Credit Valley Conservation

An Analysis of Present and Future Carbon Storage in the Forests of the Credit Valley Watershed

A report prepared for Credit Valley Conservation by
Woodrising Consulting Inc. and
ArborVitae Environmental Services Ltd.

CVC
CREDIT VALLEY
CONSERVATION

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FINAL

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by

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ABSTRACT

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The Credit Valley watershed is estimated to hold approximately 6.52 million tonnes of carbon (Mt C) with an average carbon density of 331 tC/ha. The estimate was developed using inventory data provided by the Credit Valley Conservation Authority (CVC) and the consultants' educated estimates for missing data in combination with consultation with CVC staff. Approximately 48% of this carbon is living biomass (above and below ground) while the remainder, 52%, is in dead wood, litter and soil. The natural forests are anticipated to experience the almost complete mortality of white ash as the emerald ash borer moves through the Credit Valley watershed. We estimate that this will temporarily reduce the carbon stocks by as much as 90,272 tC. Since the 1930's, CVC has planted 2,834.0 ha of new forests in the watershed. The majority of these were planted after 1971 by CVC, the Ontario Ministry of Natural Resources, Boy Scouts and private operators. These plantations will have sequestered 168,222 tC by 2010 and will sequester a total of 291,827 tC by 2030 under a hypothetical future planting scenario of 56.8 ha/year until 2014 and 90.9 ha/year from 2015 to 2030. Between 2010 and 2030, the plantations will sequester an average of 5,459 tC per year - equivalent to the annual emissions of 1,300 Ontarians.

ACKNOWLEDGEMENTS

The consultants would like to acknowledge without implicating the Credit Valley Conservation Authority staff, without whose assistance we would have been unable to undertake this project, especially Mike Puddister, Aviva Patel, Zoltan Kovacs, and Kamal Paudel. We also benefited from discussions with the former CVC forester, Bob Baker.

1.0 INTRODUCTION

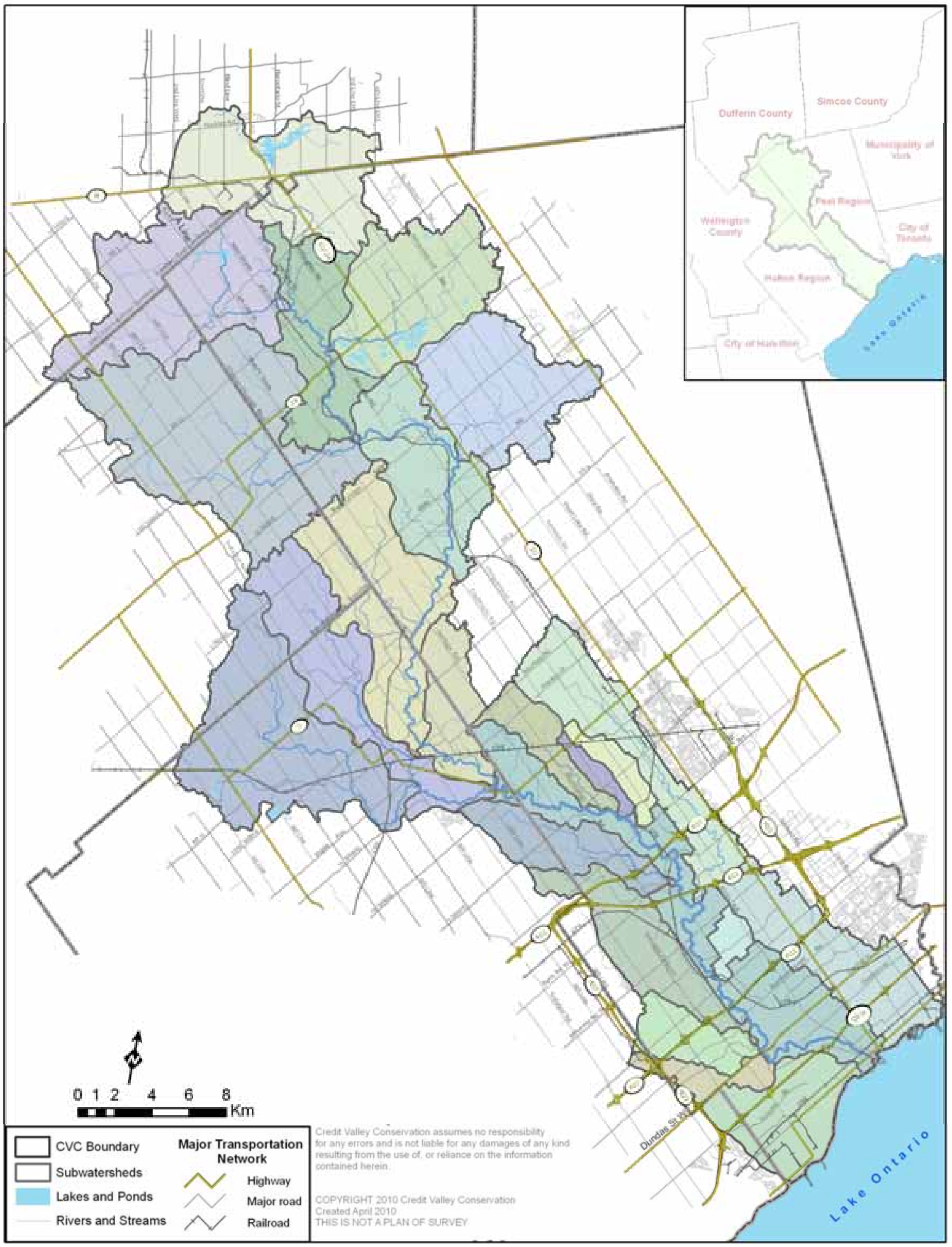
In late November 2008, the Credit Valley Conservation Authority issued a request for expressions of interest for assistance and technical guidance in determining the most practical, yet technically rigorous method to estimate current forest carbon stores and the method by which future storage can be calculated for the Credit River Watershed. This document represents one of the deliverables of that project.

Credit Valley Conservation Authority (CVC) is a community-based environmental organization which is charged with conserving, restoring, developing and managing the natural resources within the Credit River watershed. The Credit River watershed comprises 1,000 square kilometres of land, drained by the Credit River and its 1,500 kilometres of tributaries, stretching from the Town of Orangeville to Port Credit in Mississauga. The map on the next page, provided by CVC, shows the regional context of the watershed as an inset map, while the main map provides more detail.

The watershed is urbanized in the south and transitions to a well-populated rural state in most of the northern zone, with many small communities and a couple of mid-sized and large ones. The area south of Highway 401 is within Mississauga and is largely developed. Development is proceeding quickly between Highways 401 and 407, and extending northwards. The community of Orangeville lies within the northern end of the watershed, Georgetown is in the west central portion, and Caledon and Erin are among other notable communities. The watershed is located in one of the most rapidly urbanizing parts of Canada; overall the population in the watershed increased by 32% between 1996 and 2006. There are numerous large scale physiological features within the watershed. The headwaters of the Credit River are located above the Niagara Escarpment (a World Biosphere Reserve), and the Escarpment itself cuts through the CV area on a north-south gradient, as shown in the location map. In addition, there is a small part of the Oak Ridges Moraine within the watershed (in the east central portion), as well as a number of other moraines are also located within the watershed boundary. The watershed also contains a number of wetlands, including large and provincially significant wetlands near Orangeville. There are also numerous parts of the watershed that fall within the Greenbelt protected area that surrounds the GTA.

CVC is concerned that the potential impacts of climate change may adversely affect the watershed and has a number of initiatives in its strategic plan to both learn more about the potential impacts of climate change and to develop approaches to mitigate them. In addition, CVC recognizes that it can also play a role in efforts to reduce emissions of greenhouse gases (GHG) and to enhance the sequestration, or long-term removal, of GHG from the atmosphere. Forests and wetlands have the ability to act as carbon sinks, absorbing and storing carbon dioxide, the most widely known and ubiquitous GHG.

Figure 1: Credit valley watershed



Most of the land within the watershed is privately owned. However, of the 19,678 ha of forest, CVC owns 2,430 hectares, or 12.4% of the watershed's forest area. CVC's tree planting program, which is very active and anticipated to increase in extent in the next five years, is undertaken both on private lands as well as CVC-owned lands in the watershed. The plantations consist of native species, mostly conifers.

CVC is interested in understanding the carbon impacts of its afforestation efforts, as well as being able to identify the value of protecting existing forested areas from deforestation. With development expected to continue for many decades, this may gradually erode the forest area by a significant amount over the long-term. In order to assist CVC in meeting its goal of better understanding the carbon balance in the forested part of the watershed, and the impacts of its afforestation activities, ArborVitae Environmental Services Ltd and Woodrising Inc were hired to quantify the amount of carbon in the forest and project the fluxes of carbon in the forest in the future. This was done using the GORCAM model, and data regarding the forest in the watershed provided by CVC. In addition to looking at the watershed as a whole, an analysis was also done on the lands owned by CVC within the watershed.

In addition to quantifying current and future forest carbon levels, the request for proposals set out the following project objectives:

1) Review current models and approaches to address the Project Objective;

2) Assess adequacy of current data for the watershed;

3) Serve as a technical advisor to CVC in responding to carbon sequestration initiatives;

4) Consult with outside experts including MNR as necessary;

5) Make recommendations with regard to the preferred approach for CVC to establish base line carbon storage and further data needs; and,

6) Make recommendations with regard to the preferred protocols to track carbon sequestration over time.

The project authority also requested that we review the role of wetlands in the carbon cycle and state of carbon modelling for wetlands. This assessment is contained within Appendix A (page 33).

1.1 CLIMATE CHANGE, MODELS AND FORESTS

Climate change is driven by the increased concentrations of greenhouse gases in the atmosphere, and to a lesser extent by the removal of forests and native vegetation that plays a role in moderating temperatures. It is the increases in the concentration of greenhouse gases (GHG) that is by far the most significant cause of climate change. There are six GHG covered under the Kyoto Protocol, and carbon dioxide (CO_2) is the most prominent. Since 1958, the atmospheric concentration of CO_2 has risen from roughly 315 ppm to 390 ppm as of February 2010, an increase of 75 ppm, or about 1.5 ppm per year (CO2now.org). This is higher than global CO_2

concentrations have been any time during the last 400,000 years[1] and it is this increase that is primarily driving climate change.

The most influential metric for climate change is temperature, which has also been increasing. Many people are familiar with the "hockey stick" graph that shows the average temperatures in the northern hemisphere rising sharply over the last 70 – 80 years to the highest levels experienced in the last 1000 years. Hansen et al[2] calculated that the average global temperature has risen 0.2°C in each of the last three decades and has risen 0.8°C in the past century, and this rate of temperature increase has continued through the 2000's. In January 2010, NASA released data indicating that 2009 was tied for the second-warmest year on record[*]. Not only are these temperatures high when compared with the past 1000 years, Hansen et al[2] calculated that the global temperature is probably within 1°C of the maximum reached over the past one million years.

Climate is not just a function of temperature, and other aspects of climate are also changing, and are expected to continue to change, most notably moisture regimes. Most models show that in general, there will be increased rainfall in the middle latitudes of the northern hemisphere, and some analyses of rainfall data support this conclusion. This is relevant to forests of course, not only in terms of the amount of precipitation but also its occurrence throughout the year. Most notably, the weather regime will affect the forest fire regime.

One of the few concrete points of agreement to come out of the December 2009 United Nations COP-15 Climate Change Meeting in Copenhagen was that a 2°C increase in average global temperature would be considered disastrous (the reference point is the pre-industrial average temperature, and so this is equivalent to a further increase of 1.2°C from the current average temperature). This figure is a good benchmark to use in the following discussions.

From the perspective of this study, there are two relevant levels of modelling – the modelling of climate patterns, which is usually done on a global basis, and the modelling of carbon cycling within forest ecosystems. Due to the differences in scale and key variables, the connection between these two types of modelling is indirect at best. It is beyond our expertise to assess the various climate models in use, however some basics are presented in the next section. That is followed by an overview of some widely used forest carbon models.

1.2 CLIMATE CHANGE MODELS

Global climate models or general circulation models (GCMs) are based on the general principles of fluid dynamics and thermodynamics. They had their origin in numerical weather prediction and describe the dynamics of the atmosphere and ocean in an explicit way, numerically solving fundamental equations describing the

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[*] 2009 was tied with five other years as second-warmest year since record-keeping began in 1880. Four of the other years in the tie were in the 2000's and the fifth was 1998; 2005 was the warmest year on record. The warmest year on record for the southern hemisphere was 2009. (NASA, http://www.nasa.gov/topics/earth/features/temp-analysis-2009.html)

conservation of mass, energy, momentum, etc. for each atmospheric cell, while taking into account the transfer of those quantities between cells[3]. They also consider, often in parameterized form, the physical processes within the boxes, including sources and sinks of these quantities. There are atmospheric GCMs (AGCMs) and ocean GCMs (OGCMs). An AGCM and an OGCM can be coupled together to form an atmosphere-ocean general circulation model (AOGCM). With the addition of other components (such as a sea ice model or a land model), the AOGCM becomes the basis for a full climate model. A recent trend in GCMs is to extend them to become Earth system models that include such things as submodels for atmospheric chemistry or a carbon cycle model to better predict changes in carbon dioxide concentrations resulting from changes in emissions.

In addition to a range of models, there are also many forecasts of how climate change will unfold, and the many aspects about which forecasts have to made, including the nature and effectiveness of human response, have led to a large number of forecasts. The International Panel on Climate Change (IPCC) developed four sets of climate change scenarios that are intended to be used by climate modellers. Each scenario reflects a specific “storyline” developed by the IPCC[4]. For example, the storyline for scenario B1 is:

> *The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives[4].*

The Ontario government climate mapping web site[†] provides estimates of southern Ontario temperature changes in two SRES scenarios, A2 and B2, which call for relatively higher GHG emissions and lower emissions, respectively. In comparison with averages during 1971-2000, average summer and winter temperatures are expected to be between 2-3^{o}C warmer between 2041 and 2070 under the B2 scenario, while average winter temperatures are expected to be 4-5^{o}C warmer under the A2 scenario (forecast summer temperature increases are lower at 2-3^{o}C). Modest decreases in precipitation are forecast under both scenarios, with a decrease ranging from 0 – 10%. Fewer cold air outbreaks and less lake-effect snow (especially around Lake Erie and Lake Ontario) may decrease annual snowfall significantly[5], a trend that has already been observed in the past few years. These results are consistent with an earlier Ontario Ministry of Natural Resources publication[6] and with a recent federal government overview[7]. Suffice it to say, there are considerable sources of uncertainty in these forecasts, however the trends over the last several decades in particular are supportive of the general forecast of a hotter and somewhat drier climate in future.

[†] http://www.web2.mnr.gov.on.ca/mnr/ccmapbrowser/climate.html

Williamson et al.[7] describe the type of effects of climate change on forests, noting that forecasting is difficult due to the many complex interactions. These include changes to fire regimes, pest and disease ranges and behaviour, and potentially enhanced productivity due to longer growing seasons and higher atmospheric CO_2 concentrations. However, the potential for productivity increases may be counterbalanced or outweighed by decreased moisture availability. The anticipated increase in the frequency and intensity of drought and severe weather events is also likely to have significant impacts; the report notes that a nationwide drought between 2001 and 2003 is an example of the dramatic departures from average conditions that might occur.

While we must prepare for climate change through adaptation, policies to stimulate climate change mitigation through the reduction of greenhouse gas emissions and/or increased sequestration are being put in place. These policies include caps or limitations imposed on large emitters of greenhouse gases and the possibility for these companies to invest in projects that reduce greenhouse gases or purchase emission reductions generated by an organization to help the emitter make its target emissions. The actions are called “offsets” and the Government of Canada is designing *Canada’s Offset System for Greenhouse Gases*[8]. These systems include projects that reduce emissions from forests caused by deforestation or increase removals through afforestation and reforestation.

1.3 FOREST CARBON MODELS

Forests have long been recognized as important components of the carbon cycle. The Kyoto Accord made provisions for recognizing the benefits of afforestation and reforestation, while also recognizing the emissions associated with deforestation. More recently, one of the few specifics to emerge from COP-15 (Copenhagen in December 2009) was a funding agreement for Reduced Emissions from Deforestation in Developing Countries (REDD). As a result, there have been a number of forest carbon models developed that track carbon fluxes over time between various live and dead biomass pools, as well as soil pools.

The earliest forest carbon models to gain wide use include CENTURY, CO2FIX, and GORCAM. CENTURY was being used in the early 1990’s, and it provides a relatively high degree of complexity in modelling nutrient relations. The model can be used in forest, savannah, shrubland and grassland ecosystems and was designed to forecast short-term changes, with the time step between periods being one month.[‡] The model uses as input climate and site data, and carbon uptake is strongly dependent on nitrogen availability. It is not clear whether the model continues to be supported – it was developed at the Natural Resource Ecology Laboratory at Colorado State University, and the most recent entry on the web page dates from 2006.

CO2FIX was developed in 1999 as part of the “Carbon sequestration in afforestation and sustainable forest management” project conducted by the European Forest

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[‡] http://www.archive.arm.gov/Carbon/dataneeds/CENTURY.html

Institute, ALTERRA in the Netherlands, the Instituto de Ecologia from the National University of Mexico and the Centro Agronomico Tropical de Investigacion y Ensenanza (CATIE) in Cost Rica. It is an ecosystem level model designed to estimate carbon sequestration in afforestation, agroforestry and forest management projects. The model was originally designed for monocultures but was revised to enable it to handle multi-species situations. However, since the model was intended for use with plantations, instead of natural forests, it is not especially suited for use in the CVC watershed.

GORCAM (Graz / Oak Ridge Carbon Accounting Model) is a spreadsheet model that has been developed to calculate the net fluxes of carbon to and from the atmosphere associated with such strategies.[§] The model considers:

- changes of carbon (C) stored in vegetation, plant litter and soil,
- reduction of C emissions because biofuels replace fossil fuels,
- C storage in wood products,
- reduction of C emissions because wood products replace energy-intensive materials like steel or concrete,
- recycling or burning of waste-wood,
- auxiliary fossil fuels used for production of biofuels and wood products.

Input parameters of the model describe the management regime (harvest cycle, growth rate etc.), the land use before the project, and the way in which the biomass is used for carbon mitigation. The model output is presented in diagrams with cumulative carbon sequestration over time.

In addition to the more widely used models described above, the Ontario Ministry of Natural Resources has developed the FORCARB-ON model, which is actually a customization of another model from the northern US. FORCARB-ON is based on Forest Resource Inventory (FRI) data and projected forest management practices.[**] This model has not been released for outside users, and so is effectively unavailable for this study.

Finally, the Carbon Budget Model (CBM3) has been developed by the Canadian Forest Service, in partnership with the Canadian Model Forest Network.[††] The CBM-CFS3 is large and detailed process-based modelling framework. It is aspatial and operates at both stand- and landscape-levels to simulate the dynamics of all forest carbon stocks required under the Kyoto Protocol (aboveground biomass, belowground biomass, litter, dead wood and soil organic carbon). It is compliant with the carbon estimation methods outlined in the 2003 IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry report.

CBM uses much the same information that is required for forest management planning (e.g., forest inventory, tree species, growth and yield curves, natural and human-induced disturbance information, forest harvest schedule and land-use

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[§] http://www.ieabioenergy-task38.org/softwaretools/gorcam.htm

[**] http://www.mnr.gov.on.ca/en/Business/OFRI/2ColumnSubPage/STEL02_165418.html

[††] http://carbon.cfs.nrcan.gc.ca/CBM-CFS3_e.html

change information), supplemented with information from national ecological parameter databases. Users may apply their own stand- or landscape-level forest management information to calculate carbon stocks and stock changes for the past (monitoring) or into the future (projection). Users can also create, simulate and compare various forest management scenarios in order to assess impacts on carbon.

While this is an excellent model, it is complex and time-consuming to set up and run. Given the significant uncertainty associated with the CVC data, GORCAM was used to conduct the carbon analysis in this project.

2.0 THE WATERSHED AND CVC-OWNED FOREST

The area of the watershed is 94,891 ha and of this, CVC owns 2,430 ha, or 2.4%. The identification of forested lands is based on Ecological Land Classification categories[9]. There are three classes of upland forest: coniferous, deciduous, and mixed forest, and three classes of lowland forest (named “swamp” in the ELC): coniferous, deciduous, and mixed swamp. In the case of the upland forest types, at least 60% of the area must have tree cover, while it must exceed 25% in the case of the lowland (swamp) forest types. In the deciduous forest type, more than 75% of the tree canopy is composed of deciduous species, while more than 75% of the tree canopy must be in conifer for the stand to be classed as coniferous forest. Where the deciduous and coniferous species are both less than 75% of the cover, the forest is classed as a mixed forest.

In addition to these ELC community series types, there is also cultural woodland, which is a terrestrial (upland) ecosite where tree cover is between 35 and 60% - cultural woodlands were also included in this analysis. Table 1 shows the areas in each ELC community series type, and in the lower part of the table, the percentage of area in each community series. Note that the percentages of each ELC community series area owned by CVC are similar to the proportional presence of that series in the entire watershed. It is probably not surprising that CVC tends to own a generally disproportionately higher percentage of swamp lands and a lesser percentage of cultural woodland.

Within the region of the watershed, the majority of the forest is considered to be Great Lakes-St. Lawrence, which is dominated by sugar maple, yellow birch, red oak, poplar and white birch. Other hardwood species include black cherry, beech, ash, ironwood, American elm, and red maple on the lowlands. The signature coniferous species are red and white pine and eastern hemlock, however eastern white cedar, black and white spruce and balsam fir are also common.

The portion of the Credit River watershed close to Lake Ontario tends to experience warmer weather, mainly because of the moderating influence of the lake in winter. The forest in this area, south of Highway 7, is strongly Carolinian in nature. As one moves further north from the lake, species such as black cherry, walnut, and butternut become scarce while the occasional Carolinian species such as hickory, sassafras, and tulip tree completely disappear. Because the southern portion of the watershed is heavily developed, species that are more characteristic of southern climes are uncommon within the watershed as whole.

CVC has a planting program that it undertakes both on privately-owned lands in the watershed (which represent more than 90% of the watershed area) lands owned by CVC (approximately 1% of watershed lands). Plantations are therefore a meaningful component of the forest estate within the watershed.

2.1 NATURAL FOREST INVENTORY

The basis of the natural forest inventory is the ELC survey data provided to the consultants by CVC. These data provide an estimate of area on CVC lands and within the Credit Valley watershed by forest and land use type (Table 1). These data also include a breakdown of leading species within each forest type from forest sampling. For detailed carbon stock and stock change estimation, each species and forest type must be mapped to a unique site class and age. This was not available from the CVC forest inventories. Instead, we assumed a standard yield curve for each species[10] and forest type based on conversation with CVC staff and personal experience. The selected mapping for each species and forest type are shown in Appendix B (Table 10). The result is an estimate of forest area by species and Plonski yield curve. This is shown in Table 2.

Table 1: Area of natural forest by type

Ecosite	Coniferous Forest	Deciduous Forest	Mixed Forest	Cultural Woodland	Coniferous Swamp	Deciduous Swamp	Mixed Swamp	TOTAL
	(ha)							
Watershed	2,311	6,744	1,968	1,824	1,781	1,333	883	16,844
CVC Land	170	587	128	77	131	140	87	1,321
	(%)							
Watershed	13.7	40.0	11.7	10.8	10.6	7.9	5.2	
CVC Land	12.9	44.4	9.7	5.8	9.9	10.6	6.6	

2.2 EXISTING PLANTATION INVENTORY

Since 1971, CVC has been promoting the planting of trees in the Credit Valley watershed. The main tree planting organizations have been the Ministry of Natural Resources (until 1995), the Credit Valley Conservation Authority (since 1971) and Boy Scouts (from 1972 – 1999), with some participation from private contractors. As with the natural forest inventory, the existing planting records provided to the consultants included the total number of trees planted by species by year, from 1971 – 2008, with those planted by the boy scouts separated from the planting undertaken by other organizations (see Table 11 in Appendix B – page 41).

We assumed that for each planter group (Boy Scouts and others), the same proportion of each species type was planted each year, although the number of trees planted annually varied. We estimated the total area planted by dividing the number of trees planted by the planting density, which was 2,645 seedlings/ha from 1971 - 2004 and 2,200 seedlings/ha afterwards. Eastern white cedar was planted at densities of 6727 trees/ha. This analysis of the planting records yielded an area of 1,554 ha, well short of the 2,834 ha of plantations identified in the ELC inventory.

After some analysis of the ELC plot data located in plantations, and further consultation with the CVC staff forester, we decided to allocate an area of 300 ha to red and white pine plantations (50% of each species) established in the 1930's (average age = 75 years in 2010) and take the average area and species mix planted from 1971 – 1989 and assume that this was also planted each year from 1960-1970. This gave us a total of 2,108 ha, and so we expanded our original estimates of areas planted by year by 34% so that our model was consistent with the total area of 2,834 ha.

Even this estimate of the inventory of existing plantations lacks some data that are important in modelling carbon quantities, namely the survival of the plantations, the average diameter at breast height (DBH) and the average tree height. With these data, the standing biomass could be estimated from allometric equations or yield tables and the biomass of each planting could be placed on a standard yield curve which could be used to predict future growth and biomass.

These data were not available; instead we used our experience to select what we thought would be a reasonable yield curve for each species planted[10]. Accounting for mortality is difficult since there is a certain amount of mortality that takes place as any healthy stand grows from a young plantation to a mature stand. The challenge is to estimate when mortality will begin to affect the volume of the future stand, and this depends on both the spatial distribution of the mortality as well as its severity. Our best guess was that survival might be approximately 60% in the Boy Scout plantations, and 75% in the others. We felt that a 75% survival rate, evenly distributed in a plantation, would not be likely to affect the final stand, while the Boy Scout mortality was potentially detrimental to the final stand. In the end, given the mortality rates and the degree of uncertainty around relevant values, we decided not to adjust yield for low stocking due to excessive juvenile mortality. The mapping of planted species to yield curves is shown in Table 11.

Table 2: Area of natural forest by type and Plonski yield class

Entire watershed

	Black Spruce 1 (ha)	Black Spruce 2 (ha)	Red Pine 1 (ha)	Red Pine 2 (ha)	White Pine 1 (ha)	White Pine 2 (ha)	Poplar 1 (ha)	Poplar 2 (ha)	White Birch 1 (ha)	White Birch 2 (ha)	Tolerant Hardwoods 1 (ha)	Tolerant Hardwoods 2 (ha)	**Total** (ha)
Coniferous Forest	2,077	0	0	0	20	0	62	153	0	0	0	0	**2,311**
Deciduous Forest	0	0	0	0	0	0	550	346	0	0	5,848	0	**6,744**
Mixed Forest	506	0	0	0	0	0	0	279	0	0	1,183	0	**1,968**
Cultural Woodland	136	0	111	0	159	0	110	266	0	0	1,042	0	**1,824**
Coniferous Swamp	0	1,597	0	0	0	0	0	184	0	0	0	0	**1,781**
Deciduous Swamp	0	0	0	0	0	0	0	553	0	97	0	683	**1,333**
Mixed Swamp	0	204	0	0	0	0	0	243	0	156	0	280	**883**
Total	**2,718**	**1,802**	**111**	**0**	**178**	**0**	**722**	**2,025**	**0**	**253**	**8,073**	**962**	**16,844**

CVC lands only

	Black Spruce 1 (ha)	Black Spruce 2 (ha)	Red Pine 1 (ha)	Red Pine 2 (ha)	White Pine 1 (ha)	White Pine 2 (ha)	Poplar 1 (ha)	Poplar 2 (ha)	White Birch 1 (ha)	White Birch 2 (ha)	Tolerant Hardwoods 1 (ha)	Tolerant Hardwoods 2 (ha)	**Total** (ha)
Coniferous Forest	153	0	0	0	1	0	5	11	0	0	0	0	**170**
Deciduous Forest	0	0	0	0	0	0	48	30	0	0	509	0	**587**
Mixed Forest	33	0	0	0	0	0	0	18	0	0	77	0	**128**
Cultural Woodland	6	0	5	0	7	0	5	11	0	0	44	0	**77**
Coniferous Swamp	0	118	0	0	0	0	0	14	0	0	0	0	**131**
Deciduous Swamp	0	0	0	0	0	0	0	58	0	10	0	72	**140**
Mixed Swamp	0	20	0	0	0	0	0	24	0	15	0	28	**87**
Total	**192**	**138**	**5**	**0**	**8**	**0**	**57**	**167**	**0**	**26**	**630**	**100**	**1,321**

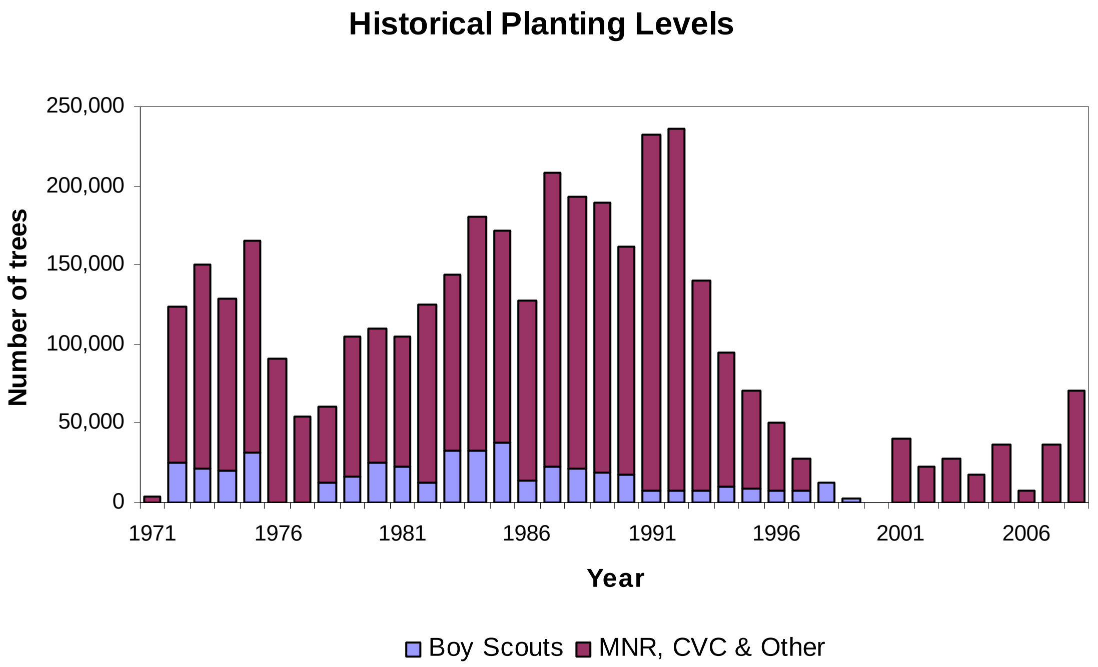

Figure 2: Historical number of trees planted by operator and year.

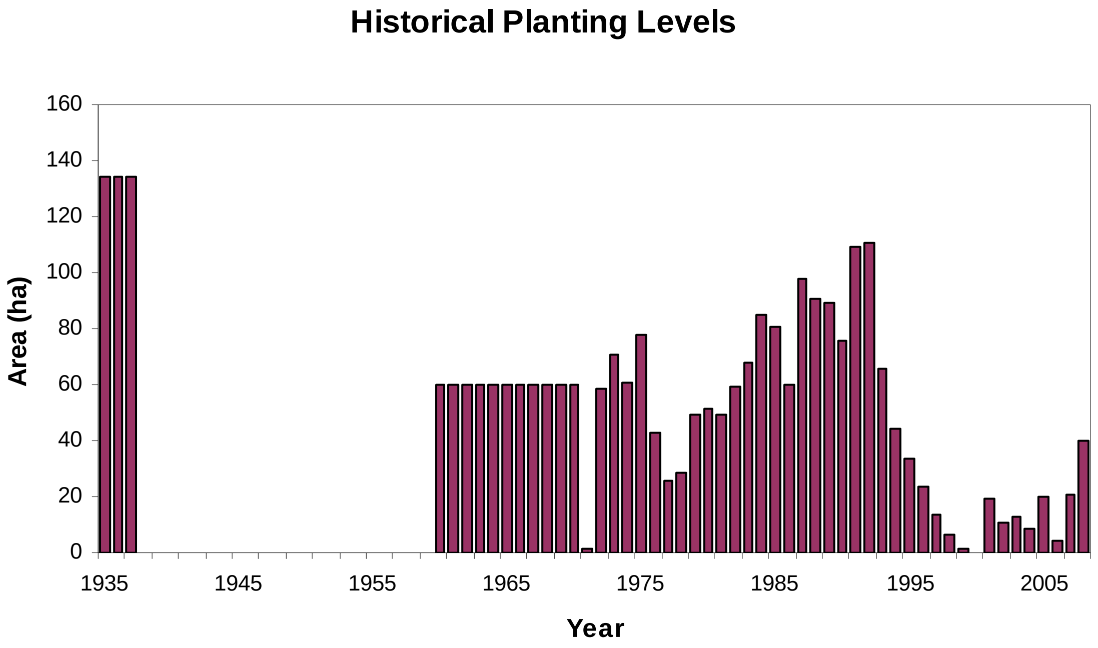

Figure 3: Historical total area planted by year.

2.3 POTENTIAL FUTURE PLANTING PLANS

We discussed the prospects for future plantings with the CVC staff forester, and arrived at a forecast that CVC potentially could plant 125,000 trees per year between 2009 and 2014 (approximately 56.8 ha / year). This could be increased to 200,000 trees per year between 2015 and 2032 (approximately 90.9 ha / year)[11]. This is a conservative projection but significantly higher than the planting rate in the last 10 years (11.0 ha / year), however there is a provincial initiative to increase tree planting and this may help lead to higher planting levels. In addition, with financial support from the Region of Peel and other partners, CVC is currently developing plans to increase planting capacity. As with the existing plantation inventory, the exact mix of species in future plantings is not known. For the purpose of this study, we will continue to assume that the historical annual average species mix is planted each year in the future.

3.0 CARBON STOCKS

3.1 NATURAL FOREST

The inventory of the natural forest contained some data gaps that were important from the perspective of this study, and led to a fairly wide range of carbon profiles. As previously mentioned, it is important to know the age of each stand but since this was unknown, we assumed that all stands were mature and in a steady-state, so that the net growth per hectare is zero. This is acknowledged to be a strong assumption, and its implications will be discussed in Section 5.0.

Finally, for an estimate of future carbon stocks, one should have some idea of future disturbances (e.g. fire, pests, harvesting and other forms of forest management). We have assumed that there are no disturbances within the next 30 years (beyond endemic losses) other than mortality due to the Emerald Ash-borer (EAB). The EAB is an exotic pest that has entered southern Canada and is beginning to appear within the CVC area. Based on discussion with staff from CVC and Halton Region, we assumed that 10% of existing ash would die per year for the next ten years and that the regenerating stands would return as other tolerant hardwoods (Plonski – Tolerant Hardwood 1 & 2). We did not explicitly consider losses of forest due to land clearing for agriculture and development, since we had only very approximate estimates of the rate of loss. This is discussed in more detail in section 4.4.

Figure 4 shows the estimated carbon stocks within the Credit Valley watershed until 2032. As shown in Figure 5, approximately 48% of total carbon stocks are in the living biomass (above ground and below ground) with 8% in dead wood[‡‡], 5% in litter and 39% in soils. Our estimates compare favourably to previous published results for moderate temperate zone of Ontario (Table 3), which is the zone within which the southern and central part of the CVC falls. Part of the northern section of

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[‡‡] For a discussion of the carbon pools in a forest, please see the appendix, page 36.

the watershed may fall into the cool temperate zone, but at the boundary, carbon values would be expected to be close to those characteristic of the moderate temperate zone.

The differences in our estimates from the ones determined by Peng et al. (2000) are caused by the selection of yield curves and our assumption that the natural forest was mature. Figure 6 shows the age class structure used by Peng et al. (2000). We believe that a higher average age is likely in the Credit Valley watershed because the relative difficulty of access probably hindered forest cutting that occurred around 1900.

Table 3: A comparison of carbon stock estimates

	This study	Quantifying Ontario's Forest Carbon Budget[12]	
		Moderate Temperate	Cool Temperate
Carbon density (tC/ha)	377	336	191
Average age (years)	150	94	47
Living biomass	48%	44%	23%
Dead wood, litter and soil	52%	56%	77%

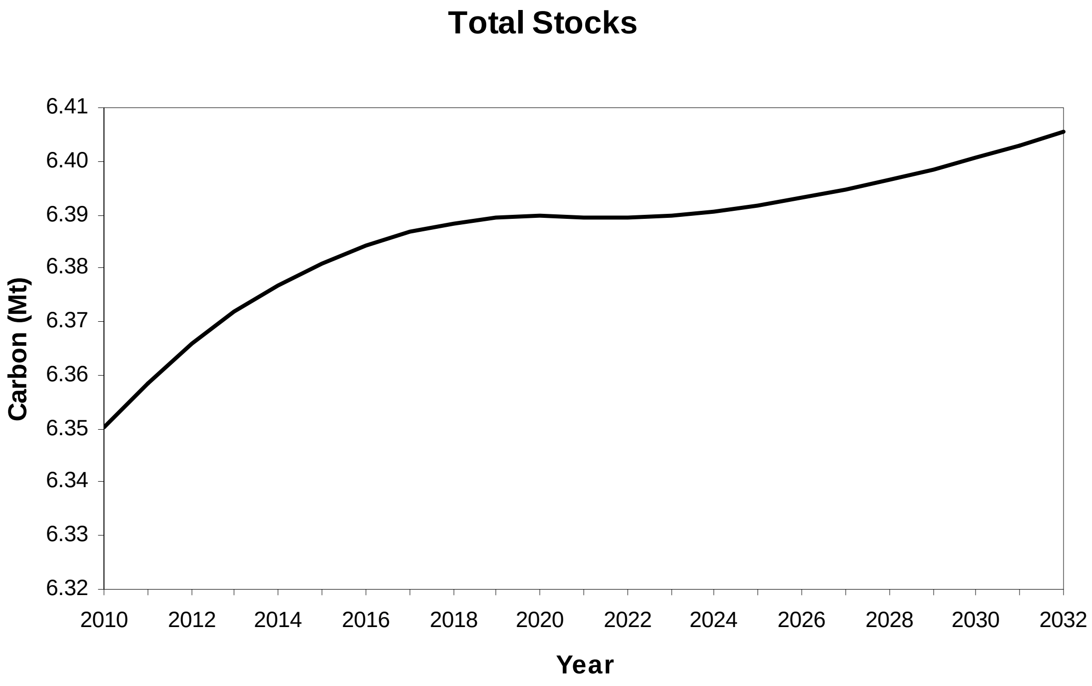

Figure 4: Carbon stocks in the natural forest within the Credit Valley watershed (million tonnes)

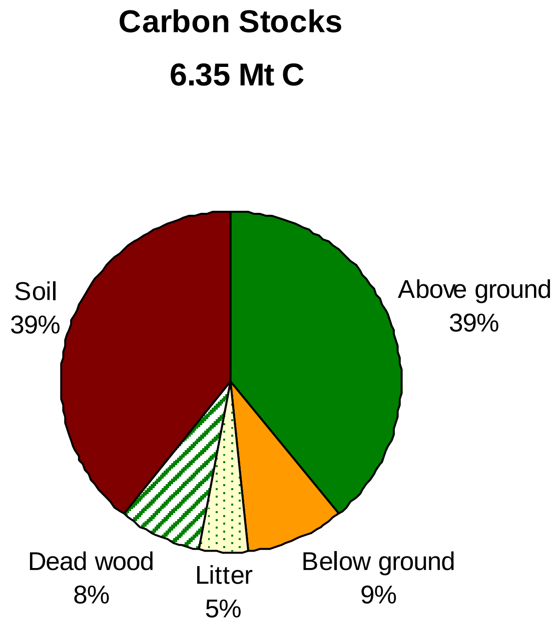

Figure 5: Distribution of carbon stocks in the natural forest

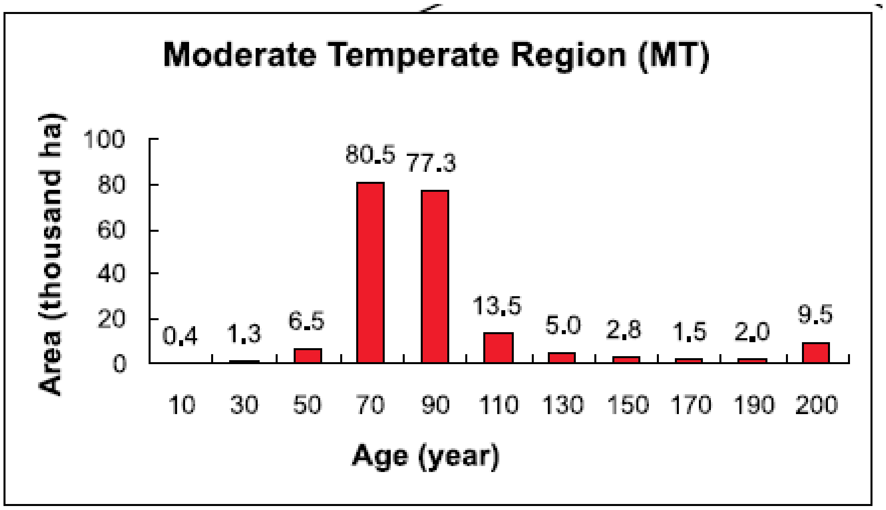

Figure 6: Age-class structure in "Quantifying Ontario's Forest Carbon Budget"

Table 4 displays the distribution of carbon stocks in natural forests by land use type within the entire Credit Valley watershed and on CVC lands only. As well, carbon density for each land use type is shown. The majority of carbon (43% - 48%) is within the deciduous forest since it has the highest area (40% of the entire watershed, 44% of CVC lands). Deciduous forest has also the highest carbon density, but it is only 7% higher than in the coniferous forest. The difference in carbon density between land categorized as forest and swamp is larger. Forests hold 28% more carbon on average than do swamp lands.

Table 4: Distribution of carbon stocks in natural forests by land use type

Land use type	Entire water shed		CVC lands only		Carbon
	Stocks	%	Stocks	%	Density
	(Mt C)		(Mt C)		(tC / ha)
Coniferous forest	0.88	14%	0.07	13%	382
Deciduous forest	2.76	43%	0.24	48%	409
Mixed forest	0.78	12%	0.05	10%	396
Cultural woodland	0.70	11%	0.03	6%	355
Coniferous swamp	0.54	8%	0.04	8%	301
Deciduous swamp	0.43	7%	0.05	9%	322
Mixed swamp	0.27	4%	0.03	5%	302
Total	**6.35**		**0.50**	**Average**	**377**

3.1.1 Sensitivity

Our estimate of carbon stocks was based on incomplete data, with age-class structure and yield curves for each stratum being the main informational gaps; several of our recommendations are directed towards improving the quality of information for this type of analysis. In order to bound the range of potential carbon stock levels, we undertook a sensitivity analysis to examine the impact of some key assumptions on carbon stocks.

Table 2 shows the Plonski yield curves and site classes assigned to each stand type in the natural forest, and it can be seen that there is a range of productivity classes selected for various species types (Site class 1 is a very productive site, site class 2 is moderately productive and site class 3 is a generally poor site that is still capable of growing a commercial timber crop, albeit more slowly and at a lesser volume than on more productive sites.) We analysed carbon stock values under the assumption that all stands were in Plonski Class 1 and then again assuming that they were all Site Class 2. We are quite certain that the true site productivity values will lie somewhere in between these two extremes. Figure 7 shows the results for both benchmark analyses, indicating that the likely range is between about 5.4 Mt and 6.7 Mt. The figure shows that the maximum estimate is approximately 5% above our best estimate (6.35 Mt). The minimum estimate is approximately 14% below the best estimate.

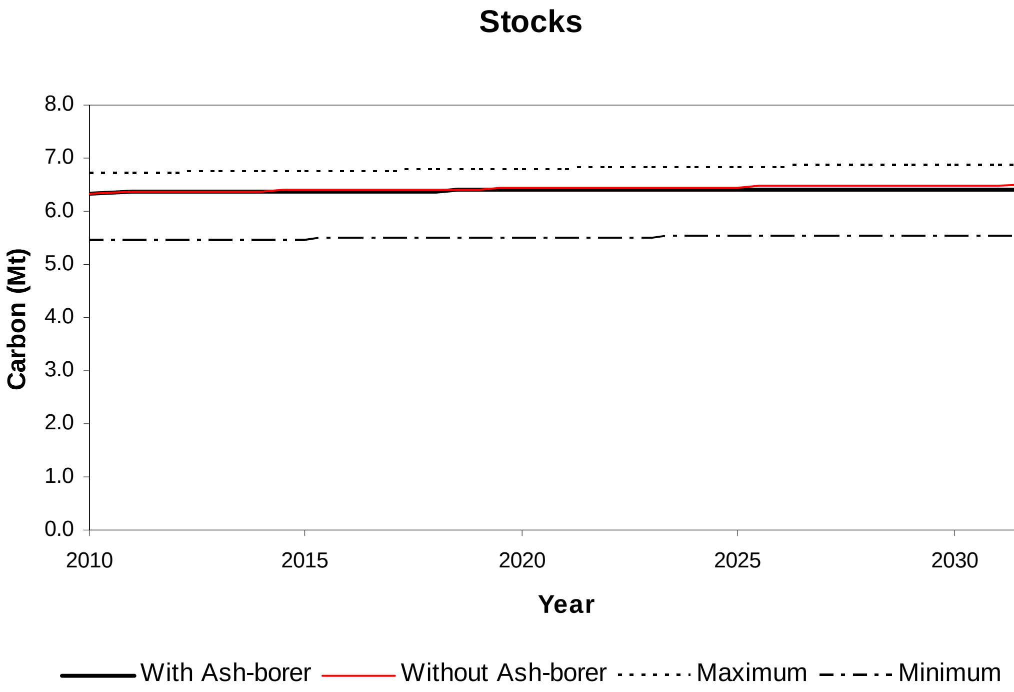

Figure 7: An estimate of the sensitivity of carbon stocks in the natural forest

We also examined the impact of the EAB on the natural forest carbon stock level and found that it made very little difference, as can be seen from the almost indistinguishable lines in Figure 7. This is due to two main factors – the first being that there is not a great deal of ash in the forest to begin with. Ash is most prevalent in the deciduous and mixed swamp forests, where it accounts for an estimated 13.6% and 12.4% of the watershed forest canopy, respectively. In the deciduous and mixed upland forests, ash accounted for 5 and 5.4% of the canopy, respectively. Thus, it is not an overly large component of the watershed forest. Secondly, when any tree dies, the carbon that it contains is not released instantaneously, but is only emitted gradually as the tree decays. Some of the dead biomass ends up within the litter and soil layers, where it might reside for a considerable period of time. This slow rate of emission also reduces the impact of the mortality. Finally, the space occupied by the ash is taken up by regeneration of other species, often tolerant hardwoods, and this serves to further mitigate losses.

3.2 EXISTING PLANTATIONS

Figure 8 shows our estimate of the increase in carbon stocks by pool for existing plantations. In 2010, the net carbon stocks due to existing plantations were 168,222 tC and this is forecast to increase to 277,409 tC by 2030. This is equivalent to the emissions from 1,300 Ontarians during the same period of time.[§§][13]. The reason for the dramatic increase is that the years of establishment of many of the

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[§§] In 2008, Ontario's emissions per capita were 15.4 t CO_2e or 4.2 t C.

plantations are centered around 1986. In 2010, the average plantation stand age is 24 years and for most species the ages of major growth are between 40 – 60 years. In 2010, the average net carbon stocks is 22 tC /ha. This increases to 61 by 2030.

Most of the carbon gain occurs in the living biomass (84%) because although the soil carbon stocks are large (approximately 130 tC / ha[14]), the change in soil carbon stocks that occurs with a land use change from grassland or cropland to forest land (the likely land uses preceding the forest use on much of the watershed area), is relatively small. There are small increases in dead wood and litter. The dead wood, litter, and soil contribute 3%, 10% and 3%, respectively, to the net increase in plantation carbon stocks.

3.2.1 Sensitivity

As previously mentioned, our estimate of carbon stocks is based on incomplete data. In the case of the plantations, we are in somewhat better position than with the natural forest because we have the age-class and overall species composition of the plantations. However, we have no growth information from which to assign site quality and yield curves and so we made our best guesses based on our experience. Figure 8 shows the trajectory of existing plantation carbon stocks, by major pool.

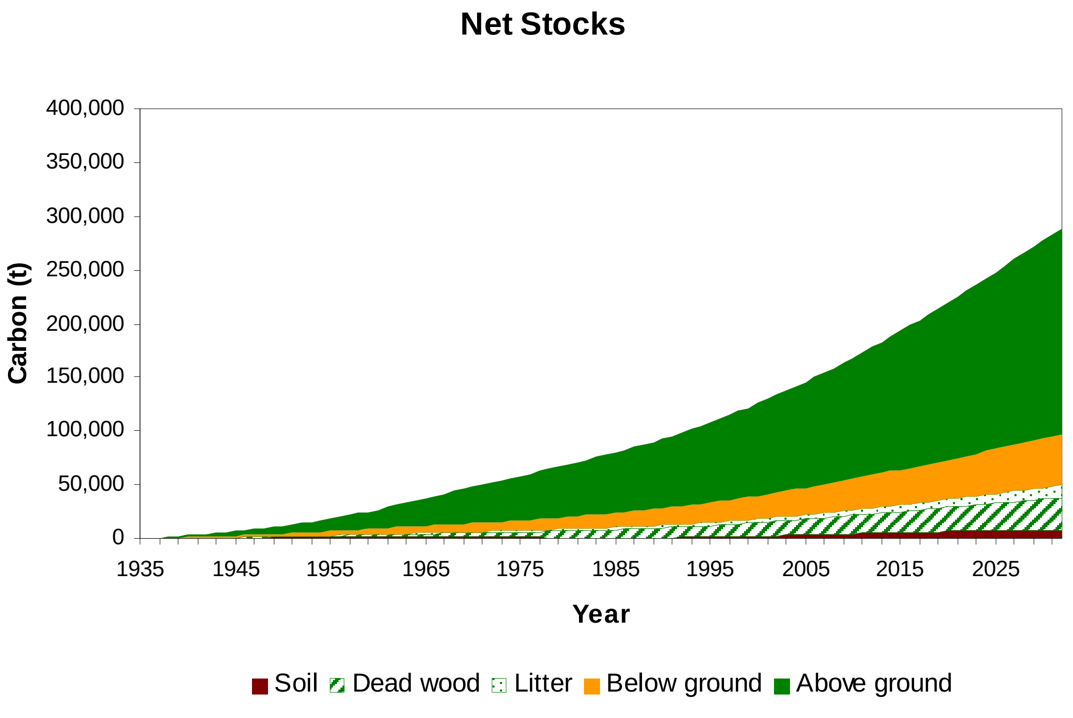

Figure 8: Net carbon stocks in the existing plantations within the Credit Valley watershed

As with the natural stands, we undertook a sensitivity analysis around productivity and yields, assigning in one case a maximum productivity (Plonski Class 1) to all stands and in the second case, assigning a Site Class 2 productivity as the lower bound of the likely range. Figure 9 also shows our maximum and minimum estimates in relation to our best estimate - the maximum net carbon gain may be 11% higher than our best estimate whereas the minimum net carbon gain may 43% below our best projection.

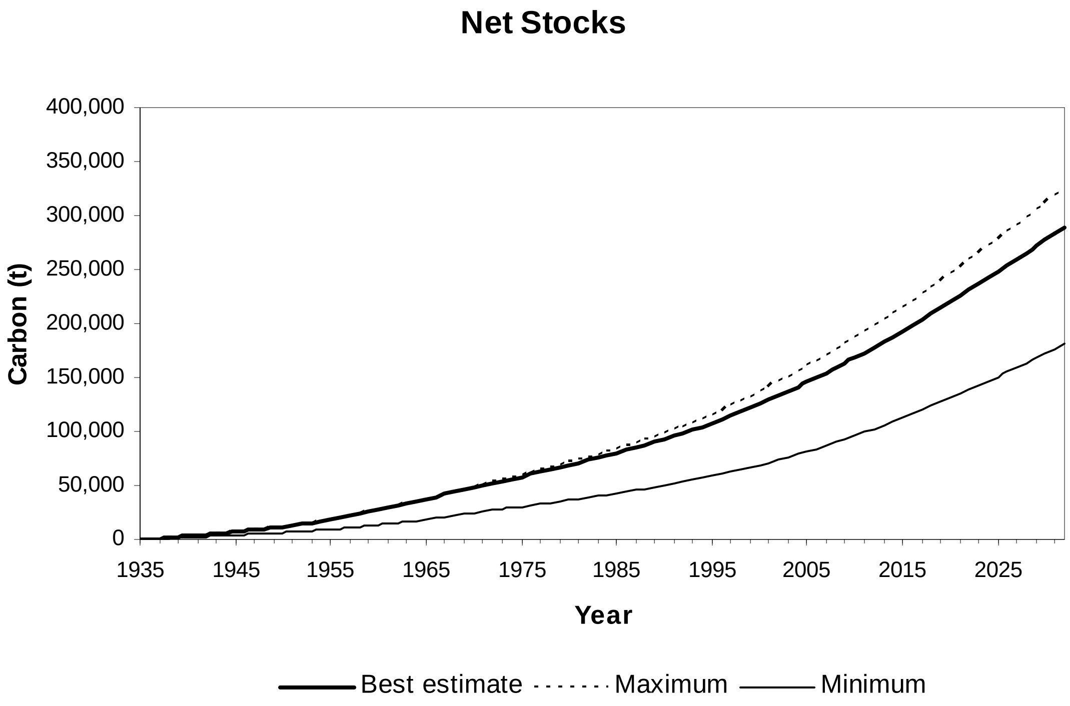

Figure 9: An estimate of the sensitivity of net carbon stocks in existing plantations to site productivity assumptions.

3.3 FUTURE PLANTATIONS

The carbon stocks associated with future plantations will be miniscule in 2010, which is not surprising since there would be only two years of growth on them. By 2030, the net carbon stock gain due to the future plantations would be 14,418 tC. While this is not a lot, it is consistent with the assumption that the species distribution in future plantings will be the same as in the past plantations - 34% cedar, larch, and jack pine (see Table 11 in the Appendix) and 35% white and red pine, all relatively slow-growing species.

Figure 10 shows the carbon sequestered in the future plantations, to 2030, in addition to the carbon sequestered by existing plantations.

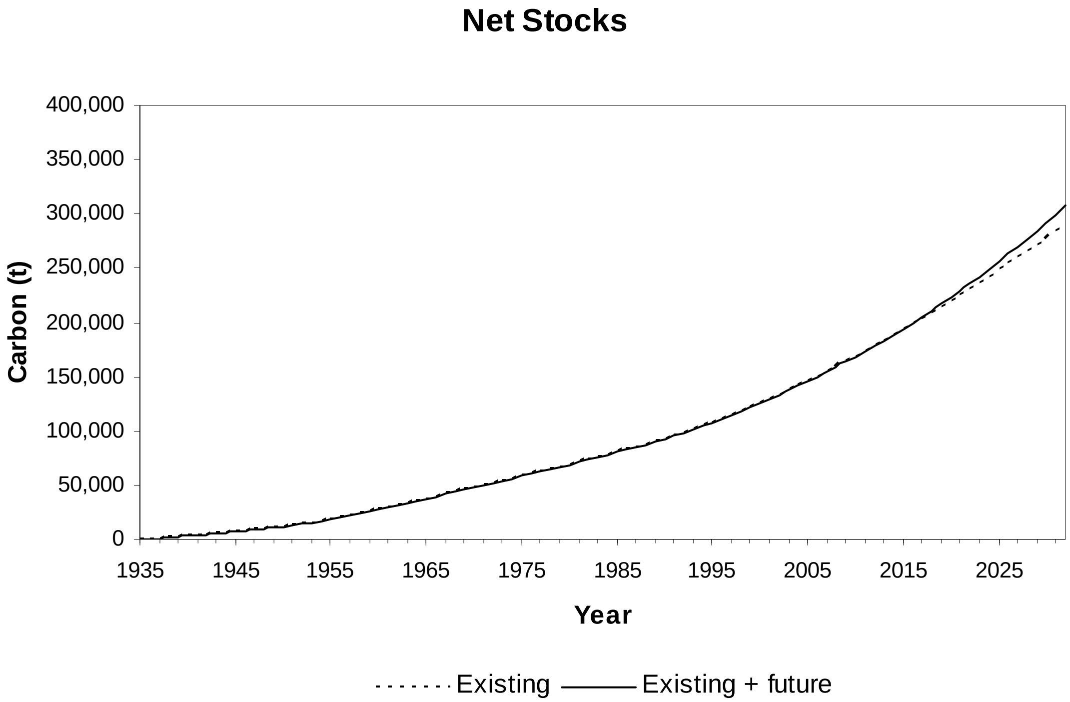

Figure 10: Net carbon stocks in the existing + future plantations within the Credit Valley watershed.

4.0 ANNUAL CARBON STOCK CHANGES

A decrease in carbon stocks between two years is equivalent to a CO_2 emission[***]. Carbon stock decreases occur with forest disturbances. Some forest disturbances, such as deforestation, cause a permanent loss of carbon stocks (that is why there is such an interest in decreasing deforestation as a greenhouse gas mitigation measure). Most disturbances cause a temporary loss of carbon stocks that is recovered as the forest regenerates (such as harvesting followed by natural or artificial renewal). On the other hand, an increase in carbon stocks is an emission removal (a negative emission). Increases in carbon stocks can occur through natural processes such as normal forest growth or by human-induced actions such as afforestation and reforestation.

Even though emissions and removals occur for a wide range of activities and causes, in the Kyoto Protocol there is mandatory accounting of carbon stock changes due to afforestation, reforestation and deforestation. Countries have the option to report carbon stock changes due to forest management, but Canada has not chosen this option. This activity-based accounting system may change to a land-based accounting system or may include other activities in the post-Kyoto period, but that will not be decided until after June 2010 (Bonn) if at all.

[***] There is an equivalency factor equal to the molecular weight of CO_2 (44) divided by the molecular weight of carbon (12).

4.1 NATURAL FOREST – IMPACTS OF ASH-BORER OUTBREAK

The natural forest area is much larger than the amount of land in plantations, and we made the strong assumption that the net growth of the natural forest was zero. However, the forest is about to experience the influx of the emerald ash borer, which will almost certainly cause significant mortality. White ash is estimated to comprise 5% of the canopy of the deciduous and mixed forest types, and the cultural woodland component, and 14% of the smaller deciduous and mixed swamp components. The impact of the expected mortality shows up clearly in the modelled carbon stock changes in the natural forest in the entire Credit Valley watershed (Figure 11) and on CVC lands only (Figure 12).

Without the ash-borer outbreak, the forest would have gained a small amount of carbon each year, largely due to gains in the soil carbon, dead wood and litter pools. This is shown by the positive carbon stock change in 2010 (the difference between carbon stocks at the end of 2010 and carbon stocks at the end of 2009). During the period of the ash-borer outbreak (starting in 2011 and running to 2020), living biomass (above and below ground) is converted to dead wood and soil biomass. Hence there is a loss of above and below ground biomass and a roughly corresponding increase in dead wood and soil pools. The dead wood pool does not increase equally with time because at same time that the ash-borer is killing living trees, the previous newly killed trees start to decay.

After 2020, the forest is dominated by regeneration (hence positive stock changes in above and below ground biomass) but the existing dead wood continues to decay and now there is no annual increase due to continued ash-borer activity. The dead wood pool then starts to lose biomass. The ash-borer outbreak causes a decrease in the annual carbon sequestration by the natural forest (i.e. a net emission) which reaches a maximum in 2011 of 7,239 tC / yr. These patterns are very similar on both the CVC lands and in the watershed as a whole.

The dead wood could be used as a biofuel, in which case there would be a decrease in carbon stocks, but there could be a decrease in emissions from fossil fuel if there is a decrease in fossil fuel use (i.e., if the use of the wood replaces consumption of fossil fuel).

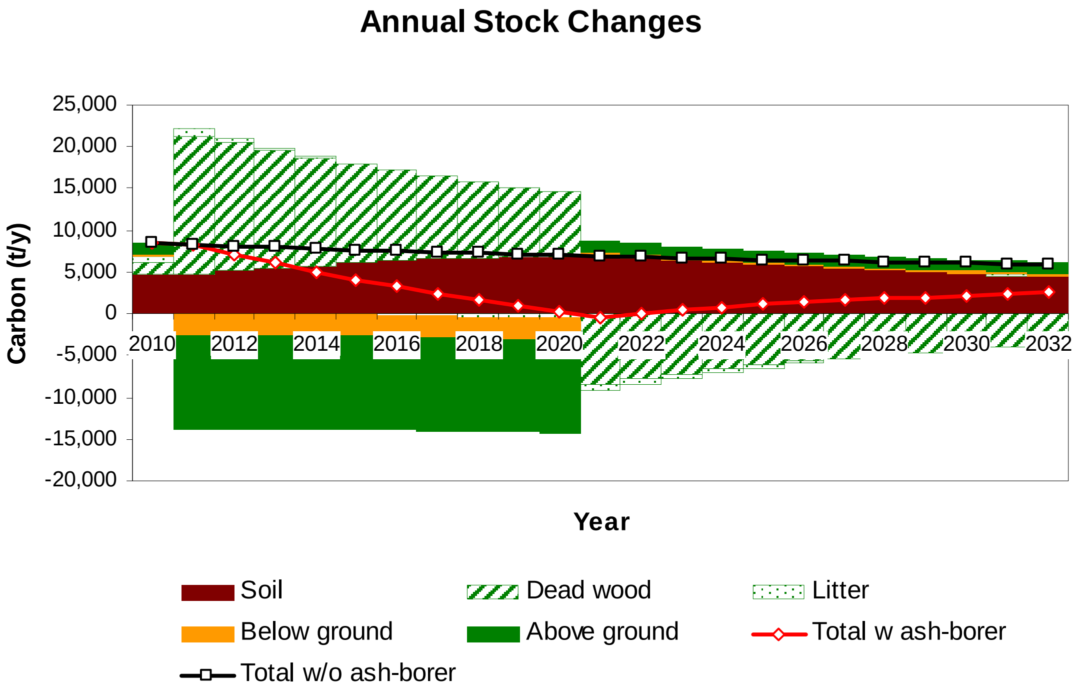

Figure 11: Carbon stock changes in the natural forest in the Credit Valley watershed

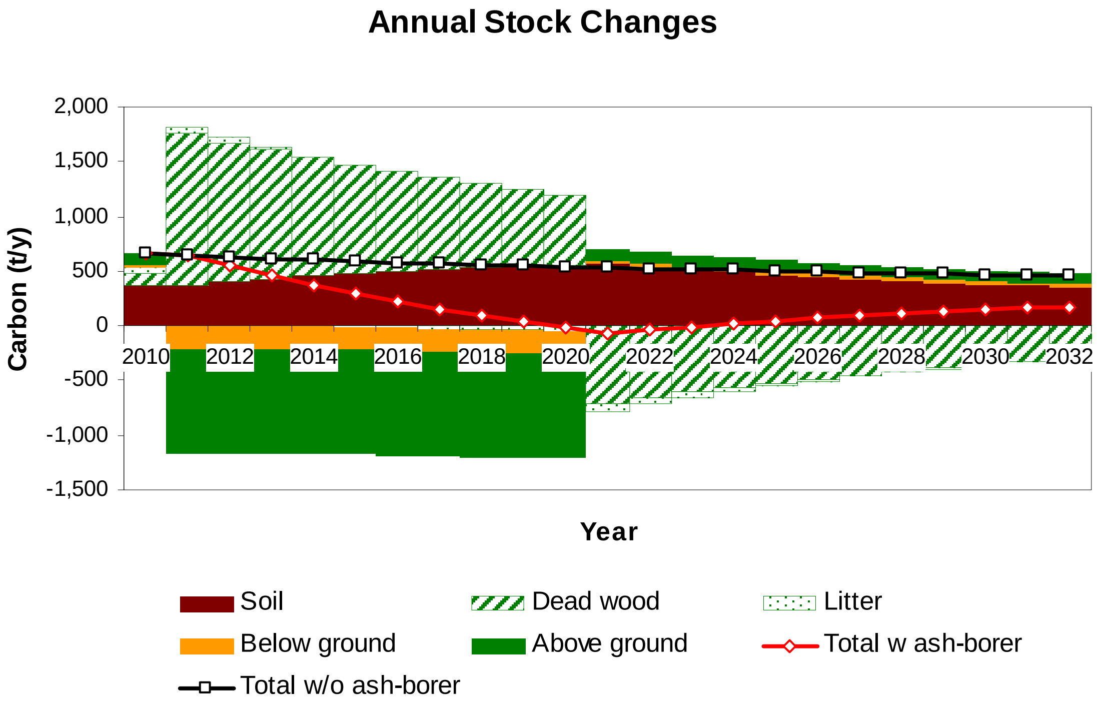

Figure 12: Carbon stock changes in the natural forest on CVC lands only

4.2 EXISTING PLANTATIONS

The year-to-year net carbon stock changes due to existing plantations are shown in Figure 13. The current increment is approximately 4,760 tC/year, which is equivalent to the annual emissions from 1,133 Ontarians.

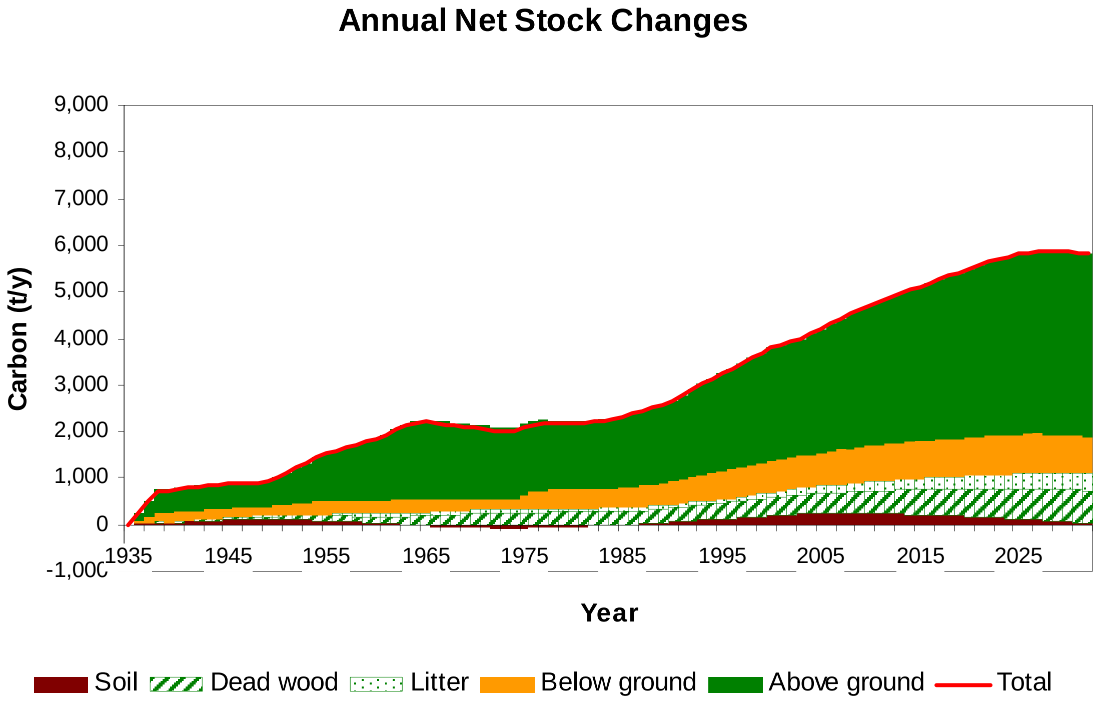

Figure 13: Annual net carbon stock changes due to existing plantations

The annual carbon increment from the existing plantations peaks in 2031 at 5,874 tC/year (equivalent to the emissions from 1,400 Ontarians). This is equivalent to an annual emission reduction of 21,540 t CO_2. As shown in the diagram, the majority of the sequestration takes place in the growing trees (above ground biomass).

Figure 14 shows the sensitivity of the estimate to the assumption of site class. The maximum sequestration is 11% above our best estimate while the minimum sequestration is 25% less than our best estimate.

It is common that there is a slight decrease in litter during the first few years after the establishment of a plantation on grasslands. This occurs because the new trees do not produce as much litter as the grasses they replace until the trees are well established. This accounts for the negative values on the vertical axes in Figure 13 and Figure 14.

4.3 FUTURE PLANTATIONS

The impact of the future plantations on annual net carbon stock changes is shown in Figure 14. The annual sequestration of the existing and future plantations in 2032 is estimated as 7,592 tC/year – equivalent to the annual emissions from 1,800 Ontarians. The future plantations increase sequestration in 2032 by 1,781 tC/year – equivalent to the annual emissions of about 425 Ontarians - or an additional 5,647 t CO_2/year removed from the atmosphere.

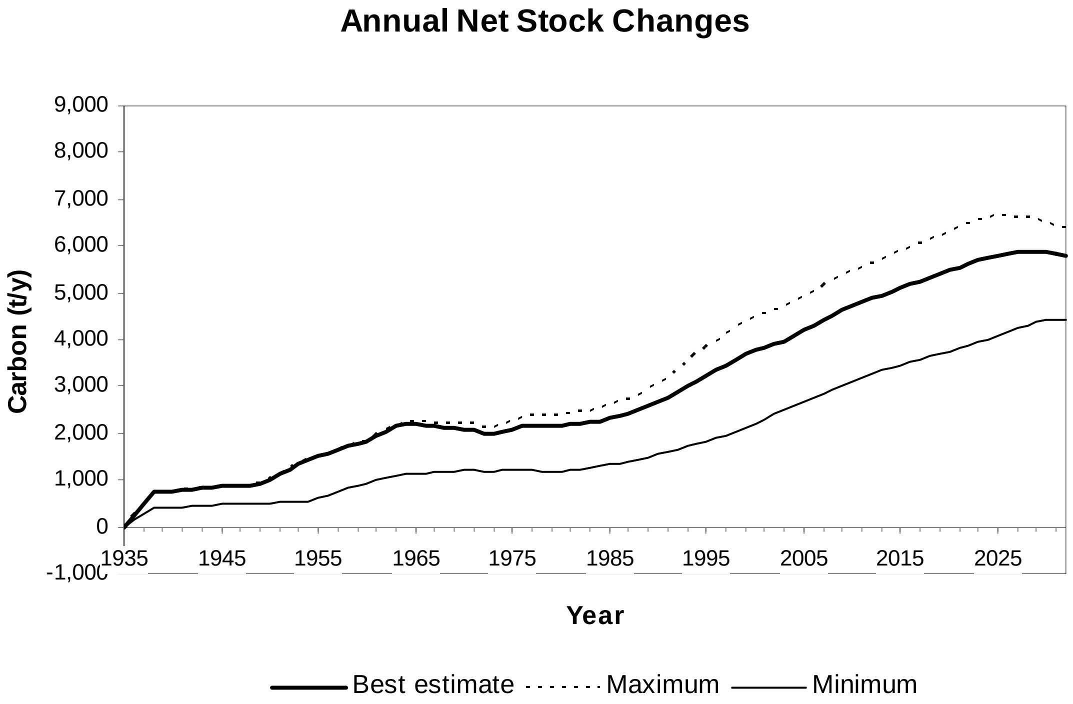

Figure 14: Sensitivity of annual net carbon stock changes due to existing plantations

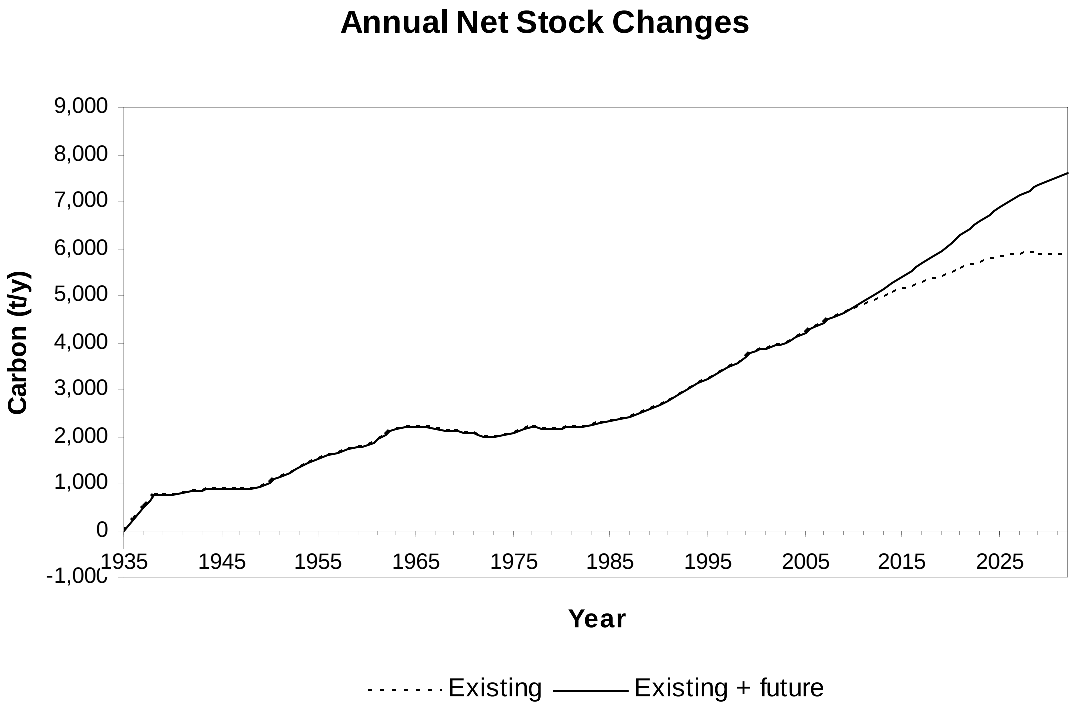

Figure 15: Annual net carbon stock changes due to existing + future plantations

4.4 DEFORESTATION IN THE CREDIT VALLEY WATERSHED

The Credit Valley Conservation Authority has information regarding the amount of land that is converted to development but unfortunately the amount of forest land that is lost is not separately identified. Between 1999 and 2008, an annual average of 688 ha of area was lost – this includes agricultural land, parks, wetlands, and forest. CVC staff felt that relatively little forest area was developed, and an annual rate of loss of 25 – 50 ha seemed plausible.

If this area was all natural forest, and it is assumed that all of the carbon is lost, then the loss is 377 tC/ha. In reality, a certain amount of soil carbon would be retained, with the amount depending on the nature of the development. Table 3 shows that 56% of the forest carbon resided in the litter, deadwood and soil, and so if approximately half of the soil carbon was not lost during development, the total carbon emission would be roughly 300 tC/ha of developed land.

Therefore, losing 25 ha of forest translates to a loss of 7,500 tC, which exceeds the current sequestration rate of plantations (approx 2,000 tC/year). In fact, the deforestation that took place between 1999 and 2008 (225 ha @ 25 ha/year) would have emitted some 67,500 tC, which is 40% of the total amount of carbon sequestered in plantations at year 2010. Given that the current cost of planting is roughly $2750/ha, and that the current plantation area is 2,834 ha, nine years of development of 25 ha of forested land per year has negated the carbon gains associated with the $3.1 million spent (in equivalent current dollars) to establish 40% of the watershed plantation estate. If the annual deforestation rate is 50 ha/yr, eleven years of development will essentially negate the carbon stock existing in 2010 in the plantation component of the watershed forest, established at a cost of $7.8 million.

5.0 DISCUSSION AND RECOMMENDATIONS

The discussion above has described the three main components of the watershed forest and their contribution to overall forest carbon stocks. Table 5 shows the total amount of carbon stocks in the watershed forest in 2010, and our forecast for 2030. Percentages are also shown, in the right-hand table columns.

The table shows that as expected, the largest proportion of the forest carbon stocks are in the natural forest, however over time, plantations make up an increasing proportion, since they are growing more rapidly than the natural forest, they provide the largest increases in carbon. By 2030, the natural forest accounts for 96% of total carbon stocks.

Table 5. Summary of Carbon Stocks in the CV Watershed, by Forest Component

Forest Component	**Amount of C (Mt)**		**Percentage (%)**	
	2010	**2030**	**2010**	**2030**
Natural	6.35	6.40	97.4	95.6
Existing Plantation	0.17	0.28	2.6	4.1
Future Plantation	0.00	0.01	0.0	0.2
Total	**6.52**	**6.69**	**100.0**	**100.0**

The annual rates of carbon stock change are shown at five-year intervals throughout the 2010-2030 period in Table 6. The rate of addition of carbon in the natural forest declines throughout the first decade as the impacts of mortality caused by the EAB take effect. Not only the mortality, but the subsequent decay of the dead trees, releases CO^2 into the atmosphere. The current plantations add increasing amounts of carbon as the majority of the area moves through the ages of highest growth rates (i.e. generally 20 – 40 years of age). The future plantations provide a small but increasing amount of sequestration as they get older and grow more rapidly.

The reader will recall our strong assumption that the natural forest is in a steady state. This assumption is probably not quite appropriate, since there are almost certainly some younger growing stands in the forest. However, given the status of the inventory, we are unable to estimate the area of younger stands, and their ages, with any degree of reliability. The impact of assigning some portion of the current forest in the younger age classes would be to reduce 2010 carbon stocks but have an additional annual increase in carbon stocks generated from the natural forest, so that the 2030 carbon stock figure would probably not be much different from the estimate shown in Table 5.

The consultants reviewed the maps associated with the last Forest Resource Inventory for the CV watershed, which was based on photography in 1978. The inventory showed a considerable area of stands in the 30 – 50 year age range, and also a lot of barren and scattered poplar. A substantial portion of the area south of Highway 401 was then in farmland and woodlot – that has essentially been developed now, and in addition, development around Orangeville and Georgetown has also resulted in the loss of forested land. The difficulty with using information from the 1978 inventory is that not only is it not compiled, but the age of the inventory would require us to make additional significant assumptions. The stands that were 30 – 50 years old in 1978 are now 60 – 80 years old, and they would be close to being in a steady state. We don't know whether the barren and scattered poplar was young poplar that was colonizing abandoned fields or whether it was scattered mature poplar in areas that were grazed. If it was the latter, it could be part of the area of cultural woodland or savannah in the current inventory. If the poplar was young ingress, then it would be about 30 – 35 years and adding a great deal of volume per hectare at present.

One of the other challenges in using the 1978 inventory information is that the nature of land use and disturbance has changed. Farming, especially raising cattle, has decreased substantially and so it is unlikely that much if any land is cleared now for agricultural purposes. On the other hand, the reduction in agriculture has probably increased the amount of young forest taking over old hay fields and pastures. There are probably very few grazed woodlands any more. Moreover, the semi-rural lifestyle has attracted many people, who have built houses (often large) and other outbuildings, and so cleared some forest in the process.

If a deforestation rate of 25 ha per year is assumed to continue from 2010 to 2030, and it is natural forest that is cleared, then the annual loss will be 7,500 tC and the total loss over the twenty-year period will be 150,000 tC. This is equivalent to a loss of roughly 3% of the forested area (upland forest + swamp).

Table 6: Summary of Carbon Stocks in the CV Watershed, by Forest Component

Forest Component	**Annual Rate of Carbon Stock Change (tC/yr)**				
	2010	**2015**	**2020**	**2025**	**2030**
Natural Forest	8,566	4,112	328	1,089	2,192
Current Plantations	4,712	5,108	5,478	5,806	5,859
Future Plantations	48	255	629	1,056	1,555
Deforestation	-7,500	-7,500	-7,500	-7,500	-7,500
Total	**5,826**	**1,975**	**-1,065**	**450**	**2,106**

There are other uncertainties that might cause our forecast to be inaccurate. One of the primary ones is that there may be additional invasive pests – notably the Asian long-horned beetle (ALB). The ALB was first identified in 2003 in a few locations in the Greater Toronto Area (GTA) and an aggressive eradication program has been undertaken. The ALB is also present in a few locations in the northeastern US (e.g.

Chicago, New York City), where similarly aggressive action has been undertaken. The concern with the pest is well-founded – it attacks almost all hardwood species and kills them by boring into the trees and feeding on the sapwood and heartwood. For now, it appears that the species has been contained, but should the eradication efforts fail, there could be extensive and widespread tree mortality.

A second potential source of uncertainty is that by 2030, climate change might have additional impacts on the forests of the CV, and these would most likely be negative. While the increased atmospheric CO_2 concentration can lead to higher growth rates, as can the higher temperatures, these factors would almost certainly be insufficient to counterbalance the loss of growth, dieback, and mortality that would accompany an increased incidence of high heat and drought, as well as a potentially lower amount of precipitation.

5.1 RECOMMENDATIONS

The discussion of the development of the carbon scenarios, and the analysis of the results, has indicated a number of areas where the available data are subject to considerable uncertainty. The consultants were asked to provide recommendations to assist CVC in monitoring and improving carbon estimates, and a number are presented below.

5.1.1 In relation to the forest inventory

Key areas of uncertainty concern the age of the stands in the natural forest and their rate of growth, the survival of plantations and their rate of growth, and the rate of loss of forest. Many of these data gaps can be filled by taking additional inventory measures. If CVC is interested in quantifying carbon offset credits or using any increases in carbon to offset emissions from either the organization as a whole (perhaps it would like to become carbon neutral) or any of the municipalities, the quality of data will need to be upgraded to produce an estimate with a narrower confidence interval.

Recommendation #1: CVC should begin two and five year survival assessments of its plantations, and also record height and diameter at five years and every five years thereafter. CVC should also plan to sample height and dbh of a sample of older plantations during the next 2-3 years to develop a sound current plantation inventory. The sample should be selected from all eligible plantations in the watershed, with the sample size based on a combination of CVC's resource availability and the desired level of accuracy.

Obtaining improved plantation information is perhaps the most straightforward exercise, since the area is relatively small and sampling procedures are simplified because the age is known and the trees are generally quite uniform in size, at least for the first several decades. It is recommended that a combination of information collection from plantings within the last 5 years and from older plantations would enable CVC to develop a very good understanding of the plantation component of the forest within 2-3 years. It is common to assess the survival of plantations after 2 years, since the mortality can be replaced and the new trees will be competitive with the survivors from the original planting. Another assessment at age five is typical to again assess survival and take an initial growth measurement. After that, growth assessments, based on height and diameter, could be undertaken every five years.

In order to assist with resourcing, it is suggested that some landowners could be entrained to monitor plantations on their land and provide reports to CVC staff.

Recommendation #2: CVC should supplement its ELC and permanent monitoring plot data collection in the natural forest with precise measurements of the height, diameter, age and growth rate of a representative sample of canopy trees.

Inventorying the existing natural forest is more complicated, because it is diverse at the stand level, and within each stand. Furthermore, with a mix of species and sizes in many stands, the dynamics are complex and forecasting stand development over an appreciable length of time requires a considerable amount of data about the trees in all size classes. The consultants have the impression that this exercise would be overly expensive for CVC and to start with, it is recommended that information gathering concentrate on the trees in the main canopy.

It is recommended that CVC include age and more precise diameter and height information in its ELC data collection procedures, and add age to its permanent sample plot data. The ELC data is very high quality but it contains a number of gaps, from the perspective of estimating tree and stand behaviour. The ELC does record tree height, however the result is expressed as a value within a series of classes, as shown below:

Table 7: ELC height classification system

Height Class	Height Range (m)	Height Class	Height Range (m)
1	> 25	5	0.5 < ht < 1
2	10 < ht < 25	6	0.2 < ht < 0.5
3	2 < ht < 10	7	< 0.2
4	1 < ht < 2		

Most of the mature stands in the CV watershed fall into Height Class 2, which is so wide that it provides no real information about age or site quality. In addition, this system is unable to record height increments that would occur in sequential measurements. Having more precise height information would be helpful, for in combination with diameter and age information (obtained by taking increment cores), it would be possible to estimate the site productivity for that species with a high level of confidence. Further useful information could be obtained by measuring the length of the outer ten years of growth in each increment core – this would provide a diameter growth rate.

Recommendation #3: CVC should develop and implement an approach to sample afforestation through natural ingress.

Recommendation #4: CVC should develop an approach to estimate forest loss, which occurs primarily through development.

In addition to the existing forest, a full inventory would also track new forest created through natural afforestation and losses through deforestation, and Recommendations 3 and 4 are directed towards each of these components, respectively. In some respects these are probably lower priority than previous recommendations, but this may not be so.

During our review of the old FRI maps, we observed a considerable amount of "Barren and Scattered" area, often in relatively large polygons. Barren and Scattered areas generally have some tree cover, but it is insufficient to be classed as forest. Usually, these areas are stands that are renewing but are too young to be assigned to a forest type, such as areas that have been disturbed and are regrowing or areas that are afforesting naturally. However, Barren and Scattered area could also represent low-stocked stands, perhaps after repeated grazing or fairly severe harvesting. Unfortunately, early stage afforestation is difficult to detect from aerial imagery, and should be identified and evaluated on the ground. This does consume a considerable amount of resources, however since there was a fairly high proportion of area in barren and scattered, it may indicate that afforestation is more significant than we realize.

Regarding deforestation, CVC obtains imagery every three years and it would seem to be a relatively straightforward exercise to overlay the coverage of two successive data years and develop an algorithm to search for areas of forest loss. Thus, it is surmised that there would be some initial cost to work out the overlay and comparison GIS routines, but once they are developed they could be used with each new set of imagery at a low cost.

5.1.2 In relation to adaptation / mitigation

The expected trajectories of climate change suggest that there will continue to be meaningful changes in southern Ontario forests. In general terms, anticipated changes can be summarized as:

- shifts in tree /ecosystem ranges;
- shifts in growing characteristics associated with changes to hydrological cycles;
- changes in native pest and disease ranges and behaviour, and potential introduction of additional exotic pests and invasive plant species; and
- changes in regimes associated with fire, wind and other disturbance agents.

In some respects, maintaining forest health and diversity is perhaps the most important approach to enable forests to survive – healthy forests are generally more resistant to pests and climate-induced stresses due to drought. However, as climate change alters the site characteristics and the competitive balance between species, a more proactive approach might also provide some benefits.

Recommendation #5: In its planting program, CVC should factor an anticipated future reduction in moisture availability when matching species to site.

It is anticipated that southern Ontario will become drier, and hence the planting program should factor this into the way it matches species and sites. Basically, the recommendation is to plant species that will do well on a given site should it become somewhat drier. Mulching is also suggested as a way of mitigating mortality from droughty conditions while the young trees become established.

Recommendation #6: In its planting program, CVC should consider sourcing stock from more southerly seed sources and planting some trees somewhat further north than their typical occurrence.

Secondly, consideration should be given to sourcing seed from seed zones with somewhat warmer climates than the seed zone that the Credit Valley is located in. In addition, some planting of more southerly species can be considered, such as hickories, tulip tree, sassafras, and sweet gums in the southern part of the watershed. Species that are currently present in the southern section but which are rare or absent in the mid and northern sections of the watershed could be planted in more northerly locations. It is suggested that perhaps 10% of the planting program could be re-configured in this way, and the results monitored and assessed. Should the survival of southern species be good, consideration could be given to expanding the program somewhat.

Recommendation #7: CVC should develop and implement an approach to conserving the genetic stock of threatened species and seeking pest-resistant strains for planting.

Lastly, it is anticipated that diseases and pests such as butternut canker, beech dieback, and emerald ash borer are set to dramatically change the composition of southern Ontario forests. While there appears to be little that can be done to prevent the anticipated wave of mortality, there may be strains of these species that are resistant, since mortality is typically about 90% in the case of butternut and beech. Efforts to locate and propagate resistant strains should be encouraged – it is likely that there would be funding available from a variety of sources for such efforts.

5.1.3 Potential for CVC to Earn Revenue from Forest Carbon

Recommendation #8: CVC could consider seeking funding for plantation activities from the carbon offset market.

The carbon offset market could provide a source of future income for CVC from the sale of certified emission reductions from the increased sequestration due to future plantations. The profitability of such a venture depends on the viability of the carbon market. This depends on the national and international political will to mitigate climate change and the wishes of corporations to become “green”. Currently. in North America there is a weak formal carbon market and a stronger voluntary carbon market.

CVC is limited in its ability to sell offsets generated from its existing plantations, because the planting program has been in place for a long period of time and many of the plantations would have been established for reasons other than climate change mitigation. The primary challenge for CVC would be to identify existing plantations that could be considered as "additional". Perhaps some of the most recently established plantations could be considered to be additional if there is sufficient information available to demonstrate that climate change mitigation was the primary purpose for their establishment.

Even if some of the existing, recently established plantations would qualify as being additional, the amount of carbon sequestered in them would be minimal. Therefore, the value of any existing carbon credits would be greatly exceeded by the transaction costs, including verification.

However, if CVC were to explicitly devote a proportion of its planting program to climate change mitigation, or better yet increase its planting program to help offset climate change, then CVC could make a good case that the carbon to be generated would be additional and it could be sold on the voluntary market. The CVC would need to revise its contracts with the landowners to give the CVC ownership of the carbon. To obtain carbon funding to assist with plantation costs, CVC would need to forward sell some or all of the offsets i.e. sell the offsets today and promise to deliver some number of offset credits at a time in the future when the plantations have matured. This creates some risk for CVC, however it can be mitigated fairly readily.

Table 8: Potential certified emission reductions from the future plantations

Year	Additional sequestration (tC)	(tCO$_2$)	Worth @ $5/t (C$)	Worth @ $15/t (C$)
2010	48	175		
2011	87	318		
2012	126	463		
2013	167	613		
2014	210	771	11,697	35,091
2015	255	935		
2016	330	1,211		
2017	402	1,474		
2018	475	1,743		
2019	551	2,020	36,913	110,739
2020	629	2,306		
2021	709	2,600		
2022	791	2,901		
2023	876	3,213		
2024	965	3,537	72,780	218,340
2025	1,056	3,870		
2026	1,149	4,213		
2027	1,245	4,565		
2028	1,344	4,929		
2029	1,448	5,308	114,427	343,281
2030	1,555	5,702		
2031	1,666	6,110		
2032	1,781	6,531	91,719	275,156
Total	**17,866**	**65,507**	**327,536**	**982,607**

The values shown here are the potential gross revenues from the sale of certified emission reductions (CERs). To develop the CERs, CVC would need to adopt an existing accepted methodology for quantification or create a methodology[†††]. To date methodologies for afforestation projects are available at the UNFCCC[15] and the Voluntary Carbon Standard[16], as well as the Climate Action Registry, Tree Canada, and Climate Change Central in Alberta. The Government of Canada offset program will have its own methodologies.

6.0 SUMMARY AND CONCLUSIONS

In late November 2008, Credit Valley Conservation issued a request for expressions of interest for assistance and technical guidance in determining the most practical, yet technically rigorous method to estimate current forest carbon stores and the method by which future storage can be calculated for the Credit River Watershed. This document represents one of the deliverables of that project.

The Credit Valley watershed has 16,844 ha of forest land of which 1,321 ha are lands owned by CVC. We estimate that these lands hold approximately 6.52 million tonnes of carbon (Mt C) with an average carbon density of 331 tC/ha. Approximately 48% of this carbon is living biomass (above and below ground) while the remainder, 52%, is in dead wood, litter and soil. The natural forests are currently subject to an ash-borer infestation. We estimate that this will temporarily reduce the carbon stocks by 90,272 tC.

Table 9: Distribution of carbon stocks in natural forests by land use type

Land use type	Entire water shed		CVC lands only		Carbon Density (tC / ha)
	Stocks (Mt C)	%	Stocks (Mt C)	%	
Coniferous forest	0.88	14%	0.07	13%	382
Deciduous forest	2.76	42%	0.24	48%	409
Mixed forest	0.78	12%	0.05	10%	396
Cultural woodland	0.70	11%	0.03	6%	355
Coniferous swamp	0.54	8%	0.04	8%	301
Deciduous swamp	0.43	7%	0.05	9%	322
Mixed swamp	0.27	4%	0.03	5%	302
Plantations	0.17	3%			59
Total	**6.52**	**100%**	**0.50**	**Average**	**331**

Since 1935, CVC has planted 2,834 ha of new forests in the watershed. The majority of these were planted after 1960 by the CVC, the Ontario Ministry of Natural Resources, Boy Scouts and private contractors. These plantations will have sequestered 168,222 tC by 2010 and will sequester 291,827 tC by 2030 under a

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[†††] Creating a methodology is costly (20,000 – 40,000 USD) and time consuming (expect at least 6 months) and should be avoided if at all possible.

hypothetical future planting scenario of 56.8 ha/year until 2014 and 90.9 ha/year from 2015 to 2030. Between 2010 and 2030 the plantations will sequester 5,459 tC per year - equivalent to the annual emissions of 1,300 Ontarians. The portion of the sequestration that is caused by the future plantings may available for sale on the carbon market. This could be as much as 14,418 tC which could have a market value, before transaction, monitoring and validation costs, of C$ 327,536 to C$982,607 depending on the strength of the carbon market.

APPENDIX A:
THE ROLE OF WETLANDS WITH RESPECT TO GREENHOUSE GASES

Wetlands are important from many perspectives. They are among the most productive ecosystems and provide disproportionately high biodiversity benefits. They also regulate water flow through their storage and groundwater recharge functions, help with flood control, and maintain water quality. Furthermore, they are significant stores of carbon, primarily due to the large amount of carbon stored in their organic soils, which are often deep. This appendix provides an overview of the role of wetlands in climate change, and draws some conclusions that are relevant to the Credit River watershed. By way of introduction, the science literature identifies that there are many unknowns and that the cycling process is especially complex.

Mitra et al 2005[17] observe that the value of wetlands has long been recognized. The Ramsar convention on wetlands, held in Iran in 1971, is the oldest global intergovernmental environmental convention. It provided the framework for national action and international cooperation for the conservation and wise use of wetlands, and is widely subscribed, with 144 Contracting Parties at present. Although wetlands occupy only 4-6% of the earth's land area, they are estimated to contain 20 – 25% of the world's organic soil carbon (350 – 535 GT C). Note that the range of carbon values is quite wide, reflecting varying definitions of wetlands, the complexity of their functions, and variation between different wetland types and different wetlands within each class.

The Credit River watershed contains approximately 5,900 ha of wetlands of different types, accounting for approximately 5.9% of the watershed area. If the global rate of proportionality applies to the Credit Valley watershed, its wetlands might contain 20-25% of the watershed's carbon. The majority of the wetland is classed as treed swamp (approx 4000 ha) and there is 818 ha of thicket swamp, which would be characterized by alder, willow, and other shrubs that favour saturated soils. There is a further 1054 ha of marsh and 3.75 ha of bog land, which is located in the upper part of the watershed and is one of the most uncommon ecosystem types in the watershed. Overall, there is very little wetland area in the lower part of the watershed (221 ha of all types); the middle and upper sections contain 2400 and 3268 ha, respectively.

While wetlands are important carbon reservoirs, there is considerable uncertainty associated with their current and future role in the carbon cycle and in terms of net GHG emissions. Part of the reason for this is that the term "wetland" applies to a wide variety of ecosystems, ranging from coastal flats to peat bogs. Carbon fluxes and pool sizes vary widely in different types of wetlands. Furthermore, most wetlands sequester considerable amounts of carbon but also emit considerable amounts of methane released during decomposition of organic matter under anaerobic conditions.[‡‡‡] Natural wetlands are the largest natural source of methane

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[‡‡‡] When organic matter decomposes under aerobic conditions, CO_2 is released.

release to the atmosphere, accounting for ~20% of the current global emission of ~450–550 Tg (1012 g). Methane is an even more potent GHG than CO_2; it has a global warming potential equal to 1.9, 6.3, or 16.9 CO_2-carbon equivalents on a mass basis across 500-year, 100-year, and 20-year time frames, respectively[18][§§§].

There is a fine balance in wetlands between carbon sequestration and methane emissions and it is difficult to predict how that balance will be affected by changing climate. The rate of decomposition, and whether it is aerobic or anaerobic, depends upon interrelated factors such as temperature, water level, flow of water and nutrients, and so varies within a wetland area over time and space (Bauer et al[1]; Bridgham et al[18]). Litter, peat and carbon-rich sediments may quickly be removed from some wetlands by frequent storms, floods and other physical processes. In contrast, organic matter in bogs may remain undisturbed for hundreds or thousands of years.

Though wetlands are globally a major sink for carbon, releases of carbon dioxide may exceed photosynthesis in some circumstances. One of the fears is that a warmer climate will increase the rates of aerobic decomposition and increase CO_2 emissions. This could occur, for example, through diminished water levels. However, the consensus seems to be that potential trade-offs between lower methane (CH_4) and higher CO_2 emissions from wetlands under an altered climate cannot be adequately quantified (see for example Bauer et al[1]). There are other relevant sets of countervailing factors. For example, Sulman et al (2005)[19] state that fluxes of both carbon dioxide and methane are expected to respond to changes in water table height. On one hand, many climate change models predict increases in summer precipitation in the areas of the world with the highest concentration of wetlands. However, increases in summer temperature and evapotranspiration are expected to result in a net lowering of summer water table in high latitudes where most of the world's wetlands are found.

Finally, there are the impacts of carbon sequestration during photosynthesis and the release of carbon dioxide through aerobic decomposition (setting aside methane emissions for now). The sum of the two processes' impacts on atmospheric CO_2 is net ecosystem exchange (NEE). Normally, over the course of a season, there is an approximate balance between the two processes, so that any change in one may significantly affect NEE. A study of CO_2 emissions and sequestration in a northern Wisconsin wetland that was experiencing a declining water table revealed an increase in ecosystem respiration of over 20% as water table depth fell through a range between 5 and 35 cm below the surface (Sulman et al 2005)[19]. However, this was almost exactly balanced by a 20% increase in average ecosystem production in years with a low water table compared to years with a high water table.

Lavoie and Pellerin[20] examined peat bogs in southern Quebec to provide evidence that the ecological processes in wetlands have been altered by anthropogenic activity. Prior to the EuroCanadian settlement of what is now southern Quebec, the

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[§§§] The atmospheric residence time of CO_2 and CH_4 varies, which account for the different equivalencies at different time periods.

fire intervals on peatland bogs were as long as 900 – 1000 years, which is longer than the case of boreal bogs. Lavoie and Pellerin[20] attribute this to the relative lack of flammability of the deciduous forest cover that usually surrounded the temperate bogs. Now, with widespread land clearing, many of the remaining bogs are surrounded by cultivated fields, ditched for drainage and/or subject to industrial uses, such as peat mining. Between the drier condition of the bogs, and the combination of accidental or intentional anthropogenic fire ignition, Lavoie and Pellerin[20] found that the bogs are now subject to more frequent fires and have become colonized by jack pine and black spruce. Climate change, which was not mentioned by Lavoie and Pellerin[20] as a causal agent, is also likely a contributing factor.

There are major knowledge gaps with respect to the role of wetlands in emitting and sequestering GHG, and the literature does not provide much management direction to improve or conserve the capacity of wetlands to continue to act as sinks. In fact, Bridgham et al[18]concluded that carbon sequestration is probably not a strong basis for advocating wetland protection and restoration measures, although they were quick to point out that the many other benefits of wetland would provide a more than adequate rationale.

At the very least, this review suggests that wetlands are important carbon sinks and that stronger efforts should be made to avoid future losses or impairment of wetlands in the CV watershed.

A potential role for the CV is to participate in efforts to better understand the dynamics of wetlands. Bridgham et al[18] found that very little attention had been paid to freshwater-mineral soil wetlands in North America (i.e. these are generally the types of wetlands in the CVC area) – carbon sequestration in sediment deposition is a potentially large and unknown carbon sink, and CH_4 emission rates are also poorly understood.

Bauer et al[1] report that active restoration and the recreation of functional wetlands can reverse effects of human disturbance and restore the GHG and environmental benefits of wetland systems. However, they are concerned that knowledge gaps limit the ability to successfully implement restoration projects and there are questions about the durability of their GHG benefits, including the long-term sustainability of restored water levels, potential effects of invasive species, and the selection of suitable species complements to maintain wetland function (or C sequestration) under a changing climate. As a result, CVC can make a contribution to our understanding of these issues by monitoring and reporting on the restoration projects that it has undertaken.

APPENDIX B
CARBON POOLS, THE CARBON MODEL AND ASSUMPTIONS

THE CARBON POOLS IN A FOREST SYSTEM

The six pools are:

a) above ground biomass[****];
b) below ground biomass[††††];
c) dead wood[‡‡‡‡];
d) litter[§§§§];
e) soil[*****] and
f) harvested wood products (HWP)[†††††].

THE CARBON MODEL

GORCAM[21] is a stand-based model used to describe the flow of carbon in an economic/ecologic forest system. The model, originally developed by B. Schlamadinger and G. Marland, in the mid- 1990's was quite simple. Both the original authors and Woodrising have made changes to the original algorithm to

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[****] Above ground biomass includes all biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds, and foliage.

[††††] Below ground biomass includes all biomass of live roots. Fine roots of less than (suggested) 2 mm diameter are often excluded because these often cannot be distinguished empirically from soil organic matter or litter.

[‡‡‡‡] Dead wood includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps, larger than or equal to 10 cm in diameter (or the diameter specified by the country).

[§§§§] Litter includes all non-living biomass with a size greater than the limit for soil organic matter (suggested 2 mm) and less than the minimum diameter chosen for dead wood (e.g. 10 cm), lying dead, in various states of decomposition above or within the mineral or organic soil. This includes the litter layer as usually defined in soil typologies. Live fine roots above the mineral or organic soil (of less than the minimum diameter limit chosen for below-ground biomass) are included in litter where they cannot be distinguished from it empirically.

[*****] Soil Includes organic carbon in mineral soils to a specified depth chosen by the country and applied consistently through the time series. Live and dead fine roots and dead organic matter (DOM) within the soil that are less than the minimum diameter limit (suggested 2 mm) for roots and DOM, are included with soil organic matter where they cannot be distinguished from it empirically. The default for soil depth is 30 cm.

[†††††] Harvested wood products include all wood material (including bark) that leaves harvest sites. This includes: wood fuel, paper, panels, boards, sawnwood, processing wastes such as mill residues, sawdust and black liquor. As well, the pool includes discarded HWP that enter solid waste disposal (SWD) sites. Slash and other material left at harvest sites should be regarded as dead organic matter. HWP is included here for completeness but the methodology for the accounting has not been agreed in international negotiations so it will not be discussed further in the document.

better simulate the flow of carbon and extend the project boundaries beyond the locality of the stand being analyzed.

The version that has been used in this analysis is a simplified version of the original GORCAM because in the original version there were many pools for which parameters were not available. As well, the original version of GORCAM did not conform to the UNFCCC definitions for forest carbon pools (see above). The version used in this study was developed by Neil Bird for a EuropeAid funded project, ENCOFOR[22]. The model is available with documentation at the ENCOFOR website. The model has 10 different carbon pools:

1. Above ground biomass
2. Below ground biomass (coarse roots)
3. Litter;
4. Above ground dead wood;
5. Below ground dead wood;
6. Soil (including fine roots);
7. Sawnwood
8. Panels
9. Paper and
10. Landfill

For this study, the three harvested wood product pools and the landfill pool were not considered.

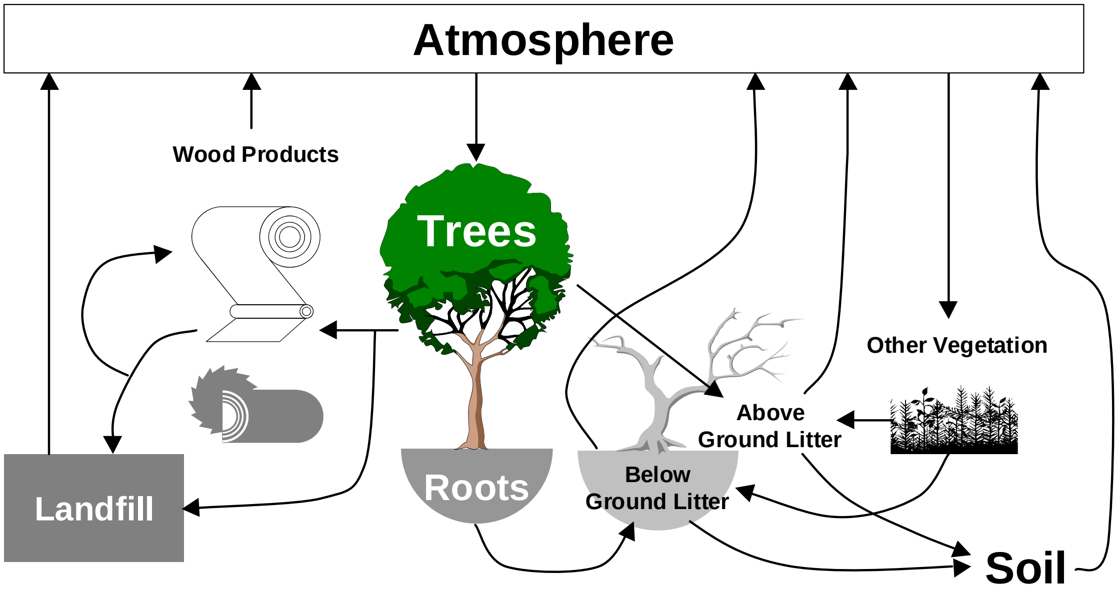

Figure 16: Carbon Flows in a Forest Ecologic/Economic System

CARBON FLOWS AND POOL RELATIONSHIPS

The flow of carbon between the twelve pools and the relationship between the pools are;

1. The below ground biomass (roots) is linked to the above ground biomass using a constant or the empirical formula developed by Kurz et al[23].
2. The litter and dead wood pools are dynamically linked to the above and below ground biomass. Each pool decays exponentially, each with its own decay constant, and the material lost through decay is transferred to the atmosphere or soil pool (each litter pool has its own transfer constants).
3. The model describing the litter and soil dynamics has been tailored to specifically fit Ontario forest conditions. This is accomplished by modelling specific stand types assuming no harvest and choosing parameters so that the carbon stored in the soil and litter pools match measurements made by Siltanen et al[24] in Ontario. They match measurements on foliage decay by Moore et al[25].
4. Two wood product pools, short-lived (paper) and long-lived (lumber) are included. These pools also decay exponentially, each pool with a different decay constant, and the material lost through decay is transferred to the atmosphere (by burning), recycled or transferred to the landfill pool. Each wood product pool has a unique transfer constant. When product is burnt, a portion is used a fuel that may displace other fossil fuels.
5. The landfill pool also decays exponentially (with a unique decay constant). The half the material lost becomes carbon dioxide (CO_2) and the other half methane (CH_4). A portion of the methane is captured and flared or burnt as a fuel.
6. The initial conditions for each pool have been established by assuming that the stand has undergone two or more cycles in the baseline scenario. In this case the stand has reached equilibrium and neither gains or loses carbon dioxide over a cycle.

ASSUMPTIONS

Table 10: Detailed inventory of species by forest type and associated Plonski yield curve

Coniferous forest

Leading Species	Area (ha)	%	Yield curve (assumed)
Thuja occidentalis	196.96	80.5%	Black Spruce 1
Pinus serotine	9.51	3.9%	Black Spruce 1
Balsam fir	7.80	3.2%	Black Spruce 1
Aspen	6.56	2.7%	Poplar 1
Hemlock	5.70	2.3%	Black Spruce 1
white/red pine	2.08	0.8%	White Pine 1
Sum	**228.61**		
Misc	16.18	6.6%	Poplar 2
Total	**244.79**	**100.0%**	

Coniferous swamp

Leading Species	Area (ha)	%	Yield curve (assumed)
Thuja occidentalis	164.32	60.0%	Black Spruce 2
Larch	11.16	4.1%	Black Spruce 2
Balsam fir	70.15	25.6%	Black Spruce 2
Aspen	7.45	2.7%	Poplar 2
hemlock	0.00	0.0%	Black Spruce 2
white/red pine	0.00	0.0%	White Pine 2
Sum	**253.08**		
Misc	20.84	7.6%	Poplar 2
Total	**273.92**	**100.0%**	

Deciduous forest

Leading Species	Area (ha)	%	Yield curve (assumed)
Maple	1,411.86	81.3%	Tolerant Hardwoods 1
Poplar	115.12	6.6%	Poplar 1
Ash	86.37	5.0%	Tolerant Hardwoods 1
Beech	26.59	1.5%	Poplar 1
Cherry	8.22	0.5%	Tolerant Hardwoods 1
Sum	**1,648.16**		
Misc	89.05	5.1%	Poplar 2
Total	**1,737.21**		

Deciduous swamp

Leading Species	Area (ha)	%	Yield curve (assumed)
Maple	100.58	32.2%	Tolerant Hardwoods 2
Poplar	109.44	35.0%	Poplar 2
Ash	42.45	13.6%	Tolerant Hardwoods 2
Birch	22.69	7.3%	White Birch 2
Elm	16.99	5.4%	Tolerant Hardwoods 2
Willow	18.19	5.8%	Poplar 2
Sum	**310.34**		
Misc	2.06	0.7%	Poplar 2
Total	**312.40**		

Mixed forest

Leading Species	Area (ha)	%	Yield curve (assumed)
Maple	111.52	50.4%	Tolerant Hardwoods 1
Ash	12.02	5.4%	Tolerant Hardwoods 1
Cherry	9.51	4.3%	Tolerant Hardwoods 1
Cedar	42.58	19.2%	Black Spruce 1
Hemlock	14.30	6.5%	Black Spruce 1
Sum	**189.93**		
Misc	31.44	14.2%	Poplar 2
Total	**221.37**		

Mixed swamp

Leading Species	Area (ha)	%	Yield curve (assumed)
Maple	43.43	13.5%	Tolerant Hardwoods 2
Poplar	73.26	22.7%	Poplar 2
Ash	39.97	12.4%	Tolerant Hardwoods 2
W. Birch	35.97	11.2%	White Birch 2
Elm	18.56	5.8%	Tolerant Hardwoods 2
Y Birch	21.01	6.5%	White Birch 2
Cedar	48.47	15.0%	Black Spruce 2
Balsam fir	25.98	8.1%	Black Spruce 2
Sum	**306.65**		
Misc	15.42	4.8%	Poplar 2
Total	**322.07**		

Cultural woodland

Leading Species	Area (ha)	%	Yield curve (assumed)
Cherry	8.47	8.2%	Tolerant Hardwoods 1
Elm	24.19	23.4%	Tolerant Hardwoods 1
maple	17.13	16.5%	Tolerant Hardwoods 1
Aspen	6.26	6.0%	Poplar 1
ash	4.41	4.3%	Tolerant Hardwoods 1
walnut	4.94	4.8%	Tolerant Hardwoods 1
Thuja occidentalis	7.73	7.5%	Black Spruce 1
white/red pine	9.01	8.7%	White Pine 1
scots pine	6.29	6.1%	Red Pine 1
Sum	**88.43**		
Misc	15.11	14.6%	Poplar 2
Total	**103.54**	**100.0%**	

Table 11: Total number of trees planted by species and associated Plonski yield curve

Species	Plonski Yield Curve	No. Of trees planted		Total
		by private operators	by Boy Scouts	
Pw	White Pine 2	968,058	144,000	1,112,058
Sw	Black Spruce 1	637,775	94,200	731,975
Cw	Black Spruce 2	354,970	94,150	449,120
Sn	Black Spruce 1	346,225	47,850	394,075
Pr	Red Pine Plantations	273,425	27,700	301,125
Unk		119,135	0	119,135
Le	Red Pine 1	108,400	7,700	116,100
Ms	Tolerant Hardwoods 2	101,830	10,200	112,030
Aw	Tolerant Hardwoods 1	88,335	7,000	95,335
Or	Tolerant Hardwoods 2	83,545	8,800	92,345
Ta	Poplar 1	51,500	0	51,500
Ag	Tolerant Hardwoods 2	28,200	1,850	30,050
Po	Poplar 1	26,450	1,800	28,250
Pj	Jack Pine 2	16,850	3,000	19,850
Lb	Tolerant Hardwoods 2	15,625	2,200	17,825
Mr	Tolerant Hardwoods 2	12,300	0	12,300
L Jap	Black Spruce 1	10,200	3,200	13,400
Ps	Jack Pine 2	9,500	5,000	14,500
Wb	Tolerant Hardwoods 2	8,700	700	9,400
M Soft	Tolerant Hardwoods 2	3,050	0	3,050
M	Tolerant Hardwoods 2	1,755	0	1,755
P Aust	Red Pine Plantations	1,300	0	1,300
Sc	Black Spruce 1	1,000	0	1,000
Pc	Jack Pine 2	950	0	950
Olive	Shrubs	650	0	650
Pe	Jack Pine 2	500	0	500
S Col	Black Spruce 1	300	0	300
Bw	White Birch 1	200	0	200
Ash	Tolerant Hardwoods 2	100	0	100
Sumac	Shrubs	100	0	100
Chestnt	Tolerant Hardwoods 2	50	0	50
A Mount	Shrubs	5	0	5
Total		**3,270,983**	**459,350**	**3,730,333**

Table 12: Existing and future planting distribution by year and yield curve

Year	Black Spruce 1	Black Spruce 2	Jack Pine 2	Red Pine 1	Red Pine Plantations	Poplar 1	Tolerant Hardwoods 1	Tolerant Hardwoods 2	White Birch 1	White Pine 1	White Pine 2	Shrubs	Total
1935	0.0	0.0	0.0	0.0	134.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**134.4**
1936	0.0	0.0	0.0	0.0	134.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**134.4**
1937	0.0	0.0	0.0	0.0	134.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**134.4**
1938	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1939	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1940	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1941	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1942	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1943	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1944	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1945	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1946	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1947	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1948	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1949	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1950	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1951	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1952	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1953	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1954	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1955	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1956	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1957	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1958	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1959	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
1960	20.6	3.2	0.6	2.1	5.5	1.4	1.7	5.0	0.0	0.0	20.1	0.0	**60.3**
1961	20.6	3.2	0.6	2.1	5.5	1.4	1.7	5.0	0.0	0.0	20.1	0.0	**60.3**
1962	20.6	3.2	0.6	2.1	5.5	1.4	1.7	5.0	0.0	0.0	20.1	0.0	**60.3**
1963	20.6	3.2	0.6	2.1	5.5	1.4	1.7	5.0	0.0	0.0	20.1	0.0	**60.3**
1964	20.6	3.2	0.6	2.1	5.5	1.4	1.7	5.0	0.0	0.0	20.1	0.0	**60.3**
1965	20.6	3.2	0.6	2.1	5.5	1.4	1.7	5.0	0.0	0.0	20.1	0.0	**60.3**
1966	20.6	3.2	0.6	2.1	5.5	1.4	1.7	5.0	0.0	0.0	20.1	0.0	**60.3**
1967	20.6	3.2	0.6	2.1	5.5	1.4	1.7	5.0	0.0	0.0	20.1	0.0	**60.3**
1968	20.6	3.2	0.6	2.1	5.5	1.4	1.7	5.0	0.0	0.0	20.1	0.0	**60.3**
1969	20.6	3.2	0.6	2.1	5.5	1.4	1.7	5.0	0.0	0.0	20.1	0.0	**60.3**
1970	20.6	3.2	0.6	2.1	5.5	1.4	1.7	5.0	0.0	0.0	20.1	0.0	**60.3**
1971	0.5	0.1	0.0	0.1	0.1	0.0	0.0	0.1	0.0	0.0	0.5	0.0	**1.6**
1972	19.9	3.1	0.6	2.0	5.3	1.4	1.7	4.9	0.0	0.0	19.4	0.0	**58.3**
1973	24.2	3.7	0.8	2.5	6.4	1.7	2.0	5.9	0.0	0.0	23.5	0.0	**70.7**
1974	20.7	3.2	0.6	2.1	5.5	1.5	1.7	5.1	0.0	0.0	20.2	0.0	**60.6**
1975	26.5	4.1	0.8	2.7	7.0	1.9	2.2	6.5	0.0	0.0	25.8	0.0	**77.6**
1976	14.6	2.2	0.5	1.5	3.9	1.0	1.2	3.6	0.0	0.0	14.2	0.0	**42.7**
1977	8.8	1.4	0.3	0.9	2.3	0.6	0.7	2.1	0.0	0.0	8.5	0.0	**25.6**
1978	9.8	1.5	0.3	1.0	2.6	0.7	0.8	2.4	0.0	0.0	9.5	0.0	**28.6**
1979	16.9	2.6	0.5	1.7	4.5	1.2	1.4	4.1	0.0	0.0	16.5	0.0	**49.5**
1980	17.5	2.7	0.5	1.8	4.7	1.2	1.5	4.3	0.0	0.0	17.1	0.0	**51.4**
1981	16.9	2.6	0.5	1.7	4.5	1.2	1.4	4.1	0.0	0.0	16.5	0.0	**49.5**
1982	20.1	3.1	0.6	2.1	5.3	1.4	1.7	4.9	0.0	0.0	19.6	0.0	**58.9**
1983	23.2	3.6	0.7	2.4	6.2	1.6	1.9	5.7	0.0	0.0	22.6	0.0	**67.9**
1984	29.0	4.5	0.9	3.0	7.7	2.0	2.4	7.1	0.0	0.0	28.3	0.0	**85.0**
1985	27.5	4.2	0.9	2.8	7.3	1.9	2.3	6.7	0.0	0.0	26.8	0.0	**80.6**
1986	20.4	3.2	0.6	2.1	5.4	1.4	1.7	5.0	0.0	0.0	19.9	0.0	**59.8**
1987	33.4	5.2	1.0	3.4	8.9	2.3	2.8	8.2	0.0	0.0	32.6	0.0	**97.8**
1988	31.1	4.8	1.0	3.2	8.3	2.2	2.6	7.6	0.0	0.0	30.3	0.0	**91.1**
1989	30.5	4.7	1.0	3.1	8.1	2.1	2.6	7.5	0.0	0.0	29.7	0.0	**89.3**
1990	26.0	4.0	0.8	2.6	6.9	1.8	2.2	6.4	0.0	0.0	25.3	0.0	**76.0**
1991	37.4	5.8	1.2	3.8	9.9	2.6	3.1	9.2	0.0	0.0	36.4	0.0	**109.5**
1992	37.9	5.9	1.2	3.9	10.1	2.7	3.2	9.3	0.0	0.0	37.0	0.0	**111.0**
1993	22.4	3.5	0.7	2.3	6.0	1.6	1.9	5.5	0.0	0.0	21.9	0.0	**65.7**
1994	15.1	2.3	0.5	1.5	4.0	1.1	1.3	3.7	0.0	0.0	14.8	0.0	**44.3**
1995	11.4	1.8	0.4	1.2	3.0	0.8	1.0	2.8	0.0	0.0	11.1	0.0	**33.4**
1996	8.1	1.3	0.3	0.8	2.2	0.6	0.7	2.0	0.0	0.0	7.9	0.0	**23.9**
1997	4.5	0.7	0.1	0.5	1.2	0.3	0.4	1.1	0.0	0.0	4.4	0.0	**13.3**
1998	2.1	0.3	0.1	0.2	0.6	0.1	0.2	0.5	0.0	0.0	2.1	0.0	**6.2**
1999	0.5	0.1	0.0	0.0	0.1	0.0	0.0	0.1	0.0	0.0	0.5	0.0	**1.4**
2000	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**0.0**
2001	6.6	1.0	0.2	0.7	1.7	0.5	0.6	1.6	0.0	0.0	6.4	0.0	**19.3**
2002	3.6	0.5	0.1	0.4	0.9	0.2	0.3	0.9	0.0	0.0	3.5	0.0	**10.4**
2003	4.4	0.7	0.1	0.5	1.2	0.3	0.4	1.1	0.0	0.0	4.3	0.0	**12.9**
2004	2.8	0.4	0.1	0.3	0.8	0.2	0.2	0.7	0.0	0.0	2.8	0.0	**8.3**
2005	7.0	0.9	0.2	0.7	1.8	0.5	0.6	1.7	0.0	0.0	6.8	0.0	**20.2**
2006	1.6	0.2	0.0	0.2	0.4	0.1	0.1	0.4	0.0	0.0	1.5	0.0	**4.5**
2007	7.1	0.9	0.2	0.7	1.9	0.5	0.6	1.7	0.0	0.0	6.9	0.0	**20.5**
2008	13.7	1.8	0.4	1.4	3.6	1.0	1.1	3.4	0.0	0.0	13.3	0.0	**39.7**
2009	19.1	2.2	0.6	1.9	5.1	1.3	1.6	4.7	0.0	18.6	0.0	2.0	**57.2**
2010	19.1	2.2	0.6	1.9	5.1	1.3	1.6	4.7	0.0	18.6	0.0	2.0	**57.2**
2011	19.1	2.2	0.6	1.9	5.1	1.3	1.6	4.7	0.0	18.6	0.0	2.0	**57.2**
2012	19.1	2.2	0.6	1.9	5.1	1.3	1.6	4.7	0.0	18.6	0.0	2.0	**57.2**
2013	19.1	2.2	0.6	1.9	5.1	1.3	1.6	4.7	0.0	18.6	0.0	2.0	**57.2**
2014	19.1	2.2	0.6	1.9	5.1	1.3	1.6	4.7	0.0	18.6	0.0	2.0	**57.2**
2015	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2016	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2017	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2018	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2019	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2020	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2021	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2022	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2023	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2024	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2025	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2026	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2027	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2028	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2029	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2030	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2031	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
2032	30.6	3.6	1.0	3.1	8.1	2.1	2.6	7.5	0.0	29.8	0.0	3.2	**91.5**
Total	**1,495.7**	**205.3**	**46.8**	**152.4**	**800.1**	**104.8**	**125.1**	**366.0**	**0.3**	**648.4**	**809.6**	**70.5**	**4,825.0**

APPENDIX C
GLOSSARY

Additionality: A carbon project is additional if the reduction in carbon emissions would not have occurred without carbon funding. Additionality is established when there is a positive difference between the emissions that occur in the baseline scenario, and the emissions that occur in the proposed project. Only the additional net emission reductions can be sold as offsets.

Afforestation: The process of establishing and growing forests on bare or cultivated land, which has not been forested in recent history. The Kyoto Protocol defines afforestation as a land-use change from non-forest to forest on land that has been non-forest for more than 50 years. In the context of a carbon project, afforestation must be undertaken by planting or seeding.

Baseline: The emission of greenhouse gases that would occur without the contemplated carbon policy intervention or carbon project activity.

Biomass Fuel: Combustible fuel composed of a biological material, for example, wood or wood by-products, rice husks, or cow dung.

Carbon Asset: The potential of greenhouse gas emission reductions that a project is able to generate and sell.

Carbon Finance: Resources provided to projects generating (or expected to generate) greenhouse gas (or carbon) emission reductions in the form of the purchase of such emission reductions.

Carbon Dioxide Equivalent (CO_2e): The universal unit of measurement used to indicate the global warming potential of each of the six greenhouse gases. Carbon dioxide— a naturally occurring gas that is a byproduct of burning fossil fuels and biomass, land-use changes, and other industrial processes— is the reference gas against which the other greenhouse gases are measured. A tonne of CO_2e is a quantity of any greenhouse gas which has the same warming effect as a tonne of CO_2. The warming potential of one tonne of methane is considered to be equivalent to 72 tonnes of CO_2 over a 20 year period and equivalent to 25 tonnes of CO_2 over a 100 year period (methane is removed more quickly from the atmosphere than CO_2). The standard reference period is 100 years, and so 0.04 tonnes of methane = 1 tonne CO_2e. Note that one tonne of carbon is equivalent to 44/12 or 3.667 tonnes of CO_2.

Carbon Standard: A set of procedures developed for a specific class of carbon projects, that sets out the scope of eligible projects, the manner in which baselines, additionality, and permanence can be addressed, as well as the methods for calculating the carbon offsets that may be created by the project. The Alberta Offset System has an Afforestation Project Protocol, and the California Action Reserve has a Forest Project Protocol, for example.

Net Emission Reductions: A reduction in atmospheric greenhouse gas concentration by removing GHGs from the atmosphere, through a process such as tree growth. Measured in metric tons of carbon dioxide equivalent.

Clean Development Mechanism (CDM): The mechanism provided by Article 12 of the Kyoto Protocol, designed to assist developing countries in achieving sustainable development by permitting industrialized countries to finance projects for reducing greenhouse gas emission in developing countries and receive credit for doing so.

Emission Reduction: The measurable reduction of release of greenhouse gases into the atmosphere from a specified activity or over a specified area, and a specified period of time. Expressed in metric tons of carbon dioxide equivalent.

Greenhouse gases (GHGs): These are the gases released by human activity that are responsible for climate change and global warming. The six greenhouse gases listed in Annex A of the Kyoto Protocol are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), as well as hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6).

Kyoto Protocol: Adopted at the Third Conference of the Parties to the United Nations Convention on Climate Change held in Kyoto, Japan in December 1997, the Kyoto Protocol commits industrialized country signatories to reduce their greenhouse gas (or “carbon”) emissions by an average of 5.2% compared with 1990 emissions, in the period 2008-2012.

Leakage: A carbon project suffers from leakage if it increases carbon emissions elsewhere. For example, closing down a factory may cause a competing factory to ramp up production.

Monitoring Plan (MP): A set of requirements for monitoring and verification of emission reductions achieved by a project.

Natural Ingress: The succession of fields to forest, generally as a result of tree seed blowing or being brought by other natural forces onto the field, germinating, and growing to become a tree.

Project-Based Emission Reductions: Emission reductions that occur from projects pursuant to JI or CDM (as opposed to “emissions trading” or transfer of assigned amount units under Article 17 of the Kyoto Protocol).

Project Design Document (PDD): A project specific document required under the CDM rules which will enable the Operational Entity to determine whether the project (i) has been approved by the parties involved in a project, (ii) would result in reductions of greenhouse gas emissions that are additional, (iii) has an appropriate baseline and monitoring plan.

Reforestation: This process increases the capacity of the land to sequester carbon by replanting forest biomass in areas where forests have been previously harvested. Registration: The formal acceptance by the CDM Executive Board of a validated project as a CDM project activity.

Sequestration: Sequestration refers to capture of carbon dioxide in a manner that prevents it from being released into the atmosphere for a specified period of time.

Growing forests sequester carbon through the process of photosynthesis and the annual growth of woody biomass.

United Nations Framework Convention on Climate Change (UNFCCC): The international legal framework adopted in June 1992 at the Rio Earth Summit to address climate change. It commits the Parties to the UNFCCC to stabilize human induced greenhouse gas emissions at levels that would prevent dangerous manmade interference with the climate system.

Validation: The assessment of a project's Project Design Document, which describes its design, including its baseline and monitoring plan, by an independent third party, before the implementation of the project against the requirements of the CDM.

Verified Emission Reductions (VERs): A unit of greenhouse gas emission reductions that has been verified by an independent auditor.

Verification Report: A report prepared by an Operational Entity, or by another independent third party, pursuant to a Verification, which reports the findings of the Verification process, including the amount of reductions in emission of greenhouse gases that have been found to have been generated.

Voluntary carbon offset: A carbon credit purchased by a concerned individual, business or other organization out of choice, not as a result of regulation.

Voluntary Carbon Standard: A certification standard for carbon offsets which covers the basic requirements needed for a project to be valid.

Primary source: World Bank Carbon Finance
http://wbcarbonfinance.org/Router.cfm?Page=Glossary&ItemID=24686

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