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ACCURATELY ASSESSING WOODY BIOMASS POTENTIAL IN NORTH CAROLINA, US

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Abstract

Since 2007, NCSU Extension Forestry has conducted over 50 detailed biomass supply assessments supporting prospective projects on behalf of bio-energy industries and economic developers. These analyses leverage data from numerous sources and scales for gross woody biomass, drain, and net woody biomass distributed spatially across timberland. Described here are details of NCSU *Fiber*Analytics processing techniques for two levels of woody biomass supply assessment offered to clients. The first level results in state-wide, coarse-resolution, gradient maps of net supply based on client feedstock preferences. These are derived from net supply-distance curve coefficients generated through a series of neighborhood functions performed on net supply maps. Web-hosting interactive assessment enables potential industries, policy developers or others to explore scenarios across the state. The second level of supply assessment is performed for clients with identified site locations. For each identified site, supply areas are developed for specified haul distances using road networks. All forms of potential woody biomass are applied to timberland distributed (derived from satellite imagery) throughout each supply area is summed and used to develop supply curves. Estimated demand from facility-specific demand regions for existing and potential competitors are subtracted yielding accurately portrayed net supply based on distance and feedstock type.

Keywoods: biomass supply analysis, ArcGIS, USFS FIA, USFS TPO, USDA NASS, spatial supply modeling.

Introduction

North Carolina State University Extension Forestry has been a major player in woody biomass promotion and policy in NC. We provide outreach and education to potential new biomass industries and economic developers across the state. Part of our efforts led to the development of a service center, *Fiber*Analytics, which provides analytic support and resources for new biomass industries scoping NC. Our analytic support is focused around biomass supply models for both woody and other biomass that utilize our knowledge of the most accurate and current information on biomass supply and demand (drain). This paper briefly outlines the data used, a course-level state-wide model and our detailed model for site specific analysis. This may be useful for other groups wishing to provide similar services across the states.

Data

Data sources used are briefly described below. All county-level tabular data are acquired for NC, VA, TN, GA, and SC as our analysis often crosses state lines. Data not provided in green tons is converted to keep the units the same in our analysis. Summary descriptions are of tabular public data sources and our derived usage are provided in Table 1.

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Table 1. Sources of county-level data used by NCSU FiberAnalytics for statewide and site specific biomass analysis.

Source: USFS Forest Inventory and Analysis (FIA)	
http://www.fia.fs.fed.us/tools-data/default.asp	
Data description: 2003-2011 running average of annual permanent inventory plot data summarized at the county level	
FIA Data	***FiberAnalytics* Use/ Derivation**
Growing stock sawtimber: 9"+ dbh softwoods (cuft); 11"+ dbh hardwoods (cuft)	same (gT)
Biomass inventory: 1-5" dbh (dT)	same (gT)
Pulpwood inventory: 5-9" dbh softwood (cu ft); 5-11" dbh hardwood (cu ft)	same (gT)
All live stems to 4" top: 5"+ dbh hardwoods, softwoods (cu ft)	Pulpwood volumes in tops of sawtimber stems (gT) Non-growing stock sawtimber volumes (gT)
Total biomass to 1.5" top and branches to 1.5": 5"+ dbh hardwoods, softwoods (cu ft)	Topwood in all merchantable stems (4" to 1.5" tops and branches to 1.5" on all stems) (gT)
Annual pulpwood growth: 5-9" dbh softwood (cu ft), 5-11" dbh hardwood (cu ft)	same (gT)
All merchantable stem growth: 5"+ dbh hardwood, softwood	same (gT)
Source: USFS Timber Products Output (TPO)	
http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int2.php	
Data description: Average of 1995-2009 county-level summaries of biannual forest products industries surveys describing timber harvest levels by product	
TPO Data	***FiberAnalytics* Use/ Derivation**
Removals: sawtimber, veneer, pulpwood, composite, fuelwood, other - hardwoods, softwoods (gT)	Sawtimber removals: hardwood, softwood (gT) Pulpwood class removals: (combined pulpwood and composite) - hardwood, softwood (gT)
Biomass inventory: 1-5" dbh (dT)	same (gT)
Logging residues: hardwood, softwoods (gT)	same at 65% recovery efficiency (gT)
Other removals: hardwoods, softwoods (gT)	same at 65% recovery efficiency (gT)
Source: USDA National Agricultural Statistics Service (NASS)	
http://www.nass.usda.gov/	
Data description: Average of 2001-2011 county-level summaries of annual surveys by commodity crop	
NASS Data	***FiberAnalytics* Use/ Derivation**
Corn harvested: (bu)	Corn stover: gT)
Hay harvested: (dT)	Hay as a surrogate for energy crops: (gT)

USFS Forest Inventory and Analysis (FIA)[2] is a national program where each state conducts annual[3] plot-level inventories of forest resources. We use their data summarized to the county level. This rich dataset is used to estimate net[4] current inventory of hardwood and softwood sawtimber, pulpwood, woody biomass from tops and non-merchantable stems, annual growth and removals by supply area[5].

[2] http://www.fia.fs.fed.us/tools-data/default.asp

[3] FIA inventories annually sample only a portion of a state's plots. Complete inventory cycles span across different years according to each state's inventory program. Current NC data spans from 2003-2011.

[4] Net growth and net volumes estimates do not include natural mortality.

[5] We caution our clients on FIA inventory data having high variability (some over 50%) at the county level making it less reliable in smaller supply areas.

USFS Timber Products Output (TPO)[6] provides summaries of biennial surveys to forest industry to estimate county-level timber removals by product class, logging residues[7], and "other removals"[8]. We use a running average of (currently1995-2009[9]) TPO data to smooth market fluctuations.

County-level potential for agricultural residues (i.e., corn stover) or hay production comes from the National Agricultural Statistic Service (NASS)[10]. Currently, corn is the only NC crop with residues large enough to be utilized. Hay is used as a surrogate for energy crops[11] production associated with marginal lands, realizing that energy crops would have 2 to 3 times the yield.

Land cover comes from the 2006 National Land Cover Database (NLCD) provided by the Multi-Resolution Land Class Consortium[12]. This is national 30m X 30m (.223 acre) resolution raster grid dataset classified to 16-land uses. Preserved forest lands are removed from this dataset using the Protected Area Database US 1.1[13] of private and public protected areas. Public forested lands are not removed realizing harvest levels may be lower than on private lands. This used to determine spatial distribution and acreages of hardwood[14], softwoods[15], crop land, and pasture/ hay land. County acreage estimates for these four land cover grids are derived by assignment of Federal Information Processing Standard (FIPS) county codes to each respective land cover[16].

The Environmental System Resource Institute (ESRI) StreetMap Road Network[17] data set provides road networks used to build supply areas using ESRI Network Analyst.

[6] http://srsfia2.fs.fed.us/php/tpo_2009/tpo_rpa_int2.php

[7] We currently suggest using a 65% recovery rate logging residues and other removals in North Carolina.

[8] "The growing-stock volume of trees removed from the inventory by cultural operations such as timber stand improvement, land clearing, and other changes in land use, resulting in the removal of the trees from timberland" (Cooper et al. 2009).

[9] 2009 is the most recent TPO data as of the date of this paper.

[10] http://www.nass.usda.gov/

[11] Currently there are is very little land in North Carolina growing energy crops.

[12] http://www.mrlc.gov/

[13] http://databasin.org/protected-center/features/PAD-US-CBI

[14] Hardwoods combines the NLCD classes "deciduous forest" and "woody wetlands"

[15] Softwoods combines the NLCD classes "conifer forest" and "mixed forest"

[16] Performed using a zonal statistics tool in ArcGIS 10.1

[17] http://www.esri.com/software/arcgis/extensions/streetmap/index.html

Our FiberAnalytics drain database[18] tracks current and potential demand of five major feedstock types[19] in NC and the four surrounding states. These include pulpmills, pellet plants, chip mills and chip export companies, OSB and fiberboard plants, power companies, combined heat and power, and other process steam facilities. This dataset is updated regularly making it the most reliable and complete data source for drain in our region.
Other spatial data used as requested by clients include poultry and swine farms by size, parcels, major powerlines, rail systems and canals, certified forestlands, deferred tax parcels, and corporate lands (TIMOs and REITs).

Statewide, Coarse Resolution Assessment

Clients have requested a statewide view of potential biomass commodities to quickly ascertain potential "hot-spots" in the state based on feedstock mix and travel cost criteria. We provide this analysis through a spatial supply-distance model for each biomass resource type outlined here. The gross supply, drain, and net supply models used for statewide analysis are provided for in Figure 1, using hardwood logging residues and hardwood whole-tree chips as an example.

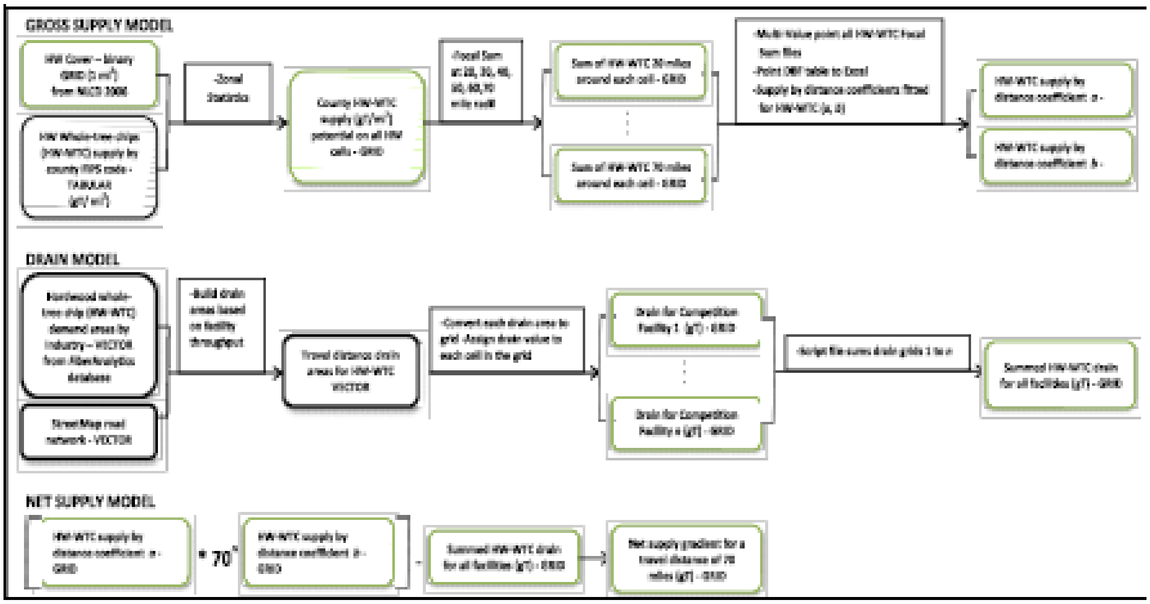

Figure 1. Flow chart for statewide biomass analysis models used by NCSU *Fiber*Analytics. This flow chart example shows the steps for the gross hardwood logging residues supply, drain for whole-tree chips (from logging residues), and the net hardwood logging residue gradient map produced. The net supply model assumes the client wants to know the amount of hardwood logging residues at a 70-mile radius search. These models are currently developed for logging residues, other removals, and pulpwood for hardwoods and softwoods, and for corn stover and hay, but can be modified for many uses.

The NLCD grid is resampled to 1-mi^2 resolution and reclassified into four binary land cover grids (hardwoods, softwoods, crops, and hay/pasture) where "1" is assigned to cells in that land use and

[18] We assume a conservative annual throughput of 90% of the boiler plate specifications, which may tend to overestimate drain for a plant, but we would rather stay on the conservative side of our net supply estimates

[19] These are hardwood pulpwood, softwood pulpwood, hardwood whole-tree chips, softwood whole-tree chips, and fuel or "dirty" chips

"0" to all other cells. County biomass estimates (in gT/mi^2)[20] are assigned to every "1" cell in the associated land cover grids. This equally distributes county-level green ton estimates to every cell in that land cover class and results in eight[21] "biomass supply" layers. Next, to each biomass supply layer, we apply a series of neighborhood functions[22], each designed to sum green ton estimates at 10-mile to 70-mile radii circles around each cell in the layer. Combined[23], these green ton values are used to develop supply curve coefficients for every cell in a given biomass supply layer. The resulting supply curve data are fitted in Excel to the exponential model:

$$gT = ad^b \qquad [1]$$

where, gT = the annual gT potential for each cell its own *d*-radius supply area
 d = maximum travel distance around each cell
 and a, b = fitted coefficients apply to each cell.

This yields two raster grids (from *a* and *b*, Eqn. 1) for each biomass resource that are the basis of the spatial model.

The demand grid is developed by: 1) creating drain polygons[24] around each facility location; 2) converting drain polygons to separate 1-mi^2 raster grids, 3) assigning each cell in the grid[25] that facility's feedstock type and annual throughput; and 4) adding up all similar feedstock requirement grids layers. This results in a statewide drain grid[26] for each of the four major feedstock types, accumulating where drain areas overlap.

Given a "prescription" by a client for annual biomass feedstock requirements and a preferred distance, we can apply the model using map algebra. An example may be a pellet mill requiring 600,000 gT annually of hardwood pulpwood. They prefer to purchase within 50-miles of their site and want to account for current demand. The spatial supply model simply becomes:

$$net\ gT_{[hw\ pulp]} = \left(a_{[hw\ pulp]} \times 50^{b_{[hw\ pulp]}}\right) - drain_{[hw\ pulp]} \quad [2]$$

Where, $gT_{[hw\ pulp]}$ = resulting hardwood pulpwood supply gradient grid
 $a_{[hw\ pulp]}, b_{[hw\ pulp]}$ = model coefficient grids for hardwood pulpwood
 $drain_{[hw\ pulp]}$ = drain grid for hardwood pulpwood

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20 Based on the county acreage estimates for the four land cover types described earlier

21 These are 1) hw logging residues, 2) hw other removals, 3) hw pulpwood, 4) sw logging residues, 5) sw other removals, 6) sw pulpwood, 7) corn stover, and 8) hay

22 Performed using the Focal Statistics tool in ArcGIS 10.1

23 Performed using the Multi-Value Point" tool in ArcGIS 10.1

24 Described in the next section of this document. These varying in sized based on the facility feedstock throughput from 30-mile to 100-mile travel distances

25 Performed using the "Polygon to Raster" tool in ArcGIS 10.1

26 Performed through Python script that performs adding multiple raster files (~85) for each feedstock demand type

The result is a gradient of net supply potential surrounding every cell in the grid that is modified by the drain for that cell. The gross volume map generated in the parentheses of Eqn. 2 is seen in Figure 3(a), the drain map is seen in Figure 3(b), and resulting net volume map sis seen in Figure 3(c).

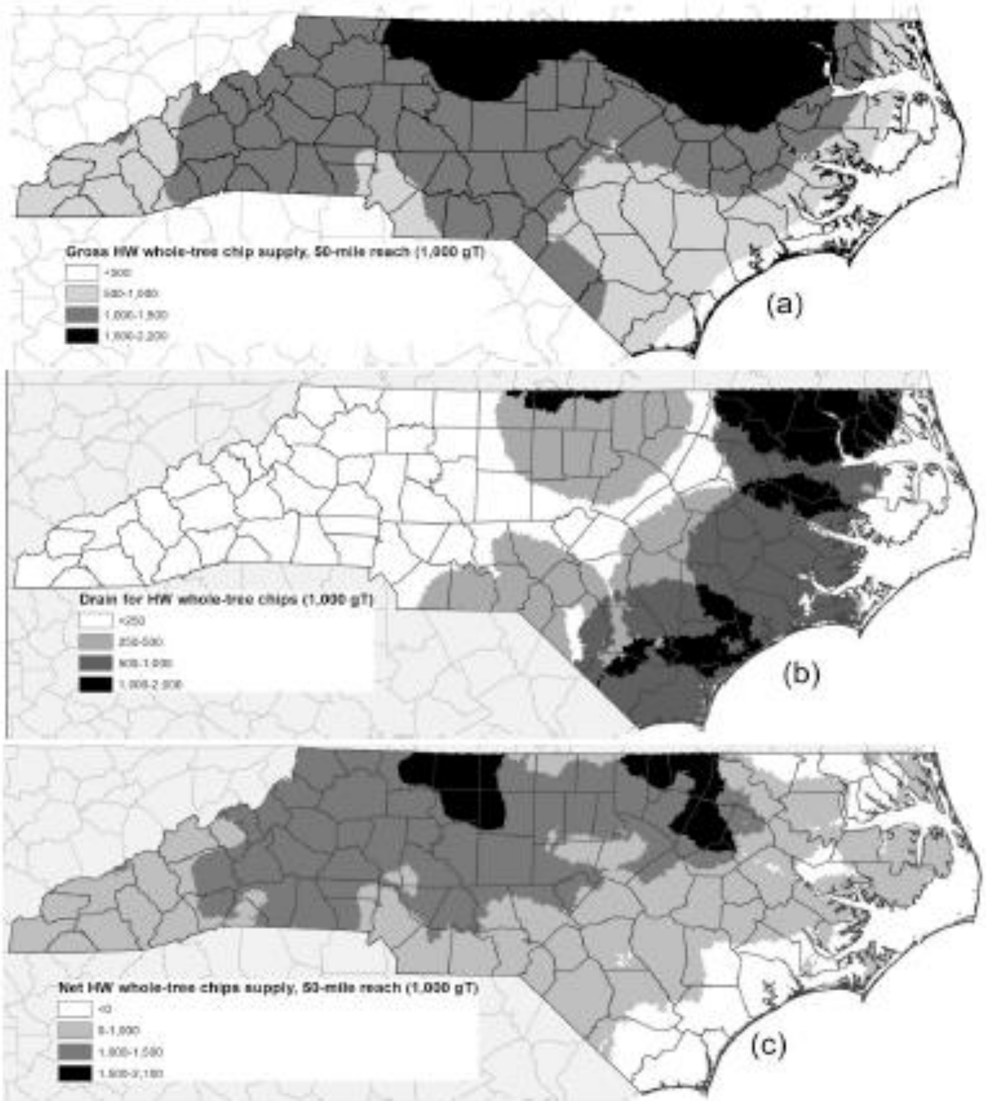

Figure 3. NC statewide biomass estimates for logging residues and other removals (whole-tree chips) in gross supply (a), drain (b), and net supply (c) for a 50-mile reach around every 1-mi² raster cell in NC. This provides an overview across the state where the best locations for net HW whole-tree supply exists.

This flexible procedure allows for numerous modifications. For one project we analyzed supply for 70-miles around rail lines to determine the locations of fiber sourcing along the lines (Figure 4). Clients might require a variety of feedstock "recipes" (i.e. 50% corn stover, 50% hardwood logging residues) which can be accommodated by the model.

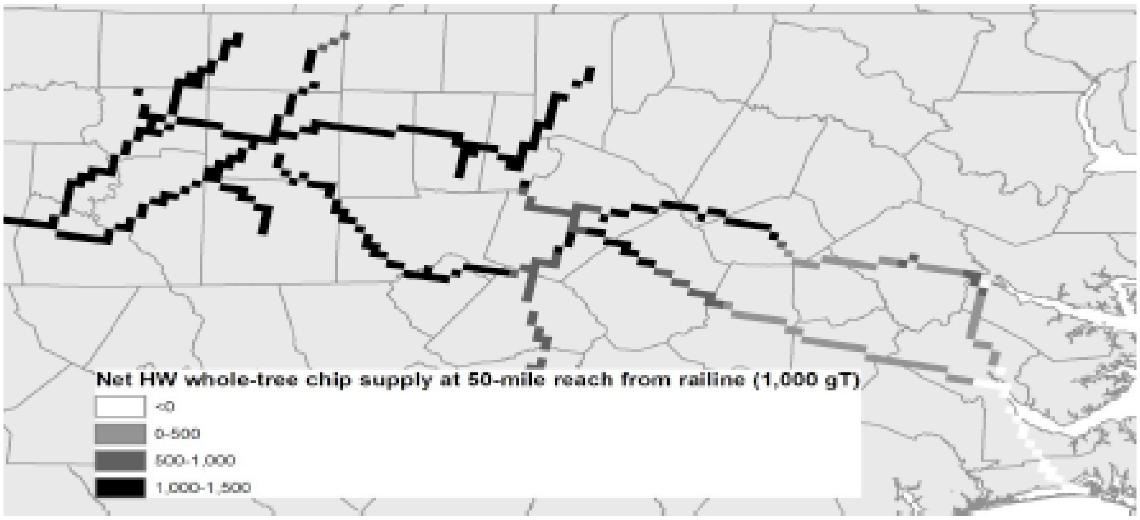

Figure 4. A modification of the statewide analysis shows net whole-tree chip supply for a 50-mile reach around selected NC rail lines, depicted in1-mi² raster cells. This shows poor supply near the coast as a result of reduced hardood loggingin that region.

Detailed, Site Specific Analysis

The majority our analysis occurs on regions surrounding predetermined sites. In the past 5 years, we have performed roughly 50 site analyses for clients. We have the ability to tailor any analysis as per a client's needs and continue to improve our methods and services; however, all projects include detailed resource supply-drain analysis described below. The gross supply and drain models for site specific analysis are depicted in Figure 2, using hardwood land cover

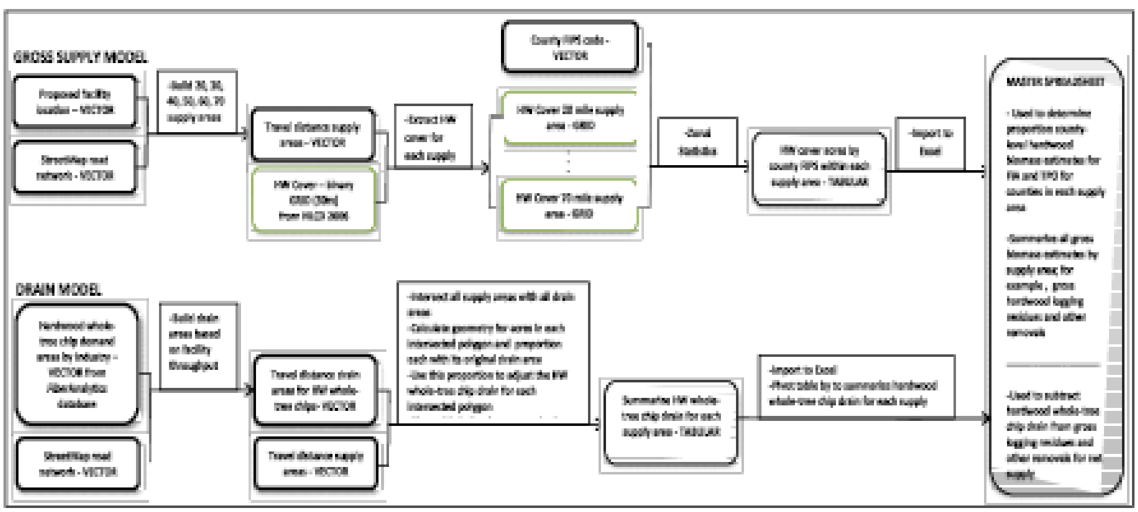

Figure 2. Flow chart for site specific biomass analysis used by NCSU *Fiber*Analytics. This flow chart example shows the steps for how the analysis for gross hardwood biomass and drain would be for a location provided by a client. Net hardwood biomass calculations are completed in the master spreadsheet. Once the acreage data is input into the spreadsheet all data listed in Table 1 are computed and summary reports and graphs are generated.

Gross supply is developed in the following steps. In a master spreadsheet for each client, FIA, TPO, and NASS data are organized by in a county using the unique FIPS number serving as the lookup key. Clients provide us location(s) they are investigating which are loaded into ArcGis 10.1 and have distance-based supply polygons constructed around them using road networks which provide a more accurate estimate of supply area based in road system response to topography[27] (Figure 5). These are built according to client specifications but we suggest a range between 20-mile to 80-mile ranges in 10-mile increments, that provides enough data points to build supply-distance curves. These supply polygons are used in extracting the four land cover types into each service area. If four service areas area required (ranging 20 to 80 miles), then sixteen land cover supply grids are produced.[28] Each resulting grid cell has its county FIPS associated to it,[29] producing tables that summarizing acres of land cover the service area has in each county. County FIPS and associated land cover acres are copied to a lookup table in master spreadsheet. For each land cover type proportions are calculated for supply area acres in the county to total county acres. This proportion is used to adjust the county-level biomass estimates for all FIA, TPO, and NASS data for each county in all supply areas which is then summarized for each supply area.

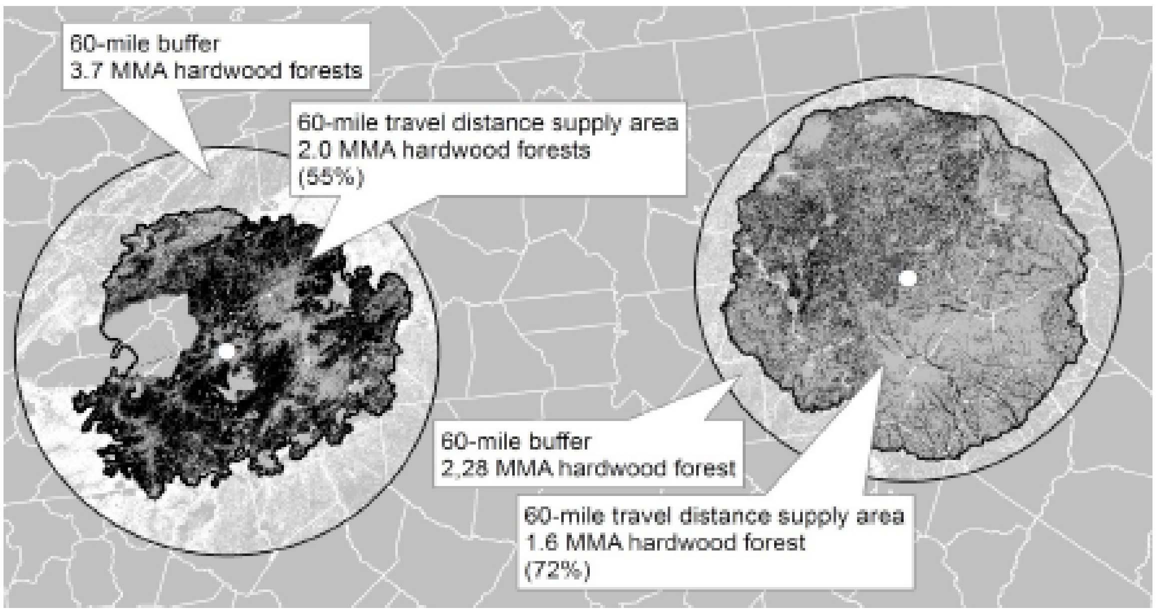

Figure 5. This illustrates the importance of generating hardwood acreage estimates using road networks compared to buffer. Hardwood forests inside 60-mile buffers are in white and hardwood forests inside 60-mile travel distances are in black. Travel distance, and thus supply area varies according to topography, thus the mountain 60-mile supply areas have only 55% of the hardwood forest land as the 60-buffer does. Piedmont road networks are better distributed, but still the 60-mile travel distance based supply area only has 72% of the hardwood forests as the 60-mile buffer.

The spatial drain model is developed from our list of pulpwood and whole-tree chips users. Drain areas are developed using road networks, the travel distance ranging from 30-miles to 100-mile

[27] Performed using the "New Service Area" tool in ArcGIS 10.1. This gives a more realistic supply area than using the Focal Statistics, which only using circles, as in the statewide, coarse resolution analysis.

[28] HW20, HW40, HW60, HW80, SW20,...,SW80, CROP20,...CROP80, PAST20,...PAST80

[29] Performed using the "Zonal Statistics as Table" using a county layer's FIPS code as the summarization attribute

depending of the facility throughput[30]. All drain polygons are then intersected[31] with the supply area polygons and the portion of each facility's drain area lying inside a service area is proportioned to the facility's total drain area. This proportion is used to estimate the amount of drain each facility contributes to each supply area. These are summed in the spreadsheet for total drain by supply area. Net supply (gross supply minus drain) is thus estimated at the supply area level. Figure 6(c) illustrates supply curves generated from the supply region landcover in Figure 6 (a) used with FIA and TPO data and *Fiber*Analytics drain model (Figure 6(c)). This is one of many outputs provided by this service.

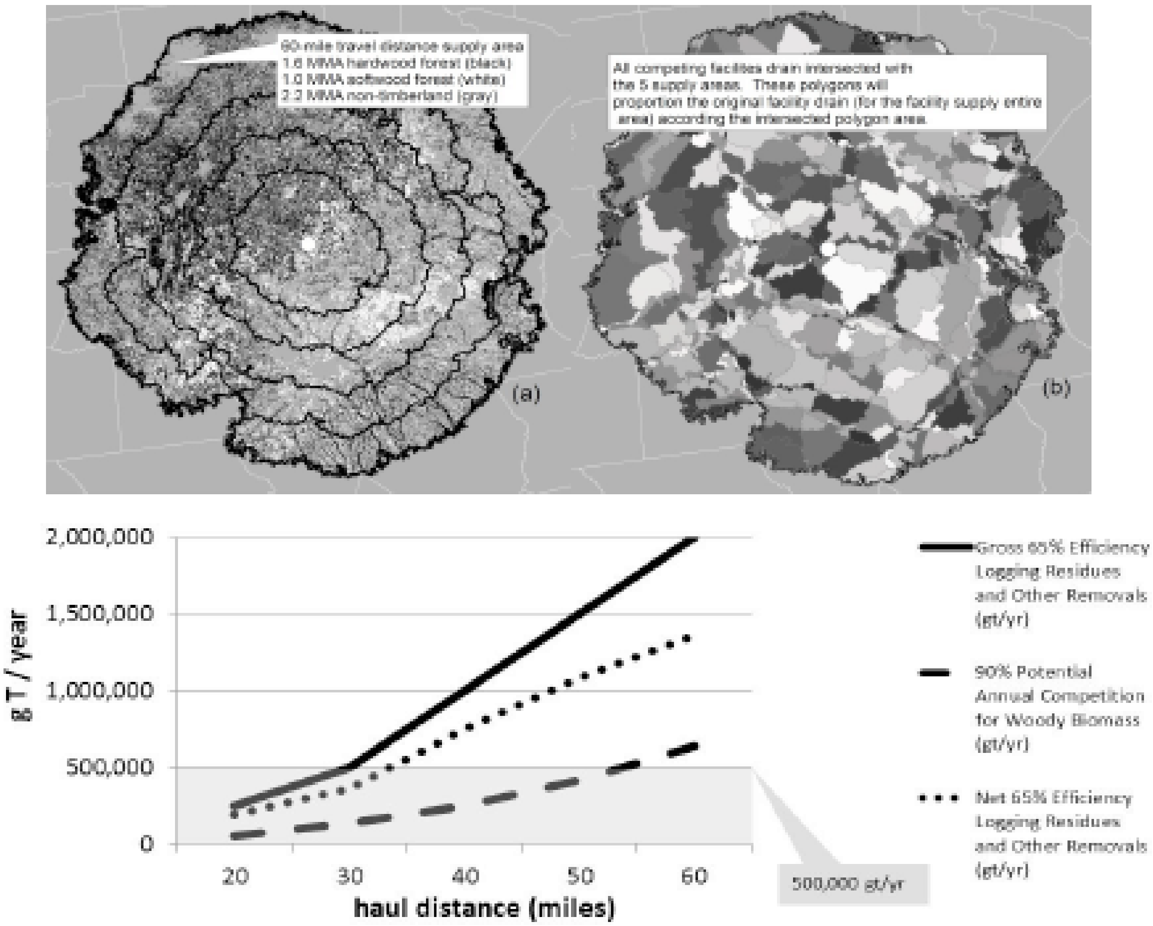

Figure 6. Site specific analysis for clients wishing for complete analysis of biomass resources for a point (center dot). Map (a) shows the spatial distribution of hardwood (black) and softwood (white) forests inside 20-mile to 60-mile travel distance supply areas. This is used in conconjuction with FIA and TPO to determine analyze a wide variety of data on whole-tree chip and pulpwood chip potential. Map (b) is a representation of the FiberAnalytic's drain model after intersection with the supply areas. This is used to derive the amount of drian within each supply region. Graph (c) is a representation of one form of supply curve generated from the analysis showing the gross volume of logging residues and other removals (all species), drain for whole-tree chips, and the net volume after drain. If a client is looking 500,000 gT/yr feedstock, this anlaysis indicates the net volume (dotted line) meets the plant needs at roughly 35 miles.

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[30] Performed using the "New Service Area" tool in ArcGIS 10.1.

[31] Performed using the "Intersection" tool in ArcGIS 10.1

In effort to continue assisting our stakeholders, continuously provide improvements to our services. For example, we are currently developing an interactive online version of this analysis tool that should be of great value to potential clients in and around NC. Another improvement is the adjustment of forestland volumes found in streamside management zones across the state.

Successful Results

NCSU Extension Forestry FiberAnalytics has leveraged this use of woody biomass analysis in a number of successful projects. We provided data necessary for the development of the southeast's first RPS (Senate Bill 3 2007). One of our clients has two pellet plants in the final planning stages. Analysis provided for regional economic developers resulted in one operating pellet plant and one under construction.

Analysis for another regional economic developer has a major pellet plant and at least one biomass power plant under consideration. A university CHP facility now planning conversion from coal to wood. Two military installations now considering a 25 MW biomass power plant from our work and an energy company has developed several CHP projects and is planning others. These all lead to a strong green economy, job growth, and better management opportunities for landowners across NC.