Peace River Site C Hydro Project

Stage 2

Baseline Greenhouse Gas Emissions Report

Prepared for BC Hydro Site C Project by

Jacques Whitford AXYS

May, 2009

PEACE RIVER SITE C HYDRO PROJECT

STAGE 2

BASELINE Greenhouse Gas Emissions REPORT

Prepared for BC Hydro Site C Project by
Jacques Whitford AXYS
May, 2009

Lead Author: Michael Murphy, PhD, PEng

Contributors: Jean-Michel DeVink, PhD

(by section) Karen Gillam, MSc

Joe Harriman, PhD

May 2009

Printed copies not controlled

May 2009

Printed copies not controlled

EXECUTIVE SUMMARY

BC Hydro commissioned Jacques Whitford Axys Limited to conduct a GHG Emissions Study of the proposed Site C Hydroelectric Generation Project to be located on the Peace River, B.C.

Estimates of GHG emissions were made for the construction phase, and for the area of the hydroelectric dam, both prior to and after flooding. Construction emissions were quantified by converting fuel and electricity consumption to the corresponding GHG emissions. The three primary GHGs considered in the Study are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). The Study Area for the analysis extended 30 m beyond the maximum flood level of the reservoir for the dam.

Three separate methods of analysis were used to model and evaluate GHG emissions at Site C following methods described by the Intergovernmental Panel on Climate Change (IPCC 2003). The first two IPCC methods used simple calculations to estimate emission rates from land flooding only (Tier 1) or land flooding and degassing at turbines and spillways (Tier 2). The third method (Tier 3) involved developing a more detailed carbon model to account for all substantive carbon stocks, processes and fluxes relevant to the Project. Emissions from facility construction and equipment use for land-clearing activities were also estimated.

The estimates of GHG emissions using the Tier 1 and Tier 2 calculations are 89,800 and 64,284 tonnes CO_2e/yr, respectively. Using detailed Tier 3 methods, emissions from the Study Area for current conditions (existing prior to dam construction) were approximately 4,900 tonnes CO_2e/yr, despite being a net sink for carbon. This is mainly a result of agricultural activities in the area (crop production and livestock) producing CH_4 and N_2O emissions.

Using the Tier 3 model for post-inundation, GHG emissions were estimated under two different scenarios: firstly, a conservative scenario with ultra conservative default settings; and secondly, a probable scenario with assumptions that were less conservative and more probable for three key parameters (*i.e.*, biomass burial, sedimentation rate, and merchantable fraction). Under the conservative scenario, GHG emissions from the reservoir were two orders of magnitude higher than for current conditions during the initial period after impoundment. These decrease rapidly in time. Thirty-five years post-inundation, the reservoir emissions were approximately the same as for current conditions. With GHG emissions from construction activities and fuel combustion from land use changes included, the average annual net Project GHG emissions would be approximately 43,000 tonnes CO_2e/yr. Under the probable emissions, the average annual net project emissions would be approximately 32,000 tonnes CO_2e/yr. These emissions are very small compared with overall global anthropogenic emissions of 5.5 to 6.3 billion tonnes CO_2e/yr.

Expressing the GHG emissions on an energy basis (g CO_2e/kWh), allows for comparison with other types of generating facilities. Averaged over a 100-year operational lifespan, the net emissions intensity from Site C would be approximately 10 g CO_2e/kWh under the default scenario, with values ranging from 142 in the first year to 1 in years 35 to 100, and 7 g CO_2e/kWh under the probable scenario, with values ranging from 108 to 0. These emissions are low when compared to life-cycle emission estimates for various fossil fuel generating options, such as modern coal plants (1,000 g CO_2e/kWh), diesel (717 g CO_2e/kWh), or natural gas (545 g CO_2e/kWh), and when compared to other Canadian boreal hydroelectric stations (8 to 60 g CO_2e/kWh).

These low relative emissions are largely due to Site C being a run-of-river type facility, which does not require a large reservoir and does not flood a large area of land, compared with a more traditional reservoir type of facility.

List of Acronyms/Units

Acronym/Unit	Definition
%	A mathematical symbol meaning percent.
<	A mathematical symbol meaning less than.
>	A mathematical symbol meaning greater than.
≤	A mathematical symbol representing less than or equal to.
≥	A mathematical symbol representing greater than or equal to.
°C	Degrees Celsius; a measurement of temperature.
µm	Micromoles; a measurement of amount of substance.
AGB	Above- .ground biomass
asl	above sea level
BGB	below ground biomass
C	A chemical symbol for carbon.
Ca	A chemical symbol for calcium.
$CaCO_3$	A chemical symbol for calcium carbonate.
CDOX1	Release of CO_2 from soil to the atmosphere.
CDOX2	Exchange of carbon between terrestrial plants and the atmosphere.
CDOX3	Exchange of CO_2 from lakes and rivers to the atmosphere.
CDOX4	Exchange of CO_2 between wetlands and the atmosphere.
CDOX5	Exchange of CO_2 between the atmosphere and the surface layer of the ocean.

Acronym/Unit	Definition
CDOX6	Release of geologically stored carbon into the atmosphere.
CH_4	A chemical symbol for methane.
$CH_4/m^2/day$	Square metres per day of methane.
CO_2	A chemical symbol meaning carbon dioxide.
$CO_2/m^2/day$	Square metres per day of carbon dioxide.
CO_2e	A chemical symbol meaning carbon dioxide equivalent.
CO_2e/year	Carbon dioxide equivalent per year.
d	Day; a measurement of time.
DIC	dissolved inorganic carbon
DOC	dissolved organic carbon
DOC1	The flux of dissolved organic carbon released from the terrestrial environment to rivers and lakes.
DOC2	The flux of dissolved organic carbon released from wetlands and the groundwater associated with wetland processes to rivers and lakes.
e.g.,	for example
ELC	Ecological Land Classification.
EOSD	Earth Observation for Sustainable Development.
et al.	and others
fsl	full supply level
g	Grams; a measurement of mass.
g C	grams of carbon

Acronym/Unit	Definition
g C/m/yr	Grams of carbon per square meter per year.
g/m^3	Grams per cubic meter.
g CO_2e	Grams of carbon dioxide equivalent.
GeoCarb	Geologically stored carbon stock.
GHG	An acronym meaning greenhouse gas.
GIS	An abbreviation meaning Geographic Information System.
GWh	Giga watt-hour, a unit of energy.
H	A chemical symbol for hydrogen.
H_2O	A chemical symbol meaning water.
Ha	Hectares; a measurement of area equalling 10,000 m^2.
i.e.,	that is to say, in other words
IPCC	Intergovernmental Panel on Climate Change.
kg	Kilograms; a measurement of mass.
kg C/ha	Kilograms of carbon per hectare.
$kg/m^2/yr$	Kilogram per square meter per year.
kg/yr	Kilograms per year.
km	Kilometres; a measurement of distance.
km^2	Kilometres squared, a measurement of area.
kV	Kilovolt
kWh	Kilowatt-hours; a unit of energy.

Acronym/Unit	Definition
L	Litres; a measurement of volume.
lsl	low supply level
m	Metres; a measurement of distance.
m^2	Metres squared; a measurement of area.
m^3	Metres cubed; a measurement of volume.
MDBD	Mud deposition boundary depth.
METH1	The emission of CH_4 from vertebrates to the atmosphere.
METH2	The emission of CH_4 from wetlands to the atmosphere.
METH3	The emission of CH_4 from lakes and rivers to the atmosphere.
METH4	The emission of CH_4 from terrestrial soils to the atmosphere.
METH5	The emission of CH_4 from surface ocean water to the atmosphere
mg	Milligrams; a measurement of mass equalling one thousandth of a gram.
Mg	A chemical symbol for magnesium.
mg/L	Milligrams per litre; a measurement of concentration.
MW	Megawatt; a unit of energy.
N_2O	A chemical symbol for nitrous oxide; a greenhouse gas.
NEP	Net Ecosystem Productivity
PCARB1	Exchange of carbon from terrestrial plants to soil.
PCARB2	Exchange of carbon from terrestrial plants to aquatic ecosystems.
Pg C	A unit of measure indicating 10^{15} grams of carbon or 10^9 metric tones.

Acronym/Unit	Definition
pH	A measurement of acidity of a solution.
POC	particulate organic carbon
ppm	parts per million
RDL	Reportable levels of detection.
s	Seconds; a measurement of time.
SED1	The exchange of organic and inorganic carbon between the water column and the sediments of lakes and rivers.
SED2	The exchange of organic and inorganic carbon between the water column and the shallow-water sediments of the oceans.
SED3	The exchange of organic and inorganic carbon between the water column and the deep-water sediments of the oceans.
Site C	Site C Hydroelectric Generation Project
t.	metric tonne
TEM	Terrestrial ecosystem mapping.
Tonnes C/yr	Tonnes of carbon per year.
TSS	total suspended sediment
WEATH	Weathering reactions that are a sink for CO_2 and release cations from soil or bedrock.
yr	Year; a measurement of time equalling 365 days.

Glossary

Term	Definition
Anaerobic	In the absence of oxygen.
Anthropogenic	Caused by human activity.
Aquatic habitat	Water environment in which an organism normally lives or occurs.
Atmosphere	The layer of air covering the Earth's surface.
BC Hydro	BC Hydro and Power Authority
Biomass	Dry weight of organic matter (*i.e.*, plants and animals) in an ecosystem.
Biomass burial	Results from the burial of non-decomposed biomass due sedimentation and shoreline erosion. Buried biomass represents organic matter that may cease to mineralize and may become permanently stored in the sediment.
Biosphere	The region of Earth (air, land, surface rocks, and water) where living organisms exist and biological processes occur.
Boreal climate	The climatic zone of northern temperate areas, having a subarctic climate characterized by long, usually very cold winters, and brief, warm summers.
Boreal reservoir	Water held above a hydroelectric dam in a boreal climate.
Bubble Emissions	Escape of CH_4 from the sediment, through the water column, to the atmosphere, as rising gas bubbles.
Carbon flux	The transfer of carbon from one carbon pool to another.
Carbon model	A model developed to analyze the movement of carbon in a natural system. This includes a detailed account for all carbon sources, pathways and fluxes.
Carbon neutral	Refer to a company with a zero carbon footprint after carbon emissions trading has been taken into account.
Carbon pathway	A path indicating the flow of carbon from one source to another.
Carbon sequestration	The removal and storage of carbon from the atmosphere into carbon sinks through physical or biological processes, such as photosynthesis.

Term	Definition
Carbon sink	A place where carbon, in some form, may be stored, usually as either underground as a liquid or bound biologically in vegetation or soils.
Carbon sink	Something (*i.e.,* body of water) that has net absorption of carbon dioxide from the atmosphere.
Carbon source	Opposite of a carbon sink; it is a carbon pool that is a source for atmospheric.
Carbon stock	The quantity of carbon held within a pool at a specified time.
Climate	Climate is the average of the variations of weather in a region over long periods of time.
Climate change	Climate change is the long term trends in the climate in a region over long periods of time.
Combustion	A chemical reaction during which a fuel is oxidized and a large quantity of energy is released.
Concentration	A measure of a substance in air, water, soil or living tissue (the medium), expressed as a mass of substance per volume of medium.
Concentration	Amount of a material per unit volume.
Degassing Emissions	Emissions of CO_2, CH_4 and N_2O resulting from a sudden change in hydrostatic pressure, as well as the increased air/water exchange surface after reservoir waters flow through a turbine and/or a spillway (bearing in mind that the natural aquatic system may have included waterfalls or rapids where similar processes took place prior to inundation).
Diffusive Emissions	Molecular diffusion of CO_2, CH_4 and N_2O across the air-water interface, taking into consideration that post-inundation concentrations of CO_2, CH_4 and N_2O in reservoir may be elevated in comparison with pre-inundation concentrations of these gases in the natural aquatic system, and that the post-inundation surface area is larger than the pre-inundation surface area.
Dissolved inorganic carbon (DIC)	Inorganic carbon of various origins (*i.e.* leached from soil) dissolved in a given volume of water.
Dissolved organic carbon (DOC)	Organic carbon of various origins (*i.e.* leached from soil) dissolved in a given volume of water.

Term	Definition
Drawdown	Refers to the lowering of the water level in a man-made reservoir.
Ecosystem	The compilation of living and non-living mechanisms and processes that make up any part of the living world. Fundamentals of an ecosystem include plants, animals, water and soil.
Emission	Release of a contaminant into the environment, typically the air or water.
Emission Flux	Emission rate (mass per time) per unit area.
Environmental Impact Assessment	Environmental Impact Assessment (EIA) is a formal process used to Predict potential environmental consequences of any development or project. EIA thus ensures that the possible issues are foreseen and addressed at an early stage in the projects planning and design.
Eutrophic	Opposite of oligotrophic, refers to a body of water which is excessively rich in dissolved nutrients and normally poor in dissolved oxygen.
Forage	All herbaceous plant parts that are available to animals for feeding, specifically grazing livestock.
Fossil fuel	Fuel formed in the earth's crust over millions of years from remains of living organisms (*e.g.* oil, coal, natural gas or their by-products).
Gas	One of the four major states of matter. Consists of freely moving atoms or molecules without a defined shape or volume.
Geologically Stored Carbon	Carbon dioxide stored in geological formations.
Global carbon cycle	Biogeochemical cycling of carbon exchanged among the biosphere, pedosphere, geosphere, hydrosphere, and atmosphere of the Earth.
Global warming	Heating of the earth caused by the trapping and absorbing heat in the form of infrared radiation due to increasing concentrations of GHG in the atmosphere.
Global warming potential (GWP)	A measure of how much a given mass of greenhouse gas is estimated to contribute to global warming.
Greenhouse effect	Trapping of heat energy in the form of infrared radiation (see Global Warming).

Term	Definition
Holocene period	The period of time since the last glaciations, approximately 10,000 years ago, characterized by the development of human civilizations.
Hydroelectric	Electricity created by channelling water through turbines in power stations located below dams.
Intergovernmental Panel on Climate Change	The Intergovernmental Panel on Climate Change (IPCC) is a scientific body, established in 1988 by the World Meteorological Organization and the United Nations Environment Program, tasked to evaluate the risk of climate change caused by human activity. It regularly publishes reports which assess the latest scientific, technical and socio-economic evidence on climate change.
Infrared radiation	Electromagnetic radiation responsible for radiant heat.
Inundation	The act of covering land with water.
Large Ruminants	Large hoofed mammals (*i.e.,* cattle, buffalo and deer) with compartmentalized stomachs.
Littoral zone	Relating to or existing on the shore of a water body.
Luvisols	A characteristic soil of forested regions identified by the presence of eluvial (Ae) horizons and illuvial (Bt) horizons where silicate clay is accumulated.
Methanogenesis	The biological production of CH_4 by anaerobic bacteria.
Methylation	The attachment or substitution of a methyl group on various substrates.
Microbial oxidation reactions	The oxidation of sugars into carbon dioxide and water induced by a microscopic organism.
Mitigation	The elimination, reduction or control of the adverse environmental effects of a project. This includes restitution of any damages to the environment caused by a project though replacement, restoration, compensation or other means.
Mitigation	To decrease, lessen or reduce.
Model Calibration Process	Process by which selected model parameters are varied either simultaneously or sequentially to determine the appropriate parameter value to achieve a particular pre-determined model outcome.

Term	Definition
Molecular diffusion coefficient	Value used to define the transport of molecules from a region of higher concentration to one of lower concentration.
Mud deposition boundary depth	The depth in lakes at which the boundary occurs between high-energy erosive environments (coarse-grained non-cohesive sediments) and low-energy depositional zones where fine-grained cohesive sediments accumulate.
Near-surface duff layer	Organic matter, at various stages of decomposition, loosely compacted just beneath the litter layer on the forest floor.
Net emissions	Measure of a projects total greenhouse gas emissions after having accounted for existing emissions.
Nitrogen fixation	Conversion of atmospheric nitrogen to plant compounds by micro organisms.
Nitrous oxide	A greenhouse gas mainly resulting from the combustion of fuels and the manufacture of nitrogen fertilizers.
Oligotrophic	Refers to a body of water which is poor in dissolved nutrients and rich in dissolved oxygen.
Ombrotrophic	Refers to soil and/or vegetation which receive all of their water and nutrients from precipitation, rather than from streams and springs.
Open Coniferous Forest	Largely continuous forest canopy (*i.e.,* approximately 26 to 60 percent crown closure) composed at least 80 percent of coniferous species.
Open Deciduous Forest	Largely continuous forest canopy (*i.e.,* approximately 26 to 60 percent crown closure) composed at least 80 percent of deciduous species.
Open Mixed Forest	Largely continuous forest canopy (*i.e.,* approximately 26 to 60 percent crown closure) composed of approximately equal percentages of coniferous and deciduous species.
Organic horizon	Referring to a soil horizon (soil material approximately parallel to the land surface which differs from adjacent layers, differing in properties such as color, structure, texture), it is a soil layer found in organic soils and commonly at the surface of mineral soils. Organic horizons typically contain > 15% organic C (approximately 30% organic matter) by weight.

Term	Definition
Particulate organic carbon	Suspended organic particulate which influences a water bodies chemistry.
Peat	Partially decomposed plants and other organic materials that build up in poorly drained wetland habitats.
Photosynthesis	A biological process in which plants convert sunlight into food energy (*e.g.* sugars) using carbon dioxide and with the aid of water and sunlight.
Plant respiration	A biochemical process in plants where certain substrates are oxidized leading to a release of carbon dioxide.
Powerhouse	Building that typically houses electric generating equipment.
Precambrian Shield	The oldest, most stable regions of the earth's crust, the largest being the Canadian Shield.
Pre-industrial (period)	Pre-industrial society refers to specific social attributes and forms of political and cultural organization that were prevalent before the advent of the Industrial Revolution (late 18^{th} and early 19^{th} centuries) and the rise of Capitalism.
Q10 effect	The ratio of the rate of biochemical reaction between two identical systems having temperature differences of 10 degrees. A ratio of 1 would indicate no effect of temperature. Typical ratios for biological processes fall between 2 and 4, with 2 being a normal default value.
Reservoir	The water held above a hydroelectric dam.
Reservoir	An impounded body of water.
River Flow	The carbon pathway represents the sum of the DOC and POC of aquatic, terrestrial or wetland origin) and inorganic (dissolved CO_2, bicarbonates, and carbonates) carbon that flows from rivers and lakes into the Ocean stock.
Ruminant	Animals having four stomach compartments for food digestion including the rumen, reticulum, omasum and abomasums.
Sediment	Material consisting of small particles (such as sand or mud), which are suspended in or settle to the bottom of a liquid. Sediment input into a water body comes from natural sources (such as erosion of soils or rock), or as a result of anthropogenic activities (such as forestry, agriculture or construction activities). Certain types of contaminants will collect on and adhere to sediment particles.

Term	Definition
Sediment	Any particulate matter (*i.e.,* soil and organic matter) that can be transported and eventually deposited as a layer of solid particles on the bottom of a body of water.
Sedimentation	The act of depositing sediment.
Senescence	The biological processes of a living organism approaching an advanced age
Sequester	To capture or store a chemical, in this case, referring to carbon emissions (see carbon storage).
Sinking and Mixing	The carbon pathway involving the circulation of water containing POC, DOC and DIC between the surface and deep ocean stocks.
Sparse Deciduous Forest	Patchy or sparse forest canopy (*i.e.,* approximately 10 to 25 percent crown closure) composed approximately 80 percent of deciduous species.
Sparse Mixed Forest	Patchy or sparse forest canopy (*i.e.,* approximately 10 to 25 percent crown closure) composed of approximately equal percentages of coniferous and deciduous species.
Spillway	Overflow structure of a dam.
Stagnant boundary film thickness	The thickness of an inactive or motionless boundary layer of two fluids.
Switchgear facility	Houses equipment used in association with the electric power system, or grid; which refers to the combination of electrical disconnects, fuses and/or circuit breakers used to isolate electrical equipment.
Temperate climate	The climatic zone of the “middle” latitudes, that is neither extremely cold nor extremely hot.
Terrestrial habitat	Soil/land environment in which an organism normally lives or occurs.
Thermal energy	Energy derived from heat.
Total inorganic carbon (TIC)	Sum of all inorganic carbon compounds in a given volume of water.
Total organic carbon (TOC)	Sum of all organic carbon compounds in a given volume of water.

Term	Definition
Tropical climate	The climatic zone of the subtropics, with warm temperatures and meager precipitation.
Tropical reservoir	Water held above a hydroelectric dam in a tropical climate.
Turbine	A machine used for generating mechanical power from the energy in a stream of fluid.
Vertebrate	An animal with a backbone.
Watershed	The entire geographical area drained by a river and its tributaries.
Wetland	An area of land where the water table is at, near or above the surface, or which is saturated for long enough periods of time to promote features such as gleyed soils and water-tolerant vegetation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

The Peace River Site C Hydroelectric Project is a potential third dam and generating station on the Peace River in northeastern BC.

The Site C Greenhouse Gas (GHG) study relates to the potential Site C Project. . Information on the GHG emissions from various Project activities is presented in this report. This includes potential GHG emissions resulting from construction, a detailed model of the global carbon cycle and analyses of the carbon fluxes in the Peace River, as it exists today (pre-dam) and Site C reservoir, with the planned facility in full operation.

1.1 SITE C HYDROELECTRIC GENERATION PROJECT

If built, the Site C Project would include a hydroelectric generating facility at Peace River, and interconnecting transmission lines to the existing BC Hydro grid. The Site C generating station would have a capacity of approximately 900 megawatt (MW), producing an average of 4600 GWh of electricity per year. Design features of the Site C dam are outlined in the Site C Feasibility Review: Stage 1 Completion Report (BC Hydro, December 2007). A summary is provided in Table 1.1a.

Table 1.1a Summary of Design Features of the Site C Dam and Related Facilities

Component	Description	
Dam	Type:	Zoned Earth Embankment
	Height from Riverbed:	60 m
	Crest Length:	1,120 m
	Dam Freeboard:	8.2 m
Reservoir (based on 461.8 m)	Type:	Run-of-River
	Max Normal Op. Level:	461.8 m
	Length:	83 km
	Width:	1-2 km
	Reservoir Surface:	9310 ha
	Water Depth at Dam Storage Volume:	52 m
	Normal Operation:	2310 million m^3; 0.6 m (0 to 1.3 m)
Power Plant	Turbine Number:	Six
	Turbine Type:	Francis - 150 MW each
	Hydraulic Head:	48.4 m
	Total Discharge at Rated Head:	2,118 m^3/s
Diversion Tunnels	Number of Tunnels:	2
	Tunnel Diameter:	9.8 m
	Tunnel #1:	688 m
	Tunnel #2:	790 m
	Discharge Capacity:	2570 m^3/s

Table 1.1a Summary of Design Features of the Site C Dam and Related Facilities

Component	Description	
Spillway	Type: Bays: Elevation of Gate Sills: Spillway Design Flood (SDF): Probable Maximum Flood (PMF):	Gated chute with stilling basin Six 446.5 m 11,700 m^3/s; 461.5 m 20,810 m^3/s inflow; 17,500 m^3/s outflow
Transmission Facilities	Type:	Two 500 kV lines from Site C to Peace Canyon south of the Peace River in place of two existing 138 kV lines

The dam will be an earthfill dam across the river with a spillway, power intake structure, powerhouse, and switchgear facilities on the right bank (downstream view). The reservoir will be 83 km long, raising the water level by 52 m at the dam, and the area of inundated land will be approximately 63 km² at full supply level. The power intake structure adjacent to the spillway would contain a six-unit powerhouse.

The interconnecting transmission lines will consist of:

- two 500 kilovolt (kV) transmission line between Site C and Peace Canyon; and
- a 138 kV loop, connecting to the existing 138 kV transmission lines adjacent to Site C.

The 500 kV transmission lines will each be 76 km long. These transmission lines will be single circuit, three-phase operating at 500 kV, utilizing both guyed and self-supporting towers carrying three bundles of four conductors (BC Hydro, 2003).

Site C would take further advantage of the regulation of the Peace River by the W.A.C. Bennett Dam, generating electricity from water that has already flowed through the G.M. Shrum and Peace Canyon generating stations. Most of the inflow into the Site C reservoir would come from Peace Canyon, but the Halfway River and the Moberly River would also contribute some flows. The Project design as presented in this report is subject to refinement as more detailed engineering information becomes available.

1.2 BACKGROUND INFORMATION

The three main greenhouse gases (GHG) of interest for this project include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Environment Canada, 2006). These gases differ in their ability to trap and store thermal energy, and because CO_2 is the most prominent GHG, comparisons among gases are made in units of CO_2 equivalents (CO_2e). The CO_2e values for CO_2, CH_4 and N_2O, are 1, 21 and 310 when measured on a 100 year global warming potential (International Panel on Climate Change (IPCC), 2006).

The Global GHG emissions resulting from human activities have been rising over the last century. Ice core data show that for thousands of years prior to 1850, the atmospheric CO_2 concentration varied between 260 and 280 ppm, and indicate that natural sources of CO_2 were generally in equilibrium with natural carbon sinks. Since about 1850, the atmospheric CO_2 concentration has risen approximately 35 percent (Houghton, 2007). The Mauna Loa monitoring site in Hawaii is one of the most favourable locations for measuring GHG concentrations in undisturbed air, because possible local influences of vegetation or human activities on atmospheric CO_2 concentrations are minimal. The atmospheric concentration of CO_2 at Mauna Loa has steadily risen year after year since it was first measured in 1958. Fossil fuel combustion and associated emissions is currently the largest single contributor to global anthropogenic CO_2 emissions, at an estimated 7.2 ± 0.3 Pg C/yr (the unit Pg C indicates 10^{15} grams of carbon, or 109 metric tonnes). However, land use change is also an important contributor to the global carbon budget, estimated to be approximately 1.5 ± 0.8 Pg C/yr (Houghton, 2007). It is generally accepted that the rise in GHG emissions, if continued, will lead to global climate change through the "greenhouse effect", whereby infrared radiation emitted from the earth's surface is absorbed and retained as heat by excess GHG in the atmosphere, instead of being radiated to space.

Land use changes, such as land clearing for agriculture, urbanization, or the development of large dams, may change the balance of local or regional GHG storage or emissions. Critics of hydroelectric development (*e.g.,* International Rivers Network (IRN), 2006) have argued that dams and their associated reservoirs are globally important sources of GHG emissions including CO_2 and CH_4. There is a consensus that N_2O emissions from reservoirs are typically very low, relative to CO_2 and CH_4 (IPCC, 2006). For instance, measured diffusive emissions of CO_2 and CH_4 were 20,000 and 5,300 times greater than N_2O emissions from a tropical reservoir (Galy-Lacaux, 1996). Similarly, diffusive CO_2 emissions were 60,000 times greater and CH_4 emissions 2,000 times greater than diffusive N_2O emissions from a boreal reservoir (Hellsten *et al.,* 1996). Since N_2O emissions measured from freshwater reservoirs have been considered negligible, it has been suggested that N_2O emissions need not be included in reservoir induced GHG research (United Nations Educational, Scientific and Cultural Organization (UNESCO) 2006). Although there are few published data on N_2O emissions from flooded lands, it is generally accepted that these emissions are typically low unless the area is under intense agricultural production (IPCC, 2006). Since farming occurs along the Peace River valley, with potential for elevated nitrogen concentrations from the application of agricultural fertilizers, the estimation of N_2O from was added to the Site C GHG emission estimate to account for anthropogenic inputs from agriculture.

Land flooding results in many changes, ranging from the obvious (*e.g.,* conversion of terrestrial habitat to aquatic habitat) to the subtle (*e.g.,* the balance between the creation of new or larger sediment traps where carbon may be stored, and the formation in reservoir sediments of CH_4 which has a stronger potential as a GHG than an equivalent amount of CO_2). The UNESCO (2006) considers CH_4 to be the most important GHG produced by a reservoir, due in part to the high CH_4 emissions measured from tropical reservoirs, and also to the relative potency of CH_4 in comparison with CO_2 as a GHG.

Many factors may influence the emissions of CO_2, CH_4 and N_2O from flooded land. Examples include the age of the reservoir, land-use prior to inundation, climate, and management practices as well as pH, salinity, depth, altitude, available carbon, and the carbon:nitrogen ratio (IPCC, 2006). It is widely understood, for example, that temperature is an important control on the overall magnitude of CH_4 and CO_2 emissions. This is demonstrated by higher GHG emissions from reservoirs situated in tropical climates than in boreal and temperate climates (Duchemin *et al.,* 2002; St. Louis *et al.,* 2000). Tropical reservoirs are 40% of the total global reservoir surface area, but account for 70 and 94 percent of CO_2 and CH_4 emissions from reservoirs respectively. Temperate reservoirs account for the remaining 60% of the surface area, but only 30 and 16 percent of CO_2 and CH_4 emissions from reservoirs respectively (Lima *et al.,* 2007). Average fluxes of CO_2 and CH_4 from five tropical reservoirs were estimated to be 3,500 $mg/m^2/d$ and 300 $mg/m^2/d$, respectively, whereas average fluxes from seventeen temperate reservoirs were estimated to be 1,400 $mg/m^2/d$ and 20 $mg/m^2/d$ for CO_2 and CH_4, respectively (St. Louis *et al.,* 2000). In a similar study, diffusive fluxes from tropical reservoirs averaged 3,625 $mg/m^2/d$ and 31 mg $mg/m^2/d$ for CO_2 and CH_4, respectively; with a mean bubble flux of 190 $mg/m^2/d$ for CH_4 (Duchemin *et al.,* 2002). In comparison, diffusive fluxes from boreal and temperate hydroelectric reservoirs averaged 1,430 mg/m2/d and 16 mg $mg/m^2/d$ for CO_2 and CH_4, respectively; with a mean bubble flux of 0.1 $mg/m^2/d$ for CH_4 (Duchemin *et al.,* 2002).

There is also a key difference between operational carbon emissions from a hydroelectric development, and carbon emissions from an electrical generating station that burns fossil fuels (*i.e.,* coal, natural gas, oil or peat). Whereas a fossil fuel burning generator emits CO_2 that was previously in some form of geological storage, the carbon emissions from a hydroelectric development represent carbon that is already engaged in the cycle between the atmosphere and green plants. The relationships between reservoir carbon emissions and the surrounding watershed (notably carbon that enters the reservoir in the form of terrestrial leaf litter, dissolved organic carbon, and dissolved inorganic carbon), as well as the role that reservoirs may play in increasing the potency of carbon emissions by providing new sites for the formation of methane, will be discussed in this report. A key theme of this report will be to evaluate reservoir emissions of GHG in the context of the whole ecosystem, so that sources, sinks, and

transformations of carbon can be fully evaluated. A new hydroelectric reservoir is a living system that integrates with the surrounding environment – the impacts to carbon cycling and whether the system as a whole is a source or sink for carbon is dependent on a number of factors, which are evaluated and modelled in this report.

The CO_2 measured at reservoir surfaces largely represents a product of the natural carbon cycle. For a relatively short period of time following inundation, the decomposition of vegetation or near-surface soil carbon that was left in the flooded areas can result in high initial fluxes of CO_2 and CH_4. In the case of a newly formed reservoir, there tends to be a peak in emissions during the first two to three years following inundation as flooded vegetation decomposes (UNESCO, 2006). However, after a period of time, a reservoir can reach a steady state that is similar in bacterial abundance and biomass to that of surrounding natural water bodies (Soumis *et al.,* 2005). According to Tremblay *et al.* (2004b), in boreal and semi-arid reservoirs greater than 10 years of age, GHG emissions are similar to those measured from natural lakes. For example, the CO_2 flux measurements from a boreal reservoir in Quebec are similar to those measured from surrounding natural lakes, while measured CH_4 fluxes are only slightly higher relative to natural lakes (Bastien *et al.,* 2007). In British Columbia, mean values for measured CO_2 emissions were approximately 250 (+/- 800) mg CO_2/m^2/day and 500 (+/-650) mg CO_2/m^2/day, for old reservoirs and natural lakes, respectively (Tremblay *et al.,* 2004a). Measured CO_2 emissions ranged from -419 mg CO_2/m^2/day to 2780 mg CO_2/m^2/day (mean of 706 mg CO_2/m^2/day) and -1786 mg CO_2/m^2/day to 3666 mg CO_2/m^2/day (mean of 198 mg CO_2/m^2/day) for natural lakes and reservoirs, respectively (Tremblay *et al.,* 2005). Mean values for measured CH_4 emissions in British Columbia ranged from <0.1 mg CH_4/m^2/day to 33.0 mg CH_4/m^2/day (mean of 11.3 mg CH_4/m^2/day) and -6.8 mg CH_4/m^2/day to 347.7 mg CH_4/m^2/day (mean of 42.1 mg CH_4/m^2/day) for natural lakes and reservoirs, respectively (Tremblay *et al.,* 2005). Overall, British Columbia reservoirs emit less CO_2 and slightly higher CH_4 emissions when compared to other boreal reservoirs of similar age (Tremblay *et al.,* 2005).

Estimating a reasonably representative value of GHG emissions from a project, such as Site C, is challenging. There are several conceptual frameworks, in which calculations are completed at increasing levels of complexity, in order to estimate emissions. IPCC, for example, has developed and published guidelines for estimating GHG emissions from common land use changes, including land flooding due to hydroelectric development. According to the IPCC (1997), there are limitations imposed by the natural variability of the system. More data and improved methods will help reduce uncertainties, but not eliminate them. In this report, CO_2, CH_4 and N_2O emissions are estimated according to best practice methods suggested by the IPCC I (2003) (referred to as “Tier 1” and “Tier 2”). In addition, a more detailed (“Tier 3”), site-specific evaluation of ecosystem carbon cycling in the Study Area has been

undertaken to develop a model to simulate and estimate carbon flows over the lifecycle of the potential Site C Study Area.

1.3 REPORT ORGANIZATION

This report is organized according to the sections outlined in Table 1.3a.

Table 1.3a Report Organization

Section	Content
Executive Summary	Provides a summary of key findings to assist in understanding the potential GHG emissions associated with Site C.
Acronym List	Provides definition of acronyms used in the report.
Glossary	Provides definition of technical terms used in the report.
Table of Contents	Table of Contents
1.0 Introduction	Provides an overview of Site C and outlines the purpose and objectives of the report, as it pertains to Site C.
2.0 Study Team	Describes the key members of the Study Team.
3.0 Study Objectives	Outlines the objectives of the study, as it pertains to Site C.
4.0 Project Location	Describes where Site C is located.
5.0 Global Carbon Cycle	Describes the key aspects (compartments and fluxes) of the global carbon cycle.
6.0 Methods Developed by the Intergovernmental Panel on Climate Change	Describes the estimated GHG emissions of Site C as obtained following IPCC Tier 1 and Tier 2 calculations.
7.0 Site C Biomass GHG Model	Describes the carbon cycle and nitrogen inputs of the Site C Study Area, and provides more detailed estimates of Site C GHG.
8.0 Site C Construction Emissions	Describes the estimated GHG emissions from the Construction Phase of the Project.
9.0 Discussion	Explains and provides context for the results of the study.
10.0 Closure	A closing statement identifying authorship and limitations of the study.
11.0 References	Provides technical references cited in the document.
Appendices	Provide additional background material discussed in the document, but not central to the narrative of the report.

2.0 STUDY TEAM

The Site C Greenhouse Gas Emissions Study was conducted by Jacques Whitford AXYS Ltd. (Jacques Whitford). The study team included project and study managers, researchers, and Geographic Information System (GIS) experts (Table 2.0a). All team members have in-depth knowledge and experience in their fields of expertise and a broad general knowledge of the work conducted by other specialists in related fields. Brief biographical statements, highlighting project roles and responsibilities and relevant education and employment experience, are provided below.

Table 2.0a Study Team for the Site C Greenhouse Gas Emissions Study

Team Member	Title	Responsibility
Mr. Peter Reid**	Senior Specialist & Group Leader, Air Quality and Climate Services	Project Manager
Ms. Magda Kingsley*	Air Quality and Climate Specialist	Assistant Project Manager and GHG Quantification
Dr. Mike Murphy	Principal, Senior Service Director Atmospheric Sciences	Senior Technical Review and Final QA/QC
Ms. Karen Gillam	Environmental Scientist	Development Lead
Dr. Joe Harriman	Air Quality and Climate Specialist	Technical Lead
Dr. Jean Michel DeVink	Environmental Scientist	Strategic Advisor, Modeller
Mr. Brent MacDonald	Air Quality and Climate Specialist	Documentation
Mr. Ned Purewal*	Geographical Information Systems	GIS Mapping
Mr. Terry Conville*	Senior Vegetation Specialist	Carbon Inventory development
Mr. Steve Parker*	Geographical Information Systems	GIS Mapping
Mr. Paul Mazzocco	Environmental Scientist	Technical Advisor and Stella® Model Conversion

Notes:
* Denotes Project Team members located in British Columbia.
** Denotes Project Team members located in Alberta.

Peter D. Reid, MSc – Project Manager

Peter D. Reid is the Jacques Whitford Project Manager. Mr. Reid is an Air Quality Specialist with over 20 years experience, most of which is in British Columbia. His training in Meteorology, Climatology and Hydro-Meteorology includes Master's Thesis work on lake evaporation, and considerable study on energy and water balance of reservoirs and lakes.

He spent 12 years at the BC Ministry of Environment in Kamloops as an Air Quality Specialist. In this role he acted as the Provinces designated expert witness respecting emissions of air pollutants from biomass burning. From 1989 through 2004 worked as an Air Quality Specialist for Westcoast Energy (now Duke Energy) in Fort St. John. He joined Jacques Whitford AXYS in a senior capacity on April 5, 2004.

Having lived and worked in Fort St. John for six years, Mr. Reid is very familiar with the climate and air quality regimes of the Peace Region. Through his work at Westcoast Energy he provided oversight for an extensive network of ambient air quality and meteorological stations in the area. One particular area of research interest was the Peace River Valley at Taylor – a region in which he performed micrometeorological studies supporting pollutant dispersion work. In the course of performing various air quality assessments he is familiar with various supplemental sources of meteorological data in the region. This includes Environmental Impact Assessments, Ministry of Forests and Ministry of Transportation sites, unpublished works, plus independently collected meteorological data.

Recently he was the Project Manager for work with BC Hydro (Engineering) developing a Terms of Reference for the Peace River Environmental Studies (Atmospheric Environment). He assisted BC Hydro in their water use planning in the Peace River Watershed by preparing a DRAFT Terms of Reference regarding the geophysical environment (local climate, global climate change) and human health (air quality, noise).

Magdalena Kingsley, MSc – Assistant Project Manager / GHG Quantification

Magdalena Kingsley is located at Jacques Whitford AXYS Ltd. Burnaby and has two years of extensive consulting experience in climate, air quality (AQ) and noise baseline, impacts studies and management systems in provincial and international mining operations. With a background in atmospheric chemistry, Mrs. Kingsley specializes in air quality analysis and assessment of toxic pollutants. She is developing her expertise in plume dispersion model simulations while assessing effects of air emissions from a range of industrial sectors. In addition, Mrs. Kingsley has experience conducting ambient air quality and meteorological data analysis, as well as emissions estimations for regulatory reporting.

As the Climate Change Coordinator for the Western Region of Jacques Whitford AXYS Ltd., Mrs. Kingsley also pursues excellence in climate legislation, GHG emissions inventories, GHG reduction strategies, carbon neutrality, climate impact mitigation and adaptation.

Michael Murphy, PhD, PEng – Senior Technical Review and Final QA/QC

Dr. Mike Murphy is a Principal of Jacques Whitford and the Senior Service Director for the Atmospheric Environment Group (Air Quality, Acoustics, Climate, Lighting) services company wide, working out of the Fredericton, New Brunswick office. He graduated from the University of Waterloo in 1987 with a PhD in Chemical Engineering, specializing in energy analyses, fluid modeling and boiling heat transfer. With more than 20 years of experience in Canada, USA and international, Dr. Murphy has conducted air quality and engineering studies on: emissions inventories of air pollutants and greenhouse gases, source emissions testing, dispersion modeling, ambient air quality, noise, odour, climate analysis, flow profiling, indoor air quality and environmental assessments. Dr. Murphy has worked on large environmental assessment (EA) projects including the NB Power Coleson Cove Refurbishment and the largest natural gas treatment plant in the world in Qatar, in the Middle East. He has conducted air quality studies for the shipping industry in Atlantic Canada (Saint John Port Authority), N.B Power, Irving Oil Limited) and in British Columbia (Vancouver Port Authority). Dr. Murphy participated in the full EA for the LNG facility proposed for New Brunswick, and Kitimat, B.C., including dispersion Modeling, air quality assessments and public consultation on all air quality aspects. Recently, he has conducted a comprehensive review of the Draft Air Pollution Rules (2005) for the Government of Trinidad and Tobago and is assisting with policy development to protect the environment in light of continued industrial expansion. He is a member of the Environment Committee for the Road Builders Association of New Brunswick. Dr. Murphy maintains close ties with the University of New Brunswick and has given courses on air pollution, process safety, and mass and energy balances.

Karen Gillam, MSc – Development Lead

Ms. Gillam joined Jacques Whitford in 2007 working in the Fredericton Air Quality group and specializing in Climate Services. Since this time, Ms. Gillam has been involved in developing a carbon cycle model of an Atlantic Canadian watershed, and developed greenhouse gas (GHG) emission calculations, for a proposed hydroelectric facility. She is accredited as a GHG Verification specialist (under ISO 14064) and has been involved in GHG verification projects including administering site visits for the verification of offset credits from tillage system management. Ms. Gillam has co-authored a Climate and GHG Management Plan for a proposed petroleum refining facility, as well as worked on Environmental Impact Statements for hydroelectric and petroleum refining projects.

Prior to joining Jacques Whitford, Karen worked as a consultant for several agencies including Agriculture and Agri-Food Canada, the Nova Scotia Agricultural College and the University of Manitoba, where she prepared several peer-reviewed scientific papers to be published in the Canadian Journal of Soil Science. She graduated in 2006 from Dalhousie University with a Master of Science in Agriculture after completing

studies on the emissions of GHGs from soils, where she managed all aspects of this large research project and instructed an upper level course for the Forestry department at University of New Brunswick. With more than 13 years of experience in both the forestry and agriculture sectors, Karen has developed specific technical expertise in the measurement, mitigation and management of GHG emissions from soils, gained detailed knowledge of soil science, soil and nutrient management, as well as best management practices in the drive towards sustainable agriculture.

Ms. Gillam has experience in developing carbon models for hydroelectric facilities and will lead the overall development of the models and research for this project.

Joe Harriman, PhD, PChem – Technical Lead

Dr. Harriman is the leader of Jacques Whitford's Air Quality and Climate Services group based in Saint John, NB. He has substantial experience and background knowledge in GHG emissions and has played a key role in the development of the climate change solutions for clients as well as Jacques Whitford's internal carbon-neutral initiative.

Dr. Harriman has the primary responsibility for Jacques Whitford's suite of Carbon and Air Pollutant emission calculation and tracking Toolkits. He has been the lead on the development of numerous greenhouse gas (GHG) emission inventories for clients ranging from large corporations to municipalities. As such, Dr. Harriman will lead all technical aspects of GHG quantification for this project.

His expertise in the areas of Air Quality and Climate Services are particularly relevant to the energy sector. Dr. Harriman has significant experience in developing GHG emission inventories ranging from large upstream oil and gas and telecommunication companies to financial institutions. Currently, Dr. Harriman is involved in the quantification of GHG emission reductions resulting from the implementation of new Steam Assisted Gravity Drainage (SAGD) technology in Alberta's oil and gas industry. In addition, Dr. Harriman is currently the strategic advisor for the development of a GHG emissions management plan for a LNG plant currently in the planning phase.

In addition, Dr. Harriman is an accredited a GHG Verification specialist (under ISO 14064) and has been involved in several GHG verification projects under the Alberta regulated cap-and-trade GHG program. Dr. Harriman has co-authored a Climate and GHG Management Plan for a proposed petroleum refining facility, as well as worked on Environmental Impact Statements for hydroelectric and petroleum refining projects.

Dr. Harriman has substantial knowledge in developing technologies for renewable energy production and has been involved in considerable green energy assessments including wind, solar and tidal projects. In addition, Dr. Harriman has a strong background and relationship various utilities in the energy generation sector. As such, Dr. Harriman has been involved with various aspects of generation policy and regulation for Jacques Whitford clients.

Jean Michel DeVink, PhD – Strategic Advisor, Modeller

Dr. DeVink is an Intermediate Environmental Scientist at Jacques Whitford. He completed his BSc (2002) in Forestry and Environmental Management at the University of New Brunswick and PhD (2007) in Biology at the University of Saskatchewan. Since 1999, his research and work experiences have focused on wildlife ecology and habitat related projects. Dr. DeVink has recently been involved in the fate and transport modeling of environmental contaminants and greenhouse gases from hydroelectric and petroleum refining facilities.

Dr. DeVink has recently co-authored a GHG emission assessment for a boreal hydroelectric facility, and has developed mass-balance models for nutrients and contaminants cycling in both aquatic and terrestrial environments. His experience and expertise lies in mass- balance process modelling using computer simulation tools.

Brent MacDonald, BPhil, ILS, BJ, – Documentation

Mr. MacDonald is a Climate and Sustainability Consultant at Jacques Whitford. He has significant research, and project work experience with government, non-governmental organizations and academia. Working on behalf of a provincial body as a project manager for three years, he has project controls skills, experience measuring the socio-economic impacts of policy changes, and significant experience as a lead facilitator for a variety of public and private sector organizations.

An active member of the Jacques Whitford sustainability practice and climate change services team, he has played an instrumental role as an advisor and contributor to the strategic development of the organizations national sustainability initiative and specifically, the climate change service line. This involved leading and participating in the development and application of a variety of unique energy and greenhouse gas emissions measurement, management and planning tools for the industrial, service, municipal, and telecommunications sector. In addition, he continues to lead a Jacques Whitford team completing a comprehensive GHG emissions inventory and reduction plan for the company.

Recently, he lead the design and deployment of an energy management, GHG emissions, and criteria air contaminants quantification tool and led a supporting technical writing exercise to develop protocols and guidance for 55 municipalities in Nova Scotia.

Ned Purewal – Geographical Information Systems

Ned Purewal is a CAD/GIS Technician with over 12 years experience in many engineering environments, including process piping, civil and structural. Mr. Purewal is well versed in ESRI products, including ArcMap, and AutoDesk products, including AutoCAD Map and AutoCAD Civil 3D.

Steve Parker – Geographical Information Systems

Steve Parker is a Senior GIS Analyst with Jacques Whitford AXYS. Mr. Parker has nine years experiences in GIS (Geographic Information Systems), six years experience in sales and marketing and four years experience in exploration geology. With Jacques Whitford AXYS, Mr. Parker has developed GIS programs to automate wildlife and vegetation modeling, constraints mapping, archaeological potential modeling, and has developed custom GIS applications. His specific technical expertise includes GIS application development in VBA (ArcObjects), VB, Avenue, AML and SQL using Access and SQL Server databases. As a GIS Programmer / Analyst with URS Corporation in Tampa, Florida, Mr. Parker developed custom GIS applications for U.S. clients and internal engineering departments. Specific projects include the Florida Gas Transmission environmental impact assessment, Florida Keys carrying capacity study, US Steel environmental screening application, Inglis dam failure assessment, FEMA flood plain mapping, Florida Department of Transportation highway monitoring system, and Volusia County socio-economic mapping. Previous to entering the field of GIS, Mr. Parker was employed as a junior assistant with the Ontario Geological Survey and a geologist with Noranda Exploration Company Ltd., based in Timmins, Ontario.

Terry Conville – Carbon Inventory Development

Mr. Conville's background includes 20 years of environmental and project management services involving technical land classification, forest monitoring, resource inventory, vegetation ecology, predictive mapping and research, and the management of large multi-year integrated projects utilizing leading-edge GIS technologies and remote imagery. His experience is gained from providing innovative sustainable resource management solutions for clients in both the private and public sector both in Canada and globally. He has founded and successfully managed environmental services businesses in British Columbia and México from 1995 to 2008 (as President and Director of both Atticus Environmental Services Ltd. in Canada and Terga Recursos S.A. de C.V. in México). In British Columbia, Mr. Conville led an experienced resource team for ten years which successfully completed more than

600 environmental projects. This included developing innovative resource information assessments and solutions, and conducting extensive TEM mapping and PEM modeling techniques to provincial standards. In Mexico, Mr. Conville was the Chief of Party for Terga Recursos providing senior management and advisement in the technical training, supervision, and quality control monitoring of the Mexican Government's 27 month National Forest and Soils Inventory. Recently, Mr. Conville worked as a Senior Resource Inventory Specialist with Winrock International (NGO) in Massachusetts, USA, leading the completion of diverse international projects in forest conservation and vegetation management. Overall Mr. Conville has advanced technical skills in terrestrial ecology and resource inventory and solid knowledge in resource information assessment techniques, financial administration, senior project management and coordination capabilities. He brings a wealth of senior vegetation and ecology experience and project managerial experience from a wide variety of jurisdictions to work for JWA clients.

Paul Mazzocco, BSc – Technical Advisor

Mr. Mazzocco is an associate hydrogeologist with over 10 years experience with Jacques Whitford. He has experience relating to the identification, assessment, and remediation of many types of contaminants. He has designed and implemented various databases in the assistance of numerous Phase II/III site assessments on residential, commercial and industrial sites. These have included groundwater, soil, air quality and hazardous material studies, recommendations for remedial options, and qualitative/quantitative human health and ecological risk assessments. Mr. Mazzocco's current focus is in the development and implementation of technology and its assistance towards automated historical data collection, statistical analysis, enhanced data management and analyses including the design, implementation and use of database, Geographic Information Systems (GIS), mathematical models and custom Visual Basic programs.

3.0 STUDY OBJECTIVES

The objective of the Site C GHG Emissions Study is to determine the net GHG emissions resulting from Site C and overall contribution to global climate change.

The main objectives include:

1) Estimation of the multi-year GHG emissions profile associated with the construction and ongoing operations of the potential Site C project;
2) Estimation of the net change in GHG emission from current conditions to post-inundation scenarios; and
3) Comparison of the GHG profile of Site C with other electricity supply options in British Columbia.

Specific components of this study include:

- Estimation of the potential GHG emissions associated with the construction phase of the proposed Site C project.
- Development of complementary conceptual models of the carbon cycle globally, and the Site C Study Area for the current (existing river) emissions regime, and the emissions regime following inundation. This will facilitate understanding of the important components of the carbon cycles before and after inundation, and add perspective to the estimated GHG emissions of Site C relative to global carbon cycles. The development of the model includes the following steps.
  - Deconstruct and parameterize the main components of the carbon cycle to represent explicit sources, processes, pathways and sinks of carbon, so that carbon emissions and storage can be quantified.
  - Estimation of the carbon fluxes for each of the pathways identified in the carbon models, using a combination of site specific data and literature-derived values.
  - Qualitatively evaluate whether the carbon fluxes represent “carbon-neutral” carbon which is already cycling rapidly (on a biogeochemical timescale) between the atmosphere and biosphere, or whether they represent stocks of carbon that were previously “in storage”, or which would not be created or released unless Site C proceeds. This will also consider whether a new storage will be created, accumulating carbon within the newly formed reservoirs over their lifetime.
- Development of an approach for comparing the estimated emission profile of Site C to other electricity supply options.
- Development of mitigation measures to reduce GHG emissions from construction and operation of Site C.

4.0 PROJECT LOCATION

If built, Site C would consist of a hydroelectric generating facility to be located on the Peace River in British Columbia, Canada, with an interconnecting electrical transmission line to the existing BC grid. The generating facility would consist of a dam and reservoir system. The Site C Study Area consisted of a 30 m buffer beyond the maximum flood level ("the Study Area").

5.0 GLOBAL CARBON CYCLE

Increasing atmospheric concentrations of CO_2 and CH_4 have been considered primary causes of global warming (Lashof and Ahuja, 1990). In light of potential changes to global climate that may be caused by GHG emissions (IPCC, 2001), attention is being given to the global carbon cycle in order to better understand the exchange of carbon and establish the primary sources of GHGs. This section provides a review of the global carbon cycle, as background information for and to set the context of this study.

The global atmospheric carbon pool is controlled by a variety of biological, geological and physical/chemical processes that add and remove CO_2 and CH_4 to and from the atmosphere. Under natural conditions for the past several thousands of years, without the influence of human activity, these processes appear to have been close to steady state, with atmospheric carbon inventories remaining stable. When considering anthropogenic perturbations (*i.e.,* industrial development and the burning of fossil fuels, land clearing for agriculture), there have been increased emissions of GHGs into the atmosphere and losses of carbon from some storage pools, at rates that are not balanced by processes that remove them from the atmosphere.

Carbon cycle models can be found in many forms, ranging from quite narrowly defined and specific (*e.g.,* the carbonate-silicate cycle of rock weathering) to large and complex conceptual models (*e.g.,* the global carbon cycle with the addition of anthropogenic carbon sources). The global carbon cycle presented here (Figure 5.1a), shows "stocks" where carbon is stored (*e.g.,* the atmosphere, terrestrial plants and soil, where carbon is generally measured in terms of mass (g) and "pathways" (*e.g.,* the flux of CO_2 from the atmosphere to terrestrial plants due to photosynthesis, or the flux of particulate organic carbon (POC) from land to the oceans with river flow, where units are expressed as a rate, (g/yr) which represent the fluxes of carbon between the various stocks.

For the purpose of this project, the global carbon cycle is used as a measure to put the carbon cycle of the Peace River Site C, and the alterations to that carbon cycle that will be associated with Site C, into the context of the global carbon cycle. By comparing local and regional CO_2 and CH_4 fluxes with those of the global carbon cycle, the potential for the Project to cause measurable environmental effects can be better understood.

The following sections provide a detailed introduction to all of the stocks and pathways found in the global carbon cycle. Each stock and pathway is discussed individually to provide the necessary context required for understanding the overall global carbon cycle and any contributions from the Site C Project.

5.1 GLOBAL CARBON CYCLE STOCKS AND PATHWAYS

The global carbon cycle is schematically illustrated in Figure 5.1a, with stocks represented by rectangles, and pathways represented by valves, with arrows indicating the possible directions of flow. The carbon inventories of the stocks (Section 5.1.1) and carbon fluxes associated with the pathways (Section 5.1.2) have been estimated from data obtained through literature reviews.

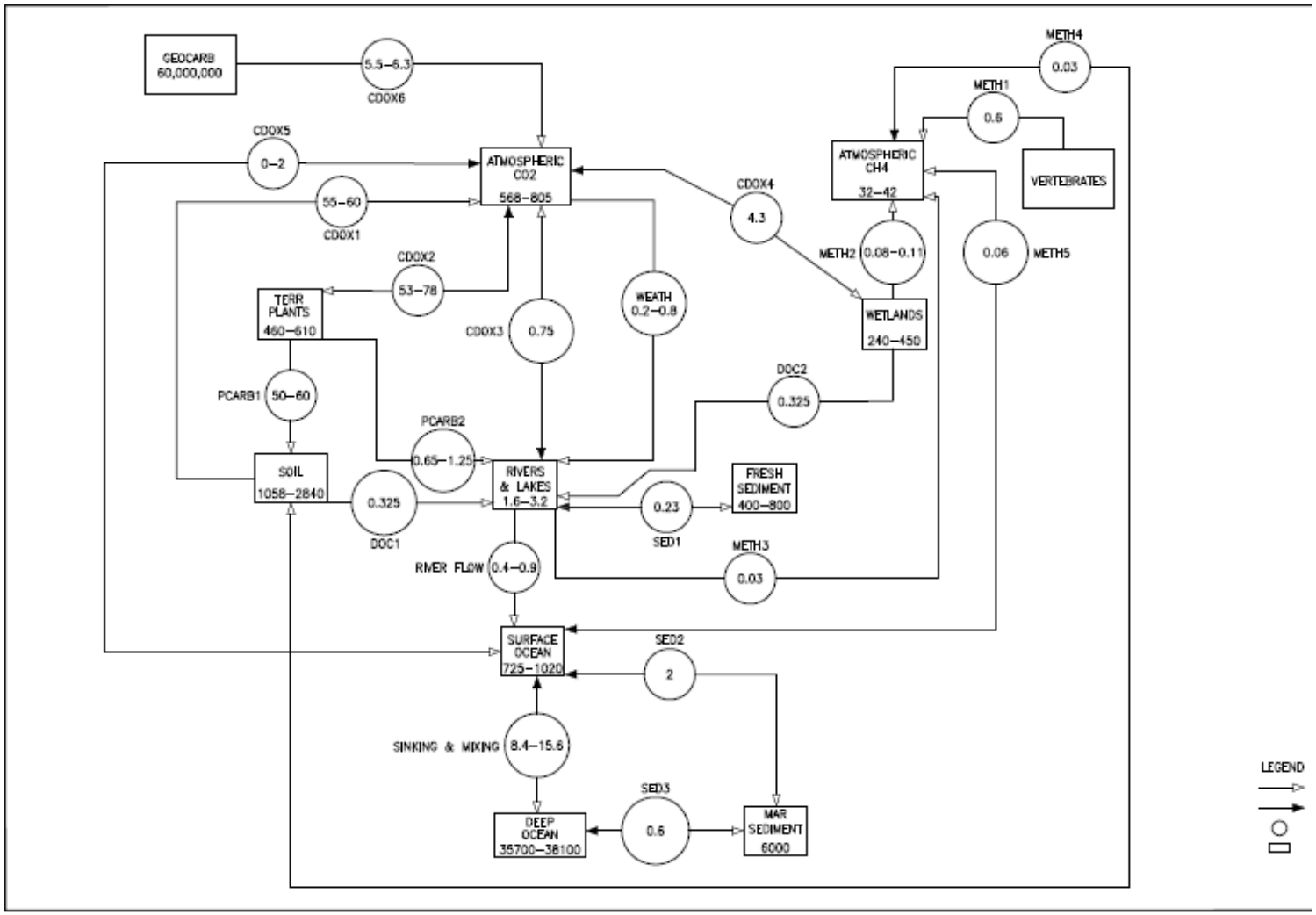

Figure 5.1a Site C Global Carbon Model

5.1.1 Global Carbon Cycle Stocks

In this Section, the stocks of carbon are briefly described for the global carbon cycle.

GEOLOGICALLY STORED CARBON: The Geologically Stored Carbon stock (GeoCarb) includes most of the near-surface or accessible geological carbon stores such as carbonate rocks and fossil fuels that remain underground. This stock does not include peat, which is included within wetlands, soils or freshwater and marine sediments, which are treated separately. The geologically stored carbon stock is estimated to contain in excess of 60,000,000 Pg C (Falkowski *et al.,* 2000). Recoverable reserves of coal, oil and gas are estimated to comprise between 5,000 and 10,000 Pg of this total.

ATMOSPHERIC CO_2: The Atmospheric CO_2 stock (Atmos CO_2) includes all of the carbon dioxide gas present in the atmosphere. This stock is estimated to contain between 568 and 805 Pg C (IPCC, 2001; Wickland *et al.,* 2003; Bice, 2007; Houghton, 2007; NASA, 2007).

ATMOSPHERIC CH_4: The Atmospheric CH_4 stock (Atmos CH_4) includes all of the methane gas present in the atmosphere. This stock is estimated to contain between 32 and 42 Pg C (IPCC, 2001; Wickland *et al.,* 2003; Bice, 2007; Houghton, 2007; NASA, 2007).

SURFACE OCEAN: The Surface Ocean stock (Surface Ocean) includes the dissolved organic carbon (DOC), POC and dissolved inorganic carbon (DIC) present in the surface layer of the ocean, which is considered to be mixed to a depth of approximately 300 m. This stock is estimated to contain between 725 and 1,020 Pg C (IPCC, 2001; Wickland *et al.,* 2003; Bice, 2007; Houghton, 2007; NASA, 2007) The oceans are believed to contain approximately 3 Pg of C in living organisms (Houghton, 2007).

DEEP OCEAN: The Deep Ocean stock (Deep Ocean) includes the DOC, POC and DIC stored in the intermediate to deep layers of the ocean, below a depth of 300 m. This stock is estimated to contain between 35,700 and 38,100 Pg C (IPCC, 2001; Wickland *et al.,* 2003; Bice, 2007; Bolin *et al.,* 2007; Houghton, 2007; NASA, 2007).

TERRESTRIAL PLANTS: The Terrestrial Plants stock (Terr Plants) includes the carbon stored in living terrestrial plants (excluding wetlands), such as forests and grasslands, including both above-ground and below-ground biomass. This stock is estimated to contain between 460 and 610 Pg C (IPCC, 2001; Wickland *et al.,* 2003; Bice, 2007; Bolin *et al.,* 2007; Cole *et al.,* 2007; Houghton, 2007; NASA, 2007).

SOIL: The Soil stock (Soil) includes the carbon stored in terrestrial soils, including both the litter layer, nominally the top 0.1 m of the soil profile, and subsoils of variable thickness extending down to mineral soil or bedrock. This stock is estimated to contain between 1,058 and 2,840 Pg C, mostly in the top metre of the soil profile (IPCC, 2001; Wickland *et al.,* 2003; Bice, 2007; Bolin *et al.,* 2007; Cole *et al.,* 2007; Houghton, 2007; NASA, 2007).

WETLANDS: The Wetlands stock (Wetlands) includes all of the carbon stored in wetlands. This includes wetland vegetation (mostly grasses, sedges, and mosses), as well as the underlying organic wetland soils and sediments such as peat. There is a poorly defined boundary between wetlands and aquatic ecosystems (see Rivers and Lakes below). For the present purpose, the general distinction is that wetlands are considered to be ecosystems that store peat, and are wet but not dominated by open water, whereas rivers and lakes are dominated by open water, and store sediments that are a mixture of inorganic and organic particles, but are not peat. The wetland stock is estimated to contain between 240 and 450 Pg C (IPCC, 2001; Roulet, 2000).

RIVERS AND LAKES: The Rivers and Lakes stock (Rivers & Lakes) and all other reference to rivers and lakes includes the carbon present in the water component of rivers, lakes, streams and all tributaries, as well as any man-made reservoirs that have been developed. Although previously considered largely as sources of carbon emission to the atmosphere, the true role of lakes and rivers in conveying and processing carbon originating in terrestrial ecosystems, and the role of lake sediments as sites where carbon may be stored for geological periods of time, has recently received more attention (Cole *et al.,* 2007).

The Rivers and Lakes stock is estimated to contain between 1.6 and 3.2 Pg C. This estimate was derived by multiplying the estimated volume of water in the world's rivers and lakes (1.30×10^{17} L, Gleick, 1996) and reservoirs (6.3×10^{15} L, Avakyan and Iakovleva, 1998) by the estimated concentrations of dissolved CO_2 (2.0×10^{-4} g CO_2-C/L, Kelly *et al.,* 2001), dissolved inorganic carbon (6.0×10^{-3} to 1.2×10^{-2} g DIC-C/L, Dillon and Molot, 1997), and dissolved organic carbon (3.0×10^{-3} to 6.0×10^{-3} g DOC-C/L, Hanson *et al.,* 2003; Dillon and Molot, 1997), and summing the inventories attributable to the various carbon fractions. The estimate does not include living biomass in lakes and rivers, or suspended POC. Assuming that lakes, rivers and reservoirs contain 1 mg/L POC suspended in the water column (which would include phytoplankton and zooplankton, as well as dead organic matter), the POC component could add approximately 0.14 Pg C to the estimate. The remaining living biomass in freshwater ecosystems (such as macrophytes and fish) would probably contain negligible additional carbon, in comparison to the concentrations of carbon in the water itself.

FRESHWATER SEDIMENT: The Freshwater Sediment stock (Fresh Sed) includes the organic and inorganic carbon stored in the freshwater sediments of rivers and lakes. Lakes generally store more organic than inorganic carbon, and lake carbon burial can represent in important, but often overlooked part of the total carbon stored in the watershed at the regional scale. An estimate of the storage of carbon in lake sediments since the last glacial period, is between 400 and 800 Pg C (Cole *et al.,* 2007), and even more carbon is stored in older lakes, some of which are millions of years old, and have sedimentary sequences thousands of metres thick. This is a very large number in comparison with the carbon inventories of terrestrial soils, and indicates that lakes can be very important sites of carbon storage within the overall terrestrial landscape.

MARINE SEDIMENT: The Marine Sediment stock (Mar Sed) includes the organic and inorganic carbon stored in ocean sediments. This stock is estimated to contain 6,000 Pg C (Houghton, 2007).

VERTEBRATES: The Vertebrates stock (Vertebrates) represents all living vertebrates that have the potential to emit CH_4 gas through digestive processes. The CH_4 emission pathway from vertebrates to the atmosphere is important, and is quantified below.

5.1.2 Global Carbon Cycle Pathways

In this Section, the pathways of carbon are briefly described for the global carbon cycle.

One pathway that is not considered below is the conversion of atmospheric CH_4 to CO_2. According to Thauer and Shima (2006), this is potentially an important conversion flux; however, it has recently been noted that including this flux can result in the double counting of atmospheric CO_2. Given that total atmospheric CO_2 and CH_4 are reported below, the CO_2 to CH_4 conversion flux is not considered.

CDOX1: The CDOX1 pathway represents the CO_2 emitted to the atmosphere as a result of organic matter decomposition and microbial respiration in soils. This flux is estimated to be between 55 and 60 Pg C/yr (IPCC, 2001; Houghton, 2007; NASA, 2007). Terrestrial net ecosystem productivity reflects the overall balance between fixation of carbon by plants (CDOX2 below), and respiration of carbon back to the atmosphere from plants and soils. Despite the relatively large amount of carbon stored globally in soils, the actual net storage rate of carbon in soils (Pg/yr) can be quite small compared to other stocks.

CDOX2: The CDOX2 pathway represents the net balance between plant fixation of CO_2 from the atmosphere as a result of photosynthesis during daylight, and the respiration of CO_2 back to the atmosphere by plant respiration at night. Effectively, this represents the growth of plant tissues, annually.

This net flux is estimated to be between 53 and 78 Pg C/yr, from the atmosphere to plants (IPCC, 2001; Bolin *et al.,* 2007; Houghton, 2007; NASA, 2007).

CDOX3: The CDOX3 pathway represents the net CO_2 exchange between fresh water (lakes and rivers, including reservoirs and associated infrastructure such as turbines and tail-races) and the atmosphere. Due to the fact that fresh water is generally slightly super-saturated with CO_2, the net flux is from aquatic ecosystems to the atmosphere at a rate of approximately 0.75 Pg C/yr (Cole *et al.,* 2007). Much of this CO_2 originates from the decomposition of carbon that was recently fixed from atmospheric CO_2 by plants, but which subsequently entered the aquatic ecosystem (as plant debris, or as dissolved organic carbon exported from soils, or as excess CO_2 dissolved in groundwater).

CDOX4: The $CDOX_4$ pathway represents the net CO_2 exchange between the living and non-living components of wetlands and peatlands, and the atmosphere. This flux is estimated to be approximately 4.3 Pg C/yr from the atmosphere to wetlands (IPCC, 2001).

CDOX5: The CDOX5 pathway represents the net CO_2 exchange between the atmosphere and the surface layer of the ocean. The estimated oceanic emission of CO_2 is approximately 90 Pg C/yr, whereas the absorption is estimated to be approximately 92 Pg C/yr (Siegenthaler and Sarmiento, 1993, Houghton, 2007). In contrast to fresh water surfaces, the ocean surface therefore appears to provide a small net sink for carbon dioxide, although there is a substantial gross exchange of carbon in both directions. Overall, the net flux is estimated to be between 0 and 2 Pg C/yr from the atmosphere to the oceans (Siegenthaler and Sarmiento, 1993; IPCC, 2001; Schlesinger, 2001; Houghton, 2007).

CDOX6: The CDOX6 pathway represents the release of geologically stored carbon into the atmosphere, primarily as carbon dioxide from combustion processes, and includes anthropogenic process related to the combustion of coal, oil and natural gas, as well as natural processes such as volcanism. This pathway is presently thought to involve a flux of between 5.5 and 6.3 Pg C/yr (Wickland *et al.,* 2003; Houghton, 2007; NASA, 2007), and is dominated by anthropogenic emissions. For example, volcanic emissions of CO_2 presently represent only approximately 0.2 percent of anthropogenic emissions (Williams *et al.,* 1992).

PCARB1: The PCARB1 pathway represents the deposition of POC derived from terrestrial plants to soils, primarily in the form of plant litter fall onto the soil. This pathway is estimated to represent a flux of between 50 and 60 Pg C/yr (Siegenthaler and Sarmiento, 1993; Houghton, 2007).

PCARB2: The PCARB2 pathway represents the deposition of POC derived from terrestrial plants to freshwater aquatic ecosystems, primarily via plant litter fall into the water. Cole *et al.* (2007) conclude that freshwater ecosystems directly or indirectly receive a considerable fraction (at least 1.9 Pg C/yr) of the terrestrial net ecosystem productivity (*i.e.,* the difference between gross primary productivity and respiration of the entire terrestrial ecosystem, estimated by various methods to be between 1 and 4 Pg/yr), and either respire it back to the atmosphere (approximately 40 percent), store it in sediments (approximately 12 percent), or convey it to the oceans (approximately 48 percent). The estimate of 1.9 Pg C/yr provided by Cole *et al.* (2007) includes all of the dissolved organic carbon leached from soils to water (DOC; 0.45 Pg C/yr, Cole *et al.,* 2007), as well as the dissolved inorganic carbon (DIC; 0.2 to 0.8 Pg/yr leached or weathered), therefore, the particulate organic fraction may represent the deposition of between 0.65 and 1.25 Pg C/yr in the form of organic debris from terrestrial plants to freshwater aquatic ecosystems (or 1 to 2 percent of the plant material formed each year).

WEATH: The WEATH pathway represents weathering reactions that are a sink for CO_2, as carbonic acid (from CO_2 in rain, in equilibrium with the atmosphere) releases cations from soil or bedrock, "fixing" the carbon dioxide as a salt solution of bicarbonate and the weathered cation. This pathway also takes into consideration the dissolved inorganic carbon present in runoff or groundwater entering rivers and lakes, and as rivers discharge to the ocean. In regions where carbonate minerals are scarce or absent (such as the Canadian Shield, which is predominantly of igneous origin), the presence of bicarbonate resulting from the dissolution of carbonate minerals (*e.g.,* chalk, calcite, limestone, dolomite) may be negligible. In areas where such rocks are present, corrections may need to be applied to differentiate between primary weathering, and dissolution of carbonate minerals. The global weathering sink of CO_2 is estimated to be between 0.2 and 0.8 Pg C/yr (IPCC, 2001; Wickland *et al.,* 2003).

DOC1 and DOC2: These pathways represent the flux of dissolved organic carbon released from the decomposition of organic matter as well as the excess CO_2 in groundwater. DOC1 represents the flux of these sources from the terrestrial environment to rivers and lakes; DOC2 represents the flux of these sources from wetlands and the groundwater associated with wetland processes to rivers and lakes. At the global scale, the terrestrial vs. wetland fluxes of DOC and CO_2 to rivers and lakes are not differentiated due to the relative scale of these processes compared to the global cycle. Instead, the flux from rivers and groundwater to the ocean was considered. However, these DOC1 and DOC2 pathways are considered separately for the Peace River Model (Section 7).

The total influx of carbon from DOC and excess CO_2 from rivers to the ocean is estimated to be 0.65 Pg/yr, half of which is placed into each of the DOC1 and DOC2 pathways for the global model. This value is based on the river DOC flux of 0.45 Pg/yr (Cole *et al.,* 2007), the river excess CO_2 flux of 0.008 Pg/yr (0.20 mg/L Cx40,000 km^3/yr river flow; (Cole *et al.,* 2007, Baumgartner and Reichel, 1975), and the groundwater CO_2 flux of 0.19 Pg/yr. The groundwater DOC flux is considered to be negligible (Cole *et al.,* 2007). Note that DIC entering rivers and lakes through the weathering process is considered separately in the WEATH pathway.

RIVER FLOW: The River Flow pathway is the sum of the DOC and POC of aquatic, terrestrial or wetland origin) and inorganic (dissolved CO_2, bicarbonates, and carbonates) carbon that flows from rivers and lakes into the Ocean stock. This flux is estimated to be between 0.4 and 0.9 Pg C/yr (Hedges *et al.,* 1997; Bolin *et al.,* 2007; Cole *et al.,* 2007).

METH1: The METH1 pathway represents the emission of methane to the atmosphere from vertebrates as a result of digestive processes. This flux is estimated to be approximately 0.6 Pg C/yr (Lerner and Matthews, 1988).

METH2: The METH2 pathway represents the emission of methane to the atmosphere from wetlands as a result of methanogenic bacteria acting on organic matter under anaerobic conditions. This flux is estimated to be between 0.08 and 0.11 Pg C/yr (Reeburgh, 1996; Marani and Alvala, 2007).

METH3: The METH3 pathway represents the emission of methane from lakes and rivers to the atmosphere as a result of methanogenic bacteria acting on organic material under anaerobic conditions in sediment. Methane may be emitted from lakes to air as a result of diffusive fluxes, or rising bubbles. This flux is estimated to be approximately 0.03 Pg C/yr (Cole *et al.,* 2007).

METH4: The METH4 pathway represents the exchange of methane between terrestrial soils and the atmosphere, bearing in mind that soils may be a site of net methane oxidation. This pathway may be a net atmospheric influx or efflux annually depending on various processes, but globally is considered to be a net sink of approximately 0.03 Pg C/yr from the atmosphere to soils (Bousquet *et al.,* 2006).

METH5: The METH5 pathway represents the emission of methane from surface ocean water to the atmosphere as a result of methanogenic bacteria acting on organic matter under anaerobic conditions in sediment. This net flux is estimated to be approximately 0.06 Pg C/yr from ocean water to the atmosphere (Reeburgh, 1996).

SED1: The SED1 pathway represents the exchange of organic and inorganic carbon between the water column and the sediments of lakes and rivers. Note that CH_4 and CO_2 may be formed in sediments, and released back to water, but that this is considered only when it is emitted to the atmosphere (METH3). Although previously given little consideration, lake sediments are now considered to be potentially active sites of carbon storage (Cole *et al.,* 2007). The SED1 flux is estimated to be approximately 0.23 Pg C/yr (Cole *et al.,* 2007).

SED2: The SED2 pathway represents the exchange of organic and inorganic carbon between the water column and the shallow-water sediments of the oceans. Note that CH_4 and CO_2 may be formed in shallow-water sediments, but that this is considered only when it is emitted to the atmosphere (METH5). The SED2 flux is estimated to be approximately 2 Pg C/yr (IPCC, 2001; Masiello and Druffel, 1998).

SED3: The SED3 pathway represents the exchange of organic and inorganic carbon between the water column and the deep-water sediments of the oceans. Note that CH_4 and CO_2 may be formed in deep-water sediments, and released back to deep ocean water, and that this is also included as part of SED3. The SED3 flux is estimated to be between 0.6 Pg C/yr (IPCC, 2001; Masiello and Druffel, 1998).

SINKING AND MIXING: The Sinking and Mixing pathway involves the circulation of water containing POC, DOC and DIC between the surface and deep ocean stocks. This flux is estimated to result in a net loss of between 8.4 and 15.6 Pg C/yr from the surface ocean to the deep ocean (IPCC, 2001; Bice, 2007; NASA, 2007).

5.2 MAJOR STOCKS AND PATHWAYS IN THE GLOBAL CARBON CYCLE

As illustrated in Figure 5.1a, the global carbon cycle comprises 12 stocks and 21 pathways, which together comprise several different "circuits" for carbon cycling. Having attempted to quantify the relative sizes of the carbon stocks, and the annual fluxes along the various pathways, it is relevant at this point to integrate the information presented. As discussed previously, prior to the accelerated anthropogenic release of carbon from geological storage due to such processes as combustion of fossil fuels, and various land use and agricultural practices, the global carbon cycle appeared to be in a state of near equilibrium over the past few millennia with respect to CO_2 and CH_4 concentrations in the atmosphere.

5.2.1 Terrestrial Plants and Soils

Globally, the loop involving terrestrial plants and soils comprises a major and highly active carbon cycling circuit. Although both the estimated carbon stocks (plants 460 to 610 Pg C; soils 1,058 to 2,840 Pg C) and fluxes from atmosphere to plants (53 to 78 Pg C/yr), from plants to soil (50 to 60 Pg C/yr), and from

soil back to the atmosphere (55 to 60 Pg C/yr) are large, the net annual carbon storage rate in plants and soils is relatively small, notwithstanding the attention that is given to forests and forest soils as potential carbon sinks.

However, recent evidence suggests that major forest regions, such as the northern boreal forests in Canada, may be close to steady state with respect to carbon cycling (Bond-Lamberty *et al.,* 2007). While earlier work suggested that boreal forests could be a substantial carbon sink, much of this work was carried out on mid-aged stands that were indeed growing and storing carbon in the form of wood and other plant tissues. However, taken as a whole, and taking into account the effects of periodic forest fires, it now appears that the Canadian boreal forest may not be a large carbon sink. Nonetheless, forests do comprise an important carbon stock, and carbon lost due to deforestation is considered an emission under the IPCC (2006) guidelines.

Similarly, soils take long periods of time to develop, and while they may contain substantial amounts of carbon, the actual carbon storage rate may be low. Canadian forest soils, and in particular soils on the Precambrian Shield, are generally thin and less than 10,000 years old. Most carbon storage in these soils occurs in the near-surface duff layer, and most of this carbon was deposited relatively recently and is actively involved in forest floor energy cycling and decomposition, and is susceptible to loss during forest fire events. Elsewhere, agricultural soils generally lose substantial amounts of carbon due to decomposition following land clearing, and as a result of tillage, so that globally soils have lost carbon to the atmosphere over the past century.

5.2.2 Ocean Water and Sediments

Ocean waters contain most of the carbon that can be considered available in the biosphere (725 to 1,020 Pg C in the surface ocean, and 35,700 to 38,100 Pg C in the deep ocean), and most of this is present in the form of inorganic carbon. There are massive exchanges of CO_2 between the atmosphere and the oceans, in both directions, although the net flux (0 to 2 Pg C/yr, approximately 33 percent of the anthropogenic carbon release rate from fossil fuel sources) is from the atmosphere to the oceans. At the same time, the oceans and coastal areas appear to be a small net source of methane (0.06 Pg C/yr) to the atmosphere.

Oceanic sediments also represent a major carbon stock, although again, the net carbon flux from ocean waters to sediments is rather small (approximately 2 Pg C/yr for shallow or coastal areas, and 0.6 Pg/C yr for deep areas). These numbers reflect both the importance of land-based carbon inputs (*i.e.,* carbon export from land) to the oceans, and the low productivity (nutrient limitation) of the mid-oceanic areas.

5.2.3 Rivers, Lakes, and Freshwater Sediments

Freshwater ecosystems have recently gained new prominence (Cole *et al.,* 2007) as their important role in processing and transporting plant-based POC and DOC from land areas to the oceans, and the significance and relatively high intensity of lake sediments as sites of long-term carbon storage have been re-evaluated. Globally, the water compartment of lakes and rivers stores little carbon (1.6 to 3.2 Pg C, due to the relatively short residence time of water in lakes and rivers), compared to that stored in sediments. However, river flow does transmit carbon to the oceans (0.4 to 0.9 Pg C/yr) in the form of DOC, DIC (some of which originates from weathering of primary minerals) and POC. Fresh water surfaces are well known as sources of CO_2 and CH_4 to the atmosphere (with fluxes estimated to be 0.75 Pg C/yr and 0.03 Pg C/yr, respectively). Lakes also contain depositional sediment areas, which can be relatively active sites for carbon storage. Globally during the Holocene period, lakes appear to have stored between 400 and 800 Pg C in sediments (Cole *et al.,* 2007).

While lakes have long been identified as net sources of CO_2 and CH_4 to the atmosphere, it is important to note that virtually all of this carbon represents carbon that is already cycling in the atmosphere-plant-soil circuit, and is not considered the same way as CO_2 that is released by fossil fuel combustion. As an analogy to further explain this differentiation, energy generated from biomass (such as heat or electricity from wood combustion) is considered to be CO_2 neutral energy because it does not release "new" CO_2, and can be conceptualized as part of a "plant-combustion-atmosphere-plant" circuit, whereas fossil fuel combustion releases new CO_2 that was previously in geological storage (IPCC 2006).

In the case of CH_4, there has been considerable discussion in the literature regarding the role of reservoirs as sites of CH_4 formation, due to the anaerobic decomposition of carbon in flooded soils and vegetation. In this respect, the literature also shows that tropical reservoirs function more intensely as sites of CH_4 formation than temperate-zone or northern reservoirs. The limnological literature (Schmid *et al.,* 2007) also shows that there are natural microbial processes of methane formation and oxidation within sediments, at the sediment-water interface, and in the water column, that can act to mitigate diffusive CH_4 fluxes at the lake-atmosphere interface. In addition, in deep lakes, bubbles that transport CH_4 from sediments can lose a considerable amount of their CH_4 by dissolution into the water as they rise, and that this dissolved CH_4 may be subject to microbial oxidation reactions that convert it to CO_2 before it is released to the atmosphere. As a result of these factors, cold, deep, oligotrophic lakes and reservoirs will generally produce and release little CH_4, whereas the potential for CH_4 emission is greatest in warm, shallow, eutrophic systems.

Freshwater sediments represent an under-appreciated carbon sink. Cole *et al.* (2007) have recently re-evaluated the role and importance that aquatic ecosystems play in processing and transporting organic carbon originating from terrestrial ecosystems. They note that although their surface area is generally small, on a regional basis lakes can affect carbon balances. Most lakes in Canada were formed following the most recent glacial period, about 10,000 years ago. Lake sediments are generally deposited below the mud deposition boundary depth (MDBD, Rowan *et al.,* 1992), which depends upon factors of lake surface area and fetch, depth, and bottom slope. For Precambrian Shield lakes, the MDBD typically occurs below a depth of about 5 m. The shallower (littoral zone) sediments tend to be dominated by sand, gravel, and coarse organic debris, whereas the sediments below the MDBD tend to be fine-grained, and somewhat organic. The carbon content of Precambrian Shield lake sediments may range from approximately 1 to 30 percent of sediment dry weight and, for depositional zone sediments in small lakes, is likely to be between 15 and 20 percent of sediment dry weight (Stephenson *et al.,* 1994). Such lakes would typically have long-term sedimentation rates of around 0.065 kg dry mass/m^2/yr (Bird *et al.,* 1992), suggesting a net carbon storage rate of around 0.01 kg C/m^2/yr in lake sediments. Sedimentary sequences in Precambrian Shield lakes can exceed 10 m in thickness, indicating that the intensity of carbon storage in lakes (per unit area) can greatly exceed the intensity of carbon storage in soils.

5.2.4 Wetlands

Like lakes, wetlands have the potential to store carbon (as peat or organic sediments) to an extent not usually found in soils. Globally, wetlands are thought to store between 240 and 450 Pg C, mostly in the form of peat and other organic sediments. Wetlands take in approximately 4.3 Pg C/yr due to net photosynthesis, and are thought to release between 0.08 and 0.11 Pg C/yr to the atmosphere as CH_4, and about 0.325 Pg C/yr to rivers and lakes as DOC.

Under water-saturated anaerobic conditions, peat provides a stable long-term storage medium for organic carbon. Peat deposits are often extensive in area, and can range in thickness from 0.5 m to over 10 m, and the carbon content of peat can range from approximately 45 to 60 percent of dry weight. Classic peatlands in Canada tend to be ombrotrophic (nutrient poor), and can take the form of domed or blanket bogs. In either case, once established, the peat generates its own water table and can become hydraulically isolated from the surrounding landscape (*i.e.,* storing and discharging water, but not receiving runoff from other land areas). In addition to fixing carbon through photosynthesis of wetland plants (including mosses and vascular plants), and storing organic carbon in peat or sediments, wetlands are also rich sources of DOC, which tends to be resistant to further degradation, and can be exported via runoff to freshwater ecosystems, and potentially to the oceans.

5.2.5 Vertebrates

Vertebrates are of concern globally due to the tendency for herbivores (especially ruminants) to produce CH_4 in their digestive tracts. This process is estimated to result in the release of approximately 0.6 Pg C/yr as methane, to the atmosphere.

5.3 EFFECTS OF RESERVOIRS ON THE GLOBAL CARBON CYCLE

The significance of hydroelectric reservoirs as components of the global carbon cycle has been the subject of much discussion (*e.g.,* Rudd *et al.,* 1993; Kelly *et al.,* 1994; St. Louis *et al.,* 2000; Tremblay *et al.,* 2004a; IRN, 2006). Undeniably, the flooding of landscapes to create reservoirs results in the conversion of terrestrial ecosystems (including carbon stored in plants and soils or wetlands, and any potential ongoing carbon storage associated with such ecosystems) to an aquatic ecosystem. Subsequently, much of the carbon previously stored in plants, soils, or wetlands may undergo decomposition and CO_2 or CH_4, resulting in enhanced GHG fluxes from the surface of the reservoir, when compared to the GHG fluxes that existed before the construction and operation of a hydroelectric dam. The magnitude and temporal extent of the release of carbon is dependent on several factors, which includes, among other, the decomposition rate of flooded biomass, sedimentation rates, burial of carbon from bank sloughing.

The studies that sparked the debate involved the experimental flooding of a peatland in northwestern Ontario with a low-head dam. As such, this was acknowledged to be a worst-case situation, since the volume of water involved was relatively small, and the volume of flooded organic matter was, relatively speaking, very large. Early in the discussion (St. Louis *et al.,* 2000) it was recognized that reservoirs which flood large areas to produce relatively few kWh (*i.e.,* expansive, low-head dams) would produce more GHG per kWh of electricity produced than “reservoir built in canyons where little area is flooded and large amounts of electricity are produced”.

St. Louis *et al.* (2000) reviewed a number of reservoir studies, concluding that average GHG fluxes from hydroelectric reservoirs around the world varied from 0.22 to 4.46 g CO_2/m^2/day, and from 0.003 to 1.14 g CH_4/m^2/day. The magnitude of the fluxes depended upon a variety of factors including the amount of organic carbon flooded, age of the reservoir, and mean annual temperature. They estimated that the global inventory of reservoirs (not limited to hydroelectric reservoirs) contributes approximately 0.27 Pg C/yr as CO_2, and approximately 0.05 Pg C/yr as CH_4, for a total CO_2 equivalent flux of approximately $2.3x10^{15}$ g/yr. These numbers appear important in the context of the annual release of 5.5 to 6.3 Pg C/yr from fossil fuels sources, although it must be qualified that emissions from reservoirs largely represent carbon that is already engaged in the atmospheric carbon cycle.

Tremblay *et al.* (2004a) reported on CO_2 fluxes from over 280 locations in Canadian reservoirs, rivers, and natural lakes. Their results indicated that water quality and the input of carbon from terrestrial systems affected CO_2 fluxes from water bodies, and that reservoirs older than about 10 years had CO_2 fluxes comparable to those of natural ecosystems. They concluded that the higher emissions associated with flooding in young reservoirs would last approximately six to eight years. In an old Quebec reservoir, mean measured emission rates of CO_2 were around 1.6 g CO_2/m^2/day, whereas natural lakes had emission rates around 0.74 g CO_2/m^2/day.

The International Rivers Network (IRN) has been critical of hydroelectric facilities because of concerns about the potential GHG emissions and other environmental effects that may be associated with reservoirs. In a recently published report (IRN, 2006) most concern is focused on tropical reservoir systems, because of their relatively large GHG emissions (said to average 2,577 g CO_2e/kWh generated), and because of the importance of CH_4 as a dominant contributor to those emissions. However, the data presented by IRN (2006), for boreal reservoirs in Canada shows much lower GHG emissions (averaging 36 g CO_2e/kWh), values which are also substantially lower than life-cycle GHG emissions from non-hydro generation technologies (IRN, 2006). For example, 1,000 g CO_2e/kWh for a modern coal-fired generating plant, or 545 g CO_2e/kWh for a combined-cycle natural gas fired plant (IRN, 2006).

As described in the IRN (2006) report, the major component of the GHG emissions from boreal reservoirs is the diffusion of CO_2 across the water surface (with production of CH_4, and in particular bubble-emissions of CH_4 being of lesser concern), in contrast with tropical reservoirs where CH_4 bubbles and turbine/spillway releases of CH_4 are of primary concern.

Notwithstanding the data presented by IRN (2006) showing that boreal reservoirs have relatively low CH_4 and overall GHG emissions in comparison with other electrical generating technologies, the key issues raised by the IRN that are relevant to the Project, and which will be addressed in this report, include the following:

- Production of GHG from decomposition of flooded soils and vegetation following reservoir creation;
- Long-term production of GHG from DOC and POC entering the reservoir from the surrounding watershed;
- Releases of GHG by diffusion and bubbling across the reservoir surface;
- Releases of GHG at turbines and spillways due to pressure drop and/or spray effects;
- The potential effects of drawdown configurations (*i.e.,* bottom or mid-depth drawdown scenarios may involve water that has elevated GHG concentrations in comparison with surface drawdown scenarios);

- Calculation of the environmental effects of reservoirs should be based on net emissions (adjusting estimates of gross emission at the reservoir surface and dam outlets for whatever sources or sinks of GHG emission existed in the flooded areas before reservoir creation, storage of carbon in sediments within the reservoir, and the effects of the reservoir on the pre-dam flows of carbon throughout the wider watershed); and
- The effects of dam construction and decommissioning should be considered, including the use of fossil fuels by machinery, and the production of building materials such as cement.

6.0 METHODS DEVELOPED BY THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

The IPCC has developed and published guidelines for estimating GHG emissions and developing emission inventories from common land use changes. According to the IPCC (2006), flooded lands are defined as water bodies where human activities have caused changes in the amount of surface area covered by water, such as reservoirs for the production of hydroelectricity.

Emissions of CO_2, CH_4 and N_2O have been measured from reservoirs and default values suggested for use in the development of national GHG inventories. Following the IPCC methods, GHG emissions from flooded lands are considered for the following pathways post-inundation (IPCC 2003, 2006).

- Diffusive Emissions: molecular diffusion of CO_2, CH_4 and N_2O across the air-water interface, taking into consideration that post-inundation concentrations of CO_2, CH_4 and N_2O in reservoirs may be elevated in comparison with pre-inundation concentrations of these gases in the natural aquatic system, and that the post-inundation surface area is larger than the pre-inundation surface area.
- Bubble Emissions: escape of CH_4 from the sediment, through the water column, to the atmosphere, as rising gas bubbles.
- Degassing Emissions: emissions resulting from a sudden change in hydrostatic pressure, as well as the increased air/water exchange surface after reservoir waters flow through a turbine and/or a spillway (bearing in mind that the natural aquatic system may have included waterfalls or rapids where similar processes took place prior to inundation).
- Emissions from decay of above-water biomass, such as trees not fully submerged by impoundment, especially those located in shallow flooded zones.

The IPCC (2003, 2006) describe how to estimate GHG emissions from reservoirs at three levels of detail (termed Tiers), with the level of detail and precision increasing as one proceeds from Tier 1 to Tier 3. The IPCC Tier 1 and 2 methods are used to estimate the change in GHG emissions from land use/land use change and forestry (LULUCF) on a national basis in order to provide broad scale methods of estimating GHG emissions under the Kyoto Protocol (IPCC, 2003). These Tier 1 and 2 methods cannot account for potential harvesting scenarios of Site C as they use generic emission coefficients. Tier 3 methods are project specific and provide a finer level of detail in estimating more realistic and comprehensive accounts of net GHG emissions.

The Tier 1 approach (IPCC, 2003) provides a simplified method for estimating GHG emissions from reservoirs, considering diffusive emissions only. Under this generalized approach, emissions from the water surface of the reservoir are calculated over a period of 1 year, or 365 days.

The Tier 2 approach (IPCC, 2003) is more detailed, with different emission factors used for the ice-free and ice-covered periods of the year. Bubble emissions through the water column are considered, as well as degassing emissions from the spillways and turbines of operating generating facilities.

A more detailed method, referred to as a Tier 3 method, will be outlined in Section 7.0 of this report. The IPCC (2006) notes that Tier 3 methods, based on detailed measurements, should include all relevant fluxes of GHG emissions from flooded lands over the lifetime of the reservoir, including degassing emissions, and taking into consideration the age, geographical location and water temperature of the reservoir.

6.1 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE CALCULATION: TIER 1

The Tier 1 approach provides a simplified approach to estimate GHG emissions from reservoirs as outlined below.

6.1.1 Tier 1: Carbon Dioxide Emissions

The following method estimates the carbon stock change in above ground living biomass due to land conversion to flooded land. It is important to note that the following methods consider only the first 10 yrs post-inundation (IPCC, 2003), after which time, emissions are assumed to be lower:

Equation 1: Tier 1 CO_2 Emissions from Flooded Lands (IPCC, 2003)

$CO_2\ emissions_{WWf} = P * E(CO_2)_d * A_f$

Where:

$CO_2\ emissions_{WWf}$ = total CO_2 emissions from flooded lands, kg CO_2/yr;

P = period of emissions, usually 365 days for annual inventory estimates, d/yr;

$E(CO_2)_d$ = averaged daily diffusive emissions, with a default value of 15.5 kg CO_2/ha/day (IPCC, 2003); and

A_f = total flooded surface area, including flooded land, flooded lake and flooded river surface area, ha, estimated to be 9,328 ha for the Site C reservoir (J. Matches pers. comm., 2008).

Based on Equation 1 and the various parameter values, the Tier 1 CO_2 emissions (estimated following the IPCC (2003) methods) for the Site C reservoir are $5.28x10^7$ kg CO_2/yr.

6.1.2 Tier 1: Methane Emissions

The Tier 1 method for estimating CH_4 emissions from flooded lands includes the diffusion and bubble pathways (Equation 2):

Equation 2: Tier 1 CH_4 Emissions from Flooded Lands (IPCC, 2003)

CH_4 emissions$_{WWf} = P * E(CH_4)_d * A_f + P * E(CH_4)_b * A_f$

Where:

CH_4 emissions$_{WWf}$ = total CH_4 emissions from flooded land, kg CH_4/yr;

$E(CH_4)_d$ = averaged daily diffusive emissions, with a default value of 0.11 kg CH_4/ha/day (IPCC, 2003); and

$E(CH_4)_b$ = averaged bubbles emissions, with a default value of 0.29 kg CH_4/ha/day (IPCC, 2003).

Based on Equation 2 and the various parameter values, the Tier 1 CH_4 emissions (estimated following the IPCC (2003) methods) for the Site C reservoir are $1.36x10^6$ kg CH_4/yr.

6.1.3 Tier 1: Nitrous Oxide Emissions

The Tier 1 method for estimating N_2O emissions from flooded lands includes the diffusion and bubble pathways (Equation 3):

Equation 3: Tier 1 N_2O Emissions from Flooded Lands (IPCC, 2003)

N_2O emissions$_{WWf} = P * E(N_2O)d * A_f$

Where:

N_2O emissions$_{WWf}$ = total N_2O emissions from flooded land, kg N_2O /yr;

$E(N_2O)_d$ = averaged daily diffusive emissions, with a default value of 0.008 kg N_2O /ha/day (IPCC, 2003).

Based on Equation 3 and the various parameter values, the Tier 1 N_2O emissions (estimated following the IPCC (2003) methods) for the Site C reservoir are $2.72x10^4$ kg N_2O/yr.

6.2 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE CALCULATION: TIER 2

The Tier 2 CO_2 and CH_4 emissions were estimated from the Site C reservoir according to Equations 4 to 6 (Tier 2 calculations outlined in IPCC 2003). These calculations include both diffusive and degassing

emissions in the ice free period, diffusive emissions from ice covered period, as well as degassing emissions released to the atmosphere when water is passing through the turbine or over the spillway.
It is important to note that the following methods only considers the first 10 yrs post-inundation (IPCC, 2003), after which time emissions are assumed to be lower.

6.2.1 Tier 2: Carbon Dioxide Emissions

The Tier 2 method for estimating net CO_2 emissions from reservoirs is as follows (Equation 4):

Equation 4: Tier 2 CO_2 Emissions from Flooded Lands (IPCC, 2003)

$$CO_2 \text{ emissions}_{WWf} = (P_f * E_f(CO_2)d * A_{fl}) + (P_i * E_i(CO_2)d * A_{fl}) + (([CO_2]_{diss} - [CO_2]_{eq}) * \text{Outflow}) + (([CO_2]_{spill} - [CO_2]_{eq}) * \text{Spillway})$$

Where:

P_f = ice-free period, (as conservative estimate, assumed to be 365 days per year for the Peace River);

P_i = period with ice cover, (assumed to be 0 days per year for the Peace River);

$E_f(CO_2)_d$ = average daily diffusive emission of $CO_2$from the air-water interface during the ice-free period, with a default value of 15.5 kg CO_2/ha/day (IPCC, 2003);

$E_i(CO_2)_d$ = average daily diffusive emission of $CO_2$from the air-water interface during the ice-covered period, with a default value of 0.45 kg CO_2/ha/day (IPCC, 2003);

A_{fl} = flooded land area (ha) estimated to be 6,345 ha (surface area at maximum flood (9,328 ha) – surface area of river under existing conditions (2,982 ha)) for the Site C reservoir;

$[CO_2]_{diss}$ = average CO_2 concentration in water before the turbines at the water intake depth, estimated to be 5.06×10^{-6} kg/L (Duchemin *et al.,* 1995);

$[CO_2]_{eq}$ = average CO_2 concentration in water downstream of the dam, or at equilibrium with the atmosphere, estimated to be 4.99×10^{-6} kg/L (Duchemin *et al.,* 1995);

$[CO_2]_{spill}$ = average CO_2 concentration in water before the spillway at the water intake depth, 5.06×10^{-6} kg/L (Duchemin *et al.,* 1995);

Outflow = the average water discharge rate at the turbines, estimated to be $3.75x10^{13}$ L/yr for the Site C reservoir (T. Siu pers. comm., 2008); and

Spillway = the average discharge rate at the spillway, estimated to be 0 L/yr for the Site C reservoir, since the facilities will be designed to minimize spillway use, and the carbon emissions from spillways in the IPCC calculations are equivalent to carbon losses from turbines. All river flow is assumed to pass through the turbines (A. Watson pers. comm., 2008).

Based on Equation 4 and the various parameter values, the Tier 2 CO_2 emissions (estimated following the IPCC (2003) methods) for the Site C reservoir are $3.87x10^{7}$ kg CO_2/yr. Note that Equation 4 assumes complete degassing of river water at each of the dam locations, in addition to the degassing of reservoir water over the newly flooded portions of the reservoir. Thus, there is considerable potential for double-counting of the CO_2 emissions by this approach.

6.2.2 Tier 2: Methane Emissions

The Tier 2 method for estimating CH_4 emissions from reservoirs is as follows (Equation 5):

Equation 5: Tier 2 CH_4 Emissions from Flooded Lands (IPCC, 2003)

$$CH_4\ emissions_{WWf} = (P_f * E_f(CH_4)_d * A_{fl}) + (P_f * E_f(CH_4)_b * A_{fl}) + (P_i * (E_i(CH_4)_d + E_i(CH_4)_b) * A_{fl}) + (([CH_4]_{diss} - [CH_4]_{eq}) * Outflow) + (([CH_4]_{spill} - [CH_4]_{eq}) * Spillway)$$

Where:

$E_f(CH_4)_d$ = the average daily diffusive emission of CH_4 from the air water-interface during the ice-free season, with a default value of 0.11 kg CH_4/ha/day (IPCC, 2003);

$E_f(CH_4)_b$ = the average bubble emission of CH_4 from air water-interface during the ice-free season, with a default value of 0.29 kg CH_4/ha/day (IPCC, 2003);

$Ei(CH_4)_d + E_i(CH_4)_b$ = the sum of the average daily diffusive and bubble emissions of CH_4 from air water-interface during the ice-covered season, with a default value of 0.05 kg CH_4/ha/day (IPCC, 2003);

$[CH_4]_{diss}$ = the average concentration of CH_4 in water before the turbines, at the water intake depth, estimated to be $3.15x10^{-8}$ kg/L (Duchemin *et al.,* 1995);

$[CH_4]_e$ = the average concentration of CH_4 in water downstream of the dam, or at equilibrium with the atmosphere, estimated to be $3.11x10^{-8}$ kg/L (interpolation based on Duchemin *et al.,* 1995); and

$[CH_4]_{spill}$ = the average concentration of CH_4 before the spillway, at the water intake depth, estimated to be $3.15x10^{-8}$ kg/L (Duchemin *et al.,* 1995).

Based on Equation 4 and the various parameter values, the Tier 2 CH_4 emissions (estimated following the IPCC (2003) methods) for the Site C reservoir are $9.46x10^5$ kg CH_4/yr.

6.2.3 Tier 2: Nitrous Oxide Emissions

Due to the lack of measured data for N_2O emissions under ice cover, N_2O concentrations in the water before the turbines and spillway and at equilibrium downstream from the dam, the Tier 2 method for estimating N_2O emissions from reservoirs is not possible as with CO_2 and CH_4. As described above (Section 6.6.1 and 6.6.2), under the Tier 2 methods, total flooded surface area (9,328 ha) is replaced by flooded land surface area (6,345 ha). Applying this revised surface area to the IPCC Tier 1 N_2O methodology (Equation 3), N_2O emissions for the Site C reservoir are $1.86x10^4$ kg N_2O /yr.

6.3 INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE CALCULATIONS: FLOODED BIOMASS AND DECOMPOSITION OF ABOVE WATER BIOMASS

IPCC (2006) Equation 6 provides an approach to estimating the change in carbon stocks due to inundation.

Equation 6: Change in Carbon Stocks in Living Biomass on Land Converted to Permanently Flooded Land (IPCC, 2006)

$\Delta C_{LWfloodLB} = [\Sigma A_i * (B_{After\ i} - B_{Before\ i})] * CF$; and

$CO_{2LWflood} = \Delta C\ L_{WfloodLB} * 44/12$

Where:

$\Delta C_{LWfloodLB}$ = the change in carbon stocks in biomass on land converted to flooded land, kg C;

A_i = area of land converted to flooded land from original land use i, ha;

$B_{After\ i}$ = biomass immediately following conversion to flooded land (kg dry matter (dm)/ha, default = 0);

$B_{Before\ i}$ = biomass on land immediately before conversion to flooded land (kg dry matter/ha, value for Site C Reservoir is estimated to be $6.95x10^4$ kg dm/ha, calculated by Jacques Whitford as

representing both above and below ground tree biomass. As a conservative estimate it was assumed that all flooded land fell under the boreal coniferous forest ecological zone. Biomass on land was then calculated based on area of flooded land, IPCC (2006) default values for above ground biomass (AGB) (ranging from 10 to 90 tonnes dm/ha with the chosen median value of 50 tonnes dm/ha), and the ratio of below ground biomass to above ground biomass (0.39) for the < 75 tonnes/ha AGB default value;

CF = carbon fraction of dry matter (default = 0.5 kg C/kg dm, IPCC, 2006); and

$CO_{2LWflood}$ = the carbon dioxide equivalent of $\Delta C_{LWfloodLB}$, where 44 is the molecular weight of CO_2, and 12 is the atomic weight of carbon.

Based on Equation 6 and the assumptions that the surface area of land inundated is covered completely by coniferous forest with no harvest prior to inundation, the carbon stock change due to land conversion to permanently flooded land is 2.20×10^8 kg C for the potential Site C reservoir.

6.4 GREENHOUSE GAS EMISSIONS DURING OPERATION - ESTIMATES FROM INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE METHODS

Previous research suggests that British Columbia reservoirs (>29 yrs of age) tend emit less CO_2, and only slightly higher CH_4 emissions, than do natural lakes in the province and other reservoirs in Canada for which data are available (Tremblay *et al.,* 2005). Since the Site C reservoir would be small and deep, relative to other reservoirs, there is no reason to believe that the Site C reservoir would not, in time, have emission fluxes comparable to those prior to reservoir creation.

Based on review of the literature, experience from similar hydroelectric generation development projects, and experience from previous environmental assessments, the existing GHG emissions from the area of Site C are expected to be low in comparison to other hydroelectric developments.

Regarding operation of the potential Site C project, the IPCC (2003) Tier 1 and Tier 2 methods are used to provide estimates (Table 6.4a) of the GHG emissions from Site C reservoir after construction. The calculations were made using the default emission values for a wet, boreal climate provided in the IPCC (2003) methods. Where appropriate, CH_4 and N_2O emissions are converted to units of CO_2 equivalent (CO_2e) by multiplying the CH_4 and N_2O emissions by the global warming potential value of 21 for CH_4 and 310 for N_2O.

Using the IPCC Tier 1 calculation with default values, the GHG emissions are estimated to be 89,792 tonnes of carbon dioxide equivalents (CO_2e) per year post-inundation. Using the IPCC Tier 2 methods, the estimated values for GHG emissions, under post-inundation operational conditions is 64,284 tonnes CO_2e/yr.

Given the predicted generating capacity of the Site C generating facility (900 MW), and electricity generation of 4,610 GWh/yr (BC Hydro, 2003), the emissions per unit energy using Tier 1 and Tier 2 calculations were 19.5 and 13.9 g CO_2e/kWh (Table 6.4a).

Table 6.4a Estimate of Greenhouse Gas Emissions - Operation of Site C Generating Facility

Method	IPCC Tier 1	IPCC Tier 2
CH_4 (Tonnes/yr)	1,362	946
CO_2 (Tonnes/yr)	52,759	38,660
N_2O (Tonnes/yr)	27	19[c]
CH_4 (Tonnes CO_2e/yr)[a]	28,592	19,862
CO_2 (Tonnes CO_2e/yr)	52,759	38,660
N_2O (Tonnes CO_2e/yr)[b]	8,441	5,762
Total Mt (CO_2e/yr)	89,792	64,284
Generating Capacity (MW)	900	900
Electricity Generation (GWh/yr)	4,610	4,610
Emissions per kWh (g CO_2e/kWh)	19.5	13.9

Notes:

[a] CO_2 equivalents (CO_2 e) calculated on a 100 yr global warming potential of 21 for CH_4.

[b] CO_2 equivalents (CO_2 e) calculated on a 100 yr global warming potential 310 for N_2O.

[c] IPCC Tier 2 N_2O estimate does not include emissions from ice cover, or degassing emissions from the spillways and turbines, due to unavailable default values. This value represents a Tier 1 estimate using the revised surface area of flooded land as suggested in Tier 2 methodology.

7.0 SITE C BIOMASS GHG MODEL

There are currently no established guidelines for estimating GHG emissions from hydroelectric reservoirs beyond the generic Tier 1 and Tier 2 guidelines for flooded land (see Section 6). These guidelines are used primarily for large-scale GHG emission inventories. Project-specific emission estimates should be calculated using models with greater levels of detail. Therefore, to estimate Site C's potential contribution to global GHG (CO_2, CH_4, and N_2O), it was necessary to construct site specific mass balance models that account for carbon and nitrogen emission to the atmosphere. As nitrous oxide emissions from most natural systems are negligible, the largest and most detailed model will represent the carbon cycle. The use of these mass-balance models allow for more detailed accounting of carbon in the Study Area than do IPCC Tier 1 and 2 calculations. For example, the carbon model will take into account the carbon storage (stocks) and fluxes (pathways) associated with the river and the adjacent land up a point 30 m beyond the point of maximum flood level (408 m asl). This ecosystem approach is necessary because carbon cycling in the river depends explicitly on inputs and outputs from the surrounding landscape. Site C would necessitate the flooding of land adjacent to the river, resulting in the conversion of this land to aquatic habitat. The more limited nitrogen mass-balance model will account for emissions resulting only from anthropogenic activities (*i.e.,* agriculture) as alpine and subalpine reservoir systems are reported to have neutral nitrogen emissions (Hendzel *et al.,* 2005; Diem *et al.,* 2008).

In order to estimate the net environmental effect of Site C on carbon storage and fluxes, two scenarios are evaluated, representing two different stages in the development and evolution of the reservoir. Models representing each scenario are programmed to run for a model period of 100 yrs to appropriately compare both GHG emission estimates. Carbon and nitrogen budgets for Site C are developed for the following scenarios:

- current conditions; and
- post-inundation.

Information on how vegetation, land areas, and carbon and nitrogen inventories were estimated for Site C is presented in Section 7.1. Information pertaining to specific carbon stocks and pathways are presented in Section 7.2 while stocks and pathways for the nitrogen model are presented and described in Section 7.3. The GHG budgets for the post-inundation scenarios, representing the potential environmental effects of the Project, are developed and presented in Sections 7.4 and 7.5 for the carbon and nitrogen models respectively. As uncertainty is unavoidable for some model parameters, a sensitivity analysis of four key parameters is outlined in Section 7.6. A summary of general results is presented in Section 7.7.

7.1 VEGETATION AND LAND AREAS AND CARBON INVENTORIES FOR SITE C

In this section the carbon budget for Site C is developed to represent present-day conditions. Sources of data are identified and presented in order that the estimated carbon budgets are transparent and can be validated. The conceptual model for current conditions Site C carbon and nitrogen cycling is shown in Figure 7.1a.

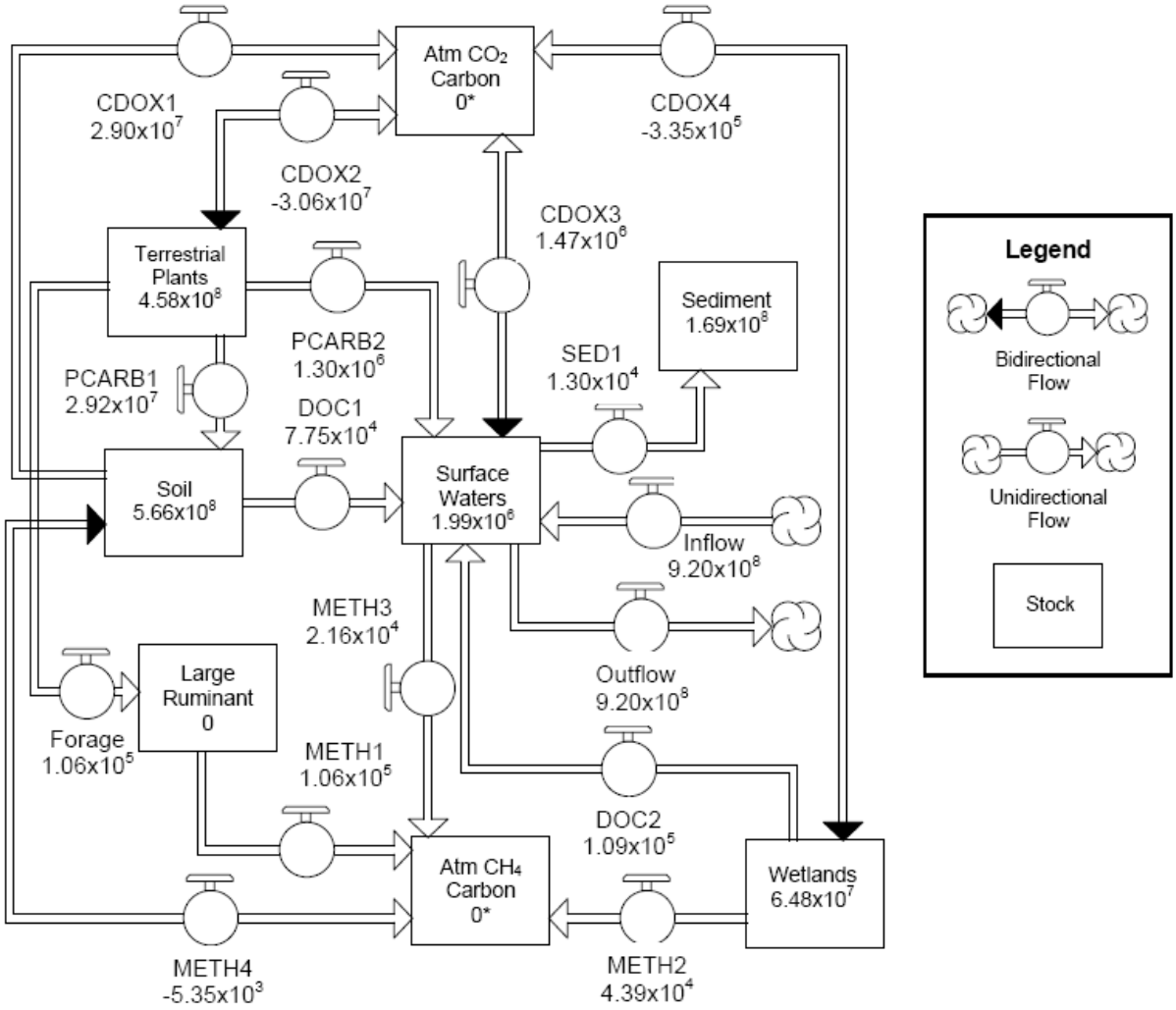

Figure 7.1a Conceptual Model of Carbon Cycling in the Site C Study Area for Current Conditions

Notes:
Values are provided in exponential form (*e.g.,* 1.0 x 10^2 = 100 and 3.3x10^4 = 33,000).

Printed copies not controlled

7.1.1 Watershed and Cover Type Area Values

All area values (*e.g.,* watershed areas, lake surface areas, and vegetation types) were derived using GIS software to interpret data from various sources. Results were limited to the Site C Study Area boundaries (Figure 4.0a).

The net effects of the Project within the zone that will be flooded are determined from the difference between the Study Area post-inundation emissions and emissions from current conditions each modeled for a 100-year period.

The Site C Study Area was established by buffering the maximum flood polygon (provided by Jack Matches, BC Hydro on July 23, 2008) by 30 meters. A 30 meter buffer was chosen to account for the particulate carbon deposited into the aquatic system along the shoreline (*e.g.,* leaves falling from trees in the fall of the year). The categorization of the Study Area followed the Canadian Forest Service Earth Observation for Sustainable Development (EOSD) national land classification coding and scheme (Appendix 2). The Study Area and Vegetation units described in the Resource Inventory Committee Standard Terrestrial Ecosystem Map (TEM) and Standard Vegetation Resource Inventory (VRI) datasets (provided by Jack Matches, BC Hydro on July 23, 2008) were used as the basis for summarizing EOSD land classifications into forest/shrub, farmland, wetland, and other land (overwhelmingly gravel bar) areas within this zone. Topographic relief was applied to these areas. The resulting values for land areas and vegetation classes are presented in Appendix 2.

The following land cover units were estimated using GIS methods (Table 7.1.1a):

- lake;
- river;
- forest and shrub;
- wetland;
- farmland; and
- other (*i.e.,* rock and road).

The known or estimated limnological characteristics (area, volume, and shoreline lengths) of Site C are presented in Table 7.1.1b. Present-day and post-inundation surface areas and volumes were estimated using GIS methods.

Table 7.1.1a Summary of Land Areas by Land Cover Type for Current Conditions and Post-inundation Scenarios

Land Cover	Current Conditions Area (m^2)	Data Source	Post-inundation Area (m^2)	Area Flooded (m^2)
Lake (pond and open water)	1.80E+05	TEM	0	1.80E+05
River	2.96E+07	TEM	9.33E+07	-6.37E+07
Forest and Shrub	4.92E+07	EOSD	6.46E+06	4.28E+07
Wetland	6.26E+06	EOSD	6.30E+05	5.63E+06
Farmland	6.27E+06	EOSD	5.80E+05	5.70E+06
Other (rock, road, *etc.*)	1.04E+07	EOSD	1.05E+06	9.35E+06
Total	**1.02E+08**		**1.02E+08**	**0**

Notes:

Detailed accounting of areas is provided in Appendix 2.

Table7.1.1b Limnological Characteristics of the Peace River within Site C Study Area

Site C Study Area	Surface Area (m^2)	Estimated Volume (m^3)	Vegetated Shoreline Length (m)[c]
Current Conditions			
Peace River	2.96E+07	8.88E+07[a]	3.17E+05
Post-inundation			
Site C Reservoir	9.33E+07	8.60E+08[b]	3.16E+05

Notes:

[a] Volume is calculated by multiplying an assumed average depth of 3 meters.
[b] Volume based on Kingston, 1977 (Table 1).
[c] The shoreline length values include the shoreline around islands.

7.1.2 Carbon Inventories

Vegetation inventories for the Study Area were based on Resource Inventory Committee Standard Terrestrial Ecosystem Map (TEM) and Standard Vegetation Resource Inventory (VRI) datasets.

Carbon content for cover types presented in the EOSD maps was derived as follows. Carbon estimates were mainly based on peer-reviewed literature values considered to be representative of the area. In some cases, professional judgement was also used to adjust these values to reflect differences in vegetation types and soil conditions.

Literature values were the main source of carbon estimates for EOSD cover type units. Open Coniferous Forest above-ground tree biomass carbon values were estimated based on an average of values contained in Perala and Alban (1982); Van Cleve *et al.* (1983); Wulder *et al.* (2008); Alban *et al.* (1978); and Fredeen *et al.* (2005). Dense and Sparse Forest above-ground tree biomass carbon values were then estimated based on percentages of the Open above-ground tree biomass value. Ground cover carbon in Open and Dense Coniferous Forest units were assumed to be the same and estimated based on Fredeen *et al.* (2005). The Sparse Coniferous Ground cover carbon was then estimated based on a

percentage of the Open and Dense Ground Cover value. Below-ground biomass (BGB) carbon in vegetation, organic horizon, and mineral soil of the Open Coniferous Forest unit were estimated based on an average of values contained in Alban *et al.* (1978); Fredeen *et al.* (2005); Ruess *et al.* (1996); and Van Cleve *et al.* (1983). Dense and Sparse Coniferous Forest units were estimated based on a percentage of the Open below-ground cover value.

The Open Deciduous Forest above-ground tree biomass carbon values were estimated based on an average of values contained in Wang *et al.* (1995b); Wang *et al.* (1995a); Grower *et al.* (1997); Perala and Alban (1982); Van Cleve *et al.* (1983); Wulder *et al.* (2008); Zasada (1977); Ruark and Bockheim (1987); and Steele *et al.* (1997). Dense and Sparse forest stand above-ground tree biomass carbon values were then estimated based on percentages of the Open value. Ground cover carbon in the Open Deciduous Forest unit was estimated based on an average of values contained in Wang *et al.* (1995b); Grower *et al.* (1997); and Perala and Alban (1982). The Dense and Sparse Deciduous ground cover carbon was then estimated based on a percentage of the Open Ground Cover value. Below-ground biomass carbon in vegetation, organic horizon, and mineral soil of the Open Coniferous Forest unit were estimated based on an average of values contained in Zasada (1977); Ruark and Bockheim (1987); Alban *et al.* (1978); Ruess *et al.* (1996); Gower *et al.* (1997); and Steele *et al.* (1997). Below-ground biomass carbon in the Dense and Sparse Deciduous Forest units were estimated based on a percentage of the Open below-ground cover value.

The Open Mixed Forest above-ground tree biomass carbon, ground-cover carbon and below-ground biomass carbon values were estimated based on the average of the Open Coniferous and Deciduous Forest units. Biomass carbon values for the Sparse Mixed Forest were then estimated based on percentages of the Open Mixed Forest value.

Values assigned for above-ground biomass carbon in Treed Wetlands were based on an average of values information contained in Vitt, *et al.* (2000); Van Cleve *et al.* (1981); Van Cleve (1970); Gower *et al.* (1997); and Steele *et al.* (1997). Above-ground biomass carbon in Shrub and Herb Wetlands was based on information contained in Moore *et al.* (2002); and Vitt, *et al.* (2000). Below-ground biomass carbon in Wetlands was estimated based on a percentage of the above-ground biomass carbon values.

Above- and below-ground biomass carbon for Shrub cover (Tall and Low) were based on an average of values information contained in Wulder *et al.* (2008); Van Cleve *et al.* (1971); and Zasada (1977). Mineral soil carbon values were based on information found in Perala and Alban (1982). Above-ground biomass

carbon for the Herbaceous category (98% Cultivated Land) was based on information found in Wulder *et al.* (2008), with total below-ground biomass carbon based on information found in Sauvé (2000).

To estimate total carbon for each cover type, total per hectare carbon values as calculated for EOSD cover type were multiplied by their respective cover type areas as measured by GIS methods; the resulting data and associated assumptions are presented in Appendix 2

Carbon emissions from CO_2 and CH_4 produced as a result of flooded vegetation decomposition were based on mass-balance model decomposition rates following first order decay models using submerged vegetation decay rates, and the estimates of carbon in the flood zone (Appendix 2). This approach allowed for alternate emission estimates to be calculated that are based on potential harvesting of trees within the flood zones prior to inundation, and other processes, such as sedimentation and biomass burial, to modify reservoir emission estimates.

7.2 SITE C CARBON CYCLE: CURRENT CONDITIONS

The following sections describe and quantify the terms used in the Site C carbon cycle and nitrogen cycle models with regards to the current and post-inundation conditions for the potential Site C project. Many of the stocks and pathways (such as those involving terrestrial plants, soils, wetlands and water bodies) may be affected by hydroelectric development, and separate models were constructed and will be described for current conditions (Section 7.3), and post-impoundment conditions (Section 7.4) scenarios.

7.2.1 Carbon Exchanges Involving Large Ruminants

The carbon exchanges, under current conditions, involving large ruminants (*e.g.,* wild moose, deer, bison and domestic cattle) are presented in this section.

LARGE RUMINANTS: Large Ruminants are known to emit large quantities of methane and according to IPCC must be considered as a potential emission where present on the landscape being modeled. In this study, we considered both wild ruminants and livestock ruminants. This stock is not a true carbon stock as the mass of carbon within ruminants is not considered in the model. Rather, this stock is included for purposes of clarity in understanding that some terrestrial vegetation is consumed and processed by large ruminants, and that the resulting emission of methane is accounted for. While some of the carbon will be emitted as organic carbon in feces, this mass of carbon is not considered in the forage or METH1 pathways, which only consider carbon being converted to CH_4 emissions. Therefore, the Large Ruminant stock contains a value of 0 as the inflows of carbon equal the outflows at each time period.

FORAGE: The Forage flow is used to indicate that vegetation consumed by ruminant vertebrates is drawn from the terrestrial vegetation stock. The mass of carbon within this flow is equivalent to the mass of carbon flowing in METH1 as the large ruminant stock is assumed constant over time at the levels determined for the current conditions or post-inundation scenarios.

METH1: In the Site C Study Area, methane emissions from ruminants includes both wild ruminants and livestock. Large wild ruminants inhabiting the Peace River watershed include moose, mule deer, and elk. These ruminant animals are considered to be the major wild vertebrate emitters of CH_4 in the Site C Study Area. Methane emissions from caribou were studied by (Lerner and Matthews, 1988) and were quantified as approximately 15 kg CH_4/animal/yr. Based on the relative body weights of the moose, mule deer, and elk, and the nominal population sizes of these animals within the Study Area (A McIntosh pers. comm., 2008), the emission rate (15 kg CH_4/animal/yr) from (Lerner and Matthews, 1988) can be pro-rated to estimate the CH_4 emission from ruminant digestive processes in the Peace River watershed in the Study Area. Lerner and Matthews (1988) did not specify the subspecies of caribou studied in their research, so it was assumed to be the smallest subspecies (woodland caribou). Based on this approach, a total ruminant CH_4 emission rate of 1.40×10^5 kg/yr (as CH_4), or 1.05×10^2 tonnes C/yr was estimated (Table 7.2.1a).

Table7.2.1a Estimated Number of Wild Ruminants and Livestock Within the Site C Study Area and Estimated Emissions per Animal for each Species

Ruminant Species	Number of Animals	Mean Animal Weight (kg)	CH_4 Emissions (kg/yr)	Herd CH_4 Emissions (kg/yr)
Wild				
Moose	123	450	42	5189
Mule Deer	232	89	8	1936
Elk	148	400	38	5550
Domestic				
Dairy Cattle	300	N/A	118	35400
Beef Cattle	1000	N/A	72	72000
Swine	300	N/A	1.5	450
Horses	150	N/A	18	2700
Bison	300	N/A	55	16500
Total Ruminant CH_4 Emissions (kg/yr)				**1.40E+05**
Total Ruminant Carbon Emissions (Tonnes C/yr)				**1.05E+02**

Notes:
N/A - not applicable, as emissions are based on species and not weight.

7.2.2 Carbon Exchanges Involving Terrestrial Plants

The following stocks and pathways represent exchanges involving the terrestrial plant community that are specific to Site C, and would be directly affected by hydroelectric development since land would be cleared and flooded as a result of the Project. Carbon is exchanged, in the form of CO_2, between the terrestrial plant stock and the atmosphere, and in the form of pollen, leaf litter, and other organic debris from terrestrial plants to the soil, as well as to nearby water bodies. The following sections detail the carbon stocks and fluxes associated with terrestrial plants.

TERRESTRIAL PLANTS: The terrestrial landscape of the Site C Study Area was classified into three vegetation types (Table 7.2.2a). GIS methods were used to calculate the area covered by each vegetation type. The carbon inventory (kg C/ha) of each vegetation type was determined through literature review (Section 7.1.2). The mass of plant carbon (kg C; including both above- and below-ground biomass, see Appendix 2) was calculated by multiplying the area of each vegetation type by the estimated carbon inventory for that vegetation type. For operational purposes, the terrestrial plant stock was constructed to include forest/shrub and farmland vegetation, but not wetlands as these are treated separately below. The estimated carbon inventory of terrestrial plants (not including wetland plants) in the Study Area (current day conditions) is 4.58×10^8 kg C or 4.58×10^5 tonnes C.

Table 7.2.2a Carbon Stored in Above Ground Biomass (AGB) and Below Ground Biomass (BGB) of all Three Vegetation Types

Cover Type	Area (ha)	BGB C Inventory (kg C/ha)	Total BGB C (kg)	AGB C Inventory (kg C/ha)	Total AGB C (kg)
Forest/shrub	4.92E+03	1.07E+05	5.28E+08	9.28E+04	4.57E+08
Farmland	6.27E+02	6.17E+04	3.87E+07	2.25E+03	1.41E+06
Wetland	6.26E+02	1.01E+05	6.35E+07	2.08E+03	1.30E+06
Total C (kg C)			**6.30E+08**		**4.60E+08**
Total C (tonnes C)			**6.30E+05**		**4.60E+05**

CDOX2: *Exchange of Carbon between Terrestrial Plants and the Atmosphere*

During the process of photosynthesis, plants absorb CO_2 from the atmosphere and transform it into sugars, starches, cellulose, and other organic compounds. During plant respiration, on the other hand, organic compounds are metabolized and CO_2 is released back to the atmosphere. Generally, slightly more CO_2 is fixed by plants than is respired, resulting in a net growth of individual plants. At a community level, net growth may also be seen. For example, as a stand of trees matures, the biomass present generally increases over time. When a steady-state condition is reached (as, for example, in a climax forest or mixed age stand where new tree growth is suppressed until older trees die and create new

space for growth), the net growth at a community level may be negligible. When catastrophic events occur (such as forest fires, storms that result in blowdown of large areas of trees, or insect infestations that kill large numbers of trees), the carbon inventory represented by the plant community may decline substantially. On a regional scale, the combined plant-soil compartments of the boreal forest region, while representing a substantial carbon stock, appear to be close to a steady state with respect to carbon storage (*i.e.,* the growth of those carbon stocks may be small on an annual basis).

Bergeron *et al.* (2007) studied the carbon exchanges in mature forest of the boreal forests of Saskatchewan, Manitoba and Quebec and estimated gross ecosystem productivity (GEP) at each location. Annual GEP varied little over the study years and locations and ranged from 565 g C/m^2 in Manitoba to 690 g C/m^2 for the Quebec site. The average annual GEP for the three sites was 613 g C/m^2. Of this GEP, annual respiration accounted for between 560 and 638 g C/m^2 and averaged at 593 g C/m^2. This resulted in a net ecosystem productivity (NEP) of 20 g C/m^2 annually. This value is very similar to that reported by Malhi *et al.* (1999) for a forest stand in boreal Saskatchewan where the NEP was estimated to be 68 g C/m^2 annually, which is more indicative of young growing forests. In this model, we assume that long-term forest/shrub vegetation growth is neutral and balanced between mortality (fire, disease, harvesting) and plant growth on the landscape. The GEP value is assumed to represent the mass of carbon sequestered by forest vegetation, while the respiration value is assumed to be the loss of carbon from decomposition of plant litter.

On farmland, the rotation period of plant cohorts in not on the scale of decades, but rather most farmland plants cycle annually. Based on crop yield reports from Alberta Agriculture (Sauvé, 2000) for the Peace Ecodistrict (representative of cropping systems of the Site C Study Area), the average carbon sequestered in cereal crops, assumed to be the most common crop type locally, is 71 g C/m^2. While it is recognized that a proportion of the farmland is covered by grasses for livestock grazing, the GEP was assumed to be similar for this cover type as they are both types of cover exhibit annual growth and senescence patterns.

Therefore, to calculate the mass of carbon sequestered by terrestrial plants, the GEPs of forest/shrub and farmland were multiplied by the area of each respective vegetation type. The area of the Site C Study Area presently covered by forest/shrub, as measured by GIS methods, is 4.92×10^7 m^2 and by farmland is 6.27×10^6 m^2. The resulting CDOX2 carbon flux of terrestrial plants is (4.92×10^7 m^2 * 613 g C/m^2) + (6.27×10^6 m^2 * 71 g C/m^2) = 3.06×10^{10} g C/yr or 3.06×10^4 tonnes C/yr.

PCARB1 and PCARB2: *Exchange of Carbon from Terrestrial Plants to Soil and Aquatic Ecosystems*
Carbon is deposited from living plants to soils (or to aquatic ecosystems) in several ways. On a landscape scale, above ground biomass (pollen, leaf litter, dead branches, and entire trees) falls to the ground and decays. Unseen, the below-ground plant biomass also undergoes processes of renewal and sloughing, and these processes appear to be even more important than the deposition of above-ground biomass (Malhi *et al.,* 1999).

Assuming that on a landscape scale, the plant biomass present in the terrestrial vegetation is at or close to a steady state (that is, the standing stock within the overall watershed is neither increasing nor decreasing), then the retained primary production in plants (*i.e.,* 3.06×10^4 tonnes C/yr) must eventually be deposited to soils or water surfaces within the watershed. On a global scale, Cole *et al.* (2007) have estimated that a very important fraction of net terrestrial ecosystem productivity may be cycled through freshwater in the form of DIC, DOC or POC.

As an upper limit, it could be assumed that all of the retained primary production in plants is deposited directly to soils; however, this would clearly be an over-estimate, since some leaf litter, pollen, and woody debris are deposited directly to water surfaces, and soils also export DOC to groundwater and surface water. As a first approximation to estimate the deposition of plant litter into the Peace River, it is assumed that any plant growth within a 10 m buffer zone along the shoreline of an aquatic ecosystem (river or lake) will be deposited into the aquatic system. This value was later varied during the current conditions model calibration process and a final buffer width of 6.7 m was obtained. Thus, an estimate of the fraction of the total plant litter loading that is deposited to aquatic ecosystems can be obtained by multiplying the shoreline length (3.17×10^5 m) by the buffer zone width (6.7 m), to provide the area of land from which GEP is deposited into waterbodies and not onto the soil. Based on this approach, the GEP from a total area of 2.13×10^7 m^2 is deposited into waterbodies. Given the annual GEP of 613 g C/m^2, this results in mass of 613 g C/m^2 * 2.13×10^7 m^2 = 1.30×10^9 g C or 1.3×10^4 tonnes C deposited into waterbodies of the Study Area annually while the GEP from the remaining area of forest/shrub land and farmland is deposited into the soils.

7.2.3 Carbon Exchanges Involving Soil

Soil: To determine the amount of carbon stored in the Soil stock it was assumed that vegetation type (forest/shrub or farmland; does not include wetlands) is related to the amount of carbon in the underlying soil. GIS software was used to calculate the area covered by soil according to vegetation type. As with the terrestrial plant carbon inventory, the soil carbon inventory (kg C/ha) for each class was estimated through literature review. The mass of soil carbon in each soil class (kg C) was calculated by multiplying

the area of each soil class by the estimated carbon inventory (Table 7.2.2a) and summing the individual classes to estimate the total soil carbon stored in the Site C Study Area (*i.e.,* $5.66x10^5$ tonnes C), with approximately $2.90x10^4$ tonnes C being added to the soil stock each year as dead plant litter. The ratio of these two numbers suggests a mean soil carbon turnover time of about 19 years, which may appear low. However, Malhi *et al.* (1999) estimated mean carbon residence times for tropical, temperate and boreal forest soils that ranged from 10 to 16 years. These low numbers indicate that much of the organic matter that is deposited to soils is readily decomposed, and that only a very small fraction is sufficiently resistant to decomposition to enter long-term storage in the soil profile.

CDOX1: *Release of CO_2 from Soil to the Atmosphere*

During the process of soil respiration, CO_2 is released to the atmosphere as organic matter is broken down by soil microorganisms. Bergeron *et al.* (2007) studied CO_2 emissions from three Canadian boreal forest soils and measured an average annual soil CO_2 flux of 593 g C/m^2. It has already been noted that the respiration rates for soil and vegetation at another boreal forest site were of similar magnitude, and, therefore, the Bergeron *et al.* (2007) value was adopted as the soil respiration rate of the forest/shrub lands. The Bergeron *et al.* (2007) values were adopted because the study provided both values for GEP and for respiration from the same sites. As the rates of respiration and photosynthesis vary among sites and over time, adopting values or closely linked processes from different studies or even averages from multiple studies can lead to imbalances within models, particularly for forest systems due to the longer stand rotation period (decades).

No studies could be found describing both GEP and respiration for farmlands, however, because crops rotate on an annual basis, the use of values from the same studies is less important than for forest systems. Sauvé *et al.* (2000) reported on the carbon balance in agricultural soils of Alberta, and estimated that on average luvisols from the Peace/boreal transition area emitted an average of 29.8 g C/m^2 annually.

To calculate the flux of CO_2 from terrestrial soils to atmosphere, the area of each forest/shrub land ($4.92x10^7$ m^2) and farmland ($6.27x10^6$ m^2) was multiplied by the soil respiration rates of 593 g C/m^2 an 29.8 g C/m^2 for forest/shrub and farmland, respectively. This yielded an average CDOX1 flux of $2.90x10^7$ kg C/m^2 or 2.90x104 tonnes C annually.

DOC1 and DOC2: *Release of DOC from Soil and Wetlands to Rivers and Lakes*

In determining the amount of soil organic matter released to freshwater aquatic ecosystems, it is important to consider the carbon stored in soil, and how it interacts with groundwater and overland flows.

Runoff is considered to be the amount of water conveyed by the Peace River from its watershed. It originates as rain or snow, and is affected by evaporation and transpiration. The average annual runoff rate in the Peace River watershed is approximately 0.47 m/yr (*i.e.,* 470 mm of precipitation over the entire watershed each year) (Environment Canada, 2008c). As this water flows through or over soil, some forms of organic carbon may become dissolved in the water and be transported as dissolved organic carbon (DOC) to nearby water bodies. Particulate carbon, either organic or inorganic, may also be picked up in surface runoff and flow into rivers and lakes. Concentrations of DOC in the Peace River were not readily available, but total organic carbon (TOC) and total inorganic carbon (TIC) were obtained (Environment Canada, 2008c). Assuming that the origins of the TOC and TIC originated largely from terrestrial sources, the mass of carbon flowing from surface runoff is then equal to the concentration of TOC and TIC in the Peace River multiplied by the precipitation rate for the area and the terrestrial surface area. Based on this calculation, the preliminary estimate for DOC1 is 7.75×10^4 kg C/yr or 7.75×10^1 tonnes C/yr. This value does not need to be corrected for rain that falls upon water surfaces, since this rain would contain negligible DOC, and is implicitly corrected for, as it would dilute the DOC concentration in runoff received directly from land areas. If DOC is actively degraded while in the water of the Peace River, then this first estimate would underestimate the true value.

The value for DOC1 does need to be corrected for the value of DOC2 (the DOC flux from wetlands). Wetlands are rich sources of DOC. The DOC concentration in water draining in boreal wetlands may be much higher than other natural water bodies (Waddington and Roulet, 1997), thus a value of 37.5 mg/L will be assumed here for the Peace River watershed (based on professional judgment). By estimating the volume of water draining from wetlands (assuming runoff of 0.47 m/yr and a wetland area of 6.26×10^6 m^2) in the Peace River watershed, and multiplying it by the estimated DOC concentration of 37.5 g/m^3, the DOC2 flux from wetlands to the Peace River is estimated to be 1.09×10^6 kg C/yr, or 1.09×10^3 tonnes C/yr for the Site C Study Area.

METH4: *Exchange of CH_4 between Soil and the Atmosphere*

Some soil microbes can oxidize methane as a way to meet their energy requirements, while others decompose organic matter under anaerobic conditions and produce methane as a by-product. The abundance of soil microbes and the biochemical processes they carry out vary widely (according to season, soil type, and within the soil profile). Some studies suggest that soils are a net sink of CH_4 while others indicate that soils may be a net source. For the purposes of this study, the mean value (-0.095 g C/m^2/yr) of multiple studies (Burke *et al.,* 1997; Savage *et al.,* 1997; Billings *et al.,* 2000; Potter *et al.,* 2001; Bubier *et al.,* 2005) in boreal and prairie parkland forest ecoregions was adopted to model the soil to atmosphere CH_4 flux for forest/shrub land. For farmland, the mean value (-0.108 g C/m^2/yr)

from multiple studies (Mosier *et al.,* 1996, 1997; Wang *et al.,* 1999) was also used. These adopted value of resulted in soils of both forest/shrub and farmland being considered weak methane carbon sinks. When multiplied by their respective land areas, the annual METH4 flux value was -5,352 kg C/yr or -5.34 tonnes C/yr.

7.2.4 Carbon Balance for Soils

Taking into consideration the estimated input of carbon to the Study Area soils ($2.92x10^7$ kg C/yr), and the estimated losses of carbon from soil to the atmosphere via microbial respiration ($2.90x10^7$ kg C/yr), losses from soil to water as OC and IC ($7.75x10^4$ kg C/yr), and metabolism of atmospheric methane ($-5.35x10^3$ kg C/yr), the carbon balance for soils appears to indicate a net storage of approximately $1.36x10^5$ kg C/yr or 136 tonnes C/yr. When divided by the land area of the watershed, this would suggest a carbon storage rate of approximately 23 g/m^2/yr. This value is perhaps on the high side, as other studies have suggested that the net carbon storage rate in boreal forest soils is somewhat lower (approximately 6 g C/m^2/yr in boreal region soils, Harden *et al.,* 2000); however, it would readily be compensated for by a small change in any of the other calculated units (particularly microbial respiration of CO_2 back to the atmosphere or if the soil DOC flux is underestimated due to the assumption that DOC is not degraded in the river) and their difference may be related to the lower latitude of the study site, which could result in greater accumulation rates.

7.2.5 Carbon Exchanges Involving Wetlands

The Wetland stock (Table 7.2.2a) includes the carbon stored in living and non-living wetland vegetation (including peat) and the underlying sediment or soil. The expected carbon inventory (kg C/ha) of the plant and soil components of wetlands was estimated through literature review. GIS methods were used to calculate the area covered by wetlands (626 ha or $6.26x10^6$ m^2). The mass of wetland carbon (kg C) was calculated by multiplying the area of wetland by the estimated mass of above ground biomass carbon ($2.08x10^3$ Kg C/ha) and BGB carbon ($1.01x10^5$ kg/ha). The Peace River watershed wetlands are thus estimated to contain $6.48x10^7$ kg or $6.48x10^4$ tonnes C, mostly in the form of peat.

METH2: *Release of Carbon (CH_4) from Wetlands to the Atmosphere*

Wetlands may absorb and emit CH_4 through various biological processes. Due to the anaerobic characteristics of most wetlands (below a surface oxidized layer), methanogenesis is an important process in wetlands, although both methane production and methane oxidation may occur at rapid rates in different strata of the same wetland profile, and methane may be released by a combination of diffusive and bubble processes. Bubbles, in particular, may be released sporadically and in a patchy or localized manner making accurate measurements difficult to obtain. A review of several publications reporting

wetland and peatland CH_4 fluxes (Klinger *et al.,* 1994; Bellisario *et al.,* 1999; Huttunen *et al.,* 2003; Bubier *et al.,* 2005; Blais *et al.,* 2005; Fluxnet 2008) demonstrated the variability of this parameter. Overall, the net flux of CH_4 ranged from 0 to 132 g C/m^2/yr, with most values between 2 and 10 g C/m^2/yr. Some of these values were estimated and reported for the growing season only, while others were averaged over the full year. To standardize values reported on a daily emission rate for only the growing season, the daily rates were multiplied by 223, which were estimated to be the biologically active period in the Study Area. This was determined as the number of days where the mean daily temperature exceeded 0 Celsius (Environment Canada 2008d). The median 7.0 g C/m^2/yr of values listed was adopted as the METH2 flux value. When multiplied by the area of the Site C Study Area covered by wetland ($6.26x10^6$ m^2), the rate of carbon released as methane from wetlands to the atmosphere is estimated to be $4.39x10^4$ kg C/yr, or 43.9 tonnes C/yr.

CDOX4: *Exchange of Carbon (CO_2) Between Wetlands and the Atmosphere*

In a review of the CO_2 fluxes between wetlands and the atmosphere, most research has shown that wetlands absorb significant amounts of carbon through photosynthesis (Klinger *et al.,* 1994; Waddington and Roulet, 2000; Whiting and Chanton, 2001; Moore *et al.,* 2002; Blais *et al.,* 2005; Fluxnet, 2008). The median of reported boreal wetland values indicated that wetlands sequester approximately 85 g C/m^2 annually. These values ranged from between -1165 to 683 g C/m^2/yr. These minimum and maximum values represent reported extreme conditions and the median value seems reasonable given that it would likely represent the long-term average storage of carbon within wetlands particularly since wetlands serve as important carbon storage areas on the landscape.

7.2.6 Carbon Exchanges Involving Rivers and Lakes

Rivers and Lakes: The Rivers and Lakes carbon stock estimate is based on the measurement of TIC and TOC concentrations in the Peace River. These concentrations are assumed to include the majority of carbon found in the water of rivers and lakes. These values used for these measures were averaged from long-term measurements of TIC and TOC in the Peace River by Environment Canada at their site above the Alces River. The mass of carbon stored within the river is the product of the volume of water and the concentrations of TIC (18.9 mg/L) and TOC (3.3 mg/L). These concentrations were assumed to equally apply to ponds and lakes

The present day standing volumes of water for the Site C Study Area are based on the surface area of rivers and lakes found within the Study Area and the estimated mean depth of 3 m assumed for both water body types. This depth is relatively shallow for larger lakes, but given that the largest lake within the Study Area is on the order of several hectares (total lake area = 13.6 ha), this depth was assumed

representative. The surface area of water bodies was calculated using GIS methods outlined in Section 7.1. According to these calculations, the mass of carbon in the Rivers and Lakes pool is estimated to be 1.99×10^6 kg C, or 1.99×10^3 tonnes C.

CDOX3: The exchange of CO_2 from lakes and rivers to the atmosphere occurs mainly because fresh water bodies tend to be supersaturated with CO_2 as a result of the decomposition of natural organic matter (in exactly the same way that soils are a net source of CO_2 to the atmosphere due to the decomposition of organic matter). To calculate the flux of CO_2 evading across the water-air interface, the following equation (Hesselin *et al.,* 1980) is typically used:

$E = D\{CO_2\}/Z$,

Where:

E = the evasion flux of CO_2 (g $CO_2/m^2/d$),

D = the molecular diffusion coefficient of CO_2 in water (1.64×10^{-4} m^2/d),

$\{CO_2\}$ = the excess CO_2 concentration in water (CO_2 dissolved - CO_2 equilibrium, g/m^3), and

Z = the stagnant boundary film thickness (2.0×10^{-4} m) at the water-air interface.

However, due to the lack of information on CO_2 concentrations in the Peace River, a review of the CO_2 surface to air emission fluxes was carried out. Emission fluxes of CO_2 from rivers and lakes varies significantly across the landscape. Soumis *et al.* (2004) found that pH was most significant determinant of emissions from reservoirs in Western North America. Tremblay *et al.* (2005) reviewed emissions from water bodies including rivers, lakes and reservoirs, including those in British Columbia. Emission fluxes of CO_2 varied in rivers from 1501 to -439 mg $CO_2/m^2/d$, and averaged 462. Given the average pH of the Peace River above Alces is approximately 8.0 measured between 2003 and 2008 (Environment Canada, 2008c), the regression equation provided by Soumis *et al.* (2004) would result in an emission of 284 mg $CO_2/m^2/d$, which is very similar to 462, which based on this equation would require an average pH of 7.9, a value well within the reported pH range of 6.1 and 8.4. Therefore, the value of 462 mg $CO_2/m^2/d$ was initially used in the current conditions model. Because of the uncertainty around this parameter, it was the second parameter varied during the calibration process of the current conditions model (see Section 7.6).

Based on anecdotal evidence, the Peace River in the Site C Study Area typically does not freeze during the winter due to warmer more turbulent water being discharge from the upstream reservoirs. For the purposes of this model, the river was assumed to remain open year-round. However, as temperature decreases, decomposition rates fall at a rate of approximately two-fold for every 10 degrees reduction in temperature according to the Q10 effect. Furthermore, gas saturation levels increase with decreasing temperature. Therefore, it was assumed that the 462 mg $CO_2/m^2/d$ would be representative of the summer period (223 d) and the winter period (142 d) would have an emission flux equal to ½ the summer flux. After the calibration process, the summer period emission flux was equal to 615 mg $CO_2/m^2/d$, which is slightly higher than the mean for BC rivers, but well within the range of values and also closer to the value of 920 mg $CO_2/m^2/d$ reported by Tremblay *et al.* (2005) for the Williston reservoir directly upriver. The winter period flux was then equal to 308 mg $CO_2/m^2/d$.

For lakes in the Site C Study Area, a value of 763 mg $CO_2/m^2/d$ was used to represent lake CO_2 diffusive fluxes. This value is based on nearby Charlie Lake, as reported in Tremblay *et al.* (2005). As this value is based on the summer diffusive flux, and lakes in this area are ice-covered during winter, this rate was assumed to apply to the summer period of 223 d only. While it is acknowledged that some decomposition occurs during winter and ice-breakup results in a significant immediate release of gases that have accumulated over the winter, this flux rate is based on the summer period and applied to the spring and fall when it would be somewhat lower than 763 mg $CO_2/m^2/d$. This then compensates for the gases released from winter decomposition.

Based on these emission rates and the summer and winter periods of 223 and 142 days, respectively, the annual flux of carbon from rivers and lakes to the atmosphere under current conditions is approximately $1.47x10^6$ kg C/yr or $1.47x10^3$ tonnes C/yr.

METH3: As with CDOX3, the exchange of CH_4 from lakes and rivers to the atmosphere is controlled by the concentration of CH_4 in the water, and molecular diffusion across the water-air interface. Because no values for BC rivers were available, the mean of values from Quebec Rives (Tremblay *et al.,* 2005) were assumed to apply to this study. This is considered a conservative approach as these eastern rivers typically have a lower pH, particularly in the boreal region, than western rivers and thus would emit higher concentrations of CH_4. Values from Quebec rivers ranged from -7.9 to 10.7 mg $CH_4/m^2/d$ and the mean value of 3.3 mg $CH_4/m^2/d$, which was very similar to the Charlie Lake value of 2.7 mg $CH_4/m^2/d$ (Tremblay *et al.,* 2005), was used in this model. The value from Charlie Lake was also applied to the small lakes within the Study Area.

The emissions estimate from rivers is based on summer flux values that are prorated to 50% the summer value for the winter period of 142 days as was done for CDOX3. This resulted in an annual emission rate of $2.16x10^4$ kg C/yr of $2.16x10^1$ tonnes C/yr.

SEDIMENT: Sediments have been accumulating in natural water bodies of the Peace River watershed since the end of the last glaciation, approximately 10,900 years before present in the Peace River area (Marshall and Clarke, 1999). The amount of sediment stored in the watershed, and the annual flux of dry mass from water to sediment, can be estimated by the following calculations and assumptions.

Assuming the average river sediment depth is one metre, and the primary substrate is cobble size rock material which has a porosity of 35%, that results in 0.35 m^3 of pore space per m^2 of riverbed. Conservatively assuming 50% of the pore space is filled with sediment with a bulk density of 1700 kg/m^3, and that the carbon fraction of the sediment is 0.01 or 1% (sediment carbon content typically ranges from 0% to 7% with lower values for faster more oxygenated waters), then the mass of sediment carbon per m^2 of riverbed area is calculated as follows:

$$\text{Sediment Carbon (kg/m}^2\text{)} = 1\ \text{m} * 0.35 * 0.5 * 1700\ \text{kg/m}^3 * 0.01$$

This results in a conservative estimate of 2.98 kg C/m^2 of riverbed area. With an estimated time since glaciations being 10,900 years, this would result in an average sedimentation rate of 0.000273 kg C/m^2 annually. Assuming that sediment deposits on only 50% of the river bed due to annual scouring/deposition processes and that the river surface area is $2.96x10^7$ m^2, this results in a deposition rate of 8,080 kg C/yr . While it is likely the rate of sedimentation is non-linear over time, a linear accumulation rate was assumed in the model for simplicity. These sedimentation rates are likely low for most river systems, but from the perspective of the current conditions model, this is a conservative estimate.

For lake sediment, carbon content estimate is based on Ruck *et al.* (1998) who studied the sediment in a small lake in the Okanagan valley. Ruck *et al.* (1998) measured the sediment depth in the deepest part of the lake to be approximately 15 m and the bottom layer of sediment was carbon dated at 4,000-5,000 years before present (a value of 5,000 was used for this study). This means that on average the rate of sediment accumulation was approximately 3 mm/yr, which is consistent with a study by Gilbert and Butler (2004) who reported a sediment deposition range of 1.8 to 16 mm/yr for a west slope, BC, lake, and who reported the sediment bulk density to be 1210 kg/m^3. If we assume that sediment depth at the shore is 0 m (*i.e.,* lens shaped sediment layer), then the average sediment depth of the lakes is 15/2 m. Therefore,

assuming 5% carbon by mass of sediment for lake sediment and a lake area of 18.4 ha (184,000 m^2), based on GIS measurements for lakes and ponds, the estimated mass of carbon in Lakes of the Study Area is $8.07x10^7$ kg C or $1.79x10^4$ kg C/yr and the estimated annual C deposition rate is 0.0975 kg C/m^2.

RIVER FLOW: In this system, river flow was divided into Inflow, which represents the mass of carbon flowing into the Peace River within the Study Area, and Outflow, which is the mass of carbon flowing out of the Peace River at the point where the Site C dam would be constructed. The mass of carbon in river flow represents the sum of the organic (particulate and dissolved organic matter of aquatic, terrestrial or wetland origin) and inorganic (dissolved CH_4, CO_2, bicarbonates, and carbonates) carbon in the water. The carbon mass in the Inflow is equal to the volume of water leaving the system and the concentration of TOC and TIC (defined above) in that water. The volume of water flowing out of the Study Area at approximately the Site C dam location (1307 m^3/s) was obtained from Environment Canada (2008c; Peace River above Pine River station). The mass of carbon flowing out of the system is equal to the Inflow less any carbon deposited into the river sediment.

Therefore the total carbon Inflow into the Site C Study Area is $9.20x10^8$ kg C/yr and the Outflow is also 9.20x108 kg C/yr as sedimentation under current conditions is much less than the mass of carbon contained in the water volume.

7.2.7 Current Conditions Model Calibration

Modeling ecosystem GHG emissions requires adopting reported information from various studies most representative of the modeled system, and incorporating assumed values based on professional judgement where no information is available. As mass balance models, such as the carbon cycle model, interconnect numerous flows and stocks, flux values obtained from various sources normally do not lead to systems that are adequately balanced at initiation. Therefore, some model calibration is required to balance fluxes.

The calibration process for the current conditions model was based on two criteria: that the Terrestrial Vegetation stock demonstrate a neutral carbon balance (± 5 kg C/100 yrs) over the modeled time period, and that the Lakes and Rivers stock also demonstrate a neutral carbon balance over the modeled time period.

The first criterion assumes that the mass of carbon stored in terrestrial vegetation will remain the same over the long-term and at large spatial scales as some stands will die and release carbon while others will grow and sequester carbon. In order to calibrate the model for neutral carbon balance in Terrestrial

Vegetation, the area width used to calculate PCARB2 was varied. Initially, this value was set to a width of 10 m, and the Terrestrial Vegetation carbon stock decreased in mass. A carbon balance was obtained when the area width of PCARB2 was set to value of 6.7 m. This suggested that the mass of carbon being transferred from terrestrial vegetation directly into Lakes and Rivers is 33% less than anticipated in this system. Due to the uncertainty around this value, it is deemed reasonable based on professional judgement.

The second criterion assumes that the mass of carbon stored in Lakes and Rivers will remain the same over time. This assumes that the concentration of TIC and TOC, and the water volume remain constant over time. This assumption is based on long-term monitoring of water flow and quality at various stations along the Peace River. In order to calibrate the model for neutral carbon balance in the Rivers and Lakes stock, the CDOX3 emission was varied because of the variability in this flux among systems and the mass of carbon involved in the flux. Initially this value was set to 462 mg $CO_2/m^2/d$ and the Rivers and Lakes stock demonstrated an increasing carbon stock over time. A final calibration constant of 1.332 was applied to this value to obtain carbon balance with this stock. The final value of 615 mg $CO_2/m^2/d$ is slightly higher than the mean for BC rivers, but well within the range of values and also closer to the value of 920 mg $CO_2/m^2/d$ reported by Tremblay *et al.* (2005) for the Williston reservoir directly upriver.

7.3 PEACE RIVER SITE C NITROGEN CYCLE: CURRENT CONDITIONS

Compared to CO_2, nitrous oxide (N_2O) has a 100-year global warming potential (GWP) of 310; meaning it is capable of trapping 310 times more heat in the atmosphere than CO_2 (IPCC, 1996); and atmospheric concentrations of N_2O have been rising since pre-industrial times from approximately 270 ppb to 317 ppb in 2006 (IPCC, 2007). As a consequence, N_2O is an important contributor to the global anthropogenic greenhouse effect (Granli and Bøckman, 1994), representing approximately 8% of the total global GHG emissions, 40% of which are believed to be caused by human activities (IPCC, 2007). Of these anthropogenic N_2O emissions, 51% originate from Agricultural sources, 26% from agricultural livestock, 17% from industry, and 6% from biomass burning (Reay, 2009).

Nitrous oxide emissions measured from freshwater reservoirs, in all major climate types, have been considered to be negligible (Hendzel *et al.,* 2005; UNESCO, 2006; Diem *et al.,* 2008). Although there are few publications with supporting data on N_2O emissions from flooded lands, it is believed that N_2O emissions are generally very low in watersheds with little anthropogenic inputs (IPCC, 2006). Therefore, for the purpose of the Site C Project, N_2O emissions are included in the GHG estimate due to presence of agricultural activities within the Study Area, but only consider emissions from these activities.

Agricultural nitrous oxide emissions originate mainly from crop and livestock production. Several N_2O sources originate from cropping practices, including: crop residues; fertilizer usage; fuel combustion; manure application; and nitrogen fixing crops. Sources of N_2O emissions from livestock production include animal excretions/wastes and indirect combustion of fuel (Kulshreshtha *et al.,* 1999).

Given these considerations, a simple N_2O mass balance model was constructed to estimate emission from agricultural activities, which were divided into crop production emissions "Crop" and livestock production emissions "Livestock" shown in Figure 7.3a.

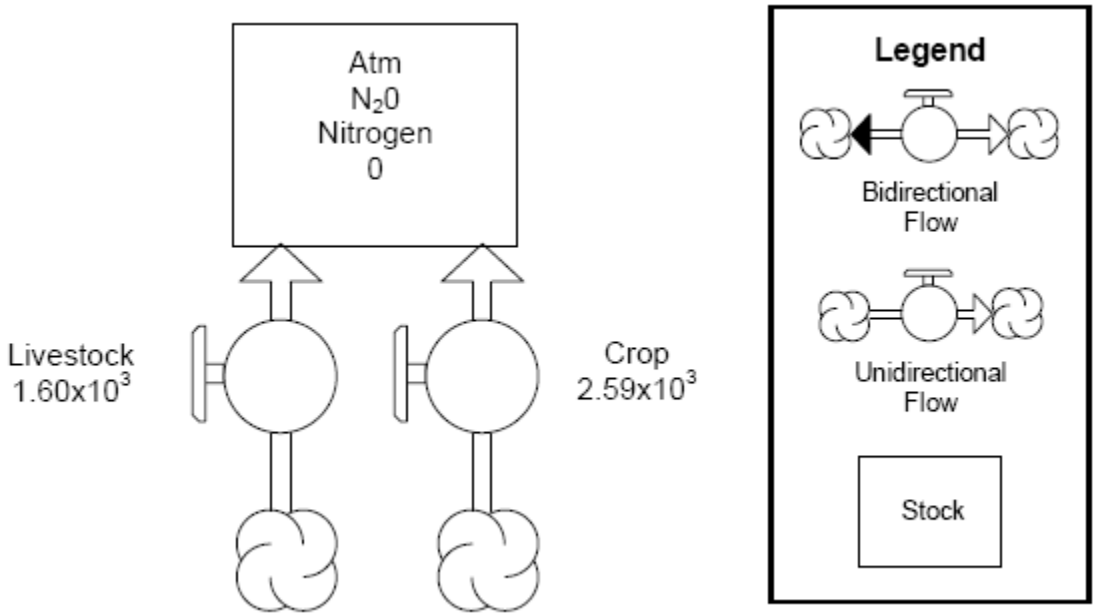

Figure 7.3a Conceptual Model of Site C Study Area Nitrous Oxide Emissions

CROP: Nitrous oxide emissions from crop production were estimated based on measurements from the Peace Ecodistricts of Alberta (Sauvé, 2000). These measurements we chosen as they are thought to best represent conditions and cropping systems (predominantly grain crops) of the Site C Study Area. The gross nitrous oxide emissions factor from crop production is estimated to be $6.49x10^{-3}$ tonnes N_2O/ha/yr; of which 27.1% originated from soil, 65.6% from crop residue, and 7.3% from fertilizer application (Sauvé 2000).

Based on the current surface area of agricultural land within the Study Area ($6.27x10^6$ m^2), the total corresponding N_2O emissions from crops are estimated to be 1,262 tonnes CO_2e/yr prior to impoundment.

LIVESTOCK: Livestock within the Site C Study Area were assumed to include beef (1000 head) and dairy cattle (300 head), swine (300 head), horses (150 head) and bison (300 head). This estimate is speculative based on professional opinion and consultation with BC Hydro. According to Kulshreshtha *et al.* (2002), N_2O emission sources associated with livestock originate from animal waste due to grazing activities, manure application and from waste handling systems (Table 7.3a). Based on the nominal population sizes of these animals and the total livestock emission factors for each, N_2O emissions from livestock under current conditions are estimated to be 781 tonnes CO_2e/yr.

Table 7.3a N2O Emissions Originating from Livestock

	Number of Head	Grazing Animals (kg N/head/yr)	Manure Application (kg N/head/yr)	Manure Storage (kg N/head/yr)	Total from Livestock (kg N/head/yr)
Dairy Cattle	300	0	0.788	0.52	1.308
Beef Cattle	1000	0.65520	0.078	0.112	0.845
Swine	300	0	0.175	0.065	0.240
Horses	150	0.524	0.062	0.090	0.692
Bison	300	0.489	0.058	0.084	0.631

Notes:
Data for dairy cattle, beef cattle and Swine from Kulshreshtha *et al.* (2002). Data for horses and Bison were unavailable and thus pro-rated based on relative body mass of a beef cow.

7.4 PEACE RIVER SITE C CARBON MODEL: POST-INUNDATION

After inundation, many of the stocks and fluxes will be altered from current conditions. Generally, terrestrial stocks and fluxes will decrease whereas aquatic stocks and fluxes will increase due to the impounding of the Peace River valley. The projected effects of inundation on stocks and fluxes were examined over a 100 year period. Certain stocks and fluxes described in the current conditions model will not be substantially altered by the inundation of the Peace River; whereas others will change and the effect of inundation is outlined below. In the post-inundation model, one addition stock (decaying biomass) and one flow (decay) were added to represent the mass of carbon flooded during the reservoir inundation. The conceptual model of carbon cycling in the Site C Study Area, post-inundation is shown in Figure 7.4.2a. Unless otherwise noted, the methods and information sources used to calculate these stocks and fluxes are the same as those presented in Sections 7.2 and 7.3 and are not repeated here.

7.4.1 Carbon Exchanges Involving Large Ruminants

The post-impoundment carbon exchanges involving large ruminants (*e.g.,* wild moose, deer, bison and domestic cattle) are presented in this section.

LARGE RUMINANTS: As the above water land of the Site C Study Area post-inundation is reduced to a 30 m buffer beyond the maximum flood level, it was assumed that all livestock within the Study Area would be removed from the Study Area and that wild ruminant populations would be reduced to

approximately 13% of current condition population levels in a manner proportional to the reduction in land surface area post-impoundment (Table 7.4.1a).

FORAGE: Under post-impoundment conditions, the forage pathway does not change. The forage pathway is simply used to indicate that vegetation consumed by ruminant vertebrates is drawn from the terrestrial vegetation stock. The mass of carbon within this flow is equivalent to the mass of carbon flowing in METH1 as the large ruminant stock is assumed constant at the respective levels estimated for the current conditions or post-inundation time periods.

METH1: Post-impoundment, the METH1 pathway functions identically to the current conditions model. Methane emissions are based on the number of livestock and wild ruminants inhabiting the Study Area and their respective emission rates (see METH1 in Section 7.3.1). Impounding of portions of the lower Peace River valley will reduce the Study Area by approximately 87%, and post-impoundment, the wild ruminant population and, concomitantly, METH1 emission from wild ruminants is anticipated to reduce by approximately 87%, assuming a land-proportional population. As livestock require larger contiguous tracts of land and are not frequently found along buffer zones due to practice restrictions in some jurisdictions, it was assumed that during post-impoundment no livestock would be found within the Site C Study Area. Based on this approach, a total wild ruminant CH_4 emission rate of $1.92x10^3$ kg/yr (as CH_4), or 1.44 tonnes C/yr was estimated (Table 7.4.1a).

Table 7.4.1a Methane Emissions of Ruminant Vertebrates in the Site C Study Area Post-inundation

Ruminant Species	Number of Animals	Mean Animal Weight (kg)	CH_4 Emissions (kg/yr)	Herd CH_4 Emissions (kg/yr)
Wild				
Moose	15	450	42	1013
Mule Deer	30	89	8	267
Elk	19	400	38	638
Domestic				
Dairy Cattle	0	N/A	118	0
Beef Cattle	0	N/A	72	0
Swine	0	N/A	1.5	0
Horses	0	N/A	18	0
Bison	0	N/A	55	0
Total Ruminant CH_4 Emissions (kg/yr)				**1.92E+03**
Total Ruminant Carbon Emissions (Tonnes C/yr)				**1.44E+00**

Notes:
N/A - not applicable as emissions are based on species and not weight.

7.4.2 Carbon Exchanges Involving Terrestrial Plants

TERRESTRIAL PLANTS: The terrestrial plant stock of the Peace River watershed was classified into two dominant vegetation types (Table 7.4.2a), including forest/shrub and farmland vegetation types. GIS methods were used to calculate the area covered by each vegetation type. Post-inundation, these areas will decrease significantly within the spatial context of the Site C Study Area. This will result in a reduction of $3.98x10^8$ kg C (87 percent) from the vegetation carbon stock to a post-inundation total of $6.00x10^7$ kg C or $6.00x10^4$ tonnes C. Under the default scenario, all vegetation inundated was assumed to be either cleared or left within the flood zone, regardless of the fate of carbon. Within the flood zone vegetation all carbon was assumed to be released as CO_2 according to IPCC guidelines (IPCC 2003, 2006).

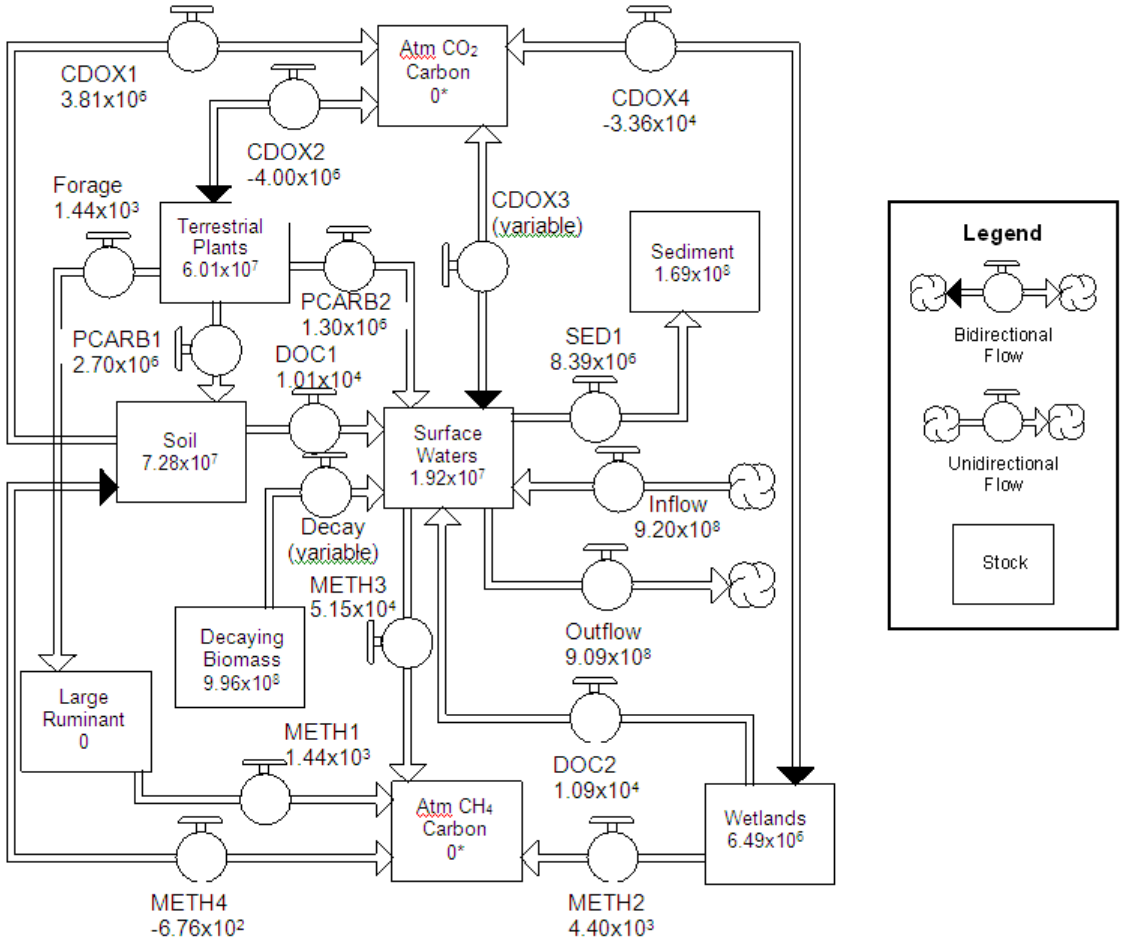

Figure 7.4.2a Conceptual Model of Carbon Cycling in the Peace Watershed Post-inundation

Notes:
The indication '2 refers to post-inundation stocks and pathways that have parallels in the current conditions model.

Printed copies not controlled

Table7.4.2a Carbon Stored in Below Ground Biomass (BGB) and Above Ground Biomass (AGB) of the Site C Study Area, Post-inundation

Cover Type	Area (ha)	BGB C Inventory (kg C/ha)	Total BGB C (kg)	AGB C Inventory (kg C/ha)	Total AGB C (kg)
Forest/shrub	6.46E+02	1.07E+05	6.92E+07	9.28E+04	6.00E+07
Farmland	5.76E+01	6.17E+04	3.56E+06	2.25E+03	1.30E+05
Wetland	6.27E+01	1.01E+05	6.36E+06	2.08E+03	1.31E+05
Total C (kg C)			**7.92E+07**		**6.02E+07**
Total C (tonnes C)			**7.92E+04**		**6.02E+04**

CDOX2: *Exchange of Carbon between Terrestrial Plants and the Atmosphere*

With a reduction in the area of land of approximately 87 percent occupied by terrestrial plants within the lower watershed post-inundation, there will be a concomitant reduction of $2.66x10^7$ kg C/yr in the net CO_2 carbon flux from the atmosphere to terrestrial plants two years post-inundation and thereafter. This reduction is directly related to the area and vegetation types (and growth) lost as inundation of the river will not otherwise affect the processes of this carbon flux. By multiplying the NEP of plants (613 g C/m^2/yr; Section 7.3.2) by the amount of land that is covered by terrestrial plants post-inundation ($6.46x10^6$ m^2), the net CO_2 flux from atmosphere to plants for the entire Peace River watershed (post-inundation) is estimated to be $4.00x10^6$ kg C/yr, or $4.00x10^3$ tonnes C/yr.

PCARB1 and PCARB2: *Exchange of Carbon from Terrestrial Plants to Soil and Aquatic Ecosystems*

Similar to CDOX2, the estimates of carbon exchange between terrestrial plants and soil will decrease in a manner directly proportional to the amount of area lost to flooding. However, as the amount of carbon lost to the aquatic system, based on the method of estimation, depends on the length of shoreline riparian buffer strip, this flux will increase in proportion to the new shoreline length. Thus, PCARB2 (the deposition of carbon to the aquatic system) is estimated by multiplying the post-inundation shoreline length ($3.16x10^5$ m) by the buffer zone width (6.7 m), and dividing this value by the land area of the watershed ($6.46x10^6$ m^2). Based on this approach, 33 percent of the retained primary production ($4.00x10^6$ kg C/yr x 0.33 = $1.31x10^6$ kg C/yr) would be deposited to aquatic ecosystems, and approximately 67 percent ($4.00x10^6$ kg C/yr x 0.67 = $2.69x10^6$ kg C/yr) would be deposited directly to soils (PCARB1).

7.4.3 Carbon Exchanges Involving Soil

Soil: As with the vegetation carbon stock, carbon stored in the soil is directly proportional to the area of terrestrial soil. These areas will decrease by a relatively large amount (87 percent) in the context of the

Site C Study Area post-inundation and the amount of carbon stored in the soil, therefore, will decrease by $4.97x10^8$ kg C to a new initial value of $7.27 x10^7$ kg C.

CDOX1: *Release of CO_2 from Soil to the Atmosphere*

As the soil area decreases due to inundation, the CO_2 carbon flux from soil to the atmosphere (CDOX1) will also decrease in proportion to the land area of each soil type (forest/shrub and farmland). The area of forest shrub will decrease by 87% or $4.28x10^7$ m^2, and the farmland area will decrease by 91% or $5.7x10^6$ m^2 post-inundation. The rate of carbon emitted as CO_2 (g C yr-1) from the soil to the atmosphere, is calculated by multiplying the unit flux (-0.03 kg C/m^2/yr for farmland and 0.59 kg C/m^2/yr for forest/shrub soils) by the amount of land (m^2) that is covered by terrestrial plants (crop or tree/shrub). The estimated flux of CO_2 from soil to the atmosphere as a result of the respiration of soil microbes is therefore $3.81x10^6$ kg C/yr, or $3.81x10^3$ tonnes C/yr.

DOC1 and DOC2: *Release of DOC from Soil and Wetlands to Rivers and Lakes*

DOC1 represents the flux of organic carbon and inorganic carbon released from the soil and transported to rivers and lakes through overland flows and groundwater. The mass of carbon in the surface runoff was determined based on the surface water concentrations of TIC (18.9 g/m^3), and TOC (3.38 g/m^3), the annual runoff rate 0.47 m/yr and the area of land ($7.03x10^6$ m^2), and was subsequently corrected to account for DOC2 (the DOC flux from wetlands), which appears to comprise approximately 15 percent of the overall DOC flux to the river water. Post-inundation, while there would be a change in the land contributing soil carbon to the Peace River within the Site C Study Area through runoff, in the context of the entire watershed, this land area likely represents a very small fraction (<1%) and it was assumed that flow and TIC or TOC concentrations would not change as a result of inundation. Therefore, the DOC1 and DOC2 fluxes decreased proportional to the amount of land in forest/shrub and farmland, and in wetland, respectively. Post-inundation, the DOC1 flux was 10,083 kg C/yr and the DOC2 10,947 kg C/yr.

METH4: *Exchange of CH_4 between Soil and the Atmosphere*

As with the exchange of CO_2 from the soil to the atmosphere, the CH_4 flux will decrease post-inundation as the area of terrestrial soil is reduced. Therefore, following the same approach as used in the pre-inundation scenario, the rate of CH_4 emission from forest/shrub soil is assumed to be -0.095 g C/m^2/yr, while the CH_4 emission from farmland soil is assumed to be -0.11 g C/ m^2/d,. The area of the watershed (m^2) covered by forest/shrub soil post-inundation is $7.03x10^8$ m^2 and farmland soil is $6.27x10^5$ m^2. The rate of CH_4 release from terrestrial soils to the atmosphere (mg C/yr), calculated by multiplying the unit CH_4 fluxes by their respective area of the watershed covered by terrestrial soil, is -676 kg C/yr, or -0.676 tonnes C/yr.

Carbon Balance for Soils

Post-inundation, the estimated input of carbon to the Study Area soils from terrestrial vegetation ($2.70x10^6$ kg C/yr), and the estimated losses of carbon from soil to the atmosphere via microbial respiration ($3.81x10^6$ kg C/yr), losses from soil to water as OC and IC ($1.08x10^3$ kg C/yr), and metabolism of atmospheric methane ($-6.76x10^2$ kg C/yr), the carbon balance for soils appears to indicate a net loss of approximately $-1.12x10^6$ kg C/yr or 1120 tonnes C/yr. While it is counter-intuitive to consider that current condition soils were a net sink, and post-impoundment soils were estimated to be a source or carbon, this is entirely due to the limited geographic boundaries of the Study Area. As the area of vegetation carbon deposited into the aquatic system does not change post impoundment (6.7 m * shoreline length), the area of soil does decrease. In natural systems, some litter would fall on adjacent land and soils within the Study Area would receive litter from land outside the Study Area. This loss of carbon from soils does not impact the estimates of GHG.

7.4.4 Carbon Exchanges Involving Wetlands

The area of wetlands in the watershed post-inundation will decrease by 563 ha (Table 7.4.5a). This results in a decrease of $1.64x10^5$ kg C/yr ($1.86x10^{-4}$ Pg C) stored in wetlands and a post-inundation amount of carbon stored in wetlands based on the new area of wetlands and the wetland carbon inventory of 1.82 $x10^4$ kg C/yr or 18.2 tonnes C/yr, mostly in the form of peat.

METH2: *Release of Carbon (CH_4) from Wetlands to the Atmosphere*

Wetlands are important producers of methane due to the anaerobic conditions below the oxidized surface layer. As described above, the daily average flux is estimated to be 7.02 g C/m^2/yr for a 223 day period of active soil biological activity, with a post-inundation area of $6.27x10^5$ m^2 of wetlands, the annual flux of CH_4 is approximately $4.4x10^3$ kg C/yr or 4.4 tonnes C/yr.

CDOX4: *Exchange of Carbon (CO_2) Between Wetlands and the Atmosphere*

As previously estimated, wetlands in the Peace River watershed take in 53.57 g C/m^2/yr (based on net photosynthesis, and including heterotrophic respiration). The area of the Peace River watershed covered by wetlands post-inundation, as measured by GIS methods, is $6.27x10^5$ m^2. By multiplying the unit flux by the amount of land (m^2) that is covered by wetlands, the post-inundation CO_2-carbon flux from the atmosphere to wetlands for the Site C Study Area post-inundation is estimated to be $3.36x10^4$ kg C/yr, or 33.6 tonnes C/yr.

7.4.5 Carbon Exchanges Involving Rivers and Lakes

The flooded carbon in soils, vegetation, and wetlands (estimated to have an inventory of $9.95x10^8$ kg C in the Site C reservoir; including biomass from road and transmission lines) can have several possible fates, including:

- Decomposition to CO_2 and CH_4, resulting in increased fluxes of these gases to the atmosphere by a combination of diffusion at the water surface, bubble degassing, or degassing at turbines and spillways;
- Decomposition and leaching to release DOC, resulting in increased DOC concentrations in water, where it may be decomposed, or exported as DOC from the river to the ocean; and
- Release of POC to the water column, which may subsequently be decomposed in the water column, buried with sediment, or exported as POC from the river to the ocean.

The final fate of all carbon flooded during impoundment is unknown and hard to predict. Following reservoir construction, shoreline erosion rates are typically high in reservoirs during the initial post-inundation period, resulting in increased concentrations of total suspended sediment (TSS) in the water column. This is particularly the case in landscapes with sandy erodible shorelines formed from depositional material, such as the Peace River valley, as opposed to bedrock material.

Sedimentation within the reservoir basin is therefore expected to be intense during the first few years following reservoir creation, and these high sedimentation rates will result in the rapid burial and preservation of some of the carbon originating from flooded soils and vegetation. However, the proportion of biomass that may become buried as a result of sedimentation and shoreline erosion, particularly mass failures (Kondratjev, 1966; Holmstead, 2001), is unknown. Therefore, it was conservatively assumed that under the default scenario no biomass burial would occur, though the effect of this was assessed in the sensitivity analysis (Section 7.6)

It is expected that a large portion of the merchantable timber found within the reservoir as well as the transmission line and road corridors will be harvested and processed. The Intergovernmental Panel on Climate Change (IPCC 2003, 2006) recognizes that some of this timber may be used in forest products that would serve as relatively permanent stores of carbon (*e.g.,* furniture and building materials), but require nonetheless that all harvested timber on land converted from forest land to flooded land be considered an emission. An alternative to this consideration would be the use of biomass for energy generation, which may be considered a carbon offset. Given this, emissions of GHG from merchantable timber were considered in the sensitivity analysis Section of 7.6.

Therefore, considering the uncertainties about the mass of carbon buried in biomass due to sedimentation and erosion, and the requirement by IPCC to consider all harvested timber an emission, it was determined that under the default scenario all flooded biomass would be available for decay and production of GHG.

DECAYING BIOMASS: This stock was added to the post-inundation model to represent all the biomass potentially flooded and decaying in the reservoir. As IPCC considers all vegetation biomass in land converted from forest land to non-forest land as an emission, regardless of the end use of the biomass (*e.g.,* timber products) this stock included all potentially harvested merchantable timber (see Sensitivity Analysis Section 7.7). Included in this stock is the biomass associated with clearing of land for construction of transmission lines and new roads. The mass of carbon from these activities was based on the total above ground biomass volumes reported by Industrial Forest Service, Ltd. (2008) for roads (35,035 m^3) and transmission line right-of-ways (149,871 m^3). These volumes were then multiplied by a conversion factor of 247 kg C/m^3 (Birdsey 1996).

The initial carbon mass within the reservoir of this stock was calculated by summing the products of the area flooded by AGB ($5.50x10^8$ kg) and BGB ($4.45x10^8$ kg) for farmland, forest/shrub, and wetlands, and the carbon mass from road and transmission lines (Table 7.4.5a). This resulted in an estimated total initial stock of $9.95x10^8$ kg C, or $9.95x10^5$ tonnes C.

While merchantable timber and other cleared biomass may not decay within the reservoir, the fate of this biomass is unknown. Therefore, as it must be considered an emission, it was considered to be included in the flooded biomass, which would likely represent the delayed emission of this carbon from decomposition or combustion of various wood products over time rather than an immediate emission upon harvesting.

Table 7.4.5a Default Total Decaying Biomass Estimate by Area Type

Cover Type	Area (ha)	BGB C Inventory (kg C/ha)	Total BGB C (kg)	AGB C Inventory (kg C/ha)	Total AGB C (kg)
Forest/shrub	4.28E+03	1.07E+05	4.58E+08	9.28E+04	3.97E+08
Farmland	5.70E+02	6.17E+04	3.52E+07	2.25E+03	1.28E+06
Wetland	5.63E+02	1.01E+05	5.69E+07	2.08E+03	1.17E+06
Roads and Transmission Lines	-	-	-	-	4.59E+07
Total C (kg C)			**5.50E+08**		**4.45E+08**
Total C (tonnes C)			**5.50E+05**		**4.45E+05**

DECAY: Flooded biomass will undergo decay according to a first order exponential decay function:

Mass*t* = mass*i* * e^{-1*kt}

Where:

Masst_{+1} = remaining biomass at time t

Mass*i* = initial biomass

e = exponent

k = decay constant

t = time

The rate of biomass decay varies according to several parameters including temperature, type of biomass, enzymes present, oxygen availability, water turbulence, among others. Therefore, after reviewing numerous literature sources (Bilby *et al.,* 1999; Harmon *et al.,* 2000; Jordan, 2001; Scherer, 2004) on the rates of biomass decay in aquatic systems, decay constants of 0.25 for the summer period of 223 d and 0.062 for the winter period of 142 d were used in this equation. The winter period decay constant was calculated based on the summer period decay constant and the principle of Q10 effect with an approximate seasonal temperature differential of 15 Celsius. The Q10 effect states that for a 10°C decrease in temperature, there is an approximate two-fold decrease in enzymatic activity. Based on this equation, the remaining biomass in the reservoir decreased according to Figure 7.4.5a. By year 14, 90% of the flooded biomass would be decomposed, and by year 24, this would have exceeded 99%.

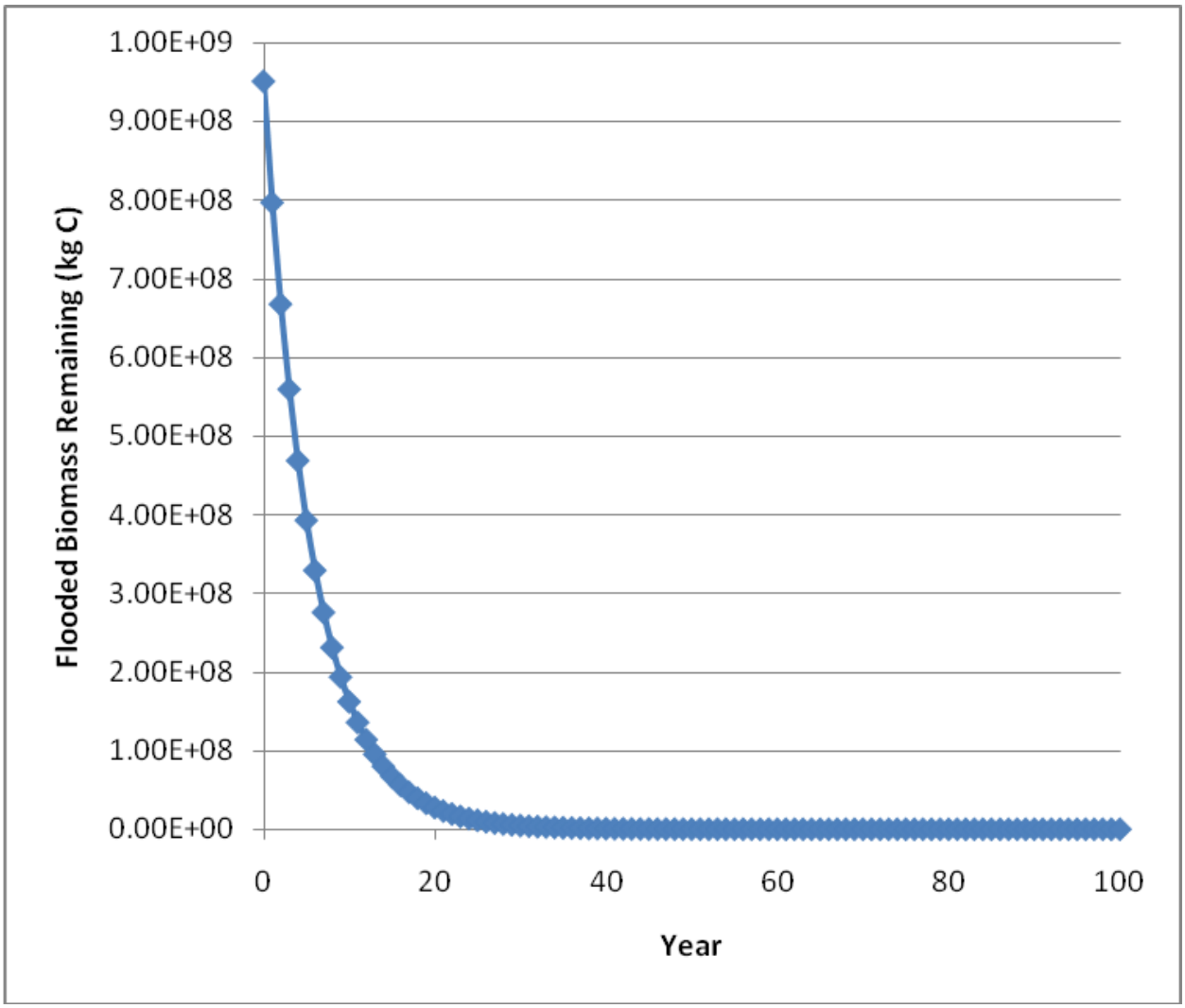

Figure7.4.5a Biomass Remaining in the Site C Reservoir Over Time During Post-inundation

CDOX3: The flux of CO_2 from rivers and lakes to the atmosphere is one of the fluxes that undergoes the greatest variation post-inundation. This is due to the decomposition of vegetation, which will result in the release of metabolic products including CO_2 and CH_4.

Given that the biomass flooded in the Site C Study Area is equal to 9.95×10^8 kg C, and that based on Duchemin *et al.* (2002) and Lima *et al.* (2007) 98.5% of carbon is assumed to be emitted as CO_2, the CDOX2 flux from Site C reservoir would resemble the trend of flooded biomass of Figure 7.4.5a. It was estimated that in total 3.59×10^9 kg CO_2 would be released as a result of the decomposition of flooded biomass. In addition to the emissions from flooded biomass, CDOX2 also includes baseline CO_2

emissions that were expected to mimic the CDOX3 flux per unit area of the calibrated current conditions model prorated to the ice-free period of 223 days. The calibrated value of 615 mg $CO_2/m^2/d$ is likely a conservative estimate given that the mean emission flux for BC reservoirs greater than 29 yrs old is 198 mg $CO_2/m^2/d$, though the Williston reservoir averages 920 mg $CO_2/m^2/d$ (Tremblay *et al.,* 2005).

While IPCC requires that degassing at turbines and spillways be considered in the estimation of GHG emissions, the process whereby emissions are estimated from gases produced as a result of biomass decomposition is comprehensive. In other words, while the release of dissolved gases resulting from biomass decomposition may not be released from either the reservoir surface or the degassing from turbines and spillways, rather it may be released further downriver, estimating GHG emissions from all biomass decomposition is independent of when and where those gases would be released and may include emissions occurring downriver of the Site C dam. This represents a more accurate estimate of emissions resulting from the potential Site C project.

METH3: As with CDOX3, the exchange of CH_4 from rivers and lakes to the atmosphere is controlled by the concentration of CH_4 in the water, and molecular diffusion across the water-air interface. Similarly to CDOX3, the concentration of CH_4 in the water of Site C reservoir would increase due to increased decomposition of vegetation post-inundation. Following the same approach as CDOX3, METH3 is calculated by assuming that 1.5% of biomass carbon will be converted to CH_4 and released to the atmosphere according to the first order exponential decay model above and in addition to the baseline reservoir emission rate of 3.3 mg $CH_4/m^2/d$. The annual METH3 flux for the 100 year modeling period will resemble that presented in Figure 7.4.5a for the biomass decomposition.

SEDIMENT: In the Study Area, the amount of carbon stored in lake and river sediment increases slightly post-inundation due to sedimentation over time. Proportional to the respective areas of river and lake, this sediment stock is largely the store of sediment in lakes as rivers store sediment at a much slower rate due to turbulent flow and seasonal fluctuations in flow rates, which causes short-term accumulations and scouring of sediment. However, the reduced flow in reservoirs has the effect of acting as sediment traps, which serve as effective carbon sinks, similar to lakes (Dean and Gorham, 1998; Einsele *et al.,* 2001).

The reservoir sedimentation rate is based on the Klohn Crippen consultants and SNC-Lavalin consulting report on the prefeasibility study of the cascade hydroelectric generating system alternative (Klohn Crippen and SNC-Lavalin, 2003). They report that the Halfway River transports 2.3 million tonnes of sediment per year into the Peace River and comprises 75% of the inflow between the Peace Canyon dam and the potential Site C dam. Assuming that the reservoir will capture 50% of the sediment

transported into the reservoir and that the fraction of sediment that is carbon is 1%, and that the reservoir surface area is 9.32×10^7 m^2, then the sedimentation rate is calculated as follows:

$$\text{Sedimentation rate} = 2.3 \times 10^9 \text{ kg/yr} / 0.75 * 0.50 * 0.01 / 9.32 \times 10^7 \text{ m}^2 = 0.18 \text{ kg/m}^2\text{/yr}$$

This rate is conservative, and likely underestimates true sedimentation, considering that much of the watershed of this system contains sedimentary material, that reservoirs have higher sedimentation rates than do lakes due to higher flow rates and shoreline erosion, and that Canadian Shield lakes are estimated to deposit 0.065 $kg/m^2/yr$ (Bird *et al.,* 1992). This rate applied to the reservoir would result in an estimated 1.69×10^7 kg C/yr deposited into the reservoir.

RIVERS AND LAKES: As described above, the Rivers and Lakes carbon stock is based on reported or estimated values of inorganic carbon (*e.g.,* CH_4, CO_2, DIC), and organic carbon (*e.g.,* DOC and POC) concentrations in water from the Peace River. The volumes of water in the Site C reservoir post-inundation is estimated to be 8.6×10^8 m^3 (Kingston, 1977). The estimated carbon mass in the Rivers and Lakes stock post-inundation is the product of the summed concentrations of TIC and TOC, and the volumes of water. The TIC and TOC concentrations post-inundation are assumed not to increase significantly from current conditions.

Initially, post-inundation, concentrations of dissolved CH_4 and CO_2 are expected to be greater than pre-inundation, due to the decomposition of flooded organic matter. However, as excess gases resulting from biomass decomposition would largely be emitted to the atmosphere in relatively short time, the mass of carbon stored in water from decomposition gases are not included in the Rivers and Lakes stock. Rather, they are considered to be transitioning between biomass and the atmosphere. Baseline or concentrations near saturation are assumed to be counted in the TIC and TOC concentrations.

Therefore, based on the volume of water and TIC and TOC concentrations of the Peace River under current conditions, the Rivers and Lakes stock is expected to contain 1.92×10^7 kg C or 1.92×10^4 tonnes C, which reflects the increased volume of water, and the increased concentrations of inorganic and organic carbon in the water.

RIVER FLOW: Post-inundation, River Flow will be calculated in a manner similar to the current conditions model. It is divided into Inflow, which represents the mass of carbon flowing into the Peace River within the Study Area, and Outflow, which is the mass of carbon flowing out of the Peace River at the point where the Site C dam would be constructed. The mass of carbon in River flow represents the

sum of the organic (particulate and dissolved organic matter of aquatic, terrestrial or wetland origin) and inorganic (dissolved CH_4, CO_2, bicarbonates, and carbonates) carbon in the water. The carbon mass in the Inflow is equal to the volume of water leaving the system and the concentration of TOC and TIC (defined above) in that water. The volume of water flowing out of the Study Area at approximately the Site C dam location (1307 m^3/s) was obtained from Environment Canada (2008c: Peace River above Pine River station). This flow rate is not expected to change substantively during post-inundation. The mass of carbon flowing out of the system is equal to the Inflow less any carbon deposited into the river sediment.

Therefore the total carbon Inflow into the Site C Study Area post-inundation is $9.20x10^8$ kg C/yr, while the Outflow is reduced to 9.09x108 kg C/yr due to the higher rate of sedimentation in the reservoir compared to current conditions.

7.5 PEACE RIVER SITE C NITROGEN CYCLE: POST-INUNDATION

The post-inundation nitrous oxide cycle model does not change from the current conditions (Figure 7.3a). Under this scenario, the N_2O emissions accounted for in the nitrogen cycle model will be greatly reduced due to the reduction in agricultural land area and the assumption of no livestock inhabiting the Site C Study Area as defined above. For those reasons, nitrous oxide emissions from Site C post-inundation are reduced by over 95% from a total of 2,043 tonnes CO_2e/yr to 116 tonnes CO_2e/yr.

CROP: Nitrous oxide emissions from crop production were estimated based on measurements from the Peace Ecodistricts of Alberta (Sauvé, 2000). These measurements we chosen as they are thought to best represent conditions and cropping systems (predominantly grain crops) of the Study Area. The gross nitrous oxide emissions factor from crop production is estimated to be $6.49x10^{-3}$ tonnes N_2O/ha/yr; of which 27.1% originated from soil, 65.6% from crop residue and 7.3% from fertilizer application (Sauvé, 2000). Post impoundment N_2O emissions from crop production (57.6 ha) are estimated to be 116 tonnes CO_2e/yr.

LIVESTOCK: Under post-inundation conditions it is assumed that no livestock will inhabit the Site C Study Area due to the very small area of unflooded land (represented by the 30 m buffer bordering the maximum flood level); N_2O emissions are therefore 0 for livestock under this scenario.

7.6 PEACE RIVER SITE C CARBON MODEL: SENSITIVITY ANALYSIS

Models frequently incorporate estimates or values that have some degree of uncertainty associated with them. The magnitude of effect of that uncertainty varies among parameters and the relative degree of

uncertainty. While it is not practical or necessarily more informative to assess the model sensitivity to the uncertainty associated with all parameters, it is often helpful to analyse the model sensitivity to parameters that are identified as having greater uncertainty, or that are anticipated to have a greater effect on the model results.

In this study, an analysis of the carbon cycle model sensitivity to three parameters (one current condition and two post-inundation) was conducted, as well as the impact of considering all merchantable timber as an emission, based on IPCC guidelines. These parameters are: Number of livestock present; biomass burial; and sedimentation rates. The process by which a sensitivity analysis is conducted is to vary one parameter at a time while holding the remaining parameters constant. Each parameter was varied by factors assumed to represent ranges that would appropriately demonstrate model sensitivity.

7.6.1 Effect of Livestock on Current Conditions GHG Emissions

Results from the current conditions carbon and nitrogen model indicated that the Site C Study Area produced an emission of GHG to the atmosphere, despite the fact that the system as a whole acted as a net sink of carbon. This was largely due to agricultural inputs, and primarily the methylation of carbon from livestock.

As the number of livestock within the Study Area were based on professional judgement and consultation with BC Hydro, the effect of number of livestock on the current conditions model was assessed. The default parameter assumes the following livestock present in the Study Area with their methane emission rates:

- Dairy Cattle = 300 head at 118 kg CH_4 per head;
- Beef Cattle = 1000 head at 72 kg CH_4 per head;
- Swine = 300 head at 1.5 kg CH_4 per head;
- Horses = 150 head at 18 kg CH_4 per head; and
- Bison = 300 head t 55 kg CH_4 per head.

These default numbers were varied by factors of 0.1, 0.5, 1, 1.5, and 2, and the resulting effect on model emissions are presented in Figure 7.6.1a.

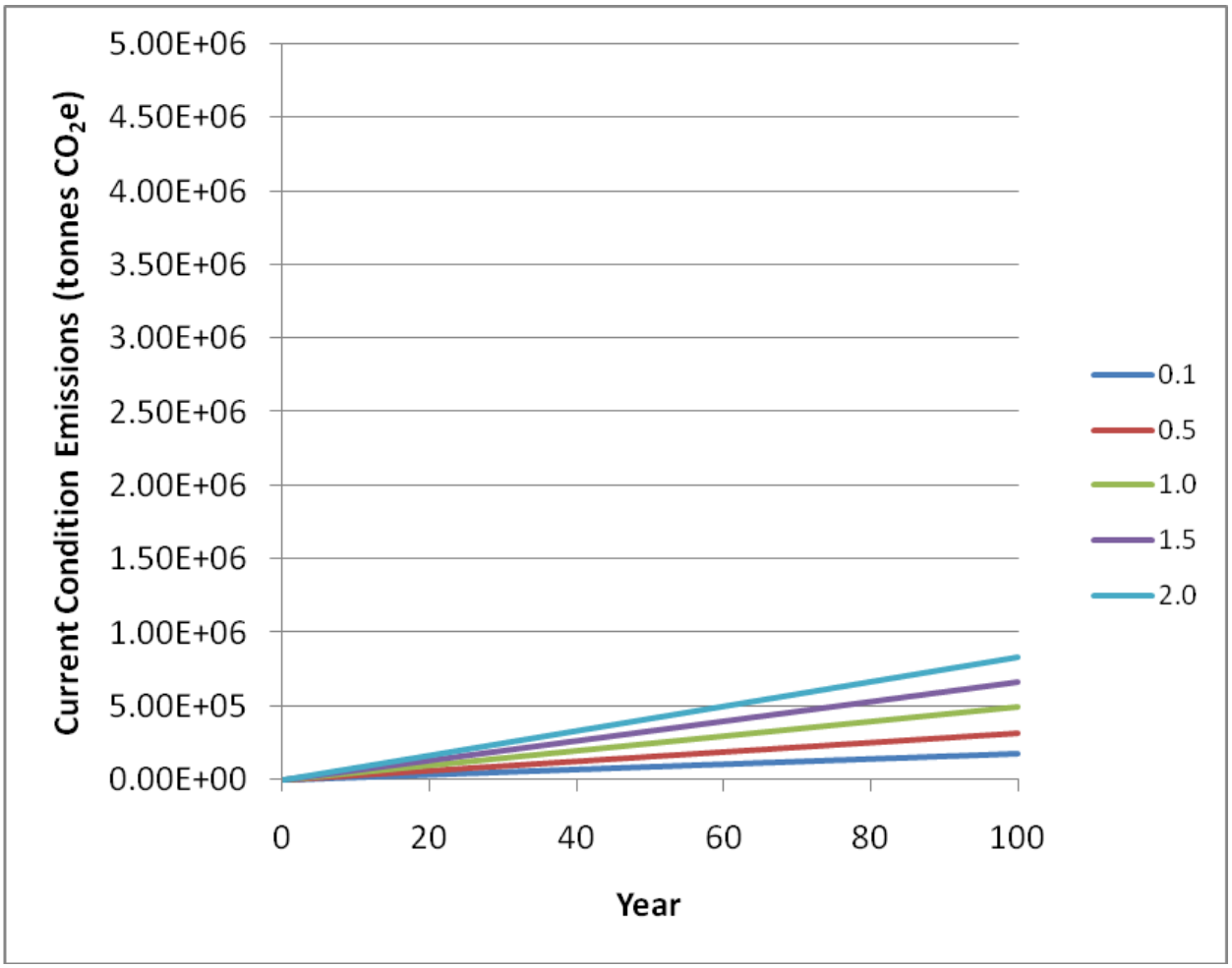

Figure7.6.1a Effect of Varying Livestock by 0.1, 0.5, 1(default), 1.5, or 2 Times Default Values on the Current Condition Emission (tonnes C) Over Time

There was a linear relationship on the sensitivity analysis factor and the current condition emission estimates (Figure 7.6.1a). Because livestock production results in the emission of CH_4 and N_2O, both of which are much more potent GHG than CO_2, this parameter greatly affected the current condition emission estimates, and would also impact the project net emissions.

7.6.2 Effect of Biomass Burial on Post-inundation GHG Emissions

Post-inundation, flooded biomass will undergo decay and release GHGs, with a large fraction of this biomass being found in the soil and low vegetation. The majority of this decay occurs over a period of approximately a decade. During this period, sedimentation and shoreline erosion will occur, which will result in the burial of non-decomposed biomass. When buried in sufficiently protected conditions, organic

matter may cease to mineralize and may become permanently stored in the sediment. This has been documented in waterlogged timber at the bottom of lakes and watercourses (Jordan, 2001), which have shown to undergo very little mineralization and decomposition. However, the extent to which burial will occur as a result of these two processes is largely unknown. Biomass may become buried, but not deep enough that decomposition would cease. Mass slope failures (land slides) within a few years post-inundation, however, could result in large quantities of biomass being buried (Kondratjev, 1966; Holmstead, 2001). Though largely undocumented in literature, this process is reservoir specific and an accurate assessment of the potential burial of biomass would require a detailed study on bank stability and sedimentation dynamics including particular locations where sediment would accumulate and the quantity of biomass in these areas. The uncertainty about this process led to the default model parameter for biomass burial being 0% of biomass unavailable for decay and mineralization. However, the effect of biomass burial on the Site C post-inundation GHG emissions was examined. Biomass burial was included as a factor between 0 and 1 multiplied to the flooded biomass indicating whether none (0) or all (1) biomass would be buried. Values for biomass burial were set to 0(default), 0.05, 0.1, 0.15, or 0.2 indicating none (default), 5%, 10%, 15% of 20% of biomass would be buried and permanently stored in sediment. The effect of varying biomass burial is shown in Figure 7.6.2a.

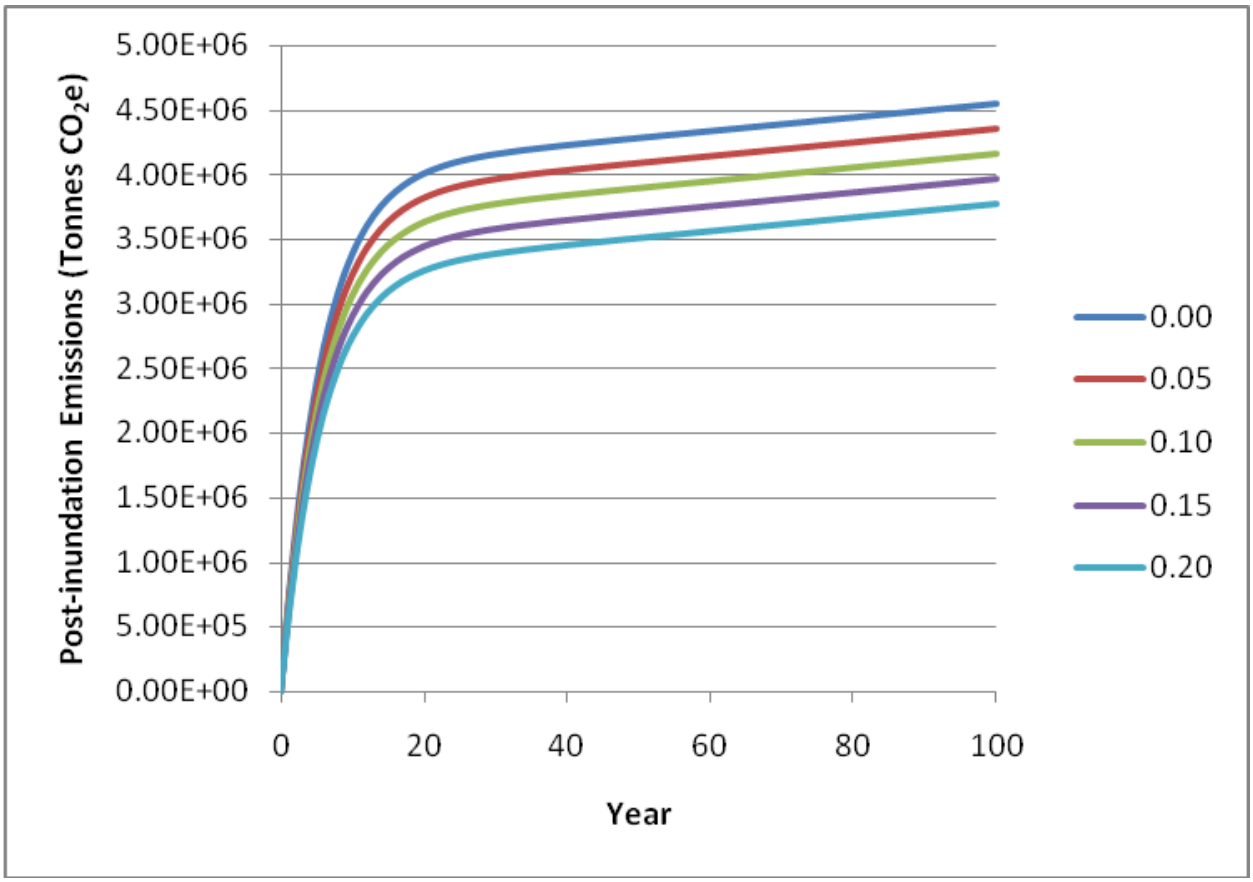

Figure7.6.2a Effect of Varying Biomass Burial from 0% (default), to 5%, 10%, 15%, or 20% on Post-inundation Emission Estimates (Tonnes C)

Biomass burial also resulted in a substantial effect on post-inundation emissions. While the default value was set to 0% burial, it is far probable that burial of between 10 and 20% would likely occur within the reservoir.

7.6.3 Effect of Sedimentation on Post-inundation GHG Emissions

Sediment deposition is considered to be an important carbon sink within hydroelectric reservoirs (Dean and Gorham, 1998; Einsele *et al.,* 2001; Cole *et al.,* 2007), and can have substantial impacts on the long-term estimates of GHG emissions from the system. Sedimentation rates are very system specific and estimates from one reservoir is not necessarily applicable to another. The reservoir sedimentation rate for Site C was based on the estimate from Kingston (1977) of suspended sediment mass in the main tributary entering the Peace River between Peace Canyon Dam and the potential Site C dam. The sedimentation rate was then calculated based on various assumptions including the suspended sediment load of the remaining tributaries, the fraction of suspended sediment deposited within the reservoir, and

the carbon content of the sediment. The resulting sedimentation rate (0.18 kg C/m^2/yr) was reasonable and likely conservative when compared to the rate for boreal shield lakes (0.065 kg C/m^2/yr). Therefore, this sensitivity of the model to sedimentation rate was tested by varying the reservoir sedimentation rate by factors of 0.5, 0.67, 1 (default), 1.5, and 2. The results of this analysis are presented in Figure 7.6.3a.

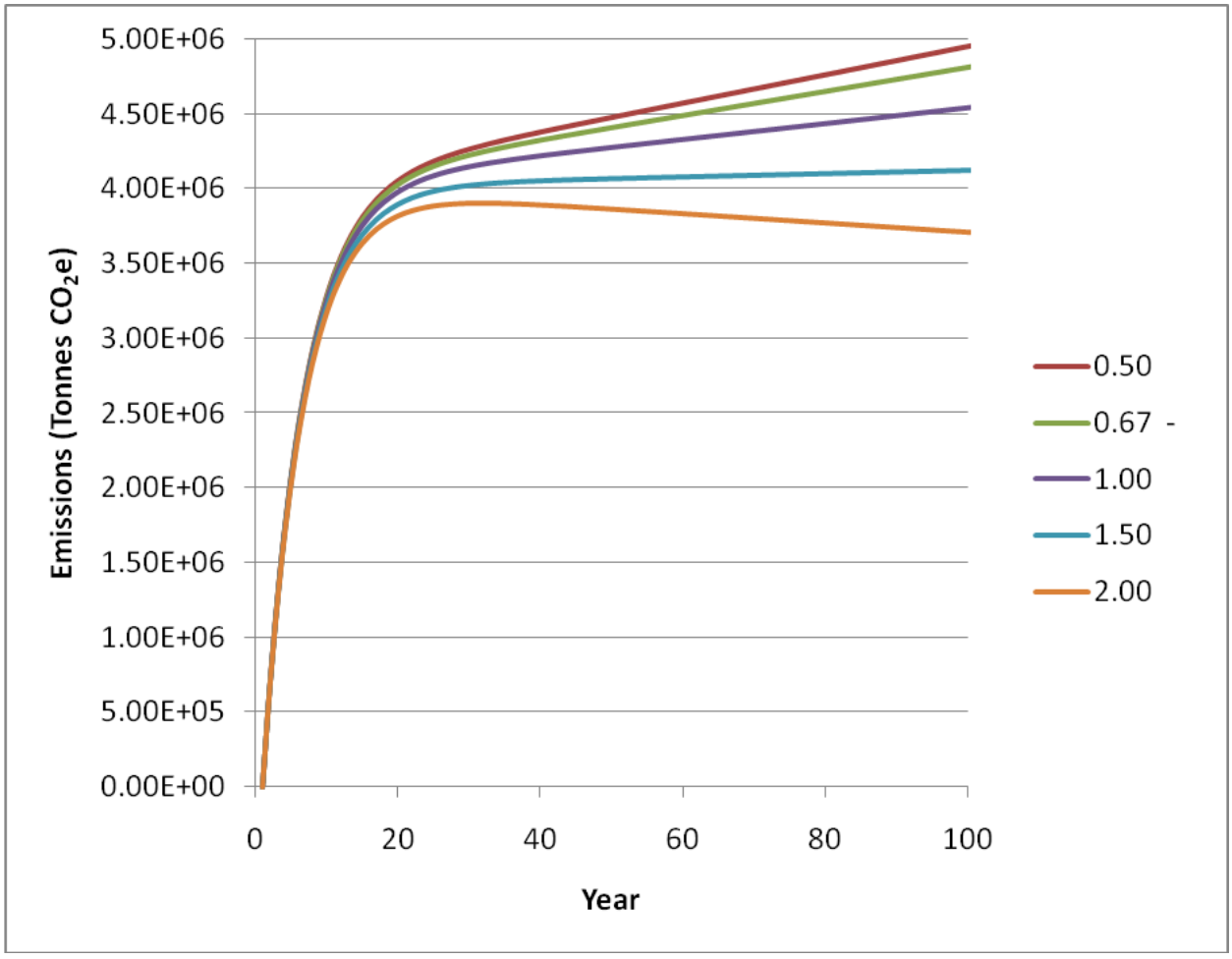

Figure7.6.3a Effect of Varying Sedimentation Rates by Factors of 0.5, 0.67, 0.1 (default), 1.5, and 2.0 on the Post-inundation Emission Estimates (Tonnes C)

The effect of varying sedimentation rate became more pronounced with time as sediment was assumed to deposit at a continuous rate over time. While either extreme of the sensitivity analysis are unlikely, it is probable that the actual sedimentation rate would fall between 1 and 1.5 given that a fraction of the suspended sediment load was conservatively assumed to be discharge from the reservoir and that no shoreline erosion would contribute to sedimentation as the quantity is largely unknown.

7.6.4 Effect of IPCC Merchantable Timber Guidelines on GHG Emissions

Though not necessarily a model parameter, the sensitivity of model outputs to the guideline put forth by IPCC were assessed. In these guidelines, all merchantable timber removed during land conversion from forest land to non-forest land should be considered an emission. While this approach leads to a more conservative estimate of GHG emissions from an activity, it is likely that some fraction of the merchantable timber would be used for in wood products that would have a long lifespan and for practical considerations could be deemed long-term storage.

To assess the effect of this guideline on Site C GHG emissions, GHG emission estimates were calculated and compared assuming that 0%(default), 25%, 50%, 75%, or 100% of merchantable timber would be stored in long-term wood products (Figure 7.6.4a).

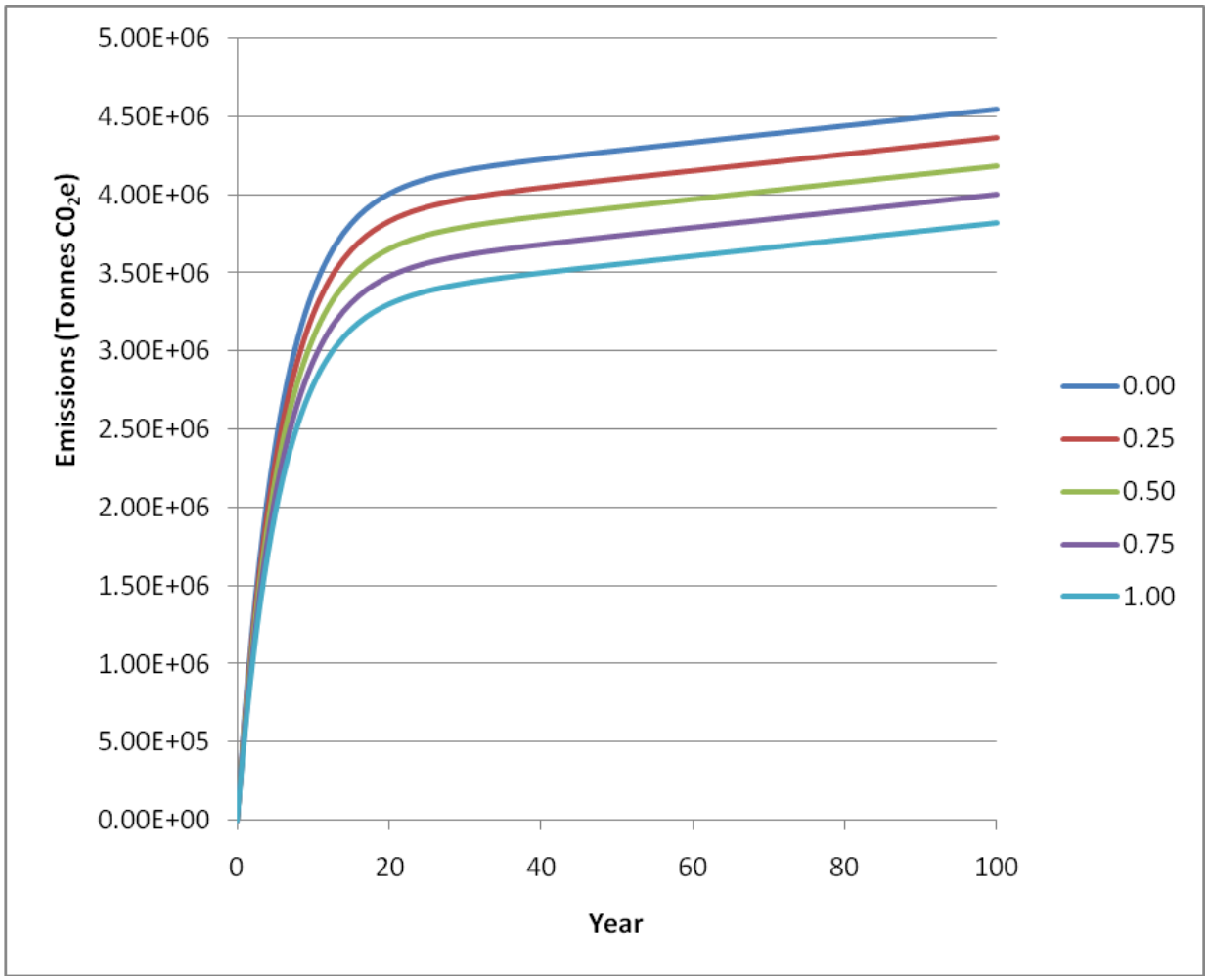

Figure7.6.4a Effect of Counting 0% (default), 25%, 50%, 75%, or 100% of Merchantable Timber as Non-emission on the Post-inundation Emission Estimates (Tonnes C)

The effect of accounting for merchantable timber as a non-emission was very similar to biomass burial. This is because both processes effectively remove the mass of carbon that would be available for decomposition and emission of GHGs. Because the GHG are produced from decomposition of biomass, the emissions occurred largely within the first 20 years post-inundation after which all scenarios followed parallel emission rates (Figure 7.6.4a).

7.6.5 Summary of Sensitivity Analyses

The sensitivity of the GHG model to four parameters or modeling approaches was tested in the sensitivity analysis. The resulting net emissions (post-inundation – current conditions = net emissions) for 100-year model periods were then calculated for each parameter and the results are presented in Table 7.6.5a.

While it is difficult to directly compare the sensitivity of the model to each parameter, as they were each varied by different levels, all four parameters had measurable effects on net project emissions (Table 7.6.5a). Note, these estimates do not include construction and equipment emissions.

Table7.6.5a Summary of Sensitivity Analysis Parameter Effects on Net Project Emissions (Construction emissions are not included in these results)

Tonnes CO_2e over 100 year lifespan					
Current Conditions			**491,562**		
Post-inundation			**4,545,825**		
Default Project Net			**4,054,263**		
Sensitivity Analysis Net Project Emissions (tonnes CO_2e/100 yr)					
Varying Livestock	4,364,646	4,226,698	**4,054,263**	3,881,828	3,709,393
Varying Sedimentation	4,473,911	4,331,230	**4,054,263**	3,634,616	3,214,968
Varying Biomass Burial	**4,054,263**	3,862,690	3,671,117	3,479,544	3,287,971
Varying Merch. Fraction.	**4,054,263**	3,873,442	3,692,621	3,511,800	3,330,979
Sensitivity Analysis Net Project Emissions (% change)					
Varying Livestock	108	104	100	96	91
Varying Sedimentation	110	107	100	90	79
Varying Biomass Burial	100	95	91	86	81
Varying Merch. Fraction.	100	96	91	87	82

7.7 SUMMARY OF SITE C BIOMASS GHG MODELS

The quantification of specific carbon stocks and fluxes, as well as anthropogenic nitrogen fluxes for Site C pre-inundation and post-inundation was described in Sections 7.2 to 7.6. These stocks and GHG fluxes with CH_4 and N_2O converted to CO_2 equivalents (CO_2e) are presented in detail in Appendix 3. Equations and documentation of the model stocks and fluxes, as produced in Stella®, are presented in Appendix 4.

Under current conditions, the Site C Study Area is a weak source of GHG, despite the landscape being a carbon sink. This was largely due to agricultural activities, which resulted in the methylation of biomass carbon into CH_4, largely through ruminants, and the anthropogenic emissions of N_2O. These GHG are far

more potent than CO_2, 21 and 310 time more, respectively, and offset the carbon sinks of CO_2 fixed and deposited in soils and wetlands.

Mass and emission rates of terrestrial stocks (soil, terrestrial vegetation, wetlands) decreased significantly post-impoundment. This was because the Site C Study Area was defined as a 30 m buffer surrounding the high water polygon, and post-inundation 87% of the land area would be flooded.

Based on the post-inundation model, which incorporated biomass decomposition, emissions from the Site C reservoir are initially much higher than normal levels, and approach current conditions by approximately year 20 (Figure 7.7a). While this extent is longer than the typical extent before emissions return to near pre-inundation level (~10 years; Tremblay *et al.,* 2004), it is not unreasonable given that several conservative assumptions were made: no biomass burial, conservatively low sedimentation estimates, and emissions include all releases from flooded biomass regardless of when and where gases are released. Furthermore, this difference in temporal pattern of emissions may be due to a slower modeled decomposition rate than occurs in reservoirs. While this may skew the emissions over a longer period of time, the total emissions of decomposing biomass would not be different, than if the modeled decomposition rates were higher. Comparing biomass removed from transmission lines and new roads ($4.6x10^4$ tonnes C) to the biomass flooded within the reservoir ($9.5x10^5$ tonnes C) indicated that the former accounted for approximately 5% of Site C emissions.

Higher sedimentation rates during the initial few years post-inundation are a reasonable expectation due to shoreline re-stabilization processes, which would result in large quantities of carbon burial. This burial would serve to partly offset the higher emission estimates for the first 5 to 10 years. Beyond year 35, under the probable scenario, emission rates would fall below current conditions largely due to the added carbon burial from sedimentation in the reservoir.

Surface water CO_2 fluxes were not directly compared to those reported in the literature. It was felt unreasonable to compare absolute emission rates from one reservoir to another as each system is unique and emission rates depend on the method used for sampling, the residency time and mass of biomass buried, and on the limnological conditions of the system (*e.g.,* pH; Soumis *et al.,* 2004). Furthermore, given that this model does not divide emissions into reservoir surface emissions, turbine and spillway degassing emissions, and emissions downstream of the dam, CDOX3 (water: air diffusive fluxes) estimates post-impoundment would be higher than those measured only from the reservoir surface. Therefore, a direct comparison would be misleading.

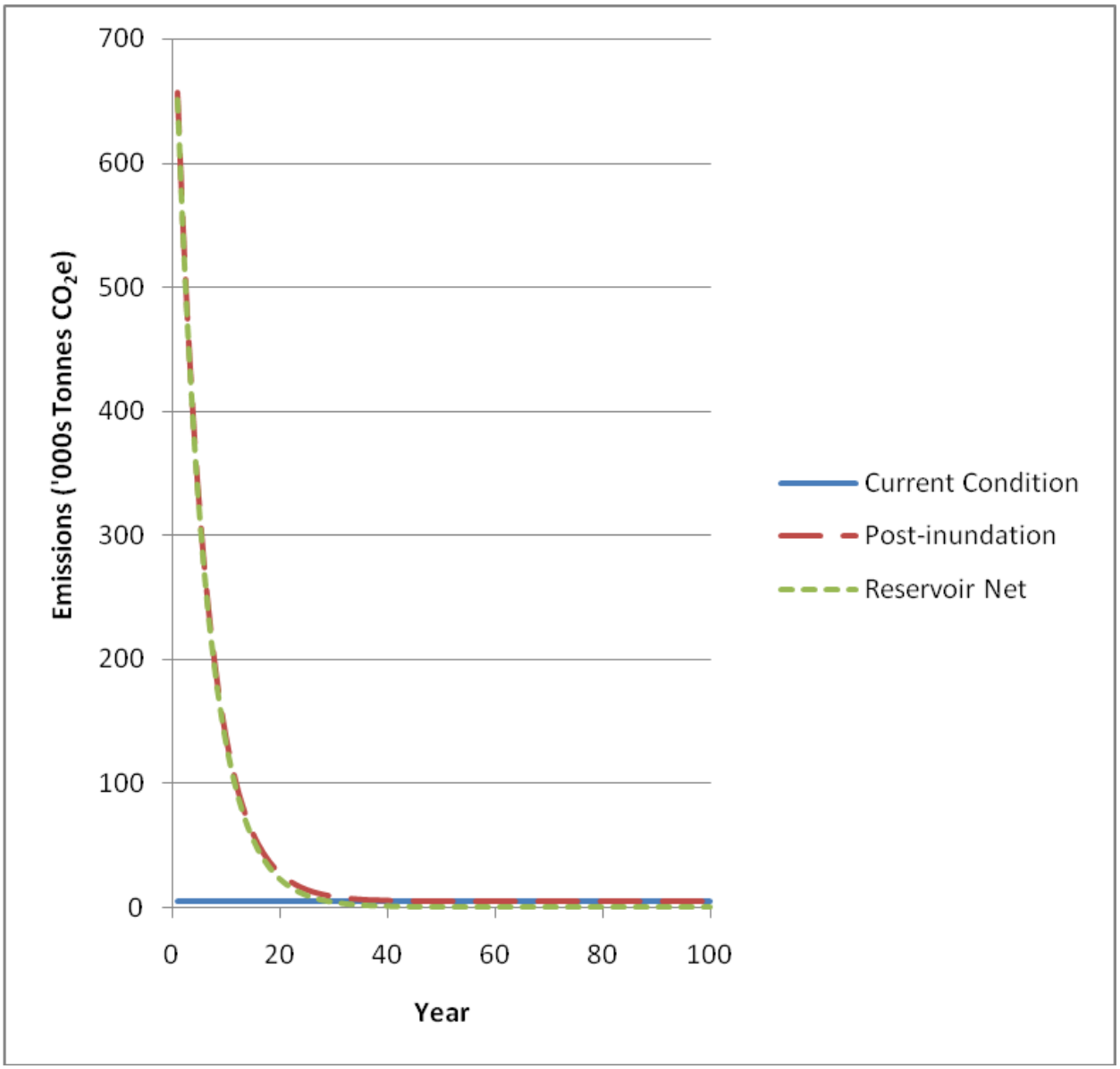

Figure 7.7a Current Condition, Post-inundation and Reservoir Net Emission Estimates in Tonnes CO_2e (reservoir net emissions do not include emissions from construction or fuel use in land clearing).

When testing the current conditions and post-inundation models sensitivities to four key parameters, emission estimates remained within 20% of default values, despite some sensitivity analysis settings being beyond the range of reasonable expectation. This indicates that the model is relatively robust and while default emission estimates are likely conservatively higher than should be expected, (likely by 5 to 10%), emission estimates are relatively precise.

7.8 CONSERVATIVE DEFAULT VS. PROBABLE EMISSIONS SCENARIOS

Throughout this study, conservative default values for certain parameters were selected to ensure that GHG emissions from Site C were not underestimated. Here, a probable emission scenario is presented that combines parameter values most likely to occur. The parameters adjusted are the biomass burial rate, sedimentation rate, and merchantable timber fraction considered an emission.

Biomass Burial: under the conservative default scenario biomass burial was set at a value of zero, indicating that none of the flooded biomass within the reservoir would be buried under sediment (depositional sediment or slope failure). Under the probable emissions scenario, it was assumed that 15% of the flooded biomass would not undergo decomposition. Given that sedimentation, in reservoirs occurs at the greatest rates early post-inundation due to shoreline erosion and bank failure, burial of a portion of the flooded biomass prior to total decomposition is very likely. The value of 15% was based on professional judgement.

Sedimentation rate: under the conservative default scenario, the sedimentation rate was based on the mass of sediment flowing into the Peace River from the Halfway River prorated to include inflow from additional tributaries found between Site C and Peace Canyon Dam. It was conservatively assumed that 50% of the mass of sediment flowing into the reservoir would be deposited and that the sediment would contain 1% carbon by mass. These estimates are both likely underestimates and based on professional judgement, the sedimentation rate deemed most probable was the default rate increased by 25%.

Merchantable Fraction: under the conservative default scenario, all biomass (AGB and BGB) within the reservoir and all AGB on the road and transmission line right-of-ways were included in emission estimates in accordance with the IPCC (2006) guidelines for land-use change emission estimation. The two primary products resulting from timber harvesting would likely be pulp and paper, and construction lumber. The life-expectancy of these products (time until combustion of decomposition) will vary with their end use. A fraction (including production waste) of the wood products produced from the merchantable timber would likely have short life-expectancy and would be emitted through combustion or decomposition soon after being produced. However, other products, such as dimension lumber, would likely be unaltered for an extended period of time (~100 years), where the carbon would be stored. Therefore, the probable emission scenario assumed that 50% of the merchantable fraction would be emitted and 50% would be stored in construction lumber and other long-term forest products.

Project net biomass emissions (excluding construction emissions) under the default and probable emission scenarios are presented in Figure 7.8a. Under both scenarios total net emission increased rapidly within the first 20 years, and slowly thereafter due to the majority of biomass decomposition occurring during this early period. In the default scenario, net emissions continued to increase very slowly between years 30 and 100, whereas under the probable emissions scenario total net emissions began to decrease very slowly during the same period (Figure 7.8a). This is due to the slightly increased sedimentation rate. At the end of the 100-year model extent, total net emissions were approximately 28% lower in the probable emissions scenario (2,908,000 tonnes CO_2e) compared to the conservative default scenario (4,054,000 tonnes CO_2e).

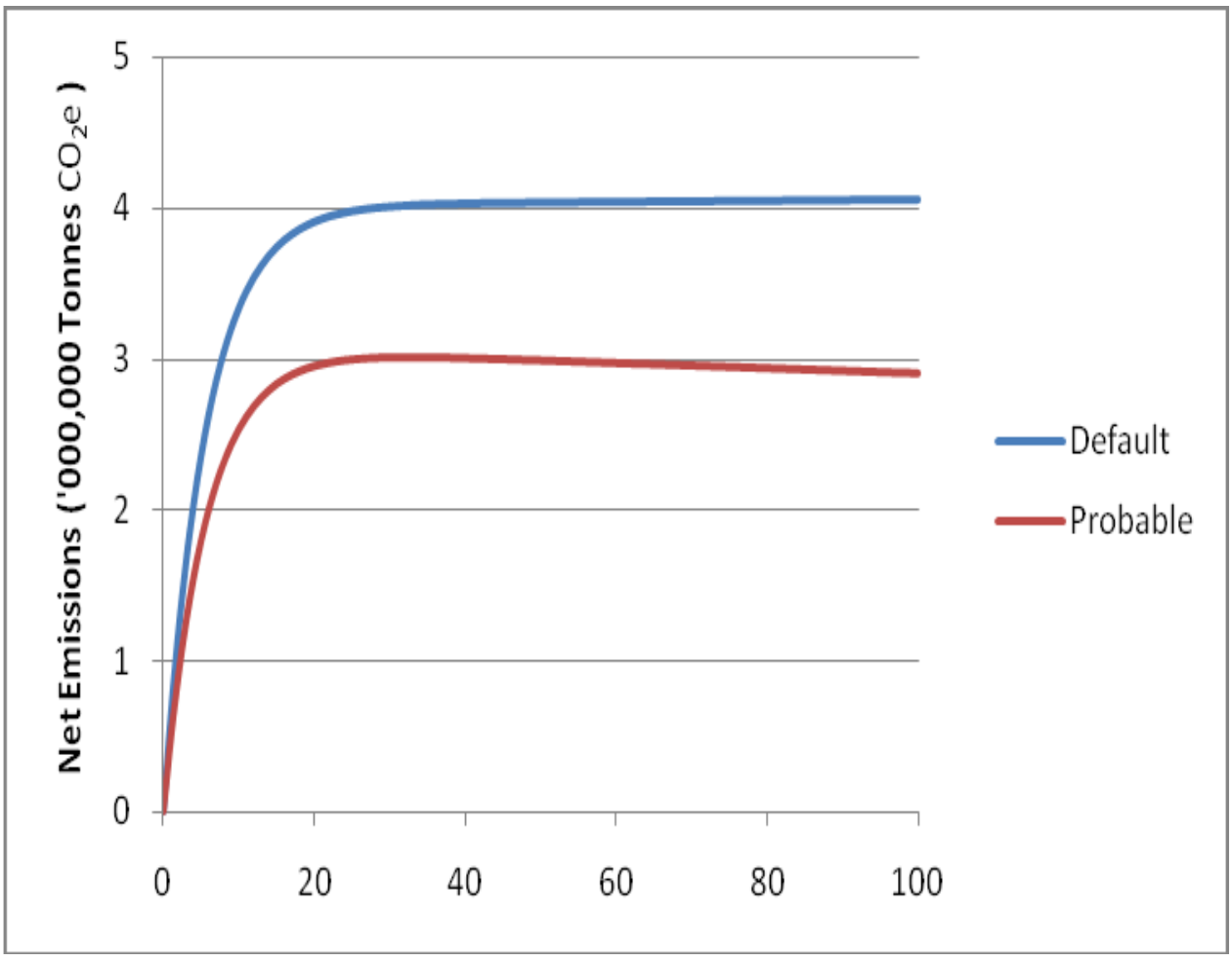

Figure 7.8a Total Net Emissions Projected Over Time for the Conservative Default and Probable Emissions Scenarios

8.0 SITE C CONSTRUCTION GHG EMISSIONS

The release of GHG emissions as a result of the Project's land clearing and construction activities, as well as decommissioning, are important considerations in estimating the life-cycle emissions of the potential Site C project. Since there is no foreseeable end to the Site C project at this time, but continued upgrades for longevity, decommissioning is not a consideration at this time. If decommissioning were to occur decades (> 100 years) from now, the variability and uncertainty in the estimation of GHG emissions necessitate a decommissioning GHG inventory consider the environmental conditions current to that time period. As a result, decommissioning is not considered further in this study.

The expected GHG emissions associated with construction activities of the Project will consist of CO_2 and N_2O, mainly from fuel combustion associated with equipment operation. For the purpose of this study, the construction emissions are assessed for the following categories of GHG emission sources:

- Excavation Activities;
- Concrete Works;
- Tunnel and Cofferdam Construction;
- Land Clearing Activities (non-biomass emissions); and
- Project Support Activities.

These activities are expected to be the primary contributors to GHG emissions associated with the construction of the Site C Project. In the following sections, the methodology, assumptions and calculations of GHG emissions associated with the construction activities are defined.

In the calculation of construction emissions, the values of CO_2, N_2O and CH_4 emissions were converted to carbon dioxide equivalent (CO_2e) using an emission factor specific to the GHG source activity. These emission factors are calculated using the individual GWPs prescribed by the IPCC as presented in Sub-section 1.2. In this study, the emission factors specific to Canadian fuel and electricity generation were employed.

Consumption estimates for fuel combustion and electricity use for each activity were provided by BC Hydro. Generally, this data includes (but is not limited to):

- General Construction Activity Category;
- Equipment Type;
- Hours of Equipment Use;
- Fuel Type; and
- Electricity Consumption.

The data provided by BC Hydro is organized by overall construction activity (as indicated above) and converted to GHG emissions using the appropriate emission factors. Three sources for emission factors were used in for the construction emissions inventory. These include publications from Environment Canada and the Industrial Forestry Service. The references for the emission factors are provided in Table 8.0a.

Table 8.0a Summary of Emission Factor Sources

GHG Emission Source	Emission Factor Reference
Fuel Combustion	Environment Canada. 2008a. Turning the Corner: Canada's Energy and GHG Emissions Projections (March 2008).
Electricity Consumption	Environment Canada. 2008b National Inventory Report 1990-2006: Greenhouse Gas Sources and Sinks in Canada (April 2008).

As indicated above, emission factors prescribed by Environment Canada and the Industrial Forest Service (IFS) were used to calculate GHG emissions associated with construction activities. These sources were chosen as they represent the most recent, Canada-specific emission factors. As such, they are compliant with any proposed regulatory regime in Canada. A detailed spreadsheet including all calculations and emission factors is presented in Appendix 4.

8.1 CONSTRUCTION EMISSION INVENTORY

In the following sections, the activities and GHG emissions associated with various construction categories are described. Data sources and assumptions are provided in each section.

8.1.1 Excavation GHG Emissions

The GHG emissions associated with excavation (also known as earthworks) represent a wide range of activities. These include (but are not limited to):

- excavation and hauling;
- drilling;
- placing and compacting fill;
- blasting;
- lighting;
- pumping; and
- stripping.

Data for these activities were provided by BC Hydro as fuel and electricity consumption estimates for the Project construction. Greenhouse gas emissions were calculated for fuel combustion and electricity

consumption using emission factors provided by Environment Canada's Turning the Corner (Environment Canada, 2008a) and National Inventory Reporting (Environment Canada, 2008b) publications respectively.

The GHG emissions estimated for excavation are presented in Table 8.1.1a.

Table 8.1.1a Excavation GHG Emissions

Activity	GHG Emissions (Tonnes of CO_2e)	Percent Contribution (%)
Excavation and Hauling	105,790	92.1
Place and Compact Fill	3,016	2.6
Drilling	484	0.4
Load and Blast	188	0.2
Generators	3,999	3.5
Lighting	25	0.02
Pumping	9	0.01
Stripping	1,344	1.2
Total	114,856	100

Based on the information presented above, excavation and hauling activities account for the majority of GHG emissions within the excavation category (92.1%).

Additional emissions associated with excavation are included in categories for which the individual activities result in the GHG emissions. For example, excavation is an important activity during the construction of tunnels and cofferdams. As such, this category has its own GHG emissions associated with excavation.

8.1.2 Concrete Works GHG Emissions

The GHG emissions associated with concrete works activity including:

- fuel truck service vehicle usage; and
- lubrication truck service vehicle usage.

Fuel consumption for these vehicles was provided by BC Hydro as estimates for the duration of construction. Greenhouse gas emissions were calculated for fuel combustion using emission factors provided by Environment Canada's Turning the Corner publications (Environment Canada, 2008a). The GHG emissions estimated for concrete works is 941 tonnes of CO_2e.

Emissions associated with concrete batch plants are included in categories for which the individual activity result in the GHG emissions.

8.1.3 Tunnel and Cofferdam GHG Emissions

The GHG emissions associated with tunnel and cofferdam construction represent a wide range of activities. These include:

- excavation and hauling;
- concrete;
- drilling;
- erection of steel;
- disposal;
- generators;
- formwork;
- slurry supply;
- grouting; and
- finishing and cleanup.

The data for these activities were provided by BC Hydro as consumption estimates for the Project construction. Greenhouse gas emissions were calculated for fuel combustion and electricity consumption using emission factors provided by Environment Canada's Turning the Corner (Environment Canada, 2008a) and National Inventory Reporting (Environment Canada, 2008b) publications respectively. The GHG emissions estimated for tunnel and cofferdam construction are presented in Table 8.1.3a.

Table 8.1.3a Tunnel and Cofferdam GHG Emissions

Activity	GHG Emissions (Tonnes of CO_2e)	Percent Contribution (%)
Excavation and Hauling	95,109	79.1
Concrete	18,924	15.7
Drilling	2,070	1.7
Erection of Steel	448	0.4
Disposal	32	0.03
Generators	1,362	1.1
Formwork	1	0.0
Slurry Supply	534	0.4
Grouting	1,787	1.5
Finishing & Cleanup	32	0.03
Total	**120,299**	**100**

Based on the information presented above, it is clear that excavation and concrete activities would account for the majority of GHG emissions within the tunnel and cofferdam construction category (at approximately 79.1% and 15.7% respectively).

8.1.4 Land Clearing GHG Emissions

The GHG emissions associated with land clearing are attributed to fuel combustion associated with equipment use. Data were provided by BC Hydro as fuel consumption estimates for the land clearing activities. Greenhouse gas emissions were calculated for fuel combustion using emission factors provided by Environment Canada's Turning the Corner (Environment Canada, 2008a). The GHG emissions estimated for land clearing is 8,389 tonnes of CO_2e.

8.1.5 Project Supported Activities GHG Emissions

Over the course of construction, various support activities are required for all of the construction categories. BC Hydro has estimated that the GHG emissions from these support activities represent approximately 2% of the fuel consumption for the other categories (excluding land clearing activities). This fuel consumption is primarily in the form of regular gasoline and therefore represents 4,736 tonnes of CO_2e. The combustion of fuel was converted to GHG using emission factors provided in Environment Canada's Turning the Corner publications (Environment Canada, 2008a).

8.1.6 Summary of Construction GHG Emissions

A summary of the GHG emissions is presented in Table 8.1.6a.

Table 8.1.6a Summary of Construction GHG Emissions

Category	GHG Emissions (Tonnes of CO_2e)	Percent Contribution (%)
Excavation	114,856	46.1
Concrete Works	941	0.4
Tunnels and Cofferdams	120,299	48.3
Land Clearing	8,389	3.4
Project Support	4,736	1.9
Total	249,221	100

Based on these estimates (Table 8.1.6a), it is clear that excavation and tunnel and cofferdam construction would be the major GHG sources from construction activities. This is primarily due to the fuel combustion associated with construction equipment for these categories. As such, this represents an area of focus for GHG mitigation during Site C construction activities.

9.0 DISCUSSION

In accordance with the objectives of this work, the global carbon cycle was reviewed, and potential GHG emissions from the implementation and operation of the Project were evaluated using the IPCC Tier 1 and Tier 2 methods. In addition, conceptual models of carbon and nitrogen cycling in Site C (Tier 3 approach) were developed and parameterized in order to provide a more site-specific analysis of the stocks, pathways and fluxes associated with GHG emissions and other potential carbon sources and sinks that might be altered by Project activities.

9.1 COMPARING IPCC TIER 1, TIER 2 METHODS AND THE TIER 3 MASS BALANCE APPROACH

Guidelines for three IPCC methods (Tier 1, Tier 2, and Tier 3) for calculating the potential carbon emissions from reservoirs are described as follows.

The Tier 1 approach (IPCC 2003) provides a simplified method for estimating GHG emissions from reservoirs, considering diffusive emissions only (Section 6.1). Under this generalized approach, emissions from the water surface of the reservoir are calculated over a period of one year, or 365 days.
The Tier 2 approach (IPCC 2003) is more detailed, with different emission factors used for the ice-free and ice-covered periods of the year (Section 6.2). Bubble emissions through the water column are considered, as well as degassing emissions from the spillways and turbines of operating generating facilities.

The Tier 3 approach (IPCC 2006) provides guidelines for developing project specific models that account for all major stocks, processes and pathways (fluxes) of carbon within the watershed (Section 7.0). This approach should provide the most precise estimate of the net emissions produced as a result of reservoir inundation and is therefore a more realistic model.

In the last two decades, lake and reservoir GHG emissions have frequently been assessed solely on the basis of surface emissions fluxes, and did not account for potentially mitigating factors such as carbon storage in lake sediment (Cole et al 1994). Consistent with this approach, Tier 1 and Tier 2 methods calculate emissions based on surface emissions fluxes (Tier 1) as well as turbine degassing and decomposition of non-submerged flooded vegetation (Tier 2). These methods assume generic GHG emission factors and ratios of CO_2 to CH_4 emitted from decomposition of flooded vegetation. Neither approach clearly addresses the temporal variation in GHG emission rates that is likely to occur as flooded soils and vegetation undergo rapid initial decomposition (as the labile carbon fractions decompose causing a high initial GHG emission rate), followed by a longer period of slower decomposition, with lower GHG emissions.

The importance of sedimentation in reservoirs as a sink of carbon was expressed by Dean and Gorham (1998) and Einsele *et al.* (2001). Dean and Gorham (1998) went so far as to state that the current rate of carbon deposited in surface water bodies, and reservoirs in particular, exceeds that of the marine environment, though the marine sediment stock is much larger. Recently, Cole *et al.* (2007) acknowledged the importance of sedimentation in inland water bodies (including reservoir) as a carbon sink. While inland water bodies represent a source of GHG to the atmosphere, much of this flux arises from the processing and decomposition of organic matter derived from terrestrial ecosystems. This organic matter would undergo decomposition regardless of whether it fell on land or in water. The important point raised by Cole *et al.* (2007) is that the intensity of carbon storage in lake sediment is high, in comparison with carbon storage intensity in terrestrial ecosystems, and that carbon stored in lake sediment is preserved for considerably longer (10,000 years or more) than forest biomass or soil (decades to centuries). This source of carbon sink is included in the mass balance models (Tier 3 approach) developed for this project.

The mass balance model for the Peace River post-inundation suggests that initially the net emissions for the Study Area would be increased due to flooded organic matter decomposition; however, once the reservoir had reached equilibrium emissions would decrease by over two orders of magnitude (Figure 7.4.5a). The average annual net project emission for Site C under the Tier 3 approach, using conservative default parameter values, is approximately 43,000 tonnes CO_2e/yr (including construction emissions). Compared to Tier 1 and 2 calculations, the Tier 3 year values are initially substantially higher due to the initial pulse of GHG emissions, but by year 20, these emissions are much lower than the Tier 1 and Tier 2 emission estimates (Figure 9.1a). These results are consistent with the observations of Bastien *et al.* (2007) that the GHG fluxes in Smallwood reservoir 30 years post-inundation are similar to those of natural lakes in the region. Using Tier 1 approaches, the net emissions for the Site C reservoir are approximately 89,792 tonnes CO_2e/yr; using Tier 2 methods, these emissions are 64,284 tonnes CO_2e/yr. When averaged over a 100 year operational lifespan, the Tier 3 net emissions, under default settings and including emissions from construction and equipment used to clear the reservoir, are notably lower than the Tier 1 and Tier 2 emission estimates (Figure 9.1a).

The Site C carbon model was developed to consider all major carbon stocks, processes and fluxes. This model indicated that initially, inundation removes 950,000 tonnes of carbon from the soil, vegetation and wetland stocks within Site C (Table 7.4.5a) due to flooding, and an additional 45,000 tonnes of carbon are removed from land cleared for new roads and transmission lines. This value does not change with respect to timber harvesting as it represents the loss of terrestrial carbon stocks. Under the assumption that all harvested timber would be stored in long-term forest products, this would reduce the mass of

flooded biomass carbon by approximately 177,000 tonnes and would have approximately an 18% reduction in net emissions over the 100 year lifespan (Table 7.6.5a).

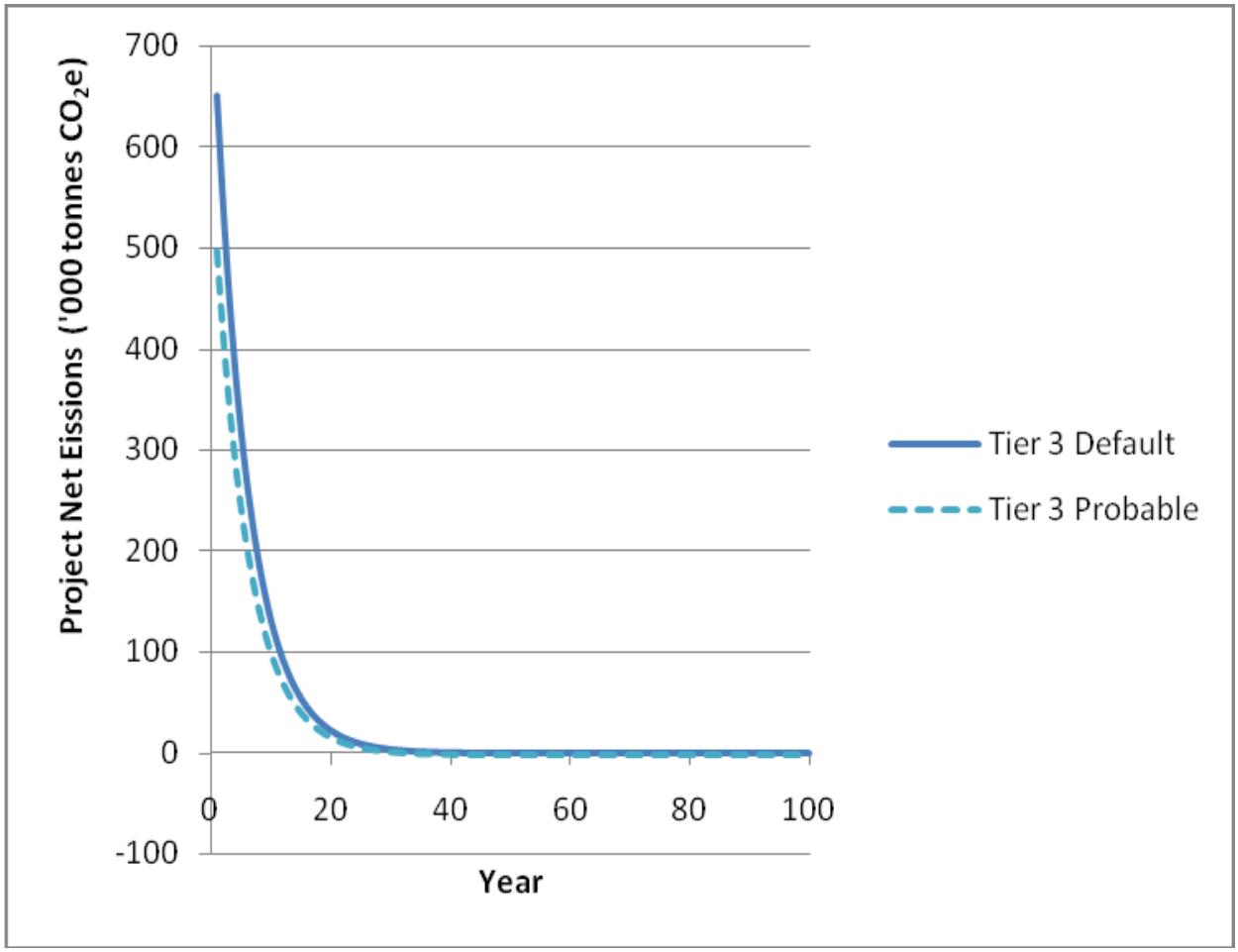

Figure 9.1a Annual Reservoir Emission Estimates ('000 tonnes CO_2e) from Tier 3 Projected over a 100 Year Time Period.

Post-inundation, there would also be erosion of new shorelines, particularly if the reservoir banks are primarily formed of sedimentary materials and have relatively steep slopes. This erosion would deposit large quantities of sandy sediment over the organic horizon of the flooded area, and would potentially bury and permanently store some of this organic matter beneath sediment. The extent of this process is difficult to forecast, but the sensitivity of the model to this process was assessed by examining the effects of biomass burial of up to 20% of flooded biomass. Coincidentally, with the multitude of processes and pathways modeled, reservoir net emissions (not including construction or fuel consumption) were directly proportional to the fraction of biomass that was buried (Table 7.4.5a). This underlines the magnitude of

effect that biomass decomposition plays in the emissions from reservoirs. Both in the short term, and in the long term, burial of carbon in the reservoir sediments is expected to approximately balance any carbon sink that is lost due to the flooding of terrestrial soils. As sediment is deposited in the reservoir, carbon will be permanently trapped and stored. Given that the Peace River, under current conditions, was assumed to deposit very small amounts of sediment, impounding would result in a large increase in surface area that accumulates carbon bearing sediment. These parameters were set to less conservative values for the probable emissions scenario. Under the probable emission scenario, the project net annual average emissions are reduced to 32,000 tonnes CO_2e/yr (including construction emissions) (Figure 9.1a).

9.2 PROJECT EMISSIONS IN THE GLOBAL CONTEXT

Recent climate change has been widely identified as being a result of anthropogenic activities that release GHGs (approximately 5.5 to 6.3 billion tonnes C/yr; Global Model CDOX6). Notably, combustion of fossil fuels and cement production as well as forest clearing and biomass burning have been identified as primary causes contributing to a net annual increase in the global atmospheric CO_2 inventory of approximately 1.3 billion tonnes C/yr of these new emissions going unchecked and contributing to the net accumulation of CO_2 and other GHGs in the atmosphere (Bice 2007). The net emissions of the Site C reservoir operation, over the 100 year operating lifespan of the project, would be approximately 40,581 tonnes CO_2e/yr under the default scenario or 29,119 tonnes CO_2e/yr under the probable scenario with an additional emission of approximately 249,000 tonnes CO_2e for the dam construction and fuel use. In the global context, these net emission rates represent a tiny fraction of the net anthropogenic emissions (5.5 to 6.3 billion tonnes CO_2e/yr). Furthermore, in the context of sediment accumulation, it is important to note that long-term use of hydroelectric reservoirs would gradually compensate for initial emissions due to land conversion. However, incremental emissions of any magnitude due to anthropogenic activities should be critically evaluated for alternative options. With respect to electricity generating facilities, absolute emissions should not be directly compared among facilities because the generating capacity also needs to be considered. The most appropriate means of comparing energy generating facilities is by examining relative emissions per unit energy generated (g CO_2/kWh).

9.3 RELATIVE EMISSIONS COMPARED TO ENERGY GENERATED

Hydroelectric development has been criticized as a potentially important net source of GHG (St. Louis *et al.,* 2000; Fernside 2004; IRN 2006). These concerns may be justified in some circumstances, primarily in tropical environments where there is evidence that some dams are large sources of CH_4 emissions. However, these concerns are not equally applicable to all hydroelectric facilities. Facilities constructed in northern (*i.e.,* temperate and boreal) environments generally emit lower quantities of GHG

(*i.e.,* g $CO_2e/m^2/yr$) emissions than tropical reservoirs (IRN 2006). The physical characteristics of the impounded system also influence the potential net emissions of a reservoir; facilities that require the impounding of relatively small areas in relation to generating capacity typically emit fewer GHGs than those that flood relatively large areas. Furthermore, cold, deep and well oxygenated systems, such as the proposed Project typically emit carbon primarily in the form of CO_2 rather than CH_4. The ratio of these gases is approximately 100:1 for boreal reservoirs whereas it may be closer to 20:1 for tropical reservoirs (IRN 2006).

In the context of increasing global energy demand and global climate change, evaluating generating facilities by their emissions (g CO_2e) per unit of energy generated (kWh) is an important relative measure when evaluating the potential climate warming impact of a project. Using Tier 1 calculation methods, the potential emissions per unit energy generated for the potential Site C project are 13.9 g CO_2e/kWh, using Tier 2 methods this values is 19.5 g CO_2e/kWh. Using the IPCC Tier 3 calculations for reservoir emissions, including construction and clearing emissions, the net emissions per unit energy generated averaged over the 100 year operating lifespan are 10 g CO_2e/kWh (Table 9.3a). Initially (in the first years of after inundation), the emissions per unit energy are much higher, due to the initial flux of GHG from the reservoir and are estimated to be 142 g CO_2e/kWh, but by year 20 this value is reduced to 6 g CO_2e/kWh and reaches 1 g CO_2e/kWh by year 35 (Figure 9.3a). Under the probable emissions scenario (see Sub-section 7.8) average emissions, including construction emissions, are 7 g CO_2e/kWh ranging from 108 to 0 g CO_2e/kWh. These values are consistent with the average range of 8 to 60 g CO_2e/kWh presented by the IRN (2006) for boreal reservoirs, though at the lower extreme. This is not surprising, given that Site C would have a constant water supply from the upstream Williston Reservoir, which would provide constant water supply for electricity generating while flooding a relatively small area of land. This type of reservoir is characterized as a run-of-river type project rather than a traditional reservoir hydro project. The IEA (2000) reported that run-of-river hydro projects are among the lowest emitting of all generating types, which is consistent with this study's results. In contrast to these figures, IRN (2006) estimated that, among other sources of electricity, modern coal-fired generating stations emit approximately 1,000 g CO_2e/kWh, and natural gas combined cycle generators emit approximately 545 g CO_2e/kWh (Table 9.3a). In fact over the life-cycle of Site C, relative emission estimates more closely resemble those of wind turbine facilities than others, but has the advantage of constant water supply compared to sporadic wind supplies.

While the construction and operation of the Site C reservoir and generating stations would result in a net increase in GHG emissions, they are "low" under the scoping considerations of the Canadian Environmental Assessment Agency Guidance (2003). They would be considered much lower than GHG

emissions from the combustion of fossil fuels to generate equivalent amounts of electricity, given the biogenic origin of the Peace River emissions. In other words, as the emissions from Site C originate primarily from decomposition of organic matter currently stored in soils and plants, this carbon could be recaptured rapidly post-decommissioning when compared to fossil fuel emissions, which is not returned to their original carbon stocks (*i.e.*, oil, coal, natural gas). As approximately 95% of emissions from the potential Site C project would originate from biomass removal and only 5% from emissions related to construction and fuel use, an analysis of measures to mitigate or offset carbon emissions from biomass decomposition would be useful.

Table 9.3a Comparative Life-cycle Project Average Emissions per Unit Energy Generated (g CO_2e/kWh)

Generating Facility Type	Range	Average
BC Hydro Site C (IPCC Tier 3)	1-142*; 0-108**	8***
Canada Boreal Hydroelectric	8 - 60	36
Tropical Hydroelectric	1,750 - 2,700	2,150
Modern Coal	959 - 1,042	1,000
IGCC (coal)	763 - 833	798
Diesel	555 - 880	717
NGCC (Natural Gas)	469 - 622	545
Photovoltaic	13 - 104	58
Wind Turbines	7 - 22	14

Notes:
Source: IRN 2006
* Range represents the maximum and minimum of annual estimates from the 100-year model estimates (default settings).
** Range represents the maximum and minimum of annual estimates from the 100-year model estimates (probable settings).
*** The average value is the 100-year average estimate over both default and probable settings.

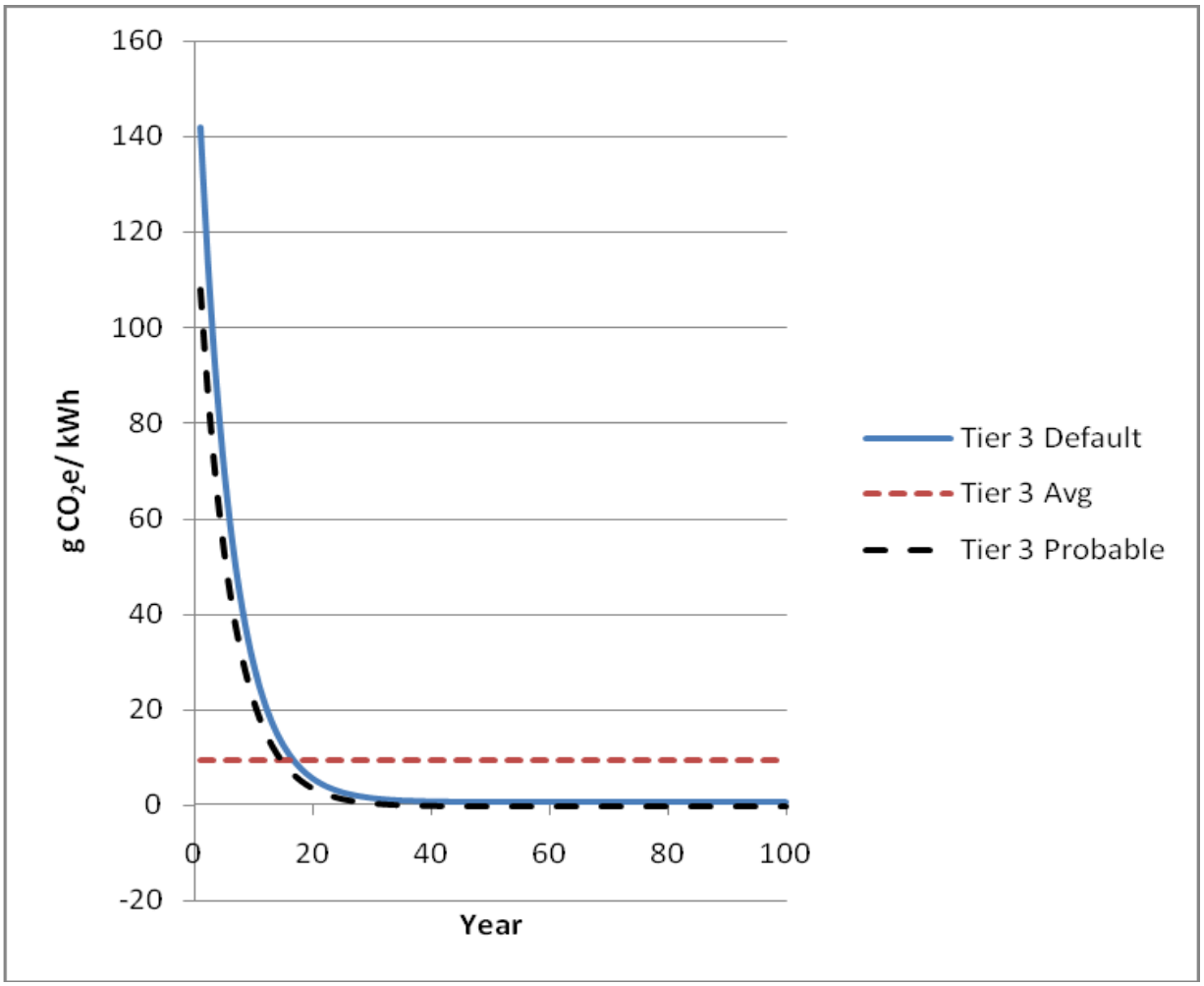

Figure 9.3a Relative Emissions per Unit Energy Generated (g CO_2/kWh) Estimated Using Tier 3 Methods

9.4 POSSIBLE MITIGATION MEASURES

Mitigation options for the potential construction and operational phases of the Project are presented in the following sections.

9.4.1 Mitigation of Construction GHG Emissions

Although the construction GHG emissions are considered to be low when compared to the overall Project, there is potential for mitigation of these emissions. In particular, many of the operational activities associated with GHG emissions, such as biomass inundation, do not present viable options for mitigation. However, the construction emissions, which are associated predominantly with vehicle and equipment

fuel combustion, are under the direct control of BC Hydro. As such, many potential mitigation options for the construction phase of the project, should the project proceed to that stage, are presented in this section.

The majority of GHG emissions during construction result from the burning of fossil fuels, namely the burning of diesel in vehicles and heavy equipment. As a result, reduced GHG emissions are linked directly to reductions in fossil fuel consumption and implementation of fuel conservation strategies. The following sections highlight some potential areas for GHG reduction throughout the construction of this Project.

9.4.1.1 Reduction in Fuel Usage

The following actions represent areas for potential reduction in fuel usage:

- Reduce the amount of time vehicles idle by implementing a "no idle" policy;
- Reduce unnecessary weight being carried in vehicles by removing extra/unwanted equipment and tools; and
- Travel at recommended speeds for optimal fuel efficiency while respecting speed limits.

9.4.1.2 Increase Fuel Efficiency

The following actions represent areas for potential increased fuel efficiency in construction equipment:

- Uphold maintenance schedules on all vehicles and equipment;
- Insure optimal tire pressure, insure air filter is clean, have wheel alignment checked, as well as regular oil changes and engine tune-ups;
- Insure gas tanks are kept two thirds full to allow for optimal fuel consumption. Low fuel may result in an inconsistent gas supply and consequently decreased efficiency;
- Insure gas caps are put back on tightly after re-fuelling to prevent evaporation of fuel;
- Further to reducing fuel loss, there is potential to mitigate harmful evaporative gases being released into the atmosphere; and
- Insure logs of millage and fuel purchases are kept to allow for fuel consumption tracking.

9.4.1.3 Fleet Management

The following actions represent areas for potential reduction in GHG emissions by management of construction equipment:

- Retire old and under-used vehicles/equipment and replace with newer more fuel efficient vehicles/equipment. State-of-the-art turbo-charged diesel engines, found in new large trucks and

heavy equipment, achieve 46 to 47 percent peak thermal efficiency, versus only 25 percent for spark-ignited gasoline engines (Green and Schafer, 2003); and
- If feasible, purchase fuel efficient (*e.g.,* hybrid) and/or smaller fleet vehicles.

9.4.1.4 Reduce Vehicle Trips

The following actions represent areas for potential reduction in GHG emissions by managing the vehicle trips to and from the construction site:
- minimize the length of haul routes where possible;
- encourage mass transport (*i.e.,* provide bus to transport construction staff to reduce amount of vehicles travelling to and from work site); and
- encourage car-pooling to reduce amount of vehicles travelling to and from work site.

9.4.2 Mitigation of Operational GHG Emissions

Mitigation of emissions resulting from operational activities is limited and has received very little attention in the literature. As outlined in IPCC (2006), emissions resulting from land-use change are relative to the land area converted from forest to non-forested land. As a result, the following areas for mitigation should be examined as BC Hydro moves forward with this Project.

9.4.2.1 Innovation in Design

Land conversion as a result of reservoir impoundment is largely based on engineering design to maximize the generating capacity of the facility. Therefore, land conversion is largely driven by engineering design and requirements. However, evaluating cost-benefit tradeoffs from optional design and generation specifications may identify design options that would result in little reduction in generating potential, yet significant reductions in land conversion and concomitant GHG emissions from loss of carbon stocks.

A second consideration in design may be examining options for transmission lines and roads that would minimize the amount of land conversion resulting from these activities.

9.4.2.2 Reduce Biomass Removal and Decomposition

While some information is available regarding the rate of organic matter decomposition in aquatic systems and the preservation of organic matter in cold, anoxic conditions (Bilby *et al.,* 1999; Harmon *et al.,* 2000; Jordan, 2001; Scherer, 2004), no information regarding the burial of biomass from the perspective of preventing decomposition in reservoirs is available. While some biomass burial will likely

take place in the reservoir, the extent of this process is largely unknown. Furthermore, successful burial of biomass to prevent biomass decomposition would depend on selecting appropriate locations that would remain anoxic and that would not be subject to erosion of overburden, which would expose the organic matter and promote decomposition. Furthermore, the risk that some burial in anoxic conditions would promote additional CH_4 production would also require careful examination. However, a study examining the potential to bury biomass within the reservoir (including the most appropriate location, depth, and quantity of biomass) may be beneficial in identifying whether this activity holds any promise as mitigation.

As the road and transmission line right-of-way biomass accounted for approximately 5% of Site C emissions, management strategies to minimize biomass removal for these project components would result in a very modest change to potential Site C emissions.

10.0 CLOSURE

This report has been prepared for the sole benefit of the British Columbia Hydro and Power Authority. The report may not be used by any other person or entity, other than for its intended purposes, without the consent of Jacques Whitford AXYS Ltd. and the British Columbia Hydro and Power Authority.

The information and conclusions contained in this report are based upon work undertaken in accordance with generally accepted engineering and scientific practices current at the time the work was performed. The information provided in this report was compiled from existing documents, design information provided by the British Columbia Hydro and Power Authority, data provided by regulatory agencies and others. Information obtained from secondary sources has been assumed to be correct; Jacques Whitford AXYS Ltd. accepts no responsibility for damages or liability that may arise from use of this data.

If any conditions become apparent that deviate from our understanding of conditions as presented in this report, Jacques Whitford AXYS Ltd. requests that we be notified immediately, and permitted to re-assess the conclusions provided herein.

This report was prepared by Karen Gilliam, MSc, Jean-Michel DeVink, PhD, and Joe Harriman, PhD, and was reviewed by Peter D. Reid, MSc and Michael C. Murphy, PhD, PEng. If you have any questions or comments on the contents of this report, please contact the undersigned.

(Original signed by)

Peter D. Reid, M.Sc
Senior Specialist & Group Leader
Project Manager

(Original signed by)

Michael C. Murphy, PhD, P.Eng
Principal
Senior Technical Review

11.0 REFERENCES

11.1 LITERATURE CITED

Alban, D.H., Perala, D.A., and Schlaegel, B.E. 1978. Biomass and nutrient distribution in aspen, pine, and spruce stands on the same soil type in Minnesota. Can. J. For. Res., Vol. 8, pp. 290–299.

Avakyan, A.B., and Iakovleva, V.B. 1998. Status of global reservoir: The position in the late twentieth century. *Lakes and Reservoir: Research and Management* Vol.3, pp. 45-52.

Bastien, J., Blais A.M., and Tremblay, A. 2007. *Study of Greenhouse Gas Fluxes Emitted from the Smallwood Reservoir, Natural Lakes and the Peace River in Labrador; 2006 Results*. Report prepared by Environnement Illimite Inc. for the direction Barrages et Environnement d'Hydro-Québec Production. 38 pp. + Appendices.

Baumgartner, A., and Reichel, E. 1975. *The World Water Balance*. Elsevier.

BC Hydro. 2003. Peace River Development Site C Project: Estimate update 2002 generating station, substations and transmission lines. Report No. PSE421.

BC Hydro. 2007. Site C Feasibility Review: Stage 1 Completion Report. December 2007.

Bellisario, L.M., Bubier, J.L., and Moore, T.R. 1999. Controls on CH_4 emissions from a northern peatland. *Global Biogeochemical Cycles* Vol.13(1), pp. 81-91.

Bergeron, O., Margolis, H.A., Black, T.A., Coursolle, C, Dunn, A.L., Barr, A.G., and Wofsy, S.C. 2007. Comparison of carbon dioxide fluxes over three boreal black spruce forests in Canada. *Global Change Biology* Vol. 13, pp. 89-107.

Bilby, R., Heffner, J., Fransen, B., Ward, J., and Bisson, P. 1999. Effects of immersion in water on deterioration of wood from five species of trees used for habitat enhancement projects. North American Journal of Fisheries Management, Vol. 19, pp. 687-695.

Billings, S.A., Richter, D.D., and Yarie, J.. 2000. Sensitivity of soil methane fluxes to reduced precipitation in boreal forest soils. *Soil Biology and Biochemistry,* Vol. 32, 1431-1441.

Bird, G.A., Stephenson, M., and Cornett, R.J. 1992. *The Surface Water Submodel for the Assessment of Canada's Nuclear Fuel Waste Management Concept*. AECL Research, Chalk River Laboratories, ON. 143 pp.

Blais, A., Lorrain, S. and Tremblay, A. 2005. Greenhouse Gas Fluxes (CO_2, CH_4 and N_2O) in Forests and Wetlands of Boreal, Temperate and Tropical Regions. p. 87-127. *In* Tremblay, A., Varfalvy, L., C. Roehm and M. Garneau [eds]. 2005. Greenhouse Gas Emissions: Fluxes and Processes, Hydroelectric Reservoirs and Natural Environments. Environmental Science. New York: Springer. 732 pp.

Bond-Lamberty, B., Peckham, S.D. Ahl, D.E., and Gower, S.T. 2007. Fire as the dominant driver of central Canadian boreal forest carbon balance. *Nature,* Vol. 450, pp. 89-93.

Bousquet, P., Ciais, P., Miller, J.B., Dlugokencky, E.J., Hauglustaine, D.A., Prigent, C., Van der Werf, G.R., Peylin, P. Brunke, E.G. Carouge, C. Langenfelds, R.L. Lathière. J. Papa, F. Ramonet, M. Schmidt, M. Steele, L.P., Tyler, S.C., and White, J. 2006. Contributions of anthropogenic and natural sources of atmospheric methane variability. *Nature,* Vol. 443, pp. 439-443.

Bubier, J., Moore, T., Savage, K., and Crill, P. 2005. A comparison of methane flux in a boreal landscape between a dry and a wet year. Global Biogeochem. Cycles, Vol. 19, GB1023, doi: 10.1029/2004GB002351

Burke, R.A., Zepp, R.G., Tarr, M.A. Miller, W.L., and Stocks B.J. 1997. Effect of fire on soil-atmosphere exchange of methane and carbon dioxide in Canadian boreal forest sites. Journal of Geophysical Research, Vol. 102, pp. 29,289-29,300.

Cole, J.J., Caraco, N.F., Kling, G.W., and Kratz, T.K. 1994. Carbon dioxide supersaturation in the surface waters of lakes. *Science, Vol.* 265, pp. 1568-70.

Cole, J.J., Prairie, Y.T. Caraco, N.F. McDowell, W.H. Tranvik, L.J. Striegl, R.G. Duarte, C.M. Kortelainen, P. Downing, J.A. Middelburg, J.J, and Melack, J. 2007. Plumbing the global carbon cycle: Integrating inland waters into the terrestrial carbon budget. *Ecosystems* Vol. 10, pp. 171-184.

Dean, W.E., and Gorham, E. 1998. Magnitude and significance of carbon burial in lakes, reservoirs, and peatlands. Geology, Vol. 26(6). pp. 535–538

Diem, T., Koch, S., Schwarzenbach, S., Wehrli, B., and Schubert, C. J. 2008. Greenhouse gas emissions (CO_2, CH_4 and N_2O) from perialpine and alpine hydropower reservoirs, Biogeosciences Discuss., Vol.5, pp. 3699-3736.

Dillon, P.J., and Molot, L.A. 1997. Dissolved organic and inorganic mass balances in central Ontario lakes. *Biogeochemistry* Vol. 36, 29-42.

Duchemin, E, Lucotte, M. Canuel, R., and Chamberland, A. 1995. Production of greenhouse gases CH_4 and CO_2 by hydroelectric reservoir of the boreal region. *Global Biogeochemical Cycles,* Vol. 9(4), pp. 529-540.

Duchemin, E., Lucotte, M., St. Louis, V and Canuel, R. 2002. Hydroelectric Reservoirs as an Anthropogenic Source of Greenhouse Gases. World Resource Review Vol. 14(3), pp. 334 – 353.

Einsele, G., Yan, J., and Hinderer, M. 2001. Atmospheric carbon burial in modern lake basins and its significance for the global carbon budget. Global and Planetary Change, Vol. 30, pp. 167-195.

Environment Canada. 2006. *Canada's Fourth National Report on Climate Change: Actions to Meet Commitments Under the United Nations Framework Convention on Climate Change*. Cat. No.: En4-73/2006E.

Falkowski, P., Scholes, R.J., Boyle, E., Canadell, J., Canfield, D., Elser, J., Gruber, N., Hibbard, K., Högberg, P., Linder, S., Mackenzie, F.T., Moore III, B., Pedersen, T., Rosenthal, Y., Seitzinger, S., Smetacek, V, and Steffen, W. 2000. The global carbon cycle: A test of our knowledge of earth as a system. *Science,* Vol. 290(5490), pp. 291-296.

Fernside, P.M. 2004. Greenhouse gas emissions from hydroelectric dams: controversies provide a springboard for rethinking a supposedly 'clean' energy source. An editorial comment. *Climatic Change,* Vol. 66, pp. 1-8.

Fluxnet. 2008. 2007-2008 Progress Report Western Peatland Flux Stations. Accessed October 2008 from http://www.fluxnet-canada.ca/pages/publications/publications_en/PDF/CCP_2007-2008%20Progress%20Report_no%20GHG.pdf

Fredeen A.L., Bois, C.H., Janzen, D.T., and Sanborn, P.T. 2005. Comparison of coniferous forest carbon stocks between old-growth and young second-growth forests on two soil types in central British Columbia, Canada. Can. J. For. Res., Vol. 35, pp. 1411–1421.

Galy-Lacaux, C. 1996. Modifications des échanges de constituants mineurs atmosphériques liées à la creation d'une retenue hydroélectrique. Impact des barrages sur le bilan du méthane dans l'atmosphère, PhD dissertation, Université Paul Sabatier, Toulouse (France), 200 p. *In* Duchemin, E., M. Lucotte, St. Louis and R. Canuel. 2002. Hydroelectric Reservoirs as an Anthropogenic Source of Greenhouse Gases. World Resource Review, Vol. 14(3), pp. 334 – 353.

Gilbert, R., and Butler, R.D. 2004. The physical limnology and sedimentology of Meziadin Lake, northern British Columbia. Arctic Antarctic and Alpine Research, Vol. 36, pp. 33–41.

Gleick, P.H. 1996. Water resources. In: S.H. Schneider (Editor), Encyclopedia of Climate and Weather. Oxford University Press, New York, pp. 817-823.

Government of British Columbia. 2007. Ministry of Energy, Mines and Petroleum Resources. The BC Energy Plan: A Vision for Clean Energy Leadership. February 2007.

Gower, S.T., Vogel, J., Snow, T.K., Norman, J.M., Steele, S.J., and Kucharik, C.J. 1997. Carbon distribution and above-ground net primary production of upland and lowland boreal forests in Saskatchewan and Manitoba. Journal of Geophysical Research, Vol., 104(24), pp. 29,029-29,041.

Granli, T., and Bøckman, O.C. 1994. Nitrous oxide from agriculture. Norw. J. Agric. Sci. Suppl. 12, 128 pp.

Green, D.L. and Schafer, A. 2003. Reducing Greenhouse Gas Emissions from U.S. Transportation. Prepared for the Pew Center for Global Climate Change. Accessed September 2008 from http://www.ethanolrfa.org/objects/documents/75/pewclimate.pdf

Hanson, P.C., Bade, D.L., Carpenter, S.R., and Kratz, T.K. 2003. Lake metabolism: Relationships with dissolved organic carbon and phosphorus. *Limnology and Oceanography*, Vol. 48(3), pp. 1112-1119.

Harden, J.W., Trumbore, S.E., Stocks, B.J., Hirsch, A., Gower, S.T., O'Neill, K.P., and Kasischke, E.S. 2000. The role of fire in the boreal carbon budget. *Global Change Biology,* Vol. 6 (1), pp. 174-184.

Harmon, M. E., Krankina, O. N., and Sexton, J. 2000. Decomposition vectors: a new approach to estimating woody detritus decomposition dynamics. Canadian Journal of Forest Research, Vol. 30, pp. 76-84.

Hedges, J., Keil, R., and Benner, R. 1997. What happens to terrestrial organic matter in the ocean. *Organic Geochemistry* Vol. 27, pp. 195-212.

Hellsten, S.K, Martikainen, P. Vaisanen, T.S, Niskanen, A. , Huttunen, J. , Heiskanen, M. , and Nenonen, O. 1996. Measured greenhouse gas emissions from two hydropower reservois in northern Finland, *In* IAEA Advisory group meeting on assessment of greenhouse gas emission from the full energy chain for hydropower, nuclear power and other energy sources, Hydro-Quebec, Monreal (Canada), 1-12 (1996). *In* Duchemin, E., M. Lucotte, St. Louis and R. Canuel. 2002. Hydroelectric Reservoirs as an Anthropogenic Source of Greenhouse Gases. World Resource Review, Vol. 14(3), pp. 334 – 353.

Hendzel, L. L., C. J D., Matthews, J. J., Venkiteswaran, V. L., St. Louis, D., Burton, E. M., Joyce, and R. A., Bodaly. 2005. Nitrous oxide fluxes in three experimental boreal forest reservoirs. Environmental Science and Technology, Vol. 39, pp. 4353–60.

Hesslein, R.H., Broecker, W.S., and Quay, P.D. 1980. Whole-lake radiocarbon experiment in an oligotrophic lake at the experimental lakes area, northwestern Ontario. *Canadian Journal of Fisheries and Aquatic Science,* Vol. 37, pp. 454-463.

Holmstead, G.L. 2001. Vegitation of the Snake River corridor in Hells Canyon—Weiser, Idaho, to the Salmon river In Technical appendices for Hells Canyon Complex hydroelectric Project. Tech. Rep. E.3.3-1. Idaho Power Co., Boise, ID.

Houghton, R.A. 2007. Balancing the carbon budget. *Annual Review of Earth and Planetary Sciences,* Vol. 35, pp. 313-47.

Huttunen J.T., Alm, J., Liikanen, A., Juutinen, S., Larmola, T., Hammar, T., Silvola, J. and Martikainen, P.J. 2003. Fluxes of methane, carbon dioxide and nitrous oxide in boreal lakes and potential anthropogenic effects on the aquatic greenhouse gas emissions. *Chemosphere*, Vol. 52, pp. 609-621.

Industrial Forestry Service, Ltd. 2008. Timber harvest and clearing plan Peace River Site C dam project. Report prepared for British Columbia Hydro and Power Authority (BC Hydro), Vancouver, BC.

Industrial Forestry Service, Ltd. 2008. Timber harvest and clearing plan Peace River Site C dam project. Report prepared for British Columbia Hydro and Power Authority (BC Hydro), Vancouver, BC.

Intergovernmental Panel on Climate Change (IPCC). 1996. Summary for Policy Makers--IPCC Working Group 1. Accessed August 2008 from http://www.ipcc.ch/pdf/climate-changes-1995/spm-science-of-climate-changes.pdf

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: Synthesis Report Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A.(eds.)]. Geneva, Switzerland. Accessed September 2008 from http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Accessed August 2008 from http://www.ipcc.ch/ipccreports/ar4-wg1.htm

International Energy Agency (IEA). 2000. Implementing agreement for hydropower technologies and programs. Annex III: Hydropower and the environment. Accessed November 2009 from www.ieahydro.org

International Rivers Network (IRN). 2006. Fizzy Science. *Loosening the Hydro Industry's Grip on Reservoir Greenhouse Gas Emissions Research*. 24 pp. Accessed October 2008 from www.irn.org

IPCC (Intergovernmental Panel on Climate Change). 1997. *IPCC/OECD/IEA Programme on National Greenhouse Gas Inventories: Expert Group Meeting on Methods for the Assessment of Inventory Quality*. Prepared by B. Lim, and P. Boileau. 45 pp.

IPCC (Intergovernmental Panel on Climate Change). 2001. Climate Change 2001: The Scientific Basis. In: J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. Van der Linden, X. Dai, K. Maskell and C A. Johnson (eds.). *Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*. Cambridge Univ. Press, Cambridge, UK. 944 pp.

IPCC (Intergovernmental Panel on Climate Change). 2003. *Good Practice Guidance for Land Use, Land-Use Change and Forestry*. J. Penman, M. Gytarsky, T. Hiraishi, T. Krug and D. Kruger (eds.). Institute for Global Environmental Strategies (IGES). 944 pp.

IPCC (Intergovernmental Panel on Climate Change). 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. Prepared by the National Greenhouse Gas Inventories Programme, H.S. Eggleston, L. Buendia, K. Miwa, T. Ngara and K. Tanabe (eds.). Published: IGES, Japan.
Jordan, B.A. 2001. Site characteristics impacting the survival of historic waterlogged wood: A review. Int. Biodeterior. Biodegrad., Vol. 47, pp. 47-54.

Kelly, C.A., Everett, F., Ramlal, P.S., Rudd, J.W.M., Hesslein, R.H., Anema, C, and Schindler, E.U. 2001. Natural variability of carbon dioxide and net epilimnetic production in surface water of boreal lakes of different sizes. *Limnology and Oceanography*, Vol. 46(5), pp. 1054-1064.

Kelly, C.A., Rudd, J.W.M., St. Louis, V.L., and Moore, T. 1994. Turning attention to reservoir surfaces, a neglected area in greenhouse studies. *EOS*, Vol. 75, pp. 332-333.

Kingston, G.W. 1977. Fisheries of McGregor and Peace River Hydroelectric Developments. B.C Fish and Wildlife, Prince George, B.C. 52 pp.

Klinger, L.F., Zimmerman, P.R., Greenberg, J.P., Heidt, L.E. and Guenther, A.B. 1994. Carbon trace gas fluxes along a successional gradient in the Hudson Bay lowland. *Journal of Geophysical Research,* Vol. 99(D1), pp. 1469-1494.

Klohn Crippen and SNC-Lavalin, 2003. Prefeasibility Study for a Cascade of Low Consequence Structures as an Alternative to Site C. Report prepared by Klohn Crippen Consultants Ltd. and SNC-Lavalin Inc.for B.C Hydro, January, 2003. Report No. 186 PP 1448-02-01.

Kondratjev, N.E. 1966. Bank formation of newly established reservoirs. State Hydrological Institute, USSR. Accessed December 2008 from http://www.cig.ensmp.fr/~iahs/redbooks/a071/071028.pdf

Kulshreshtha , S.N, Bonneau, M., Boehm, M., and Giraldez, J.C. 1999. Canadian Economic and Emissions model for agriculture (C.E.E.M.A. Version 1.0). Report 1: Model Description. 248 pp. Accessed September 2008 from http://www4.agr.gc.ca/resources/prod/doc/pol/pub/ceema-mcpeea/pdf/rpt1_e.pdf

Kulshreshtha, S.N, Ravinderpal, G., Junkins, B Desjardins, R., Boehmand, M, and Bonneau, M. 2002. Canadian Economic and Emissions model for agriculture (C.E.E.M.A. Version 2.0): Technical Documentation. 248 pp. Accessed September 2008 from
http://www.csale.usask.ca/PDFDocuments/cndEconEmissionMdl.pdf

Lashof, D.L., and D.R. Ahuja. 1990. Relative contributions of greenhouse gas emissions to global warming. *Nature,* Vol. 344, pp. 529-531.

Lerner, J., and Matthews, E. 1988. Methane emission from animal: A global high-resolution data base. *Global Biogeochemical Cycles*, Vol. 2(2), pp. 139-156.

Lima, I., Ramos, F., Bambace, L., and Rosa, R. 2007. Methane emissions from large dams as renewable energy resources: A developing nation perspective. *Mitigation and Adaptive Strategies for Global Change*. DOI 10.1007/s11027-007-9086-5.

Malhi, Y., Baldocchi, D.D., and Jarvis, P.G. 1999. The carbon balance of tropical, temperate and boreal forests. *Plant, Cell and Environment,* Vol. 22, pp. 715-740.

Marani, L., and Alvala, P.C. 2007. Methane emissions from lakes and floodplains in Pataal, Brazil. *Atomspheric Environment* Vol. 41(8), pp. 1627-1633.

Marshall, S.J., and Clarke, K.C. 1999. Modeling North American freshwater runoff through the last glacial cycle. *Quaternary Research,*Vol. 52, pp. 300-315.

Masiello, C.A., and Druffel, E.R.M. 1998. Black carbon in deep-sea sediments. *Science*, Vol. 280, pp. 1911-1913.

Moore, T.R, Bubier, J.L., Frolking, S.E., Lafleur, P.M., and Roulet, N.T. 2002. Plant biomass and production and CO_2 exchange in an ombrotrophic bog. Journal of Ecology, Vol. 90, pp. 25–36.

Moore, T.R., Bubier, J.L , Frolking, S.E., LaFleur, P.M. and Roulet, N.T. 2002. Plant biomass and production and CO_2 exchange in an ombrotrophic bog. *Journal of Ecology,* Vol. 90, pp. 25-36.

Mosier, A.R., Parton, W.J., Valentine, D.W., Ojima, D.S., Schimel, D.S., Heinemeyer, O. 1997. CH_4 and N_2O fluxes in the Colorado shortgrass steppe: 2. Long-term impact of land use change. Global Biogeochem. Cycles, Vol. 11, pp. 29–42. *In* Wang, F.L., Bettany, J.R., and Huang, P.M. 1999. Methane uptake by cultivated Canadian prairie and forest soils. Geoderma, Vol. 88, pp. 39–53.

Mosier, A.R., Parton, W.J., Valentine, D.W., Ojima, D.S., Schimel, D.S., Delgado, J.A. 1996. CH_4 and N_2O fluxes in the Colorado shortgrass steppe: 1. Impact of landscape and nitrogen addition. Global Biogeochem. Cycles, Vol. 10, pp. 387–399. *In* Wang, F.L., Bettany, J.R., and Huang, P.M. 1999. Methane uptake by cultivated Canadian prairie and forest soils. Geoderma, Vol. 88, pp. 39–53.

Perala, D.A., and Alban, D.H. 1982. Biomass, nutrient distribution and litterfall in Populus, Pinus and Picea stands on two different soils in Minnesota. Plant and Soil ,Vol. 64, pp. 177-192.

Potter, C., Bubier, J., Crill, P., and Lafleur, P. 2001. Ecosystem modeling of methane and carbon dioxide fluxes for boreal forest sites. Can. J. For. Res., Vol. 31, pp. 208–223.

Reay, D. 2009. Greenhouse Gas Online: All about greenhouse gas science. 2009. Accessed October 2008 from http://www.ghgonline.org/index.htm

Roulet, N.T. 2000. Peatlands, carbon storage, greenhouse gases, and the Kyoto protocol: Perspectives and significance for Canada. *Wetlands* Vol. 20(4), pp. 605-615.

Rowan, D.J., Kalff, J., and Rasmussen, J.B. 1992. Estimating the mud deposition boundary depth in lakes from wave theory. *Canadian Journal of Fisheries and Aquatic Sciences,* Vol. 49, pp. 2490-2497.

Ruark, G.A ,and Bockheim, J.G. 1988. Biomass, net primary production, and nutrient distribution for an age sequence of Populus temuloides ecosystems. Can. J. For. Res., Vol. 18, pp. 435–443.

Ruck A., Walker, I.R., and Hebda, R. 1998. A palaeolimnological study of Tugulnuit Lake, British Columbia, Canada, with special emphasis on river influence as recorded by chironomids in the lake's sediment. Journal of Paleolimnology, Vol. 19, pp. 63–75.

Rudd, J.W.M., Harris, R. Kelly, C.A., and Hecky, R.E. 1993. Are hydroelectric reservoir significant sources of greenhouse gases? *Ambio* Vol. 22, pp. 246-248.

Ruess, R.W., Cleve, K.V., Yarie, J., and Viereck, L.A. 1996. Contributions of fine root production and turnover to the carbon and nitrogen cycling in taiga forests of the Alaskan interior. Can. J. For. Res. 26: 1326–1336. *In* Li, Z., Kurz, W.A., Apps, M.J., and Beukema, S.J. 2003. Belowground biomass dynamics

in the Carbon Budget Model of the Canadian Forest Sector: recent improvement and implications for the estimation of NPP and NEP. Can. J. For. Res., Vol. 33, pp. 126-136. Accessed October 2009 http://carbon.cfs.nrcan.gc.ca/downloads/RootData_CJFR_2003.xls

Sauvé, J.L. 2000. A Preliminary Assessment of Carbon Dioxide and Nitrous Oxide Emissions from Agricultural Soils in Alberta. Report prepared for AESA Soil Quality Committee. Accessed November 2008 from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/aesa8424

Savage, K, Moore, T.R., and Crill, P.M. 1997. Methane and carbon dioxide exchanges between atmosphere and northern boreal forest soils. Journal of Geophysical Research, Vol, 102 (D24), pp. 29,279-29,288.

Scherer, R. 2004. Decomposition and longevity of in-stream woody debris: a review of literature from North America, pp. 127-133 *In* G.J. Scrimgeour, G. Eisler, B. McCulloch, U. Silins and M. Monita. Editors. Forest Land–Fish Conference – Ecosystem Stewardship through Collaboration. Proc. Forest-Land-Fish Conf. II, April 26-28, 2004, Edmonton, Alberta.

Schlesinger, W.H. 2001. *The Carbon Cycle: Human Perturbations and Potential Management Options*. Presented at the symposium: global climate change: the science, economics and policy, the Bush School of Government and Public Service, Texas A & M University, 06 April, 2001.

Schmid, M., De Batist, M., Granin, N.G., Kapitanov, V.A., McGinnis, D.F., Mizandrontsev, I.B., Obzhirov, A.I., and Wuest, A. 2007. Sources and sinks of methane in Lake Baikal: a synthesis of measurements and modeling. *Limnology and Oceanography,* Vol. 52, pp. 1824-1837.

Siegenthaler, U., and Sarmiento, J.K. 1993. Atmospheric carbon dioxide and the ocean. *Nature* Vol. 365, pp. 119-125.

Soumis, N., Duchemin, E., Canuel, R., Lucotte, M., 2004. Greenhouse gas emissions from reservoirs of the Western United States. Global Biogeochem. Cycles, Vol. 18, doi:10.1029/2003GB002197.

Soumis, N., Lucotte, M., and Canuel, R. 2005. Hydroelectric reservoir as anthropogenic sources of greenhouse gases. Pp. 203-210. *In*: J.H. Lehr and J Keeley (eds.). *Water Encyclopedia: Surface and Agricultural Water*. Wiley-Interscience, Hoboken, NJ.

St. Louis, V.L., Kelly, C.A., Duchemin, E., Rudd, J.W., and Rosenberg, D.M. 2000. Reservoir surfaces as sources of greenhouse gases to the atmosphere: A global estimate. *BioScience* Vol. 50(9), pp. 766-775.

Steele, S.J., Gower, S.T., Vogel, J.G., and Norman, J.M. 1997. Root mass, net primary production and turnover in aspen, jack pine and black spruce forests in Saskatchewan and Manitoba, Canada. Tree Physiol., Vol. 17, pp. 577–587.

Stephenson, M., Motycka, M., and Schwartz, W.J. 1994. Carbon-14 Activity in the Water, Sediments and Biota of Lakes 226 North, 226 South and 224, Experimental Lakes Area, 1989 to 1994. *Atomic Energy of Canada Limited Technical Record* TR-634, COG-94-97.

Thauer, R.K., and Shima, S. 2006. Biogeochemistry: methane and microbes. *Nature* Vol. 440, pp. 878-879.

Tremblay, A., Lambert, M., and Gagnon, L. 2004a. Do hydroelectric reservoir emit greenhouse gases? *Environmental Management,* Vol. 33(Suppl. 1), pp. S509-S517.

Tremblay, A., Therrien, J., Hamlin, B, Wichmann, E, and LeDrew, L.J. 2005. GHG Emissions from Boreal Reservoirs and Natural Aquatic Ecosystems. p. 209-232 *In* Tremblay, A., Varfalvy, L., C. Roehm and M. Garneau (editors). 2005. Greenhouse Gas Emissions: Fluxes and Processes, Hydroelectric Reservoirs and Natural Environments. Environmental Science. New York: Springer. 732 pp.

Tremblay, A., Varfalvy, L. Roehm C., and Garneau, M. 2004b. The issue of greenhouse gases from hydroelectric reservoirs: from boreal to tropical regions. In: Proceedings of the United Nations Symposium on Hydropower and Sustainable Development, Beijing, China, October 27-29, 2004

UNESCO (United Nations Educational, Scientific and Cultural Organization). 2006. *UNESCO Workshop on Greenhouse-Gas Emissions from Freshwater Reservoir*. 5-6 December, 2006. Accessed December 2008 from http://www.unesco.org/water/ihp/pdf/ghg_participants_statement.pdf

Van Cleve, K., Barney, R., and Schlentner, R. 1981. Evidence of temperature control of production and nutrient cycling in two interior Alaska black spruce ecosystems. Can. J. For. Res., Vol. 11, pp. 258–273.
Van Cleve, K., Oliver, L, Schlentner, R., Viereck, L.A., and Dyrness, C.T. 1983. Productivity and nutrient cycling in taiga forest ecosystems. Can. J. For. Res., Vol. 13, pp. 747–766.

Vitt, D.H., Halsey, L.A., Bauer, I.E., and Campbell, C. 2000. Spatial and temporal trends in carbon storage of peatlands of continental western Canada through the Holocene. Can. J. Earth Sci., Vol. 37, 683–693.

Waddington, J.M., and Roulet, N.T. 1997. Groundwater flow and dissolved carbon movement in a boreal peatland. *Journal of Hydrology,* Vol. 191, pp. 122-138.

Waddington, J.M., and Roulet, N.T. 2000. Carbon Balance of boreal patterned peatland. *Global Change Biology,* Vol. 6, pp. 87-97.

Wang, F.L., Bettany, J.R., and Huang, P.M. 1999. Methane uptake by cultivated Canadian prairie and forest soils. Geoderma, Vol. 88, pp. 39–53

Wang, J.R., Comeau, P., and Kimmins, J.P. 1995a. Simulation of mixedwood management of aspen and white spruce in northeastern British Columbia. Water, Air, & Soil Pollution, Vol. 82, pp. 171-178.

Wang, J.R., Zhong, A.L., Comeau, P., Tsze, M., and Kimmins, J.P. 1995b. Aboveground biomass and nutrient accumulation in age sequences of aspen stands in Boreal White and Black Spruce zone of British Columbia. Forest Ecology and Management, Vol. 78, pp. 127-138.

Whiting, G.J., and Chanton, J.P. 2001. Primary production control of methane emission from wetlands. Letters to Nature, Vol. 364, pp. 794-795.

Wickland, D.E., Dahlman, R., Orrego, J., Dirdsey, R.A., Bontempi, P., Buford, M., Cavallaro, N., Conard, S., Craig, R., Jawson, M., Palminsano, A., Rice, D., Sheffner, E., Shultz, D., Stokes, B., Tedesco, K., and Trees, C. 2003. Chapter 7: Carbon cycle. In: *Strategic Plan for the U.S. Climate Change Science Program*. 211 pp.

Williams, S.N., Schaefer, S.J., Calvache, V.M.L., and Lopez, D. 1992. Global carbon dioxide emission to the atmosphere by volcanoes. *Geochimica et Cosmochimica Acta* Vol. 56(4), pp. 1765-1770.

Wulder, M.A., White, J.C., Fournier, R.A., Luther, J.E., and Magnussen., S. 2008. Spatially explicit large area biomass estimation: Three approaches using forest inventory and remotely sensed imagery in a GIS. Sensors, Vol. 8, pp. 529-560.

11.2 INTERNET SITES

Bice, D. 2007. Chapter 7: The global carbon cycle. In: *Exploring the Dynamics of Earth Systems: A Guide to Constructing and Experimenting with Computer Models of Earth Systems using STELLA*. Accessed November 2008 from http://www.carleton.edu/departments/geol/DaveSTELLA/Carbon/carbon_intro.htm

Bilby, R., Heffner, J., Fransen, B., Ward, J., and Bisson, P. 1999. Effects of immersion in water on deterioration of wood from five species of trees used for habitat enhancement projects. *North American Journal of Fisheries Management* , Vol.19: pp. 687-695.

Bolin, B., Degens, E.T. Duvigneaud, P., and Kempe, S. 2007. The global biogeochemical carbon cycle. In: *Scope 13: The Global Carbon Cycle*. Accessed December 2008 from http://www.icsu-acope.org/downloadpubs/scope13/chapter01.html#t

Canadian Environmental Assessment Agency. 2003. Incorporating climate change considerations in environmental assessment: general guidance for practitioners. Accessed December 2008 from *http://www.ceaa.gc.ca/012/014/index_e.htm*

Environment Canada. 2008a. Turning the Corner: Canada's Energy and GHG Emissions Projections (March 2008). Accessed November 2008 from http://www.ec.gc.ca/default.asp?lang=En&n=75038EBC-1

Environment Canada. 2008b. National Inventory Report 1990-2006: Greenhouse Gas Sources and Sinks in Canada (April 2008). Accessed October 2008 from http://www.ec.gc.ca/pdb/ghg/inventory_report/inventory_archi_e.cfm

Environment Canada. 2008c. Peace River above Alces River Federal-Provincial monitoring station. Accessed September 2008 from http://www.waterquality.ec.gc.ca/WaterQualityWeb/dataDownload.aspx?stationId=BC07FD0005

Environment Canada. 2008d. National Climate Data and Information Archive. Climate Normals data http://climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html?Province=BC%20%20&StationName=&SearchType=&LocateBy=Province&Proximity=25&ProximityFrom=City&StationNumber=&IDType=MSC&CityName=&ParkName=&LatitudeDegrees=&LatitudeMinutes=&LongitudeDegrees=&LongitudeMinutes=&NormalsClass=A&SelNormals=&StnId=1413&

Harmon, M. E., Krankina, O. N., and Sexton, J. 2000. Decomposition vectors: a new approach to estimating woody detritus decomposition dynamics. *Canadian Journal of Forest Research* Vol. 30: pp. 76-84

NASA (National Aeronautics and Space Administration). 2007. The carbon cycle: The human role. In: *Earth Observatory*. Accessed August 2008 from http://earthobservatory.nasa.gov/Library/CarbonCycle/carbon_cycle4.html

Reay, D. 2009. Greenhouse Gas Online: All about greenhouse gas science. 2009. Accessed January 2008 from http://www.ghgonline.org/index.htm

Reeburgh, W.S. 1996. Global Methane Budget Studies Contributed by W.S. Reeburgh, University of California - Irvine, USA and P.M. Crill, University of New Hampshire, USA. Reprinted from *IGACtivities Newsletter* No. 6, September 1996. Accessed September 2008 from http://www.igac.noaa.gov/newsletter/highlights/old/ch4.html

Van Cleve (1970) *In* DeAngelis et al. *In* Li, Z., Kurz, W.A., Apps, M.J., and Beukema, S.J. 2003. Belowground biomass dynamics in the Carbon Budget Model of the Canadian Forest Sector: recent improvement and implications for the estimation of NPP and NEP. Can. J. For. Res. 33: 126-136. Accessed October 2008 from http://carbon.cfs.nrcan.gc.ca/downloads/RootData_CJFR_2003.xls

Van Cleve et al. (1971) *In* M.G.R. Cannell 1982 *In* Li, Z., Kurz, W.A., Apps, M.J., and Beukema, S.J. 2003. Belowground biomass dynamics in the Carbon Budget Model of the Canadian Forest Sector: recent improvement and implications for the estimation of NPP and NEP. Can. J. For. Res. 33: 126-136. Accessed October 2008 from http://carbon.cfs.nrcan.gc.ca/downloads/RootData_CJFR_2003.xls

Van Cleve et al. (1981) *In* E.B. Peterson - Env. Can. Inf. Rep. NOR-X-254 *In* Li, Z., Kurz, W.A., Apps, M.J., and Beukema, S.J. 2003. Belowground biomass dynamics in the Carbon Budget Model of the Canadian Forest Sector: recent improvement and implications for the estimation of NPP and NEP. Can. J. For. Res. 33: 126-136. Accessed October 2008 from http://carbon.cfs.nrcan.gc.ca/downloads/RootData_CJFR_2003.xls

Zasada (1977) *In* E.B. Peterson - Env. Can. Inf. Rep. NOR-X-254 *In* Li, Z., Kurz, W.A., Apps, M.J., and Beukema, S.J. 2003. Belowground biomass dynamics in the Carbon Budget Model of the Canadian Forest Sector: recent improvement and implications for the estimation of NPP and NEP. Can. J. For. Res. 33: 126-136. Accessed October 2008 from http://carbon.cfs.nrcan.gc.ca/downloads/RootData_CJFR_2003.xls

11.3 PERSONAL COMMUNICATIONS

McIntosh, Anré. Personal Communication, October 2, 2008. Wildlife Lead BC Hydro, BC Hydro, Vancouver, BC.

Watson, Andrew. Personal Communication, August, 11, 2008. Senior Engineer, BC Hydro, Vancouver, BC.

Jack Matches, Personal Communication, August, 22, 2008. GIS Specialist, BC Hydro, Vancouver, BC.

Thomas Siu, Personal Communication, August, 14, 2008. BC Hydro, Vancouver, BC.

APPENDIX 1

Terms of Reference from Request for Proposal

Appendix 1

SCOPE OF SERVICES

Project Background

BC Hydro wishes to retain a consultant to develop an approach to model and estimate greenhouse gas (GHG) emissions for the potential Site C project, and to provide an estimated emissions profile associated with the construction and ongoing operations of the potential project.

The Peace River Site C hydroelectric project is a potential third dam and generating station on the Peace River and associated local transmission in north-eastern BC, approximately 7 km southwest of Fort St. John.

The Site C project is currently in Stage 2, Project Definition and Consultation. BC Hydro is taking a stage-by-stage approach to the evaluation of Site C. At the end of each stage of the process, BC Hydro will make a recommendation to the provincial government about whether to proceed to the next stage of project planning and development.

For further information on the potential Site C project, please refer to www.bchydro.com/sitec.

Study Background

Since the original conception of the Site C project over twenty-five years ago, climate change has emerged as a new topic for environmental assessment.

GHG emissions from reservoirs is a topic that BC Hydro has explored in the past. In 2001, BC Hydro contracted a consultant to review scientific literature regarding reservoir emissions of GHGs, and estimate emissions from BC Hydro reservoirs. The literature review indicates that the rate of emission from a reservoir depends on the carbon content of inundated land area, the area of land inundated, and the age of the reservoir... The studies show that emissions from boreal reservoirs have typically declined substantially after initial flooding and thereafter have emission rates similar to natural lakes in the same areas.

BC Hydro has also conducted limited sampling of GHG emissions from reservoirs in British Columbia as part of an industry initiative to better understand emissions from Canada's boreal reservoirs. This study suggests that the reservoirs sampled have emission rates similar to natural lakes and rivers in the same regions. However, the net impact on GHG emissions from these reservoirs in unknown because pre-impoundment emissions were never estimated. BC Hydro has an environmental long term goal of achieving no net incremental environmental impact by 2020, from a 2004 baseline. An important consideration for the potential Site C project will be to determine how the project can align and contribute to this goal.

Study Objectives

The purpose of the study is to:

a) estimate the multi-year GHG emissions profile associated with the construction and ongoing operations of the potential Site C project,

b) estimate the net change in GHG emissions from pre-project conditions; and

c) develop an approach for comparing the GHG profile of Site C with other electricity supply options in British Columbia

The consultants will:

1. Review current, relevant protocols and methods related to estimating GHG emissions from hydroelectric projects and reservoirs;
2. Update the previous literature review as it relates to the project deliverables;
3. Develop an overall assessment methodology;
4. Determine the current rate of GHG emissions or sequestration in the study area;
5. Estimate the potential GHG emissions associated with the construction phase of the Site C project;
6. Estimate the potential GHG emissions from the initial inundation of the Site C reservoir during the operating phase of the project (i.e., the net change in emission rate for the first five to ten years post-inundation);
7. Estimate the long term potential GHG emissions associated with ongoing operations of the Site C project;
8. Develop an approach for comparing the estimated emission profile of Site C to other electricity supply options.
9. Recommend options for achieving a goal of no net incremental increase in GHG emissions associated with the project.

Study Approach

The consultant will develop the assessment methodology, participate in BC Hydro's Site C GHG Technical Advisory Committee, implement any required field data collection, and develop and run any models required to meet the deliverables.

In developing the assessment methodology, the contractor will update the previous literature review, focusing on current protocols and methods for estimating emissions associated with new hydro-electric projects, for obtaining direct measurements of GHG emissions from existing reservoirs, and for estimating pre-impoundment emission rates from new reservoirs. Additionally, the literature review will include current methods for assessing the life cycle emissions associated with project construction, including materials, services, transportation and other major construction inputs.

GHG emissions from boreal reservoirs result from a number of complex biological and physiochemical processes. Influences include regional climate; microbial activity; the type and quantity of vegetation inundated; and the soil characteristics. The contractor will review current methods for measuring GHG emissions from boreal reservoirs *in situ*, including, but not limited to, emissions by diffusion, ebullition, and degassing. Prior to inundation, the area of a reservoir may be a net GHG sink or a net GHG emitter. The estimate of the GHG emission rate associated with the potential Site C reservoir will review current methodology respecting comparisons of post-inundation and pre-inundation emission rates.

In developing the model to estimate potential net emissions from the Site C reservoir, the consultant should consider variables such as:

- Pre-impoundment emissions
- The quantity and type of vegetation inundated
- Climate and reservoir characteristics
- Soil characteristics
- Seasonality

The project-related emissions estimate should consider pertinent life cycle effects of Site C during construction and during operations, for example construction materials, services, equipment operation, transportation of dam construction materials, and the multi-year emission profile of the reservoir over the life of the project

Deliverables
The deliverables will include:

- Technical support to and participation in a GHG Technical Advisory Committee process, including government agencies, BC Hydro and subject matter experts process. Support includes preparation of materials and consideration of input and advice; The consultant can expect to participate in up to 6 meeting days throughout the next 12 months.
- An updated annotated literature review;
- An electronic and written emissions estimate report that includes:
    - A plain language executive summary
    - A description of the method and approach to conduct the study
    - A detailed description of any field sampling programs
    - A detailed description of any models developed and/or used
    - The study results
    - Recommendations for further analysis and monitoring
    - A detailed schedule of field work completed and recommendations for ongoing monitoring, if recommended, including sampling sites and consultation with other parties.
- An electronic and written report for comparing Site C to other electricity supply options;
- An electronic and written report on options for achieving a goal of no net incremental increase in GHG emissions associated with the project;
- An electronic plain language information sheet summary of the emissions study and results for use in public consultation and First Nations consultation; and
- An electronic copy of all models developed for the purposes of this work, assumptions used in the calculations, and all associated data.

Schedule
The literature review should be initiated as soon as possible. If required, field sampling should commence through spring and summer of 2008. A GHG Technical Advisory Committee is tentatively planned for June / July 2008. An interim progress report will be required by September 30, 2008, and all final deliverables due by January 31, 2009

APPENDIX 2

GIS and Vegetation Carbon Calculations

Table B.1 - Site C Study Area TEM Database Indicating Area (ha) by TEM Cover Type and Representative EOSD Code

Eco_Sec	Bgc_Zone	Bgc_Subzon	Bgc_Vrt	SITE	MC	HA	EOSD_TEM
PEL	BWBS	mw	1	0	OW	13.63	20
PEL	BWBS	mw	1	0	PD	4.77	20
PEL	BWBS	mw	1	0	RI	2,960.18	20
PEL	BWBS	mw	1	1	AM	0.78	210
PEL	BWBS	mw	1	1	AM	80.23	210
PEL	BWBS	mw	1	1	AM	72.15	210
PEL	BWBS	mw	1	1	AM	5.83	210
PEL	BWBS	mw	1	1	AM	8.62	210
PEL	BWBS	mw	1	1	AM	13.19	210
PEL	BWBS	mw	1	1	AM	3.62	210
PEL	BWBS	mw	1	1	AM	2.53	210
PEL	BWBS	mw	1	1	AM	2.34	210
PEL	BWBS	mw	1	1	AM	1.46	210
PEL	BWBS	mw	1	1	AM	22.21	210
PEL	BWBS	mw	1	1	AM	5.02	210
PEL	BWBS	mw	1	1	AM	0.31	210
PEL	BWBS	mw	1	1	AM	0.07	210
PEL	BWBS	mw	1	1	AM	1.93	210
PEL	BWBS	mw	1	1	AM	5.63	210
PEL	BWBS	mw	1	1	AM	12.48	210
PEL	BWBS	mw	1	1	AM	34.46	210
PEL	BWBS	mw	1	1	AM	98.62	210
PEL	BWBS	mw	1	1	AM	0.63	210
PEL	BWBS	mw	1	1	AM	1.07	210
PEL	BWBS	mw	1	1	AM	28.26	210
PEL	BWBS	mw	1	1	AM	5.41	210
PEL	BWBS	mw	1	2	LL	2.47	210
PEL	BWBS	mw	1	2	LL	5.52	210
PEL	BWBS	mw	1	2	LL	3.39	210
PEL	BWBS	mw	1	2	LL	9.67	210
PEL	BWBS	mw	1	2	LL	5.7	210
PEL	BWBS	mw	1	3	SW	0.37	210
PEL	BWBS	mw	1	3	SW	35.97	210
PEL	BWBS	mw	1	3	SW	0.45	210
PEL	BWBS	mw	1	3	SW	5.27	210
PEL	BWBS	mw	1	3	SW	17.53	210
PEL	BWBS	mw	1	3	SW	3.03	210
PEL	BWBS	mw	1	3	SW	0.36	210
PEL	BWBS	mw	1	3	SW	6.25	210
PEL	BWBS	mw	1	3	SW	29.26	210
PEL	BWBS	mw	1	3	SW	4.03	210
PEL	BWBS	mw	1	3	SW	1.29	210
PEL	BWBS	mw	1	3	SW	12.05	210
PEL	BWBS	mw	1	3	SW	4.4	210
PEL	BWBS	mw	1	3	SW	11.19	210
PEL	BWBS	mw	1	3	SW	0.86	210
PEL	BWBS	mw	1	3	SW	4.48	210
PEL	BWBS	mw	1	3	SW	11.04	210
PEL	BWBS	mw	1	3	SW	15.48	210
PEL	BWBS	mw	1	3	SW	0.09	210
PEL	BWBS	mw	1	3	SW	3.04	210

Table B.1 - Site C Study Area TEM Database Indicating Area (ha) by TEM Cover Type and Representative EOSD Code

Eco_Sec	Bgc_Zone	Bgc_Subzon	Bgc_Vrt	SITE	MC	HA	EOSD_TEM
PEL	BWBS	mw	1	4	BL	1.8	210
PEL	BWBS	mw	1	5	SO	5.56	210
PEL	BWBS	mw	1	5	SO	29.56	210
PEL	BWBS	mw	1	5	SO	65.37	210
PEL	BWBS	mw	1	5	SO	38.35	210
PEL	BWBS	mw	1	5	SO	0.82	210
PEL	BWBS	mw	1	5	SO	6.65	210
PEL	BWBS	mw	1	5	SO	0.56	210
PEL	BWBS	mw	1	5	SO	0.28	210
PEL	BWBS	mw	1	5	SO	34.27	210
PEL	BWBS	mw	1	5	SO	45.36	210
PEL	BWBS	mw	1	5	SO	51.43	210
PEL	BWBS	mw	1	5	SO	42.48	210
PEL	BWBS	mw	1	5	SO	1.56	210
PEL	BWBS	mw	1	6	SC	15.82	210
PEL	BWBS	mw	1	6	SC	30.92	210
PEL	BWBS	mw	1	6	SC	1.25	210
PEL	BWBS	mw	1	6	SC	3.28	210
PEL	BWBS	mw	1	6	SC	7.32	210
PEL	BWBS	mw	1	6	SC	0.16	210
PEL	BWBS	mw	1	6	SC	73.89	210
PEL	BWBS	mw	1	7	SH	20.44	210
PEL	BWBS	mw	1	7	SH	19.95	210
PEL	BWBS	mw	1	7	SH	108.29	210
PEL	BWBS	mw	1	7	SH	1.3	210
PEL	BWBS	mw	1	7	SH	12.02	210
PEL	BWBS	mw	1	7	SH	80.05	210
PEL	BWBS	mw	1	7	SH	211.5	210
PEL	BWBS	mw	1	7	SH	17.86	210
PEL	BWBS	mw	1	7	SH	4.46	210
PEL	BWBS	mw	1	7	SH	18.15	210
PEL	BWBS	mw	1	7	SH	183.14	210
PEL	BWBS	mw	1	7	SH	24.24	210
PEL	BWBS	mw	1	8	BT	14.2	210
PEL	BWBS	mw	1	1	AM	120.7	220
PEL	BWBS	mw	1	1	AM	235.44	220
PEL	BWBS	mw	1	1	AM	8.06	220
PEL	BWBS	mw	1	1	AM	9.49	220
PEL	BWBS	mw	1	1	AM	94.92	220
PEL	BWBS	mw	1	1	AM	5.26	220
PEL	BWBS	mw	1	1	AM	0.27	220
PEL	BWBS	mw	1	1	AM	2	220
PEL	BWBS	mw	1	1	AM	7.36	220
PEL	BWBS	mw	1	1	AM	0.02	220
PEL	BWBS	mw	1	1	AM	22.21	220
PEL	BWBS	mw	1	1	AM	5.93	220
PEL	BWBS	mw	1	1	AM	15.95	220
PEL	BWBS	mw	1	1	AM	3.25	220
PEL	BWBS	mw	1	1	AM	0.81	220
PEL	BWBS	mw	1	1	AM	17.15	220
PEL	BWBS	mw	1	1	AM	22.24	220

Table B.1 - Site C Study Area TEM Database Indicating Area (ha) by TEM Cover Type and Representative EOSD Code

Eco_Sec	Bgc_Zone	Bgc_Subzon	Bgc_Vrt	SITE	MC	HA	EOSD_TEM
PEL	BWBS	mw	1	1	AM	2.72	220
PEL	BWBS	mw	1	1	AM	6.17	220
PEL	BWBS	mw	1	1	AM	55.74	220
PEL	BWBS	mw	1	1	AM	7.31	220
PEL	BWBS	mw	1	1	AM	0.24	220
PEL	BWBS	mw	1	1	AM	0.21	220
PEL	BWBS	mw	1	1	AM	0.83	220
PEL	BWBS	mw	1	1	AM	0.15	220
PEL	BWBS	mw	1	1	AM	63.05	220
PEL	BWBS	mw	1	1	AM	75.69	220
PEL	BWBS	mw	1	1	AM	6.85	220
PEL	BWBS	mw	1	1	AM	4.67	220
PEL	BWBS	mw	1	1	AM	57.91	220
PEL	BWBS	mw	1	1	AM	20.53	220
PEL	BWBS	mw	1	1	AM	67.43	220
PEL	BWBS	mw	1	1	AM	9.66	220
PEL	BWBS	mw	1	1	AM	22.05	220
PEL	BWBS	mw	1	1	AM	7.15	220
PEL	BWBS	mw	1	2	LL	0.82	220
PEL	BWBS	mw	1	2	LL	63.32	220
PEL	BWBS	mw	1	3	SW	22.3	220
PEL	BWBS	mw	1	3	SW	52.59	220
PEL	BWBS	mw	1	3	SW	0.16	220
PEL	BWBS	mw	1	3	SW	3.36	220
PEL	BWBS	mw	1	3	SW	1.23	220
PEL	BWBS	mw	1	3	SW	12.31	220
PEL	BWBS	mw	1	3	SW	2.74	220
PEL	BWBS	mw	1	3	SW	8	220
PEL	BWBS	mw	1	3	SW	11.96	220
PEL	BWBS	mw	1	3	SW	6.14	220
PEL	BWBS	mw	1	3	SW	6.83	220
PEL	BWBS	mw	1	3	SW	0.41	220
PEL	BWBS	mw	1	3	SW	6.78	220
PEL	BWBS	mw	1	3	SW	7.13	220
PEL	BWBS	mw	1	3	SW	26.46	220
PEL	BWBS	mw	1	3	SW	7.16	220
PEL	BWBS	mw	1	3	SW	0.13	220
PEL	BWBS	mw	1	4	BL	8.47	220
PEL	BWBS	mw	1	4	BL	0.45	220
PEL	BWBS	mw	1	5	SC	9.29	220
PEL	BWBS	mw	1	5	SC	11.95	220
PEL	BWBS	mw	1	5	SC	8.53	220
PEL	BWBS	mw	1	5	SC	24.63	220
PEL	BWBS	mw	1	5	SC	8.98	220
PEL	BWBS	mw	1	5	SC	12.01	220
PEL	BWBS	mw	1	5	SC	2.83	220
PEL	BWBS	mw	1	5	SC	0.92	220
PEL	BWBS	mw	1	5	SC	7.58	220
PEL	BWBS	mw	1	5	SC	2.93	220
PEL	BWBS	mw	1	5	SC	3.9	220
PEL	BWBS	mw	1	5	SC	0.01	220

Table B.1 - Site C Study Area TEM Database Indicating Area (ha) by TEM Cover Type and Representative EOSD Code

Eco_Sec	Bgc_Zone	Bgc_Subzon	Bgc_Vrt	SITE	MC	HA	EOSD_TEM
PEL	BWBS	mw	1	5	SC	7.96	220
PEL	BWBS	mw	1	5	SC	3.94	220
PEL	BWBS	mw	1	5	SC	19.62	220
PEL	BWBS	mw	1	7	SH	47.64	220
PEL	BWBS	mw	1	7	SH	48.39	220
PEL	BWBS	mw	1	7	SH	95.19	220
PEL	BWBS	mw	1	7	SH	1.41	220
PEL	BWBS	mw	1	7	SH	1.37	220
PEL	BWBS	mw	1	7	SH	0	220
PEL	BWBS	mw	1	7	SH	5.81	220
PEL	BWBS	mw	1	7	SH	6.22	220
PEL	BWBS	mw	1	7	SH	5.27	220
PEL	BWBS	mw	1	7	SH	16.43	220
PEL	BWBS	mw	1	7	SH	69.81	220
PEL	BWBS	mw	1	0	RO	0.8	32
PEL	BWBS	mw	1	0	CB	17.3	33
PEL	BWBS	mw	1	0	CB	13.57	33
PEL	BWBS	mw	1	0	CB	15.04	33
PEL	BWBS	mw	1	0	CB	5.3	33
PEL	BWBS	mw	1	0	CB	91.85	33
PEL	BWBS	mw	1	0	CB	35.27	33
PEL	BWBS	mw	1	0	CB	2.06	33
PEL	BWBS	mw	1	0	CB	1.32	33
PEL	BWBS	mw	1	0	CB	38.36	33
PEL	BWBS	mw	1	0	CB	28.68	33
PEL	BWBS	mw	1	0	ES	0.33	33
PEL	BWBS	mw	1	0	ES	0.05	33
PEL	BWBS	mw	1	0	ES	1.94	33
PEL	BWBS	mw	1	0	ES	1.93	33
PEL	BWBS	mw	1	0	ES	1.09	33
PEL	BWBS	mw	1	0	GB	743.29	33
PEL	BWBS	mw	1	0	GP	6.35	33
PEL	BWBS	mw	1	0	RW	11.2	33
PEL	BWBS	mw	1	0	RZ	15.06	33
PEL	BWBS	mw	1	0	UR	7.33	33
PEL	BWBS	mw	1	0	AS	29.83	51
PEL	BWBS	mw	1	0	AS	5.93	51
PEL	BWBS	mw	1	0	AS	1.45	51
PEL	BWBS	mw	1	0	AS	2.95	51
PEL	BWBS	mw	1	0	AS	39.11	51
PEL	BWBS	mw	1	0	AS	3.35	51
PEL	BWBS	mw	1	0	AS	1	51
PEL	BWBS	mw	1	0	AS	0.39	51
PEL	BWBS	mw	1	0	AS	0.07	51
PEL	BWBS	mw	1	0	AS	0	51
PEL	BWBS	mw	1	0	AS	0.63	51
PEL	BWBS	mw	1	0	AS	0.33	51
PEL	BWBS	mw	1	1	AM	2.43	51
PEL	BWBS	mw	1	1	AM	52.67	51
PEL	BWBS	mw	1	1	AM	16.76	51
PEL	BWBS	mw	1	1	AM	3.54	51

Table B.1 - Site C Study Area TEM Database Indicating Area (ha) by TEM Cover Type and Representative EOSD Code

Eco_Sec	Bgc_Zone	Bgc_Subzon	Bgc_Vrt	SITE	MC	HA	EOSD_TEM
PEL	BWBS	mw	1	1	AM	1.19	51
PEL	BWBS	mw	1	1	AM	0.02	51
PEL	BWBS	mw	1	1	AM	1.26	51
PEL	BWBS	mw	1	1	AM	0.91	51
PEL	BWBS	mw	1	1	AM	2.67	51
PEL	BWBS	mw	1	1	AM	0.09	51
PEL	BWBS	mw	1	1	AM	11.88	51
PEL	BWBS	mw	1	1	AM	18.68	51
PEL	BWBS	mw	1	1	AM	7.29	51
PEL	BWBS	mw	1	1	AM	14.29	51
PEL	BWBS	mw	1	3	SW	0.95	51
PEL	BWBS	mw	1	3	SW	7.06	51
PEL	BWBS	mw	1	3	SW	0.02	51
PEL	BWBS	mw	1	3	SW	0.61	51
PEL	BWBS	mw	1	3	SW	0.05	51
PEL	BWBS	mw	1	3	SW	0.67	51
PEL	BWBS	mw	1	3	SW	0.56	51
PEL	BWBS	mw	1	5	SC	6.9	51
PEL	BWBS	mw	1	5	SC	1.12	51
PEL	BWBS	mw	1	5	SC	0.41	51
PEL	BWBS	mw	1	5	SC	3.73	51
PEL	BWBS	mw	1	5	SO	22.71	51
PEL	BWBS	mw	1	7	SH	59.02	51
PEL	BWBS	mw	1	7	SH	4.56	51
PEL	BWBS	mw	1	7	SH	25.2	51
PEL	BWBS	mw	1	7	SH	2.33	51
PEL	BWBS	mw	1	7	SH	12.52	51
PEL	BWBS	mw	1	0	AS	6.71	52
PEL	BWBS	mw	1	0	AS	2.18	52
PEL	BWBS	mw	1	0	AS	0.01	52
PEL	BWBS	mw	1	9	Fm02	103.97	51
PEL	BWBS	mw	1	9	Fm02	36.07	51
PEL	BWBS	mw	1	9	Fm02	5.11	51
PEL	BWBS	mw	1	9	Fm02	391.82	51
PEL	BWBS	mw	1	9	Fm02	0.92	51
PEL	BWBS	mw	1	9	Fm02	1.46	51
PEL	BWBS	mw	1	9	Fm02	11.5	51
PEL	BWBS	mw	1	9	Fm02	6.08	51
PEL	BWBS	mw	1	9	Fm02	3.01	51
PEL	BWBS	mw	1	10	TS	3.68	81
PEL	BWBS	mw	1	10	TS	6.98	81
PEL	BWBS	mw	1	10	TS	2.45	81
PEL	BWBS	mw	1	0	WH	66.05	82
PEL	BWBS	mw	1	0	WH	17.34	82
PEL	BWBS	mw	1	0	WH	7.03	82
PEL	BWBS	mw	1	0	WH	34.67	82
PEL	BWBS	mw	1	0	WH	79.25	82
PEL	BWBS	mw	1	0	WH	25.94	82
PEL	BWBS	mw	1	0	WH	37.22	82
PEL	BWBS	mw	1	0	WH	1.32	82
PEL	BWBS	mw	1	0	WS	10.76	82

Table B.1 - Site C Study Area TEM Database Indicating Area (ha) by TEM Cover Type and Representative EOSD Code

Eco_Sec	Bgc_Zone	Bgc_Subzon	Bgc_Vrt	SITE	MC	HA	EOSD_TEM
PEL	BWBS	mw	1	0	WS	16.95	82
PEL	BWBS	mw	1	0	WW	12.3	82
PEL	BWBS	mw	1	0	WW	0.63	82
PEL	BWBS	mw	1	0	WW	2.49	82
PEL	BWBS	mw	1	0	WW	0.06	82
PEL	BWBS	mw	1	0	SE	8.15	83
PEL	BWBS	mw	1	0	SE	39.31	83
PEL	BWBS	mw	1	0	WH	8.47	83
PEL	BWBS	mw	1	0	WH	92.99	83
PEL	BWBS	mw	1	0	WH	22.16	83
PEL	BWBS	mw	1	0	WW	48.45	83
PEL	BWBS	mw	1	0	WW	62.85	83
PEL	BWBS	mw	1	0	WW	3.56	83
PEL	BWBS	mw	1	0	WW	2.2	83
PEL	BWBS	mw	1	0	WW	1.91	83
PEL	BWBS	mw	1	0	WW	1.86	83
PEL	BWBS	mw	1	0	WW	1.81	83
PEL	BWBS	mw	1	0	WW	1.51	83
PEL	BWBS	mw	1	0	WW	5.36	83
PEL	BWBS	mw	1	0	CF	6.22	100
PEL	BWBS	mw	1	0	CF	194.93	100
PEL	BWBS	mw	1	0	CF	1.58	100
PEL	BWBS	mw	1	0	CF	0.1	100
PEL	BWBS	mw	1	0	CF	17.91	100
PEL	BWBS	mw	1	0	CF	291.79	100
PEL	BWBS	mw	1	0	CF	113.2	100
PEL	BWBS	mw	1	9	Fm02	100.5	230
PEL	BWBS	mw	1	9	Fm02	159.7	230
PEL	BWBS	mw	1	9	Fm02	217.5	230
PEL	BWBS	mw	1	9	Fm02	16.85	230
PEL	BWBS	mw	1	9	Fm02	4.96	230
PEL	BWBS	mw	1	9	Fm02	0.79	230

Table B.2 - TEM Summary using assigned EOSD classes in the Site C Study Area, using crown closure from VRI for forest density classification.

EOSD	Description	Structural Stage[3]	Current Conditions		Post Flood		Change
			HA	%	HA	%	HA
20	water, lakes, reservoirs, rivers, streams	NA	2,982.3	29.2%	9,327.5	91.5%	6,345.2
32	rock, rubble, bedrock, talus	NA	0.8	0.0%	0.5	0.0%	-0.3
33	non vegetated surfaces	NA	1,039.1	10.2%	104.1	1.0%	-935.1
51	shrub tall	NA	928.2	9.1%	68.8	0.7%	-859.4
52	shrub low	NA	11.5	0.1%	2.5	0.0%	-9.0
81	wetland - treed	NA	13.1	0.1%	0.0	0.0%	-13.1
82	wetland - shrub	NA	312.0	3.1%	3.6	0.0%	-308.4
83	wetland - herb	NA	300.9	3.0%	59.1	0.6%	-241.8
100	herbaceous (incl cultivated land)	NA	627.2	6.2%	57.6	0.6%	-569.6
211	treed coniferous - dense	NA	0.5	0.0%	0.5	0.0%	0.0
		4	15.3	0.1%	0.0	0.0%	-15.3
		5	117.9	1.2%	16.2	0.2%	-101.7
		6	90.3	0.9%	13.6	0.1%	-76.7
212	treed coniferous - open	NA	6.0	0.1%	3.4	0.0%	-2.5
		4	80.0	0.8%	19.5	0.2%	-60.5
		5	461.5	4.5%	91.6	0.9%	-369.9
		6	953.2	9.3%	78.5	0.8%	-874.7
		7	46.2	0.5%	8.0	0.1%	-38.3
213	treed coniferous - sparse	4	0.9	0.0%	0.7	0.0%	-0.2
		5	7.1	0.1%	1.4	0.0%	-5.7
		6	0.0	0.0%	0.0	0.0%	0.0
221	treed deciduous - dense	NA	0.0	0.0%	0.0	0.0%	0.0
		4	39.1	0.4%	9.9	0.1%	-29.2
		5	102.3	1.0%	31.1	0.3%	-71.2
		6	2.9	0.0%	1.8	0.0%	-1.1
222	treed deciduous - open	NA	3.0	0.0%	2.9	0.0%	-0.1
		4	473.2	4.6%	96.1	0.9%	-377.1
		5	698.0	6.8%	140.7	1.4%	-557.3
		6	288.0	2.8%	31.1	0.3%	-256.9
		7	1.4	0.0%	0.0	0.0%	-1.4
223	treed deciduous - sparse	4	12.8	0.1%	1.1	0.0%	-11.6
		5	21.6	0.2%	2.5	0.0%	-19.1
		6	11.5	0.1%	0.0	0.0%	-11.5
232	treed mixed - open	NA	50.3	0.5%	19.2	0.2%	-31.0
		4	101.3	1.0%	0.4	0.0%	-100.9
		5	153.3	1.5%	2.6	0.0%	-150.8
		6	216.8	2.1%	0.7	0.0%	-216.1
233	treed mixed - sparse	5	23.2	0.2%	1.0	0.0%	-22.2
		6	5.7	0.1%	0.0	0.0%	-5.7
		Total	***10,198.2***	***100.0%***	***10,198.2***	***100.0%***	***0.0***

Notes:

1) The post flood scenario is based on the maximum flood polygon, provided by Jack Matches.
2) All post flood areas have been assigned to the EOSD category = 20 (water, lakes, reservoirs, rivers, streams).
3) Structural Stages are: (1) Sparse/Bryoid; (2) Herb; (3) Shrub/Berb; (4) Pole Sapling; (5) Young Forest; (6) Mature Forest; (7) Old Forest.

Table B.3 - TEM Map Code Summary in the Assessment Area, without VRI data added)

Site Series	Map Code	Ecosystem Name	Current Conditions		Post Flood		Change
			HA	Percent	HA	Percent	HA
00	AS	SwAt - Soopolallie	93.9	0.9%	24.4	0.2%	-69.5
00	CB	Cutbank	248.7	2.4%	91.0	0.9%	-157.7
00	CF	Cultivated Field (includes pastures)	625.7	6.1%	56.1	0.6%	-569.6
00	ES	Exposed Soil	5.3	0.1%	1.2	0.0%	-4.2
00	GB	Gravel Bar	743.3	7.3%	3.9	0.0%	-739.4
00	GP	Gravel Pit	6.4	0.1%	1.1	0.0%	-5.3
00	OW	Shallow Open Water	13.6	0.1%	0.0	0.0%	-13.6
00	PD	Pond	4.8	0.0%	0.3	0.0%	-4.4
00	RI	River	2,960.2	29.0%	9,325.5	91.4%	6,365.3
00	RO	Rock	0.8	0.0%	0.5	0.0%	-0.3
00	RW	Rural	11.2	0.1%	1.1	0.0%	-10.1
00	RZ	Road Surface	15.1	0.1%	2.7	0.0%	-12.3
00	SE	Sedge Wetland	47.5	0.5%	0.4	0.0%	-47.0
00	UR	Urban	7.3	0.1%	1.5	0.0%	-5.9
00	WH	Willow - Horsetail - Sedge - Riparian Wetland	392.4	3.8%	1.1	0.0%	-391.3
00	WS	Willow - Sedge - Wetland	27.7	0.3%	0.0	0.0%	-27.7
00	WW	Fuzzy-spiked Wildrye - Wolf willow	145.0	1.4%	60.9	0.6%	-84.1
01	AM	SwAt - Step moss	1,519.9	14.9%	324.9	3.2%	-1,195.1
02	LL	Pl - Lingonberry - Velvet-leaved blueberry	90.9	0.9%	9.5	0.1%	-81.4
03	SW	Sw - Wildrye - Peavine	352.1	3.5%	116.3	1.1%	-235.7
04	BL	Sb - Lingonberry - Coltsfoot	10.7	0.1%	1.5	0.0%	-9.2
05	SC	Black Twinberry and red-osier dogwood (ab & ep seral)	137.2	1.3%	46.9	0.5%	-90.4
05	SO	Sw - Currant - Oak fern	345.0	3.4%	49.6	0.5%	-295.4
06	SC	Sw - Currant - Bluebells	132.6	1.3%	4.8	0.0%	-127.8
07	SH	Cow parsnip and Ep-Dogwood (ac & ep seral)	1,102.6	10.8%	28.9	0.3%	-1,073.7
08	BT	Sb - Labrador tea - Sphagnum	14.2	0.1%	0.8	0.0%	-13.4
09	Fm02	ActSw - Red-osier dogwood	1,060.2	10.4%	9.0	0.1%	-1,051.2
10	TS	Tamarack - Sedge - Fen	13.1	0.1%	0.0	0.0%	-13.1
		Unknown - Gaps in the TEM	70.6	0.7%	34.4	0.3%	-36.3
		Total	***10,198.2***	***100.0%***	***10,198.2***	***100.0%***	***0.0***

Notes:

1) All post flood areas have been assigned to the mape code = RI (river).

Table B.4 - TEM Summary Using Assigned EOSD Classes in the Assessment Area (using crown closure from VRI for forest density classification)

EOSD	Description	Structural Stage	HA	%	Total Area by EOSD Cover Type	AGB_Tree Kg C /ha	AGB_Other Kg C /ha	Total AGB kg C /ha	Total AGB kg C	BGB_veg Kg C /ha	Organic Horizon Kg C /ha	Mineral Soil Carbon Kg C /ha	Total BG kg C / Ha	Total BG Kg C	TOTAL Kg C /ha	Comments/Assumptions
20	water, lakes, reservoirs, rivers, streams		2,982.3	29.2%	-											
32	rock, rubble, bedrock, talus		0.8	0.0%	-											
33	non vegetated surfaces		1,039.1	10.2%	-											
51	shrub tall		928.2	9.1%	928.2	-	15,307	15,307	14,207,464	7,639	-	24,500	32,139	29,830,383	47,446	AGB_other; BGB =roots, Soil = soil carbon for pure young aspen stand
52	shrub low		11.5	0.1%	11.5	-	7,654	7,654	88,032	3,820	-	24,500	28,320	325,735	35,973	AGB_other same as tall shrub *50% (TC); BGB same as (51); Soil same as (51) * 50% (TC)
81	wetland - treed		13.1	0.1%	626.0	-	34,200	34,200	448,667	136,798	-	93,150	229,948	3,016,706	264,148	AGB_Other included in AGB_Tree; BGB =4x AGB as per Moore et al (2002), & includes organic; Soil =
82	wetland - shrub		312.0	3.1%		-	1,515	1,515	472,705	6,060	-	93,150	99,210	30,955,164	100,725	BGB= 4x AGB as per Moore et al (2002) & includes organic; soil same as (81)
83	wetland - herb		300.9	3.0%		-	1,273	1,273	382,891	5,090	-	93,150	98,240	29,560,105	99,513	BGB= 4x AGB as per Moore et al (2002) & includes organic; soil same as (81)
100	herbaceous (incl cultivated land)		1.5	0.0%	627.2	-	2,250	2,250		-	-	-	61,745	38,726,110	2,250	AGB reported from Mulder et al (2008)
		1	6.2	0.1%									-			
		2	617.8	6.1%									-			
		3	1.7	0.0%					1,411,194				-			
211	treed coniferous - dense		0.5	0.0%	223.9	108,468	36,378	144,846		21,550	44,888	69,560	135,997	30,453,268	280,843	AGB + 18.1 % of conifer open (Mulder 2008); no change mineral soil or AGB other due to compensating ecological factors & long term soil development; organic horizon carbon is estimated @ 5% less due to less foliage/crown surface area/deposition (TC).
		4	15.3	0.1%									-			
		5	117.9	1.2%									-			
		6	90.3	0.9%					32,434,674				-			
212	treed coniferous - open		6.0	0.1%	1546.8	91,922	36,378	128,300		18,263	47,250	69,560	135,073	208,933,664	263,373	AGB_other includes woody debris; added 1.5% of AGB_tree total for non_tree understorey component (based on Perala, 1982)
		4	80.0	0.8%									-			
		5	461.5	4.5%									-			
		6	953.2	9.3%									-			
		7	46.2	0.5%					198,457,539				-			
213	treed coniferous - sparse	4	0.9	0.0%	8.0	87,050	38,197	125,247		17,295	49,613	69,560	136,467	1,093,735	261,714	Decrease AGB by 5.3 % of open (Mulder 2008); other AGB increase by 5% of open due to increase in woody debris & shrubs (TC);
		5	7.1	0.1%									-			
		6	0.0	0.0%					1,003,809				-			
221	treed deciduous - dense		0.0	0.0%	144.4	101,462	12,030	113,492		19,115	40,814	58,438	118,367	17,087,880	231,858	Increase AGB by 32.6 % (Mulder 2008); no change to organic or mineral soil carbon; other AGB reduced by 5% (less light - less understorey development) (TC); increase BGB (roots due to increase in root mass) (TC)
		4	39.1	0.4%									-			
		5	102.3	1.0%									-			
		6	2.9	0.0%					16,384,134				-			
222	treed deciduous - open		3.0	0.0%	1463.5	76,517	12,663	89,180		14,415	40,814	58,438	113,667	166,354,932	202,848	AGB_other includes woody debris & understorey veg;
		4	473.2	4.6%									-			
		5	698.0	6.8%									-			
		6	288.0	2.8%									-			
		7	1.4	0.0%					130,517,897				-			
223	treed deciduous - sparse	4	12.8	0.1%	45.9	75,752	13,297	89,048		14,271	40,814	58,438	113,523	5,205,926	202,571	AGB reduced by 1% (Mulder 2008); increase AGB_other by 5% due to increase in shrub development (TC); BGB reduced by 1% (TC); no change in mineral or organic soil carbon
		5	21.6	0.2%									-			
		6	11.5	0.1%					4,083,572				-			
232	treed mixed - open		50.3	0.5%	521.7	84,220	24,521	108,740		16,339	44,032	63,999	124,370	64,883,071	233,110	MIXED VALUES = averaged of coniferous & deciduous values (TC)
		4	101.3	1.0%									-			
		5	153.3	1.5%									-			
		6	216.8	2.1%					56,729,137				-			
233	treed mixed - sparse	5	23.2	0.2%	28.9	81,525	25,747	107,271		15,816	44,032	63,999	123,847	3,576,360	231,118	Reduce AGB tree carbon by 3.2 % (Mulder 2008); increase AGB other by 5% due to increased light & nutrients to understorey vegetation (TC); no change to soil or organic carbon
		6	5.7	0.1%					3,097,696				-			
Total			***10,198.2***	***100.0%***												

Notes:

1) Structural Stages are: (1) Sparse/Bryoid; (2) Herb; (3) Shrub/Herb; (4) Pole Sapling; (5) Young Forest; (6) Mature Forest; (7) Old Forest.

APPENDIX 3

GHG emissions (CO_2e): Current Conditions and Post-Inundation

Table C.1 - Mass of Carbon (kg C) in Each Mass-balance Model Stock for Current Conditions Over a 100-year Model Extent

Year	Atm CH_4 (kg C)	Atm CO_2 (kg C)	Atm N_20 (kg C)	Sediment (kg C)	Soil (kg C)	Surface Water (kg C)	Terrestrial Plants (kg C)	Wetlands (kg C)	Net carbon Stock (kg C)
0	0	0	0	168,916,360	566,475,238	1,994,471	458,419,338	64,832,942	1,260,638,349
1	166,571	-484,871	4,193	168,929,371	566,611,434	1,994,471	458,419,338	65,015,045	1,260,969,659
2	333,142	-969,741	8,386	168,942,381	566,747,631	1,994,471	458,419,338	65,197,149	1,261,300,969
3	499,712	-1,454,612	12,579	168,955,392	566,883,827	1,994,471	458,419,338	65,379,252	1,261,632,280
4	666,283	-1,939,482	16,771	168,968,403	567,020,024	1,994,471	458,419,338	65,561,356	1,261,963,590
5	832,854	-2,424,353	20,964	168,981,413	567,156,220	1,994,471	458,419,338	65,743,459	1,262,294,901
6	999,425	-2,909,223	25,157	168,994,424	567,292,416	1,994,471	458,419,338	65,925,562	1,262,626,211
7	1,165,995	-3,394,094	29,350	169,007,435	567,428,613	1,994,471	458,419,338	66,107,666	1,262,957,522
8	1,332,566	-3,878,964	33,543	169,020,445	567,564,809	1,994,471	458,419,338	66,289,769	1,263,288,832
9	1,499,137	-4,363,835	37,736	169,033,456	567,701,006	1,994,471	458,419,338	66,471,873	1,263,620,143
10	1,665,708	-4,848,706	41,928	169,046,467	567,837,202	1,994,471	458,419,338	66,653,976	1,263,951,453
11	1,832,278	-5,333,576	46,121	169,059,477	567,973,398	1,994,470	458,419,338	66,836,079	1,264,282,764
12	1,998,849	-5,818,447	50,314	169,072,488	568,109,595	1,994,470	458,419,338	67,018,183	1,264,614,074
13	2,165,420	-6,303,317	54,507	169,085,499	568,245,791	1,994,470	458,419,338	67,200,286	1,264,945,384
14	2,331,991	-6,788,188	58,700	169,098,509	568,381,987	1,994,470	458,419,338	67,382,390	1,265,276,695
15	2,498,562	-7,273,058	62,893	169,111,520	568,518,184	1,994,470	458,419,338	67,564,493	1,265,608,005
16	2,665,132	-7,757,929	67,085	169,124,531	568,654,380	1,994,470	458,419,338	67,746,596	1,265,939,316
17	2,831,703	-8,242,799	71,278	169,137,541	568,790,577	1,994,470	458,419,338	67,928,700	1,266,270,626
18	2,998,274	-8,727,670	75,471	169,150,552	568,926,773	1,994,470	458,419,338	68,110,803	1,266,601,937
19	3,164,845	-9,212,540	79,664	169,163,563	569,062,969	1,994,470	458,419,338	68,292,907	1,266,933,247
20	3,331,415	-9,697,411	83,857	169,176,573	569,199,166	1,994,470	458,419,338	68,475,010	1,267,264,558
21	3,497,986	-10,182,282	88,050	169,189,584	569,335,362	1,994,470	458,419,338	68,657,113	1,267,595,868
22	3,664,557	-10,667,152	92,242	169,202,595	569,471,559	1,994,470	458,419,338	68,839,217	1,267,927,179
23	3,831,128	-11,152,023	96,435	169,215,605	569,607,755	1,994,470	458,419,338	69,021,320	1,268,258,489
24	3,997,698	-11,636,893	100,628	169,228,616	569,743,951	1,994,470	458,419,338	69,203,424	1,268,589,800
25	4,164,269	-12,121,764	104,821	169,241,627	569,880,148	1,994,470	458,419,338	69,385,527	1,268,921,110
26	4,330,840	-12,606,634	109,014	169,254,637	570,016,344	1,994,470	458,419,338	69,567,630	1,269,252,420
27	4,497,411	-13,091,505	113,207	169,267,648	570,152,541	1,994,470	458,419,338	69,749,734	1,269,583,731
28	4,663,982	-13,576,375	117,399	169,280,659	570,288,737	1,994,470	458,419,338	69,931,837	1,269,915,041
29	4,830,552	-14,061,246	121,592	169,293,670	570,424,933	1,994,470	458,419,338	70,113,941	1,270,246,352
30	4,997,123	-14,546,117	125,785	169,306,680	570,561,130	1,994,470	458,419,338	70,296,044	1,270,577,662
31	5,163,694	-15,030,987	129,978	169,319,691	570,697,326	1,994,470	458,419,338	70,478,147	1,270,908,973
32	5,330,265	-15,515,858	134,171	169,332,702	570,833,522	1,994,470	458,419,338	70,660,251	1,271,240,283
33	5,496,835	-16,000,728	138,364	169,345,712	570,969,719	1,994,470	458,419,338	70,842,354	1,271,571,594
34	5,663,406	-16,485,599	142,556	169,358,723	571,105,915	1,994,470	458,419,338	71,024,458	1,271,902,904
35	5,829,977	-16,970,469	146,749	169,371,734	571,242,112	1,994,470	458,419,338	71,206,561	1,272,234,215
36	5,996,548	-17,455,340	150,942	169,384,744	571,378,308	1,994,470	458,419,338	71,388,664	1,272,565,525
37	6,163,118	-17,940,210	155,135	169,397,755	571,514,504	1,994,470	458,419,338	71,570,768	1,272,896,835
38	6,329,689	-18,425,081	159,328	169,410,766	571,650,701	1,994,470	458,419,338	71,752,871	1,273,228,146
39	6,496,260	-18,909,952	163,521	169,423,776	571,786,897	1,994,470	458,419,338	71,934,975	1,273,559,456
40	6,662,831	-19,394,822	167,713	169,436,787	571,923,094	1,994,470	458,419,338	72,117,078	1,273,890,767
41	6,829,402	-19,879,693	171,906	169,449,798	572,059,290	1,994,470	458,419,338	72,299,181	1,274,222,077
42	6,995,972	-20,364,563	176,099	169,462,808	572,195,486	1,994,470	458,419,338	72,481,285	1,274,553,388
43	7,162,543	-20,849,434	180,292	169,475,819	572,331,683	1,994,470	458,419,338	72,663,388	1,274,884,698
44	7,329,114	-21,334,304	184,485	169,488,830	572,467,879	1,994,470	458,419,338	72,845,492	1,275,216,009
45	7,495,685	-21,819,175	188,678	169,501,840	572,604,076	1,994,470	458,419,338	73,027,595	1,275,547,319
46	7,662,255	-22,304,045	192,870	169,514,851	572,740,272	1,994,470	458,419,338	73,209,698	1,275,878,630
47	7,828,826	-22,788,916	197,063	169,527,862	572,876,468	1,994,470	458,419,338	73,391,802	1,276,209,940
48	7,995,397	-23,273,787	201,256	169,540,872	573,012,665	1,994,470	458,419,338	73,573,905	1,276,541,250
49	8,161,968	-23,758,657	205,449	169,553,883	573,148,861	1,994,470	458,419,338	73,756,009	1,276,872,561
50	8,328,538	-24,243,528	209,642	169,566,894	573,285,057	1,994,470	458,419,338	73,938,112	1,277,203,871
51	8,495,109	-24,728,398	213,835	169,579,904	573,421,254	1,994,470	458,419,338	74,120,215	1,277,535,182
52	8,661,680	-25,213,269	218,027	169,592,915	573,557,450	1,994,470	458,419,338	74,302,319	1,277,866,492
53	8,828,251	-25,698,139	222,220	169,605,926	573,693,647	1,994,470	458,419,338	74,484,422	1,278,197,803
54	8,994,822	-26,183,010	226,413	169,618,936	573,829,843	1,994,470	458,419,338	74,666,526	1,278,529,113
55	9,161,392	-26,667,880	230,606	169,631,947	573,966,039	1,994,470	458,419,338	74,848,629	1,278,860,424
56	9,327,963	-27,152,751	234,799	169,644,958	574,102,236	1,994,470	458,419,338	75,030,732	1,279,191,734
57	9,494,534	-27,637,621	238,992	169,657,968	574,238,432	1,994,470	458,419,338	75,212,836	1,279,523,045
58	9,661,105	-28,122,492	243,184	169,670,979	574,374,629	1,994,470	458,419,338	75,394,939	1,279,854,355
59	9,827,675	-28,607,363	247,377	169,683,990	574,510,825	1,994,470	458,419,338	75,577,043	1,280,185,666
60	9,994,246	-29,092,233	251,570	169,697,000	574,647,021	1,994,470	458,419,338	75,759,146	1,280,516,976
61	10,160,817	-29,577,104	255,763	169,710,011	574,783,218	1,994,470	458,419,338	75,941,249	1,280,848,286
62	10,327,388	-30,061,974	259,956	169,723,022	574,919,414	1,994,470	458,419,338	76,123,353	1,281,179,597
63	10,493,958	-30,546,845	264,149	169,736,032	575,055,611	1,994,470	458,419,338	76,305,456	1,281,510,907
64	10,660,529	-31,031,715	268,342	169,749,043	575,191,807	1,994,470	458,419,338	76,487,560	1,281,842,218
65	10,827,100	-31,516,586	272,534	169,762,054	575,328,003	1,994,470	458,419,338	76,669,663	1,282,173,528
66	10,993,671	-32,001,456	276,727	169,775,064	575,464,200	1,994,470	458,419,338	76,851,766	1,282,504,839
67	11,160,242	-32,486,327	280,920	169,788,075	575,600,396	1,994,470	458,419,338	77,033,870	1,282,836,149
68	11,326,812	-32,971,198	285,113	169,801,086	575,736,592	1,994,470	458,419,338	77,215,973	1,283,167,460
69	11,493,383	-33,456,068	289,306	169,814,096	575,872,789	1,994,470	458,419,338	77,398,077	1,283,498,770
70	11,659,954	-33,940,939	293,499	169,827,107	576,008,985	1,994,470	458,419,338	77,580,180	1,283,830,081
71	11,826,525	-34,425,809	297,691	169,840,118	576,145,182	1,994,470	458,419,338	77,762,283	1,284,161,391
72	11,993,095	-34,910,680	301,884	169,853,128	576,281,378	1,994,470	458,419,338	77,944,387	1,284,492,701
73	12,159,666	-35,395,550	306,077	169,866,139	576,417,574	1,994,470	458,419,338	78,126,490	1,284,824,012
74	12,326,237	-35,880,421	310,270	169,879,150	576,553,771	1,994,470	458,419,338	78,308,594	1,285,155,322

Table C.1 - Mass of Carbon (kg C) in Each Mass-balance Model Stock for Current Conditions Over a 100-year Model Extent

Year	Atm CH_4 (kg C)	Atm CO_2 (kg C)	Atm N_20 (kg C)	Sediment (kg C)	Soil (kg C)	Surface Water (kg C)	Terrestrial Plants (kg C)	Wetlands (kg C)	Net carbon Stock (kg C)
75	12,492,808	-36,365,291	314,463	169,892,160	576,689,967	1,994,470	458,419,338	78,490,697	1,285,486,633
76	12,659,378	-36,850,162	318,656	169,905,171	576,826,164	1,994,470	458,419,338	78,672,800	1,285,817,943
77	12,825,949	-37,335,033	322,848	169,918,182	576,962,360	1,994,470	458,419,338	78,854,904	1,286,149,254
78	12,992,520	-37,819,903	327,041	169,931,192	577,098,556	1,994,470	458,419,338	79,037,007	1,286,480,564
79	13,159,091	-38,304,774	331,234	169,944,203	577,234,753	1,994,470	458,419,338	79,219,111	1,286,811,875
80	13,325,661	-38,789,644	335,427	169,957,214	577,370,949	1,994,470	458,419,338	79,401,214	1,287,143,185
81	13,492,232	-39,274,515	339,620	169,970,225	577,507,146	1,994,470	458,419,338	79,583,317	1,287,474,496
82	13,658,803	-39,759,385	343,813	169,983,235	577,643,342	1,994,470	458,419,338	79,765,421	1,287,805,806
83	13,825,374	-40,244,256	348,005	169,996,246	577,779,538	1,994,470	458,419,338	79,947,524	1,288,137,116
84	13,991,945	-40,729,126	352,198	170,009,257	577,915,735	1,994,470	458,419,338	80,129,628	1,288,468,427
85	14,158,515	-41,213,997	356,391	170,022,267	578,051,931	1,994,470	458,419,338	80,311,731	1,288,799,737
86	14,325,086	-41,698,868	360,584	170,035,278	578,188,128	1,994,470	458,419,338	80,493,834	1,289,131,048
87	14,491,657	-42,183,738	364,777	170,048,289	578,324,324	1,994,470	458,419,338	80,675,938	1,289,462,358
88	14,658,228	-42,668,609	368,970	170,061,299	578,460,520	1,994,470	458,419,338	80,858,041	1,289,793,669
89	14,824,798	-43,153,479	373,162	170,074,310	578,596,717	1,994,470	458,419,338	81,040,145	1,290,124,979
90	14,991,369	-43,638,350	377,355	170,087,321	578,732,913	1,994,470	458,419,338	81,222,248	1,290,456,290
91	15,157,940	-44,123,220	381,548	170,100,331	578,869,109	1,994,470	458,419,338	81,404,351	1,290,787,600
92	15,324,511	-44,608,091	385,741	170,113,342	579,005,306	1,994,470	458,419,338	81,586,455	1,291,118,911
93	15,491,081	-45,092,961	389,934	170,126,353	579,141,502	1,994,470	458,419,338	81,768,558	1,291,450,221
94	15,657,652	-45,577,832	394,127	170,139,363	579,277,699	1,994,470	458,419,338	81,950,662	1,291,781,532
95	15,824,223	-46,062,702	398,319	170,152,374	579,413,895	1,994,470	458,419,338	82,132,765	1,292,112,842
96	15,990,794	-46,547,573	402,512	170,165,385	579,550,091	1,994,470	458,419,338	82,314,868	1,292,444,152
97	16,157,365	-47,032,444	406,705	170,178,395	579,686,288	1,994,470	458,419,338	82,496,972	1,292,775,463
98	16,323,935	-47,517,314	410,898	170,191,406	579,822,484	1,994,470	458,419,338	82,679,075	1,293,106,773
99	16,490,506	-48,002,185	415,091	170,204,417	579,958,681	1,994,470	458,419,338	82,861,179	1,293,438,084
100	16,657,077	-48,487,055	419,284	170,217,427	580,094,877	1,994,470	458,419,338	83,043,282	1,293,769,394

Table C.2 - CO_2, CH_4, and N_2O Emissions, in CO_2e for the Current Conditions Mmass-balance Model Over a 100-yr Time Extent

Year	CO_2 (kg CO_2e)	CH_4 (kg CO_2e)	N_20 (kg CO_2e)	Sum (kg CO_2e)	Tot Atm Carbon (kg C)	Total Emissions (kg CO_2e)	Total Emissions (tonnes CO_2e)	Annual Emission (kg CO_2e/yr)	Annual Emission (Tonnes CO_2e/yr)
0	0	0	0	0	0	0	0	0	0
1	-1,777,859	4,663,982	2,042,510	4,928,633	-318,300	4,915,622	4916	4,915,622	4916
2	-3,555,717	9,327,963	4,085,020	9,857,266	-636,600	9,831,245	9831	4,915,623	4916
3	-5,333,576	13,991,945	6,127,530	14,785,899	-954,899	14,746,867	14747	4,915,622	4916
4	-7,111,435	18,655,926	8,170,040	19,714,532	-1,273,199	19,662,489	19662	4,915,622	4916
5	-8,889,293	23,319,908	10,212,551	24,643,165	-1,591,499	24,578,112	24578	4,915,623	4916
6	-10,667,152	27,983,889	12,255,061	29,571,798	-1,909,799	29,493,734	29494	4,915,622	4916
7	-12,445,011	32,647,871	14,297,571	34,500,431	-2,228,098	34,409,356	34409	4,915,622	4916
8	-14,222,870	37,311,852	16,340,081	39,429,064	-2,546,398	39,324,979	39325	4,915,623	4916
9	-16,000,728	41,975,834	18,382,591	44,357,696	-2,864,698	44,240,600	44241	4,915,621	4916
10	-17,778,587	46,639,815	20,425,101	49,286,329	-3,182,998	49,156,222	49156	4,915,622	4916
11	-19,556,446	51,303,797	22,467,611	54,214,962	-3,501,298	54,071,845	54072	4,915,623	4916
12	-21,334,304	55,967,778	24,510,121	59,143,595	-3,819,597	58,987,467	58987	4,915,622	4916
13	-23,112,163	60,631,760	26,552,631	64,072,228	-4,137,897	63,903,089	63903	4,915,622	4916
14	-24,890,022	65,295,741	28,595,142	69,000,861	-4,456,197	68,818,712	68819	4,915,623	4916
15	-26,667,880	69,959,723	30,637,652	73,929,494	-4,774,497	73,734,334	73734	4,915,622	4916
16	-28,445,739	74,623,704	32,680,162	78,858,127	-5,092,797	78,649,956	78650	4,915,622	4916
17	-30,223,598	79,287,686	34,722,672	83,786,760	-5,411,096	83,565,579	83566	4,915,623	4916
18	-32,001,456	83,951,667	36,765,182	88,715,393	-5,729,396	88,481,201	88481	4,915,622	4916
19	-33,779,315	88,615,649	38,807,692	93,644,026	-6,047,696	93,396,823	93397	4,915,622	4916
20	-35,557,174	93,279,630	40,850,202	98,572,659	-6,365,996	98,312,446	98312	4,915,623	4916
21	-37,335,033	97,943,612	42,892,712	103,501,292	-6,684,295	103,228,068	103228	4,915,622	4916
22	-39,112,891	102,607,594	44,935,222	108,429,925	-7,002,595	108,143,690	108144	4,915,622	4916
23	-40,890,750	107,271,575	46,977,732	113,358,558	-7,320,895	113,059,313	113059	4,915,623	4916
24	-42,668,609	111,935,557	49,020,243	118,287,191	-7,639,195	117,974,935	117975	4,915,622	4916
25	-44,446,467	116,599,538	51,062,753	123,215,823	-7,957,495	122,890,556	122891	4,915,621	4916
26	-46,224,326	121,263,520	53,105,263	128,144,456	-8,275,794	127,806,179	127806	4,915,623	4916
27	-48,002,185	125,927,501	55,147,773	133,073,089	-8,594,094	132,721,801	132722	4,915,622	4916
28	-49,780,043	130,591,483	57,190,283	138,001,722	-8,912,394	137,637,423	137637	4,915,622	4916
29	-51,557,902	135,255,464	59,232,793	142,930,355	-9,230,694	142,553,045	142553	4,915,622	4916
30	-53,335,761	139,919,446	61,275,303	147,858,988	-9,548,994	147,468,668	147469	4,915,623	4916
31	-55,113,619	144,583,427	63,317,813	152,787,621	-9,867,293	152,384,290	152384	4,915,622	4916
32	-56,891,478	149,247,409	65,360,323	157,716,254	-10,185,593	157,299,912	157300	4,915,622	4916
33	-58,669,337	153,911,390	67,402,834	162,644,887	-10,503,893	162,215,535	162216	4,915,623	4916
34	-60,447,196	158,575,372	69,445,344	167,573,520	-10,822,193	167,131,157	167131	4,915,622	4916
35	-62,225,054	163,239,353	71,487,854	172,502,153	-11,140,492	172,046,779	172047	4,915,622	4916
36	-64,002,913	167,903,335	73,530,364	177,430,786	-11,458,792	176,962,402	176962	4,915,623	4916
37	-65,780,772	172,567,316	75,572,874	182,359,419	-11,777,092	181,878,024	181878	4,915,622	4916
38	-67,558,630	177,231,298	77,615,384	187,288,052	-12,095,392	186,793,646	186794	4,915,622	4916
39	-69,336,489	181,895,279	79,657,894	192,216,685	-12,413,692	191,709,269	191709	4,915,623	4916
40	-71,114,348	186,559,261	81,700,404	197,145,318	-12,731,991	196,624,891	196625	4,915,622	4916
41	-72,892,206	191,223,242	83,742,914	202,073,951	-13,050,291	201,540,513	201541	4,915,622	4916
42	-74,670,065	195,887,224	85,785,425	207,002,583	-13,368,591	206,456,135	206456	4,915,622	4916
43	-76,447,924	200,551,206	87,827,935	211,931,216	-13,686,891	211,371,757	211372	4,915,622	4916
44	-78,225,782	205,215,187	89,870,445	216,859,849	-14,005,190	216,287,379	216287	4,915,622	4916
45	-80,003,641	209,879,169	91,912,955	221,788,482	-14,323,490	221,203,002	221203	4,915,623	4916
46	-81,781,500	214,543,150	93,955,465	226,717,115	-14,641,790	226,118,624	226119	4,915,622	4916
47	-83,559,359	219,207,132	95,997,975	231,645,748	-14,960,090	231,034,246	231034	4,915,622	4916
48	-85,337,217	223,871,113	98,040,485	236,574,381	-15,278,390	235,949,869	235950	4,915,623	4916
49	-87,115,076	228,535,095	100,082,995	241,503,014	-15,596,689	240,865,491	240865	4,915,622	4916
50	-88,892,935	233,199,076	102,125,505	246,431,647	-15,914,989	245,781,113	245781	4,915,622	4916
51	-90,670,793	237,863,058	104,168,016	251,360,280	-16,233,289	250,696,736	250697	4,915,623	4916
52	-92,448,652	242,527,039	106,210,526	256,288,913	-16,551,589	255,612,358	255612	4,915,622	4916
53	-94,226,511	247,191,021	108,253,036	261,217,546	-16,869,889	260,527,980	260528	4,915,622	4916
54	-96,004,369	251,855,002	110,295,546	266,146,179	-17,188,188	265,443,603	265444	4,915,623	4916
55	-97,782,228	256,518,984	112,338,056	271,074,812	-17,506,488	270,359,225	270359	4,915,622	4916
56	-99,560,087	261,182,965	114,380,566	276,003,445	-17,824,788	275,274,847	275275	4,915,622	4916
57	-101,337,945	265,846,947	116,423,076	280,932,078	-18,143,088	280,190,470	280190	4,915,623	4916
58	-103,115,804	270,510,928	118,465,586	285,860,710	-18,461,387	285,106,091	285106	4,915,621	4916
59	-104,893,663	275,174,910	120,508,096	290,789,343	-18,779,687	290,021,713	290022	4,915,622	4916
60	-106,671,522	279,838,891	122,550,607	295,717,976	-19,097,987	294,937,336	294937	4,915,623	4916
61	-108,449,380	284,502,873	124,593,117	300,646,609	-19,416,287	299,852,958	299853	4,915,622	4916
62	-110,227,239	289,166,854	126,635,627	305,575,242	-19,734,587	304,768,580	304769	4,915,622	4916
63	-112,005,098	293,830,836	128,678,137	310,503,875	-20,052,886	309,684,203	309684	4,915,623	4916
64	-113,782,956	298,494,818	130,720,647	315,432,508	-20,371,186	314,599,825	314600	4,915,622	4916
65	-115,560,815	303,158,799	132,763,157	320,361,141	-20,689,486	319,515,447	319515	4,915,622	4916
66	-117,338,674	307,822,781	134,805,667	325,289,774	-21,007,786	324,431,070	324431	4,915,623	4916
67	-119,116,532	312,486,762	136,848,177	330,218,407	-21,326,086	329,346,692	329347	4,915,622	4916
68	-120,894,391	317,150,744	138,890,687	335,147,040	-21,644,385	334,262,314	334262	4,915,622	4916
69	-122,672,250	321,814,725	140,933,197	340,075,673	-21,962,685	339,177,937	339178	4,915,623	4916
70	-124,450,109	326,478,707	142,975,708	345,004,306	-22,280,985	344,093,559	344094	4,915,622	4916
71	-126,227,967	331,142,688	145,018,218	349,932,939	-22,599,285	349,009,181	349009	4,915,622	4916
72	-128,005,826	335,806,670	147,060,728	354,861,572	-22,917,584	353,924,804	353925	4,915,623	4916
73	-129,783,685	340,470,651	149,103,238	359,790,205	-23,235,884	358,840,426	358840	4,915,622	4916
74	-131,561,543	345,134,633	151,145,748	364,718,838	-23,554,184	363,756,048	363756	4,915,622	4916

Table C.2 - CO_2, CH_4, and N_2O Emissions, in CO_2e for the Current Conditions Mmass-balance Model Over a 100-yr Time Extent

Year	CO_2 (kg CO_2e)	CH_4 (kg CO_2e)	N_20 (kg CO_2e)	Sum (kg CO_2e)	Tot Atm Carbon (kg C)	Total Emissions (kg CO_2e)	Total Emissions (tonnes CO_2e)	Annual Emission (kg CO_2e/yr)	Annual Emission (Tonnes CO_2e/yr)
75	-133,339,402	349,798,614	153,188,258	369,647,470	-23,872,484	368,671,670	368672	4,915,622	4916
76	-135,117,261	354,462,596	155,230,768	374,576,103	-24,190,784	373,587,292	373587	4,915,622	4916
77	-136,895,119	359,126,577	157,273,278	379,504,736	-24,509,083	378,502,914	378503	4,915,622	4916
78	-138,672,978	363,790,559	159,315,788	384,433,369	-24,827,383	383,418,537	383419	4,915,623	4916
79	-140,450,837	368,454,540	161,358,299	389,362,002	-25,145,683	388,334,159	388334	4,915,622	4916
80	-142,228,695	373,118,522	163,400,809	394,290,635	-25,463,983	393,249,781	393250	4,915,622	4916
81	-144,006,554	377,782,503	165,443,319	399,219,268	-25,782,282	398,165,403	398165	4,915,622	4916
82	-145,784,413	382,446,485	167,485,829	404,147,901	-26,100,582	403,081,026	403081	4,915,623	4916
83	-147,562,272	387,110,466	169,528,339	409,076,534	-26,418,882	407,996,648	407997	4,915,622	4916
84	-149,340,130	391,774,448	171,570,849	414,005,167	-26,737,182	412,912,270	412912	4,915,622	4916
85	-151,117,989	396,438,430	173,613,359	418,933,800	-27,055,482	417,827,893	417828	4,915,623	4916
86	-152,895,848	401,102,411	175,655,869	423,862,433	-27,373,781	422,743,515	422744	4,915,622	4916
87	-154,673,706	405,766,393	177,698,379	428,791,066	-27,692,081	427,659,137	427659	4,915,622	4916
88	-156,451,565	410,430,374	179,740,890	433,719,699	-28,010,381	432,574,760	432575	4,915,623	4916
89	-158,229,424	415,094,356	181,783,400	438,648,332	-28,328,681	437,490,382	437490	4,915,622	4916
90	-160,007,282	419,758,337	183,825,910	443,576,965	-28,646,981	442,406,004	442406	4,915,622	4916
91	-161,785,141	424,422,319	185,868,420	448,505,597	-28,965,280	447,321,626	447322	4,915,622	4916
92	-163,563,000	429,086,300	187,910,930	453,434,230	-29,283,580	452,237,248	452237	4,915,622	4916
93	-165,340,858	433,750,282	189,953,440	458,362,863	-29,601,880	457,152,870	457153	4,915,622	4916
94	-167,118,717	438,414,263	191,995,950	463,291,496	-29,920,180	462,068,493	462068	4,915,623	4916
95	-168,896,576	443,078,245	194,038,460	468,220,129	-30,238,479	466,984,115	466984	4,915,622	4916
96	-170,674,435	447,742,226	196,080,970	473,148,762	-30,556,779	471,899,737	471900	4,915,622	4916
97	-172,452,293	452,406,208	198,123,481	478,077,395	-30,875,079	476,815,360	476815	4,915,623	4916
98	-174,230,152	457,070,189	200,165,991	483,006,028	-31,193,379	481,730,982	481731	4,915,622	4916
99	-176,008,011	461,734,171	202,208,501	487,934,661	-31,511,679	486,646,604	486647	4,915,622	4916
100	-177,785,869	466,398,152	204,251,011	492,863,294	-31,829,978	491,562,227	491562	4,915,623	4916

Table C.3 - Mass of carbon (kg C) in each mass-balance model stock post-inundation over a 100-year model extent.

Year	Atm CH_4 (kg C)	Atm CO_2 (kg C)	Atm N_20 (kg C)	Sediment (kg C)	Soil (kg C)	Surface Water (kg C)	Terrestrial Plants (kg C)	Wetlands (kg C)	Net carbon Stock (kg C)
0	0	0	0	212,727,320	72,789,501	19,195,200	60,082,443	6,493,651	1,367,548,816
1	2,479,089	162,342,807	238	221,120,270	71,669,813	19,195,200	60,082,443	6,511,890	1,213,343,322
2	4,565,491	298,899,129	476	229,513,220	70,550,125	19,195,200	60,082,443	6,530,130	1,085,316,999
3	6,322,862	413,849,039	714	237,906,170	69,430,438	19,195,200	60,082,443	6,548,369	979,226,122
4	7,804,537	510,695,002	952	246,299,120	68,310,750	19,195,200	60,082,443	6,566,609	891,514,885
5	9,055,209	592,371,726	1,189	254,692,070	67,191,062	19,195,200	60,082,443	6,584,848	819,203,891
6	10,112,324	661,338,192	1,427	263,085,020	66,071,374	19,195,200	60,082,443	6,603,087	759,796,712
7	11,007,258	719,654,774	1,665	271,477,970	64,951,686	19,195,200	60,082,443	6,621,327	711,201,600
8	11,766,300	769,047,850	1,903	279,870,920	63,831,999	19,195,200	60,082,443	6,639,566	671,665,883
9	12,411,480	810,963,949	2,141	288,263,870	62,712,311	19,195,200	60,082,443	6,657,806	639,721,006
10	12,961,256	846,615,112	2,379	296,656,820	61,592,623	19,195,200	60,082,443	6,676,045	614,136,469
11	13,431,091	877,016,906	2,617	305,049,770	60,472,935	19,195,200	60,082,443	6,694,285	593,881,242
12	13,833,945	903,020,270	2,855	313,442,720	59,353,247	19,195,200	60,082,443	6,712,524	578,091,426
13	14,180,676	925,338,203	3,093	321,835,670	58,233,560	19,195,200	60,082,443	6,730,763	566,043,164
14	14,480,382	944,568,125	3,330	330,228,620	57,113,872	19,195,200	60,082,443	6,749,003	557,129,939
15	14,740,685	961,210,612	3,568	338,621,570	55,994,184	19,195,200	60,082,443	6,767,242	550,843,551
16	14,967,972	975,685,096	3,806	347,014,520	54,874,496	19,195,200	60,082,443	6,785,482	546,758,181
17	15,167,596	988,343,017	4,044	355,407,470	53,754,808	19,195,199	60,082,443	6,803,721	544,517,039
18	15,344,041	999,478,845	4,282	363,800,420	52,635,121	19,195,199	60,082,443	6,821,961	543,821,168
19	15,501,065	1,009,339,316	4,520	372,193,370	51,515,433	19,195,199	60,082,443	6,840,200	544,420,075
20	15,641,815	1,018,131,171	4,758	380,586,320	50,395,745	19,195,199	60,082,443	6,858,439	546,103,873
21	15,768,930	1,026,027,634	4,996	388,979,270	49,276,057	19,195,199	60,082,443	6,876,679	548,696,697
22	15,884,619	1,033,173,852	5,234	397,372,220	48,156,369	19,195,199	60,082,443	6,894,918	552,051,191
23	15,990,736	1,039,691,441	5,471	405,765,170	47,036,682	19,195,199	60,082,443	6,913,158	556,043,887
24	16,088,831	1,045,682,305	5,709	414,158,120	45,916,994	19,195,199	60,082,443	6,931,397	560,571,330
25	16,180,206	1,051,231,828	5,947	422,551,070	44,797,306	19,195,199	60,082,443	6,949,637	565,546,835
26	16,265,949	1,056,411,551	6,185	430,944,020	43,677,618	19,195,199	60,082,443	6,967,876	570,897,771
27	16,346,973	1,061,281,421	6,423	439,336,970	42,557,930	19,195,199	60,082,443	6,986,116	576,563,278
28	16,424,044	1,065,891,667	6,661	447,729,920	41,438,243	19,195,199	60,082,443	7,004,355	582,492,364
29	16,497,802	1,070,284,373	6,899	456,122,870	40,318,555	19,195,199	60,082,443	7,022,594	588,642,302
30	16,568,784	1,074,494,803	7,137	464,515,820	39,198,867	19,195,199	60,082,443	7,040,834	594,977,292
31	16,637,440	1,078,552,506	7,375	472,908,770	38,079,179	19,195,199	60,082,443	7,059,073	601,467,334
32	16,704,148	1,082,482,239	7,612	481,301,720	36,959,491	19,195,199	60,082,443	7,077,313	608,087,296
33	16,769,223	1,086,304,746	7,850	489,694,670	35,839,804	19,195,199	60,082,443	7,095,552	614,816,117
34	16,832,929	1,090,037,409	8,088	498,087,620	34,720,116	19,195,199	60,082,443	7,113,792	621,636,149
35	16,895,489	1,093,694,791	8,326	506,480,570	33,600,428	19,195,199	60,082,443	7,132,031	628,532,609
36	16,957,089	1,097,289,097	8,564	514,873,520	32,480,740	19,195,199	60,082,443	7,150,270	635,493,106
37	17,017,884	1,100,830,550	8,802	523,266,470	31,361,052	19,195,199	60,082,443	7,168,510	642,507,260
38	17,078,004	1,104,327,719	9,040	531,659,420	30,241,365	19,195,199	60,082,443	7,186,749	649,566,373
39	17,137,559	1,107,787,782	9,278	540,052,370	29,121,677	19,195,199	60,082,443	7,204,989	656,663,156
40	17,196,641	1,111,216,754	9,516	548,445,320	28,001,989	19,195,199	60,082,443	7,223,228	663,791,505
41	17,255,326	1,114,619,675	9,753	556,838,270	26,882,301	19,195,199	60,082,443	7,241,468	670,946,300
42	17,313,679	1,118,000,769	9,991	565,231,220	25,762,613	19,195,199	60,082,443	7,259,707	678,123,257
43	17,371,753	1,121,363,572	10,229	573,624,170	24,642,925	19,195,199	60,082,443	7,277,946	685,318,781
44	17,429,594	1,124,711,051	10,467	582,017,120	23,523,238	19,195,199	60,082,443	7,296,186	692,529,864
45	17,487,239	1,128,045,689	10,705	590,410,070	22,403,550	19,195,199	60,082,443	7,314,425	699,753,983
46	17,544,721	1,131,369,568	10,943	598,803,020	21,283,862	19,195,199	60,082,443	7,332,665	706,989,024
47	17,602,065	1,134,684,432	11,181	607,195,970	20,164,174	19,195,199	60,082,443	7,350,904	714,233,218
48	17,659,294	1,137,991,742	11,419	615,588,920	19,044,486	19,195,199	60,082,443	7,369,144	721,485,081
49	17,716,427	1,141,292,723	11,657	623,981,870	17,924,799	19,195,199	60,082,443	7,387,383	728,743,369
50	17,773,478	1,144,588,401	11,894	632,374,820	16,805,111	19,195,199	60,082,443	7,405,622	736,007,042
51	17,830,463	1,147,879,635	12,132	640,767,770	15,685,423	19,195,198	60,082,443	7,423,862	743,275,225
52	17,887,390	1,151,167,146	12,370	649,160,720	14,565,735	19,195,198	60,082,443	7,442,101	750,547,189
53	17,944,270	1,154,451,537	12,608	657,553,670	13,446,047	19,195,198	60,082,443	7,460,341	757,822,319
54	18,001,111	1,157,733,315	12,846	665,946,620	12,326,360	19,195,198	60,082,443	7,478,580	765,100,104
55	18,057,918	1,161,012,902	13,084	674,339,570	11,206,672	19,195,198	60,082,443	7,496,820	772,380,112
56	18,114,697	1,164,290,654	13,322	682,732,520	10,086,984	19,195,198	60,082,443	7,515,059	779,661,983
57	18,171,452	1,167,566,868	13,560	691,125,470	8,967,296	19,195,198	60,082,443	7,533,298	786,945,415
58	18,228,188	1,170,841,794	13,798	699,518,420	7,847,608	19,195,198	60,082,443	7,551,538	794,230,156
59	18,284,908	1,174,115,640	14,035	707,911,370	6,727,921	19,195,198	60,082,443	7,569,777	801,515,992
60	18,341,613	1,177,388,582	14,273	716,304,320	5,608,233	19,195,198	60,082,443	7,588,017	808,802,747
61	18,398,307	1,180,660,766	14,511	724,697,270	4,488,545	19,195,198	60,082,443	7,606,256	816,090,271
62	18,454,992	1,183,932,314	14,749	733,090,220	3,368,857	19,195,198	60,082,443	7,624,496	823,378,440
63	18,511,668	1,187,203,331	14,987	741,483,170	2,249,169	19,195,198	60,082,443	7,642,735	830,667,149
64	18,568,338	1,190,473,901	15,225	749,876,120	1,129,482	19,195,198	60,082,443	7,660,974	837,956,311
65	18,625,002	1,193,744,098	15,463	758,269,070	9,794	19,195,198	60,082,443	7,679,214	845,245,852
66	18,681,661	1,197,013,982	15,701	766,662,020	-1,109,894	19,195,198	60,082,443	7,697,453	852,535,711
67	18,738,316	1,200,283,604	15,938	775,054,970	-2,229,582	19,195,198	60,082,443	7,715,693	859,825,836
68	18,794,968	1,203,553,006	16,176	783,447,920	-3,349,270	19,195,198	60,082,443	7,733,932	867,116,185
69	18,851,617	1,206,822,224	16,414	791,840,870	-4,468,957	19,195,198	60,082,443	7,752,172	874,406,720
70	18,908,264	1,210,091,287	16,652	800,233,820	-5,588,645	19,195,198	60,082,443	7,770,411	881,697,412
71	18,964,908	1,213,360,222	16,890	808,626,770	-6,708,333	19,195,198	60,082,443	7,788,650	888,988,235
72	19,021,551	1,216,629,048	17,128	817,019,720	-7,828,021	19,195,198	60,082,443	7,806,890	896,279,168
73	19,078,193	1,219,897,783	17,366	825,412,670	-8,947,709	19,195,198	60,082,443	7,825,129	903,570,193
74	19,134,834	1,223,166,442	17,604	833,805,620	-10,067,396	19,195,198	60,082,443	7,843,369	910,861,296
75	19,191,473	1,226,435,037	17,842	842,198,570	-11,187,084	19,195,198	60,082,443	7,861,608	918,152,463
76	19,248,112	1,229,703,579	18,079	850,591,520	-12,306,772	19,195,198	60,082,443	7,879,848	925,443,685
77	19,304,750	1,232,972,076	18,317	858,984,470	-13,426,460	19,195,198	60,082,443	7,898,087	932,734,951
78	19,361,387	1,236,240,536	18,555	867,377,420	-14,546,148	19,195,198	60,082,443	7,916,326	940,026,256
79	19,418,024	1,239,508,965	18,793	875,770,370	-15,665,835	19,195,198	60,082,443	7,934,566	947,317,593
80	19,474,661	1,242,777,367	19,031	884,163,320	-16,785,523	19,195,198	60,082,443	7,952,805	954,608,957
81	19,531,297	1,246,045,747	19,269	892,556,270	-17,905,211	19,195,198	60,082,443	7,971,045	961,900,342

Table C.3 - Mass of carbon (kg C) in each mass-balance model stock post-inundation over a 100-year model extent.

Year	Atm CH_4 (kg C)	Atm CO_2 (kg C)	Atm N_20 (kg C)	Sediment (kg C)	Soil (kg C)	Surface Water (kg C)	Terrestrial Plants (kg C)	Wetlands (kg C)	Net carbon Stock (kg C)
82	19,587,933	1,249,314,108	19,507	900,949,220	-19,024,899	19,195,198	60,082,443	7,989,284	969,191,747
83	19,644,569	1,252,582,454	19,745	909,342,170	-20,144,587	19,195,198	60,082,443	8,007,524	976,483,167
84	19,701,204	1,255,850,787	19,983	917,735,120	-21,264,274	19,195,197	60,082,443	8,025,763	983,774,601
85	19,757,840	1,259,119,109	20,220	926,128,070	-22,383,962	19,195,197	60,082,443	8,044,002	991,066,046
86	19,814,475	1,262,387,422	20,458	934,521,020	-23,503,650	19,195,197	60,082,443	8,062,242	998,357,499
87	19,871,110	1,265,655,728	20,696	942,913,970	-24,623,338	19,195,197	60,082,443	8,080,481	1,005,648,961
88	19,927,745	1,268,924,027	20,934	951,306,920	-25,743,026	19,195,197	60,082,443	8,098,721	1,012,940,429
89	19,984,380	1,272,192,320	21,172	959,699,870	-26,862,713	19,195,197	60,082,443	8,116,960	1,020,231,902
90	20,041,015	1,275,460,610	21,410	968,092,820	-27,982,401	19,195,197	60,082,443	8,135,200	1,027,523,380
91	20,097,650	1,278,728,895	21,648	976,485,770	-29,102,089	19,195,197	60,082,443	8,153,439	1,034,814,862
92	20,154,284	1,281,997,177	21,886	984,878,720	-30,221,777	19,195,197	60,082,443	8,171,678	1,042,106,347
93	20,210,919	1,285,265,457	22,124	993,271,670	-31,341,465	19,195,197	60,082,443	8,189,918	1,049,397,835
94	20,267,554	1,288,533,734	22,361	1,001,664,620	-32,461,152	19,195,197	60,082,443	8,208,157	1,056,689,325
95	20,324,189	1,291,802,010	22,599	1,010,057,570	-33,580,840	19,195,197	60,082,443	8,226,397	1,063,980,817
96	20,380,823	1,295,070,284	22,837	1,018,450,520	-34,700,528	19,195,197	60,082,443	8,244,636	1,071,272,310
97	20,437,458	1,298,338,557	23,075	1,026,843,470	-35,820,216	19,195,197	60,082,443	8,262,876	1,078,563,805
98	20,494,092	1,301,606,828	23,313	1,035,236,420	-36,939,904	19,195,197	60,082,443	8,281,115	1,085,855,301
99	20,550,727	1,304,875,099	23,551	1,043,629,370	-38,059,591	19,195,197	60,082,443	8,299,354	1,093,146,798
100	20,607,362	1,308,143,369	23,789	1,052,022,320	-39,179,279	19,195,197	60,082,443	8,317,594	1,100,438,295

Table C.4 - Gross CO_2, CH_4,and N_2O emissions in CO_2e for the post -inundation mass-balance model over 100 years, conservative scenario.

CO_2 (kg CO_2e)	CH_4 (kg CO_2e)	NO_2 (kg CO_2e)	Sum CO_2e (kg)	Tot Atm Carbon (kg C)	Total Post Emissions (kg CO_2e)	Total Post Emissions (Tonnes CO_2e)	Gross Annual Emissions (kg CO_2e/yr)	Gross Annual Emissions (Tonnes CO_2e/yr)
0	0	0	0	0	0	0	0	0
595,256,958	69,408,821	115,885	664,781,664	164,821,693	656,388,714	656,389	656,388,714	656,389
1,095,963,475	127,822,390	231,771	1,224,017,635	303,464,215	1,207,231,735	1,207,232	550,843,021	550,843
1,517,446,475	177,023,072	347,656	1,694,817,203	420,171,291	1,669,638,353	1,669,638	462,406,618	462,407
1,872,548,341	218,504,305	463,542	2,091,516,187	518,498,727	2,057,944,387	2,057,944	388,306,034	388,306
2,172,029,663	253,517,436	579,427	2,426,126,525	601,425,920	2,384,161,775	2,384,162	326,217,388	326,217
2,424,906,705	283,110,964	695,313	2,708,712,982	671,449,298	2,658,355,282	2,658,355	274,193,507	274,194
2,638,734,170	308,163,425	811,198	2,947,708,793	730,660,610	2,888,958,143	2,888,958	230,602,861	230,603
2,819,842,115	329,410,939	927,084	3,150,180,138	780,812,526	3,083,036,538	3,083,037	194,078,395	194,078
2,973,534,478	347,470,301	1,042,969	3,322,047,749	823,373,602	3,246,511,199	3,246,511	163,474,661	163,475
3,104,255,412	362,858,320	1,158,854	3,468,272,587	859,574,338	3,384,343,087	3,384,343	137,831,888	137,832
3,215,728,657	376,008,029	1,274,740	3,593,011,426	890,445,765	3,500,688,976	3,500,689	116,345,889	116,346
3,311,074,324	387,282,265	1,390,625	3,699,747,214	916,851,780	3,599,031,814	3,599,032	98,342,839	98,343
3,392,906,745	396,985,048	1,506,511	3,791,398,304	939,516,240	3,682,289,954	3,682,290	83,258,139	83,258
3,463,416,458	405,371,117	1,622,396	3,870,409,971	959,045,665	3,752,908,671	3,752,909	70,618,717	70,619
3,524,438,911	412,653,913	1,738,282	3,938,831,106	975,948,252	3,812,936,856	3,812,937	60,028,185	60,028
3,577,512,019	419,012,281	1,854,167	3,998,378,467	990,649,820	3,864,091,267	3,864,091	51,154,411	51,154
3,623,924,395	424,596,075	1,970,052	4,050,490,522	1,003,507,162	3,907,810,372	3,907,810	43,719,105	43,719
3,664,755,764	429,530,854	2,085,938	4,096,372,556	1,014,819,232	3,945,299,456	3,945,299	37,489,084	37,489
3,700,910,826	433,921,827	2,201,823	4,137,034,476	1,024,836,524	3,977,568,426	3,977,568	32,268,970	32,269
3,733,147,625	437,857,145	2,317,709	4,173,322,479	1,033,768,926	4,005,463,479	4,005,463	27,895,053	27,895
3,762,101,324	441,410,672	2,433,594	4,205,945,590	1,041,792,301	4,029,693,640	4,029,694	24,230,161	24,230
3,788,304,123	444,644,298	2,549,480	4,235,497,900	1,049,054,005	4,050,853,000	4,050,853	21,159,360	21,159
3,812,201,951	447,609,879	2,665,365	4,262,477,196	1,055,677,508	4,069,439,346	4,069,439	18,586,345	18,586
3,834,168,453	450,350,867	2,781,251	4,287,300,570	1,061,766,265	4,085,869,770	4,085,870	16,430,425	16,430
3,854,516,702	452,903,668	2,897,136	4,310,317,505	1,067,406,959	4,100,493,755	4,100,494	14,623,985	14,624
3,873,509,021	455,298,788	3,013,021	4,331,820,831	1,072,672,222	4,113,604,131	4,113,604	13,110,375	13,110
3,891,365,212	457,561,789	3,128,907	4,352,055,907	1,077,622,914	4,125,446,257	4,125,446	11,842,127	11,842
3,908,269,444	459,714,086	3,244,792	4,371,228,322	1,082,310,027	4,136,225,722	4,136,226	10,779,465	10,779
3,924,376,033	461,773,625	3,360,678	4,389,510,336	1,086,776,288	4,146,114,786	4,146,115	9,889,064	9,889
3,939,814,279	463,755,443	3,476,563	4,407,046,286	1,091,057,498	4,155,257,786	4,155,258	9,143,000	9,143
3,954,692,524	465,672,139	3,592,449	4,423,957,111	1,095,183,654	4,163,775,661	4,163,776	8,517,875	8,518
3,969,101,544	467,534,268	3,708,334	4,440,344,146	1,099,179,892	4,171,769,746	4,171,770	7,994,085	7,994
3,983,117,402	469,350,677	3,824,220	4,456,292,299	1,103,067,270	4,179,324,949	4,179,325	7,555,203	7,555
3,996,803,832	471,128,777	3,940,105	4,471,872,714	1,106,863,436	4,186,512,414	4,186,512	7,187,465	7,187
4,010,214,235	472,874,777	4,055,990	4,487,145,002	1,110,583,176	4,193,391,752	4,193,392	6,879,338	6,879
4,023,393,355	474,593,882	4,171,876	4,502,159,112	1,114,238,878	4,200,012,912	4,200,013	6,621,160	6,621
4,036,378,684	476,290,451	4,287,761	4,516,956,896	1,117,840,923	4,206,417,746	4,206,418	6,404,834	6,405
4,049,201,637	477,968,137	4,403,647	4,531,573,420	1,121,398,010	4,212,641,320	4,212,641	6,223,574	6,224
4,061,888,535	479,630,001	4,519,532	4,546,038,068	1,124,917,425	4,218,713,018	4,218,713	6,071,697	6,072
4,074,461,432	481,278,608	4,635,418	4,560,375,458	1,128,405,276	4,224,657,458	4,224,657	5,944,440	5,944
4,086,938,810	482,916,107	4,751,303	4,574,606,220	1,131,866,679	4,230,495,270	4,230,495	5,837,812	5,838
4,099,336,152	484,544,299	4,867,188	4,588,747,639	1,135,305,922	4,236,243,739	4,236,244	5,748,469	5,748
4,111,666,431	486,164,692	4,983,074	4,602,814,197	1,138,726,597	4,241,917,347	4,241,917	5,673,608	5,674
4,123,940,519	487,778,551	5,098,959	4,616,818,030	1,142,131,713	4,247,528,230	4,247,528	5,610,883	5,611
4,136,167,526	489,386,935	5,214,845	4,630,769,305	1,145,523,794	4,253,086,555	4,253,087	5,558,325	5,558
4,148,355,082	490,990,730	5,330,730	4,644,676,542	1,148,904,951	4,258,600,842	4,258,601	5,514,287	5,514
4,160,509,583	492,590,682	5,446,616	4,658,546,881	1,152,276,956	4,264,078,231	4,264,078	5,477,388	5,477
4,172,636,387	494,187,413	5,562,501	4,672,386,301	1,155,641,292	4,269,524,701	4,269,525	5,446,471	5,446
4,184,739,984	495,781,446	5,678,387	4,686,199,816	1,158,999,203	4,274,945,266	4,274,945	5,420,565	5,421
4,196,824,136	497,373,217	5,794,272	4,699,991,625	1,162,351,730	4,280,344,125	4,280,344	5,398,859	5,399
4,208,891,995	498,963,093	5,910,157	4,713,765,246	1,165,699,745	4,285,724,796	4,285,725	5,380,671	5,381
4,220,946,202	500,551,382	6,026,043	4,727,523,627	1,169,043,981	4,291,090,227	4,291,090	5,365,431	5,365
4,232,988,970	502,138,341	6,141,928	4,741,269,239	1,172,385,050	4,296,442,889	4,296,443	5,352,662	5,353
4,245,022,154	503,724,184	6,257,814	4,755,004,152	1,175,723,464	4,301,784,852	4,301,785	5,341,963	5,342
4,257,047,307	505,309,095	6,373,699	4,768,730,101	1,179,059,655	4,307,117,851	4,307,118	5,332,998	5,333
4,269,065,731	506,893,222	6,489,585	4,782,448,538	1,182,393,983	4,312,443,338	4,312,443	5,325,487	5,325
4,281,078,516	508,476,694	6,605,470	4,796,160,681	1,185,726,750	4,317,762,531	4,317,763	5,319,193	5,319

Table C.4 - Gross CO_2, CH_4,and N_2O emissions in CO_2e for the post -inundation mass-balance model over 100 years, conservative scenario.

CO_2 (kg CO_2e)	CH_4 (kg CO_2e)	NO_2 (kg CO_2e)	Sum CO_2e (kg)	Tot Atm Carbon (kg C)	Total Post Emissions (kg CO_2e)	Total Post Emissions (Tonnes CO_2e)	Gross Annual Emissions (kg CO_2e/yr)	Gross Annual Emissions (Tonnes CO_2e/yr)
4,293,086,578	510,059,616	6,721,356	4,809,867,550	1,189,058,209	4,323,076,450	4,323,076	5,313,919	5,314
4,305,090,681	511,642,079	6,837,241	4,823,570,000	1,192,388,572	4,328,385,950	4,328,386	5,309,500	5,310
4,317,091,467	513,224,155	6,953,126	4,837,268,748	1,195,718,016	4,333,691,748	4,333,692	5,305,798	5,306
4,329,089,474	514,805,908	7,069,012	4,850,964,394	1,199,046,691	4,338,994,444	4,338,994	5,302,696	5,303
4,341,085,152	516,387,391	7,184,897	4,864,657,440	1,202,374,721	4,344,294,540	4,344,295	5,300,096	5,300
4,353,078,879	517,968,646	7,300,783	4,878,348,308	1,205,702,211	4,349,592,458	4,349,592	5,297,918	5,298
4,365,070,972	519,549,712	7,416,668	4,892,037,352	1,209,029,248	4,354,888,552	4,354,889	5,296,093	5,296
4,377,061,694	521,130,618	7,532,554	4,905,724,866	1,212,355,906	4,360,183,116	4,360,183	5,294,564	5,295
4,389,051,269	522,711,391	7,648,439	4,919,411,099	1,215,682,246	4,365,476,399	4,365,476	5,293,283	5,293
4,401,039,882	524,292,052	7,764,324	4,933,096,258	1,219,008,320	4,370,768,608	4,370,769	5,292,209	5,292
4,413,027,689	525,872,619	7,880,210	4,946,780,518	1,222,334,171	4,376,059,918	4,376,060	5,291,310	5,291
4,425,014,821	527,453,107	7,996,095	4,960,464,024	1,225,659,835	4,381,350,474	4,381,350	5,290,556	5,291
4,437,001,387	529,033,530	8,111,981	4,974,146,898	1,228,985,342	4,386,640,398	4,386,640	5,289,925	5,290
4,448,987,480	530,613,898	8,227,866	4,987,829,244	1,232,310,718	4,391,929,794	4,391,930	5,289,395	5,289
4,460,973,175	532,194,219	8,343,752	5,001,511,146	1,235,635,984	4,397,218,746	4,397,219	5,288,952	5,289
4,472,958,537	533,774,502	8,459,637	5,015,192,676	1,238,961,158	4,402,507,326	4,402,507	5,288,580	5,289
4,484,943,620	535,354,753	8,575,523	5,028,873,895	1,242,286,254	4,407,795,595	4,407,796	5,288,269	5,288
4,496,928,470	536,934,976	8,691,408	5,042,554,854	1,245,611,286	4,413,083,604	4,413,084	5,288,008	5,288
4,508,913,124	538,515,176	8,807,293	5,056,235,593	1,248,936,264	4,418,371,393	4,418,371	5,287,790	5,288
4,520,897,614	540,095,358	8,923,179	5,069,916,150	1,252,261,196	4,423,659,000	4,423,659	5,287,607	5,288
4,532,881,966	541,675,523	9,039,064	5,083,596,553	1,255,586,091	4,428,946,453	4,428,946	5,287,453	5,287
4,544,866,203	543,255,675	9,154,950	5,097,276,828	1,258,910,953	4,434,233,778	4,434,234	5,287,325	5,287
4,556,850,344	544,835,816	9,270,835	5,110,956,995	1,262,235,789	4,439,520,995	4,439,521	5,287,217	5,287
4,568,834,404	546,415,947	9,386,721	5,124,637,072	1,265,560,602	4,444,808,122	4,444,808	5,287,127	5,287
4,580,818,396	547,996,071	9,502,606	5,138,317,073	1,268,885,396	4,450,095,173	4,450,095	5,287,051	5,287
4,592,802,332	549,576,187	9,618,492	5,151,997,010	1,272,210,175	4,455,382,160	4,455,382	5,286,988	5,287
4,604,786,219	551,156,299	9,734,377	5,165,676,895	1,275,534,941	4,460,669,095	4,460,669	5,286,935	5,287
4,616,770,067	552,736,405	9,850,262	5,179,356,735	1,278,859,695	4,465,955,985	4,465,956	5,286,890	5,287
4,628,753,882	554,316,508	9,966,148	5,193,036,538	1,282,184,440	4,471,242,838	4,471,243	5,286,853	5,287
4,640,737,669	555,896,608	10,082,033	5,206,716,310	1,285,509,178	4,476,529,660	4,476,530	5,286,822	5,287
4,652,721,432	557,476,705	10,197,919	5,220,396,055	1,288,833,909	4,481,816,455	4,481,816	5,286,795	5,287
4,664,705,175	559,056,799	10,313,804	5,234,075,779	1,292,158,635	4,487,103,229	4,487,103	5,286,774	5,287
4,676,688,902	560,636,892	10,429,690	5,247,755,484	1,295,483,356	4,492,389,984	4,492,390	5,286,755	5,287
4,688,672,615	562,216,983	10,545,575	5,261,435,174	1,298,808,073	4,497,676,724	4,497,677	5,286,740	5,287
4,700,656,317	563,797,073	10,661,460	5,275,114,850	1,302,132,787	4,502,963,450	4,502,963	5,286,727	5,287
4,712,640,009	565,377,161	10,777,346	5,288,794,516	1,305,457,499	4,508,250,166	4,508,250	5,286,716	5,287
4,724,623,693	566,957,249	10,893,231	5,302,474,173	1,308,782,208	4,513,536,873	4,513,537	5,286,707	5,287
4,736,607,370	568,537,336	11,009,117	5,316,153,823	1,312,106,915	4,518,823,573	4,518,824	5,286,699	5,287
4,748,591,042	570,117,422	11,125,002	5,329,833,466	1,315,431,621	4,524,110,266	4,524,110	5,286,693	5,287
4,760,574,708	571,697,508	11,240,888	5,343,513,103	1,318,756,325	4,529,396,953	4,529,397	5,286,688	5,287
4,772,558,371	573,277,593	11,356,773	5,357,192,737	1,322,081,028	4,534,683,637	4,534,684	5,286,683	5,287
4,784,542,030	574,857,678	11,472,659	5,370,872,366	1,325,405,730	4,539,970,316	4,539,970	5,286,679	5,287
4,796,525,687	576,437,762	11,588,544	5,384,551,993	1,328,730,432	4,545,256,993	4,545,257	5,286,676	5,287

Table C.5 - Gross CO_2, CH_4, and N_2O emissions in CO_2e for the post -inundation mass-balance model over 100 years, probable scenario.

CO_2 (kg CO_2e)	CH_4 (kg CO_2e)	NO_2 (kg CO_2e)	Sum CO_2e (kg)	Tot Atm Carbon (kg C)	Total Post Emissions (kg CO_2e)	Total Post Emissions (Tonnes CO_2e)	Gross Annual Emissions (kg CO_2e/yr)	Gross Annual Emissions (Tonnes CO_2e/yr)
0	0	0	0	0	0	0	0	0
459,282,313	53,596,356	115,885	512,994,555	127,172,968	502,503,367	502,503	502,503,367	502,503
846,056,103	98,760,711	231,771	945,048,585	234,269,742	924,066,210	924,066	421,562,843	421,563
1,172,075,231	136,859,918	347,656	1,309,282,805	324,544,735	1,277,809,243	1,277,809	353,743,033	353,743
1,447,188,217	169,039,260	463,542	1,616,691,019	400,724,812	1,574,726,269	1,574,726	296,917,027	296,917
1,679,647,109	196,258,366	579,427	1,876,484,902	465,094,803	1,824,028,965	1,824,029	249,302,696	249,303
1,876,366,269	219,321,306	695,313	2,096,382,887	519,569,159	2,033,435,762	2,033,436	209,406,797	209,407
2,043,139,220	238,901,806	811,198	2,282,852,224	565,751,995	2,209,413,912	2,209,414	175,978,150	175,978
2,184,820,337	255,564,383	927,084	2,441,311,803	604,987,391	2,357,382,303	2,357,382	147,968,391	147,968
2,305,477,084	269,782,039	1,042,969	2,576,302,093	638,401,550	2,481,881,405	2,481,881	124,499,102	124,499
2,408,517,580	281,951,106	1,158,854	2,691,627,540	666,938,113	2,586,715,665	2,586,716	104,834,259	104,834
2,496,797,472	292,403,664	1,274,740	2,790,475,876	691,387,753	2,675,072,814	2,675,073	88,357,149	88,357
2,572,709,503	301,417,967	1,390,625	2,875,518,094	712,412,974	2,749,623,844	2,749,624	74,551,031	74,551
2,638,258,540	309,227,159	1,506,511	2,948,992,209	730,568,883	2,812,606,772	2,812,607	62,982,927	62,983
2,695,124,458	316,026,592	1,622,396	3,012,773,447	746,320,607	2,865,896,822	2,865,897	53,290,050	53,290
2,744,714,818	321,979,953	1,738,282	3,068,433,052	760,057,871	2,911,065,240	2,911,065	45,168,418	45,168
2,788,209,011	327,224,391	1,854,167	3,117,287,569	772,107,225	2,949,428,569	2,949,429	38,363,329	38,363
2,826,595,244	331,874,826	1,970,052	3,160,440,122	782,742,284	2,982,089,935	2,982,090	32,661,366	32,661
2,860,701,534	336,027,547	2,085,938	3,198,815,019	792,192,311	3,009,973,644	3,009,974	27,883,709	27,884
2,891,221,673	339,763,236	2,201,823	3,233,186,732	800,649,403	3,033,854,169	3,033,854	23,880,525	23,881
2,918,736,987	343,149,493	2,317,709	3,264,204,190	808,274,517	3,054,380,440	3,054,380	20,526,270	20,526
2,943,734,569	346,242,965	2,433,594	3,292,411,128	815,202,521	3,072,096,190	3,072,096	17,715,751	17,716
2,966,622,550	349,091,111	2,549,480	3,318,263,140	821,546,417	3,087,457,015	3,087,457	15,360,825	15,361
2,987,742,903	351,733,700	2,665,365	3,342,141,968	827,400,891	3,100,844,656	3,100,845	13,387,640	13,388
3,007,382,167	354,204,053	2,781,251	3,364,367,471	832,845,281	3,112,578,971	3,112,579	11,734,315	11,734
3,025,780,430	356,530,091	2,897,136	3,385,207,657	837,946,062	3,122,927,970	3,122,928	10,348,999	10,349
3,043,138,863	358,735,207	3,013,021	3,404,887,092	842,758,934	3,132,116,217	3,132,116	9,188,247	9,188
3,059,626,025	360,839,004	3,128,907	3,423,593,936	847,330,569	3,140,331,874	3,140,332	8,215,657	8,216
3,075,383,153	362,857,904	3,244,792	3,441,485,850	851,700,071	3,147,732,600	3,147,733	7,400,726	7,401
3,090,528,587	364,805,671	3,360,678	3,458,694,936	855,900,207	3,154,450,498	3,154,450	6,717,899	6,718
3,105,161,484	366,693,835	3,476,563	3,475,331,883	859,958,431	3,160,596,258	3,160,596	6,145,759	6,146
3,119,364,929	368,532,059	3,592,449	3,491,489,436	863,897,749	3,166,262,623	3,166,263	5,666,366	5,666
3,133,208,536	370,328,436	3,708,334	3,507,245,307	867,737,435	3,171,527,307	3,171,527	5,264,683	5,265
3,146,750,638	372,089,752	3,824,220	3,522,664,609	871,493,639	3,176,455,422	3,176,455	4,928,115	4,928
3,160,040,108	373,821,689	3,940,105	3,537,801,902	875,179,895	3,181,101,527	3,181,102	4,646,105	4,646
3,173,117,899	375,529,010	4,055,990	3,552,702,900	878,807,541	3,185,511,338	3,185,511	4,409,810	4,410
3,186,018,326	377,215,706	4,171,876	3,567,405,907	882,386,078	3,189,723,157	3,189,723	4,211,820	4,212
3,198,770,138	378,885,119	4,287,761	3,581,943,018	885,923,467	3,193,769,081	3,193,769	4,045,924	4,046
3,211,397,428	380,540,052	4,403,647	3,596,341,126	889,426,378	3,197,676,001	3,197,676	3,906,920	3,907
3,223,920,380	382,182,851	4,519,532	3,610,622,763	892,900,400	3,201,466,451	3,201,466	3,790,449	3,790
3,236,355,909	383,815,483	4,635,418	3,624,806,810	896,350,216	3,205,159,310	3,205,159	3,692,859	3,693
3,248,718,185	385,439,597	4,751,303	3,638,909,085	899,779,750	3,208,770,398	3,208,770	3,611,088	3,611
3,261,019,084	387,056,574	4,867,188	3,652,942,846	903,192,290	3,212,312,971	3,212,313	3,542,573	3,543
3,273,268,554	388,667,570	4,983,074	3,666,919,197	906,590,590	3,215,798,135	3,215,798	3,485,164	3,485
3,285,474,932	390,273,554	5,098,959	3,680,847,446	909,976,959	3,219,235,196	3,219,235	3,437,061	3,437
3,297,645,205	391,875,340	5,214,845	3,694,735,390	913,353,331	3,222,631,952	3,222,632	3,396,756	3,397
3,309,785,224	393,473,608	5,330,730	3,708,589,562	916,721,326	3,225,994,937	3,225,995	3,362,985	3,363
3,321,899,893	395,068,928	5,446,616	3,722,415,437	920,082,303	3,229,329,624	3,229,330	3,334,688	3,335
3,333,993,323	396,661,778	5,562,501	3,736,217,602	923,437,398	3,232,640,602	3,232,641	3,310,978	3,311
3,346,068,956	398,252,558	5,678,387	3,749,999,901	926,787,566	3,235,931,713	3,235,932	3,291,111	3,291
3,358,129,677	399,841,605	5,794,272	3,763,765,553	930,133,605	3,239,206,178	3,239,206	3,274,465	3,274
3,370,177,903	401,429,198	5,910,157	3,777,517,258	933,476,185	3,242,466,695	3,242,467	3,260,517	3,261
3,382,215,659	403,015,574	6,026,043	3,791,257,276	936,815,866	3,245,715,526	3,245,716	3,248,830	3,249
3,394,244,644	404,600,929	6,141,928	3,804,987,501	940,153,118	3,248,954,564	3,248,955	3,239,038	3,239
3,406,266,278	406,185,430	6,257,814	3,818,709,522	943,488,335	3,252,185,397	3,252,185	3,230,833	3,231
3,418,281,754	407,769,215	6,373,699	3,832,424,668	946,821,846	3,255,409,356	3,255,409	3,223,958	3,224
3,430,292,069	409,352,399	6,489,585	3,846,134,053	950,153,929	3,258,627,553	3,258,628	3,218,198	3,218
3,442,298,061	410,935,081	6,605,470	3,859,838,612	953,484,815	3,261,840,925	3,261,841	3,213,371	3,213

Table C.5 - Gross CO_2, CH_4, and N_2O emissions in CO_2e for the post -inundation mass-balance model over 100 years, probable scenario.

CO_2 (kg CO_2e)	CH_4 (kg CO_2e)	NO_2 (kg CO_2e)	Sum CO_2e (kg)	Tot Atm Carbon (kg C)	Total Post Emissions (kg CO_2e)	Total Post Emissions (Tonnes CO_2e)	Gross Annual Emissions (kg CO_2e/yr)	Gross Annual Emissions (Tonnes CO_2e/yr)
3,454,300,429	412,517,342	6,721,356	3,873,539,127	956,814,698	3,265,050,252	3,265,050	3,209,327	3,209
3,466,299,762	414,099,249	6,837,241	3,887,236,253	960,143,740	3,268,256,190	3,268,256	3,205,938	3,206
3,478,296,552	415,680,861	6,953,126	3,900,930,539	963,472,077	3,271,459,289	3,271,459	3,203,099	3,203
3,490,291,210	417,262,225	7,069,012	3,914,622,446	966,799,825	3,274,660,009	3,274,660	3,200,720	3,201
3,502,284,082	418,843,381	7,184,897	3,928,312,360	970,127,078	3,277,858,735	3,277,859	3,198,726	3,199
3,514,275,458	420,424,363	7,300,783	3,942,000,604	973,453,917	3,281,055,792	3,281,056	3,197,056	3,197
3,526,265,581	422,005,199	7,416,668	3,955,687,448	976,780,409	3,284,251,448	3,284,251	3,195,657	3,196
3,538,254,653	423,585,914	7,532,554	3,969,373,120	980,106,610	3,287,445,932	3,287,446	3,194,484	3,194
3,550,242,844	425,166,525	7,648,439	3,983,057,809	983,432,567	3,290,639,434	3,290,639	3,193,501	3,194
3,562,230,299	426,747,052	7,764,324	3,996,741,675	986,758,320	3,293,832,112	3,293,832	3,192,678	3,193
3,574,217,135	428,327,506	7,880,210	4,010,424,850	990,083,902	3,297,024,100	3,297,024	3,191,988	3,192
3,586,203,453	429,907,900	7,996,095	4,024,107,448	993,409,341	3,300,215,511	3,300,216	3,191,410	3,191
3,598,189,338	431,488,243	8,111,981	4,037,789,562	996,734,659	3,303,406,437	3,303,406	3,190,926	3,191
3,610,174,859	433,068,545	8,227,866	4,051,471,269	1,000,059,877	3,306,596,957	3,306,597	3,190,520	3,191
3,622,160,075	434,648,810	8,343,752	4,065,152,637	1,003,385,010	3,309,787,137	3,309,787	3,190,180	3,190
3,634,145,036	436,229,047	8,459,637	4,078,833,720	1,006,710,073	3,312,977,032	3,312,977	3,189,895	3,190
3,646,129,784	437,809,258	8,575,523	4,092,514,564	1,010,035,077	3,316,166,689	3,316,167	3,189,657	3,190
3,658,114,352	439,389,448	8,691,408	4,106,195,208	1,013,360,031	3,319,356,146	3,319,356	3,189,457	3,189
3,670,098,770	440,969,621	8,807,293	4,119,875,685	1,016,684,943	3,322,545,435	3,322,545	3,189,289	3,189
3,682,083,062	442,549,780	8,923,179	4,133,556,021	1,020,009,821	3,325,734,583	3,325,735	3,189,149	3,189
3,694,067,249	444,129,926	9,039,064	4,147,236,239	1,023,334,669	3,328,923,614	3,328,924	3,189,031	3,189
3,706,051,347	445,710,062	9,154,950	4,160,916,359	1,026,659,493	3,332,112,546	3,332,113	3,188,932	3,189
3,718,035,372	447,290,189	9,270,835	4,174,596,396	1,029,984,296	3,335,301,396	3,335,301	3,188,850	3,189
3,730,019,334	448,870,309	9,386,721	4,188,276,364	1,033,309,083	3,338,490,176	3,338,490	3,188,780	3,189
3,742,003,245	450,450,423	9,502,606	4,201,956,274	1,036,633,855	3,341,678,899	3,341,679	3,188,722	3,189
3,753,987,112	452,030,532	9,618,492	4,215,636,135	1,039,958,614	3,344,867,573	3,344,868	3,188,674	3,189
3,765,970,942	453,610,637	9,734,377	4,229,315,956	1,043,283,364	3,348,056,206	3,348,056	3,188,633	3,189
3,777,954,742	455,190,738	9,850,262	4,242,995,742	1,046,608,105	3,351,244,805	3,351,245	3,188,599	3,189
3,789,938,516	456,770,836	9,966,148	4,256,675,500	1,049,932,840	3,354,433,375	3,354,433	3,188,570	3,189
3,801,922,269	458,350,932	10,082,033	4,270,355,234	1,053,257,568	3,357,621,922	3,357,622	3,188,546	3,189
3,813,906,004	459,931,025	10,197,919	4,284,034,948	1,056,582,291	3,360,810,448	3,360,810	3,188,526	3,189
3,825,889,724	461,511,117	10,313,804	4,297,714,645	1,059,907,010	3,363,998,958	3,363,999	3,188,510	3,189
3,837,873,431	463,091,207	10,429,690	4,311,394,328	1,063,231,726	3,367,187,453	3,367,187	3,188,495	3,188
3,849,857,128	464,671,296	10,545,575	4,325,073,999	1,066,556,438	3,370,375,937	3,370,376	3,188,484	3,188
3,861,840,816	466,251,385	10,661,460	4,338,753,661	1,069,881,149	3,373,564,411	3,373,564	3,188,474	3,188
3,873,824,496	467,831,472	10,777,346	4,352,433,314	1,073,205,857	3,376,752,876	3,376,753	3,188,466	3,188
3,885,808,170	469,411,558	10,893,231	4,366,112,960	1,076,530,563	3,379,941,335	3,379,941	3,188,459	3,188
3,897,791,839	470,991,644	11,009,117	4,379,792,600	1,079,855,268	3,383,129,787	3,383,130	3,188,453	3,188
3,909,775,504	472,571,730	11,125,002	4,393,472,235	1,083,179,972	3,386,318,235	3,386,318	3,188,448	3,188
3,921,759,164	474,151,814	11,240,888	4,407,151,867	1,086,504,675	3,389,506,679	3,389,507	3,188,444	3,188
3,933,742,822	475,731,899	11,356,773	4,420,831,494	1,089,829,376	3,392,695,119	3,392,695	3,188,440	3,188
3,945,726,478	477,311,983	11,472,659	4,434,511,119	1,093,154,078	3,395,883,557	3,395,884	3,188,437	3,188
3,957,710,131	478,892,067	11,588,544	4,448,190,742	1,096,478,778	3,399,071,992	3,399,072	3,188,435	3,188

APPENDIX 4

Construction Emissions Spreadsheet

BC Hydro - Site C GHG Construction Emissions Estimate
Project No. 1042302.

Name	Date	Action
Dr. Joe Harriman, Ph.D., P.Chem.	17-Nov-08	Input of preliminary fuel consumption values based on BC Hyrdo information (Received from Fred Bonn - Nov. 10, 2008 via email)
Dr. Joe Harriman, Ph.D., P.Chem.	8-Dec-08	Update of calculations based on revised BC Hydro Information (Received from Sarah Nathan - Dec. 4, 2008 via email)
Dr. Mike Murphy, Ph.D., P.Eng.	9-Dec-08	Senior review of revised calculations
Dr. Joe Harriman, Ph.D., P.Chem.	4-Feb-09	Update of calculations to include land clearing based on information provided by BC Hydro (Received from Sarah Nathan - Feb. 2, 2009 via email)

Notes:
All emission factors used in the calculations are provided by Environment Canada publications. As such, they satisfy BC MOE requirements for data integrity and accuracy.
The following emission factor publications are employed in the calculations:

Fuel Combustion
Environment Canada, Turning the Corner: Canada's Energy and GHG Emissions Projections, Reference Case: 2006-2020, Conversion and Emission Factors.
Published in March 2008. Available at:
http://www.ec.gc.ca/default.asp?lang=En&n=75038EBC-1

Electricity Consumption
Environment Canada, National Inventory Report 1990-2005: Greenhouse Gas Sources and Sinks in Canada.
Publised in April 2007. Available at:
http://www.ec.gc.ca/pdb/ghg/inventory_report/2005_report/tdm-toc_eng.cfm

BC Hydro - Site C GHG Construction Emissions Estimate
Project No. 1042302.
Prepared by: Dr. Joe Harriman, Ph.D., P.Chem.
Senior Reviewed by: Dr. Mike Murphy, Ph.D., P.Eng.

Summary of Potential GHG Emissions for Site C Construction Activities

Site C Work Category [1]	Equipment	General Activity [1]	Units of Fuel/Electricity Comsumption	Fuel Type	Energy in Fuel (GJ/m^3) [2]	Energy in Fuel (GJ/L)	Fuel Combustion Energy (TJ)	Fuel Emission Factor ($t\ CO_2e/TJ$) [3]	Electricity Emission Factor ($kg\ CO_2e/kWh$) [4]	GHG Emissions (tonnes CO_2e)
Excavation (earthworks)	CAT 245D Backhoe	Excavation and Hauling	825,493	Diesel	38.3	0.0383	31.61638661	71.61	-	2,264
	GRADALL G-880E	Excavation and Hauling	94,235	Diesel	38.3	0.0383	3.60919284	71.61	-	258
	Compression Diesel 900 CFM	Drilling	78,884	Diesel	38.3	0.0383	3.021260264	71.61	-	216
	BOMAG BP23/60 VIBRATORY COMP	Place and Compact Fill	10,823	Diesel	38.3	0.0383	0.414535454	71.61	-	30
	BOMAG BW 60S DOUBLE DRUM VIB	Place and Compact Fill	19,482	Diesel	38.3	0.0383	0.746161749	71.61	-	53
	CAT CS431B SMOOTH DRUM VIB	Excavation and Hauling	9,976	Diesel	38.3	0.0383	0.382074672	71.61	-	27
	CAT CS563 SMOOTH DRUM VIB C	Place and Compact Fill	432,934	Diesel	38.3	0.0383	16.5813722	71.61	-	1,187
	CAT D6H DOZER C/W S-BLADE 16	Place and Compact Fill	392,800	Diesel	38.3	0.0383	15.04424268	71.61	-	1,077
	CAT D6H DOZ LOW GRD.PRES.C/W	Excavation and Hauling	136,640	Diesel	38.3	0.0383	5.233329618	71.61	-	375
	CAT D9R DOZER C/W U-BLADE 30	Excavation and Hauling	4,289,671	Diesel	38.3	0.0383	164.2944031	71.61	-	11,765
	CAT 10R DOZER C/W U-BLADE 4	Excavation and Hauling	1,374,411	Diesel	38.3	0.0383	52.6399413	71.61	-	3,770
	CAT 10R DOZER C/W U-BLADE &	Excavation and Hauling	841,189	Diesel	38.3	0.0383	32.21753104	71.61	-	2,307
	MAST DRILL 7" DIA TO 11" DIA	Drilling	97,641	Diesel	38.3	0.0383	3.739633065	71.61	-	268
	ANFO POWER TRUCK 12 TON CAP	Load and Blast	52,097	Diesel	38.3	0.0383	1.995331952	71.61	-	143
	POWDER TRUCK P/UP 1 TON CAP	Load and Blast	16,280	Diesel	38.3	0.0383	0.623541235	71.61	-	45
	DIESEL GENERATOR 20 KW CAP	Generators	1,386,107	Diesel	38.3	0.0383	53.08788853	71.61	-	3,802
	DIESEL GENERATOR 150 KW CAP	Generators	44,866	Diesel	38.3	0.0383	1.71835248	71.61	-	123
	DIESEL GENERATOR 250 KW CAP	Generators	27,271	Diesel	38.3	0.0383	1.0444793	71.61	-	75
	CAT 16H GRADER 205 Kw	Excavation and Hauling	624,873	Diesel	38.3	0.0383	23.93264356	71.61	-	1,714
	LIGHT TOWER 6 LIGHTS	Lighting	1,270,876	Electricity	-	-	-	-	0.02	25
	CAT 980F F.E.L. 4.0 M3 CAP.R	Place and Compact Fill	243,526	Diesel	38.3	0.0383	9.327047715	71.61	-	668
	CAT 992G F.E.L.11.5 M3 CAP.R	Excavation and Hauling	3,960,727	Diesel	38.3	0.0383	151.695825	71.61	-	10,863
	CAT 994 F.E.L.16.2 M3 CAP.RO	Excavation and Hauling	2,932,077	Diesel	38.3	0.0383	112.2985414	71.61	-	8,042
	SUBMERSIBLE PUMP 4" - 6"	Pumping	474,049	Electricity	-	-	-	-	0.02	9
	CAT 627F P/P SCRAPER 15 M3 C	Stripping	490,016	Diesel	38.3	0.0383	18.76761893	71.61	-	1,344
	CAT D40D ART.DUMP TR.36t/22	Excavation and Hauling	3,893,828	Diesel	38.3	0.0383	149.1336001	71.61	-	10,679
	CAT 777D DUMP TRUCK 97t/60 m	Excavation and Hauling	9,669,174	Diesel	38.3	0.0383	370.3293719	71.61	-	26,519
	CAT 785B DUMP TRUCK 136t/78	Excavation and Hauling	9,919,711	Diesel	38.3	0.0383	379.9249313	71.61	-	27,206
	SUBTOTAL - EXCAVATION									**114,856**
Concrete Works	FUEL TRUCK 3600 GAL.CAP.	Service Trucks	171,616.00	Diesel	38.3	0.0383	6.5728928	71.61	-	471
	LUBE TRUCK 2000 GAL.CAP.	Service Trucks	171,616.00	Diesel	38.3	0.0383	6.5728928	71.61	-	471
	SUBTOTAL - CONCRETE WORKS									**941**

BC Hydro - Site C GHG Construction Emissions Estimate
Project No. 1042302.
Prepared by: Dr. Joe Harriman, Ph.D., P.Chem.
Senior Reviewed by: Dr. Mike Murphy, Ph.D., P.Eng.

Summary of Potential GHG Emissions for Site C Construction Activities

Site C Work Category [1]	Equipment	General Activity [1]	Units of Fuel/Electricity Comsumption	Fuel Type	Energy in Fuel (GJ/m^3) [2]	Energy in Fuel (GJ/L)	Fuel Combustion Energy (TJ)	Fuel Emission Factor (t CO_2e/TJ) [3]	Electricity Emission Factor (kg CO_2e/kWh) [4]	GHG Emissions (tonnes CO_2e)
Tunnels & Cofferdams	CONCRETE BATCH PLANT PORT. 5	Concrete	46,875	Diesel	38.3	0.0383	1.7953125	71.61	-	129
	CAT 225D BACKHOE C/W 1.5 M3	Excavation and Hauling	306,375	Diesel	38.3	0.0383	11.7341625	71.61	-	840
	CAT 245D BACKHOE C/W 3.2 M3	Excavation and Hauling	27,139	Diesel	38.3	0.0383	1.039406848	71.61	-	74
	CAT 345B BACKHOE C/W 2.6 & 1	Excavation and Hauling	1,381,773	Diesel	38.3	0.0383	52.9219105	71.61	-	3,790
	CONCRETE TRUCK 6 M3 CAP.	Concrete	6,634,385	Diesel	38.3	0.0383	254.0969332	71.61	-	18,196
	CONCRETE PUMP TRAILER RATED	Concrete	8,207	Diesel	38.3	0.0383	0.31431278	71.61	-	23
	CONCRETE PUMP TRUCK RATED 85	Concrete	163,223	Diesel	38.3	0.0383	6.25142175	71.61	-	448
	COMPRESSOR DIESEL 250 C.F.M.	Excavation and Hauling	205,900	Diesel	38.3	0.0383	7.88597	71.61	-	565
	COMPRESSOR DIESEL 750 C.F.M.	Drilling	700,666	Diesel	38.3	0.0383	26.8355078	71.61	-	1,922
	CAT CS431B SMOOTH DRUM VIB.	Excavation and Hauling	2,028	Diesel	38.3	0.0383	0.077684656	71.61	-	6
	HYDRAULIC CRANE 20 TON CAP.	Erection of Steel	147,725	Diesel	38.3	0.0383	5.65787516	71.61	-	405
	MOBILE CRANE 100 TON CAP.	Excavation and Hauling	53,550	Diesel	38.3	0.0383	2.050965	71.61	-	147
	CAT D8N DOZER C/W U-BLADE &	Disposal	9,540	Diesel	38.3	0.0383	0.365382	71.61	-	26
	CAT D9R DOZER C/W U-BLADE 30	Excavation and Hauling	3,105,505	Diesel	38.3	0.0383	118.9408367	71.61	-	8,517
	AXIAL FAN 48"DIA.40 HP	Excavation and Hauling	1,176,600	Electricity	-	-	-	-	0.02	24
	DIESEL GENERATOR 20 KW CAP.	Generators	350,303	Diesel	38.3	0.0383	13.41659264	71.61	-	961
	DIESEL GENERATOR 365 KW CAP.	Generators	146,300	Diesel	38.3	0.0383	5.60329	71.61	-	401
	DIESEL GENERATOR 900 KW CAP.	Excavation and Hauling	795,000	Diesel	38.3	0.0383	30.4485	71.61	-	2,180
	GROUT PLANT 1.3 M3/HR CAP.	Grouting	6,300	Diesel	38.3	0.0383	0.24129	71.61	-	17
	GROUT PLANT 5.5 M3/HR CAP.	Grouting	3,360	Diesel	38.3	0.0383	0.128688	71.61	-	9
	FORKLIFT 2.5 TON CAPACITY	Grouting	30,800	Diesel	38.3	0.0383	1.17964	71.61	-	84
	SCISSORLIFT RUBBER TIRED	Grouting	610,987	Diesel	38.3	0.0383	23.40080976	71.61	-	1,676
	ELECTRIC WINCH 15 TON CAP.	Formwork	49,898	Electricity	-	-	-	-	0.02	1
	LIGHT TOWER 2 LIGHTS	Excavation and Hauling	18,900	Electricity	-	-	-	-	0.02	0
	LIGHT TOWER 4 LIGHTS	Formwork	7,485	Electricity	-	-	-	-	0.02	0
	LIGHT TOWER 6 LIGHTS	Excavation and Hauling	250,216	Electricity	-	-	-	-	0.02	5
	CAT 966F F.E.L. 3.3 M3 CAP.G	Excavation and Hauling	10,667,399	Diesel	38.3	0.0383	408.5613763	71.61	-	29,257
	CAT 992G F.E.L.11.5 M3 CAP.R	Excavation and Hauling	599,449	Diesel	38.3	0.0383	22.9588967	71.61	-	1,644
	JUMBO 1-BOOM	Drilling	111,720	Electricity	-	-	-	-	0.02	2
	SUBMERSIBLE PUMP 2"	Excavation and Hauling	15,900	Electricity	-	-	-	-	0.02	0
	SUBMERSIBLE PUMP 4"- 6"	Concrete	6,477,577	Electricity	-	-	-	-	0.02	130
	SLURRY PUMP 750 GAL/SEVEN MI	Slurry Supply	188,283	Diesel	38.3	0.0383	7.21121975	71.61	-	516
	BENTONITE RECLAIMING SYSTEM	Slurry Supply	6,375	Diesel	38.3	0.0383	0.2441625	71.61	-	17
	CAT D30D ART.DUMP TR.27t/17	Excavation and Hauling	3,434,400	Diesel	38.3	0.0383	131.53752	71.61	-	9,419
	CAT D40D ART.DUMP TR.36t/22	Excavation and Hauling	4,088,796	Diesel	38.3	0.0383	156.6009052	71.61	-	11,214
	CAT 777D DUMP TRUCK 97t/60 m	Excavation and Hauling	4,021,427	Diesel	38.3	0.0383	154.0206618	71.61	-	11,029
	HIGHWAY TRUCK END DUMP 15CY	Disposal	2,000	Diesel	38.3	0.0383	0.0766	71.61	-	5
	PICK UP TRUCK 3/4 TON 4x3	Excavation and Hauling	3,108,101	Diesel	38.3	0.0383	119.0402606	71.61	-	8,524
	FLAT BED TRUCK 5 TON	Excavation and Hauling	2,526,240	Diesel	38.3	0.0383	96.75497285	71.61	-	6,929
	FLAT BED TRUCK 12 TON	Erection of Steel	13,640	Diesel	38.3	0.0383	0.522412	71.61	-	37
	WATER TRUCK 3600 GAL.CAP.	Drilling	53,200	Diesel	38.3	0.0383	2.03756	71.61	-	146
	WATER TRUCK 4000 GAL.CAP.	Finishing & Cleanup	11,770	Diesel	38.3	0.0383	0.450791	71.61	-	32
	WELDER DIESEL 350 AMP.CAP.	Excavation and Hauling	343,990	Diesel	38.3	0.0383	13.17482275	71.61	-	943
	WELDER ELECTRIC 400 AMP.CAP.	Erection of Steel	294,285	Electricity	-	-	-	-	0.02	6
	SUBTOTAL - TUNNELS & COFFERDAMS									**120,299**
Project Support Consumption (2%) [5]			2,000,000	Gasoline	35	0.035	70	67.66	-	**4,736**
									TOTAL	**240,833**

Notes:
1) Construction activities, equipment type, estimate of fuel consumption and fuel type by activity provided by Sarah Nathan of BC Hydro via email on December 4, 2008.
Construction activites grouped into broad categories of the predominant activity for purposes of clarity. Note that equipment may be used for other activites not specifically listed in general activity.
2) Energy content provided by Environment Canada in Turning the Corner Canada's Energy and GHG Emissions Projections (March 2008) in the Conversions and Emission Factors.
3) GHG emissions provided as Carbon Dioxide Equivalents (CO_2e) which includes emission contributions from CO_2, N_2O and CH_4.
4) Emission factors for electricity consumption as published in Canada's National Inventory Report 1990-2005: Greenhouse Gas Sources and Sinks in Canada (April 2007).
5) Project support fuel consumption provided by Fred Bonn of BC Hydro on November 10, 2008. Assumed to be approximately 2% of total fuel consumed in other construction tasks.

BC Hydro - Site C GHG Construction Emissions Estimate
Project No. 1042302.
Prepared by: Dr. Joe Harriman, Ph.D., P.Chem.
Senior Reviewed by: Dr. Mike Murphy, Ph.D., P.Eng.

Summary of Potential GHG Emissions for Site C Land Clearing Activities

Equipment[1]	Total Hours	Distance Traveled (km)	Fuel Type	Fuel Consumption (L / 100km)	Fuel Consumption (L/hour)	Fuel Consumed (L)	Energy in Fuel (GJ/m^3)[2]	Energy in Fuel (GJ/L)	Fuel Combustion Energy (TJ)	Fuel Emission Factor ($t\ CO_2e/TJ$)[3]	GHG Emissions (tonnes CO_2e)	Reference/Note
Bell 214 helicopter	1,139	-	Aviation Turbine		105.20	119,822.80	33.52	0.034	4.02	69.86	281	Bell 206B3 Product Specifications January 2006. Available at http://www.bellhelicopter.com/en/aircraft/commercial/bell206B-3.cfm
Bell 206 helicopter	1,974	-	Aviation Turbine		105.20	207,664.80	33.52	0.034	6.96	69.86	486	Bell 206B3 Product Specifications January 2006. Available at http://www.bellhelicopter.com/en/aircraft/commercial/bell206B-3.cfm
Aerospatial AS350 BA Helicopter	1,046	-	Aviation Turbine		105.20	110,039.20	33.52	0.034	3.69	69.86	258	Bell 206B3 Product Specifications January 2006. Available at http://www.bellhelicopter.com/en/aircraft/commercial/bell206B-3.cfm
John Deere 753J Tracked Feller Buncher or CAT 501 Track Harvester	13,213	-	Diesel		20.80	274,830.40	38.30	0.04	10.53	71.61	754	Caterpillar Incorporated. 2004. Caterpillar Performance Handbook. Edition 35. Prepared by Caterpillar Inc., Peoria, Illinois, U.S.A. Value for 525 Wheeled Skidder.[4]
John Deere 2054 Tracked Stroke Delimber or Cat 320 Excavator	13,702	-	Diesel		20.00	274,040.00	38.30	0.038	10.50	71.61	752	Caterpillar Incorporated. 2004. Caterpillar Performance Handbook. Edition 35. Prepared by Caterpillar Inc., Peoria, Illinois, U.S.A. Value for CAT 320C.[4]
John Deere 648 or CAT 525 Grapple Skidder	27,761	-	Diesel		20.80	577,428.80	38.30	0.038	22.12	71.61	1,584	Caterpillar Incorporated. 2004. Caterpillar Performance Handbook. Edition 35. Prepared by Caterpillar Inc., Peoria, Illinois, U.S.A.[4]
CAT 517 Tracked Skidder	1,422	-	Diesel		15.00	21,330.00	38.30	0.038	0.82	71.61	59	Caterpillar Incorporated. 2004. Caterpillar Performance Handbook. Edition 35. Prepared by Caterpillar Inc., Peoria, Illinois, U.S.A.[4]
CAT 320D FM Tracked Loader	14,755	-	Diesel		25.00	368,875.00	38.30	0.038	14.13	71.61	1,012	Caterpillar Incorporated. 2004. Caterpillar Performance Handbook. Edition 35. Prepared by Caterpillar Inc., Peoria, Illinois, U.S.A. Value for CAT 320C FM.[4]
CAT 966 Wheeled Front-end Loader	1,581	-	Diesel		27.00	42,687.00	38.30	0.038	1.63	71.61	117	Caterpillar Incorporated. 2004. Caterpillar Performance Handbook. Edition 35. Prepared by Caterpillar Inc., Peoria, Illinois, U.S.A.[4]
CAT 320 Tracked Excavator	3,800	-	Diesel		20.00	76,000.00	38.30	0.038	2.91	71.61	208	Caterpillar Incorporated. 2004. Caterpillar Performance Handbook. Edition 35. Prepared by Caterpillar Inc., Peoria, Illinois, U.S.A. Value for CAT 320C.[4]
CAT D7G Crawler Tractor	16,000	-	Diesel		29.00	464,000.00	38.30	0.038	17.77	71.61	1,273	Caterpillar Incorporated. 2004. Caterpillar Performance Handbook. Edition 35. Prepared by Caterpillar Inc., Peoria, Illinois, U.S.A.[4]
CAT 330 Tracked Excavator	1,504	-	Diesel		34.00	51,136.00	38.30	0.038	1.96	71.61	140	Caterpillar Incorporated. 2004. Caterpillar Performance Handbook. Edition 35. Prepared by Caterpillar Inc., Peoria, Illinois, U.S.A. Value for CAT 330C.[4]
CAT D8 Crawler Tractor	1,824	-	Diesel		41.50	75,696.00	38.30	0.038	2.90	71.61	208	Caterpillar Incorporated. 2004. Caterpillar Performance Handbook. Edition 35. Prepared by Caterpillar Inc., Peoria, Illinois, U.S.A.[4]
CAT 12M Motor Grader	8,400	-	Diesel		19.00	159,600.00	38.30	0.038	6.11	71.61	438	Caterpillar Incorporated. 2004. Caterpillar Performance Handbook. Edition 35. Prepared by Caterpillar Inc., Peoria, Illinois, U.S.A. Value for CAT 12H.[4]
CAT 450E Backhoe Loader	3,600	-	Diesel		15.10	54,360.00	38.30	0.038	2.08	71.61	149	Caterpillar Incorporated. 2004. Caterpillar Performance Handbook. Edition 35. Prepared by Caterpillar Inc., Peoria, Illinois, U.S.A. Value for CAT 446D.[4]
Kenworth T170 Truck[5]	800	2,448	Diesel	34	-	832.32	38.30	0.038	0.03	71.61	2	Natural Resources Canada: Office of Energy Efficiency. 2005 Canadian Vehicle Survey. Fuel consumption value for Diesel Consumption rates of Heavy Truck (For-hire trucking).
Kenworth W900 or Peterbuilt 388 Truck Tractor[5]	93,090	284,855	Diesel	34	-	96,850.84	38.30	0.038	3.71	71.61	266	Natural Resources Canada: Office of Energy Efficiency. 2005 Canadian Vehicle Survey. Fuel consumption value for Diesel Consumption rates of Heavy Truck (For-hire trucking).
Ford F250 4x4 Crew Cab[6]	75,111	52,728	Gasoline	11.7	-	6,169.17	35.00	0.035	0.22	67.66	15	Natural Resources Canada. Fuel Consumption Guide 2009.
Stihl MS660 or Husqvarna 395XP Chainsaw	28,526	-	Gasoline	-	3.80	108,398.80	35.00	0.035	3.79	67.72	257	Stihl Canada. Product Specification. Available at http://www.stihl.ca/
Honda Volume Water Pump	16,700	-	Gasoline	-	3.35	55,908.70	35.00	0.035	1.96	67.72	133	Honda Motor Company Ltd. Owner's Manual. GX240/GX340 Motor Specifications. Available at: http://www.honda-engines.com/Engines_owners_manuals/owners-manuals/gx340.htm
										TOTAL	**8,389**	

Notes:

1. Hours estimated by BC Hydro using components of IFS Timber Harvest and Clearing Plan December 10, 2008 as well as professional experience and average productivity and payload estimations. Detailed investigation and calculation of equipment hours should be undertaken if the project proceeds to Stage 3. Values are estimates at +/- 25% accuracy.
2. Energy content provided by Environment Canada in Turning the Corner Canada's Energy and GHG Emissions Projections (March 2008) in the Conversions and Emission Factors.
3. GHG emissions provided as Carbon Dioxide Equivalents (CO_2e) which includes emission contributions from CO_2, N_2O and CH_4.
4. Load on CAT equipment assumed to be at the medium to high load interface. Fuel consumption values based on this assumption.
5. Assume an average speed of 90 km/hour. Fuel consumption assumed to be highway travel.
6. Assume an average speed of 60 km/hour. Fuel consumption assumed to be city travel. Based on a automatic transmission 2004 Ford F-150 4X4 (4.2L/6 cycle) using a regular gasoline fuel source.

BC Hydro - Site C GHG Construction Emissions Estimate
Project No. 1042302.
Prepared by: Dr. Joe Harriman, Ph.D., P.Chem.
Senior Reviewed by: Dr. Mike Murphy, Ph.D., P.Eng.

Summary of Construction GHG Emissions Inventory

Category	Activity	Percent Contribution of GHG Emissions	Total GHG Emissions (tonnes CO_2e)
Excavation	Excavation and Hauling	92.1%	105,790
	Place and Compact Fill	2.6%	3,016
	Drilling	0.4%	484
	Load and Blast	0.2%	188
	Generators	3.5%	3,999
	Lighting	0.02%	25
	Pumping	0.01%	9
	Stripping	1.2%	1,344
	Subtotal	46.1%	114,856
Concrete Works	Service Trucks	100.0%	941
	Subtotal	0.4%	941
Tunnels and Cofferdams	Excavation and Hauling	79.1%	95,109
	Concrete	15.7%	18,924
	Drilling	1.7%	2,070
	Erection of Steel	0.4%	448
	Disposal	0.03%	32
	Generators	1.1%	1,362
	Formwork	0.0%	1
	Slurry Supply	0.4%	534
	Grouting	1.5%	1,787
	Finishing & Cleanup	0.03%	32
	Subtotal	48.3%	120,299
Land Clearing	Equipment Use		8,389
	Subtotal	3.4%	8,389
Project Support (2%)	Various	100.0%	4,736
	Subtotal	1.9%	4,736
Total		100.0%	**249,221**

Turning the Corner GHG Emission Factors

Energy content provided by Environment Canada in Turning the Corner Canada's Energy and GHG Emissions Projections (March 2008) in the Conversions and Emission Factors for transportation.
GHG emissions provided as Carbon Dioxide Equivalents (CO_2e) which includes emission contributions from CO_2, N_2O and CH_4.

Comments:
Completed by Joe Harriman - November 14, 2008.

Residential

Fuel Type	Energy Content (GJ/m^3)	Energy Content (GJ/L)	Energy Content (TJ/L)	Emission Factor (t CO_2e/TJ)
Natural Gas	0.038	0.000038	0.000000038	49.95
Coal	NA	NA	NA	84.74
Light Fuel Oil	38.68	0.03868	0.00003868	73
Kerosene	37.68	0.03768	0.00003768	67.74
LPGs	22	0.022	0.000022	59.95
Wood	NA	NA	NA	20.26

Commercial

Fuel Type	Energy Content (GJ/m^3)	Energy Content (GJ/L)	Energy Content (TJ/L)	Emission Factor (t CO_2e/TJ)
Natural Gas	0.038	0.000038	0.000000038	49.95
Coal	NA			84.74
Light Fuel Oil	38.68	0.03868	0.00003868	73
Kerosene	37.68	0.03768	0.00003768	67.74
LPGs	22	0.022	0.000022	59.95
Residual Fuel (HFO)	42.5	0.0425	0.0000425	73.22

Transportation

Fuel Type	Energy Content (GJ/m^3)	Energy Content (GJ/L)	Energy Content (TJ/L)	Emission Factor (t CO_2e/TJ)
Natural Gas (Pipelines)	0.038	0.000038	0.000000038	50.16
Natural Gas (other)	0.038	0.000038	0.000000038	49.95
Motor Gasoline	35	0.035	0.000035	67.66
Aviation Gasoline	33.52	0.03352	0.00003352	69.86
Jet/Turbo Fuel	37.4	0.0374	0.0000374	68.4
Diesel Fuel	38.3	0.0383	0.0000383	71.61
LPGs	22	0.022	0.000022	60.47
Residual Fuel (HFO)	42.5	0.0425	0.0000425	73.34

Power Generation

Fuel Type	Energy Content (GJ/m^3)	Energy Content (GJ/L)	Energy Content (TJ/L)	Emission Factor (t CO_2e/TJ)
Natural Gas	0.038	0.000038	0.000000038	50.31
Residual Fuel (HFO)	42.5	0.0425	0.0000425	73.2
Petroleum Coke	42.38	0.04238	0.00004238	97.16
Coal NS	See Turning the Corner document for additional details.			77.8
Coal NB	See Turning the Corner document for additional details.			77.45
Coal ON	See Turning the Corner document for additional details.			85.49
Coal MN	See Turning the Corner document for additional details.			91.1
Coal SK	See Turning the Corner document for additional details.			95.83
Coal AL	See Turning the Corner document for additional details.			91.38

Industry

Energy Related Fuel Combustion

Fuel Type	Energy Content (GJ/m^3)	Energy Content (GJ/L)	Energy Content (TJ/L)	Emission Factor (t CO_2e/TJ)
Natural Gas	0.038	0.000038	0.000000038	49.93
Motor Gasoline	35	0.035	0.000035	67.72
Kerosene	37.68	0.03768	0.00003768	67.78
Distillate	38.68	0.03868	0.00003868	72.22
Residual Fuel (HFO)	42.5	0.0425	0.0000425	73.2
LPGs	22	0.022	0.000022	60.03
Coal Metalurgical	29	0.029	0.000029	82.12
Coke Oven Gas	18.6	0.0186	0.0000186	84.2
Pet Coke (Refineries)	46.35	0.04635	0.00004635	82.47
Pet Coke (Aluminum)	46.35	0.04635	0.00004635	82.47
Still Gas (Refineries)	36.08	0.03608	0.00003608	50.46

Non-Energy Related Fuel Combustion (i.e. Feedstock)

Fuel Type	Energy Content (GJ/m^3)	Energy Content (GJ/L)	Energy Content (TJ/L)	Emission Factor (t CO_2e/TJ)
LPGs	22	0.022	0.000022	12.1
Petrochemical	35.17	0.03517	0.00003517	14.18
Lubes & Greases	39.16	0.03916	0.00003916	35.58

Oil and Gas Industries

Fuel Type	Energy Content (GJ/m^3)	Energy Content (GJ/L)	Energy Content (TJ/L)	Emission Factor (t CO_2e/TJ)
Natural Gas (Own Use)	0.038	0.000038	0.000000038	66.57
Pet Coke (Upgraders)	40.57	0.04057	0.00004057	104.08
Still Gas	43.24	0.04324	0.00004324	50.46