Methodology for using the Forest Soil Carbon Loss Lookup Table

Prepared for the Climate Action Reserve by EcoShift Consulting

Objective and general description

The purpose of this tool is to assist the Reserve with identifying potentials for soil carbon losses as a result of management practices, as well as to allow a crediting system for soil carbon savings that result from changes in management practices. The development of this tool is a result of discussions following the completion of the white paper on this subject. Rationale for many of the decisions can be found in the white paper, prepared for the Reserve by EcoShift consulting. In this text it is referenced as WP. The major difficulty in translating the general rationales from the white paper to this tool lies in the fact that, although there is a lot of literature on forest management impacts on soil carbon, much of it is not reported in a way that allows for recommendations that are soil-type specific. Although there are several other ways to examine this issue and classify land based on, for instance, productivity, soil texture, parent material, etc., any classification will have its limitations, and we chose to use the taxonomic system in order to obtain most uniform and universally understood categories. Numerous studies do not report soil characteristics that can be generalized, such as soil order information. Due to this methodological difficulty, we were forced to rely on a smaller subset of studies, and in the cases where specific studies were not available we had to rely on average values from meta-analyses. As is the case with all soil carbon data, the range of reported results is very large. We sought to identify areas and practices of particular significance and potential impact, although this was not possible in all cases.

For the purposes of this project, soils are defined as all soil profiles, including the O horizon. In this document, whenever a range of potential carbon loss is given, the lower bound is the value for avoided losses (losses that would have occurred in the baseline, but do not occur in the project), and the larger value is the expected impact of a project activity.

In order to use the table, first identify the soil type of the unit using the NRCS web database lookup methodology described in Appendix 1. Then, identify the type of management activity that is planned, as well as the time interval that will occur after the chosen management activity. In the corresponding cell, you will find a value for soil carbon loss, as well as supporting citations and explanations for the choice of value in this supporting document.

We owe a special thanks to Dr. Nave, who provided his extensive article database for our use for this project, and to Drs. Nave and Coleman for their thorough and thoughtful review of this manuscript.

General statement of caution:

This tool is based on imperfect data. In many cases we have had to arrive at lookup table values that were based on only a few studies. In some cases those studies were in disagreement with each other. We made every effort to be objective, and to ensure that our estimates reflected a conservative range of carbon loss values, in order to avoid crediting uncertain gains or penalizing for uncertain losses. As more studies are published, the table can be updated to reflect better and more recent studies, but at this time this is as comprehensive of a data set as we could provide.

General Document Notes

Doc 1.

Andisols are particularly sensitive to soil surface disturbance. In general, Andisols are characterized by lower bulk density, and disturbance overall should be minimized in order to ensure that the surface soils are not lost through erosion.

Doc 2

Unless we were able to find specific studies reporting otherwise, any losses in soil carbon that result from partial stem removal will likely be compensated for by increased forest productivity due to compensatory growth of the remaining trees at time intervals greater than 10 years. For further discussion, see WP.

Doc 3

Histosols are organic soils that have formed through an interaction of long-term inputs of plant matter and low decomposition due to high saturation of the soil profile with water. Such soils are major reservoirs of terrestrial carbon, and may be meters thick. However, since the main factor for histosols being such an important carbon reservoir is the saturation of soil pores with water, any decrease in soil moisture saturation, which is the typical result of ditching and draining, will result in significant losses of soil carbon, according to some reports up to 11 tC/ha/y (Leifeld et al. 2011). If the soils are drained, the organic matter will continue decomposing indefinitely, and ultimately most of the carbon will be lost to the atmosphere due to microbial respiration. There are few studies on the effect of logging on histosols directly, partially due to the fact that such logging is rare, and partially because management of histosols has been synonymous with draining, which is known to result in almost total losses of soil carbon. Any management regime that has the potential for decreasing the soil saturation of histosols must, therefore, be considered as a 100% loss of soil carbon in the long run.

Ranges of histosol carbon losses due to increased microbial decomposition following higher oxygen availability after reduction of soil saturation differ (Gesch et al. 2007; Kasimir-Klemedtsson et al. 1997; Leifeld et al. 2011); however, most reports come from European studies and we have few direct studies of US histosol carbon losses. The overall dynamic that controls losses of carbon from histosols is the increase of soil respiration due to drainage and increased C mineralization to CO_2, as well as a change in the balance between methane and nitrous oxide losses, with methane emissions decreasing, and nitrous oxide emissions increasing. The resulting land-use has a significant effect on overall losses, where conversions to grazing use result in smaller losses than conversions to arable use for cereals and row crops. Due to the complex nature of changes in gas fluxes that occur after drainage, simple evaluations of changes in soil carbon stocks of histosols using the standard methodology based on bulk density and soil carbon content are insufficient for overall GHG accounting, as they ignore the changes in other trace gasses. However, direct measurement of changes in trace gasses is expensive and not practical. Based on result reported in the above studies and review papers, we propose a conservative estimate of 5 tC/ha/y losses for histosols converted to grassland/grazing and 15 tC/ha/y for histosols converted to till-based agriculture. These values are likely to be constant, since the rates of histosol subsidence have been found to be constant as well (Leifeld et al. 2011). For the purposes of the Reserve, losses of carbon at these rates can be credited up to 80% loss of the original soil carbon.

Doc 4

The question of the effect of site preparation activities on soil carbon storage does not have a straightforward answer. The landmark Covington study (Covington 1981) estimated that site disturbance resulted in significant losses of soil carbon that were not mitigated until 50+ years after harvest. Although some meta-analyses show significant losses of soil carbon due to site preparation activities (between 15-20% loss, depending on the site and treatment (Johnson 1992) and as much as 41% on Spodosols (Orlander et al. 1996), other analyses show a lack of a distinguishable effect (Paul et al. 2002). In order to be conservative, and in order to account for potential losses of soil carbon as a result of project activity, we recommend not giving credit for avoided losses, and using an area-based fraction of total maximum loss to account for project's potential for soil carbon loss due to site preparation activities. In the cases where we could not locate soil-type specific studies, we use the 20% upper bound value from Johnson, 1992. Where we could locate soil-type specific studies, we used the average of reported values for the lower bound, and the lower quartile for the upper bound. Again, in order to be conservative, we assume that the effects of site preparation activity as a result of project activities are not mitigated over the medium term, since there are a number of studies that show that these losses persist, but we assume that over the long term, these effects are mitigated, per Yanai et al., (2003). The only exception to this assumption is for Spodosols, which have been shown to recover more slowly from site preparation by Orlander (1998), and, specifically at the soil surface, in a meta-analysis by Nave et al., (2010). Note: In cases where published literature values for non-intensive site preparation are higher than our estimates of site preparation impact, we use the higher values from the literature. More detailed discussion can be found in the WP.

Doc 5

Since data are not always available for all soil types and all harvest intervals, in some instances we have to rely on general published meta-analyses in order to estimate the most conservative values for potential impact of forest management activities. In the case of very high harvest intensities (harvesting whole trees, or removing residue after harvest), we use a conservative value of 6% loss, derived from Johnson and Curtis, (2001). Although subsequent meta-analyses have shown that this effect may not be as strong (Nave et al. 2010), general understanding of soil carbon dynamics suggests that removal of residues will decrease soil carbon content due to a reduction of inputs. We therefore decided to use this value, following our overall conservative approach. For a more detailed discussion, see WP.

Doc 6

Andisols present a significant challenge for impact prediction. Located in the Northern Sierra Nevada and parts of the Pacific Northwest, these soils are characterized by a volcanic origin, and very low bulk density. There are very few studies that we were able to locate that evaluate harvest impacts on Andisols (Antos et al. 2003; Inagaki et al. 2008; Klopatek 2002; Law et al. 2003), and the results range from losses of 32% (Antos et al. 2003) to overall soil carbon increases (Law et al. 2003). Since these sites are generally dominated by conifers, if we use the general trends identified by Johnson and Curtis (2001), we will assume no losses of soil carbon due to sawlog only harvests (harvest intensity: High) and 6% soil carbon losses in the cases of whole-tree harvests (harvest intensity: Very High). However, a special note must be made that any management on these soils must minimize disturbance of the soil surface, since soil compaction and erosion, and potential change in soil carbon dynamics, is a significant danger on soils with such low bulk density.

Doc 7

Mollisols are typically associated with grasslands, rather than forests. One significant departure from the rule is Northern Arizona, where Ponderosa pine-dominated forests grow on Mollisols. Data on soil carbon dynamics in this system are very sparse, but we will use the general trends outlined in Johnson and Curtis (2001) and Nave et al. (2010), and assume that unless the intensity of harvest is very high, or that slash is removed from the site, there is no effect of harvest on soil carbon.

Doc 8

Results from soil carbon impact studies on Alfisols generally report no significant losses in soil carbon, regardless of harvest intensity, harvest type, or time interval, except for two studies that examined effects of harvesting of hardwoods (Herman et al. 2003; Small and McCarthy 2005), although there is some indication that even under conifer vegetation the thickness and carbon content of the surface soil horizons is affected by harvest activities as far as 17 years after harvest (Black 1995). As discussed by Nave et al. (2010), and consistent with general findings of Johnson and Curtis (2001), the impacts of hardwood harvest versus conifer harvests appear to be significantly different. Therefore, in this instance, we propose 2 different values, one for conifers, and in parentheses a value for hardwood systems. We assume that these losses in hardwoods are mitigated at the Ex-Long time interval. We could not find intensive site preparation studies on Alfisols, so we will use average values from Johnson (1992).

Doc 9

Spodosol results are driven, in large part, by research focused on impacts to the surface horizons. Spodosols are characterized by a carbon-rich topsoil decomposing organic layer that leaches carbon to the subsurface horizons, so the form in which carbon exists in the surface horizons is fundamentally different, in terms of chemical composition, from the subsurface horizons. Research of impacts of forest management on surface horizons shows that impacts are significant, and long-lasting, with the forest floor taking over 50 years to recover and return to original carbon values (Nave et al. 2010). However, the upper mineral horizons do not appear to be affected as much, if at all, and the deeper mineral horizons show a significant decrease in carbon. Since subsurface carbon is largely a product of decomposition of carbon at the surface in both the forest floor and upper mineral horizons, we feel that, in order to be conservative, we must use documented forest floor horizon losses as equivalent to whole soil carbon losses, since they may result in a long-term loss of soil carbon for the whole system, which is the likely mechanism for long-term losses reported by Orlander (1998). One of the things that becomes apparent is that, unlike in other soil types, the documented losses due to whole tree harvesting (ex-high harvest intensity) are significantly lower than soil carbon losses due to stem-only harvest (high harvest intensity). Such a result is likely due to a higher number of studies that focus on the sub-surface horizons in the whole-tree harvest literature, and generally limited data. However, it could also be due to reduced influence of leftover litter on decomposition of the surface organic material, as suggested by Sanscrainte et al. (2003).

Doc 10

Conversion of forest land to agricultural land has been shown to result in varying carbon losses, but on average, 30% losses are expected (Davidson and Ackerman 1993; Guo and Gifford 2002; Murty et al. 2002). The large variety of agricultural practices and original forest types and ages from conversion do not lend themselves to a robust finer analysis of soil-type specific effects.

Doc 11

Conversion to residential-commercial use is problematic from a soil carbon perspective, because urban environments receive a large amount of fossil-fuel intensive inputs, and disturbance effects are often masked by increased productivity due to the use of fertilizers and pesticides, and exclusions of herbivores. In an analysis of multiple cities, Pouyat et al. (2006) found that soil carbon content changes due to urbanization range from 60% losses to 4-6% gains, depending on the parent material, amount of original organic matter present, and use. In a review of urban carbon cycle studies, Pataki et al. (2006) also present a very diverse set of results, showing that urban soils can range as much as tenfold in their soil carbon content, depending on the final use of the soils (i.e.

parking lots vs. golf courses). Depending on the level of disturbance, and the amount of subsequent management, soil carbon content will vary significantly in forests converted for urban use. However, most of the management of urban soils that will result in gains in soil carbon will be due to intensive inputs, such as the case of soils of golf courses (Qian and Follett 2002). In order to be conservative, we propose not crediting for avoided soil carbon losses due to conversion to urban use, since it will avoid potential issues with over-crediting.

Site preparation definitions (roman numerals) **For the purposes of the table, thinning is the short-term small intensity harvest. The differences in categories are due to slightly different definitions of disturbance that accompany thinning literature.**

I Thinning categories of site treatment range: none (no disturbance, residue left on-site), light (minimal disturbance, residue burned on-site), medium (some disturbance, residue removed), heavy(significant surface modification, residue removed)

II Harvest categories of site treatment range: none (Less than 5% disturbance of soil exposed from below litter and duff), light (5%-25% disturbance of the soil surface), medium (25-50% disturbance of the soil surface), heavy (60-100% disturbance of the soil surface)

Footnotes (lower case letters)

aa Inceptisol thinning data are sparse, so the estimate cannot be broken out into different site management categories

ab Mollisol thinning data are sparse, so estimates cannot be broken out into different site management categories

ac Spodosol thinning data are sparse, so estimates cannot be broken out into different site management categories. However, Orlander et al. (1998) reports that even after 60+ years there is still considerable effect of site preparation on Spodosols.

ad Ultisol lower impact data are sparse, so estimates for the two lowest levels of disturbance cannot be broken out into different site management categories

da Johnson and Curtis (2001) find that, irrespective of other factors, removal of whole trees results in a 6% loss of soil carbon. Please see Doc 5.

db Overall, with time intervals spanning over 45 years, we do not expect to see soil carbon losses due to site preparation(Yanai et al., 2003)

dc Although the literature is sparse, Orlander et al. (1998) reports that even after 60+ years there is still considerable effect of site preparation on Spodosols.

dd In Ultisol studies that were undertaken in sites with heavy disturbance, there are some reports of significant losses (as much as 30%), but these results mostly come from short duration studies. When we average the results of multiple studies, we see a very small effect (2%)

de Although we could not find studies for this time period, using the results for a shorter time period we assume a lower bound value of 0% for this category

df There are no studies for medium disturbance levels, so we use the non-disturbed values, since they are higher than 50% of the values from the high site preparation activities

dg Although this is relying only on one study, from Spain, the results are robust enough to warrant this conservative figure

dh The data are very sparse for whole tree harvests on Inceptisols, we assume data from published meta analyses

di There are no data for this time interval, so we use the data from the prior interval for which data are available

References (numbers)

101 (Esquilin et al. 2008; Murphy et al. 2006)

102 (Gundale et al. 2005; Murphy et al. 2006; Vesterdal et al. 1995)

103 (Gundale et al. 2005; Hart et al. 2006; Murphy et al. 2006)

104 (Murphy et al. 2006)

105 (Elliott and Knoepp 2005; Mattson and Smith 1993)

106 (Korb et al. 2004; Stone et al. 1999)

107 (Strong 1997) (Hendrickson 1989)

108 (Boerner et al. 2006; Maassen and Wirth 2004; Shelburne et al. 2004)

109 (Boerner et al. 2006; Hwang and Son 2006; Neher et al. 2003; Shelburne et al. 2004)

110 (Carter et al. 2002)

111 (Inagaki et al. 2008)

112 (Orlander et al. 1996)

201 (Antos et al. 2003)

202 (Edwards and Ross-Todd 1983; Laiho et al. 2003; Riley and Jones 2003)

203 (Gresham 2002; Johnson 1998; Mattson and Smith 1993)

204 (Mattson and Smith 1993)

205 (Knoepp and Swank 1997)

206 (Mattson and Smith 1993; Prietzel et al. 2004)

207 (Cromack et al. 1999; Griffiths and Swanson 2001; Knoepp and Swank 1997; Mattson 1989)

208 (Fraterrigo et al. 2005; Griffiths and Swanson 2001)

209 (Black 1995; DeByle 1980; DeLuca and Zouhar 2000; Prietzel et al. 2004; Waldrop et al. 2003)

210 (Waldrop et al. 2003)

211 (Herman et al. 2003; Small and McCarthy 2005)

212 (Alban and Perala 1992; Cade-Menun et al. 2000; Edmonds and McColl 1989; Gough et al. 2007; Hendrickson 1989; Keenan et al. 1994; Yanai et al. 2000)

213 (Holscher et al. 2001; McLaughlin and Phillips 2006; Yanai et al. 2000)

214 (Strong 1997; Yanai et al. 2000)

215 (Alban and Perala 1992; Goodale and Aber 2001; Gough et al. 2007; Yanai et al. 2000)

216 (Johnson 1995; Johnson et al. 1991; Johnson et al. 1997; McLaughlin et al. 1996; Ussiri and Johnson 2007)

217 (Dai et al. 2001; Ussiri and Johnson 2007)

302 (Merino and Edeso 1999)

303 (Gresham 2002; Laiho et al. 2003; Riley and Jones 2003; Sanchez et al. 2007)

304 (Edwards and Ross-Todd 1983; Laiho et al. 2003)

305 (Johnson 1998)

306 (Goh and Phillips 1991; Mattson and Smith 1993; Merino and Edeso 1999)

307 (Knoepp and Swank 1997)

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Appendix 1. Methodology for estimating Soil Carbon content based on the NRCS database

1. Import GIS coordinates, and create an Area of Interest (AOI) in the NRCS web portal (http://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx)
In order to determine soil classification, select the Soil reports tab, then select land classifications, then select "Taxonomic Classification of Soils". This report will provide a detailed taxonomic classification of each of the soils in the AOI. The last four letters of the soil descriptor correspond to the major soil type (example: a soil classified as a Xerochrepts belongs to the Inceptisol soil type). Soil order identifying endings: -- Alfisol (-alfs) Andisol (-ands) Inceptisol (-epts) Mollisol (-olls) Spodosol (-ods) Ultisol (-ults) Histosol (-ists). If the data do not exist, attempt to obtain these from a local or state soil conservation/environmental protection agency.

2. Obtain soil organic matter values by selecting Soil Properties and Qualities tab, select Soil Organic Matter under Soil Physical Properties, and in the advanced options select Weighted Average for the aggregation method, Higher as the tie break rule, and designate soil depth (unless noted otherwise, 0-30cm). Click "View Ratings", the ratings will provide organic matter percentage for each soil type in the AOI. Convert the number from the rating to decimal percent (divide by 100). If the data do not exist, conduct soil testing to obtain the value.

3. Obtain soil bulk density values by selecting Soil Properties and Qualities tab, select Bulk Density, One-third Bar, and specify Weighted Average method and soil depth (unless noted otherwise, 0-30cm). Click "View Ratings", the ratings will provide bulk density values for each soil type in the AOI. If the bulk density values are not available in the database, use default values of 1.2 g/cm^3 for clay soils, 1.6 g/cm^3 for sand soils, and 1.4 g/cm^3 for loam soils. Soil texture can be obtained by selecting the "Surface texture" value in the Soil Properties and Qualities tab. If the data do not exist, conduct soil testing to obtain the value.

5. In order to calculate total soil carbon per acre, use the following formula for each of the soil types identified in your AOI:

<# from step 2>*0.58*<# from step 3>*<depth in cm you have chosen(default=30cm)*40468564.2*10^{-6}

Where 0.58 is a conversion factor to convert soil organic matter to soil carbon, and 40468564.2 is the conversion of an acre to cm^2 and the multiplier of 10^{-6} is to convert from grams to metric tons. To convert this value to metric tons of CO_2 per acre, multiply by 44/12.