Incorporating Wetland Carbon Values into Spatially Explicit Tools to Inform Land Use Decisions – Final Report

4 November 2015

Ducks Unlimited Canada
Conserving Canada's Wetlands

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Table of Contents

Executive Summary

Wetlands are some of the most productive ecosystems on the planet and as a result store approximately 25-35% of the world's terrestrial carbon. In addition to sequestering greenhouse gases, wetlands confer a range of benefits to society including as habitat for a diverse range of wildlife species, regulating water flows to mitigate the effects of floods and droughts, by removing excess nutrients and other pollutants from water sources, and as important recreational sites. Despite these benefits, wetlands continue to be lost. In the prairies, we estimate that from the period from 1985-2001, an average of ~32 ha was lost every day (Watmough and Schmoll 2007). More recent estimates suggest that losses continue at similar rates (Michael Watmough, Pers. Comm.). Freshwater wetlands sequester and store substantial amounts of organic carbon. Once a wetland is drained, carbon loss is rapid. If hydrology is restored, greenhouse gases will again be sequestered, but decades may elapse before carbon stores are completely recharged. Accordingly, decision support tools are required to better inform future land-use decisions and help ensure that economic development fully accounts for the impacts on natural capital.

We generated spatially explicit decision support tools that represent the distribution of wetland-related soil organic carbon stores throughout the Prairie and Boreal Plain Ecozones. Model development occurred through a series of phases:

- In Phase I of the project, we gathered data to obtain and evaluate established relationships between carbon storage/sequestration and wetland attributes from research conducted by DUC, estimates from peer-reviewed literature and partnerships with ongoing research efforts.
- In Phase II of the project, we developed mapping products that predict carbon currently stored in prairie wetlands and carbon losses that have resulted from recent (2001-2011) wetland drainage.
- In Phase III of the project, we evaluated and modified mapping products that predict carbon currently stored in prairie wetlands using independent data sources. We also modeled expected carbon losses that have resulted from recent (2001-2011) wetland drainage using newly available data. Additionally, we provide insight into new data collections that could further refine spatial predictions of carbon stores, especially for large permanent prairie wetlands that have rarely been sampled. Finally, we developed mapping tools to predict carbon currently stored in wetlands throughout the Boreal Plains.
- Finally, in Phase IV, we updated Alberta's Wetland Restoration Offset Protocol to comply with the Intergovernmental Panel on Climate Change's (IPCC) Guidelines for National Greenhouse Gas Inventories

These products provide powerful tools to guide the conservation of wetland-related soil organic carbon stores. These tools also can serve as the foundation for developing conservation offset programs that ensure sustainability of wetland functions. Including measures of carbon storage and flux will help focus research on activities and areas with the greatest cumulative carbon exposure and could form an essential information layer for assessing cumulative carbon exposure under different future activity scenarios. Such applications also facilitate avoidance and

minimization of impact on carbon stores, comparison with trade-offs in operational costs, and, possibly, valuation of carbon conserved by sound carbon management.

Disclaimer:

This report has been produced independently by Ducks Unlimited Canada at the request of the Climate Change and Emissions Management (CCEMC) Corporation as specified under contract. The views expressed in this report are not necessarily the views of the Climate Change and Emissions Management (CCEMC) Corporation.

Introduction

Wetlands are some of the most productive ecosystems on the planet and as a result store approximately 25-35% of the world's terrestrial carbon. In addition to sequestering greenhouse gases, wetlands confer a range of benefits to society including as habitat for a diverse range of wildlife species, regulating water flows to mitigate the effects of floods and droughts, by removing excess nutrients and other pollutants from water sources, and as important recreational sites. Despite these benefits, wetlands continue to be lost. In the prairies, we estimate that from the period from 1985-2001, an average of >32 ha every day was lost (Watmough and Schmoll 2007). More recent estimates suggest that losses continue at similar rates (Michael Watmough, Pers. Comm.). Freshwater wetlands sequester and store substantial amounts of organic carbon. Once a wetland is drained, carbon loss is rapid. If hydrology is restored, greenhouse gases will again be sequestered, but decades may elapse before carbon stores are completely recharged. Accordingly, decision support tools are required to better inform future land-use decisions and help ensure that economic development fully accounts for the impacts on natural capital.

Chapter 1. Prairie Carbon Stores

Peer-reviewed literature was reviewed for explanatory relationships between covariates related to prairie pothole wetlands and carbon stores. Similarly, scientists currently working to quantify these relationships were interviewed to determine their willingness to collaborate in this project. Specific focus was placed on covariates for which geospatial data existed across the region of interest, though all covariates were retained in the literature review.

Wetland data: Canada lacks a comprehensive wetland inventory, complicating the modelling of wetland-related carbon stores and other values. Accordingly, predictive equations were developed using generalized modeling techniques to scale Natural Resource Canada's CanVec 3.0 data (Figure 1.1) to Ducks Unlimited Canada's high resolution wetland inventory data (Figure 1.2). CanVec is a vector dataset that has been developed by Natural Resources Canada, and is based on various sources of information[1]. To account for the variation of scale (1:10000 - 1:50000) and accuracy of CanVec data, CanVec hydrography and water saturated

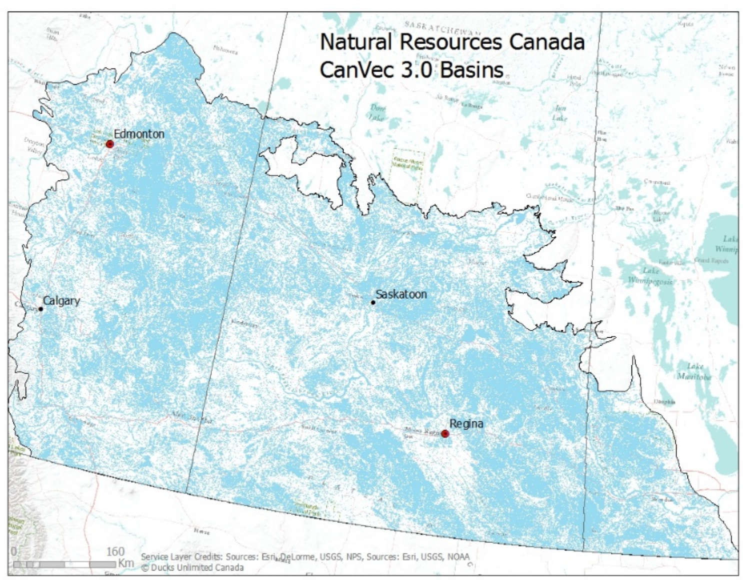

Figure 1.1. CanVec 3.0 wetland basins

[11] *CanVec Product Specifications v.1.0., Natural Resources Canada, Earth Sciences Sector, Centre for Topographic Information, Sherbrooke, Quebec, Canada, 2007.*

soils features, Soil Landscapes of Canada 3.1.1 data**[2] (SLC), and Ducks Unlimited Canada's high resolution wetland inventory data were used to model an adjustment factor to be applied to the CanVec features. This adjusted layer (Figure 1.33) provided the base for applying carbon models.

Cropped vs. Intact wetlands:
Agricultural practices can drastically affect both carbon stores and GHG fluxes. Therefore, it was important to develop a layer that incorporated land use practices into our model. Accordingly we used a detailed wetland classification from study sites (Figure 1) across the region to estimate the expected proportion of tilled wetlands within a 16-square-mile landscape by regressing the proportion of tilled wetland as a function of proportion cropland.

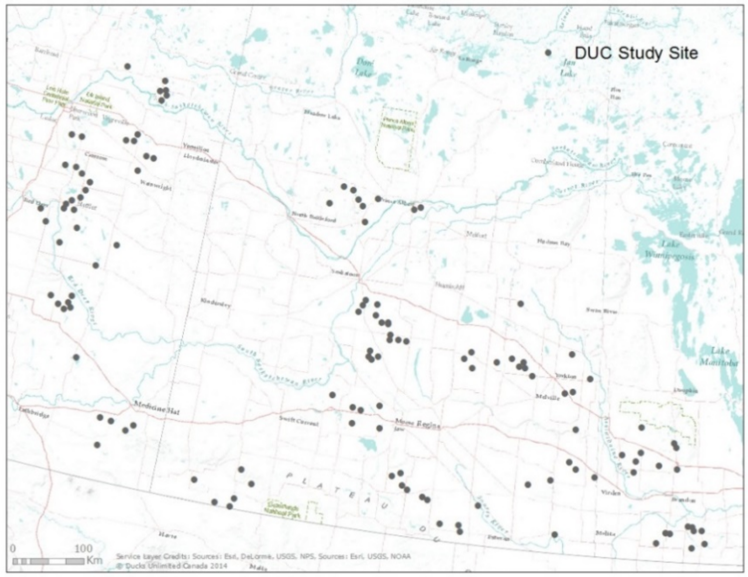

Figure 1.2. DUC Wetland Inventory Sites

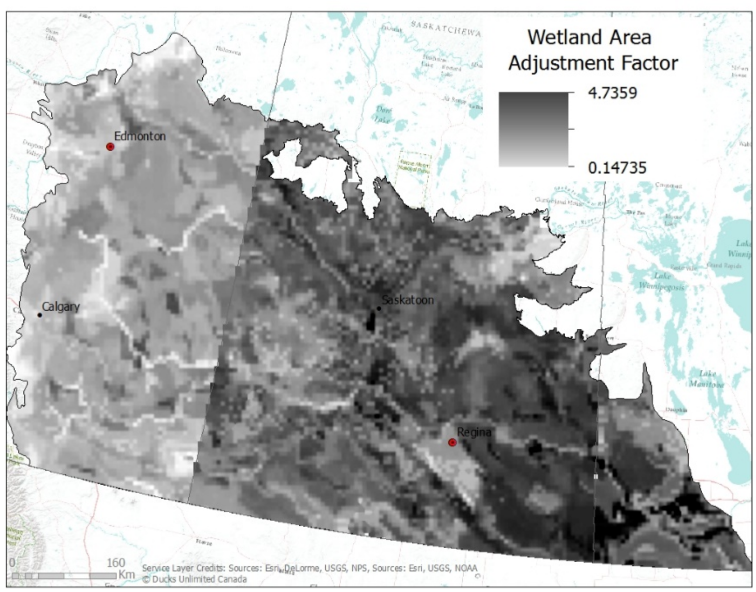

Figure 1.3. Wetland Area Adjustment Surface

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[2] *Soil Landscapes of Canada Working Group, 2010. Soil Landscapes of Canada version 3.1.1. Agriculture and Agri-Food Canada.*

Soil Zone: Though a somewhat dated method of classifying soils, published literature identify relationships between carbon stores and major soil zones. Accordingly, we generated a spatial layer from ecoregions (Agriculture and Agri-Food Canada, Eastern Cereal and Oilseed Research Centre) using a soil map from Agriculture and Agri-Foods Canada soil zones (2009; Figure 1.4).

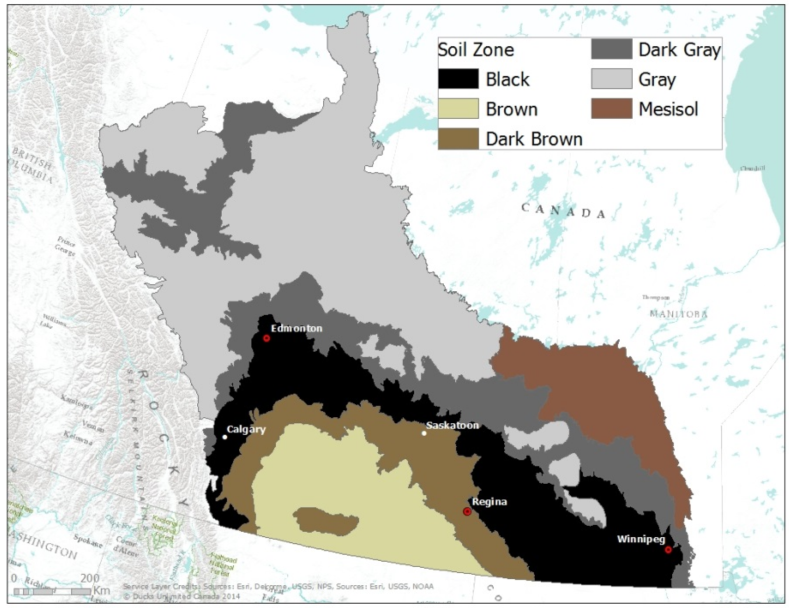

Figure 1.4. Soil Zones

Model Evaluation and revision

Following development of the 1st generation wetland soil organic carbon (SOC) stock map, we evaluated model predictions and revised the resulting model as appropriate. Several new datasets were used for this evaluation. These included BIOCAP's *Wetlands Hydrology Database*, Ducks Unlimited Canada's *Carbon Sequestration and Greenhouse Gas Emission in Restored Prairie Wetlands*, and ACAAF's *Management of Agricultural Landscapes with Wetlands and Riparian Zones: Economic and Greenhouse Gas Implications*. New data also were collected from the analysis of wetland soil samples taken from St. Denis National Wildlife Area (SDNWA) from 1999 – 2002 which were archived at the National Hydrology Research Centre.

Revised Default SOC Stock Values for Wetland Land Use Status Classifications:

Our wetland SOC predictor model uses the same model structure as outlined in the IPCC's *2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*. The default SOC stock value is established for native wetlands with no history of cultivation and any variables (i.e., land use status) that may affect the wetland SOC stock are captured in stock change factors that are applied to the default value.

Default Native Stock Value: In the 1st gen. model, the IPCC's (2013) default stock value of 87 Mg C ha^{-1} for native inland mineral wetland soils located in cool, temperate dry climates was used as the default 0 – 30 cm SOC stock value for native wetlands located the Dark Brown soil zone. Applying the soil zone stock adjustment factor of 1.628, the 0 – 30 cm SOC stock value for native wetlands in the Black soil zone becomes 141.65 Mg C ha^{-1}. This value was comparable to the IPPC's default 0 – 30 cm stock value of 128 Mg C ha^{-1} for native inland mineral wetland soils located in cool, temperate moist climates and SOC values found elsewhere in the literature (Table 1.1).

As a clear relationship between SOC stocks and soil zones cannot be substantiated, the soil zone stock adjustment factor is not incorporated into our wetland SOC predictor model. Likewise, the model does not use different SOC stock values for wetlands located in cool, temperate moist climates (128 Mg C ha^{-1}) and cool, temperate dry climates (87 Mg C ha^{-1}) as is done in the IPCC's wetland supplement because these differences cannot be substantiated by studies conducted in the Prairie Pothole Region (PPR). A default 0 – 30 cm SOC stock value for native wetlands representative of the whole Canadian PPR must be established. The 0 – 30 cm SOC stock value of 87 Mg C ha^{-1} is relatively low compared to most values found in the literature for wetlands in the PPR (Table 1.1) and, therefore, does not reflect a representative stock value for the Canadian PPR. The source for this value is also unclear in the IPCC's documentation and no error estimate is given. The value of 128 Mg C ha-1 with a ±17 error estimate (95% C.I.) established by the IPCC for inland mineral wetland soils located in cool, temperate moist climates was derived from studies conducted both in the PPR and internationally but the value still reflects a reasonable average over a wide range of SOC stocks reported for native wetlands in the PPR (Table 1.1).

Table 1.1. Average 0 – 30 cm SOC stocks for native wetlands in the PPR found in the literature and derived from contributing data. See Figure 1.5 for a map of the study sampling locations.

Source	Study Location	Average SOC (Mg C ha-1)	Number of Sites
Badiou et al. (2011)	AB, MN, SK	205	22
Bedard-Haughn et al. (2006)	SK	175.1	12
IPCC Cool, temperate moist (2013)	Globally (fig. 2.2.2)	128	42
Contributing data (BIOCAP, ACAAF, SDNWA Samples)	AB, MN, SK	127.1*	39
Euliss et al. (2006)	ND, SD, MN	106.1	40
IPCC Cool, temperate dry (2013)	Globally (fig. 2.2.2)	87	-

*The SOC average from the contributing data sources involves wetlands that had cultivation in their history and are therefore not native but were included in the table to reflect more SOC averages for wetlands in the PPR.
As discussed, there may have been issues with obtaining reliable bulk density measures in the Badiou et al. study (2011) which may have resulted in relatively high SOC stock values.

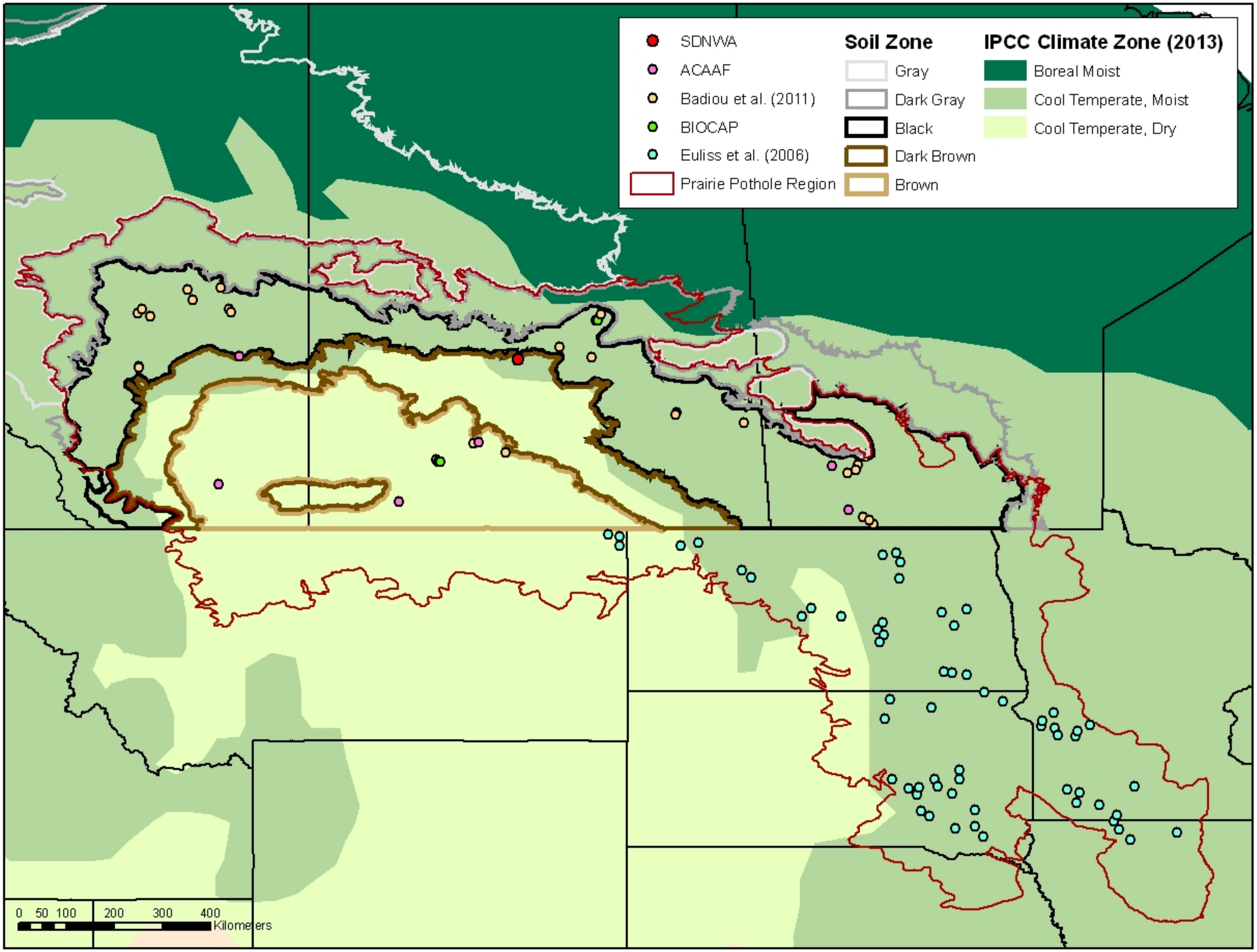

Figure 1.5. PPR Study Locations. SDN

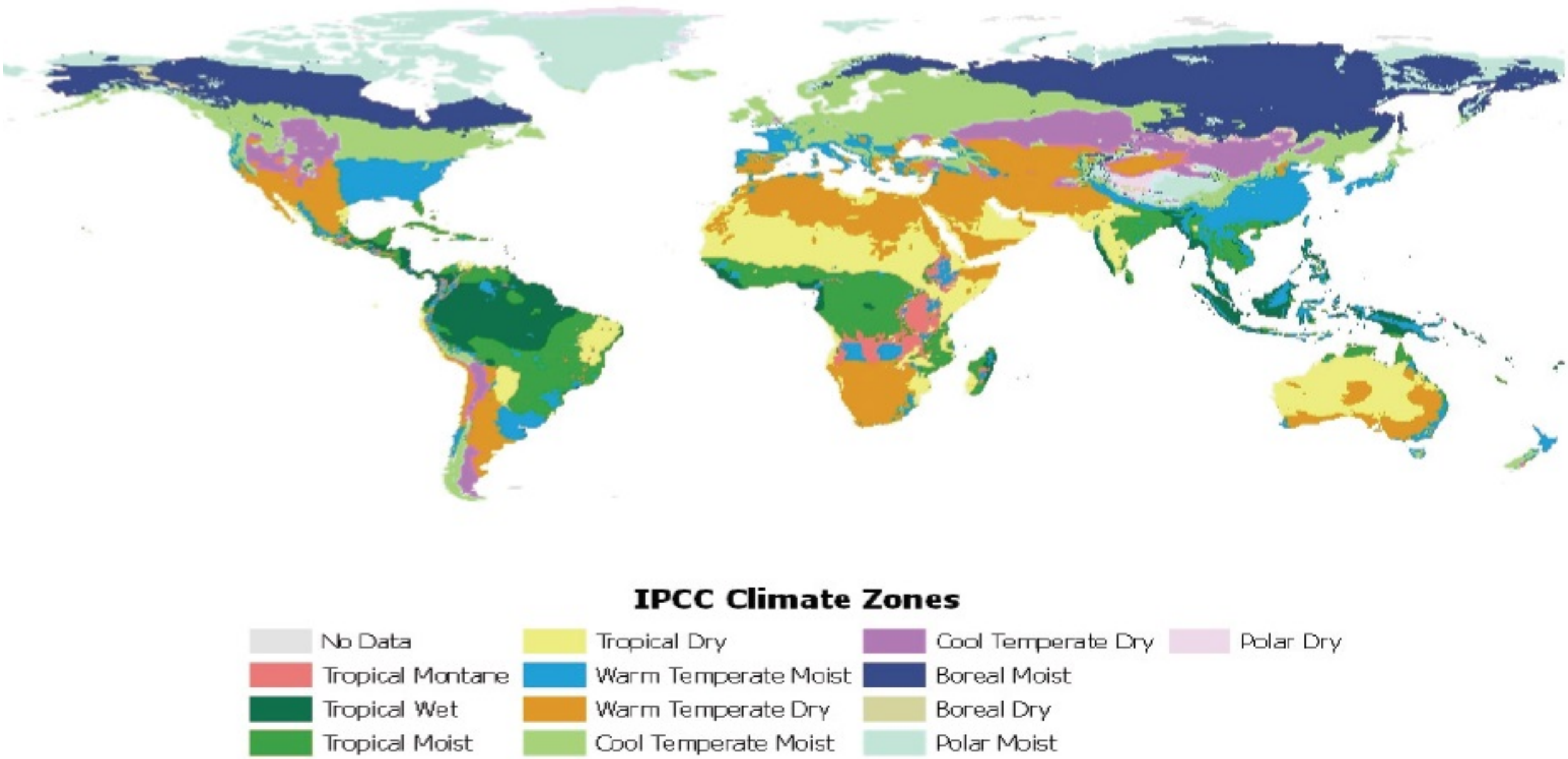

Figure 1.6. IPCC Climate Zones (2013). The default native SOC stock values for inland mineral wetland soils used in our wetland predictor model established by the IPCC for the cool, temperate dry and cool, temperate moist climate zones were determined using data collected internationally throughout each of their respective climate zones.

Wetland Land Use Status Change Factors:

Wetland land use status is a determining factor of wetland SOC content. When a wetland is drained and cropped, the SOC stock will be depleted over time. If a drained wetland is hydrologically restored and revegetated, the SOC stock will return (over a number of years) to a level close to that which existed before the wetland was drained (Gleason et al., 2009).

The 5 wetland land use status classifications of interest to this project are:

- **Cultivated Drained** – wetlands subject to draining and cultivation
- **Cultivated Non-drained** – wetlands located in agricultural fields where permanent vegetation is not established but the wetland is not drained, these wetlands can be subject to tilling in drier years
- **Newly Restored** – wetlands with a history of cultivation that have been hydrologically restored and left to revegetate for 20 years or less
- **Long-term Restored** – wetlands with a history of cultivation that have been hydrologically restored and left to revegetate for more than 20 years
- **Native** – wetlands with permanent vegetation that have never been drained or cultivated

The effect on SOC stock values of wetland land use is captured in stock change factors that are applied to the default native SOC stock value of 128 Mg C ha^{-1}. The IPCC's 2013 Wetland Supplement provides the following stock change factors for wetlands located temperate climates:

Table 1.2. Wetland stock change factors from the IPCC (2013)

Land Use	Stock Change Factor	Error
Long term cultivated (>20 years)	0.71	41%
Hydrologically restored (<20 years)	0.8	10%
Hydrologically restored (>20 years)	1.0	NA

These stock change factors are derived from studies conducted internationally, although many of the studies used in their calculation were conducted in the PPR (Table 1.3)

Table 1.3. Locations of studies used for the derivation of the IPCC's default SOC stock change factors. From Annex 5A.1 of 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands

Study	Location	Stock Change Factor (LC = Long term cultivation; R = Rewetting)
Badiou *et al.*, 2011	Saskatchewan, Alberta, Manitoba, Canada	LC, R
Ballantine *et al.*, 2009	New York, USA	R
Bedard-Haughn *et al.*, 2006	Saskatchewan, Canada	LC
Besasie *et al.*, 2012	Wisconsin, USA	LC, R
David *et al.*, 2009	Illinois, USA	LC
Euliss *et al.*, 2006	North Dakota, South Dakota, Minnesota,	LC, R
Gleason *et al.*, 2009	North Dakota, USA	R
Huang *et al.*, 2010	Sanjiang Plain, China	LC
Hunter *et al.*, 2008	Louisiana, USA	LC, R
Jacinthe *et al.*, 2001	Ohio, USA	LC
Lu *et al.*, 2007	Lake Taihu, China	LC, R
Meyer *et al.*, 2008	Nebraska, USA	LC, R
Morse *et al.*, 2012	North Carolina, USA	LC
Norton *et al.*, 2011	California, USA	LC
Wang *et al.*, 2012	Sanjiang Plain, China	LC, R
van Wesemael *et al.*, 2010	Belgium	LC

Work is currently underway to determine if there is value in developing new stock change factors using only results from studies conducted within the PPR. This may result in a reduced error estimate associated with the long term cultivated stock change factor. A preliminary new stock change factor of 0.72 for the long-term cultivated wetland land use status has been calculated using the study information readily available in the literature. This value is not substantially different from that provided in the IPCC 2013 Wetland Supplement. More detailed study information is needed to calculate the stock change factor for the hydrologically restored (<20 years) wetland land use status and the error estimate associated with the long-term cultivated stock change factor.

There is large variation between the results from studies conducted in the PPR on SOC stock changes from long-term cultivation. Euliss et al. (2006) found that long-term cultivated wetlands contained on average 92% of the SOC amount that was held in native wetlands in the 0 – 30 cm depth whereas Bedard-Haughn et al. (2006) and Besasie et al. (2011) reported values closer to 50%. This difference is likely a major reason for the large error associated with the IPCC's long-term cultivated stock change factor. Until new stock change factors with smaller error estimates can be established, the IPCC's values outlined in Table 1.2 are used in the wetland SOC predictor model.

Applying the stock change factor of 0.71 (41% error) to the default native stock value (128 Mg C ha^{-1} [± 17 error]) results in the 0 – 30 cm SOC stock value of 90.88 Mg C ha^{-1} (± 38.30 error). This value is used for both Cultivated Drained and Cultivated Non-drained wetland status classifications. There has not been significant study done on the difference in SOC content between cultivated drained and cultivated non-drained mineral wetlands of the PPR and so a distinction in terms of SOC cannot be made at this point. Similarly, investigations on the rate of carbon loss following drainage have not been conducted. Values presented here represent asymptotic SOC stocks.

Applying the stock change factor of .80 (10% error) to the default native stock value (128 Mg C ha^{-1} [± 17 error]) results in the 0 – 30 cm SOC stock value of 102.4 Mg C ha-1 (± 17.02 error). This is used for the Newly Restored classification. A wetland that has been hydrologically restored for more than 20 years is considered to have returned to its reference (Native) SOC stock level (Euliss et al. 2006). This means the reference stock value of 128 Mg C ha^{-1} for 0 – 30 cm can be used for both Native and Long-term Restored (>20 years) classifications.

Table 1.4. Wetland SOC stocks used in the wetland SOC map for the Canadian PPR

Wetland Status	SOC stock (Mg SOC ha-1)	Error
Cultivated Drained	90.88	±38.30
Cultivated Non-drained	90.88	±38.30
Newly Restored	102.40	±17.02
Long-term Restored	128.00	±17.00
Native	128.00	±17.00

A model of SOC stocks is presented in Figure 1.7.

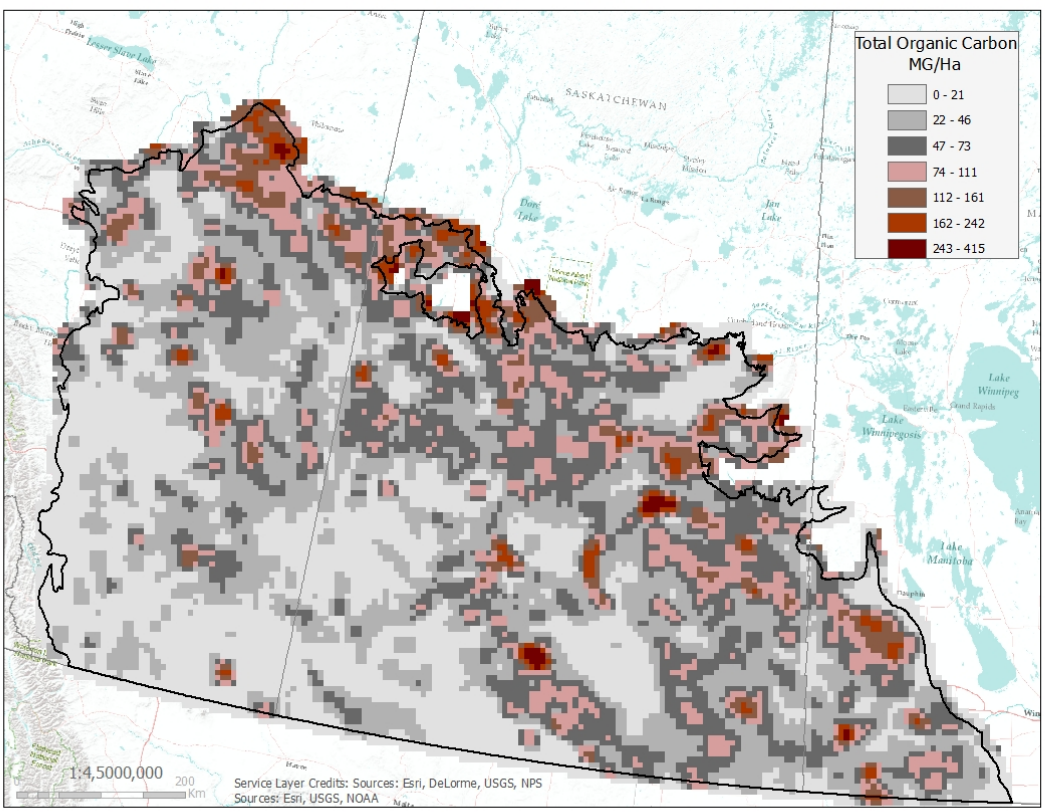

Figure 1.7. A model of wetland-related Soil Organic Carbon for the prairie Pothole Region represented as mg CO_2 equivalents/ha.

Wetland Land Use Change:

Estimates of wetland loss since settlement are scarce and fraught with methodological issues (e.g., drought influence, scale of measurement) that confound regional generalizations. Watmough and Schmoll (2007) examined wetland loss on 141 transects within the boundary described by the Prairie Habitat Joint Venture (PHJV) of the North American Waterfowl Management Plan. They indicated an overall gross loss of ~5% of wetland area from 1985−2001 (-0.31%/year). Wetland area lost varied among transects from 0 to 61% and these estimates are expected to be conservative given the strict definition of wetland loss applied. Wetland loss varied also among ecoregions: Boreal Transition -5%, Aspen Parkland -5%, Moist Mixed Grassland -4%, Mixed Grassland -8%, Fescue Grassland -5%, and Lake Manitoba Plain -5% (Watmough and Schmoll 2007).

A recent update of the PHJV habitat monitoring transects identified a continuing decrease in wetland area and numbers between 2001 and 2011 (Source: M. Watmough, Environment Canada Prairie Habitat Monitoring GeoDatabase). In this most recent update, estimated wetland loss on 221 transects within the PHJV area was an overall average gross loss of -3% (95% confidence interval [CI] = - 4% to -2%), representing an average annual decline of -0.35%/year in wetland area. On average, transects lost -4% (95% CI = -5% to -3%) of wetland basin numbers, with basin losses varying among transects (range = 0 to -53% loss). As in the previous time period the magnitude of loss varied considerably amongst transects within the PHJV landscape, ranging from 0% to -62% of wetland area. Average gross area lost (as a percentage of total baseline wetland area) on transects also varied across ecoregions: Boreal Transition -3% (95% CI = - 6% to -1%), Aspen Parkland -3% (95% CI = - 5% to -2%), Moist Mixed Grassland -3% (95% CI = - 5% to 0%), Mixed Grassland -2% (95% CI = - 3% to -1%), Fescue Grassland -0.4% (95% CI = - 1% to 0%), and Lake Manitoba Plain -5% (95% CI = - 9% to -1%).

To describe spatial variation in wetland loss, wetland area loss rates were estimated for the period 2001−2011 from data gathered during the most recent update of the PHJV Habitat Monitoring program on 250 transects within the planning area (M. Watmough, unpubl. data). Wetland losses across the PHJV were estimated by constructing a suite of candidate models relating wetland loss to specific broadly available landscape covariates (Table 1.5) associated with surveyed transects. Information theoretic techniques (Akaike's Information Criterion) were used to select the best-approximating model.

Table 1.5. Candidate covariates for wetland loss modeling

Topography	**Mean_slope**	Mean slope within 5 mile radius buffer...calculated from SRTM data using ArcMap's calculate slope utility
	STD_slope	STD of mean slope pixels within 5 mile radius buffer
	CV_slope	STD/Mean slope
	CV_ELEV	CV (STD/MEAN) of elevation (SRTM) within the 5 mile radius buffer
Wetlands	**AdjWetCnt_Mean**	Mean of DUC's Adjusted Wetland Count surface within 5 mile radius buffer

	AdjWetArea_Mean_m2	Mean of DUC's Adjusted Wetland Area surface within 5 mile radius buffer
	AdjWetArea_Mean_Ha	Mean wetland area converted to hectares
	WetSizeNDX	An index of wetland size…Wetland area in hectares/Wetland number
AgLands	**MEAN_CLIag**	Mean pixel value of CLI_ag capability within 5 mile radius buffer
Wetlands	**PropWater_LC**	Proportion of 5 mile radius buffer composed of wetland and water categories (AAFC 2000 Landcover)
AgLands	**PropCrop_LC**	Proportion of 5 mile radius buffer composed of Cropland (AAFC 2000 Landcover)
	PropGrass_LC	Proportion of 5 mile radius buffer composed of Grassland categories (AAFC 2000 Landcover)
Roads	**TOTROAD_m**	Total length of roads from National Road Infrastructure database (in meters)
	RoadDen	Road density...measured in m/km2 of 5 mile radius buffer area (i.e., 203 km2)
Available Drains	**WATERCOURSE_m**	Total length of watercourses within the 5 mile radius buffer (from watercourse layer on DUC's SDE)

For this sample, the best-approximating model of wetland loss included only a positive nonlinear relationship with the amount of cropland in the surrounding landscape. We applied this model using Agriculture and Agri-Foods Canada's land cover map (Canada Centre for Remote Sensing 2008) to generate spatially explicit estimates of wetland loss (Figure 1.8).

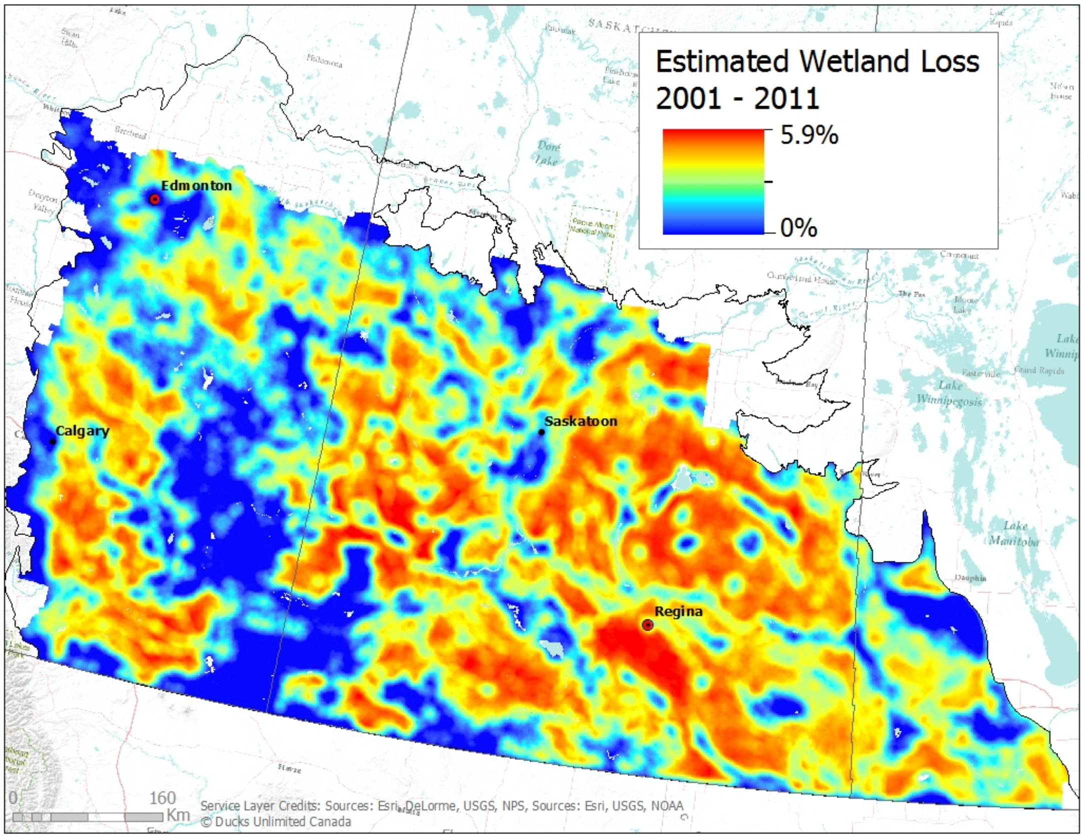

Figure 1.8. Modeled wetland losses from 2001 - 2011

Change in SOC stocks:

Combining our estimate of contemporary carbon stores with the model of wetland loss over the last decade, we were able to project the loss of stored carbon resulting from wetland drainage (Figure 1.9). Using a similar approach, we can project where future carbon losses are likely to be most extreme without changes to wetland protection policies. Conversely, by incorporating these models into land use planning exercises, these tools can be used to avoid losses to carbon stores.

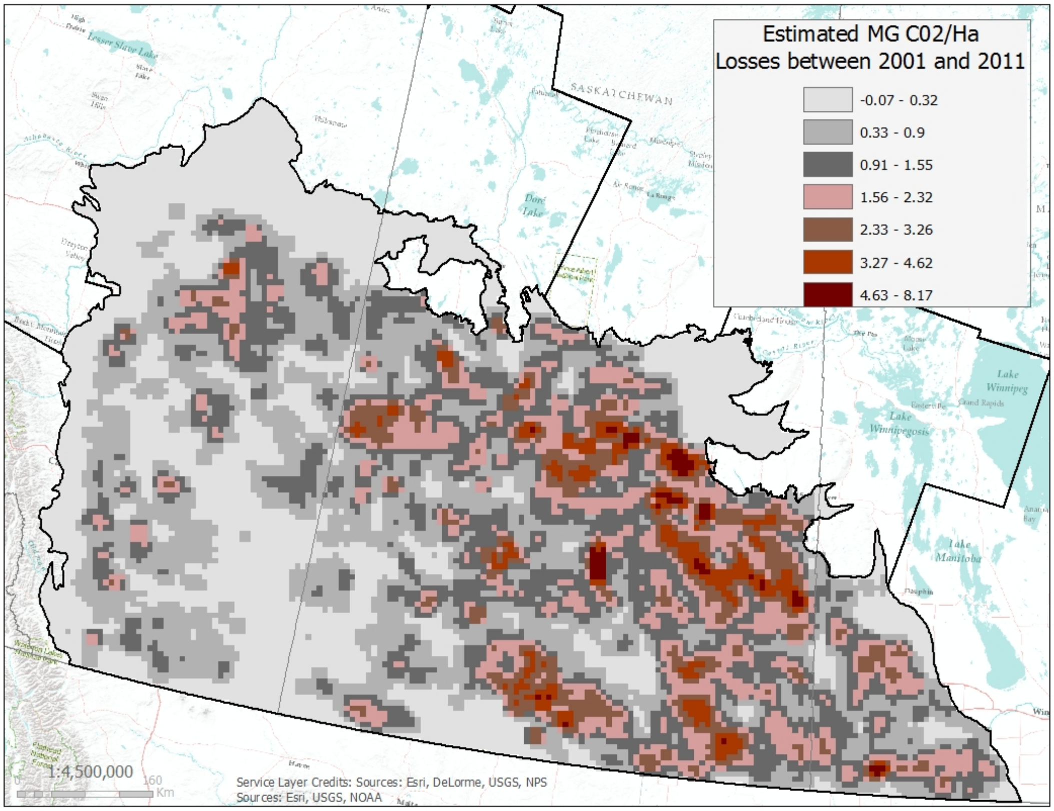

Figure 1.9. Expected loss of SOC as a result of wetland drainage

New SOC findings to be considered in future model versions

SOC Stocks in Large, Permanent Wetlands: How much and how quickly large, permanent wetlands accumulate SOC are unknown. Although these large, permanent wetlands are much less vulnerable to drainage and cultivation, it is valuable to understand their ability to store carbon to have a comprehensive understanding of wetland carbon stocks across the PPR. The SDNWA samples taken during the drought period 1999 - 2002 provide new information on SOC stocks beneath large, permanent wetlands which otherwise would be very difficult to obtain.

One issue with this sample set is that soil volume was not recorded for many of the samples. Soil volume is required to calculate bulk density which is required to calculate SOC. Several methods (Garth Van der Kamp, personal communication) were used to calculate sample porosity values which can be used to estimate bulk density. Samples deep in the soil profile, located near or below the water table, can be assumed to be at full saturation. For these samples, the water content can be used to calculate porosity. For shallower samples, located above the water table, average porosity values were calculated per depth from the samples taken at St. Denis in 2000 as a part of the BIOCAP study. Bulk density was then estimated using these porosity values.

Another issue with this sample set is that the samples from the large, permanent wetlands were taken from only the top 10 cm of every 50 cm depth increment (i.e., 0 – 10 cm, 50 – 60 cm and so on, to 200 – 210 cm). It would be difficult to obtain reliable estimates for the depths between these increments and so comparisons with other soil profile datasets are made at only these 10 cm increments.

The SOC values at the available increments for the large, permanent wetlands were compared with the SOC values from the samples of the smaller, temporary wetlands. These wetlands were typically sampled in 15 cm increments for the top 30 cm of the profile and then in 30 cm increments to a depth ~2 m. The values from these profiles were adjusted to reflect SOC values that would be found at the specific increments of 0 – 10 cm, 50 – 60 cm, etc. To calculate the SOC value of the 0 – 10 cm increment, the SOC value for 0 – 15 cm was multiplied by .75% (slightly greater than 1/3 of the 0 – 15 cm increment SOC value). This is considered a reasonable assumption as the greatest SOC accumulation typically occurs in the surface horizon and decreases with increased depth (Jobbagy & Jackson, 2000). To calculate the SOC values for the deeper depth increments, averages of the SOC values for the adjacent 30 cm depths were taken. These methods were used to give preliminary estimates. More exact estimates will be made by creating average SOC profile distribution curves for each wetland type.

The ponds selected to represent large, permanent ponds were ponds 25, 50, 65, 66, 67, and 90 (circled blue). The ponds selected to represent the small, temporary ponds were 86, 105, 108, 108a, and 110a (circled red). The ponds were selected based on size and known hydro-periods (Figure 1.10).

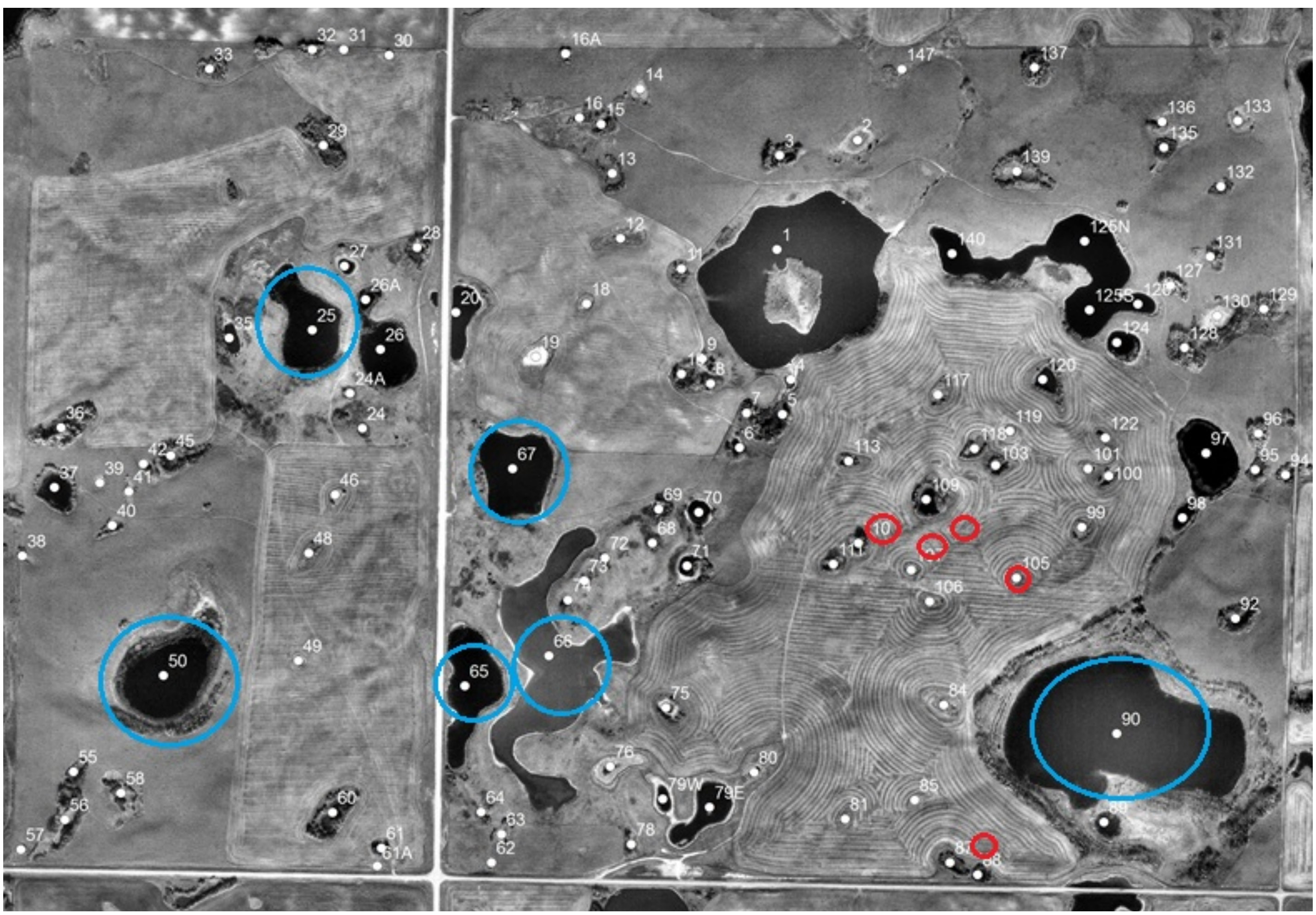

Figure 1.10. Map of large, permanent and small, temporary ponds at St. Denis used in SOC comparison

On average, the larger, permanent ponds and the smaller, temporary ponds hold a similar amount of SOC in the surface 0 - 10 cm increment. The larger ponds do, however, seem to hold greater amount of SOC throughout the profile (samples were taken to ~ 210 cm in depth).

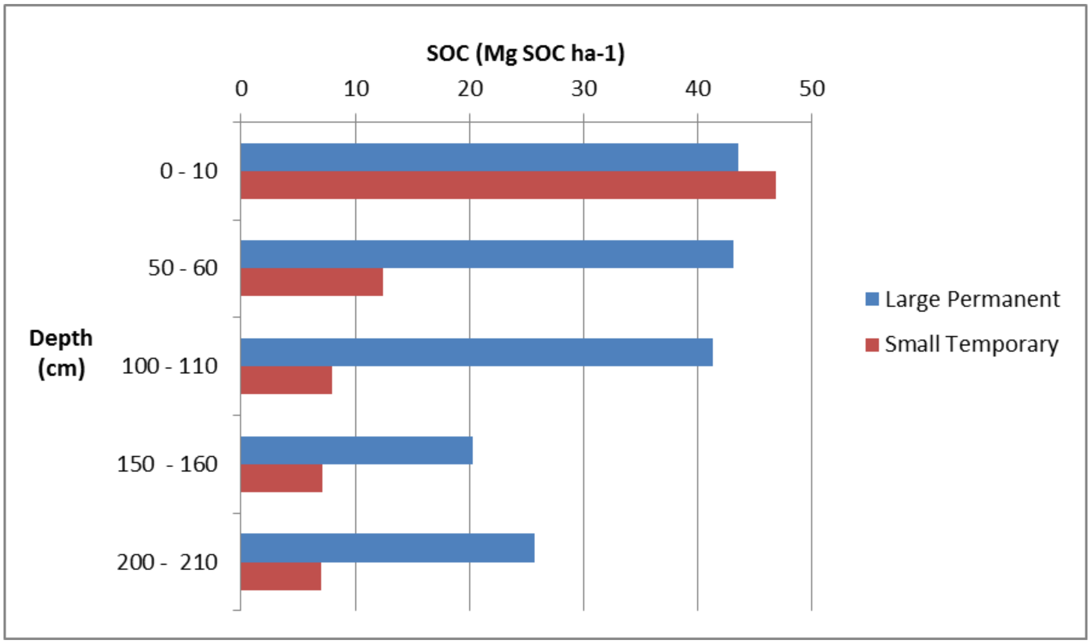

Figure. 1.11. Average SOC in 10 cm depth increments per wetland type

The amount of SOC held in the deeper depths of the large permanent wetlands is substantial (Figure 1.11). The focus of the wetland SOC predictor model has been on the 0 – 30 cm depth thus far and so this substantial SOC stock is not captured in the wetland SOC map. The full SOC distribution for the small, temporary wetlands is represented in Figure 1.12. The majority of the SOC for these ponds is found within the 0 – 30 cm, although there are also increased SOC values found in the 30 – 60 cm increments.

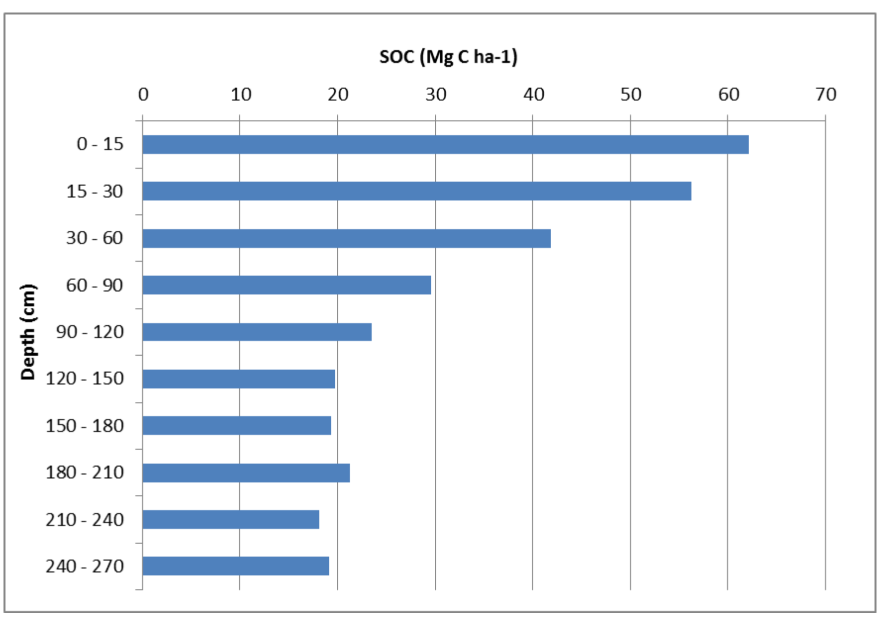

Figure 1.12. Average SOC distribution for small, temporary wetlands at St. Denis

The literature on wetland SOC inventories focuses on the 0 – 30 cm depth increment because the majority of SOC change, resulting from land use changes, occurs within this depth (Euliss et al. 2006). If the focus is to map the SOC stores of all wetlands in the PPR rather than map the potential SOC to be lost with land use changes, then future phases of the model should determine how to incorporate SOC estimates beyond 30 cm. How large, permanent wetlands would be defined using available spatial information would also need to be determined.

Wetland Salinity Effect on Surface SOC Stocks:

Wetlands with high salinity have not been studied for SOC content as they are not typically viable for cultivation. The ability of these wetlands to store SOC is of interest to this project, again, to gain a comprehensive understanding of how the different wetlands present in the PPR store SOC. A number of the samples taken from St. Denis between 1999 and 2002 were taken from highly saline ponds. The soil samples were analyzed for electrical conductivity (a measure of salinity) and compared in terms of their SOC accumulation.

It is difficult to determine from the sample set whether the fresh water ponds accumulated SOC differently than saline ponds due to size and permanency variables. However, there is a possibility that the degree of salinity in saline ponds may affect the accumulation of SOC in the surface 0 – 10 cm horizon. The surface horizon SOC values of the highly saline ponds were compared.

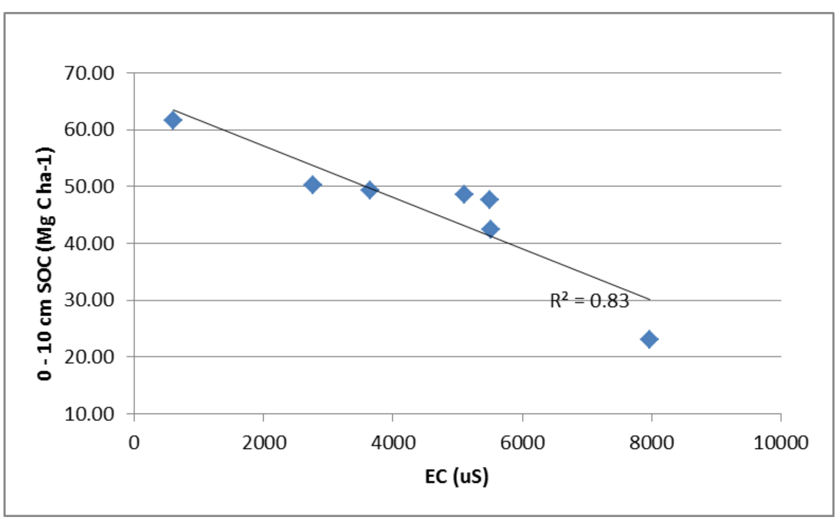

Figure 1.13. Electrical conductivity (EC) vs SOC stock in surface 0 – 10 cm depth increment of highly saline ponds.

There is an apparent decrease in surface SOC with increased salinity (Figure 1.13). This may be due to reduced development of vegetative biomass with increased salinity. More sampling is required to determine if this relationship is significant.

Salinity content has been found to affect the amount of methane produced in a wetland (Pennock 2014). If a relationship between salinity and SOC does exist, determining a method for mapping the distribution of saline wetlands on a landscape would be a valuable tool for developing SOC and GHG predictor models for the PPR.

Chapter 2. Boreal Plains Carbon Stores

Introduction

Ducks Unlimited Canada's (DUC) Enhanced Wetland Classification (EWC) dataset can be used to provide a variety of land management products across the Western Boreal Forest. With the knowledge of spatial locations of specific wetland types, we have the ability to provide added value to that dataset in terms of examining the amount of wetland soil carbon values held within the various EWC wetland classes. This will foster our ability to understand the amount of carbon that is currently held within the boreal and how changes to wetland composition and structure will change the carbon values for a given region.

Data Sources/Literature review:

Data for this product must contain for each site: soil depth, bulk density, proportion / percent of organic matter or organic carbon, and a means to classify the site according to the EWC. Soil characteristics described either in Zoltai et al. (2000) or Canada's National Forest Inventory (Table 2.1) were used to add average carbon stock values of each EWC wetland class.

Table 2.1: Primary data sources

Name	Source	Coverage	EWC Classification Method	EWC Class Breakdown
Zoltai Database	Zoltai et Al. (2000). A Wetland Data Base For The Western Boreal, Subarctic, and Arctic Regions Of Canada.	626 cores across Canada wetlands with 178 in the EWC.	EWC Field Guide	Classification In Progress
Canada's National Forest Inventory (NFI)	Canada's National Forest Inventory. 2004. Canada's National Forest Inventory: Design Overview v3.2. https://nfi.nfis.org	232 ground sites across the boreal and taiga plains ecozone of Canada with 97 in the EWC.	Spatial Overlay	Meadow Marsh (1), Shrubby Bog (1), Treed Bog (4), Treed Rich Fen (5), Treed Poor Fen (5), Shrub Swamp (2), Conifer Swamp (4), Tamarack Swamp (2), Mixedwood Swamp (1)

DUC's Enhanced Wetland Classification (Smith, 2007): EWC classification for the boreal region was based on multispectral Landsat 5 and Landsat 7 TM imagery as well as field data collected for each project area. Images were orthorectified and mosaicked to cover project areas and field data were collected for each wetland class. Classification of the imagery was completed based on spectral signatures using supervised classification methods together with ancillary data (such as DEMs). Field data were used partially as training sites to set up the classification method and the remaining unused field sites were used to assess the accuracy of the classification method. The final result is a raster dataset with a 30 m pixel size and 19 wetland classes.

Zoltai et al. (2000) database: The Canadian Forestry Service conducted research in 1970 to determine environmental sensitivity of permafrost peat lands. This study was later expanded to include non-frozen wetlands (Zoltai et al., 2000). The study produced 640 soil cores in 426 wetlands across the Canadian Boreal forest.

Data from these samples contained:

- geographic locations to the hundredth of a decimal degree
- soil nutrient regime
- peat depth
- wetland characteristics
- profile layer material
- profile layer thickness
- bulk density
- percent ash after dry ashing
- vegetation species
- cover percent of each vegetation layer at the site or sub-site

A total of 178 sites and sub-sites overlapped the EWC (3 sites sampled in 1970 do not contain vegetation information). An additional 64 sites overlap EWC projects that are currently in progress (Figure 2.1). The geographic locations given for these sites are only to the hundredth of a decimal degree which has a potential variance of 1 km. This

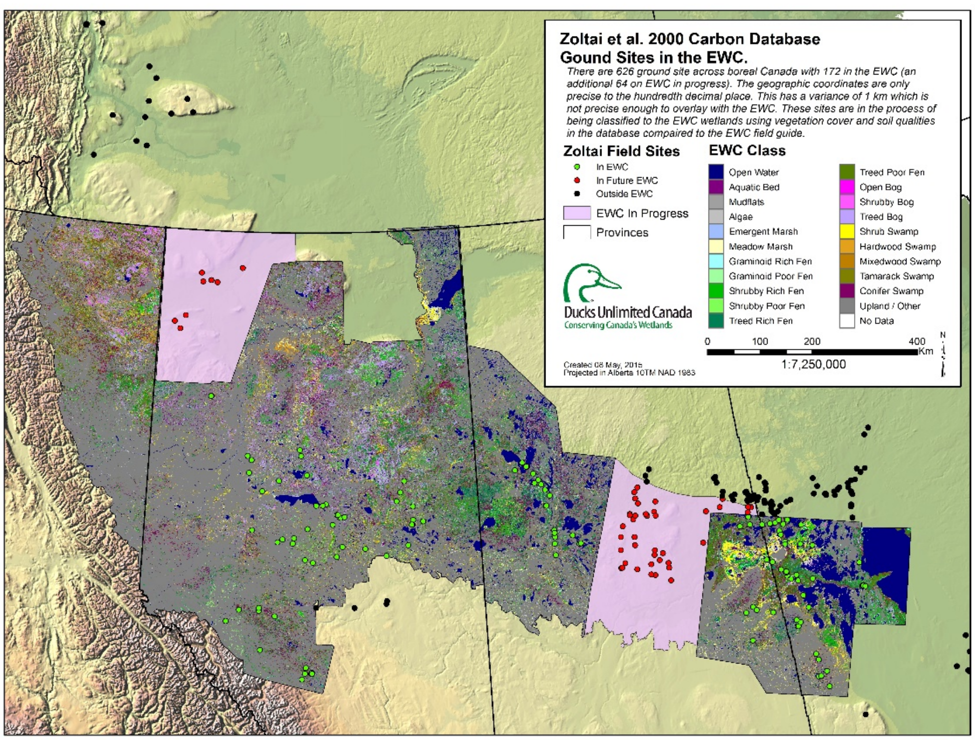

Figure 2.1 Zoltai et al 2000 sample sites

was not sufficiently precise to overlay directly onto the EWC and, therefore, needed to be classified to the EWC using site and vegetation information.

Canada National Forest Inventory: The NFI is an ongoing inventory of forest features containing sites across all of Canada's forested areas. It collects data from all provincial and territorial jurisdictions using a set of standards for data collection and compilation. The purpose of the inventory is to "assess and monitor the extent, state, and sustainable development of Canada's forests in a timely and accurate manner" (CNFI, 2004).

The database contained two varieties of spatial data: photo plots and ground plots. The photo plots covered an area of 2 by 2 km. Photo plot locations were placed every 20 km on a 4 by 4 km national grid. They consist of polygon data derived from land features on 1:20,000 aerial imagery. The photo plots contained data on landscape features for the polygons in the 2 km plot.

The ground plots were physically sampled sites at the center of one out of ten photo plots. Ground sites contain data from sample tree plots, 2 transects, soil pit, and four microsites. Organic carbon proportion and bulk density measures are present for the under 8 mm in diameter soil material samples taken from the soil pit and microsites. These sites have spatial coordinates projected in the appropriate UTM zone of the site however, only sites in British Columbia, Saskatchewan, and Northwest Territories have accurate locations. Out of these accurate locations, 17 sites with carbon samples fell on EWC wetlands (Figure 2.2).

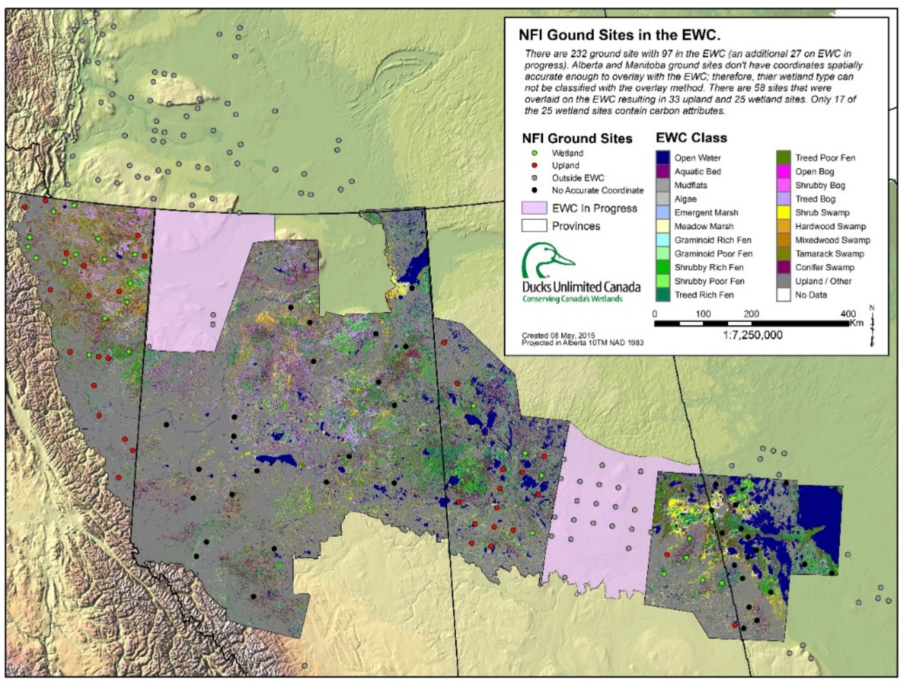

Figure 2.2. National Forest Inventory Sample sites

Analysis:

Wetland Classification: For the soil sites and their average carbon values to be applied to the EWC, these sites first needed to be classified to one of the EWC's 19 wetland classes. For data with precise spatial locations, the soil site was overlaid on the EWC raster and assigned the

wetland class onto which it falls. Datasets without precise coordinates were classified by comparing site information with the DUC Boreal Wetland Classes Field Guide (2015).
Sites from the Zoltai et al. (2000) database were classified using the DUC field guide. This field guide uses parameters such as percent tree, shrub, ground cover, and sphagnum, along with dominant plant species, nutrient class, and peat material to determine wetland class. Zoltai et al. (2000) contains all of these data for the sites in the database. Every site that overlaps the EWC is was classified one at a time using this field guide and a level of confidence value given to each site based on how well the site information lined up with the field guide (Appendix A).

Average Organic Carbon: The calculation for average organic carbon at a soil site differed for each dataset depending on method of data collection, how data were recorded, and specific units of measure. The essential data required to calculate average organic carbon for the 30 by 30 m ($900m^2$) pixels of the EWC includes: depth of soil sample, bulk density (measure of soil mass per volume of sample), and proportion of organic carbon in the soil sample. Carbon proportion can be derived from proportion of soil mass left after dry ashing. The remaining ash is inorganic material (Schumacher 2002) while the volume that was burned is organic material. An average carbon proportion in organic matter was used based on literature review to acquire a total organic carbon value. Alternately, soil organic carbon can be calculated by chemical analysis of dry soil samples using an elemental analyzer.

Zoltai et al. (2000): The soil site data in this database was split into the individual horizons of the soil profile. Each horizon contains a horizon depth (cm), bulk density (g/cm^3), and ash remaining after dry ashing (fraction of dry weight). To estimate per cent of carbon in organic matter, we used a proportion of 52% *(Bauer et al., 2006)*. Total organic carbon (g/cm^2) for each horizon was calculated using the following formula: Horizon Depth (cm) * Horizon Bulk Density (g/cm^3) * (1 - Proportion Ash) * 0.52. The total organic carbon for each horizon in a soil profile was summed for total site organic carbon.

NFI: Organic soil sites in this database were split into fixed sampling depths: 0 – 15 cm, 15 – 35 cm, 35 – 55 cm, and 55 – 75 cm. These sampling depths are recommended procedures described in the NFI Ground Sampling Guidelines (2008) and the actual depths may vary depending on sampling jurisdiction. The data contains bulk density (g/cm^3) for each depth interval and total carbon (g/kg) by using a LECO CNS 2000 Elemental Analyzer on the under 8 mm diameter dried soil material. The database has an estimated organic carbon per cent and bulk density value for each soil site. These values were derived from the mean of organic carbon per cent and bulk densities of each sample in the soil profile. Total organic carbon (g/cm^2) at each site was estimated with the following formula: Profile Depth (cm) * Mean Bulk Density (g/cm^3) * (Mean Total Carbon (g/kg) / 1000)

EWC: With each soil site containing an estimated total organic carbon value (g/cm^2) and an EWC wetland class, the total carbon values were averaged (mean) over all the classes. This was initially be done on the major classes (marsh, bog, fen, and swamp) and expanded to the detailed classes using the following equation: Sum of Total Organic Carbon (for one wetland class) / Total # of values (for same class). The average organic carbon values for each EWC class was expanded to the pixel size. The EWC pixels were 30 by 30 m with an area of 900 m^2. The total organic carbon values needed to be converted from g/cm^2 to kg/m^2 by multiplying the carbon value by 10; then applying that value to 900 m^2 for one pixel. The formula for Average Organic Carbon per Pixel (kg/m^2) is as follows: (Average Organic Carbon for EWC Class (g/cm^2) * 10) * 900 m^2). This produced a raster layer with an average estimated organic carbon stock in wetlands across the western boreal forest. Carbon values can be updated with acquisition of new data.

Carbon stores map:

The end product for this project is a 30 by 30km raster based on the EWC. Each EWC wetland class has an average carbon stock value based on data from soil site locations collected from various data sources across the boreal forest. The average carbon stock value for a particular wetland class was applied to the EWC wetland pixels of that class (Figure 2.3).

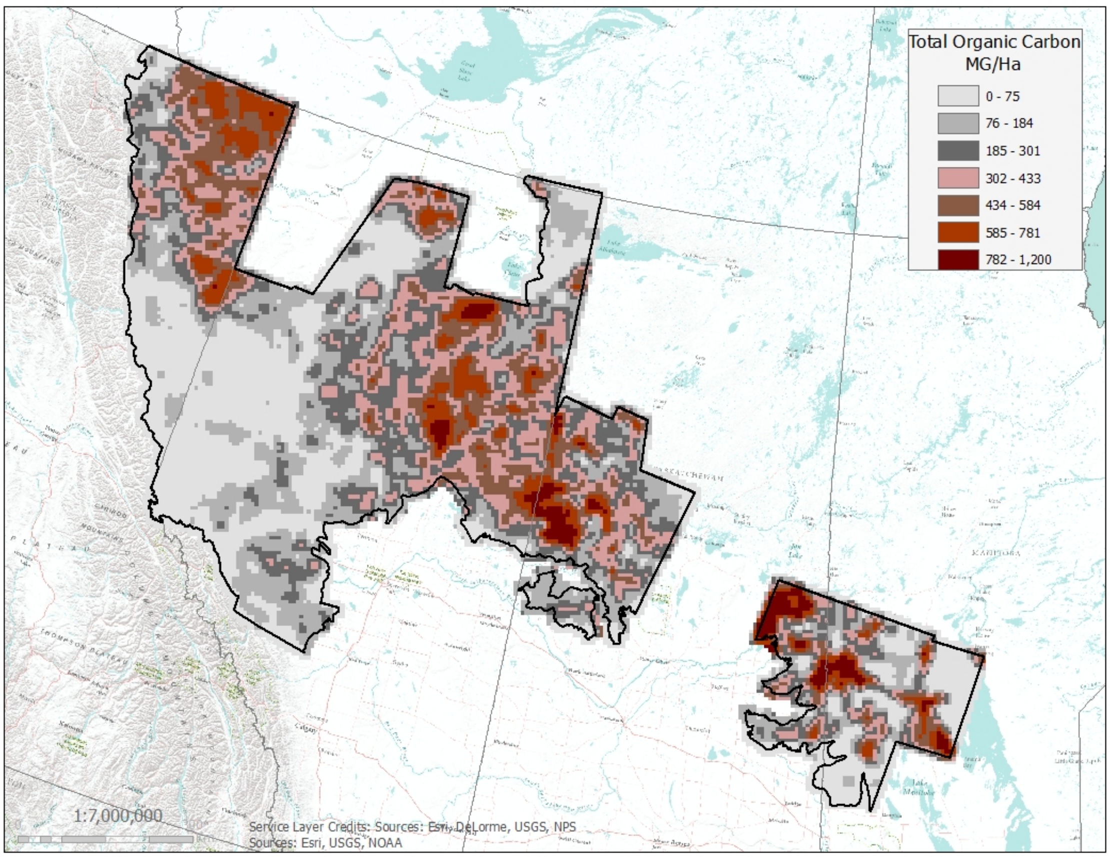

Figure 2.3 Wetland SOC stores in the Boreal Plains represented as mg CO_2 equivalents/ha.

Chapter 3. Compliance of Alberta's Wetland Restoration Offset Protocol with the IPCC Guidelines for National Greenhouse Gas Inventories

Introduction

As a result of the number of carbon offset programs developed internationally, there has been increased emphasis on developing guidelines and requirements for carbon offset programs and greenhouse gas (GHG) emissions reporting associated with land use change. Following an invitation from the UNFCCC to "undertake further methodological work on wetlands, focusing on the rewetting and restoration of peatland, with a view to filling in the gaps in the 2003 IPCC Guidelines for National Greenhouse Gas Inventories", the IPCC developed the *2013 Supplement to the IPCC Guidelines on National Greenhouse Gas Inventories: Wetlands*. This supplement provides nation-level guidance on inventorying methods for soil organic carbon (SOC) and GHG sinks and sources from various wetland types. Alberta's Wetland Restoration Carbon Offset Protocol provides a reporting framework for carbon offsets achieved through restoration of wetlands located within the Prairie Pothole Region (PPR). The methodologies and requirements of this protocol should comply with the standards established in the IPCC Guidelines on National GHG Inventories and other international carbon accounting frameworks (Verified Carbon Standard, American Carbon Registry) in order to be internationally recognizable. Compliance with international standards allows for the offset values reported by the protocol to be submitted to the international carbon accounting frameworks. This document details the compliance of Alberta's Wetland Restoration Offset Protocol with the reporting standards established in the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* and the *2013 Supplement to the IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands*.

To comply with the IPCC Guidelines for National GHG Inventories, the Wetland Restoration Offset Protocol will, firstly, need to include requirements to categorize the upland management adjacent to the restored wetlands as either Cropland or Grassland in order to report the GHG emissions and removals from restored wetlands to the appropriate IPCC reporting category. To do this, the protocol will need to include definitions of Cropland and Grassland; this document recommends using definitions similar to those included in Canada's National Inventory Report on GHG Sources and Sinks. Second, the requirements outlined in the Wetland Restoration Offset Protocol for land area reporting meet the standards set in the IPCC Guidelines for National GHG Inventories but uncertainty estimates of reported wetland areas should be required by the protocol. Lastly, to meet the standards set by the IPCC for GHG emission and removal factors, the Wetland Restoration Protocol will need to either include uncertainty estimates for its SOC and CH_4 change rates or utilize the GHG emission and removal factors provided by the IPCC as a part of its Tier 1 methodological approaches.

Land-Use Categories

Anthropogenic GHG emissions and removals for the Agriculture, Forestry and Other Land Use (AFOLU) Sector are defined as those occurring on "managed land". Managed land is defined as land where human interventions and practices have been applied to perform production, ecological or social functions. As restored wetlands of the PPR are considered managed lands, their GHG emissions and removals are reported in the AFOLU Sector of the IPCC's National GHG Inventory Framework. Guidance for preparing GHG inventories for the AFOLU sector are provided in Volume 4 of the *2006 IPCC Guidelines for National Greenhouse Gas Inventories* and in the *2013 Supplement to the IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands.*

GHG reporting for the AFOLU Sector is divided into 6 land-use categories:

- Forest Land
- Cropland
- Grassland
- Wetlands
- Settlements
- Other Land

The Wetlands land use category refers exclusively to peatlands cleared and drained for production of peat for energy, horticultural, and other uses; and reservoirs or impoundments for energy production, navigation, irrigation, or recreation. The freshwater inland mineral wetlands of the Prairie Pothole Region (PPR) reported on in the Wetland Restoration Offset Protocol do not correspond with this definition of wetlands. GHG emissions and removals from inland mineral wetlands are not given their own land use category, but are reported in whichever of the 6 land use categories within which the wetlands are located. The GHG emissions and removals from freshwater inland mineral wetlands of the PPR reported on by Alberta's Wetland Restoration Offset Protocol would be reported in the land use categories Cropland and Grassland as these are the land uses that occur in the focus area of the protocol.

Land use categories are further subdivided into *land remaining in land use* subcategories (e.g. Cropland Remaining Cropland) and *land converted to other land-use* subcategories (e.g. Grassland Converted to Cropland). GHG emissions and removals from land being converted to another land-use category are reported for the land-use category that the land is converted to, for example: GHG emissions and removals from Cropland Converted to Grassland are reported for the Grassland land-use category. The restored inland mineral wetlands focused on in the Wetland Restoration Offset Protocol are restored from cultivated conditions and fall under the land-use category of Cropland. The land-use category that the GHG emissions and removals from wetland restoration are reported to is dependent on the management fate of the uplands adjacent to the restored wetlands. If adjacent uplands are to remain in cultivation, the GHG emissions and removals from the restored wetland are reported as Cropland Remaining Cropland under the Cropland land use category. If the adjacent uplands are restored to grassland, the GHG emissions and removals from the restored wetland are reported as Cropland Converted to Grassland under the Grassland land use category. Item (6.) of the minimum information required to support project documentation in the Wetland Restoration Offset Protocol requires that the plans for wetland and **upland** management are reported. The protocol will need to categorize the plans for upland management as either Cropland or Grassland in order to properly categorize wetland GHG emissions and sinks for IPCC reporting.

Definitions of each land use category are left by the IPCC to be defined nationally. In order to be consistent with Canadian GHG reporting standards, Cropland and Grassland definitions used in the Wetland Restoration Offset Protocol should correspond with the definitions used in Canada's 2014 National Inventory Report GHG Sources and Sinks in Canada Inventory. The methodology for Canada's National Inventory Report (McConkey et al., 2007) defines cropland as:

All agricultural land (all pasture, hayland, summerfallow, and land in crops, fruits, vegetables, and Christmas trees) reported in the Census of Agriculture that does not meet the Canadian definition of agricultural grassland.

Grassland is defined as:

Natural land used for grazing domestic livestock located in regions where the vegetation would not naturally convert to forest or woody shrubs if abandoned except for fire suppression (i.e. the current and former natural vegetation is grassland). The agricultural grassland exists in the natural short- and mixed-grass prairie in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. Grassland is represented in the Census of Agriculture for these regions as "unimproved pasture" or "natural land used for pasture and grazing." **An important concept of agricultural grassland is that it has never been tilled.** Areas meeting Canada's definition of forest but also used for grazing domestic livestock were deemed forestland.

The second last sentence of the definition is included because Canada's National Inventory system does not inventory Cropland Converted to Grassland because the uncertainty of estimating these areas is too great (McConkey et al., 2007). This definition will need to be changed in order for restored wetlands to be properly inventoried according to the IPCC's standards. The Wetland Restoration Offset Protocol should define Grassland as:

Natural land used for grazing domestic livestock located in regions where the vegetation would not naturally convert to forest or woody shrubs if abandoned except for fire suppression (i.e. the current and former natural vegetation is grassland). The agricultural grassland exists in the natural short- and mixed-grass prairie in southern Saskatchewan and Alberta and the dry, interior mountain valleys of British Columbia. Areas meeting Canada's definition of forest but also used for grazing domestic livestock were deemed forestland.

Land Use Area Reporting

GHG inventories for AFOLU activities require land-use areas to be delineated. National GHG emission and removals estimates are made by applying per hectare GHG emission and removal factors to the reported land use areas. The IPCC Guidelines provide 3 methodological approaches for estimating land use area. They are defined in Volume 4, Chapter 3 of the 2006 Guidelines:

- Approach 1 identifies the total area for each individual land use category within a country, but does not provide detailed information on the nature of conversions between land uses.

- Approach 2 introduces tracking of conversions between land use categories.
- Approach 3 extends the information available in Approach 2 by allowing land use conversions to be tracked on a spatially explicit basis.

The Alberta Wetland Protocol requires exact area measurements and locations of restored wetlands to be reported; this corresponds to the IPCC's Approach 3 for land use area reporting. The IPCC does not provide a definition for wetland area boundaries for which GHG emissions and removals are reported; it is left to be determined nationally. The Alberta Wetland Protocol defines wetland area boundaries as the full supply level for reporting GHG emissions and removals. The full supply level is defined as:

An engineering term that describes the flood contour corresponding with maximum operating level of a water control structure. In the context of a restored wetland, full supply level is the contour corresponding to the spill elevation of the ditch plug. Any volume of water added to the restored wetland additional to the full supply level will pass through a spillway (or outlet) around the earth plug shoulders and contribute to the downstream basin.

The full supply level boundary does not always encompass the complete margin area of the wetland. The Wetlands Restoration Protocol requires that the complete margin area is properly managed according to the protocol, but GHG emissions and removals for the margin area outside the full supply level are not reported.

Although the IPCC does not provide a definition for wetland area boundaries, they do require that uncertainties associated with wetland boundary areas are documented and quantified. The IPCC stresses the importance of reporting accurate uncertainty estimates in Chapter 5 of the IPCC's *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. Assessing the uncertainty of estimates is considered valuable as it helps prioritize efforts to improve inventory accuracy in the future and guide decisions on methodological choice. They are also considered valuable for judging the level of agreement between national inventories developed through different approaches. The Wetland Restoration Offset Protocol requires the Wetland Restoration Agency to provide survey documentation on wetland full supply area after drainage reversal is completed. Although wetland area uncertainties will be minimal to non-existent with the completion of post-restoration surveys, the wetland restoration agencies should be required by the protocol to report any uncertainties associated with the wetland full supply level area surveys.

GHG Emission and Removal Factors

The IPCC's Guidelines for National GHG Inventories identifies three tiers of methodological approaches for determining GHG emissions and removal estimates for AFOLU activities. The three tiers are hierarchical in terms of complexity and accuracy; Tier 1 methodologies are the most simple and Tier 3 methodologies are the most complex. Methodological approaches are selected based on available information; the IPCC recommends higher tiered approaches to be used where possible to increase GHG emission and removal estimate accuracy.

The IPCC provides 3 tiers of approaches for estimating inland mineral wetland SOC stocks and stock changes and methane emissions. The 3 tiers of approaches to estimate inland mineral wetland 0 – 30 cm SOC stock and stock changes are described in section 5.2.1.2 of Chapter 5 of the 2013 Supplement to the 2006 IPCC Guidelines for National GHG Inventories: Wetlands as follows:

Tier 1

The Tier 1 estimation method for mineral soils in land remaining in a land use category, including IWMS, is based on changes in SOC stocks over a finite transition period following such changes in management that impact the SOC. Equation 2.25, Chapter 2, Volume 4 of the 2006 IPCC Guidelines ($\Delta C_{mineral}$ = (SOC0 – SOC (0-T)) / D; see the 2006 IPCC Guidelines for full equation) is used to estimate change in SOC stocks in mineral soils by subtracting the SOC stock in the last year of an inventory time period (SOC0) from the C stock at the beginning of the inventory time period (SOC (0 –T)) and dividing by the time dependence of the stock change factors (D). SOC stocks are estimated for the beginning and the end of the inventory time period using default reference carbon stocks (SOCREF) (Table 5.2) and default stock change factors (FLU, FMG, FI), based on the land use (LU), the management regime (MG) and the input of organic matter (I) at the time of the inventory. In practice, country-specific data on land use and management must be obtained and classified into appropriate land management systems, and then stratified by IPCC climate region and soil type. The Tier 1 assumptions for carbon stock changes in mineral soils in land remaining in a land use category for specific land use categories will also apply to managed lands with IWMS in those land use categories.

Tier 2

For Tier 2, the same basic equations are used as in Tier 1 (Equation 2.25 in Chapter 2, Volume 4 of the 2006 IPCC Guidelines), but country-specific information is incorporated to improve the accuracy of the stock change factors, reference SOC stocks, climate regions, soil types, and/or land management classification systems.

Tier 3

Tier 3 approaches may use empirical, process-based or other types of models as the basis for estimating annual carbon stock changes. Examples include the Century ecosystem model (Parton et al., 1987, 1994, 1998; Ogle et al., 2010), and the Wetland-DNDC model (Zhang et al., 2002). Estimates from models are computed using equations that estimate the net change in soil carbon. Key criteria in selecting an appropriate model include its capability to represent all of the relevant management practices/systems for the land use category; model inputs (i.e. driving variables) that are compatible with the availability of country-wide input data; and verification against experimental, monitoring or other measurement data (e.g. Ogle et al.,2010). 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. A much higher density of benchmark sites will likely be needed than with models to adequately represent the combination of land use and management systems, climate, and soil types. Additional guidance is provided in Section 2.3.3.1 of Chapter 2 of this supplement.”

The 3 tiers of approaches to estimate inland mineral wetland CH_4 stocks are described in section 5.2.2.1 of Chapter 5 of the 2013 Supplement to the 2006 IPCC Guidelines for National GHG Inventories: Wetlands as follows:

"Tier 1

CH_4 emissions from managed lands on IWMS, or dry mineral soils, where management activities have resulted in the water table being raised to, or above, the land surface are estimated using a simple emission factor approach (Equation 5.1), stratified by climate region. The default methodology considers boreal, temperate, and tropical climate regions.

EQUATION 5.1
ANNUAL CH_4 EMISSIONS FROM REWETTED AND CREATED WETLANDS ON MANAGED LANDS WITH IWMS

$$CH_{4-IWMS} = \sum_c (A_{IWMS} \bullet EF_{CH_4-IWMS})_c$$

Where:

$CH_{4\text{-}IWMS}$ = Annual CH_4 emissions from managed lands on IWMS where management activities have raised the water table level to or above the land surface, kg CH_4 yr^{-1}

$A_{IWMS,\,c}$ = Total area of managed lands with mineral soil where the water table level has been raised in climate region *c*, ha

$EF_{CH4\text{-}IWMS,\,c}$ = Emission factor from managed lands with mineral soil where water table level has been raised in climate region *c*, kg CH_4 ha^{-1} yr^{-1}

The area of managed lands with IWMS, or dry mineral soil, where water table level has been raised, should be stratified by climate region (boreal, temperate, or tropical), and the appropriate emission factor applied.

Tier 2

The Tier 2 approach uses country-specific emission factors based on information on important parameters such as water table level and hydroperiod. It is good practice when developing and using country-specific emission factors to consider the water table position and its relationship to CH_4 emissions. Annual CH_4 emissions from IWMS are generally larger when the water table is continuously at or above the land surface, rather than intermittently at or below the land surface (Annex 5A.2). Seasonal and interannual changes in water table position, and duration above the land surface, are determined by multiple variables including fluctuations in water source such as river discharge in the case of riparian wetlands, as well as evapotranspiration and precipitation.

Tier 3

A Tier 3 approach involves a detailed consideration of the dominant drivers of CH_4 emission from IWMS, including but not limited to: water table position; seasonal changes in inundation; temperature of soils; importance of CH_4 ebullition; and vegetation community dynamics. CH_4 ebullition is a poorly quantified component of CH_4 emission from inundated soils, but has been shown to be a significant contributor to annual CH_4 emission in some systems (Wilson et al., 1989). Vegetation can have important implications for CH_4 emissions, by facilitating transport from inundated soils to the atmosphere, and by providing a substrate for CH_4 production. Possible methods to determine the importance of these drivers to CH_4 emissions, and thus to reduce uncertainty in emission factors, include detailed field studies of CH_4 emission and/or the use of models specific to carbon cycling in wet soils, such as the Wetland-DNDC model (Zhang et al., 2002; http://www.globaldndc.net)."

The Wetland Restoration Offset Protocol provides a sequestering value, which accounts for methane emissions, of 0.88 Mg C ha^{-1} yr^{-1} (3.25 Mg CO2 eq. ha^{-1} yr^{-1}) for restored wetlands. This sequestration rate is applied only to wetlands that have been restored for less than 33 years. This value was determined from extensive research in the PPR by Badiou et al. (2011). This value is based on an annual 0 – 30 cm SOC accumulation rate of 2.7 Mg SOC ha^{-1} yr^{-1} (9.9 Mg CO2 eq. ha^{-1} yr^{-1}) and a methane emission rate of 0.20 Mg CH_4-C ha^{-1} yr^{-1} (6.65 Mg CO2 eq. ha^{-1} yr^{-1}).

Using a country specific removal rate is similar to the IPCC's Tier 2 methodological approach, although the Tier 2 approach requires that a default SOC stock value is established so that carbon stock change factors associated with Cropland and Grassland land use management (tillage, inputs, grazing pressures, etc. [outlined in Chapters 5 & 6 of Volume 4 of the 2006 IPCC Guidelines]) can be incorporated into the GHG emission and removal estimates. The stock values established in the paper by Badiou et al. (2011) could be used along with the SOC accumulation rate of 2.7 Mg SOC ha^{-1} yr^{-1} for GHG removal estimations but the IPCC also requires that uncertainty estimates associated with country specific GHG emission and removal factors are reported. Uncertainty estimates would need to be established for the SOC stocks, SOC change rates, and CH_4 emission rates determined by Badiou et al. (2011).

The *2013 Supplement to the 2006 IPCC Guidelines for National GHG Inventories: Wetlands* also provides default SOC and CH4 emission and removal factors (with uncertainty estimates) that are comparable to those established by Badiou et al. (2011) which could be adopted into the Wetland Restoration Offset Protocol. The factors for inland freshwater mineral wetlands provided by the IPCC were developed internationally from studies conducted in areas with similar landscape features and climate; a majority of these studies were conducted within the North American PPR (including the study by Badiou et al. [2011]) and would therefore represent reasonable GHG emission and removal estimates for the Canadian PPR.

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