ca/ on 16 March 2004.

Huston, M.A. and Marland, G. 2003. *Carbon management and biodiversity*. Journal of Environmental Management, 67, pp. 77-86.

IPCC. 2000. *Land Use, land-use change, and forestry.* R.T. Watson, I.R. Noble, B. Bolin, N.H. Ravindranath, D.J. Verardo and D.J. Dokken (eds). Cambridge University Press, for the Intergovernmental Panel on Climate Change, Cambridge, UK.

IPCC. 2003. *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. Penman, J., Gytarsky, Hiraishi, M.T., Krug, T., Kruger, D., Pipatti, R., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. and Wagner, F. IGES, Japan.

IPCC. 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*, Vol. 4. *Agriculture, Forestry and Other Land Use*, Prepared by the National Greenhouse Gas Inventories Programme. H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara and K. Tanabe (eds). IGES, Japan.

Iwaasa, A. and Schellenberg, M. 2005. *Final report on reestablishment of a mixed native grassland in southwest Saskatchewan.* ADF Project 20010042.

Izaurralde R.C.C., Rosenberg, N.J. and Lal. R., 2001. *Mitigation of Climatic Change by Soil Carbon Sequestration: Issues of Science, Monitoring, and Degraded Lands*. In Advances in Agronomy, vol. 70, pp. 1-75. Elsevier, San Diego, CA.

Janzen, H. H., Angers, D. A., Boehm, M., Bolinder, M., Desjardins, R. L., Dyer, J. A., Ellert, B. H., Gibb, D. J., Gregorich, E. G.,Helgason, B. L., Lemke, R., Massé, D., McGinn, S. M., McAllister, T. A., Newlands, N., Pattey, E., Rochette, P., Smith, W., VandenBygaart, A. J. and Wang, H. 2006. *A proposed approach to estimate and reduce net greenhouse gas emissions from whole farms.* Can. J. Soil Sci. 86: 401–418.

Janzen, H. H., Desjardins, R.L., Rochette, P., Boehm, M. and Worth, D. 2008. *Better Farming Better Air - A scientific analysis of farming practice and greenhouse gases in Canada.* Agriculture and Agri-Food Canada.

Johnson, J.M.-F., Reicosky, D.C., Allmaras, R.R., Sauer, T.J., Venterea, R.T. and Dell, C.J.. 2005. *Greenhouse gas contributions and mitigation potential of agriculture in the central USA*. Soil & Tillage Research 83(1): 73–94.

Kollmus. A., Lazarus, M. and Smith, G. July 2010. *Discounting offsets: issues and options.* Stockholm Environment Institute.

Lal, R., Kimble, J.M., Follett, R.F. and Cole, C.V. 1999. *The Potential of U.S. Cropland to Sequester Carbon and Mitigate the Greenhouse Effect*. CRC Press, Boca Raton, FL.

Lal, R. 2003. *Global potential of soil carbon sequestration to mitigate the greenhouse effect.* Critical Reviews in Plant Sciences 22(2): 151–84.

Lal, R., R.F. Follett and J.M. Kimble. 2003. *Achieving soil carbon sequestration in the United States: A challenge to the policy makers.* Soil Science 168(12): 827–45.

Lark, R.M. 2009. *Estimating the regional mean status and change of soil properties: Two distinct objectives for soil survey*. European Journal of Soil Science 60(5):748–56.

Lauenroth W.K. and Gill, R.A. 2003. *Turnover of root systems.* In: de Kroon H, Visser EJW (eds) Root ecology. Springer, New York, pp 61–89.

Levine, E. and Stewart, B.A. *Advances in soil science: soils and global change*. CRC Press, Inc., Boca Raton, Florida, USA.

Liebig, M.A., Gross, J.R., Kronberg, S.L., Phillips, R.L. and Hanson, J.D. 2010. *Grazing management contributions to net global warming potential: A long-term evaluation in the northern Great Plains*. Journal of Environmental Quality 39(3): 799–809.

Lynch, D.H., Cohen, R.D.H., Fredeen, A., Patterson, G. and Martin, R.C. 2005. *Management of Canadian prairie region grazed grasslands: Soil C sequestration, livestock productivity and profitability*. Canadian Journal of Soil Science 85(2): 183–92.

MacDougall, A.S. and Wilson, S.D. *The Invasive Grass Agropyron Cristatum doubles belowground productivity but not soil carbon*. (in press Ecology 2011).

Machefert, S.E., Dise, N.B., Goulding, K.W.T. and Whitehead, P.G. 2002. *Nitrous oxide emissions from a range of land uses across Europe*. Hydrology and Earth System Sciences 6(3): 325–37.

Mahli, S. S., Brandt, S. and Gill, K. S. 2003. *Cultivation and grassland type effects on light fraction and total organic C and N in a dark Brown Chernozemic soil.* Can. J. Soil Sci. 83: 145-153.

Martens, D.A., Emmerich, W., McLain, J.E.T. and Johnsen, T.N. 2005. *Atmospheric carbon mitigation potential of agricultural management in the southwestern USA.* Soil & Tillage Research 83(1): 95–119.

McConkey, B. G ., Liang, B. C. and Campbell, C. A. 1999. *Estimating gains of soil carbon over 15-yr period due to changes in fallow frequency, tillage system, and fertilization practices for the Canadian prairies (an expert opinion)*. Semiarid Prairie Agricultural Research Centre. Miscellaneous Publication No.379M0209. Agriculture and Agri-Food Canada, Ottawa, ON.

McConkey, B., and Lindwall, W. 1999. *Measuring soil carbon stocks. A system for quantifying and verifying changes in soil carbon stocks due to changes in management practices on agricultural land*. Agriculture and Agrifood Canada.

McConnell, S.G., and Quinn, M.L. 1988. *Soil productivity of four land use systems in southeastern Montana*. Soil Sci. Soc. of Am. J. 52:500-506.

McPherson, B., Allis, R., Biediger, B., Brown, J, Cappa, J., Guthrie, G., Hughes, R., Kim, E., Lee, R, Leppin, D., Mankin, C., Kobos, P., Pawar, R., Peterson, T., Rauzi, S., Stuth, J. and Young, G. 2006. *Southwest Regional Partnership on Carbon Sequestration, Final Report*. DE-PS26-03NT41983.

Mensah, F., Schoenau, J. J. and Malhi, S. S. 2003. Carbon changes in cultivated and excavated land converted to grasses in east-central Saskatchewan. Biogeochemistry 63: 85-92.

Mortensen, M.C., Schuman, G.E. and Ingram, L.J. 2004. *Carbon sequestration in rangelands interseeded with yellow-flowering alfalfa (Medicago sativa ssp. falcata).* Environmental Management 33(Suppl. 1): S475–81.

Mosier, A.R. 1994. *Nitrous oxide emissions from agricultural soils.* Fert. Res. 37:191-200.

Murray, B.C., Sohngen, B., Sommer, A.J., Depro, B., Jones, K., McCarl, B.A., Gillig, D., DeAngelo B. and Andrasko, K.J. 2005. *Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture.* EPA-430-R-05-006. U.S. Environmental Protection Agency, Office of Atmospheric Programs, Washington, D.C.

Ogle, S., Conant, R., and Paustian, K. 2004. *Deriving Grassland Management Factors for a Carbon Accounting Method Developed by the Intergovernmental Panel on Climate Change.* Environmental Management. 33(4): 474-484.

Ogle, S.M., Breidt, F.J., Easter, M., Williams, S. & Paustian, K. 2007. *An empirically based approach for estimating uncertainty associated with modeling carbon sequestration in soils.* Ecol. Model., 205: 453–463.

Olander L.P., Eagle, A.J., Baker, J.S., Haugen-Kozyra, K., Henry, L.R., Murray, B.C., and Jackson, R.B. 2010. *Assessing Greenhouse Gas Mitigation Opportunities and Implementation Options for Agricultural Land Management in the United States - DRAFT.* Nicholas Institute for Environmental Policy Solutions, Duke University.

Olander L.P. and Malin, D. 2010. *Comparison of three biogeochemical models for quantifying greenhouse gas effects of agricultural management - DRAFT.* Nicholas Institute for Environmental Policy Solutions, Duke University.

Parrish, D. J., Fike, J.H., Bransby, D.I. and Samson, R. 2008. *Establishing and managing switchgrass as an energy crop.* Online. Forage and Grazinglands doi:10.1094/FG-2008-0220-01-RV

Parton, B, Ojima, D., Del Grosso, S., Keough, C. 2001. *CENTURY Tutorial.*

Paustian, K, Elliott, E.T., Peterson, G.A. and Killian, K. 1996. *Modeling climate, CO2 and management impacts on soil carbon in semi-arid agroecosystems*. Plant and Soil 187:351-365.

Paustian, K., Brenner, J. M., Easter, K., Killian, S., Ogle, C., Olson, J., Schuler, R., Vining, and Williams, S. 2009. *Counting carbon on the farm: Reaping the benefits of carbon offset programs*. Journal of Soil and Water Conservation 64:36A-40A.

Reeder, J.D., Schuman, G.E. and Bowman, R.A. 1998. *Soil C and N changes on conservation reserve program lands in the Central Great Plains.* Soil & Tillage Research 47(3–4): 339–49.

Reeder, J.D., Franks, C.D. and Milchunas, D.G. 2001. *Root Biomass and Microbial Processes*. CRC Press, Boca Raton, FL.

Robles, M.D. and Burke, I.C.. 1998. *Soil organic matter recovery on conservation reserve program fields in southeastern Wyoming.* Soil Science Society of America Journal 62: 725–30.

Rochette, P., Worth, D. E., Huffman, E. C., Brierley, J. A., McConkey, B. G., Yang, J., Hutchinson, J. J., Desjardins, R.L., Lemke, R. and Gameda, S. 2008. *Estimation of N2O emissions from agricultural soils in Canada 1990-2005 inventory.* Canadian Journal of Soil Science 88: 655-669.

Russell, J. S., and Williams, C.H. 1982. *Biogeochemical interactions of carbon, nitrogen, sulfur and phosphorus in Australian agroecosystems*. Pages 61–75 in J. R. Freney, and I. E. Galbally, editors. Cycling of carbon, nitrogen, sulfur and phosphorus in terrestrial and aquatic ecosystems. Springer-Verlag, Berlin, Germany.

Samson, R.A. 2007. *Resource Efficient Agricultural Production (REAP) – Canada*. Joint publication by Resource Efficient Agricultural Production (REAP) – Canada and the Research and Technology Transfer Section of the Collège d'Alfred of the University of Guelph.

Schimel, D.S., Parton, W.J., Kittel, T.G.F, Ojima, D.S., Cole, C.V. 1990. *Grassland biogeochemistry: Links to atmospheric processes*. Climate Change, 17, 13-25.

Sims, P.L., and Singh, J.S. 1978. *The structure and function of ten western North American grasslands*. II. Intra-seasonal dynamics in primary producer compartments. J. Ecol. 66:547-572.

Smith, P. 2005. *An overview of the permanence of soil organic carbon stocks: influence of direct human-induced, indirect and natural effects*. Eur. J. Soil Sci., 56: 673–680.

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C., Scholes, B., Sirotenko, O., Howden, M., McAllister, T., Pan, G., Romanenkov, V., Schneider, U., Towprayoon, S., Wattenbach, M. and Smith, J. 2008. *Greenhouse gas mitigation in agriculture*. Philosophical Transactions of the Royal Society B: Biological Sciences 363(1492): 789–813.

Smith, W.N., Desjardins, R.L. and Grant, B. 2001. *Estimated changes in soil carbon associated with agricultural practices in Canada.* Canadian Journal of Soil Science 81: 221–227.

Smith, W.N., Grant, B.B., Desjardins, R.L., Worth, D., Li, C., Boles, S.H., Huffman, E.C. 2010. *A tool to link agricultural activity data with the DNDC model to estimate GHG emission factors in Canada*. Agriculture, Ecosystems and Environment 136 (2010) 301–309.

Sperow, M., Eve, M.D. and Paustian, K. 2003. *Potential soil C sequestration on U.S. agricultural soils.* Climatic Change 57(3): 319–39.

Steinaker, D.F. and Wilson, S. 2008. *Scale and density dependent relationships among roots, mycorrhizal fungi and collembola in grassland and forest*. Oikos 117: 703-710.

Steinbeiss, S., Temperton, V.M. and Gleixner, G. 2008. *Mechanisms of short-term soil carbon storage in experimental grasslands.* Soil Biology and Biochemistry 40:2634-2642.

Stewart, A. and Frank, D. 2008. *Short sampling intervals reveal very rapid root turnover in a temperate grassland*. Oecologia 157: 453-458.

Tate, K. R., Giltrap, D.J., Claydon, J.J., Newsome, P.F., Atkinson, I.A.E., Taylor, M.D., and Lee, R. 1997. *Organic carbon stocks in New Zealand's terrestrial ecosystems*. Journal of the Royal Society of New Zealand 27:315–335.

Teixeira, R., Domingos, T., Canaveira, P., Avelar, T., Basch, G., Belo, C., Calouro, F., Crespo, D., Ferreira, V.G., Martins, C. *Carbon sequestration in biodiverse sown grasslands*. In Porqueddu C. (ed.), Tavares de Sousa M.M. (ed.) . Sustainable Mediterranean grasslands and their multi-functions.

Tilman, D., Hill, J. and Lehman, C. 2006. *Carbon-negative biofuels from low-input high-diversity grassland biomass.* 659 Science 314:1598-1600.

Troughton, A. 1957. *The underground organs of herbage grasses.* Bulletin no: 44. Commonwealth Bureau of Pastures and Field Crops.

VandenBygaart, A. J., Gregorich, E. G. and Angers, D. A. 2003. *Influence of agricultural management on soil organic carbon: A compendium and assessment of Canadian studies*. Canadian Journal of Soil Science 83: 363–380.

VandenBygaart, A. J. and Kay, B. D. 2004. *Persistence of soil organic carbon after plowing a long-term no-till field in southern Ontario, Canada*. Soil Sci. Soc. Am. J. 68: 1394–1402.

Vandenbygaart, A.J., Gregorich, E.G., Angers, D.A. and McConkey, B.G. 2007. *Assessment of the lateral and vertical variability of soil organic carbon*. Can. J. Soil Sci. 87: 433–444.

VandenBygaart, A. J., McConkey, B. G., Angers, D A., Smith, W., de Gooijer, H., Bentham, M. and Martin, T. 2008. *Soil carbon change factors for the Canadian agriculture national greenhouse gas inventory.* Canadian Journal of Soil Science 88: 671-680.

VandenBygaart, A. J., Bremer, E., McConkey, B. G., Janzen, H. H., Angers, D. A., Carter, M. R., Drury, C. F., Lafond, G. P. and McKenzie, R. H. 2010. *Soil organic carbon stocks on long-term agroecosystem experiments in Canada*. Canadian Journal of Soil Science 90: 543-550.

Voluntary Carbon Standard - VCS. 2008. *Guidance for Agriculture, Forestry and Other Land Use Projects.*

Wang, X-Y., Willms, W.D., Hao, X., Zhao, M.G., and Han, G.D. 2010. *Cultivation and reseeding effects on soil organic matter in the mixed prairie.* Soil Science Society of America Journal. 74(4): 1348-1355.

Weaver, J.E. and Zink, E. 1945. *Extent and longevity of seminal roots of certain grasses*. Plant Physiol. 20:359-379.

West, O.T. and Six, J. 2006. *Considering the influence of sequestration duration and carbon saturation on estimates of soil carbon capacity*. Climatic Change 80, number 1-2: 25-41.

Western Climate Initiative. July 2010. *Offset System Essential Elements Final Recommendations Paper.*

Western Climate Initiative. July 2010. *Design for the WCI Regional Program*.

White, E.M., Krueger, C.R. and Moore, R.A. 1976. *Changes in total N, organic matter, available P, and bulk densities of a cultivated soil 8 years after tame pastures were established.* Agronomy Journal 68: 581–3.

Wu, J. S., Guo, S. L. and Dang, T. H. 2003. *Mechanisms in the accumulation and movement of mineral N in soil profiles of farming land in a semi-arid region*. Acta Ecol. Sin. 23: 2041-2049.

Yang, X. M. and Kay, B. D. 2001. *Rotation and tillage effects on soil organic carbon sequestration in a typic Hapludalf in southern Ontario.* Soil Tillage Res. 59: 107-114.

APPENDIX I – LIST OF CONTACTS

The following are the persons, mainly research scientists at universities and in government departments, who the authors communicated with for the purposes of this project.

Name	Position and Institution	Interests
Angers, Denis	Agriculture and Agri-Food Canada	Understanding processes of GHG emissions/removals - soil C Estimating net GHG emissions from whole farms Nitrogen use efficiency and N_2O emission reduction in corn receiving mineral fertilizer
Apfelbaum, Steven I.	Applied Ecological Services, Inc.	The Earth's Partner protocol development
Banks, Scott	OMAFRA	Evaluation of Perennial Grass Biomass Systems in Ontario Bioenergy Crop Trials at Thunder Bay and New Liskeard N trials on switchgrass Literature Review on Agricultural Residues
Bolinder, Martin	Laval Univerrsity Department of Soils and Agrifood Engineering	Soil carbon balance modeling Introductory Carbon Balance Model (ICBM)
Camirand, Jeanne	Agronome Nature Québec	Analysis of Quebec agricultural sector contribution to the reduction of GHG
Conant, Richard	Natural Resource Ecology Laboratory Colorado State University	Ecosystem ecology Grazing and browsing ecosystems Terrestrial ecosystem responses to atmospheric changes Remote sensing and GIS Soil ecosystem ecology Carbon and nitrogen cycling
Creed, Irina	Associate Professor Departments of Geography and Earth Sciences University of Western Ontario	Biogeochemistry, Hydrology, Geographic Information Systems, Remote Sensing, Simulation Modelling. Developing a tallgrass prairie research project in Ontario, aiming at quantifying carbon sequestration in tallgrass prairie and the impact of management practices on carbon sequestration

Deen, Bill	University of Guelph Department of Plant Agriculture	Determination of sources of temporal and spatial variability in no-till and conventional tillage corn production systems Evaluation of reflectance as a crop based indicator for corn nitrogen requirement Long-term effects of tillage system on soil quality and crop yield
Dell, Randal	Ducks Unlimited inc.	Avoided grasslands conversion, protocol development under VCS
Desjardins, Raymond	Agriculture and Agri-Food Canada	Climate variability and climate change Greenhouse gas emissions and mitigation Soil carbon sequestration Quantifying methane and ammonia emissions from point sources Estimating greenhouse gas and ammonia emissions from whole farms
Eagle, Alison J.	Duke University (Nicholas Institute)	Coordinate research activities for T-AGG (Technical Working Group on Agricultural Greenhouse Gases)
Fynn, Andrew	C Restored LLC	co-author of Environmental Defense Fund paper: Soil Carbon Sequestration in U.S. Rangelands (2009)
Goldman, Katie	Senior Policy Manager Climate Action Reserve	Forest and agriculture GHG accounting
Grady, Mary	Winrock International	Director of ACR Marketing, Communications and Registry Services
Haak, Dennis	Senior Soil Resource Specialist Agriculture and Agri-Food Canada Soil Resources Unit	Soil resources, offset protocols, carbon sequestration
Hager, Heather	Grad Student (Bill Deen) University of Guelph Department of Plant Agriculture	Bioenergy crops

Haugen-Kozyra, Karen	Principal KHK Consulting	Agricultural project offset system design and implementation Development of agricultural quantification protocols for Alberta Offset System
Hayes, Adam	Soil Management Specialist - Field Crops Ridgetown Resource Centre	Evaluation of Perennial Grass Biomass Systems in Ontario
Henry, Hugh	University of Western Ontario	Member of the QUEST project: The Quest for Understanding Ecological Services of the Tallgrass Prairie, aiming at quantifying carbon sequestration in tallgrass prairie and the impact of management practices on carbon sequestration
Iwaasa, Alan	Agriculture and Agri-Food Canada	Carbon sequestration, methane production, and nitrous oxide emission from cattle grazing native prairie
Janzen, Henry	Agriculture and Agri-Food Canada	Carbon, nitrogen, and sulfur cycling greenhouse gas emissions and mitigation soil C sequestration
Lal, Rattan	University of Ohio	Soil physics; carbon sequestration; climate change; food security; tropical soils.
Lorenz, Klaus	Ohia State University Ohio Agricultural Research and Development Center	Effects of land use and soil management on the vertical distribution of soil organic carbon in chemically and physically separated fractions
Lundgren, Britt	Environmental Defense Fund Agricultural Policy Specialist	USDA conservation programs Environmental issues associated with agricultural production Sustainable production of bioenergy feedstocks
MacDougall, Andrew	Department of Integrative Biology University of Guelph	Plant invasion: impacts on ecosystem function and global carbon sequestration in semi-arid prairie Infrastructure for studies of grasslands, species loss and global environmental change
Martin, Nick	Winrock international ACR Chief Technical Officer	Development of ACR standards and methodologies through the application of sound science as well as the validation of new methodologies through scientific peer review

McConkey, Brian	Agriculture and Agri-Food Canada	Estimating net GHG emissions from whole farms Methodology for quantifying GHG emissions/removals Regional and national estimates of GHG emissions/removals
McDonald, Ian	Applied Research Coordinator Field Crops Unit, Ag. Dev. Br. OMAFRA	Research project: Evaluation of Perennial Grass Polycultures for Biomass Production and Agri-Environmental Sustainability
McKeown, Alan	Department of Plant Agriculture University of Guelph Simcoe Campus	Locally adapted species of native grasses for biomass production Identify diseases with potential to affect production
Morris, Belinda	Environmental Defense Fund Regional Director, Center for Conservation Incentives	Environmental stewardship on working landscapes Reducing greenhouse gas emissions from land use Advancing land-based carbon offsets Improving water quality
Nolan, Sheilah	Climate Change Specialist Government of Alberta Agriculture and Rural Development	Development of Alberta Offset system protocols and guidelines
Ogle, Stephen	NREL, Colorado State University	Plant and SOC modeling
O'Sullivan, John	Department of Plant Agriculture University of Guelph, Simcoe Campus	Evaluation of Perennial Grass Polycultures for Biomass Production and Agri Environmental Sustainability.
Parent, Léon-Étienne	Université Laval Département des sols et de génie agroalimentaire	Carbon sequestration potential for Canadian agricultural ecoregions calculated using the Introductory Carbon Balance Model
Raven, Heather	Policy Coordinator Climate Action Reserve	Maintenance of existing protocols Development of new protocols Coordination of policy activities
Rennie, Tim	University of Guelph Kemptville Campus	Biofuels Food processing Postharvest biology and technology

Sen, Aditi	Program Coordinator VCS	Coordination of interactions between validation/verification bodies, methodology developers, and other market participants
Swickard, Naomi	AFOLU Program Coordinator VCS	Works with VCS AFOLU Steering Committee and manages the AFOLU program Development of new guidance and tools Expansion of the scope of the program
Tarnocai, Charles	Research Scientist Agriculture and Agri-Food Canada	Characterization of the distribution of soil biota and their contribution to topsoil development in Canadian agro-ecosystems Impact of climate change on soil carbon
Thimmanagari, Mahendra	University of Guelph Crop Bioproducts Specialist OMAFRA	Crop bioproducts Cooperate on applied research and demonstration projects related to crop bioproducts
Van Acker, Rene	Professor Department of Plant Agriculture University of Guelph	Evaluation of Perennial Grass Biomass Systems in Ontario Assessment of Availability of Agricultural Biomass for Electricity and Heat Generation in Ontario
Vanden Bygaart, Bert	Soil Scientist Agriculture and Agri-Food Canada	Modeling soil organic carbon dynamics in agro-ecosystems Accounting and verifying soil organic carbon change in agro-ecosystems Effect of soil erosion and deposition on carbon dynamics and the carbon cycle
Wilson, Scott	Department of Biology University of Regina	Grass belowground productivity relationship with soil carbon Grass root dynamics
Yang, Xueming	Agriculture Canada	Understanding the impacts of agronomic practices on soil organic carbon dynamics and sequestration for fine-textured soils in southwestern Ontario
Young, Doug	University of Guelph Ridgetown campus	Research project ending in late 2011 on alternative renewable fuel crops in Ontario (miscanthus, switch-grass, cordgrass, big blue stem)

APPENDIX II – UNDERWAY SCIENTIFIC RESEARCH PROJECTS ON GRASSLANDS

Lead reseachers	Institution	Research project overview	Timeline
MacDougall, Andrew	Department of Integrative Biology University of Guelph	Recently turned a former soybean field in Cambridge, ON into tallgrass prairie cover Will observe the change in SOC pools, planned 10-year project Will study the impacts on ecosystem function and global carbon sequestration in semi-arid prairie	Started in 2010
Creed, Irina; Henry, Hugh	University of Western Ontario	The Quest for Understanding Ecological Services of the Tallgrass Prairie (QUEST) Project Objectives: To quantify the magnitude and rate of carbon storage along a chronosequence (1, 10, 100, 1000 year-old) of tallgrass prairie To assess how management practices affect biofuel production efficiency, sustainability and carbon sequestration To compare the productivity, carbon sequestration and fertilization responses of tallgrass prairie under current and future climate scenarios To assess the benefits of tallgrass prairie for promoting increased animal biodiversity relative to monoculture crops used for cellulosic biofuel production	Planned start date - 2011 (project in planning stages)
MacDonald, Ian: Van Acker, Rene	OMAFRA/University of Guelph	Evaluation of Perennial Grass Polycultures for Biomass Production and Agri Environmental Sustainability Objective: To evaluate the potential for introduced legumes to supply nitrogen to C-4 perennial grasses and estimate the proportion of the N requirements that can be met. To compare the productivity and sustainability of mono species vs poly species sward mixtures of C-4 perennial grasses.	2011- 2014

		To determine if polycultures maintain themselves in long term swards. To compare the productivity of native, locally adapted cultivars of the various C-4 grasses to selected varieties.	
Thimmanagari, Mahendral	OMAFRA/University of Guelph	Comparative Performance of Perennial Grasses and Short Rotation Woody Crops (poplar, willow) on Different Soil Types for Energy and Carbon Sequestration. Species: miscanthus, switchgrass, bluestem Experimental plot at Guelph University Campus Funded by Environmental Sustainability Directed Research Program OMAFRA	Concludes 2012
Rennie, Tim	OMAFRA/University of Guelph (Kemptville)	Evaluation of biomass crops as an industrial energy source Field trials of annuals and C-4 grasses in 2 ON locations, focuses on bionergy production matters, but also collects carbon & N_2O data	Concludes 2012, may receive funding for a second phase
Deen, Bill	University of Guelph	Ontario biomass availability assessment: evaluation of perennial grass biomass systems in Ontario (Species: miscanthus, switchgrass, cordgrass, bluestem) 7 research plots across Ontario: Elora Research Station (established 2008) Ridgetown Campus (established 2008) Simcoe Research Station (2009) Nanticoke (OPG) (2010) New Liskeard Research Station (2009) Emo Agricultural Research Station (2010) Kemptville College (2009)	Concludes 2012
Bowley, Stephen; Deen, Bill	University of Guelph	Switchgrass/Big Bluestem/Prairie Cordgrass breeding/agronomy Funded by Environmental Sustainability Directed Research Program, OMAFRA	Concludes 2012
Young, Doug; Deen, Bill	University of Guelph	Multi-site perennial grass comparison Funded by OMAFRA – Alternative Renewable Fuels Program Compared crops: Switchgrass, corn-soybean rotations, big bluestem, miscanthus and prairie cord grass Objectives: assess soil quality impacts (organic carbon, aggregate stability)	Concludes 2012

		Quantify N yield response Establish research platform for GHG assessments	
Janzen, Helmut	Agriculture and Agri-Food Canada	Managing carbon and nitrogen to sustain productivity and preserve environmental health in a changing world	2007-2011
Yang, Xueming	Agriculture Canada	Understanding the impacts of agronomic practices on soil organic carbon dynamics and sequestration for fine-textured soils in southern Ontario LTAE focused on bluegrass	2007-2011
Gregorich, Edward	Agriculture Canada	The impact of agricultural management practices and abiotic factors on the turnover and storage of soil carbon and nitrogen	2007-2011
Iwaasa, Alan	Agriculture Canada	Grassland/Beef management impacts on Greenhouse Gases and Ammonia Emissions in Prairie Ecosystems (2008-2011/12) Sustaining grassland ecosystems in the face of climate change (2009-2012/13) Quantifying nitrous oxide emission factors from animal manure on pasture, range and paddock by grazing cattle in Canada (2009-2011/12) Development of a grassland health monitoring and productivity prediction system in adaptation of climate change (2009-2011/12)	2008-2013
Lal, Rattan	University of Ohio, Carbon Management and Sequestration Center	Effect of ungrazed winter cover crops (rye) and rotations on the soil organic carbon of annual corn-based crop rotations. Research will involve 20 partners across 10 US states. Funded by USDA – National Institute for Food and Agriculture (CAP program)	March 2011 -