
The Prairie Soil Carbon Balance Project Modelling and GIS Component: Landscape-Scale Modelling of Changes in Soil Organic Carbon and Extrapolation to Regional Scales

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Abstract

Carbon sequestration in soils has potential to reduce atmospheric CO₂ levels and help Canada meet its commitments under the Kyoto Protocol. However, in order for soil carbon sinks to be recognized for purposes of the Protocol, a method for quantifying and verifying changes in soil carbon stocks at regional and national levels must be developed.

The objective of the Prairie Soil Carbon Balance Project is to develop a scientifically defensible methodology for quantifying and verifying soil organic carbon (SOC) changes in response to various agricultural management practices. The objective of the modelling and GIS component of the project, being conducted at the University of Saskatchewan, is to combine CENTURY model predictions of changes in SOC levels under alternative management practices, with soil, land-use, and climate databases in order to provide Prairie-wide predictions of changes in SOC storage.

This modelling process requires “scaling-up” of model point-based output to larger areas. A key element to scaling-up is to define the spatial units over which average sets of driving variables are to be used as model input. The distribution of important driving variables for modelling changes in SOC, such as water inputs, plant residue production, soil redistribution, and initial SOC levels are largely controlled by topography at the landscape scale. Thus, the basic spatial unit to which model runs are applied should be topography-based landscape segments.

An approach is being developed to apply landscape-scale SOC modelling to regional scale estimates. This approach involves using soil inventory data to define landscape units and using soil series information to define distinct modal landscape segments and their spatial extent within the larger unit. The model would then be run for each landscape segment, using a segment-specific set of driving variables. Model output would be scaled-up using the spatial extent of each landscape segment within the larger unit.

Background

Under the Kyoto Protocol to the United Nations Convention on Climate Change, Canada has committed to reduce its overall emissions of greenhouse gases to six percent below 1990

levels. One method being explored to reduce net CO₂ emissions is the sequestration of atmospheric CO₂ in ecosystem “sinks”, such as vegetation or soils.

Soils can sequester atmospheric CO₂ by storing carbon in soil organic matter. In agricultural soils, a variety of farm management practices, such as reduced summer fallow frequency, reduced tillage (e.g., direct seeding), and increased use of forages in rotations have been shown to increase soil organic matter levels compared to conventional historic practices.

However, there are still ongoing international negotiations on whether agricultural soils should be included in the Kyoto Protocol as a potential sink for CO₂. One of the issues in the negotiation is to determine how regional and national changes in the amount of carbon stored in agricultural soils can be quantified and verified for the purposes of this agreement. The Prairie Soil Carbon Balance (PSCB) Project was initiated in response to these issues, and involves researchers from across Western Canada, including the Department of Soil Science at the University of Saskatchewan.

Objective

The objective of the PSCB project is to develop a cost-effective, scientifically defensible set of tools for quantifying and verifying soil organic carbon (SOC) changes in response to various agricultural management practices.

The PSCB project has adopted the conceptual framework proposed by Bruce et al. (1998) for quantification and verification of regional stores of SOC. Figure 1 illustrates how the various components of the PSCB project relate to this framework and each other.

The project team at the University of Saskatchewan is conducting the modelling and Geographic Information System (GIS) component of the project (Figure 1). The objectives of this component are:

- 1) To adapt the CENTURY soil organic matter model to predict SOC changes in Prairie soils in response to various management practices;
- 2) To examine methods to extrapolate or “scale-up” model results to the regional scale using soil inventory, land-use, and climate databases and GIS; and
- 3) To use modelling and scaling-up procedures to quantify the potential change in SOC stocks in Prairie agricultural soils with adoption of various management practices.

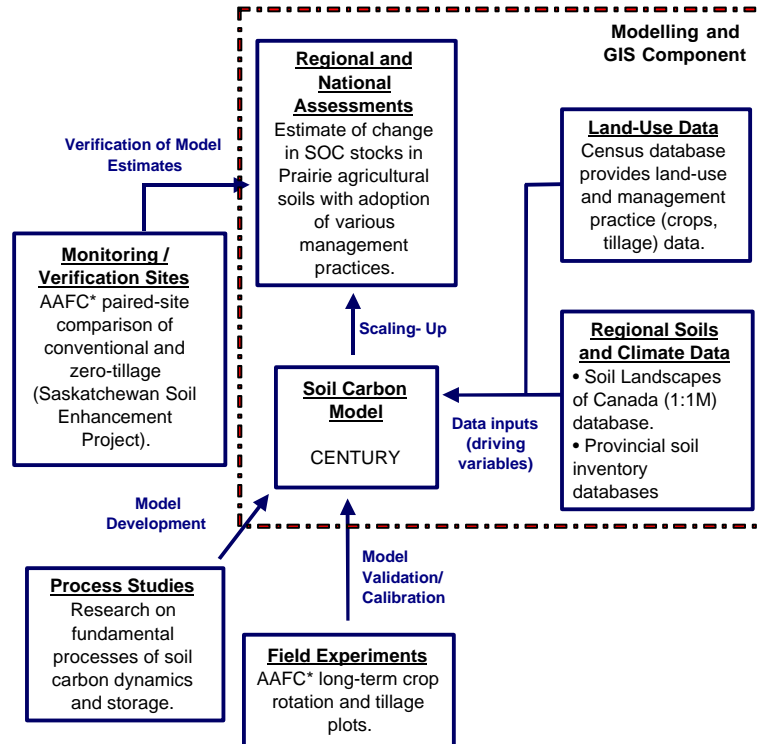


Figure 1. Framework for Quantification and Verification of Changes in Soil Carbon Stocks being used by the Prairie Soil Carbon Balance Project. (Adapted from Bruce et al., 1998). *Agriculture and Agri-Food Canada.

The CENTURY Model

The CENTURY model is a general model of plant-soil nutrient cycling which has been used to simulate carbon and nutrient dynamics for grassland, agricultural, forest, and savanna ecosystems (Parton et al., 1987). The primary model components are a soil organic matter decomposition submodel, a water budget submodel, and a plant production submodel.

As a process-based model, carbon and nutrient dynamics within CENTURY respond to soil/environmental controlling factors (e.g., soil temperature, soil moisture, soil texture, plant residue inputs). The values of these controlling factors are estimated on a monthly time step within the model based on ecological driving variables. In agricultural systems, management (e.g., crop type, tillage type and frequency, fertilizer inputs) is also a significant driving variable because of its effects on soil/environmental factors. The primary model inputs (driving variables) and output are summarized in Figure 2.

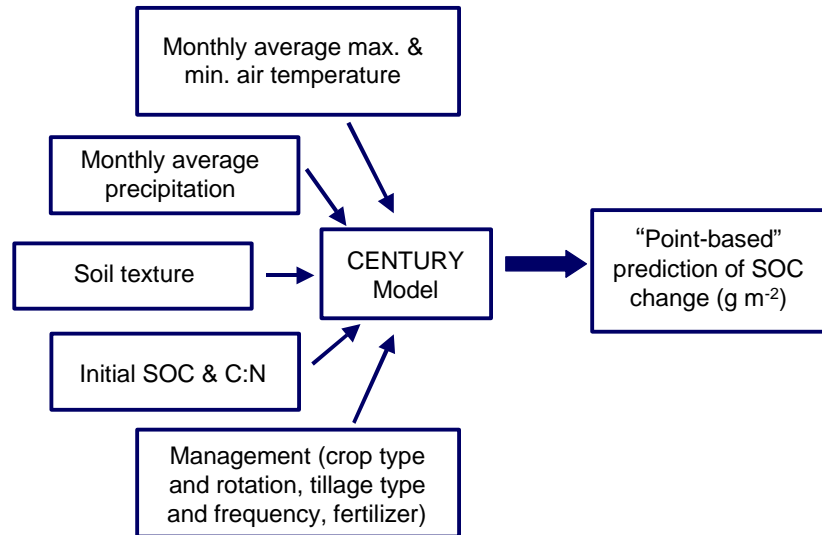


Figure 2. Primary input and output for the CENTURY model.

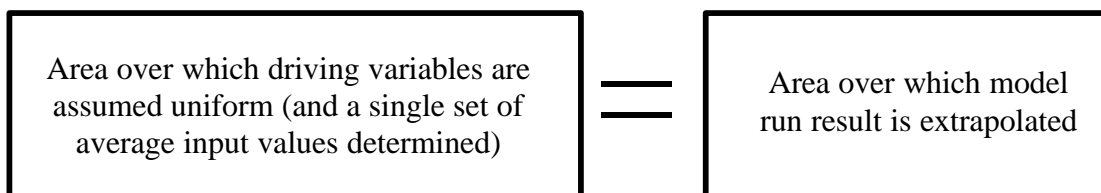
Issues for Spatial Resolution and Scaling-Up of Model Simulations

The CENTURY model uses ecological and management-based driving variables to simulate carbon dynamics on a point (per-square-meter) basis (Figure 2).

CENTURY has been used extensively to model SOC changes in small plot experiments, where it is assumed that the driving variables are uniform over the plots, and therefore the model result can be applied to the entire plot area.

When applying CENTURY predictions to larger areas, or “scaling-up”, the issue of spatial resolution of model input and output becomes crucial.

In the “scaling-up” process:



The key issue in the scaling-up process then becomes how to divide a land surface or region into areas with reasonably uniform driving variables. These areas become the basic spatial units to which the model runs are applied.

The conventional approach for this process is to use soil map units or polygons from existing soil maps, for example, the Soil Landscapes of Canada (1:1,000,000) map polygons, or map units from Provincial soil surveys (e.g., 1:100,000). With this approach, a single average value for each of the driving variables (e.g., precipitation, soil texture, initial SOC content, erosion rates) is estimated for the map unit or polygon area, based on soil inventory and other regional databases (Figure 3).

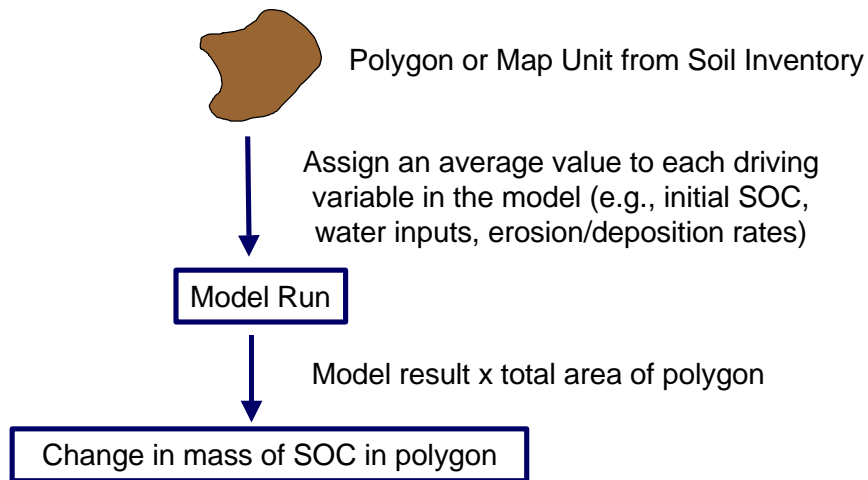


Figure 3. Conventional approach for scaling-up model results.

The assumption here is that the value for each driving variable is more or less uniform within the map unit. This may be a valid assumption in level landscapes but is less valid for the non-level landscapes that dominate the agricultural regions of Western Canada.

In a non-level landscape, many of the key driving variables for SOC will vary significantly within a map unit according to topography. For example, the following factors will vary with topography within a landscape:

- Water inputs (redistribution of precipitation by runoff)
- Initial SOC levels
- Plant residue production or crop yield
- Soil redistribution (erosion or deposition)

Because these ecological and management-related driving variables vary with topography, it is appropriate that topography-based landscape segments be used as the basic spatial unit for the modelling and scaling-up process (Figure 4).

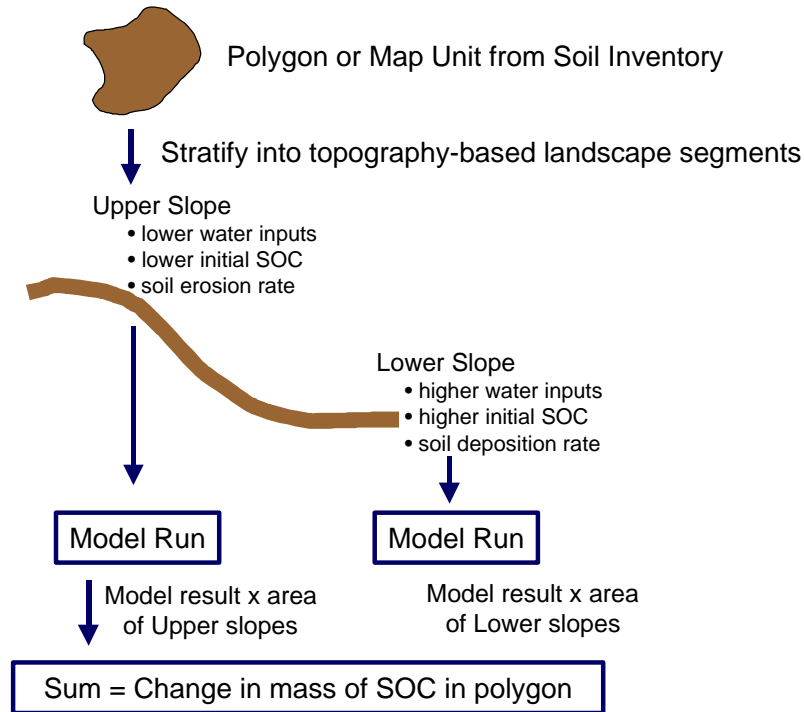


Figure 4. Landscape-scale approach for scaling-up model results.

Applying Landscape-Scale Estimates to the Regional Scale

The landscape-scale approach involves defining distinct types of landscape segments within a larger landscape unit, and assigning a set of driving variables to each type of landscape segment. For regional-scale assessments, the primary source for these data are regional soil, land-use, and climate databases.

In the Saskatchewan soil inventory, the relationship between soil types and landscape position is described with the concept of soil series. This soil series information can be used to derive a set of “modal” or typical landscape segments that describe a given landscape. For example, upper slope segments may correspond to the Rego and Calcareous soil series in a landscape, mid slopes to Orthic series, and lower slope segments to Eluviated and Gleyed series. In addition, many of the driving variables for each modal landscape segment, such as initial SOC levels, soil bulk density, and soil texture, can be derived from data for individual soil series. The soil inventory also provides information on the spatial extent of each soil series in a landscape, which is essential for scaling-up model point estimates. Additional data that are not present in the soil inventory information, such as water and soil redistribution for different modal landscape segments, can be derived using simulation models.

The details of the approach being developed for this project are illustrated below (Figure 5). One of the initial challenges of this approach is to limit the number of distinct landscape units on a regional basis, in order to reduce the number of model runs and the detail of input data required.

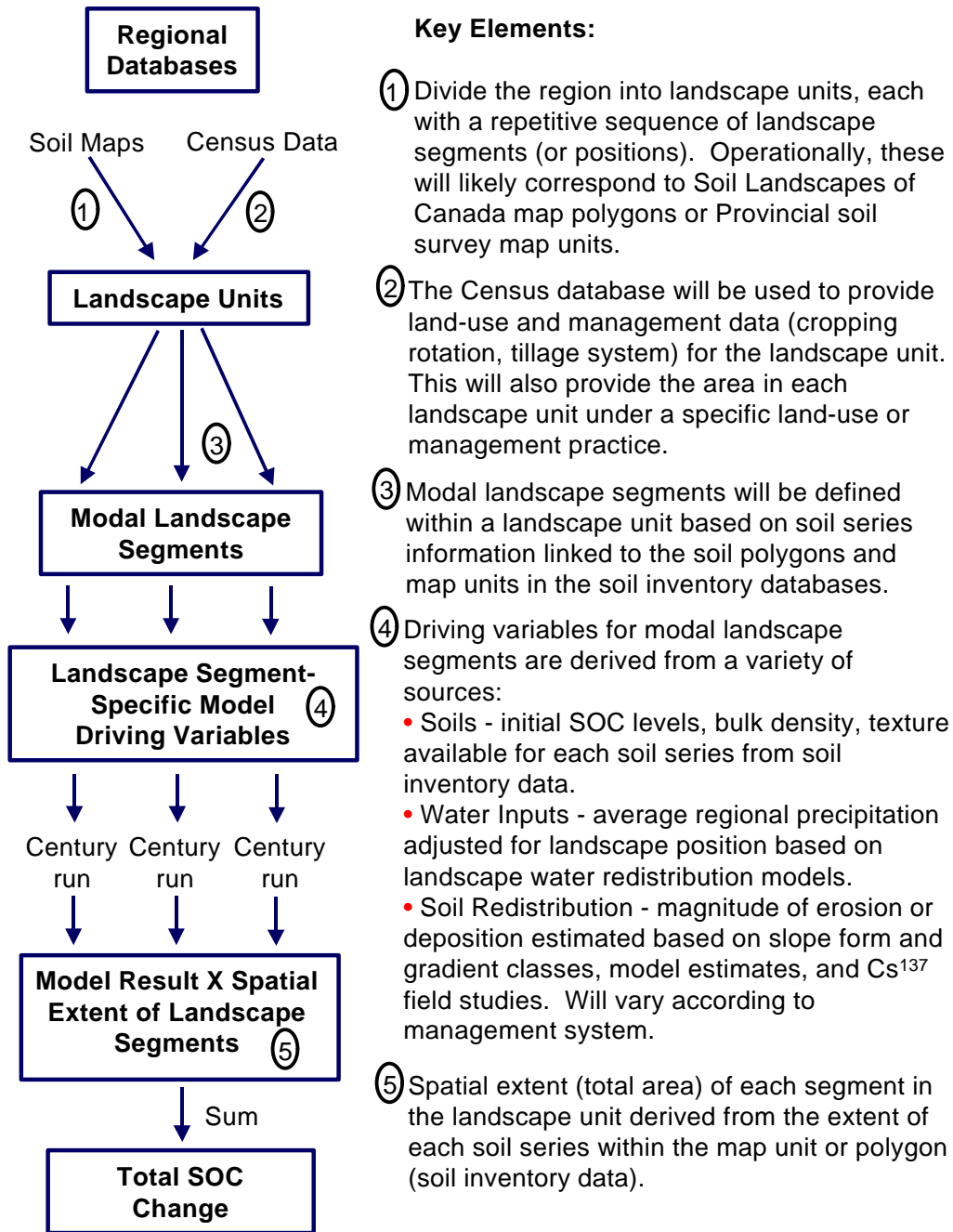


Figure 5. Approach being developed for applying the CENTURY model at the landscape scale in order to provide regional estimates of SOC change.

References

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