Appendix

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This appendix details the calculations used to determine the available forest residue biomass available on each township in each year of the study period.

# Utilization standards

For administrative purposes, the Green Area of Alberta is divided into Forest Management Units (FMUs). The province enters into long term agreements with forest products companies giving the companies the rights to timber harvest and the responsibility to manage the forest sustainably. These agreements are called Forest Management Agreements, and the areas under agreement are called Forest Management Agreement Areas (FMAAs). For the most part, the boundaries of the FMAAs are coincident with FMU boundaries, except for the Alberta-Pacific FMAA in eastern Alberta which comprises 12 FMUs. Maps of the FMUs [1] and the FMAAs [2] can be found on the Government of Alberta website. The FMU and FMAA boundaries are used to assign utilization standards (discussed here) and average piece size (discussed in the next section).

Many forest products companies operate in Alberta, and the details of their agreements with the government with respect to forest management differ. Some companies have harvesting rights to just the needleleaf species, others have rights to just the broadleaf species, and some have rights to both needleleaf and broadleaf.

Utilization standards in Alberta are specified based on stump height, minimum stump diameter (outside bark), and minimum log length to a specified top diameter (inside bark). Utilization standards vary by FMU. Stump heights used in Alberta are 15 and 30 cm; stump diameters are 13 or 15 cm; top diameters range between 7 and 12 cm; and minimum log lengths range between 2.44 and 4.88 m. These utilization standards are necessary to relate volumes calculated to the 13+/7 cm standard for the National Forest Inventory to the harvest volumes reported by the companies. Perhaps most importantly, the minimum top diameter will influence the volume of residue left in the forest corresponding to the tops of trees.

Based on the FMU boundaries, we assigned a needleleaf and broadleaf utilization standard to each township.

# Characteristics of the average tree

## Piece size

FMA holders are required by Alberta to project average piece size of harvested trees in the detailed forest management plans (DMFPs) for their FMAAs. We use these piece sizes projected for the first period of the DMFP. They range from 0.110 to 0.599 m3 per tree. We used the piece size reported for the first 5-year period of the 200-year planning horizon. For those areas where piece size was not reported we assumed an average piece size of 0.278 m3 for needleleaf trees and 0.264 m3 for broadleaf trees. These are the average of the values reported in the forest management plans. These values are based on the utilization standards used on the FMA. Based on the FMU boundaries we assign an average piece size for broadleaf and needleleaf trees to each township.

## Taper functions

Ref. [3] presents taper models and the associated coefficients for the tree species found in Canada. These taper models can be used to find the diameter at any point along the main bole of a tree given species and diameter at breast height (DBH). DBH is a commonly used tree measurement and is the diameter of the tree measured at 1.3 m above ground level, in most jurisdictions, including Alberta. It is straightforward to determine cross-sectional area of the tree at any height. Integrating this area function will yield volume between any two heights.

Ung *et al.* [4] describe a one-parameter model which is useful when both tree DBH and height measurements are available.

where is the diameter (cm) at height (m), and is the diameter at breast height (1.3 m above ground level), and is tree height (m).

For those cases where height measurements are unavailable, they present a 3-parameter model, where H is replaced with .

where is the diameter (cm) at height (m), and is the diameter at breast height (1.3 m above ground level)

Implicit in this equation is an equation for tree height

which we will use to create input for the biomass calculator.

The radius of the tree (m) can be calculated from and using

where the constant 200 is used to convert a diameter (cm) to a radius (m).

The volume of the merchantable log between stump height and the height of the tree at the minimum top diameter () can then be calculated through integration.

Ung *et al.* [4] also present a simple linear model relating outside bark to inside bark diameter. The taper function is for outside bark diameter, but piece sizes are reported as inside bark volume.

## DBH and height estimates

From information collected from forest management plans we have an estimate of average piece size calculated to a specified utilization standard for every combination of township and FMU, for both needleleaf and broadleaf trees. We used a binary search procedure to find DBH and height of the “average” broadleaf and needleleaf tree in each township based on the FMU utilization standard. An average piece size to the 13+/7 utilization standard was also calculated by integrating the cross-sectional area function using the appropriate limits.

Most forest stands in Alberta are even-aged, as the majority originated following stand-replacing fire or clearcut harvest. It is common to describe stands using a distribution of diameters at breast height (DBH). The diameter distribution for an even-aged stand is usually approximately normal [5]. We use this to justify the use of the average tree.

Using these equations, we can calculate wood volumes and bark volumes between any two heights along the tree stem. We calculate the proportions of total tree and bark volumes in the top of the tree. We use this volume proportion later to calculate biomass of stemwood and bark in the top.

The merchantable volume for the average tree is calculated to both the 13+/7 cm utilization standard and the utilization standard specified for the FMU. The 13+/7 cm utilization standard is used to calculate the stand density (stems/ha) for both the needleleaf and the broadleaf species. The FMU utilization standard is used to calculate the volume adjustment factor.

## Individual tree residual biomass

Canada’s National Forest Inventory website provides a useful individual tree biomass calculator [6]. It calculates the biomass of tree components (stem wood, stem bark, branches, foliage, and total) using province/territory, terrestrial ecozone, species, DBH, and tree height as input. It is possible to upload a file to the calculator so that the biomass of many trees can be calculated at once. The calculator is based on Lambert [7]. We created an input file for the NFIS biomass calculator that included all 125 unique combinations of species, ecozone, DBH, and height determined for each township in Alberta.

We assume that the residual biomass comes from the stem wood and stem bark from the tops of the harvested trees, and the branches and foliage removed by the stroke delimber. The residual biomass from the tops is calculated using the total biomass of stem wood and stem bark adjusted by the volume proportions calculated as described above.

# Spatial variability in residual biomass production

There is considerable spatial variability in the amount of timber harvest residues available for biomass collection. The variability relates to the distribution of harvested species and age classes across the landscape, to the timber harvesting practices of different operators, and to other factors. We used the 250 m resolution raster maps of Canada’s forest attributes for 2011 from Natural Resources Canada [8] to retrieve information on species composition, age classes, and merchantable volume. The data were clipped to the Alberta boundary. Merchantable volumes for Alberta in this dataset were compiled to the 13+/7 cm utilization standard, meaning that stump height for each merchantable tree was assumed to be 30 cm, that stump diameter (outside bark) was at least 13 cm, and that the length of the log to a 7 cm inside bark diameter was at least 4.88 m. This is one of the utilization standards used in Alberta and was the one used for Alberta data in Canada’s National Forest Inventory (NFI henceforth).

Forestry companies are selective in the stands they harvest. Some stands will be comprised of undesirable species. The most commercially important needleleaf species in Alberta are white spruce (*Picea glauca* (Moench) Voss), lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) and jack pine (*Pinus banksiana* Lamb.). Trembling aspen (*Populus tremuloides* Michx.) is the most commercially important broadleaf species. Some stands may have too little volume to be worth harvesting. Some stands may be too young. We selected cells that contained at least 50 m3·ha-1 of merchantable volume, as that corresponds with stand merchantability limits specified in Alberta. We filtered out cells with more than 50% crown closure of larch (*Larix spp.* Mill.) and birch (*Betula spp.* L.) combined, as those genera are rarely harvested at a commercial scale in Alberta. We filtered out cells with stand age less than 80 years as it is unusual to harvest stands younger than that in Alberta. QGIS zonal statistics were used to average the merchantable volume per ha of the merchantable cells in each township.

Then for each township, we determined the most common needleleaf and broadleaf species, and calculated the average volume per hectare of needleleaf and broadleaf these harvestable stands.

These average volumes are still considerably less than the average volume per hectare harvested in Alberta, indicating that the forestry companies are even more selective about timber harvest than our simple filter rules suggest.

Based on data retrieved from the National Forestry Database, the average harvest volume in Alberta between 1990 and 2015 was 277.8 m3·ha-1 [9]. The average township volume after the filter was applied was 100.3 m3·ha-1. We used a harvest volume adjustment factor of 2.77 to make the volumes we calculated comparable to the average harvest volume (m3·ha-1) for Alberta.

# Recovery Factor

For each township, we calculate the number of stems by dividing the adjusted volume per hectare by the average piece size for both needleleaf and broadleaf trees. We assume that for the types of stands being harvested that the stem count per hectre for the 13/+7 utilization standard is close to the stem count based on the FMU utilization standard. We multiply the stem count by the average tree residual biomass. We assume an average recovery factor of 0.624 following what Peltola et al. [10] determined for Finland, recognizing that some of the residual biomass will be unrecoverable. Together this gives us an estimate of the average residue yield when a hectare of a stand in a particular township is harvested.

# References

[1]

Alberta. [Forest management units [map]](https://open.alberta.ca/publications/forest-management-units-map) <https://open.alberta.ca/publications/forest-management-units-map> 2021 (accessed 2021-12-06).

[2]

Alberta. [Forest management agreement boundaries [map]](https://open.alberta.ca/publications/forest-management-agreement-boundaries-map) <https://open.alberta.ca/publications/forest-management-agreement-boundaries-map> 2021 (accessed 2021-12-06).

[3]

Natural Resources Canada. [Wood volume calculation using taper models](https://apps-scf-cfs.rncan.gc.ca/calc/en/volume-calculator) <https://apps-scf-cfs.rncan.gc.ca/calc/en/volume-calculator> 2015 (accessed 2021-12-06).

[4]

Ung C-H, Guo XJ, Fortin M. Canadian national taper models. The Forestry Chronicle 2013;89:211–24.

[5]

Bettinger P, Boston K, Siry JP, Grebner DL. Forest Management and Planning. 2nd ed. Elsevier; 2017. <https://doi.org/10.1016/B978-0-12-809476-1.00002-3>.

[6]

NFIS. [Individual tree biomass calculator](https://nfi.nfis.org/en/biomass_calc) 2016.

[7]

Lambert MC, Ung CH, Raulier F. Canadian national tree aboveground biomass equations. Canadian Journal of Forest Research 2005;35:1996–2018. <https://doi.org/10.1139/x05-112>.

[8]

Beaudoin A, Bernier PY, Guindon L, Villemaire P, Guo XJ, Stinson G, et al. Mapping attributes of Canada’s forests at moderate resolution through *k* NN and MODIS imagery. Canadian Journal of Forest Research 2014;44:521–32. <https://doi.org/10.1139/cjfr-2013-0401>.

[9]

Canadian Council of Forest Ministers. National forestry database - Canada (version 2.0.0) [data set] 2020. <https://doi.org/10.5281/zenodo.3690046>.

[10]

Peltola S, Kilpeläinen H, Asikainen A. Recovery rates of logging residue harvesting in Norway spruce (Picea abies (L.) Karsten) dominated stands. Biomass & Bioenergy 2011:1545–51. <https://doi.org/10.1016/j.biombioe.2010.12.032>.