# City of Richmond Northeast bog forest carbon project: Project description and GHG calculations


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# 1 Introduction

Under the existing Green Communities Committee (GCC) Avoided Forest Conversion Project (AFCP) protocol, a majority of offsets are derived from avoided emissions associated with conserving the carbon stored in living forest biomass. There is no consideration of soil carbon in the AFCP protocol. The assumption is that in upland soils, this carbon pool is relatively stable such that any increase in emissions associated with land-use would occur only very slowly. In addition, measuring soil carbon is time-consuming and expensive since a relatively large number of samples is usually required to derive statistically meaningful results.

Though generally applicable in 'dry' forests, this assumption of a stable soil carbon pool may not apply to forests located in areas where the water table is close to the soil surface. In these 'bog' forests, a high water-table reduces rates of decomposition with the result that organic matter accumulates, often in the form of peat deposits. Peat accumulation can be substantial and over time can be the dominant carbon pool within these ecosystems (Armentano and Menges 1986). When they are subject to land use change (conversion to agriculture, for example), drainage is required to create conditions suitable for growing the alternative crops. Lowering the water table can initiate peat oxidation resulting in large emissions of carbon over a relatively short time frame, as compared to rates of accumulation (Byun et al. 2018, and references therein). A component of this GCC Option 2 project was the development of a relatively simple methodology (described in the supporting documentation) to estimate the carbon losses from peat oxidation due to drainage. These estimates can be combined with calculations of living forest biomass carbon to determine the total ecosystem carbon lost to conversion.

The City of Richmond has identified carbon sequestration in natural ecosystems as important to mitigating and offsetting its greenhouse gas (GHG) emissions, and as part of its Ecological Network Management Strategy (3GreenTree Ecosystem, 2017). In conjunction with maintaining the appropriate hydrology, vegetation communities play a key role in the stored carbon within bog ecosystems (Couwenberg et al., 2011) through impacts on net ecosystem production. This carbon project aims to minimize GHG emissions (both $CO_2$ and $CH_4$) from the City of Richmond Northeast bog forest by conserving existing live biomass carbon stocks and through management of site hydrology to minimize drainage, maintain water table levels, and preserve the peat carbon pool. It is an avoided forest conservation project whereby acquisition of the project site has prevented it being cleared, drained and converted to agricultural production. As shown below, this activity would have resulted in substantial emissions of carbon via removal of the live biomass and oxidation of the underlying peat deposit. The project meets all of the eligibility requirements for Option 2 emission reduction projects (see Appendix 1).

## 2 Project area

Owned by the City of Richmond, the Richmond Northeast bog (the project area) is a remnant ombrotrophic, raised bog located on the north arm of the Fraser River (Claque et al., 1991). The site (49° 10’55.48” N, 122° 59’40.51” W) is bound by Cambie Road to the north, River Road and the Fraser River to the northeast and a railway line to the south and west. It is part of the Lesser Lulu Island Bog, a remnant of the much larger raised bog referred to as the Greater Lulu Island Bog (Genier and Bijsterveld, 1982, cited in Davis and Klinkenburg, 2008). Water table depth on the site is already heavily impacted by deep perimeter ditches and a bisecting ditch.

Richmond first acquired a 13.7-ha portion of the property in 1991, and a second 6.1-ha parcel, in 2011, for a total of 19.8 ha. It is the latter parcel that forms the basis for the carbon project though the 13.7 parcel must be included in the carbon calculations due to its hydrological connectivity (further details below).

Figure 1. Location of the City of Richmond Northeast bog forest

# 3 Additionality

Additionality refers to whether claimed carbon emission reductions are a direct consequence of the implementation of project activities, or whether emission reductions would have occurred due to typical practice or other financial or legal requirements. In layman's terms, key tests are to ensure project activities are not required by a pre-existing legal requirement, that there are no financial benefits to undertaking the project activities that override alternative uses, and/or proposed activities are not "typical practice". This project satisfies Step 4 of the GCC project eligibility requirements (see Appendix 1), and which therefore establishes project additionality.

# 4 Baseline scenario

The baseline scenario is a counterfactual argument as to what would have occurred on the project area had no project action/activity been undertaken – a projection of what would have happened under business-as-usual or typical practice. There are a variety of approaches to the determination of the baseline scenario depending on the methodology employed, but in general the idea is there should be comparable properties, documented practices, and/or other professionally defendable evidence supporting the baseline activities. Establishing the baseline then usually includes evidence of prior practices and current management, assuming the latter represents a change in activities. A key consideration is to ensure the project does not create an unreasonable baseline scenario or that does not have evidentiary support, or is not sufficiently conservative that it overestimates potential emissions.

The baseline scenario is that the 6.1-ha parcel would have been converted to a cranberry operation. The project site is surrounded by active cranberry farms (Figure 1) and this activity is thus consistent with current land use practices. In fact, a new cranberry field was installed in 2016, to the immediate north of the project site. Under the baseline, all surface vegetation and any forest floor would have been removed in preparation for planting. Ditching and control structures would then be constructed to lower the water table and allow for manipulation of water levels. Cranberry yield is very sensitive to wet anaerobic conditions and an ideal water table depth for fruit production lies between 30 and 60 cm below surface (Caron et al. 2017). A change to the hydrological regime, however, would also impact the remaining 13.7 ha and lower its water table. This would likely enhance vegetation growth but also initiate peat oxidation and a net loss of carbon across the entire bog complex, which will be accounted for in calculations of the carbon balance (see Section 5.1).

The project scenario describes current and intended management activities that reduce carbon emissions over the life of the project below that which would have occurred under the baseline.

In the project scenario, soil water levels are maintained at existing levels through a program of passive management (simply allowing existing ditches to fill in naturally) or, if necessary, actively blocking ditches. The difference in emissions between the project and baseline scenarios yields the net emission reductions associated with the project.

# 5 Calculation of GHG emission reductions

The following sections provide a detailed summary of landscape stratifications and modelling work conducted to calculate the GHG emission reductions resulting from the Richmond Bog Forest Carbon Project.

## 5.1 Quantification of GHG emissions for the baseline scenario

**Stratification of project landbase**

To facilitate a calculation of the GHG implications of baseline activities it is necessary to stratify the project area into strata that have similar properties with respect to current carbon storage, vegetation cover, future growth rates, and ground water hydrology characteristics. With these features in mind, the project landbase was stratified using the data and criteria outlined in Table 1. A map of the vegetation inventory produced from the stratification exercise is shown in Figure 2, and a summary of area by parcel ID and vegetation cover type is provided in Table 2. The spatial data files are included as part of the supporting material described in Appendix 2.

Table 1. Description of criteria and data used to stratify the project landbase.

| Layer | Description | Values | Source |
|---|---|---|---|
| Parcel Boundaries | Spatial area of official parcel boundaries | Parcel 338 (6.21 ha, purchased 2011); Parcel 339 (13.74 ha, purchased 1991) | City of Richmond |
| Vegetation cover | Vegetation cover types determined from orthophotos and field visits | Closed bog forest (digitized); open bog forest (estimate at 5% of closed forest); wetland (non-forest vegetation; other | Digitized using ArcGIS |
| Ground water depth | Depth to ground water | Based upon data from a hydrological analysis conducted at the site[1]. Spatial boundaries assumed to be consistent with vegetation cover[2]. | See Vegetation cover |

[1] See Wood Environment and Infrastructure Solutions (2018) for hydrological and additional site data.

[2] The spatial distribution of vegetation communities is commonly regulated by soil hydrology, particularly average annual depth to ground water.


Figure 2. Map showing the boundaries of each parcel and the extent of the vegetation types digitized from the underlying orthophoto.

Table 2. Summary of area by parcel and vegetation cover type within the project landbase.

| Parcel ID | Cover_Type | Shape_Area (m2) | Adj_Cover type[1] | Adjusted area (ha) |
|---|---|---|---|---|
| 338 | Forest | 24277.0 | Forest-Closed | 2.31 |
| 338 | Wetland | 37326.1 | Wetland | 3.73 |
| 339 | Forest | 83029.5 | Forest-Closed | 7.89 |
| 339 | Wetland | 54402.8 | Wetland | 5.44 |
| 338 | Forest | | Forest-Open | 0.12 |
| 339 | Forest | | Forest-Open | 0.42 |
| 338 | Riverbank | 530.9 | Riverbank | 0.05 |

[1.] The Forest-Open types were added to account for the fact there were sections of the forest with only a sparse tree cover. These were difficult to accurately map but were estimated at 5% of the total forest area. Closed forest area was thus assumed to represent 95% of the total forest area.

### Carbon storage in biomass

The FORECAST model (v8.8.1) and an Excel-based Landscape Summary Tool (LST) were the principal modelling tools used for the carbon storage calculations. FORECAST is a management-oriented, stand-level forest ecosystem dynamics simulator (Kimmins, et al., 1999). It was constructed using a hybrid modelling approach whereby the rates of ecological processes are calculated from a combination of historical bioassay data (biomass accumulation in component pools, stand density, etc.) and calculated measures of specific ecosystem variables (decomposition rates, foliar N efficiency, nutrient uptake demand, for example). This is achieved by relating 'biologically active' biomass components (foliage and small roots) to calculations of nutrient uptake, the capture of light energy, and net primary production (see Seely, et al., 1999; Kimmins, et al., 1999). Since FORECAST is a biomass-based model, its core simulation routines reflect the accumulation and decay of all the principal biomass pools within a forest ecosystem, including foliage, branches, stemwood, bark, coarse and fine roots, and the various pools of dead organic matter (litter, snags & logs). As such it is well suited to carbon budget assessments (see, for example, Seely, et al., 2002). Further detailed information on FORECAST, its structure and simulation algorithms, and application can also be found at www.forestry.ubc.ca/ecomodels/moddev/forecast/forecast.htm.

FORECAST has been subject to on-going development and testing for over 3 decades and its application documented in almost 40 refereed publications. The model has been applied in many parts of Canada, the United States, Europe (Norway, Spain, and the UK), China, and Cuba. It is approved by the British Columbia Ministry of Forests as a model suitable for carbon budget assessments. FORECAST has been calibrated with a regional dataset that represents forest species and forest types that are common throughout the southwestern part of British Columbia (see, for example, Blanco et al., 2007).

### Preparation of stand-level carbon (C) curves

The FORECAST model was used to create ecosystem C storage curves for the closed and open forest types and for the cranberry bog vegetation type represented in the baseline scenario. The C curves do not account for peat storage; GHG emissions associated with carbon stored in the peat layer are provided in the subsequent section. Descriptions of regeneration assumptions, species percentages and biomass removal levels for vegetation cover type are shown in Table 3. Aside from crop yields, there is little information available on cranberry biomass accumulation. *Vaccinium* shrub (blueberry) data were therefore used to approximate cranberry vegetation growth (C content). Plot-measured data were used to verify and refine model accuracy (see Section 5.2). The carbon curve data are provided in the 'Carbon Curves' worksheet of the LST model spreadsheet (see Appendix 2).

Table 3. Parameters and assumptions for the FORECAST model runs used to generate the stand-level ecosystem carbon curves.

| **Run#** | **Cover type** | **Scenario** | **SPH[1]** | **Sp1[2]** | **Sp2** | **Sp3** | **Sp1%** | **Sp2%** | **Sp3%** | **Biomass Removal at Clearing[3]** |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Closed Forest | Project | 1200 | Hw | Ep | Pl | 75% | 15% | 10% | 95% of stem and bark biomass; 75% root biomass, 95% dead wood, 50% litter |
| 2 | Cranberry Bog | Baseline | 95% | Vac | na | na | na | na | na | No clearing |
| 3 | Open Forest | Project | 0 | na | na | na | na | na | na | 100% dead wood, 50% litter |
| 4 | Wetland | Project | 95% | Vac | na | na | na | na | na | No clearing |

1. SPH = Stems per hectare [2.]

2. Hw = western hemlock, Ep = paper birch, Pl = Shore pine, Vac = Vaccinium

3. The proportion of each biomass component removed at clearing.

### Biomass calculations in the LST model

The inventory data, summarized by parcel and vegetation cover types, were used in combination with the stand-level ecosystem carbon curves to quantify the amount of biomass C stored in each period represented, in the baseline scenario. These calculations are provided in the Excel spreadsheet version of the LST model included as part of the supporting materials listed in Appendix 2.

### GHG emissions from the peat layer

The average depth of the peat layer in the project area was determined to be 4 m (Wood Environment and Infrastructure Solutions, 2018). Field measurements conducted in August of 2016 (Section 6) were used to verify peat depth and to determine C content of peat.

Carbon emissions from peat were calculated, as per equations and protocol described in the GCC Methodology supporting document, and summarized as follows.

Annual methane emissions from peat soils in relation to the mean annual water level were estimated as:

$$y = 16.79(x+20);\ n=24;\ r^2 = 0.76,\ p = 0.01 \qquad (1)$$

where *y* are annual methane emissions (kg $CH_4$ $ha^{-1}$ $year^{-1}$), and *x* the mean annual water level (cm; negative values indicate below the surface). This relationship applies only to sites with mean annual water level $\geq$ -20 cm and aerenchymous shunt species present (see Couwenberg et al. 2011). Deeper water levels have zero methane emissions.

Net annual $CO_2$ fluxes (kg $CO_2$ $ha^{-1}$ $year^{-1}$) from peat soils in relation to mean annual water level, were estimated as:

$$y = - 752 * x - 4750; n = 35; r^2 = 0.71, p = 0.01 \quad (2)$$

This relationship applies to sites where mean water levels are above -50 cm. For deeper water levels, emissions are assumed to be equal to that at 50-cm depth (Couwenberg et al. 2011).

The project start date is year 2011, with a total project length of 29 years. Annual peat GHG emissions in the baseline were estimated using equations 1 and 2 first, by assuming that, in year 2012, mean annual water table depth on the 6.1-ha parcel (# 338; Figure 1) was lowered as a result of drainage installed in preparation for its immediate conversion to cranberry production. Optimal mean annual depth to groundwater in cranberry bogs in the Pacific northwest is ~60 cm (Caron et al., 2017) and it is assumed therefore that ground water depth in parcel 338 would be reduced to this level.  Secondly, it is assumed that the drainage on parcel #338 would also cause a reduction in groundwater depth on the adjacent parcel (#339) due to hydrological connectivity. In the latter, it was assumed that the mean annual depth to groundwater would be the midpoint between -60 cm and the measured groundwater depths prior to drainage. Mean annual water table depths for each vegetation cover type and parcel combination in year 2016, are shown Table 4. Detailed calculations for the baseline scenario are provided in the 'GHG Calcs' worksheet of the LST model spreadsheet (as listed in Appendix 2).

Table 4. Measured and predicted mean annual depth to groundwater by vegetation cover type and parcel in the project and baseline scenarios. Values in the baseline scenario represent conditions after drainage on parcel #338, in 2011.  The impact of drainage on peat oxidation is also shown.

| | **Project Scenario** | **Baseline scenario** | | | |
|---|---|---|---|---|---|
| **Index** | **Mean annual Depth to GW (cm)1** | **Mean annual Depth to GW (cm)** | **Drop in GW depth (cm)** | **Expected peat loss rate (cm $yr^{-1}$)** | **Expected peat loss over project duration (cm)2** |
| 338_Forest | -40.8 | -60 | 19.2 | 0.77 | 22.3 |
| 338_Wetland | -14.6 | -60 | 45.4 | 1.82 | 52.7 |
| 339_Forest | -40.8 | -50.4 | 9.6 | 0.38 | 11.1 |
| 339_Wetland | -14.6 | -37.3 | 22.7 | 0.91 | 26.3 |

[1.] Based upon the analysis conducted by Wood Environment and Infrastructure Solutions (2018).
[2.] The number of years drained is assumed to encompass years 2012-2040.

**Peat depletion time (PDT)**

The GCC Methodology requires that, in the case of the baseline scenario, peat stores are sufficient that oxidation does not result in total depletion within the project lifespan. In that regard, it specifies that the PDT must exceed the time required for half of the peat deposit present at the project start date to decay. In tropical peatlands, peat is depleted at a rate of about 0.4 cm year$^{-1}$ for each 10 cm of additional drainage depth (references in Couwenberg et al. 2010). Using this rate, the expected losses of peat by vegetation cover type and parcel in the baseline scenario due to drainage would range from 11.5 cm to 54.5 cm over the 30-year project timeline (see Table 4). Peat oxidation rates in tropical peatlands are likely higher than for peatlands in the cooler temperate regions and, hence, the estimated depletion time is likely conservative. Thus, the time required to deplete the average 4 m of peat in the project area would far exceed the loss values expected for the baseline scenario. As such, the project meets the peat depletion requirements specified in the methodology.

## 5.2 Quantification of GHG emissions for the project scenario

In contrast to the baseline scenario, the project scenario is focused on conserving the bog forest vegetation and protecting the underlying peat from the impacts of additional drainage. Like the baseline scenario, the GHG emissions and reductions for the project scenario were quantified in terms of carbon storage in biomass and forest soil, and GHG emissions associated with the peat layer.

**Carbon storage in biomass**

Ecosystem carbon storage in biomass, litter, forest floor, and deadwood components were quantified for the project scenario using the same modelling tools and methods described for the baseline scenario in Section 5.1. The parameters used to generate the project-scenario carbon curves with the FORECAST model are shown in Table 3. As in the baseline scenario, the stand-level carbon curves were linked with the inventory data summarized by parcel and vegetation cover type to determine carbon storage on the project landbase for each year in the 30-year project period using the LST model (see Appendix 2 for supporting documents). Modeled carbon storage contents in tree biomass were verified using data from field measurements (see Appendix 3).

**GHG emissions from the peat layer**

Field measurements conducted in August of 2016 (Appendix 3) were used to verify peat depth and determine its C content.

Carbon emissions from peat were calculated according to the GCC Methodology using field-measured values of mean annual depth to groundwater (Table 4) in combination with equations to predict annual $CH_4$ and $CO_2$ fluxes as described in Section 5.1. The specific calculations for the project scenario are shown in the 'GHG Calcs' worksheet of the LST model spreadsheet.

## 5.3 Leakage

Leakage refers to the potential that the implementation of the project (as an alternative to the baseline) triggers additional carbon emissions elsewhere. One form is “activity-shifting” leakage, where a project proponent/owner shifts emission-causing activity to other areas over which they have ownership or management control. The City of Richmond does not conduct agricultural activities for commercial gain and this form of leakage is thus not applicable.

Another is “market” leakage, whereby the implementation of a carbon project changes the availability of land or products in the overall economy, potentially increasing prices for related products and incentivizing additional development due to the higher price. In this case, is conservation of the 6.1 ha sufficient to increase cranberry prices and incentivize land conversion elsewhere in the region? In 2011, cranberry production in Metro Vancouver totaled 2388 ha[3]. Hence, it is improbably that this project is of a size sufficient to induce market leakage.

In the case of wetlands, a potential third source is “Ecological” leakage. Generally, this relates to the hydrological connectivity that characterizes these ecosystems, and how changes to the water table in one area can affect levels in adjacent (but non-project) areas in a manner that increases their emissions. Ecological leakage would be an issue for the 13.8 ha portion under the baseline scenario if the project area was restricted to only the 6.1-ha portion. This is not the case, however.

## 5.4 Non-permanence

A key concern in all ecosystem-based carbon projects is the risk that carbon stored in the project area and claimed as carbon emission reductions is later “reversed” and emitted into the atmosphere. The risk of non-permanence can be related to “planned” or “unplanned” reversal. A planned reversal might be related to a decision made by government to alter implementation of the project activities. Examples include a change in ownership and associated priorities, a change in management plans, or financial constraints that restrict the implementation of intended project activities. There is no precedent of BC municipal governments reversing conservation-based areas, which would support a low risk rating for this type of planned reversal.

An unplanned reversal event can be natural disturbances that remove carbon stocks (fire, wind, flood, drought, etc.) and/or illegal or other human disturbances (for example, timber harvesting, escaped campfires, etc.). For the Richmond bog, prominent natural risks are fire and drought. Maintaining soil water levels actually serves to mitigate both of these risks, however. Due to its relative isolation, the bog forest is not likely to receive substantial

[3] 2011 Census of Agriculture Bulletin. Available from: http://www.metrovancouver.org/services/regional-planning/PlanningPublications/Census2011-Agriculture.pdf

anthropogenic disturbance. Nevertheless, we have employed a net-down deduction of 1.5% to account for this uncertainty (see section 5.5)[4].

## 5.5 Project GHG emission reductions

Total project emissions were determined by summing the biomass carbon storage and peat-based GHG emission for both the baseline scenario (Section 5.1) and the project scenario (Section 5.2), respectively. The difference between the project and baseline scenarios determined the annual net emission reductions generated by the project (t $CO_2e$). After accounting for uncertainty (see below), the annual credits generated by the project activities are shown in Table 5. The specific calculations used to derive these values are provided in the Richmond LST v1.2.xlsx spreadsheet (listed in Appendix 2). Upon successful verification in 2019, the Richmond Forest Carbon Project will be eligible to claim credits associated with project activities that occurred from 2011 (the start date) to 2018. These amounted to 3,180 $tCO_2e$. Any unused credits from this amount may be banked for future use.

**Determination of uncertainty**

Deductions for uncertainty were calculated as specified in the 'Methodology (v1.2)' document.

Total uncertainty associated with project activity is calculated as (adapted from Emmer and Couwenberg 2017):

$$Uncertain_{Total} = \frac{\sqrt{(Uncertain_{BSL} \times GHG_{BSL})^2 + (Uncertain_{WPS} \times GHG_{WPS})^2}}{GHG_{BSL} + GHG_{WPS}} \qquad (3)$$

Where,
$Uncertain_{Total}$ is the total uncertainty for project activities; decimal %
$Uncertain_{BSL}$ is the total uncertainty in the baseline scenario; decimal %
$Uncertain_{WPS}$ is the total uncertainty in the project scenario; decimal %
$GHG_{BSL}$ is the net $CO_2$ equivalent emissions in the baseline scenario up to year $t$; t $CO_2e$
$GHG_{WPS}$ is the net $CO_2$ equivalent emissions in the project scenario up to year $t$; t $CO_2e$

To account for uncertainty in the estimation of emissions and carbon stock changes, a precision threshold target of a 90% or 95% confidence interval equal to or less than 20% or 30%, respectively, of the recorded value is required. Where this precision level is met no deduction is required for uncertainty. Where exceeded, the deduction is equal to the amount that the uncertainty exceeds the allowable level.

[4] It is also worth noting that unplanned reversals can be mitigated by netting against future project emission reductions – in the event a disturbance occurs, the project scenario can be adjusted going forward to net out any increased emissions against future reductions over time.

$NER_{RDP,t}$ (t $CO_2$e) is the total net $CO_2$ equivalent emission reductions from the project to year, *t* (see Table 5, column 5). It is adjusted for uncertainty, as follows:

$adjusted\_ NER_{RDP,t} = NER_{RDP,t} - NER\_ERR_{RDP,t}$ (Table 5, column 8)

and

$NER\_ERR_{RDP,t} = NER_{RDP,t} * max(0, Uncertain_{Total} – allowable\_uncert) + 0.015$ (Table 5, column 7)

where,
$NER\_ERR_{RDP,t}$ is the net uncertainty error for project activities at time *t*; (t $CO_2$e)
$adjusted\_ NER_{RDP,t}$ *is the* total net GHG emission reductions at time *t* adjusted to account for uncertainty; t $CO_2$e,
$NER_{RDP,t}$ *is as defined above*,
*allowable_uncert* is the allowable uncertainty (= 20%).

A base uncertainty factor of 1.5% is added in the determination of adjusted uncertainty to account for non-permanence (see section 5.4).

Table 5. Project emission reductions and credits for the Richmond Forest Carbon Project. Year 2011 is the project start date.

| **Year** | Period | Peat-based Emission Reductions (t $CO_2$e) | Biomass-based Emission Reductions (t $CO_2$e) | Total Emission Reductions, $NER_{RDP,t}$ (t $CO_2$e) | Adjusted Project Error % | Uncertainty deduction $NER\_ERR_{RDP,t}$ (t $CO_2$e) | Total Credits, $adjusted\_ NER_{RDP,t}$ (t $CO_2$e) | Cumulative Credits (t $CO_2$e) |
|---|---|---|---|---|---|---|---|---|
| 2010 | 0 | 0 | 0 | 0 | | 0 | 0 | 0 |
| 2011 | 1 | 0 | 0 | 0 | 1.5% | 0 | 0 | 0 |
| 2012 | 2 | 295 | 1122 | 1417 | 3.5% | 50 | 1,366 | 1,366 |
| 2013 | 3 | 295 | 20 | 315 | 3.5% | 11 | 304 | 1,670 |
| 2014 | 4 | 295 | 17 | 311 | 3.4% | 11 | 301 | 1,971 |
| 2015 | 5 | 295 | 16 | 310 | 3.3% | 10 | 300 | 2,271 |
| 2016 | 6 | 295 | 18 | 312 | 3.3% | 10 | 302 | 2,573 |
| 2017 | 7 | 295 | 17 | 312 | 3.3% | 10 | 302 | 2,875 |
| 2018 | 8 | 295 | 21 | 316 | 3.3% | 10 | 305 | 3,180 |
| 2019 | 9 | 295 | 22 | 317 | 3.2% | 10 | 306 | 3,487 |
| 2020 | 10 | 295 | 21 | 316 | 3.2% | 10 | 306 | 3,792 |
| 2021 | 11 | 295 | 24 | 318 | 3.2% | 10 | 308 | 4,100 |
| 2022 | 12 | 295 | 23 | 317 | 3.2% | 10 | 307 | 4,407 |
| 2023 | 13 | 295 | 24 | 318 | 3.2% | 10 | 308 | 4,715 |
| 2024 | 14 | 295 | 24 | 318 | 3.2% | 10 | 308 | 5,024 |
| 2025 | 15 | 295 | 24 | 319 | 3.2% | 10 | 309 | 5,332 |
| 2026 | 16 | 295 | 26 | 321 | 3.2% | 10 | 311 | 5,643 |
| 2027 | 17 | 295 | 24 | 318 | 3.2% | 10 | 308 | 5,951 |
| 2028 | 18 | 295 | 27 | 322 | 3.2% | 10 | 312 | 6,263 |
| 2029 | 19 | 295 | 25 | 319 | 3.2% | 10 | 309 | 6,572 |
| 2030 | 20 | 295 | 25 | 320 | 3.2% | 10 | 310 | 6,882 |
| 2031 | 21 | 295 | 25 | 320 | 3.2% | 10 | 310 | 7,192 |

| **Year** | Period | Peat-based Emission Reductions (t $CO_2$e) | Biomass-based Emission Reductions (t $CO_2$e) | Total Emission Reductions, $NER_{RDP,t}$ (t $CO_2$e) | Adjusted Project Error % | Uncertainty deduction $NER\_ERR_{RDP,t}$ (t $CO_2$e) | Total Credits, $adjusted\_ NER_{RDP,t}$ (t $CO_2$e) | Cumulative Credits (t $CO_2$e) |
|---|---|---|---|---|---|---|---|---|
| 2032 | 22 | 295 | 25 | 320 | 3.2% | 10 | 310 | 7,501 |
| 2033 | 23 | 295 | 26 | 321 | 3.2% | 10 | 311 | 7,812 |
| 2034 | 24 | 295 | 25 | 319 | 3.2% | 10 | 309 | 8,121 |
| 2035 | 25 | 295 | 24 | 318 | 3.2% | 10 | 308 | 8,429 |
| 2036 | 26 | 295 | 25 | 320 | 3.2% | 10 | 310 | 8,739 |
| 2037 | 27 | 295 | 25 | 319 | 3.2% | 10 | 309 | 9,048 |
| 2038 | 28 | 295 | 26 | 320 | 3.2% | 10 | 310 | 9,358 |
| 2039 | 29 | 295 | 24 | 318 | 3.2% | 10 | 308 | 9,667 |
| 2040 | 30 | 295 | 25 | 319 | 3.2% | 10 | 309 | 9,976 |
| **Total** | | **8,546** | **1768** | **10,314** | **3.2%** | **338** | **9,976** | **9,976** |

# 6 Monitoring activities

Monitoring provides a high level of confidence in the impacts of project management activities on carbon storage and the flux of GHGs within the project area. The fundamental objective of monitoring is to reliably quantify carbon stocks and GHG emissions from the project landbase as managed in accordance with the project scenario. The monitoring program will be managed by the City of Richmond and may include, as needed, input and activities from third parties.

The monitoring program should be installed and the initial series of measurements conducted prior to the first project verification[5]. This is the case here. Each claim for subsequent credits must be preceded by a successful verification, as supported through the monitoring plan.

**Monitoring Plan**
Development of a well-organized monitoring plan is an essential part of a successful carbon project and should be followed throughout the lifespan of the project. The monitoring plan will contain at least the following sections:

- A description of each monitoring task to be undertaken, and the technical requirements
- Parameters to be measured
- Data to be collected and data collection techniques
- Frequency of monitoring
- Quality Assurance and Quality Control (QA/QC) procedures
- Data archiving procedures
- Roles, responsibilities and capacity of monitoring team and management

**Stratification and sampling framework**
Projects are often comprised of a variety of vegetation types, each of which can differ broadly in their carbon stocks. A key component of many ecosystem carbon projects therefore is the necessity to stratify the landbase into relatively homogenous analysis units. Most methodologies require monitoring activities to be conducted such that each analysis unit (stratum) is independently measured through the establishment of a plot network. An initial set of strata has been identified as part of the project design. These strata provide the framework for the first round of monitoring work.

[5] Verification is the systematic, independent, and documented process for the evaluation of a GHG assertion against specific criteria. The verification process is intended to assess the degree to which a project has correctly quantified net GHG reductions or removals per the validated GHG Project Plan, correctly utilizes the adopted methodologies and tools, and continues to meet applicable ongoing requirements. A successful verification provides reasonable assurance that the GHG assertion is without material misstatement.

The proponent will develop a monitoring plan with sampling representation in each stratum. The number of plots established in each stratum will be determined through a cost-benefit analysis, whereby the cost of establishing and measuring new plots is weighed against the potential costs associated with sampling error.  Finally, stratification of the landbase may change in subsequent time periods due to plant community succession and/or if the results of the monitoring suggest that a particular stratum should be split or merged with another stratum. Alternatively, strata may be combined if monitoring results suggest they are not statistically different.

**Focus of monitoring**
The focus of monitoring will be centered on: 1) the mapping and condition of discrete vegetation communities, 2) the systematic measurement and projection of mean annual water table depths, 3) measurement of carbon storage in peat and other dead organic matter, and 4) quantification of carbon storage in perennial plant biomass (particularly trees).

1. Vegetation mapping.
Once the key vegetation communities have been defined, their distributions within the project area will be confirmed during each monitoring period. The principal method for vegetation mapping can be aerial photography or satellite (hyperspectral) imagery for vegetation mapping. A network of ground plots will be established to verify carbon stocks. Given the relatively small area, we used aerial photography in conjunction with ground-truthing to stratify the Richmond bog into three communities: Forest – upland site with overhead canopy; Open – upland site with no overhead canopy; and Wetland – seasonally flooded with no tree cover.

2. Water table depth
Reasonably accurate measurements of water table depth represent an essential component of the project.  The following provides a summary of the key aspects of water table measurements:

- The water table depth measurements must be conducted in each of the four seasons to capture seasonal variation. Measurements can be continuous with data loggers, using min-max devices or simple water level gauges.
- Water table depth will be monitored at least once prior to verification.
- The intensity of sampling in terms of spatial distributions will be in accordance with previous monitoring.

3.  Measurement of peat depth and carbon content
The following provides a summary of the key aspects of peat measurements:

- Initial peat carbon contents (at project establishment) has been made based upon a systematic measurement of peat depth over the project area, measurement of bulk density over depth profiles, and measurements of carbon content in peat material
- Subsequent measurements of peat carbon content may be estimated from depth measurements taken in each of the identified strata.
- Samples of peat depth should be made at least once prior to verification.

4. Measurement of carbon storage in plant biomass
The following provides a summary of the key aspects of biomass measurements:

- Aboveground carbon storage in tree biomass will be estimated using published species-specific allometric biomass equations that rely upon measures of diameter at breast height (1.3 m) and top height.
- Biomass plots will be established in strata with significant tree components and measured during each monitoring period, prior to verification. The size of the plots should be determined as a function of tree size such that a minimum number of trees are captured in each plot.
- Belowground biomass may be estimated as a function of aboveground biomass using standard relationships.
- Carbon storage in plant biomass should be estimated at least once prior to verification.

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## Appendix 1. Option 2 eligibility requirements

1. Emissions reductions are from projects undertaken in BC and are outside of the local government corporate boundaries.

The project is located in the City of Richmond Northeast bog forest. This is a forest conservation project, which is outside the local government corporate boundaries.

2. Emission reductions have occurred before they are counted

The anticipated project start date is January 1, 2011.

3. Emission reductions are credibly measured

The project has undergone third party validation to ensure credibility.

4. GHG reductions are beyond business as usual

To be considered beyond BAU a project must meet the following criteria:

a) Have commenced after the initial signing of the Climate Action Charter on September 26th, 2007;
   The project start date is January 1, 2012.
b) Not be required to fulfill federal or provincial government legislative or regulatory requirements; excludes local government regulations/bylaws except in the case of Avoided Forest Conversion Projects (AFCP).
   Project is compliant with this criterion.
c) Meet one of the following tests:
   i. Financial Test: A project can only be considered 'beyond BAU' if it is not financially viable without investment from the local government(s) that will use the resulting emission reductions to balance its / their corporate carbon emissions;
   ii. Barriers Test: A project can only be considered 'beyond BAU' if there are barriers, such as significant local resistance, lack of know-how, institutional barriers, etc., that prevent its being implemented regardless of its profitability; or
   iii. Common Practice Test: A project can only be considered beyond BAU if it employs technologies or practices that are not already in common use.

Financial test:
There is no financial incentive to private-sector parties purchasing the property without its conversion to higher-and-better use (most likely agricultural production). In this case, government purchase for conservation purposes will ensure carbon stocks are retained and the associated emission reductions used against the City of Richmond's corporate emissions

5. Accounting of emission reductions is transparent
   a) Project plan templates will be completed, signed and kept on file in accordance with the local government’s administrative policies and procedures.

b) Project verification templates for Option 2 projects will be completed and signed, prior to a GHG reduction being claimed, to demonstrate that the projected GHG reductions have occurred by the time they are being claimed.

Carbon Neutral Public Reports (included in CARIP Report):

a) The LG will make public (on an annual basis) a carbon neutral report which includes, at a minimum:

i. Total annual corporate GHG emissions for the LG;
ii. The amount of GHG reductions being claimed in that year;

6. Emission reductions are only counted once

The GHG reductions being claimed by the City of Richmond under this Carbon Neutral Framework will not have been previously committed or sold as an emission reduction under any other alternate emission-offset scheme.

7. Project proponents have clear ownership of all emission reductions

The City of Richmond has clear and demonstrable title to the property.

# Appendix 2.  Supporting documents and materials

The following table includes the key data files used in the PDD.

Table A1.  List of supporting data files used in the creation of the King County Carbon Project Description Document.

| Description | Filename | Format | Date |
|---|---|---|---|
| Spatial inventory data for the Richmond Bog Forest area including vegetation cover types and parcel boundaries. | Richmond project.mdb | Personal geodatabase | 04/2/2019 |
| Plot locations | Richmond plots.kml | Kml file | 10/13/2016 |
| Summarized data from field sampling | Richmond field data.xlsx | MS Excel | 04/09/2019 |
| Landscape Summary Tool including:  stand-level ecosystem C curves, biomass C calculations, and calculations of GHG emissions associated with the peat layer, calculations of total emissions & reductions | Richmond LST v1.1.xlsm | MS Excel | 04/09/2019 |
| Hydrological analysis report prepared by Wood Environment and Infrastructure Solutions (2018) | NEBog_VE52629_Report_Rev 0_20181123.pdf | PDF | 11/23/2018 |

## Appendix 3. Field measurements[6]

**Measurements of C storage in biomass, forest floor, and peat**
In August of 2016, nine plots were installed using a quasi-systematic selection procedure designed to ensure sampling in proportion to the areal coverage of the dominant vegetation (Figure 3). Five plots were in installed in the closed forest areas, one in the open forest area, and 3 in wetland areas[7].

**Forest living biomass**
Circular plots were established within the forest cover type (Fig. 2), each of a 10-m radius. All living trees of dbh ≥ 5cm within a plot were measured for height (m) and diameter (cm) at breast height (1.3 m). Tree biomass was estimated from equations relating biomass to DBH and/or height for British Columbia tree species (Standish et al., 1985). Belowground biomass was then calculated using equations in Li et al. (2003). Tree-level biomass estimates were converted to area-based stand-level measurements (t ha-1) and a conversion factor (0.5) used to convert biomass into carbon. Living biomass measurements were not made in wetland plots because their C stocks were insignificant relative to the forest or peat C pools.

**Surface soil and peat**
On the upland sites, the surface layer was sampled to a depth of 20 cm, using a hand-held plunge corer of 282 cm3 volume. This technique was not utilized in the wetland because the site was under water. Subsurface soil was sampled on all sites using a standard metal soil corer. 20-cm length samples were removed from coring depths of 20-70, and 90-140 cm; each sample represented a soil volume of 63.6 cm3.

Samples were oven-dried for 24 h and then weighed. A weight at 16 h was also taken to verify that subsequent mass loss was minimal. The mean change in weight over the intervening 8-h period was less than 3% (n = 22) confirming that samples were essentially completely dry after a 24 h drying time. Organic content in each sample was estimated using the loss-on-ignition (LOI) method. Two LOI temperatures were utilized, 375 and 550 °C, the latter to derive an estimate of recalcitrant carbon. The mean difference in organic matter content was less than 4% (n=23), indicating that labile (biologically available) carbon was the predominant organic fraction in the samples.

A series of deep cores were taken at the six plots located in the forested area to gain an estimate of total peat depth. Plots 7,8, and 10, located in the wetlands, were excluded because soil bulk densities were too high for penetration, indicating a lack of peat formation. Cores were

6 Further details can be found in the reports: "Provision of Carbon Assessment Consulting services for the Richmond Northeast Bog Forest. File no. 5672P, Interim report 1, and 2". City of Richmond.
7 Data and calculations are reported in the supporting document 'Richmond field data.xlsx'

obtained by manually inserting a 1.25 cm diameter plastic pipe into the ground. Maximum peat depth can be calculated from the point at which insertion is strongly resisted by the bulk density of the mineral layer underlying the peat deposit (Les Lavkulich, pers. comm.).

**Hydrological Analysis**

A hydrological analysis of the project area was conducted by Wood Environment and Infrastructure Solutions. Beginning in March, 2017, a series of wells and drive points were established in the project area (Figure 4). Surface elevations were measured for each sampling point and water table elevations measured on hourly intervals using pressure transducers and data loggers. A complete description of the methods is provided in the report prepared by Wood Environment and Infrastructure Solutions (2018).

Mean annual depths to water table from March 2017 to April 2018 were estimated for each vegetation cover type within the project area (Table 4). While the network of wells was limited spatially, the distribution of vegetation communities was assumed to represent the spatial distribution of depth to groundwater.


Figure 3. Map showing the location of the temporary biomass and soil plot locations within the project area. Plot numbers can be referenced against plot IDs included in the Richmond field data spreadsheet referenced in Appendix 2.

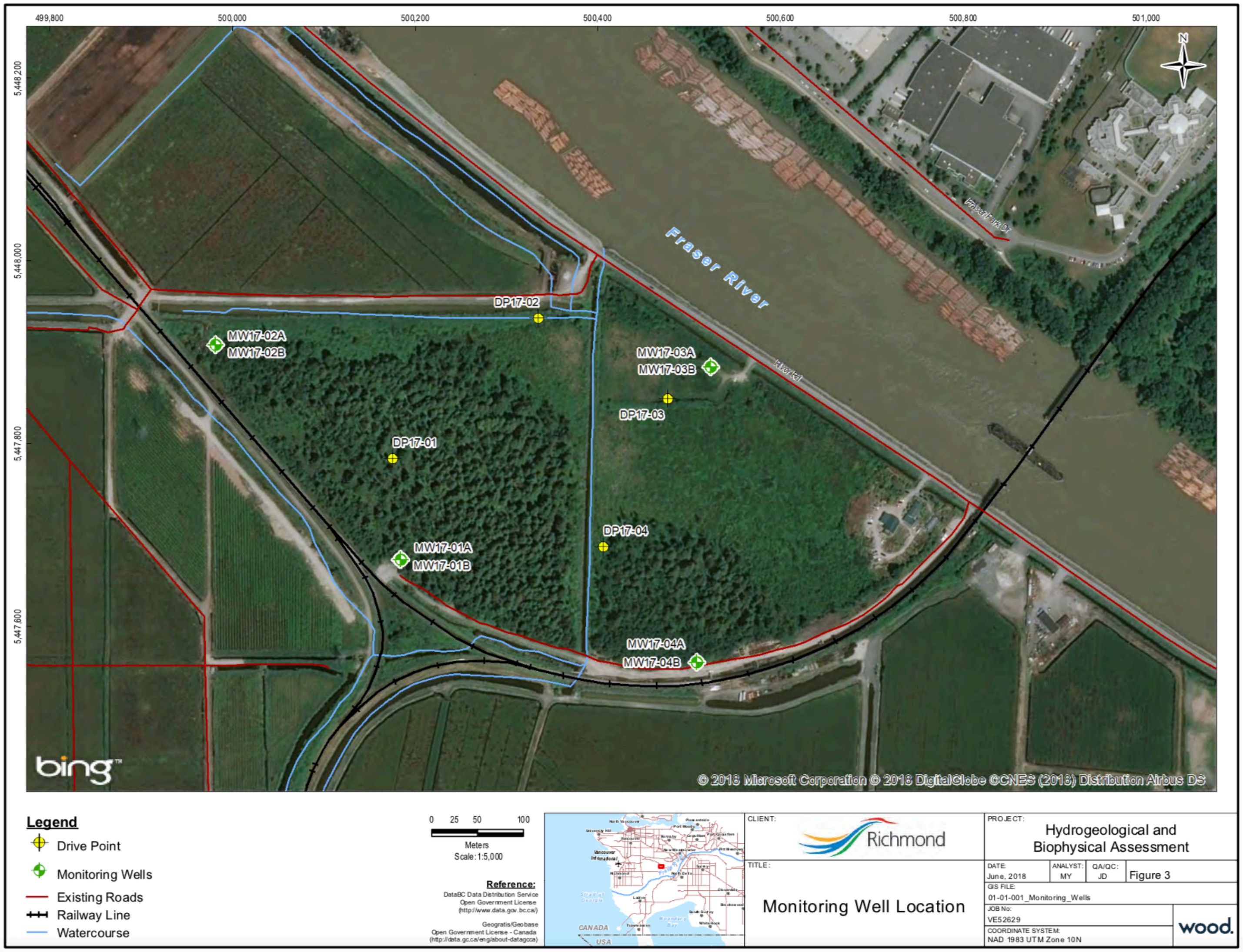


Figure 4. Map showing the location of wells and drive points established in the project area (From Wood Environment and Infrastructure Solutions, 2018).