Department of Revenue
Forest Productivity Project
Contract #014-06

Final Report

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Introduction

From 1991 to 1994, a previous forest productivity study was completed for the MT Department of Revenue (**DOR**) using the latest timber growth and yield modeling science, remotely-sensed imagery and computer science and GIS technology. The end product of that work was two Mylar map sheets for each county depicting several color-coded classes of forest productivity, roads, hydrography, county boundaries, annotation and other map features. A deterministic growth model (**FOREST_BGC**) was used and modeling was based on an incomplete state-wide input dataset. Full coverage for topographic and climatic variables were not available and a considerable amount of filling holes had to be done with the conversion of 1:100,000 scale map data to 1:24,000 scale map data where that map data was lacking. Also, soil attributes were not considered.

In the spring of 2006 the faculty at the U of M College of Forestry & Conservation was asked to submit a new proposal to rework the productivity for private forested lands across the state of Montana using the latest modeling science and taking soil attributes into consideration. The focus would be on modeling site index, no remotely-sensed imagery would be needed, and timber polygons would be delineated by DOR staff.

Although this project was officially approved on July 1, 2006, it in fact started March 1, 2006 because field equipment needed to be purchased, students needed to be hired and plans had to be made to conduct field work during the summer of 2006. This field work commenced on May 23, 2006 using three 2-person crews and continued through August 22, 2006. Our task was to derive forest productivity maps for each county in Montana containing timber polygons regardless of ownership. Ultimately the property boundaries of private landowners having 15 or more acres of commercial timber would be taxed on a sliding scale based on classes of timber productivity. The main thrust of this project was to collect site index (**SI**) data for four species [Douglas-fir (**DF**), western larch (**WL**), ponderosa pine (**PP**) and lodgepole pine (**LP**)] of trees located across Montana covering a wide range of topographic and climatic conditions and, together with soil attributes obtained from a national NRCS data mart, predict Douglas-fir SI as a function of these biogeoclimatic variables. The big advantage of deriving a soil-site equation by statistical methods was that DFSI and hence forest productivity would be estimated with a known error term. Estimated DFSI together with clumpiness (a measure of growing space) were used to derive timber yield at the culmination of mean annual increment (CMAI) of a fully stocked stand. When annual precipitation was less than 18 inches but greater than 10 inches a stocking factor was applied to CMAI so as to reduce it due to the fact that the stand was not fully stocked. The units for CMAI were net Scribner board feet per acre per year and it was judged that timber land producing less than 100 board feet per acre per year was to be classified as <u>non-commercial</u>. Timber lands producing greater than 100 board feet per acre per year were classified as <u>commercial</u> and grouped into multiple productivity classes that were 75 board feet per acre per year in width. Ultimately productivity maps were created in 30 x 30m raster (grid) format using multiple spatial analysis functions in ArcGIS v9.x for <u>each</u> of the 48 counties in Montana designated as having timber stands. For the sake of appearance and ease-of-use these raster maps were converted to polygonal maps after a complex process of aggregating/dissolving adjacent pixels (grid cells) into noncommercial/commercial groups based on a set of rules (at least 5 acres or more in size for noncommercial and 15 acres in size for commercial) and then assigning average productivity values to classes (grades) of commercial timber.

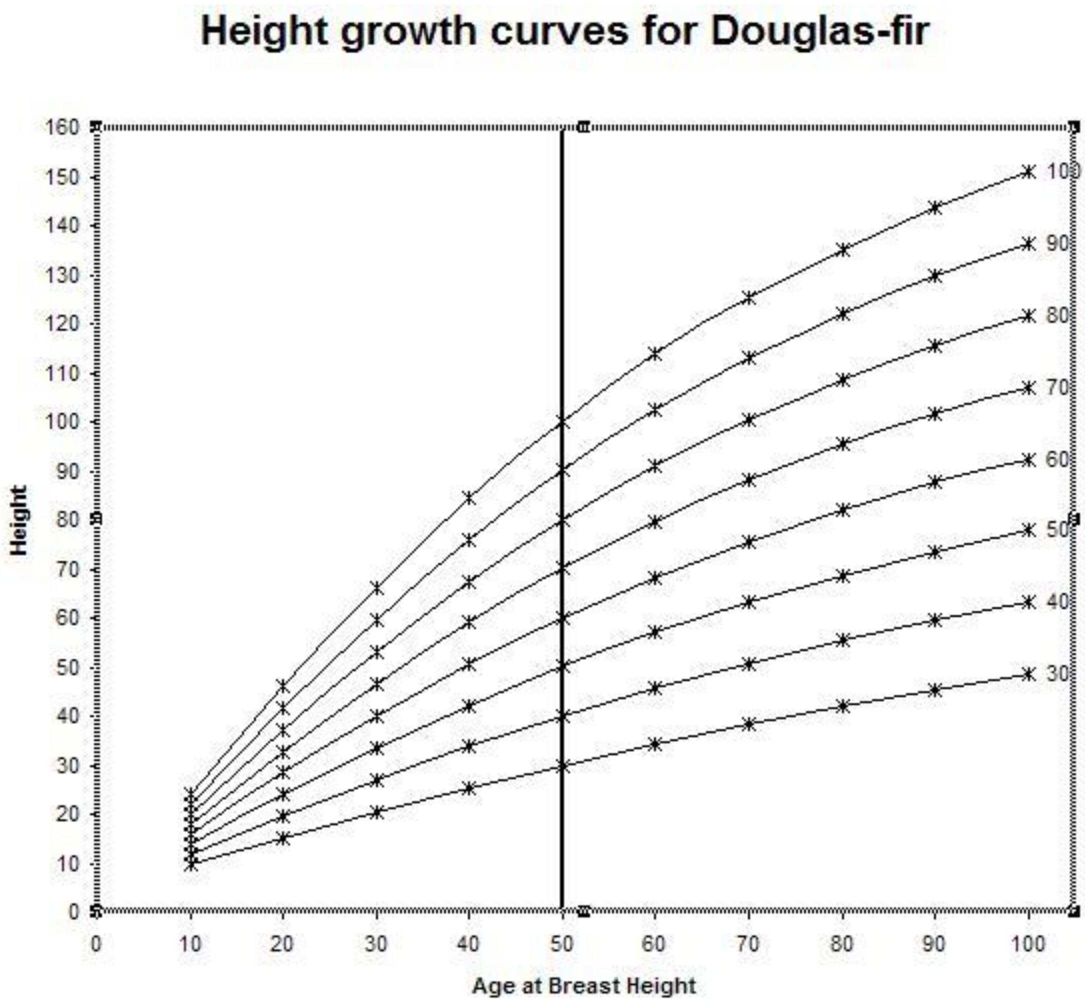


Figure 1. Site index curves for Douglas-fir growing in Montana.

Site index is a measure of site quality and represents the height of a vigorous, free-growing, unsuppressed tree at the reference age of 50 years (Figure 1).

Field work

For 70 days during the summer of 2006 three 2-person field crews sampled a total of **276** locations and recorded the age, height, and radial growth for **1209** trees (Figure 2). In addition field crews took digital photos of all the measured trees at the above locations as well as their x, y coordinates recorded with a GARMIN GPS receiver. We used a stratified-list sampling method based on precipitation zones within ecoregions covering the state of Montana. We wanted our sampling locations to capture the wide range of naturally-occurring biogeoclimatic conditions (environmental gradients) under which timber stands grow in Montana. Subsequent graphic displays (histograms) comparing the distributions of the collected data to the naturally-occurring distributions across Montana by slope, aspect, elevation, precipitation, and heat showed a reasonably close match. Thus a very good response surface was produced from which the modeling of site quality (**DFSI**) could proceed with confidence and reliability.

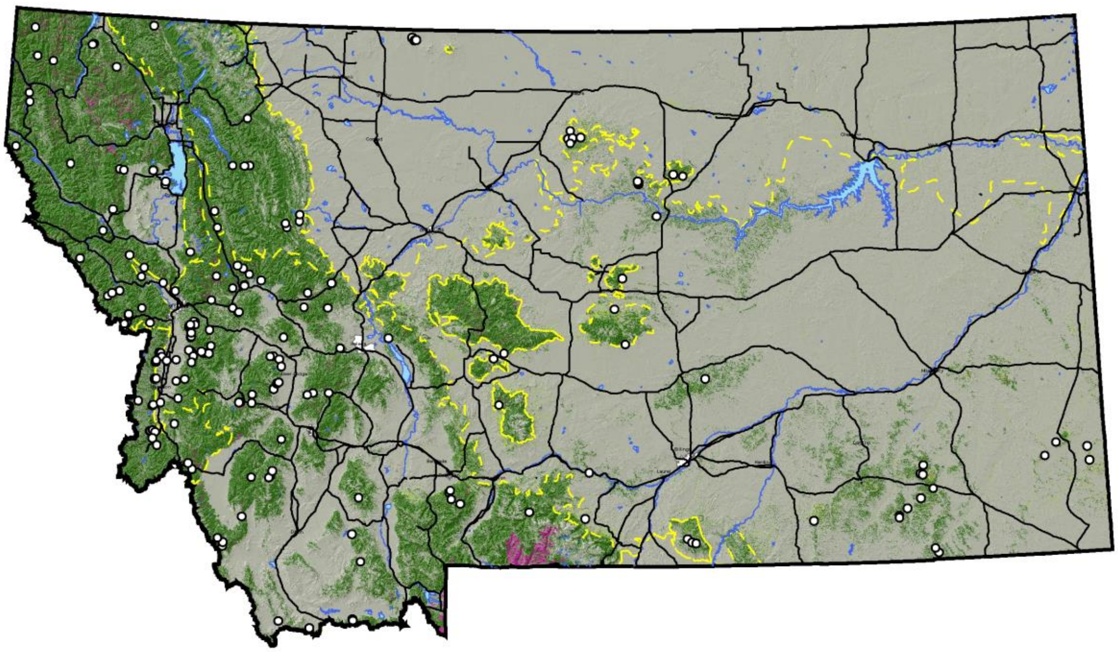


Figure 2. Location of 204 SI sites visited by field crews by August 2, 2006.

Data collection/organization

Spatial (Geographic)

Soils:
From the NRCS Soil Data Mart Web Page http://soildatamart.nrcs.usda.gov
The state of Montana was chosen first, followed by the selection of a specific county, and finally followed by the selection of a specific Soil Survey Area (SSA). A given county may be covered by one to six SSAs, each one of which must be retrieved separately. At this point only the spatial data, i.e. soil survey polygons, are retrieved and not any soil attribute data. A total of **58** unique SSAs were retrieved to represent 48 counties.

Precipitation:
The staff at the State Soil Survey office located in Bozeman have developed raster maps by county containing relative effective annual precipitation (REAP). These 30 x 30m raster GRID data became available from the State Library, Natural Resource Information System (**NRIS**) over the period December 20, 2007 to January 11, 2008 in either Universal Transverse Mercator (**UTM**) or State Plane Coordinate (**SPC**) map

projection format (Appendix H). As it turns out this precipitation data was not found to be as useful as 1 x 1km raster precipitation data for modeling DFSI. Apparently precipitation is not a small area (30 x 30m = 0.22 acre cell) phenomenon and is better represented by a 247 acre (1 x 1km) cell.

Elevation/slope/aspect:
As part of the National Elevation Dataset (**NED**) managed by the USGS, a seamless digital elevation model (**DEM**) spanning the entire state of Montana was obtained from NRIS. This 30m grid was named **ELE30** (Figure 3). While the DEM was available as a floating point file, to increase computational efficiency, we converted elevations to integer format in meters.

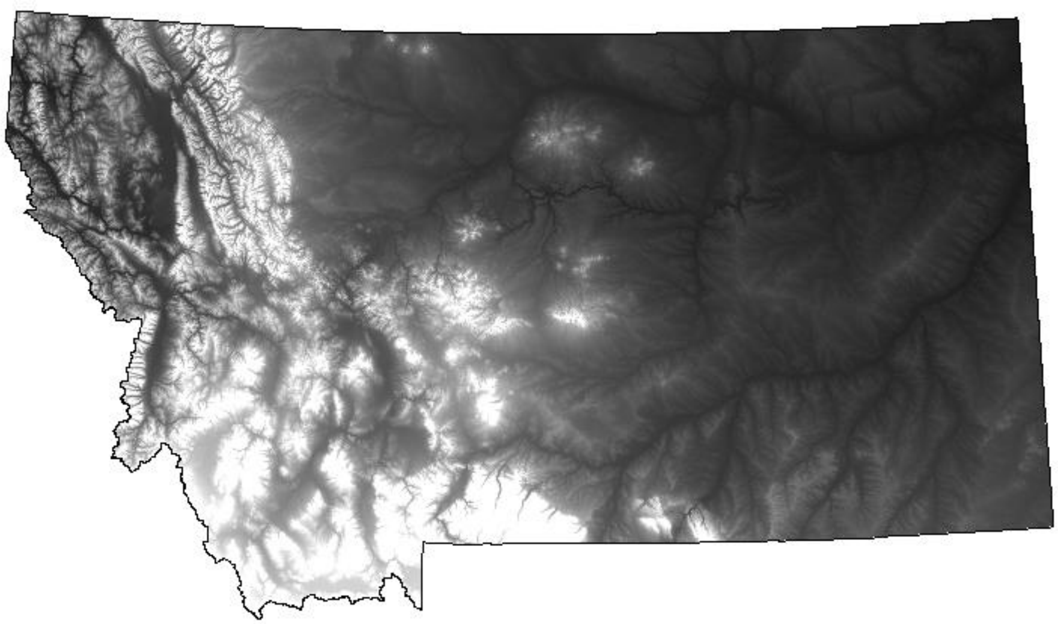


Figure 3. 30m elevation grid for the state of Montana

From this DEM two more topographic 30m raster grids were generated namely 1) degree slope and 2) aspect, in integer format using Spatial Analyst in ArcGIS v9.x. Decimal values were rounded up when converted from floating point to integer format.

Climate:
Spatial climate data were obtained from http://www.daymet.org/. Based on 30 years of daily data from 1975-2005, a 1 km raster grid (**PCP1000**) representing total annual precipitation in cm was obtained and resampled into a 30m raster grid (**PRECIP30**) covering the whole state of Montana. From the Rocky Mountain Research Station Fire Science Laboratory, who created the **WXFIRE** 30m raster dataset based on both DAYMET and Biome BGC (NTSG, 2006) output (Keane, 2006), several useful grids were obtained. Note: WX stands for 'weather' and refers to a process where DAYMET data drove BGC to create a suite of biophysical variables that were mapped with a spatial resolution of 30 m by ecoregion that covered the entire USA. Three useful 30m raster grids were: average annual degree-days in centigrade (**ZxxDDAY1**), average

annual photosynthetically active radiation (**ZxxPAR1**) in mJ/sqm/day and average daily temperature in centigrade (**ZxxTAVE1**). Note: **xx** refers to one of the ecoregion numbers listed below, and radiation was derived by averaging values over three grids having mean daily values for the months of May, June, and July. These latter three grids were obtained by seven ecoregions numbered 10, 19, 20, 21, 22, 29 and 30 that covered the state of Montana (Figure 4). Note: Some of these raster grids were mosaicked together in ArcToolbox on an as-needed basis when the boundary of a specific county whose timber productivity was being modeled straddled more than one ecoregion.

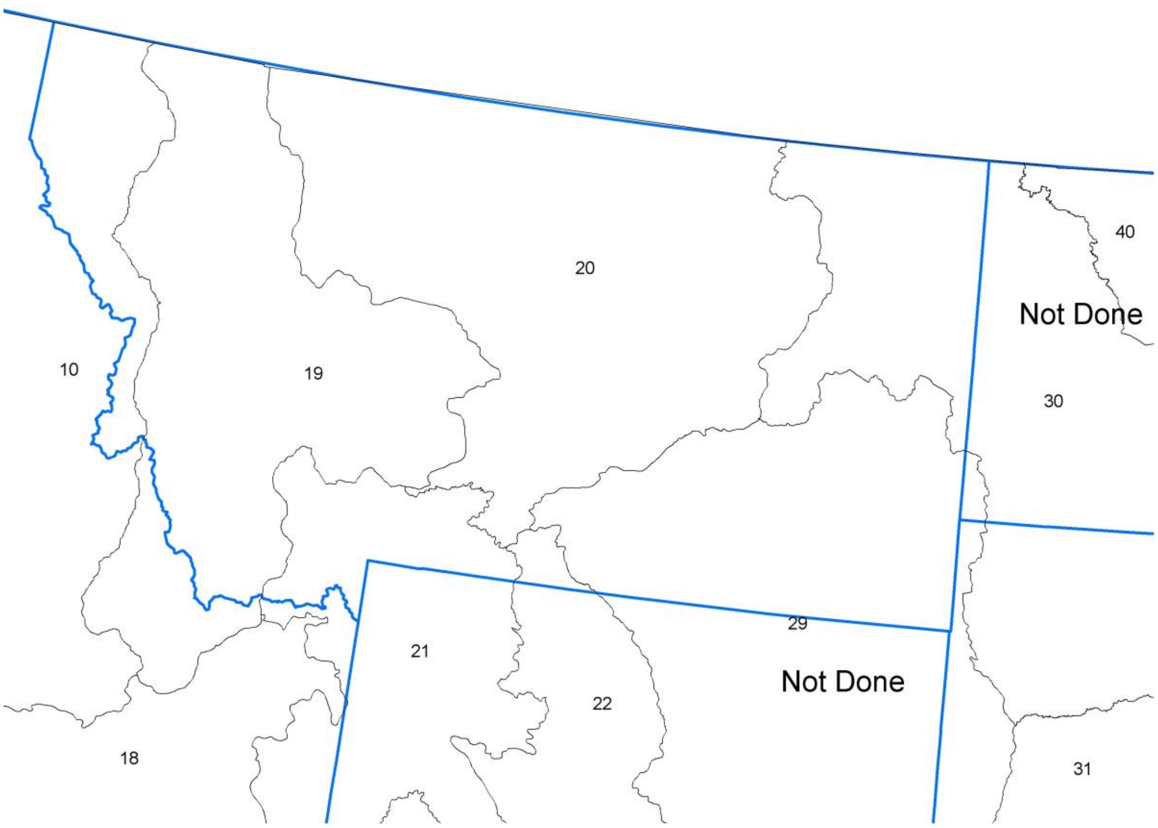


Figure 4. Boundaries of completed and uncompleted ecoregion climate 30m raster datasets as of January 19, 2007.

Note: All **58** SSA polygon files covering the 48 counties and all **23** (2 + 2 * 7) 30m raster grids had to have their map projections converted from either Albers or UTM to SPC.

County boundaries/timber polygons:
A state-wide geodatabase named "**statewide_flu.gdb**" containing county boundaries and final land use polygons became available on June 25, 2008. From this geodatabase a boundary and timber polygon shapefile was extracted for each county and placed into separate subdirectories named "new_counties" and "forest map layers" respectively. Each county timber polygon shapefile had a field named "flag" added to it that contained an integer value of 1. Using this field, a raster timber mask was later created.

Non-spatial (tabular) databases

Soils:
Approximately seven months were spent retrieving, processing and organizing the four soil attributes that were judged by the State Soil scientist to be relevant to modeling DFSI. These were available water content (**AWC**) in inches/foot, cation exchange capacity (**CEC**), **PH**, and percent bare ground (**BARE**). The first three soil attributes were related to soil profiles by horizon over the first 61 cm (24 inches) while the fourth soil attribute was based on a field-estimated amount of ground covered by rock, water and not soil located in a given soil survey polygon.

For each of these soil attributes a custom set of standard query language (**SQL**) commands were submitted in a text box on the NRCS National Soil Data Mart at http://sdmdataaccess.nrcs.usda.gov/ and click "Submit a custom request for soil tabular data". Embedded in the script is a county code of the form "**MTxxx**" where **xxx** ranges from 001 to 111, a unique code for each of the 48 counties having timber stands. So a total of **192** soil data mart queries were made. Note: Select the proper time frame and format for the results, the desire for the inclusion of column names and setting a field delimiter (Appendices B and C).

Once the requested files have been downloaded in zipped form they must be unzipped and processed further. Records are uniquely identified by MUKEY and consist of a number of fields. AWC is derived from USDA soil textural classes and requires no further processing (Appendix D). For percent bare ground, most soil survey polygons do not have any bare ground, so the matching MUKEY must be located and the non-zero value assigned to that record. With respect to CEC and PH, further processing is required because multiple records appear for a given MUKEY since there are a variable number of horizons for a given soil pit. Using a 2 tiered pivot table process in Microsoft EXCEL these two soil attributes are weighted by horizon depths in a given soil profile and averaged across multiple soil pits to result in a single CEC and PH value for every single occurrence of a MUKEY (Appendix F). These four soil attributes are merged into a single EXCEL spreadsheet which is converted to a .DBF file. This county soil attribute combination file was later joined to the spatial soil survey polygons for a given SSA in ArcGIS v9.x.

An examination of the soils data revealed that a number of SSAs had missing soils data. In some cases an entire SSA had no soil data at all. This fact would have a major impact on the subsequent modeling of DFSI. Even the modeling dataset had **57** records out of **325** with missing soils data. These missing soil attribute values were hand-cranked or obtained from soils publications by Mike Hansen on February 8, 2008.

Site index:
A second dataset (841.DAT) consisting of **154** tree records that represented **89** sites was added to the DOR field dataset so as to increase the sample size. This second dataset was gathered by Kelsey Milner for his Ph.D. dissertation research in 1984 on Champion International Corporation (**CIC**) fee lands, now Plum Creek Timber Co. Due to the rejection of unacceptable SI trees (tree age outside acceptable range of 40 to 80 years old or variable radial growth) the DOR dataset collected during the summer of

2006 was reduced from **276** to **236**. So the combined dataset was **325** (89 + 236) sites (Figure 5). The locations of all these installations was determined by obtaining the centroid of the x, y coordinates of all measured site index trees at a given site (clustered on an approximate 0.5-acre area).

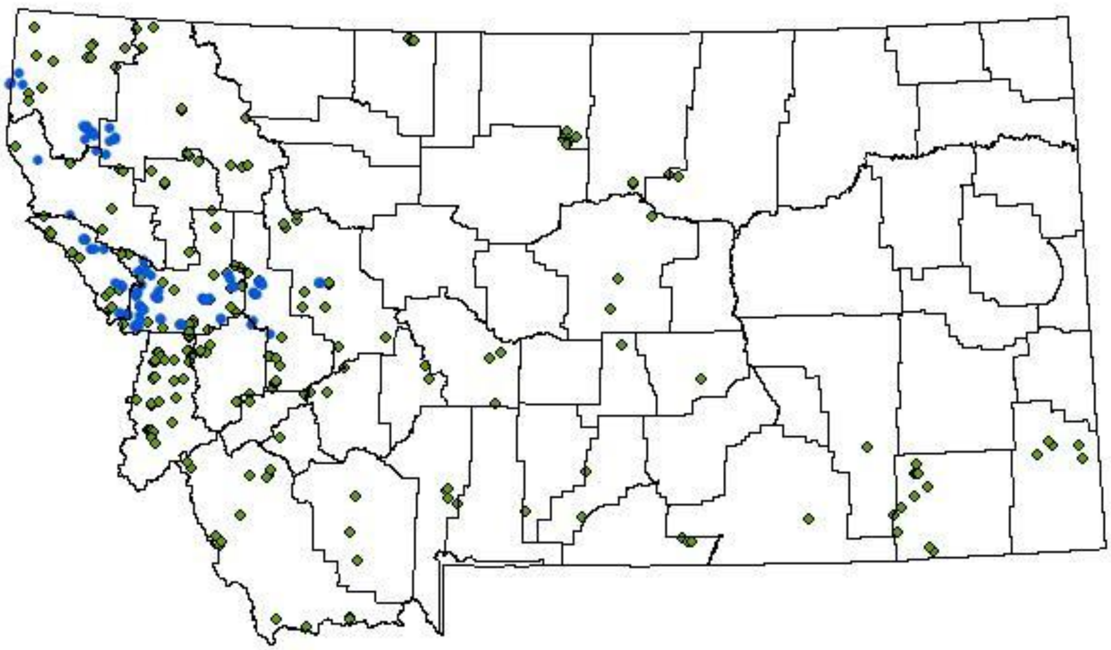


Figure 5. Location of all 325 site index installations (DOR in green and CIC in blue) in relation to MT counties

Other attributes:
Because the coordinates of the centroid of all 325 site index installations were known these points could be superimposed over the various topographic and climate raster grids in ArcGIS to retrieve and export a .dbf file containing elevation (in meters), slope (in degrees), aspect, TAVE, PAR, DDAY and RAIN together with the four soil attributes already mentioned above.

NRCS soil-woodland field records:
Robert Logar, USDA NRCS, MT State Staff Forester, lent The University of Montana two legal-sized boxes containing some 3,000 original soil-woodland field data sheets for a three-month period. The purpose was to enter the location coordinates for all those plots judged to be useful for modeling DFSI. Four different persons worked on this task for three months manually converting information on section sketches and plot narratives into position data. A total of **2,267** records were processed using a specially-designed soil-woodland field record form in Microsoft ACCESS (Appendix G). Previously these plot records had been retrieved from NRCS in a database format but, because of privacy issues, plot locations were omitted from those on-line records. As it turned out, numerous records had missing or incomplete soils data as well as associated tree records with missing attributes such as age, diameter, radial growth, height and other stand variables such as SI, CCF and stand density (BA/ac).

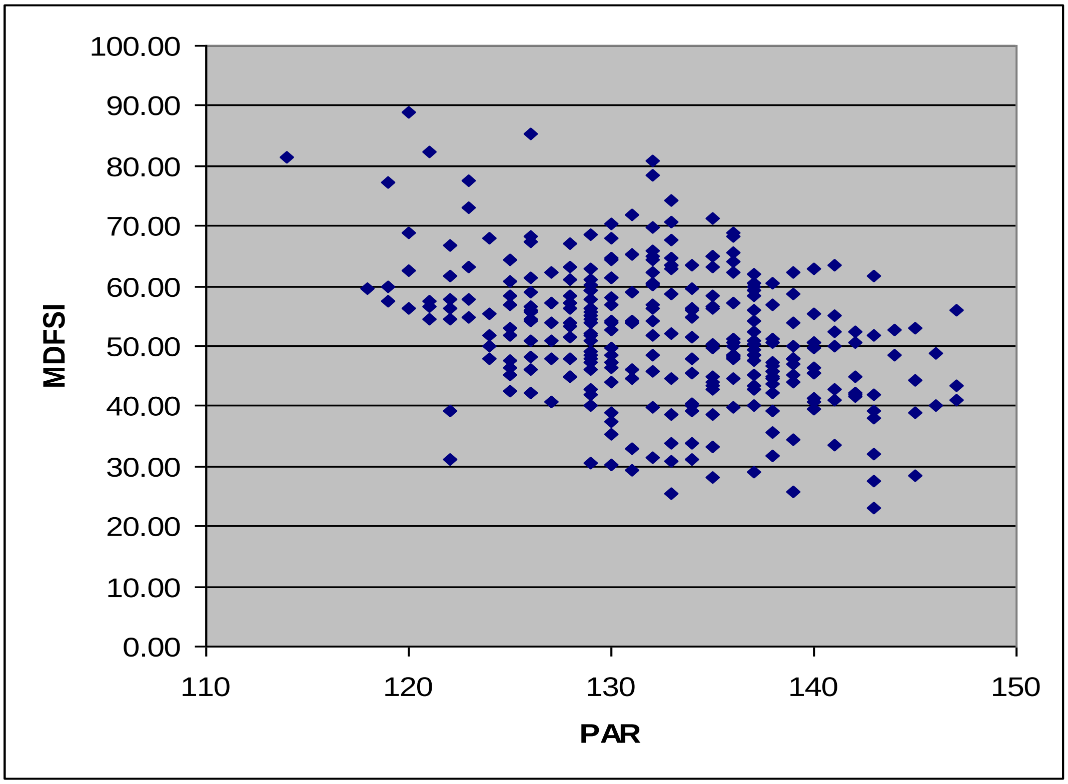
The intent was to use these data (after careful screening) to augment our DFSI modeling either to increase the sample size or use some of these data for validation purposes. In the end none of these data were used.

Tabular Data Processing

The soils, climate and topographic attributes could now be identified at these installation locations and linked to the previously recorded SI values by species. This constituted the final dataset named "**allpts.mdb**" containing 11 possible predictor variables as well as plot ID and x, y UTM coordinates. This database was combined with the SI estimates from the 841 and DOR datasets to produce a new database named "**Alldata.mdb**" using SAS v9.3.

A large SAS program was written by Kelsey Milner to perform data management tasks, compute preliminary data summaries (tabular and graphical), create various interaction terms and perform regression analyses to estimate DFSI as a function of soil, topographic and climate variables (Appendix J). Specifically, data from three different databases was merged by Plot ID, scatter diagrams were produced to display DFSI by various predictor variables to look for trends, identify additional data outliers having high coefficients of variation (CVs), display SI summary statistics, and compute SI ratios between DF and the other three tree species (PP, WL and LP) so as to convert all SI values to DF.

Here are some scatter diagrams of MDFSI plotted against selected predictor (input) variables namely PAR, a 4^{th}-order interaction and ELEV30 showing trends (Figures 6 – 8).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80.00
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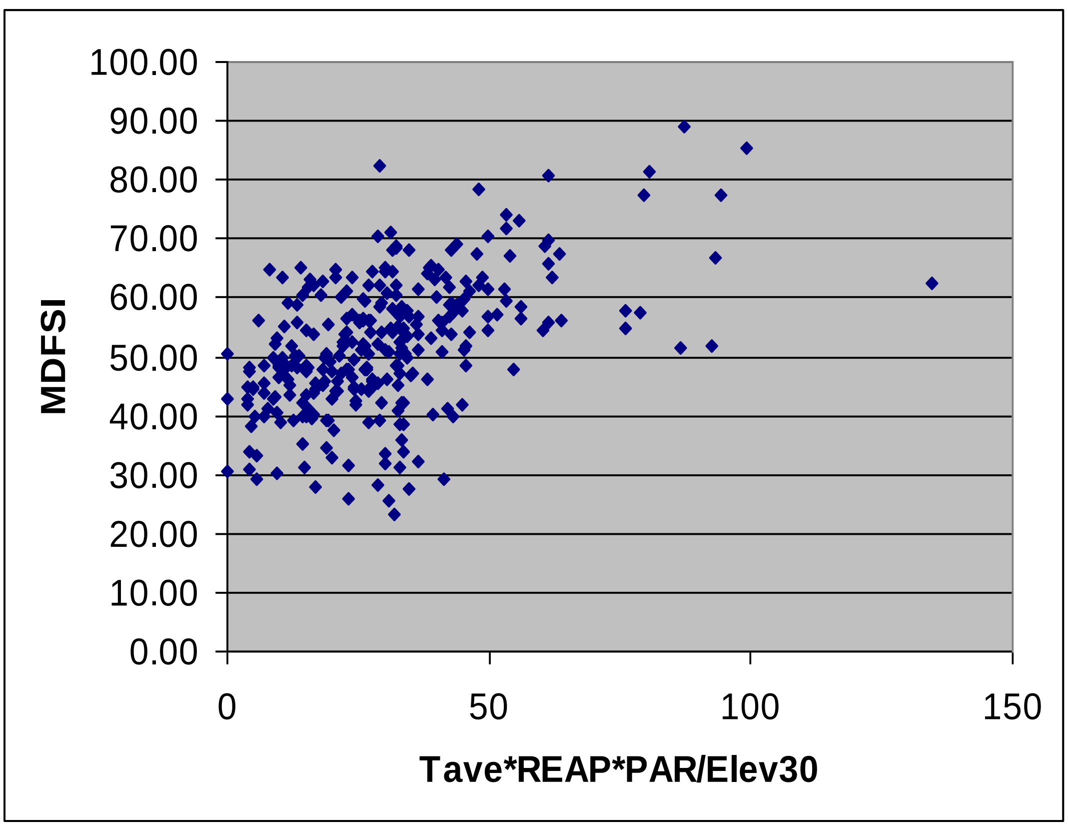
130
140
150
PAR
MDFSI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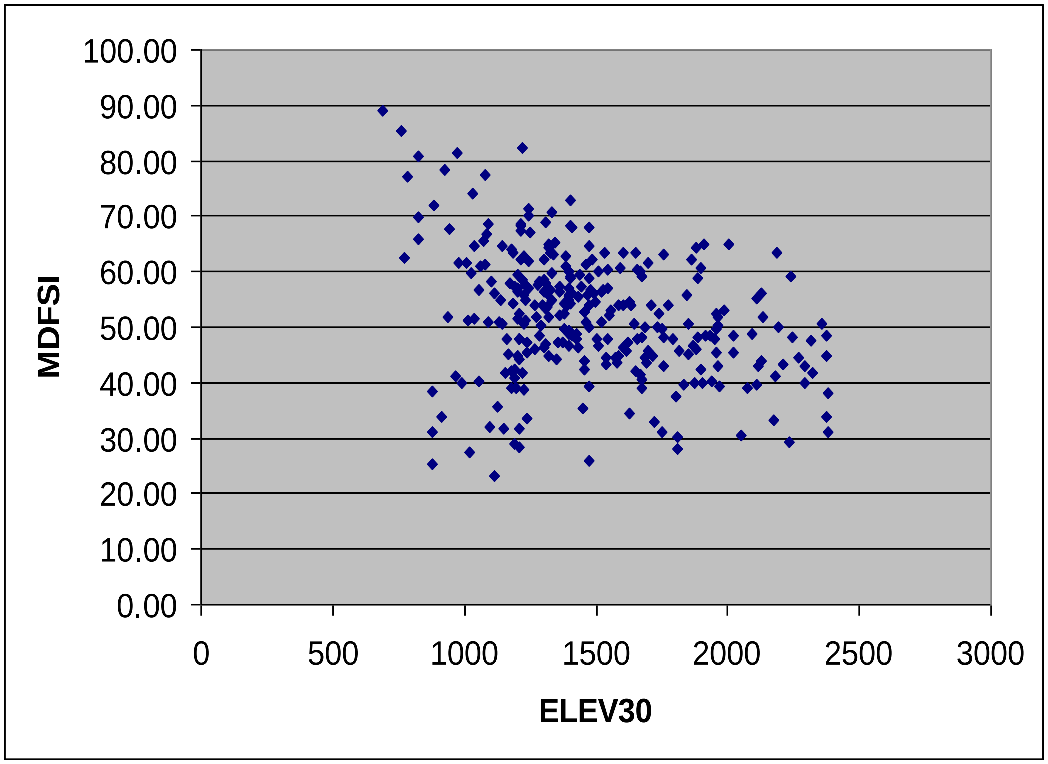


Figures 6, 7 & 8. Scatter diagrams of MDFSI (in feet) versus PAR, a 4th-order interaction and ELEV30.

Notice that PAR and ELEV30 are negatively related to MDFSI while the 4th-order interaction is positively related to MDFSI.

DFSI Modeling

Given the problems with missing soil attributes for many counties, an initial thought was to derive average soil attribute values for soil survey polygons having <u>no</u> soils data from adjacent/nearby soil survey polygons having soils data. Since some soil survey polygons having missing soils data were quite large in area it was judged to <u>not</u> be the preferred method of dealing with this situation. We preferred to develop two DFSI models, one using soil attributes and another without soil attributes, since they would better capture the variability in SI across a wide range of biogeoclimatic conditions.

In the end **two** Douglas-fir site index (**DFS**I) prediction models were developed. **Model 1** predicts DFSI at locations where there are soil attributes present, namely AWC, CEC, PH and % bare ground, while **Model 2** predicts DFSI at all other remaining locations <u>without</u> the use of soil attributes. In addition both models make use of topographic and climatic variables. The predictive behavior of these two DFSI models is similar but not identical. Model 1 shows greater variability as compared to Model 2. Specifically the models are as follows:

Model 1

$$MDFSI = 88.46551 + 164.25967 * [X4\_ccccc] - 2.431415 * [X7\_ccccc] + 1.5038 * [tave\_ccccc] - 0.14095 * [slope\_ccccc] - 4.999 * [ph\_ccccc] - 0.27543 * [cec\_ccccc] - 0.12935 * [bare\_ccccc]$$

where $[X4\_ccccc] = [tave\_ccccc] * [rain\_ccccc] * [awc\_ccccc] / [par\_ccccc] * [elev\_ccccc]$

and $[X7\_ccccc] = [par\_ccccc] / [rain\_ccccc]$

n = 193 $R^2 = 0.52$ SEE = 7.1 feet

Model 2

$$PDFSI = 48.89996 + 2487.80425 * [X8\_ccccc] - 1.1143 * [X11\_ccccc] - 0.13136 * [slope\_ccccc] + 2.01491 * [tave\_ccccc]$$

where $[X8\_ccccc] = [tave\_ccccc] / [elev\_ccccc]$, ccccc = county name,

and $[X11\_ccccc] = [tave\_ccccc] * [par\_ccccc] / [rain\_ccccc]$

n = 219 $R^2 = 0.42$ SEE = 7.7 feet

Notice that the sample sizes for both DFSI equations are substantially lower than the original sample size of 325. This is due to the elimination of installations having high SI CVs. These two DFSI equations were applied to each county separately and then their values were merged into one raster dataset that was then reduced in area to match the existing timber polygons. It should be noted that some counties such as Lincoln had DFSI values as high as **105** ft while other counties like Big Horn had DFSI values below **33** ft.

DFSI Model Validation

In June 2008 Randy Piearson, a private DOR contractor, conducted field sampling and subsequently determined actual DFSI at **14** installation locations, chosen both east and west of the continental divide, that exhibited a range of site conditions. A total of **35** trees were measured and their site index computed. The average SI was **44.99** feet with a standard deviation of **7.26** feet and it varied from a low of **30.68** to a high of **56.88** feet. In all instances it was found that predicted DFSI was within 7 feet of actual DFSI.

Timber Yield Modeling

A commonly-used tree/stand growth simulator named **Forest Projection System** (FPS v. 6) developed by Dr. Jim Arney was used to grow a plantation of DF trees at 10’ by 10’ spacing (435 trees/acre) and assuming a fully stocked managed stand to grow over a 150-year growth projection period for different combinations of site index and clumpiness (a measure a site occupancy). FPS is an embedded Microsoft ACCESS application and has the ability to display stand visualizations over time using **SVS** (Stand Visualization System) and connect to ArcView. Thirteen different SI levels (0.35 to 0.95 in steps of 0.05) in combination with six levels of clumpiness (0.4 to 0.9 in steps of 0.1) produced **78** simulations over the 150-year growth period. Yield was recorded in Scribner Decimal C board feet and the culmination of mean annual increment (**CMAI**) was determined from each of these **78** growth curves (Figure 9). A complex yield model was derived to describe this yield surface as a function of site index and clumpiness as follows:

$$CMAI = 335.809 - 14.987\,(SI) - 695.882\,(CLUMPY) + 34.696\,(X1) - 13.484\,(X2) + 0.03263\,(X3)$$

where

$$X1 = SI * CLUMPY$$
$$X2 = SI * CLUMPY^2$$
$$X3 = SI^2 * Exp\,(CLUMPY)$$

and $n = 78$, $F_C = 2{,}015.39$ $R^2 = .993$ SEE = 20.636 bd. ft./ac/yr

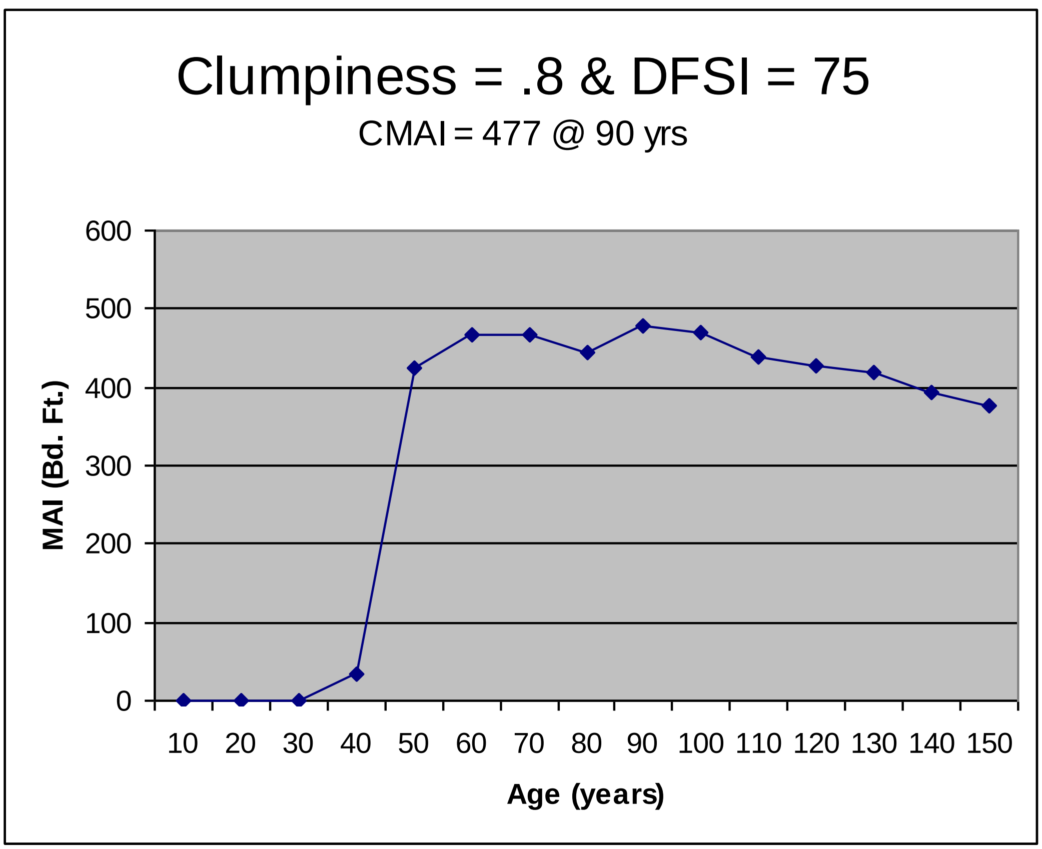


Figure 9. Example of MAI growth curve for DFSI = 75 and clumpiness = 0.8 over the 150-yr projection period.

It was determined that the best value for clumpiness was **0.75** regardless of whether trees were growing west or east of the continental divide. This was based on an examination of the resultant yields derived for a number of test counties such as Lincoln, Rosebud and Big Horn using various clumpiness values from **0.6** to **0.9** with the former producing yields that were judged to be <u>too low</u> and the latter producing yields that were judged to be <u>too high</u>. So the mid-point clumpiness value was chosen.

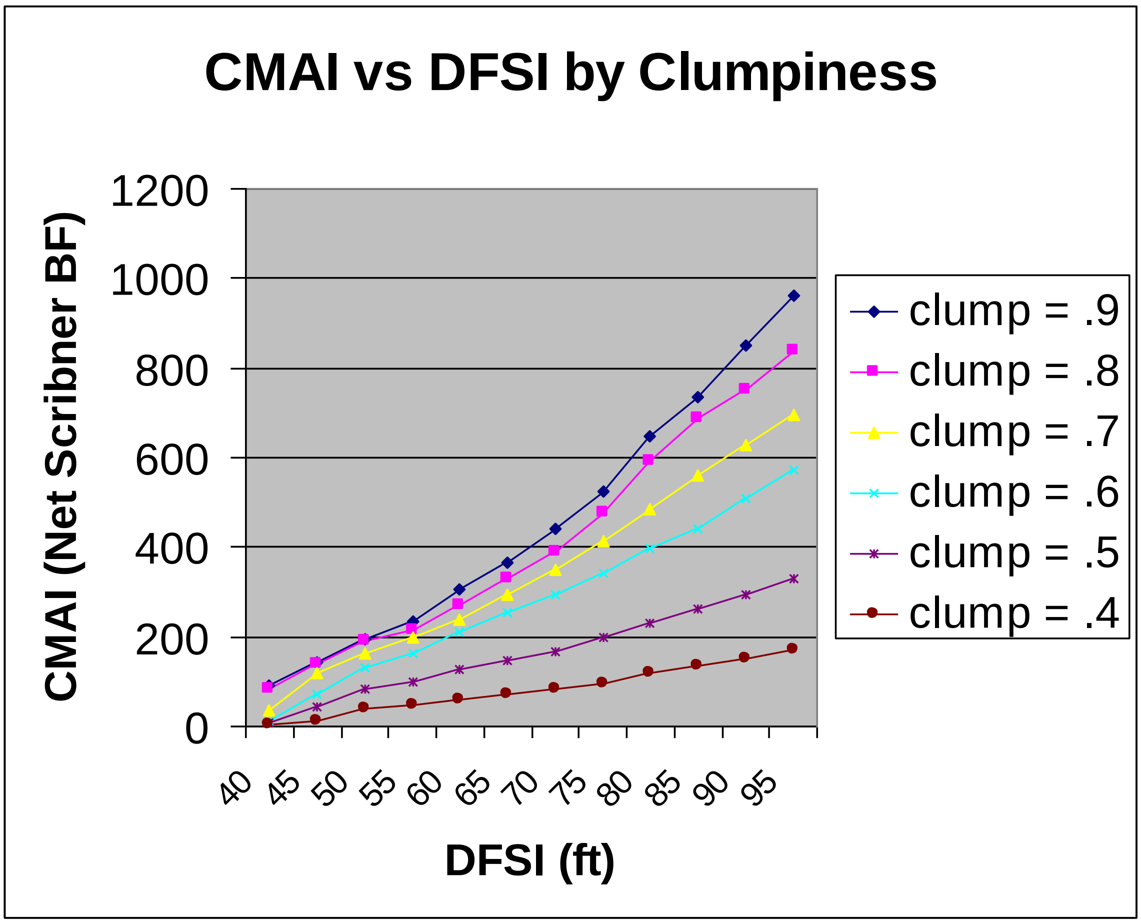


Figure 10. Yield response surface of CMAI versus DFSI and clumpiness based on 78 simulations.

Using a value for CLUMPY = 0.75, the above CMAI equation became:

CMAI75 = -186.1025 + 3.45025 * [DFSI_timball] + 0.069078 * [DFSI_timball] * [DFSI_timball] where [DFSI_timball] = aggregated DFSI that combines Models 1 and 2 masked for timber polygons.

Notice that this function produces negative yields when [DFSI_timball] < 32.627'

The units for CMAI75 are bd. ft./acre/year. For illustration here is a table showing values of CMAI75 for different DFSI values:

DFSI	**CMAI**
32.627	0.00
35	19.28
40	62.43
45	109.04
50	159.10
55	212.62
60	269.59
65	330.02
70	393.90
75	461.23
80	532.01
85	606.26
90	683.95
95	765.10

Stocking Factor Modeling

In some situations, especially east of the continental divide, precipitation is limiting and, as a result, timber stands do not fully occupy a given site. It was judged that a stocking factor equation should be developed that was a function of precipitation and would be used to <u>reduce</u> the timber productivity (CMAI75) on a given site. The following stocking equation was developed from climate and stockability data listed in Pfister's Forest Habitat Types of Montana (Tables D-2, E3 and E4) only for locations where the annual precipitation was between 10 and 18 inches (25 to 46 cm):

STOK = -0.47722 + 0.0320157 * [rain_ccccc]

n = 25 R^2 = 0.93 SEE = .00355

This stocking equation produced values in a range from 1.0 down to 0.323 and was applied to CMAI75 as appropriate.

Final CMAI75 Grid Mapping Procedures

Overview
For each chosen county, nine grid layers, each representing a specific DFSI predictor variable, must be created. These are **elev_ccccc**, **slope_ccccc**, **rain_ccccc**, **par_ccccc**, **tave_ccccc**, **awc_ccccc**, **cec_ccccc**, **ph_ccccc** and finally **bare_ccccc** where **ccccc** = abbreviated county name. Next, as many as eight and as few as three vector shapefiles have to be added to the current ArcMap project depending on whether a county is composed of more than one SSA (soil survey area). The first shapefile represents the county boundary and the second contains the county timber polygons. The third through eighth shapefiles contain the soil attributes that need to be extracted into separate raster grids, one for each of the four soil attributes (and also for other SSA --then mosaicked-- if need be for the particular county) to produce the four soil grids mentioned above namely **awc_ccccc**, **cec_ccccc**, **ph_ccccc** and **bare_ccccc**. Finally another six grid layers must be generated before a timber productivity grid (**CMAI75_ccccc**) can be computed. Four of these additional grids are predictor interaction terms named **x4_ccccc**, **x7_ccccc**, **x8_ccccc** and **x11_ccccc** that are derived via the Raster Calculator in Spatial Analyst. The remaining two grids are analysis masks for the presence of nonzero soil attributes (**soil_mask**) and the presence of timber polygons (**timb_mask**). With these input raster grids, **MDFSI** (Douglas-fir site index based on the inclusion of soil attributes) and **PDFSI** (Douglas-fir site index based on the omission of soil attributes) can be calculated using the Raster Calculator in Spatial Analyst. Next, **MDFSI** is applied only to those map locations where non-zero soil attributes are present (using soil_mask) to produce a new grid named **DFSI_sol;** this grid is then mosaicked with **PDFSI** to produce a composite grid named **DFSI_all**. This composite grid is then applied to timber polygon locations (using timb_mask) only to produce yet another grid named **DFSI_timball**. This latter grid becomes the input for producing the timber productivity grid named **CMAI75_ccccc**. Further, a **STOCK** (stocking factor) grid, which is a function of rainfall, is also created (and truncated if necessary to confine the range of stocking factors between 1 and 0.323) which in turn is used to modify the CMAI75 grid to produce a final CMAI grid named **CMAI_fnl_ccc**.

Detailed steps

Here are the steps to produce the final forest productivity map for a given county:

- Open an existing map project in **ArcMap** named “**mtxxx.mxd**” where xxx is a 3-digit numeric soil survey area (SSA) id. Note: Make sure that the SSA polygon map layers are projected in the State Plane Coordinate System having meters as distance units. If this is not the case (which you can determine by right-clicking on the map file name and selecting **Properties…** from the pull-down menu and clicking the **Source** tab) you must re-project this map layer and save it with a new name, e.g. mt613_spc.

- To re-project a feature map layer expand the **ArcToolbox** function tree by clicking **Data Management Tools** => **Projections and Transformations** => **Feature** => **Project** and the Project dialog window appears.

  For the **Input Dataset or Feature Class** select the only existing map project feature map layer, e.g. mt613_new.
  For the **Output Dataset or Feature Class** type **mtxxx_spc.shp** at the end of the directory path string.
  For the **Output Coordinate System** click the **Browse** button and the Spatial Preference Properties dialog window appears.
    Click **Select** and the first Browse for Coordinate System dialog window appears. Click **Projected Coordinate Systems** and click **Add**.
    On the second window click **State Plane** and click **Add**.
    On the third window click **NAD 1983** and click **Add**.
    On the fourth and final window scroll and click **NAD 1983 StatePlane Montana FIPS 2500.prj** and click **Add** to return to the Spatial Preference System dialog window.
  Click **OK** to return to the Project dialog window.
  Click **OK** to execute the map projection. Upon successful execution and clicking **Close** the new map is added to the map project TOC.

- Click **Add** icon to add an appropriate county boundary feature map file, i.e. "bighornco.shp", from the "**new_counties**" subdirectory and an appropriate county timber polygon map file, i.e. "bighorn_timber.shp", from the "**forest map layers**" subdirectory to the current map project.

- Click **Add** icon to add <u>additional</u> soil survey area (SSA) polygon map files, i.e. "mt617_spc" and "mt618_spc", from the chosen county name subdirectory to the current map project. Most counties west of the continental divide comprise anywhere from <u>two</u> to <u>six</u> soil survey areas (SSA) while counties east of the divide typically consist of only one or maybe two SSAs.

- Click **Add** icon to add "elev30" from the "grids" subdirectory to the current map project. This 30m elevation grid covers all of Montana and must be clipped.

- Expand the **ArcToolbox** function tree by clicking **Spatial Analyst Tools** => **Extraction** => **Extract by Mask** and clip the **elev30** grid using the county boundary feature map layer and save results as "**elev_ccccc**" where **ccccc** is the county name (up to 6 characters).

- From the Spatial Analyst menu bar select **Options…** and the Options dialog window appears with <u>three</u> tabs labeled General, Extent, and Cell Size.

  - Click on the **Extent** tab and select the current county boundary map layer as the **Analysis extent**: Note that the <u>four</u> text boxes (Top, Left, Right and Bottom) are filled with coordinates.

  - Click on the **Cell Size** tab and select “elev_ccccc” as the **Analysis cell size**: Note that the three text boxes (Cell size, Number of rows, and Number of columns) are filled with numbers.

  - Click on the **General** tab and select the current county boundary map layer as the **Analysis mask**.

  - Click **OK** to accept all these options and close this dialog window.

- From the Spatial Analyst menu bar select **Convert** => **Features to Raster…** and select a soil survey area polygon map file, i.e. mt607_spc, for the **Input features:**, a specific soil attribute like AWS0100WTA or MU_CEC or MU_PH or COMPPCT_R for **Field:**, an **Output cell size**: 30 and save the results in the appropriate subdirectory under **Output raster**: as “**awc_ccccc**” or “**cec_ccccc**” or “**ph_ccccc**” or “**bare_ccccc**” respectively.

- Click **OK** to start the conversion process; another small dialog window appears indicating that execution has started. When execution has completed this dialog window can be closed by clicking **Close**. Note that a new grid appears in the project TOC.

- Repeat this process creating a new grid for each of the four soil attributes for each of the SSA covering the chosen county.

- If there are two or more SSAs for a county, the grids associated with each soil attribute, i.e. AWC, CEC, PH and bare, must be mosaicked together as follows: Expand the **ArcToolbox** function tree by clicking **Data Management Tools** => **Raster** => **Mosaic to New Raster**. A new dialog window appears containing a number of text boxes that must be filled.

  - For **Input Rasters**: select a single soil attribute associated with two or more SSAs, i.e. “awc_634” and “awc618”, navigate and select the **Output Location**, e.g. “spatial”, followed by the **Raster dataset name with extension** (no extension if creating a grid).

  - Select an appropriate **Pixel type (optional)** from the pulldown list, i.e. 32_BIT_FLOAT in this case for the first three soil attributes, AWC, CEC and PH, and the default 16_BIT_SIGNED for bare.

  - Type **30** for **Cellsize (optional)**

  - Finally select an appropriate **Mosaic method (optional)** as either LAST (default), FIRST, BLEND, MEAN, MINIMUM or MAXIMUM. Note: if soil attribute values are radically different from each other across SSA boundaries select BLEND. Otherwise accept the default LAST.

- Click **OK** to start the execution and a small dialog window appears indicating that execution has started. When execution has been completed this dialog window can be closed by clicking **Close**. Note that a new grid appears in the project TOC.

- Repeat the above mosaic process for each of the four soil attributes across two or more SSAs covering the current chosen county.

- Expand the **ArcToolbox** function tree by clicking **Spatial Analyst Tools** => **Surface** => **Slope** and select "elev_ccccc" as the **Input raster** and browse to the appropriate subdirectory and type "slop_ccccc" for the file name and click **Add** to return to the Slope dialog window and click **OK** to start the execution. Again another small dialog window appears indicating that execution has started. When execution has been completed this dialog window can be closed by clicking **Close**. Note that a new grid appears in the project TOC.

- Click **Add** icon to add "precip" from the "grids" subdirectory to the current map project. This file is a resampled 30m grid from "pcp1000" which was a 1km resolution precipitation map for all of Montana and must be clipped.

- Expand the **ArcToolbox** function tree by clicking **Spatial Analyst Tools** => **Extraction** => **Extract by Mask** and clip the **precip** grid using the county boundary feature map layer and save results as "rain_ccccc" where ccccc is the county name (up to 8 characters).

- Click **Add** icon to add TAVE, and PAR from the "grids" subdirectory to the current map project. These climate variables deal with temperature, solar radiation and daylight respectively. They are listed by ecoregion and there are seven of them that cover the state of Montana. They are Z10, Z19, Z20, Z21, Z22, Z29 and Z30 (ecoregion codes). So you need to find out which ecoregion the current county is located in. This could be one or more ecoregions. The grid naming convention is ecoregion code <u>plus</u> underscore <u>plus</u> climate variable acronym <u>plus</u> 1, i.e. Z19_tave1 or Z30_par1.

- If <u>only one ecoregion</u> is involved, the above two grids can be clipped as follows: Expand the **ArcToolbox** function tree by clicking **Spatial Analyst Tools** => **Extraction** => **Extract by Mask** and clip each grid in turn, i.e. Z19_tave1, using the county boundary feature map layer and save results as climate variable acronym plus county name, i.e. "tave_bighorn" (up to 6 characters for county name). Do this operation for both climate variables.

- If <u>more than one ecoregion</u> is involved, then the grids associated with each of the two climate variables must be mosaicked together <u>before</u> clipping as follows: Expand the **ArcToolbox** function tree by clicking **Data Management Tools** => **Raster** => **Mosaic to New Raster**. A new dialog window appears containing a number of text boxes that must be filled.

- For **Input Rasters**: select a single climate variables associated with two or more ecoregions, i.e. “Z10_tave1” and “Z19tave1”, navigate and select the **Output Location**, e.g. “spatial”, followed by the **Raster dataset name with extension** (no extension if creating a grid).

- Next select an appropriate **Pixel size (optional)** from the pulldown list, i.e. 8_BIT_UNSIGNED (default) or 32_BIT_FLOAT, type **30** for the **Cellsize (optional)** and finally select an appropriate **Mosaic method (optional)** as either LAST (default), FIRST, BLEND, MEAN, MINIMUM or MAXIMUM.

- Click **OK** to start the execution and a small dialog window appears indicating that execution has started. When execution has been completed this dialog window can be closed by clicking **Close**. Note that a new grid appears in the project TOC.

- In preparation for computing the DFSI grid we need to calculate four interaction term grids named **x4_ccccc**, **x7_ccccc**, **x8_ccccc** and **x11_ccccc** using map algebra. From the Spatial Analyst menu bar select **Raster Calculator…** and the Raster Calculator dialog window appears. This window has many buttons for performing arithmetic operations as well as some common functions. In the large textbox a character string of grid file names are typed, starting with the temporary output grid name followed by an equal sign (=) followed by an arithmetic expression involving operators and input grid names selected from a list by double-clicking. These input grid names are placed in square brackets, i.e. [tave_lincoln], automatically. Click **Evaluate** to perform the specified map algebra. A progress bar appears at the bottom of the map pane with a message to hit the **ESC** key if you want to exit this operation. If the evaluation is successful the new temporary grid will appear in the TOC. Here are the four interaction grids that need to be generated:

  X4 = [tave_ccccc] * [rain_ccccc] * [awc_ccccc] / ([par_ccccc] * [elev_ccccc])

  X7 = [par_ccccc] / [rain_ccccc]

  X8 = [tave_ccccc] / [elev_ccccc]

  X11 = [tave_ccccc] * [par_ccccc] / [rain_ccccc])

- Once these interaction grids have been created we proceed to calculate the **MDFSI** and **PDFSI** grids. From the Spatial Analyst menu bar select **Raster Calculator…** and the Raster Calculator dialog window appears. This window has many buttons for performing arithmetic operations as well as some common functions. In the large textbox a character string of grid file names are typed, starting with the temporary output grid name followed by an equal sign (=) followed by an arithmetic expression involving operators and input grid names selected from a list by double-clicking. These input grid names are placed in square brackets, i.e. [X4_lincoln], automatically. Click **Evaluate** to perform the specified map algebra. A progress bar appears at the bottom of the map pane with a message to hit the **ESC** key if you want to exit this operation. If the evaluation is successful the new temporary grid will appear in the TOC. The following equations are used:

MDFSI = 88.46551 + 164.25967 * [X4_ccccc] - 2.431415 * [X7_ccccc] + 1.5038 * [tave_ccccc] - 0.14095 * [slope_ccccc] - 4.999 * [ph_ccccc] - 0.27543 * [cec_ccccc] - 0.12935 * [bare_ccccc]

PDFSI = 48.89996 + 2487.80425 * [X8_ccccc] - 1.1143 * [X11_ccccc] - 0.13136 * [slope_ccccc] + 2.01491 * [tave_ccccc]

Note that the MDFSI grid is based on climate, topographic and soil terms while the PDFSI grid is only based on climate and topographic terms (no soil attributes).

- The **MDFSI** grid contains site index values for all locations ignoring whether soil attributes are present (greater than zero) or absent (zero or missing). This site index model is only to be applied to those locations that have non-zero soil attributes. To accomplish this task a digital raster mask needs to be created named “**soil_mask**” that contains a value of **1** for those cells where soil PH (and hence all other soil attributes) is greater than zero and **null** otherwise. In turn this mask is multiplied by the MDFSI grid to produce a new grid named **MDFSI_sol**. Do the following:
    - Expand the ArcToolbox function tree by clicking **Spatial Analyst Tools**, then **Conditional,** and double-click **Con** to display a dialog window.
        - Fill in the five text boxes as follows:

          Input conditional raster: **ph_ccccc**
          Input true raster or constant value: **1**
          Input false raster or constant value (optional):
          Output raster: **soil_mask**
          Expression (optional): **Value > 0**
        - Click **OK** to start the creation of this raster mask.
    - Upon completion this raster mask’s name appears in the map project TOC.
    - Click **Spatial Analyst/Raster Calculator…** and a dialog window appears:
        - Type **MDFSI_sol = [soil_mask] * [MDFSI_ccccc]**
        - Click **Evaluate** to create a temporary grid that appears in the map project TOC.
        - This new grid needs to be made <u>permanent</u> via right-clicking on the new grid name and selecting **Data/Export Data…** and selecting the proper subdirectory <u>Location</u>, typing **MDFSI_sol** for <u>Name</u> and selecting **GRID**

from a pull-down list for Format followed by clicking **Save** to start the copying process.

- ➢ Upon completion this raster mask's name appears in the map project TOC.

- Next a composite DFSI grid name **DFSI_all** is created that combines **MDFSI_sol** with **PDFSI** as follows:

  - Click **Spatial Analyst/Options…** and check to make sure that the Analysis mask under the General tab, the Analysis extent under the Extent tab and Analysis cell size under the Cell Size tab are properly defined for the current county.

    - ➢ Click **OK** to accept the chosen options and exit the dialog window.

    - ➢ Expand the ArcToolbox function tree by clicking **Data Management Tools** followed by **Raster** and finally double-click **Mosaic To New Raster** and a dialog window appears and do the following:

      Input Rasters: **PDFSI_cccccc** and **MDFSI_sol** (both selected in this order from pull-down list)
      Output Location: navigate to proper subdirectory
      Raster dataset name with extension: **DFSI_all** (no extension if GRID)
      Pixel type (optional): **32_BIT_FLOAT**
      Cellsize (optional): **30**
      Mosaic Method (optional): **LAST**

    - ➢ Click **OK** to create a new grid that appears in the map project TOC.

- Next, the composite **DFSI_all** grid created above must be applied to the timber polygon cells only via the use of a grid mask named **timb_mask** to produce a new grid named **DFSI_timball**. To produce the mask and final DFSI grid do the following:
  - Click **Spatial Analyst** and select **Options…** and verify or select the proper Analysis mask under the **General** tab, Analysis extent under the **Extent** tab and Analysis cell size under the **Cell Size** tab. Note: the analysis mask and extent should always be "**ccccco**" (county boundary shapefile) and cell size should be "**elev_ccccc**" (30m county elevation grid). Remember **ccccc** (5 letters) represent a specific county name.

  - Click **OK** to accept these options.

  - Click **Spatial Analyst** and select **Convert/Features to Raster…** and a dialog window appears.

  - Fill in or verify that the four text boxes are filled as follows:

Input features: **ccccc_timber**
Field: **flag** (selected from pull-down list)
Output cell size: **30**
Output raster: **timb_mask** (navigate to appropriate subdirectory)

  - Click **OK** to start the selection process.

  - Upon completion this raster mask's name appears in the map project TOC. This grid contains a value of **1** for all cells representing various timber polygons and null values otherwise.

- Click **Spatial Analyst/Raster Calculator…** and a dialog window appears again:

  - Type **DFSI_timball = [timb_mask] * [DFSI_all]**

  - Click **Evaluate** to create a temporary grid that appears in the map project TOC.

  - Save this temporary grid to the current ArcMap project by right-clicking on this grid name and selecting **Data/Export Data…** and selecting the proper **Location:**, typing a **Name:** DFSI_timball, and selecting a **Format:** GRID.

  - Click **Save** and at the end of the exporting process and click **Yes** to add this grid to the current map project and remove the temporary grid created earlier.

- Once this final DFSI grid has been created and saved, the following CMAI75 timber productivity grid can be computed as follows:

  - Click **Spatial Analyst/Raster Calculator…** and a dialog window appears again:

    - Type **CMAI75 = -186.1025 + 3.45025 * [DFSI_timball] + 0.069078 * [DFSI_timball] * [DFSI_timball]**

    - Click **Evaluate** to create a temporary grid that appears in the map project TOC.

- CMAI75 can produce negative results if DFSI_timball values are less than 32.627 ft. When this happens the negative values must be set to zero using the following truncation technique:

  - Open ArcToolbox

  - Click on **Spatial Analyst Tools** to expand the items tree

  - Click on **Conditional** to expand the items tree

  - Double-click on **Con** and a dialog window appears:

For the *Input conditional Raster* select "**CMAI75_ccc**" from the pulldown list or browse to the proper directory and click **Add**.

For the *Input true raster or constant value* type **0**.

For the *Input false raster or constant value* select "**CMAI75_ccc**" from the pulldown list or browse to the proper directory and click **Add**.

For the *Output Raster* click on **Browse** button to navigate to the desired directory and type **CMAI75_ccccc** and click **Save**.

For the Expression (optional) type **Value <= 0**.

Click **OK** to execute procedure and upon successful completion click **Add** to include this new temporary grid in the current ArcMap project.

- Next a stocking factor grid (**STOCK**) must be created via the following equation:

  STOCK = -0.47722 + 0.0320157 * [rain_ccccc]

  Again as before from the **Spatial Analyst** menu bar select **Raster Calculator…** and the Raster Calculator dialog window appears. This window has many buttons for performing arithmetic operations as well as some common functions. In the large textbox a character string of grid file names are typed, starting with the <u>temporary</u> output grid name followed by an equal sign (=) followed by an arithmetic expression involving operators and input grid names selected from a list by double-clicking. These input grid names are placed in square brackets, i.e. [rain_lincoln], automatically. Click **Evaluate** to perform the specified map algebra. A progress bar appears at the bottom of the map pane with a message to hit the **ESC** key if you want to exit this operation. If the evaluation is successful the new temporary grid will appear in the TOC.

- If precipitation if either above 18 inches (46 cm) or below 10 inches (25 cm) stocking factors will be greater than 1 or less than 0.323 respectively, which is invalid. If either or both of these conditions occur, the **STOCK** grid values must be truncated. To set stocking factors greater than 1 equal to 1 do the following:

  - Open ArcToolbox
  - Click on **Spatial Analyst Tools** to expand the items tree
  - Click on **Conditional** to expand the items tree
  - Double-click on **Con** and a dialog window appears:

  For the *Input conditional Raster* select "**STOCK_ccccc**" from the pulldown list or browse to the proper directory and click **Add**.

For the *Input true raster or constant value* type **1**.

For the *Input false raster or constant value* select "**STOCK_ccccc**" from the pulldown list or browse to the proper directory and click **Add**.

For the *Output Raster* click on **Browse** button to navigate to the desired directory and type **STOCK_ccc_fix** and click **Save**.

For the Expression (optional) type **Value > 1**.

Click **OK** to execute procedure and upon successful completion click **Add** to include this new grid in the current ArcMap project.

- To set stocking factors less than 0.323 equal to 0.323 do the following:

  - Open ArcToolbox
  - Click on **Spatial Analyst Tools** to expand the items tree
  - Click on **Conditional** to expand the items tree
  - Double-click on **Con** and a dialog window appears:

  For the *Input conditional Raster* select "**STOCK_ccccc**" from the pulldown list or browse to the proper directory and click **Add**.

  For the *Input true raster or constant value* type **0.323173**.

  For the *Input false raster or constant value* select "**STOCK_ccccc**" from the pulldown list or browse to the proper directory and click **Add**.

  For the *Output Raster* click on **Browse** button to navigate to the desired directory and type **STOCK_ccc_fix** and click **Save**.

  For the Expression type **Value < 0.323173**.

  Click **OK** to execute procedure and upon successful completion click **Add** to include this new grid in the current ArcMap project.

- The final step involves adjusting the **CMAI75_ccccc** grid values with the stocking factor (**STOCK_ccc_fix**) using the following equation:

  CMAI75fnl_ccc = [STOCK_ccc_fix] * [CMAI75_ccccc]

  Again as before from the **Spatial Analyst** menu bar select **Raster Calculator…** and the Raster Calculator dialog window appears. This window has many buttons for performing arithmetic operations as well as some common functions. In the large textbox a character string of grid file names are typed, starting with the temporary output grid name followed by an equal sign (=) followed by an arithmetic expression involving operators and input grid names selected from a list by double-clicking. These input grid names are placed in square brackets, i.e. [STOCK_lin_fix] and [CMAI75fnl_lin], automatically. Click **Evaluate** to perform the specified map algebra. A progress bar appears at the bottom of the map pane with a message to hit the **ESC** key if you want to exit this operation. If the evaluation is successful the new temporary grid will appear in the TOC.

- The resultant grid named **CMAI75fnl_ccc** should be classified into 6 categories as follows:

0 – 100, 100 – 175, 175 – 250, 250 – 325, 325 – 400, 400+ (units are bd.ft./ac/yr)

The first CMAI class has been designed as non-commercial timber while all the remaining classes represent commercial timber from poor to very good.

Right-click on CMAI75fnl_ccc and select **Properties…** from the pulldown menu and the Properties dialog window appears having 7 tabs.
Click on the **Symbology** tab and click **Classified** under **Show:** resulting in the creations of 5 classes which need to be color coded from tan → yellow → light green → medium green → dark green.
Click **OK** to return to the image window in ArcMap.

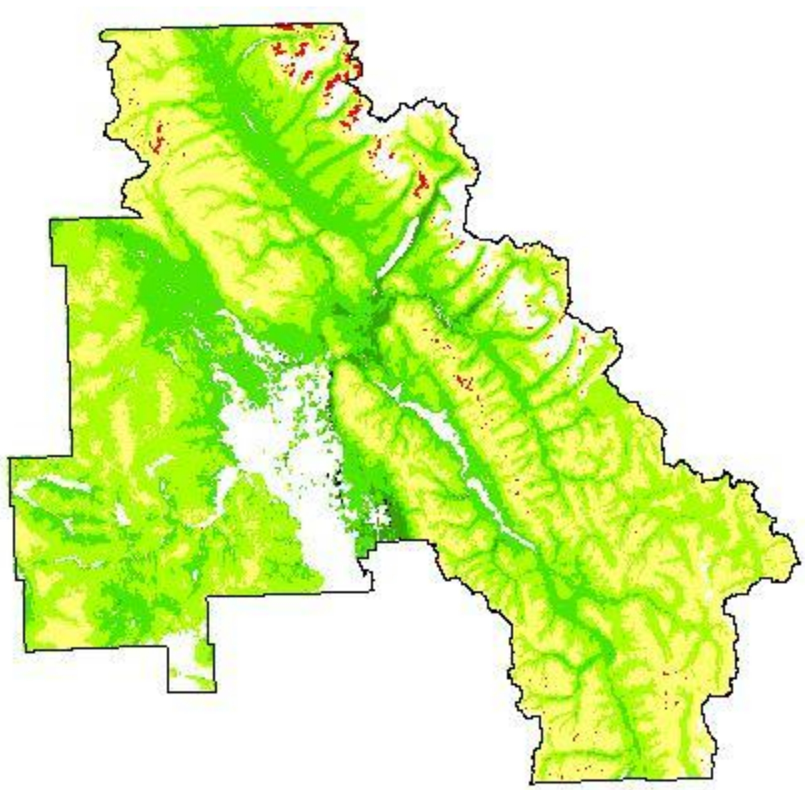
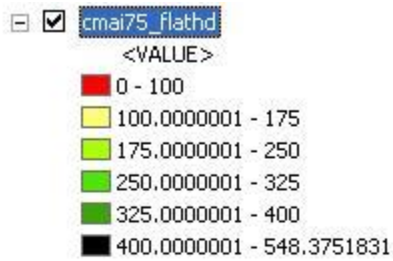


Figure 11. Final CMAI75 grid for Flathead county showing ranges of productivity from noncommercial (< 100 bd. ft./ac/yr) to classes of commercial forest ranging from 100 to 548 board feet/ac/year as follows:



Legend associated with above CMAI75 grid showing colors for noncommercial (red) and commercial productivity classes

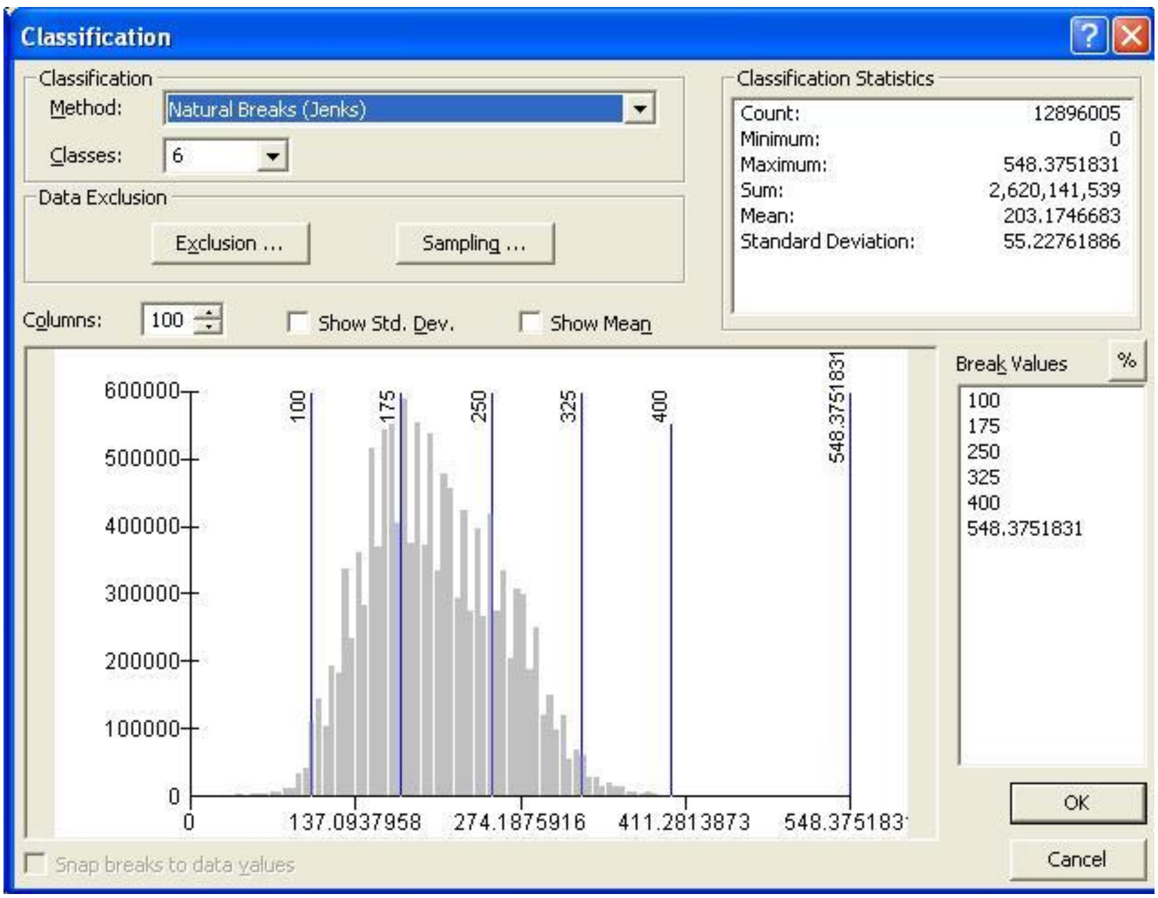


Figure 12. Histogram of CMAI75 for Flathead county showing a mean productivity of **203**, standard deviation of **55** and a range of 0 to 548 net Scriber Decimal C board feet/acre/year.

The 99 percent confidence limits on CMAI75 forest productivity for Flathead county would be 203.17 $\pm$ 2.57 * 55.23 = **62** to **345** bd. ft./ac/yr. This shows that productivity values beyond 400 are very rare.

Final GIS Processing of CMAI75 County Grids

Judy Troutwine, a temporary U of M GIS analyst/programmer, has developed Visual Basic code to semi-automate the process of creating the final CMAI75 grid for any given county provided there is only one soil survey area. The code is to be modified if additional funding is made available so that counties having as many as 6 soil survey areas can also be accommodated.

Finally, Judy has developed a very complicated automated process written in Visual Basic, involving some 50+ programming routines that aggregates/ dissolves CMAI75 raster cells that are in the non-commercial class based on the minimum 5-acre (approximately 22 30m cells). Further the remaining commercial class cells are aggregated/dissolved into five commercial grades, and finally the raster layer is converted to vector to produce eye-pleasing polygons with smooth boundaries via the use of mathematical piece-wise smoothing functions. The average CMAI75 value is calculated for each resulting noncommercial and commercial polygon. Randy Piearson, a DOR contractor, visited with Judy on multiple occasions to guide/facilitate this process and is satisfied that her automated process produces the desired results.

Delineation of Noncommercial and Commercial Timber Areas

By Judy Troutwine, dated August 18, 2008

Introduction

Based on GIS product requirements described by the Department of Revenue (DOR) representative, the University of Montana GIS analyst/programmer (Judy Troutwine) devised, implemented, and carried out a three-stage method to delineate graded noncommercial and commercial timber polygons. Further, possible methods for edge-matching at county boundaries were evaluated. (It is expected that further coding will (if additional funding is made available) enable updating user-selected areas as underlying data is updated – that would include all reprocessing as needed to update the CMAI75 values and delineate graded timber polygons.)

The delineated areas were derived from the final CMAI75 (culmination of mean annual increment based on a 0.75 clumpiness factor) raster datasets for each county in the study as provided by Principal Investigator Dr. Zuuring. The timber shapefiles provided by DOR were also crucial in certain processing steps, and timber polygon boundaries and attribute values were included in final output shapefiles as required. In general, the noncommercial timber areas represented a stand-alone grade whereas the commercial timber polygons were further subdivided into five more categories or grades. Mean CMAI75 values were calculated for each resulting graded timber polygon. The results are to then be modified slightly at county borders where needed by another ‘raster & vector’ method near county borders for a seamless state-wide forest productivity dataset.

The method stages were implemented via procedures coded within ArcGIS ArcMap VBA projects. Programming utilized VBA, ArcGIS geoprocessing, and ArcGIS ArcObjects software development capabilities. Investigations into methods for edge-matching between counties led to a decision to prepare and implement code for stages one to three in a separate ArcMap - VBA project document for each county. Coding and processing for all 48 counties with positive CMAI75 values has been completed.

Test Counties

Two counties were used for testing the methods developed: Lincoln County and Bighorn County. Lincoln County provided the test case for high productivity and the presence of all five commercial grades with very little noncommercial grade timber present. Bighorn County provided a test case for primarily noncommercial grade timber and only moderately productive commercial timber present. Further, the timber areas in Bighorn County were naturally more fragmented and provided a good test of the aggregation principles used to combine small areas of one grade into larger areas of another grade.

Principles and Methods

Introduction. The methods devised were implemented in three processing stages. The first stage delineated noncommercial and commercial timber areas. The second stage delineated among the five commercial grades. Both of these delineation processing stages were carried out in raster data format. The third stage converted the results from stages one and two to vector polygon data format and performed smoothing and simplifying operations. Carefully planned and approved aggregation steps were included in each stage. Each county-wide final polygon shapefile consists of original timber polygon boundaries and internal, smoothed boundaries delineating the noncommercial and commercial timber grades as aggregated for the county.

Stage One Processing. In this stage timber areas were separated into two categories, non-commercial and commercial, based on values in the CMAI75 raster dataset for each county. Grid cells having CMAI75 values less than 100 bd. ft./ac/yr were considered noncommercial while values greater than or equal to 100 bd. ft./ac/yr were considered commercial timber. For each, the distinct, contiguous timber areas or polygons were identified and the acreage of each polygon calculated. Contiguity was based on side adjacency, that is, if a raster cell representing noncommercial timber meets the side of another raster cell also representing noncommercial timber, then both cells belong in the same noncommercial timber polygon. Contiguity was determined in the same way for commercial timber cells and polygons.

Aggregation of small polygons into larger polygons was based on minimum size and adjacency requirements stated by the DOR representative. The minimum size specified for a noncommercial timber area or polygon was 5 acres and the minimum size for commercial timber areas or polygons was 15 acres. As an example of the aggregation principles, consider a timber polygon which is comprised of one distinct commercial area 10 acres in size and one distinct, adjacent noncommercial area 5 acres in size. The commercial area would be aggregated with the noncommercial area to be one 15 acre noncommercial contiguous area or polygon. As a variation of that example, consider a commercial area 8 acres in size with noncommercial areas 2 acres and 5 acres in size but on opposite sides of the commercial area. The aggregation principle for that type of situation was to first merge the 8 acres of commercial timber into the 5 acres of noncommercial timber, and then merge the 2 acres of noncommercial timber into that result. After deriving the noncommercial areas, a similar process derived commercial areas: remaining noncommercial areas less than 5 acres and adjacent to commercial areas greater than or equal to 15 acres were merged with those commercial areas. Also in parallel to the process for creating noncommercial areas, remaining commercial areas less than 15 acres in size were merged into the intermediate commercial aggregated areas. In some rare cases a timber polygon represented by the CMAI75 raster dataset was under the minimum size (for its category -- noncommercial or commercial). Those were located and managed during processing Stages two and three.

<u>Stage Two Processing (up to 500 steps per county)</u>. This processing stage separated commercial timber areas into five productivity categories as listed below:

Fair (**V**): 100 –175 bd. ft./ac/yr.
Average (**IV**): 175.1 – 250 bd. ft./ac/yr.
Good (**III**): 250.1 – 325 bd. ft./ac/yr.
Very good (**II**): 325.1 – 400 bd. ft./ac/yr.
Excellent (**I**): > 400 bd. ft./ac/yr.

The inputs for this stage were the commercial timber areas as delineated in Stage One and also the same CMAI75 raster dataset used in Stage One. First, the raster cells in the commercial timber areas were categorized (according to the grades as listed above, and also including small noncommercial areas within the delineated commercial areas as being in grade V) to make an initial delineation of the commercial grade areas present in each commercial timber area. The resulting distinct, contiguous graded commercial timber areas or polygons were assigned unique identifiers and the acreage of each polygon calculated. Contiguity in defining areas was again based on side adjacency; that is, if a raster cell representing a commercial timber grade meets the side of another raster cell also representing the same commercial timber grade, then both cells are considered to be in the same commercial timber grade area or polygon.

The principles of aggregation were very similar to those used in Stage One, carried out for a specific sequence of pairs of commercial grades. Here, the minimum size allowed was 5 acres for each of grades I – V. While Stage One processing aggregated first into noncommercial areas and then into commercial areas, this stage first merges any small (< 5 acres) areas of a higher grade into larger (>= 5 acres) areas of a lower grade. For example, small areas of grade IV were merged into larger areas of grade V, grade III into grade V, and so on. The complete sequence for each county is as follows: IV and V, III and V, II and V, I and V, III and IV, II and IV, I and IV, II and III, I and II, I and II. Remaining small areas were merged after conversion to vector data model polygons (Stage Three). It might be interesting to note that processing for each of the ten pair combinations of commercial grades generates approximately 50 (temporary) datasets. The categorized commercial areas raster dataset is updated during each of the ten rounds of processing. For some counties, not all commercial grades are present; the program code checks for their presence and also monitors the amounts of small areas of each category remaining at benchmark steps in each round. The end result is a raster dataset of graded commercial areas or polygons greater than or equal to 5 acres in size for only the grades present in a county.

Stage Three Processing (approximately 50 steps per county). This stage involved final aggregation, smoothing, and attributing of vector data model timber polygons. The original timber polygons were retained while subdividing them with boundaries derived in Stages One and Two.
First, the noncommercial and graded commercial raster datasets were mosaicked together to make one raster dataset. The result was converted to vector polygons, polygon boundaries simplified, and then overlayed with the county timber polygons shapefile. Areas inside the county timber polygons were selected and further cleaned: Interior slivers (resulting from the overlay) and anomalous areas (artifacts of rasterization prior to Stage One or of conversion back to vector mode) less than 5 acres were merged into adjacent graded polygons. At this point, the original timber polygon boundaries reached a restored (after the raster processing) state, and the timber polygons included smoothed noncommercial and graded commercial polygons. Some small isolated polygons near county borders remained, to be merged with polygons in neighboring counties during the edge-matching processing.

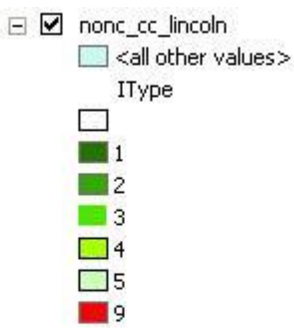
Once the sub-polygon boundaries were complete, to calculate the CMAI75 mean for each final polygon, the shapefile (with noncommercial and commercial polygons) was converted to a raster dataset at a finer resolution of 10 meters. This provided raster 'zones' as reference to calculate the CMAI75 mean values for each zone or polygon. The result was joined to the current polygon shapefile, and attribute table fields added, calculated, or removed as needed to meet specifications. The field IType contains the values for the noncommercial and commercial grades.

A final method based on table values was devised to detect small raster areas missed during Stages One and Two, often located within small timber polygons or adjacent to a county border. They were assigned IType values according to the mean value that had been calculated from CMAI75 for those polygons.

Disclaimer

The data, maps, equations and associated documents are provided on an “as-is” basis and no warranty is in affect or implied. U of M College of Forestry & Conservation staff and faculty, retired or not, shall be held harmless and free from litigation or lawsuits that might occur in the future as a result of the application of county timber productivity values for the purpose of computing property taxation on private forested lands of Montana. Further let it be known that the aggregating/dissolving of forest productivity pixels into noncommercial and commercial timber, the creation of productivity grades, the application of weighted average productivity values to commercial timber classes and finally the conversion of 30m raster grids into smoothed polygons has compromised the integrity of the timber productivity values. The impact of this generalization process on the final outcome of property taxation on private forested lands is therefore unknown. As a result the U of M faculty and staff who worked on this project take no responsibility for any subsequent consequences that this post-processing might have on timber productivity and hence property taxation.

Figure 13. Final CMAI75 map for Lincoln Co. delineating noncommercial and commercial productivity grades.



Legend associated with above CMAI75 polygons showing colors for timber productivity grades

Appendix A

Joining SSA polygon attributes to SI point dataset

Joining SSA polygon attributes to SI point dataset

1. Add point data set “comboxydata” to map project.

2. Add new short integer field named “SSA_ID” to point attribute table to store soil survey area (SSA) codes.

3. Add 1st SSA polygon layer named “mtxxx_spm” to above point data set.

4. Populate SSA_ID field in point data set “comboxydata” for selected records as follows:

   - Click **Selection/Select by Location** and dialog window appears.
   - Respond as follows: I want to: [select features from] the following layer(s): check box next to “comboxydata” that: [intersect] the features in this layer: **mtxxx_spm** (current SSA polygon layer) and click **OK**.
   - Right-click on “comboxydata” and select **Open Attribute Table**.
   - Scroll down table to confirm that one or more records have been selected (highlighted in cyan).
   - Right-click on SSA_ID field name and a pulldown list appears.
   - Select **Field Calculator…** and type **xxx** in lower textbox so as to set SSA_ID = xxx and click **OK** to assign current SSA code to selected records (highlighted) in point attribute table named “comboxydata”.
   - Close point attribute table.
   - Click **Selection/Clear Selected Features** to unselect the previous records.

5. Create a spatial join so that the attributes associated with the current SSA polygons are joined to the point data set whose key field matches xxx as follows:

   - Right-click on point data set “comboxydata” and select **Properties**.
   - Click on the **Definition Query** tab followed by the **Query Builder** button.
   - In the Query Builder dialog window type current SSA code xxx in lower textbox and click **OK**. Note: This defines a query “SSA_ID = xxx. All the points outside the current SSA polygon layer will have disappeared and only the points inside the current SSA polygon layer remain visible.
   - Right-click on point data set “comboxydata” and select **Joins & Relates/Join…**
   - Select “Join data from another layer based on spatial location”
   - Select layer to join to this layer from pulldown list, a SSA polygon file named “mtxxx_spm” and finally specify an output file named “join_xxx” where the results of the join will be stored in a new shapefile. Click **Save**.
   - Click **OK** at bottom of Join Data dialog window and the processing proceeds. Note: The newly created shapefile appears in TOC of the file geodatabase if processing has completed successfully.

6. Right-click on point data set “comboxydata” and select **Properties**.

7. Click on the **Definition Query** tab and press the **Delete** key on your PC keyboard followed by the **OK** button to delete the existing query and restore all the points.

8. Remove the current SSA polygon layer name “mtxx_spm” from the map project.

9. After all SSAs have been processed, use the **Merge** function in **ArcToolbox** to combine all the new point shapefiles into one.

Appendix B

Soil Data Mart Access Directions for SSA polygons

Soil Data Mart Access Directions for Official Soil Survey Data
By Mike Hansen dated June, 2007

1. Enter the following URL into your browser, or if you are viewing this document in Word, pressing the control key while left clicking the mouse with your curser on the URL will launch the Soil Data Mart Web Page.

   http://soildatamart.nrcs.usda.gov

2. Click the "Select State" button in the middle of the screen.

3. Scroll to and click on the row for Montana.

4. Click on the "Select County" button at the bottom of the list. **Take special note of the county code as this will be the ID used/edited in the attribute queries within the Soil Data Access Query function/process.**

5. This view will provide a list of soil survey areas (SSA) that need to be down-loaded to represent a full county area. Some counties have one SSA while others have many soil survey areas.

6. You may select and pull down spatial data following your list of surveys in the target county, or by survey area.

7. Click on the survey area desired. **At this point you will be able to run national reports, view metadata or download the data etc… by selecting desired buttons at the bottom of the screen.** You are encouraged to subscribe to the data as then you will be notified when a new version is posted.

8. To download a copy of the dataset, click the download button. You will be faced with a screen full of choices. You may take the default projection for the spatial data or choose one of the many available**. For the purposes of this project, download "spatial data only". The soil attribute data will come from the separate Soil Data Access Query process.**

9. Enter your email address as this is where notification will be sent when the download has been prepared.

10. Your request will be logged and you will be notified when it is ready.

11. An email like the one below will be sent to you. Follow the directions included in it to pull the data back to your system. Timing will depend on how busy the system is. It ranges from a few minutes to about 24 hours. The following is a listing of the text file content e-mailed to the requestor:

```
The export file requested for michael.hansen@mt.nrcs.usda.gov is available at
```

```
ftp://ftp-fc.sc.egov.usda.gov/SoilDataMart/export/330/soil_MT661.zip (If hot
links are not supported, cut and paste the URL into your browser's address
line).

Export Zip File Size:   54738 KB

The export contains the following soil survey area (SSA) data:

SSA Symbol:             MT661
SSA Name:               Roosevelt and Daniels Counties, Montana
SSA Version:            2
SSA Version Est.:       1/16/2004 10:22:46 AM
Tabular Data Version:   1
Tabular Version Est.:   1/15/2004 7:40:23 AM
Spatial Data Version:   2
Spatial Version Est.:   1/16/2004 10:22:46 AM
Spatial Format:         ArcView Shapefile
Coordinate System:      UTM Zone 13, Northern Hemisphere (NAD 83)

This data conforms to the SSURGO Version 2.1 format. This export file will be
removed from the FTP server 5 days after the date of this notice.

After the export file has been copied to your PC, it must be unzipped using
either WinZip or a similar program.  For additional information, please see
the file named README.txt in the root directory that is created by unzipping
the export file.

The export also contains the following MS Access SSURGO template database:

Template DB Name:       soildb_MT_97.mdb
Template DB Version:    29
Template DB State:      MT
MS Access Version:      Access 97
```

12. Place the data in a directory on your system. First unzip the .zip file of data by double clicking on it and specifying a temporary location. Next double click on the unzipped template, type the location of the unzipped soils data files as prompted and the shapefiles will be ready to use.

Appendix C

Sample SQL code to extract soil attributes from NRCS Soil Data Mart

Sample SQL code to extract soil attributes from NRCS Soil Data Mart

- AWC by county are overlap

```
SELECT lo.areasymbol, lo.areaname, mo.mukey, mua.aws0100wta
FROM laoverlap lo inner join muaoverlap mo ON mo.lareaovkey = lo.lareaovkey
inner join mapunit m ON m.mukey = mo.mukey
inner join muaggatt mua ON m.mukey = mua.mukey
WHERE lo.areasymbol = 'MTxxx'
```

- CEC for all horizons up to 24 inches in depth (61 cm)

```
SELECT
lo.areasymbol, lo.areaname, -- data from legend overlap table
mo.mukey, -- data from map unit overlap table
compname, comppct_r, -- data from component table
ch.cokey, hzname, hzdept_r, hzdepb_r, cec7_r, ecec_r  -- data from horizon table
FROM
laoverlap lo
inner join muaoverlap mo ON mo.lareaovkey = lo.lareaovkey
        and lo.areasymbol = 'MTxxx'
 inner join mapunit m ON m.mukey = mo.mukey
  inner join component c ON c.mukey = m.mukey
     and compkind != 'Miscellaneous area'
   left outer join chorizon ch on ch.cokey = c.cokey and
    hzdept_r <= 61
     and hzname NOT IN ('R','Cr','Oi','Oi1','Oi2')
```

- Ph for all horizons to 24 inches in depth (61 cm)

```
SELECT
lo.areasymbol, lo.areaname, -- data from legend overlap table
mo.mukey, -- data from map unit overlap table
compname, comppct_r, -- data from component table
ch.cokey, hzname, hzdept_r, hzdepb_r, ph1to1h2o_r, ph01mcacl2_r  -- data from horizon
table
FROM
laoverlap lo
inner join muaoverlap mo ON mo.lareaovkey = lo.lareaovkey
        and lo.areasymbol = 'MTxxx'
 inner join mapunit m ON m.mukey = mo.mukey
  inner join component c ON c.mukey = m.mukey
     and compkind != 'Miscellaneous area'
   left outer join chorizon ch on ch.cokey = c.cokey and
    hzdept_r <= 61
     and hzname NOT IN ('R','Cr','Oi','Oi1','Oi2')
```

- Miscellaneous Components by county area overlap

```
SELECT lo.areasymbol, lo.areaname, m.mukey, c.compname, c.compkind, c.comppct_r
FROM laoverlap lo
 inner join muaoverlap mo ON mo.lareaovkey = lo.lareaovkey
   inner join mapunit m ON m.mukey = mo.mukey
    inner join component c ON c.mukey = m.mukey
      and c.compkind = 'Miscellaneous Area'
WHERE lo.areasymbol = 'MTxxx'
```

Note: **xxx** is a Montana county numeric code.

Appendix D

Guide for Estimating Available Water-holding Capacity for Montana Soils by Textural Class

Guide for Estimating Available Water-holding Capacity for Montana Soils by Textural Class

USDA Textural Classes	Available Water-Holding Capacity	
	inches/inch	inches/foot
Coarse sand	<0.4	<0.5
Sand Fine sand Loamy sand	0.4-0.8	0.5-1.0
Loamy sand Loamy fine sand Coarse sandy loam Very fine sand	0.06-0.12	0.7-1.4
Loamy very fine sand Sandy loam Sandy clay Fine sandy loam	0.10-0.16	1.2-2.0
Clay loam Clay Silty clay Sandy clay loam	0.12-0.18	1.4-2.2
Loam Silty clay loam Very fine sandy loam	0.14-0.20	1.7-2.4
Silt loam Silt	0.18-0.22	2.2-2.6

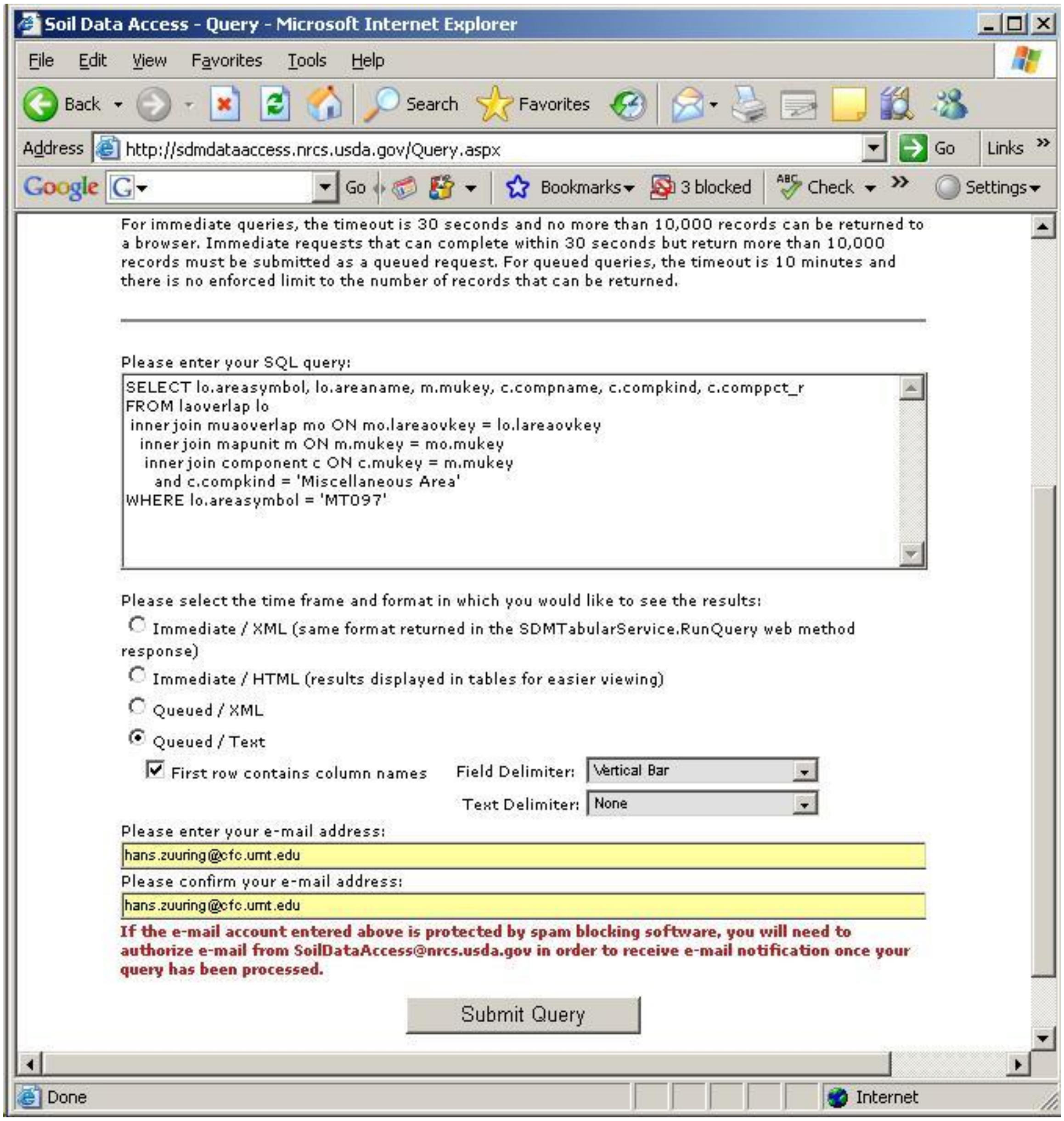
Appendix E

Custom requests for soil tabular data from NRCS Soil Data Access

Custom requests for soil tabular data from NRCS Soil Data Access

1. Go to http://sdmdataaccess.nrcs.usda.gov/

2. Click on “**Submit a custom request for soil tabular data**” and the following screen appears:



3. Place the appropriate SQL query text in the box. Note: Be sure to specify the appropriate Montana county code “MTxxx”. A bare ground query is illustrated.

4. Click the indicated radio button and checkbox and select **Vertical Bar** for Field Delimiter and **None** for Text Delimiter.

5. Enter your e-mail address twice and then click on **Submit Query** command button.

6. The results of all these queries can be obtained from a URL embedded in e-mail messages sent to the requestor by the soil data mart computer center once the requested processing has been completed.

7. A zipped file named **SDMQueryxxx.zip** is retrieved which contains an ASCII text file where **xxx** is a 3-digit query request number generated by the server.

8. The CEC and PH text files will each need to be loaded into EXCEL so that further processing (dual-level aggregation) can occur.

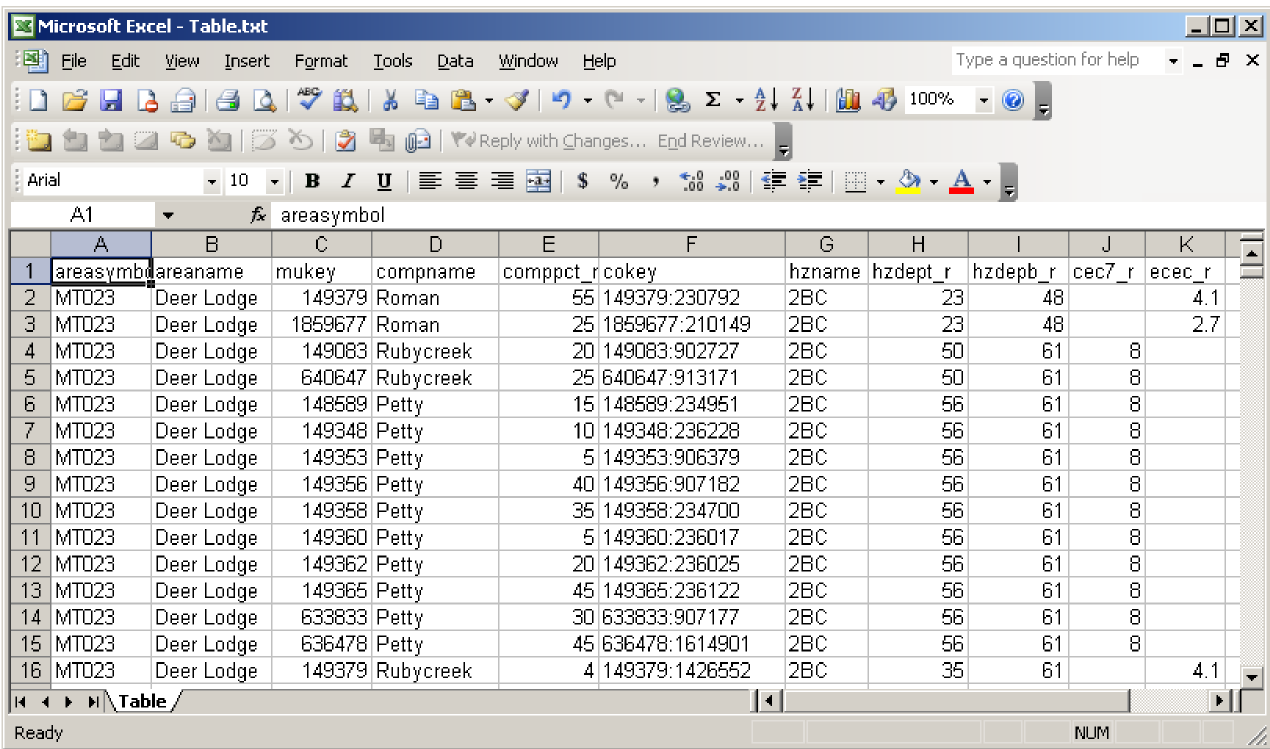
Appendix F

Dual-level Aggregation Processing Instructions of Soil Data Mart Query Results using MS-EXCEL.

Dual-level Aggregation Processing Instructions of Soil Data Mart Query Results using MS-EXCEL.
July 2, 2007
By: Mike Hansen, Robert Spokas, MT Soils Staff
Modified by: Hans Zuuring August 21, 2007

For this example the raw CEC data for Deer Lodge Co., MT (parts of 3 Soil Survey Areas) is loaded into an MS-EXCEL worksheet using standard load procedures. Note view of loaded data below…

Note that this same dual-level aggregation process must be applied to PH also.



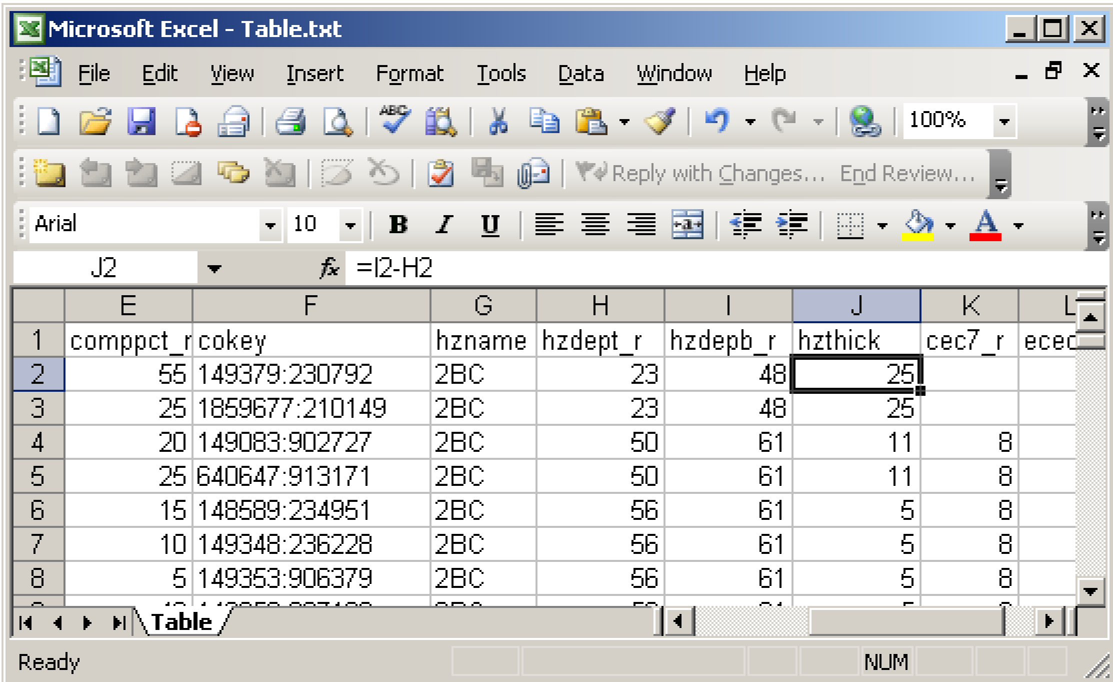
	A	B	C	D	E	F	G	H	I	J	K
1	areasymbol	areaname	mukey	compname	comppct_r	cokey	hzname	hzdept_r	hzdepb_r	cec7_r	ecec_r
2	MT023	Deer Lodge	149379	Roman	55	149379:230792	2BC	23	48		4.1
3	MT023	Deer Lodge	1859677	Roman	25	1859677:210149	2BC	23	48		2.7
4	MT023	Deer Lodge	149083	Rubycreek	20	149083:902727	2BC	50	61	8	
5	MT023	Deer Lodge	640647	Rubycreek	25	640647:913171	2BC	50	61	8	
6	MT023	Deer Lodge	148589	Petty	15	148589:234951	2BC	56	61	8	
7	MT023	Deer Lodge	149348	Petty	10	149348:236228	2BC	56	61	8	
8	MT023	Deer Lodge	149353	Petty	5	149353:906379	2BC	56	61	8	
9	MT023	Deer Lodge	149356	Petty	40	149356:907182	2BC	56	61	8	
10	MT023	Deer Lodge	149358	Petty	35	149358:234700	2BC	56	61	8	
11	MT023	Deer Lodge	149360	Petty	5	149360:236017	2BC	56	61	8	
12	MT023	Deer Lodge	149362	Petty	20	149362:236025	2BC	56	61	8	
13	MT023	Deer Lodge	149365	Petty	45	149365:236122	2BC	56	61	8	
14	MT023	Deer Lodge	633833	Petty	30	633833:907177	2BC	56	61	8	
15	MT023	Deer Lodge	636478	Petty	45	636478:1614901	2BC	56	61	8	
16	MT023	Deer Lodge	149379	Rubycreek	4	149379:1426552	2BC	35	61		4.1

This set has about 16,500 rows of data initially. Data for R, Cr and Oi horizons is deleted. This could be done in the query as well. In addition, the data is reviewed for data gaps as well as cases where both CEC types are populated (corrected by removing the offending column data entries).

Next, sort the dataset by **hzdepb_r**, editing all values > 61 (61cm = 24 inches) to be equal to **61**. This limits the weighted results to a maximum soil pit depth of the intended 61cm (24 inches).

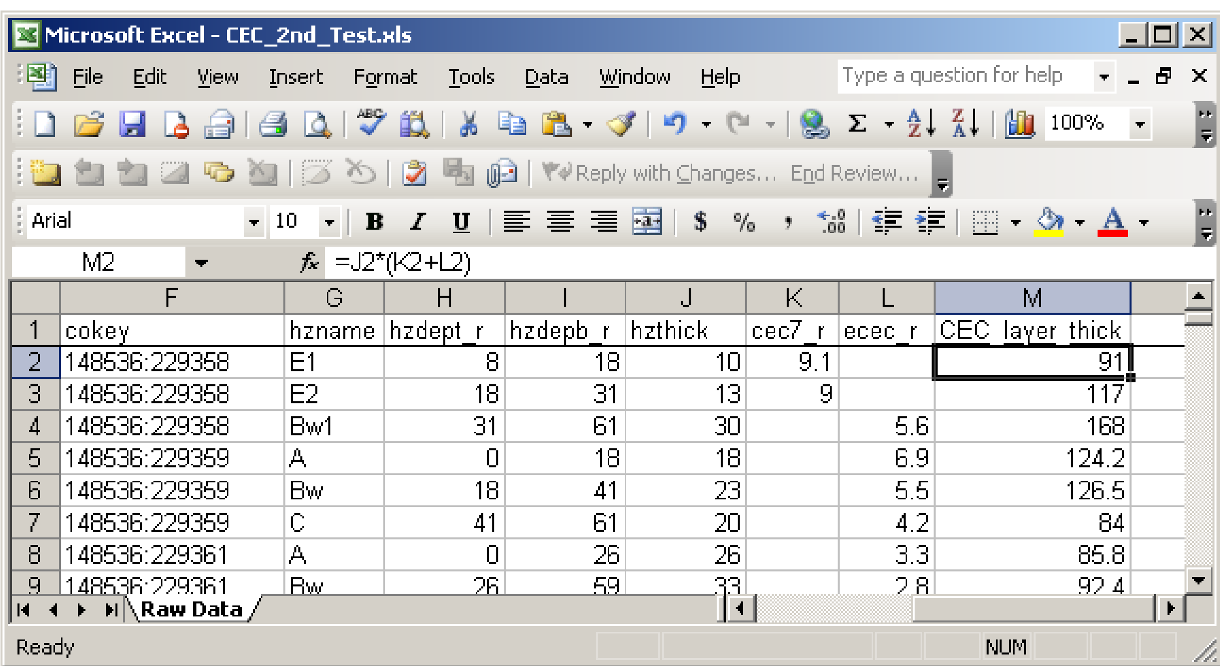
The next step, following this data cleanup, is to add two columns to the existing worksheet.

First, create a column for horizon thickness – to be named **hzthick**, populated with the calculation "= i2 – h2" (hzdepb_r - hzdept_r effectively). This formula is pasted into all records in the column labeled **hzthick**, a new column inserted to the right of hzdepb_r.



	E	F	G	H	I	J	K	L
1	comppct_r	cokey	hzname	hzdept_r	hzdepb_r	hzthick	cec7_r	ecec
2	55	149379:230792	2BC	23	48	25		
3	25	1859677:210149	2BC	23	48	25		
4	20	149083:902727	2BC	50	61	11	8	
5	25	640647:913171	2BC	50	61	11	8	
6	15	148589:234951	2BC	56	61	5	8	
7	10	149348:236228	2BC	56	61	5	8	
8	5	149353:906379	2BC	56	61	5	8	

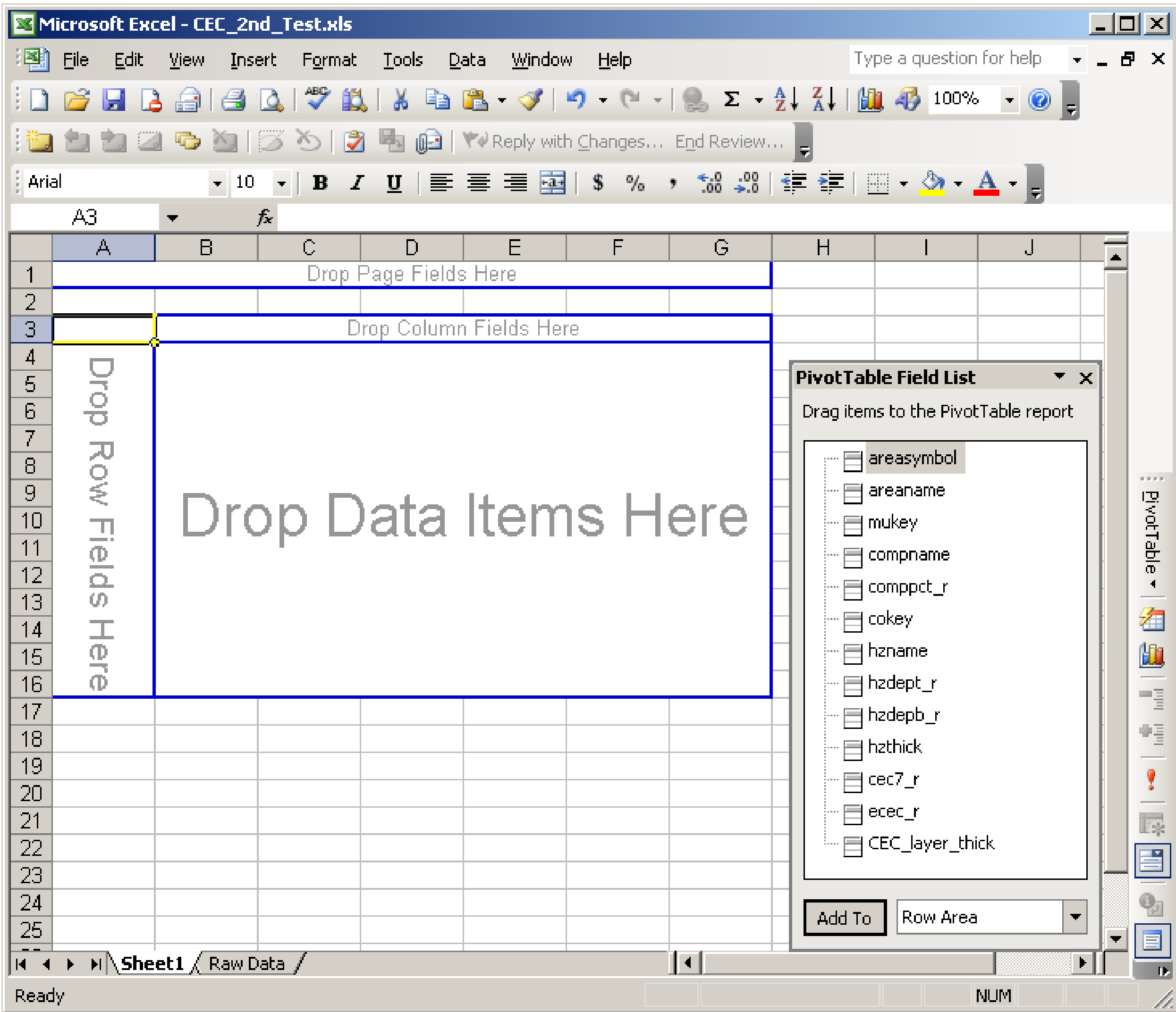
Next, create another column for layer depth accumulated CEC. Add the column **CEC_lyr_thick**. Populate it with the calculation "= J2*(K2+L2)" (hzdepth X [cec7_r + ecec_r]). Note that this worksheet has been named "raw data".



	F	G	H	I	J	K	L	M
1	cokey	hzname	hzdept_r	hzdepb_r	hzthick	cec7_r	ecec_r	CEC_layer_thick
2	148536:229358	E1	8	18	10	9.1		91
3	148536:229358	E2	18	31	13	9		117
4	148536:229358	Bw1	31	61	30		5.6	168
5	148536:229359	A	0	18	18		6.9	124.2
6	148536:229359	Bw	18	41	23		5.5	126.5
7	148536:229359	C	41	61	20		4.2	84
8	148536:229361	A	0	26	26		3.3	85.8
9	148536:229361	Bw	26	59	33		2.8	92.4

We are now ready to run two tiers of calculations using the Pivot Table capability within MS-Excel. This functionality enables the dual aggregation needed.

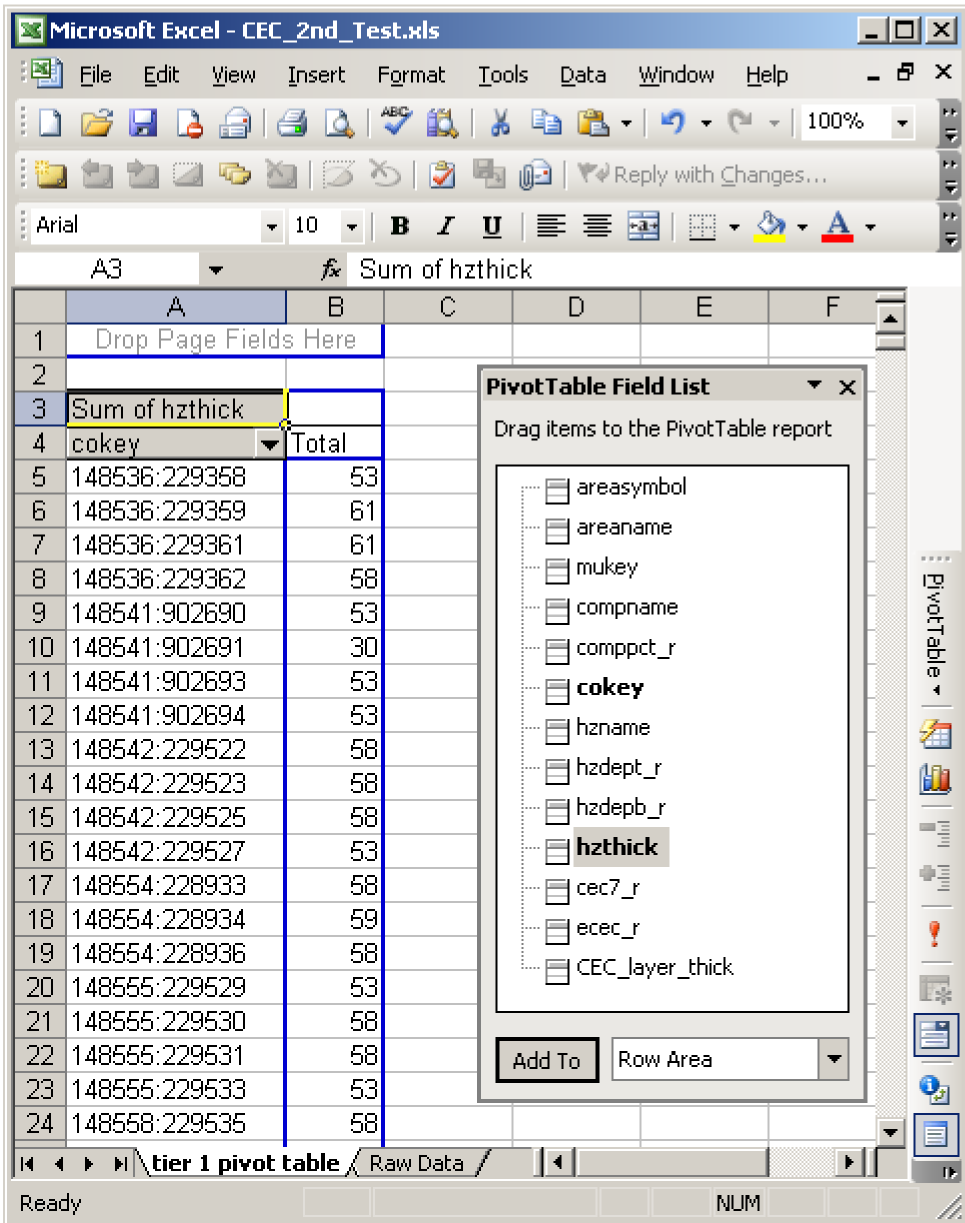
Selecting the entire contents of the raw data worksheet, choose top menu option **Data/Pivot Table…** and the following screen appears:



We will ultimately use this "tier 1 pivot table" twice, but for now we are totaling weighted CEC values over the profile depth to 61 cm (may not be 61).

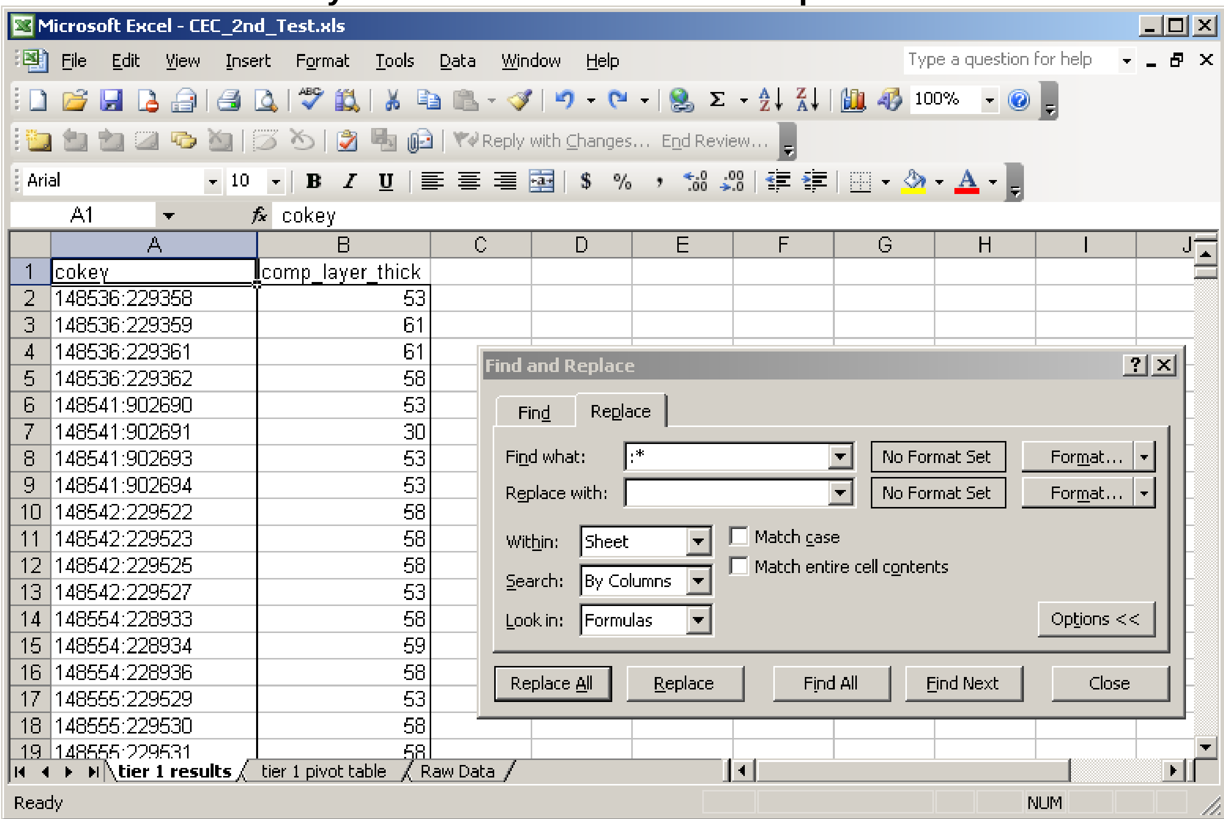
- Drag/drop row field "**cokey**" into cell **A4** and drag/drop column field "**hzthick**" into cell **B5**.
- Double-click heading in cell **A3** (Count of hzthick) and a Pivot Table Field dialog window appears.
- Select Summarize by: **Sum** and click **OK**.

The results in <u>both</u> columns from row 5 thru the end of the data are selected and copied into a new worksheet named “tier 1 results” referenced above, starting in row 2. Type the label “**cokey**” in the first column, row 1 and the label “**comp_lyr_thick**” in the second column, row 1.

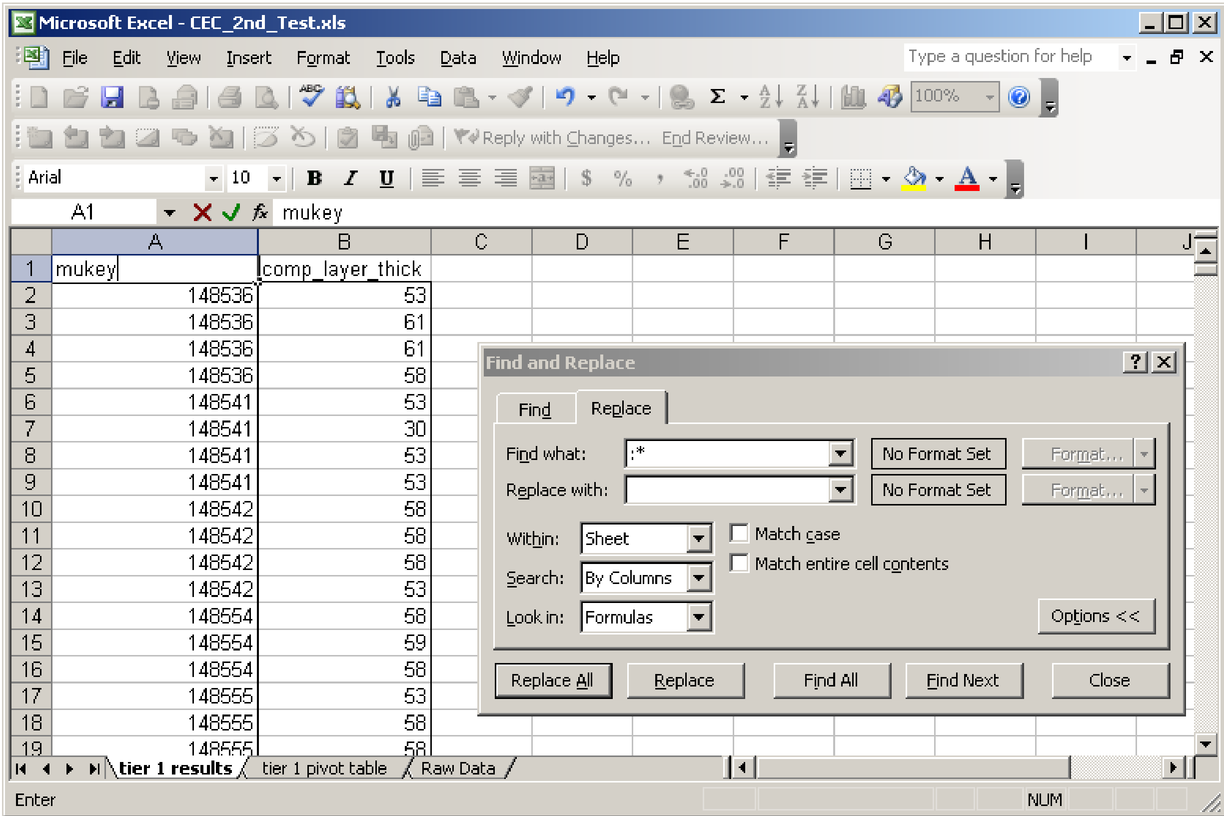


Before continuing with the second part of the data calculation, to enable eventual aggregation at the map unit level, we convert the values in the **cokey** column to **mukey** using the MS-Excel Edit/Replace function on the tier 1 results as follows:

- Highlight the “**cokey**” column and select **Edit/Replace** and a Find and Replace dialog window appears.
- Click the **Options** button to expand this window and type “**:***” in the **Find what:** box.
- Select Search: **By Columns** and then click the **Replace All** button.

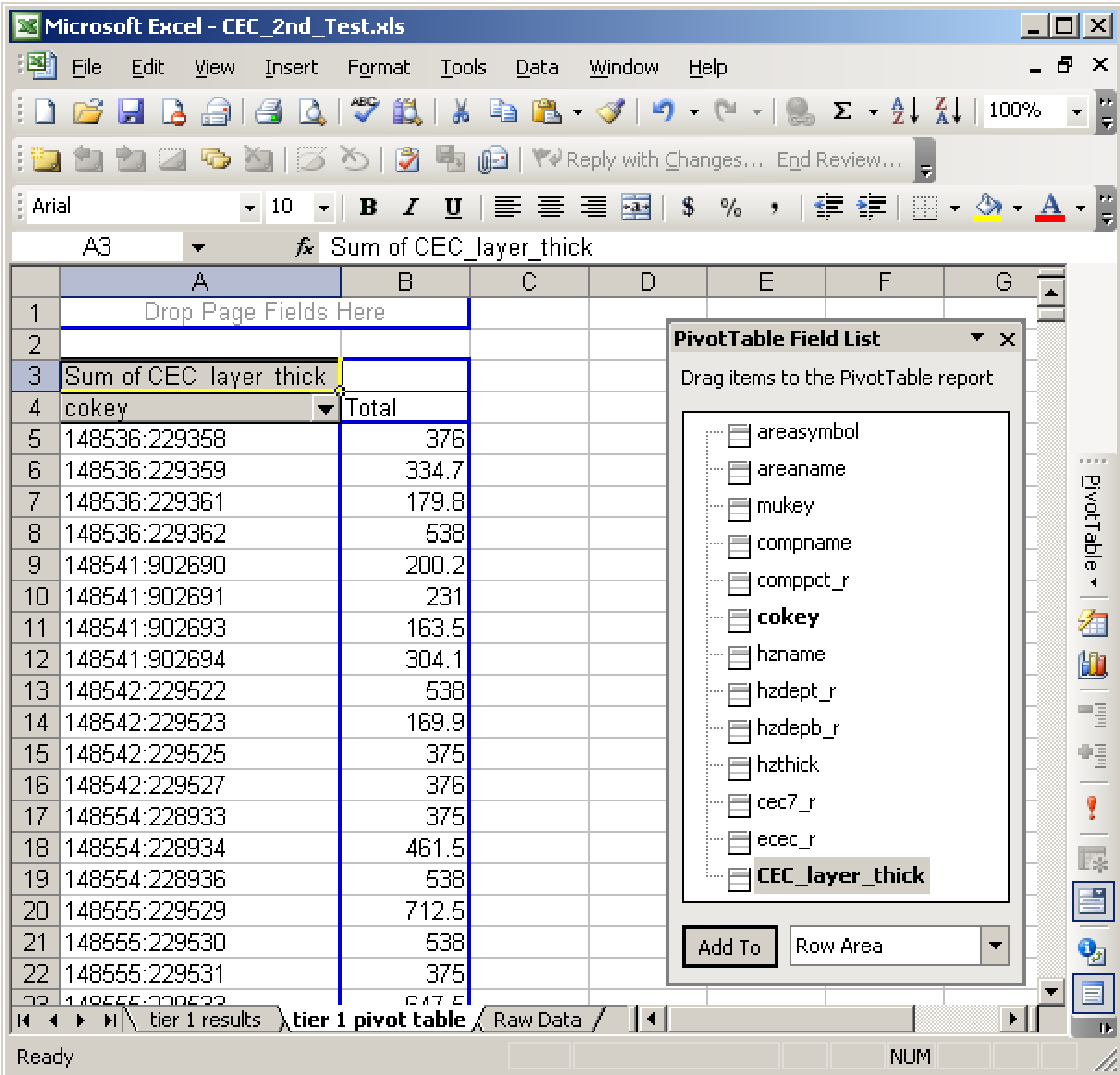


- Rename the first column label “**mukey**” as illustrated below and type “**comp_lyr_thick**” for the second column label.

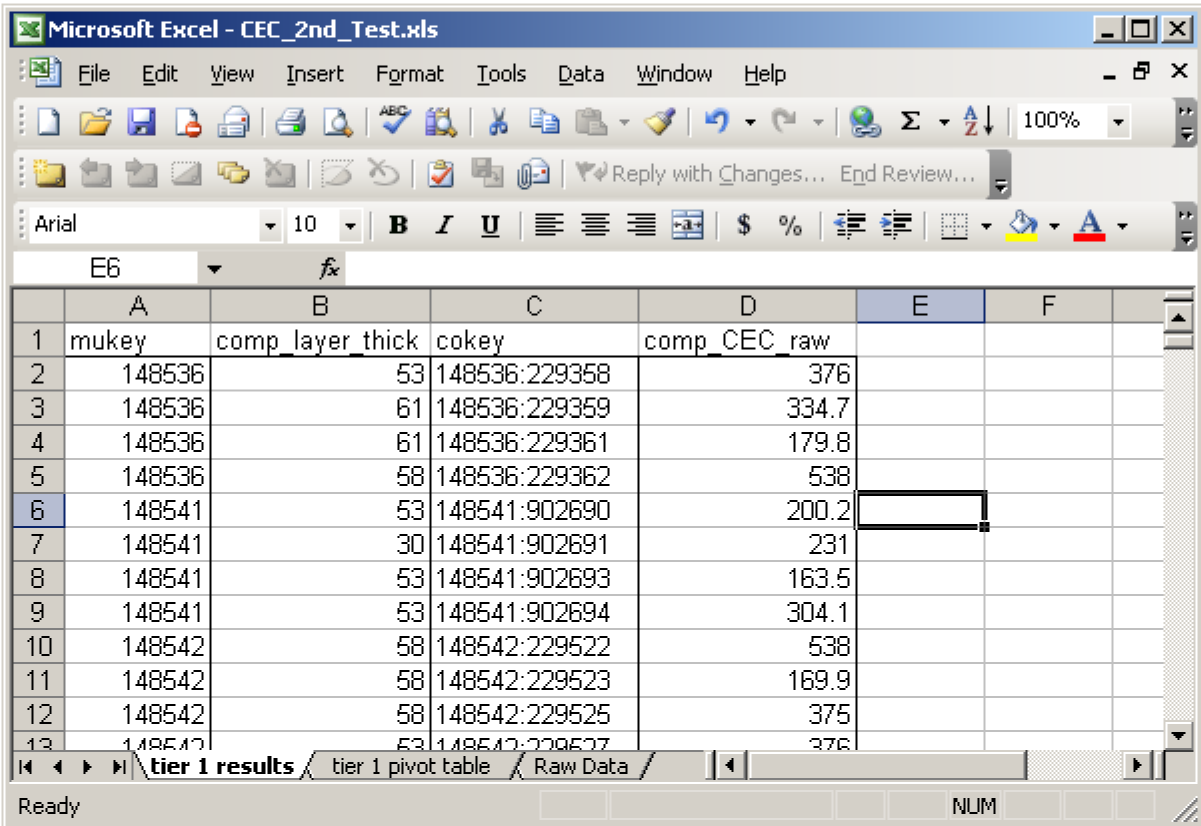


…secondly, we calculate the total the layer CEC values using the pivot table function on worksheet tab "tier 1 pivot table" by:

- Drag/dropping the contents of cell **A3** to empty cell **C5** so as to delete the previous column field.
- Drag/drop "**CEC_lyr_thick**" into cell **B5** and new results appear in column B. Note: make sure the label in **A3** reads "Sum of CEC_lyr_thick" and not "Count CEC_lyr_thick". If the latter appears, double-click on this cell (A3) and change the selection in the resultant Pivot Table Field dialog window under Summarize by: and click **OK**.


Microsoft Excel - CEC_2nd_Test.xls
File Edit View Insert Format Tools Data Window Help
Reply with Changes... End Review...
Arial 10
A3 Sum of CEC_layer_thick
Drop Page Fields Here
Sum of CEC_layer_thick
cokey Total
148536:229358 376
148536:229359 334.7
148536:229361 179.8
148536:229362 538
148541:902690 200.2
148541:902691 231
148541:902693 163.5
148541:902694 304.1
148542:229522 538
148542:229523 169.9
148542:229525 375
148542:229527 376
148554:228933 375
148554:228934 461.5
148554:228936 538
148555:229529 712.5
148555:229530 538
148555:229531 375
PivotTable Field List
Drag items to the PivotTable report
areasymbol
areaname
mukey
compname
comppct_r
cokey
hzname
hzdept_r
hzdepb_r
hzthick
cec7_r
ecec_r
CEC_layer_thick
Add To Row Area
PivotTable
tier 1 results
tier 1 pivot table
Raw Data
Ready
NUM

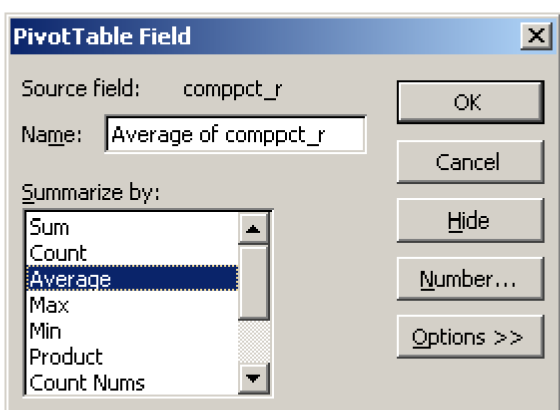
The results of this second pivot table calculation (two columns of values starting at row 5 and ending at the last data record) are copied onto the previously created “tier 1 results” worksheet alongside the previously relabeled “comp_lyr_thick” (alias “hzdepth”) column. The 3rd column is labeled “**cokey**” and the 4th column is labeled “**comp_CEC_raw**” (alias “CEC_lyr_thick”).



	A	B	C	D	E	F
1	mukey	comp_layer_thick	cokey	comp_CEC_raw		
2	148536	53	148536:229358	376		
3	148536	61	148536:229359	334.7		
4	148536	61	148536:229361	179.8		
5	148536	58	148536:229362	538		
6	148541	53	148541:902690	200.2		
7	148541	30	148541:902691	231		
8	148541	53	148541:902693	163.5		
9	148541	53	148541:902694	304.1		
10	148542	58	148542:229522	538		
11	148542	58	148542:229523	169.9		
12	148542	58	148542:229525	375		

Next we will add the component percent composition to this “tier 1 results” worksheet.

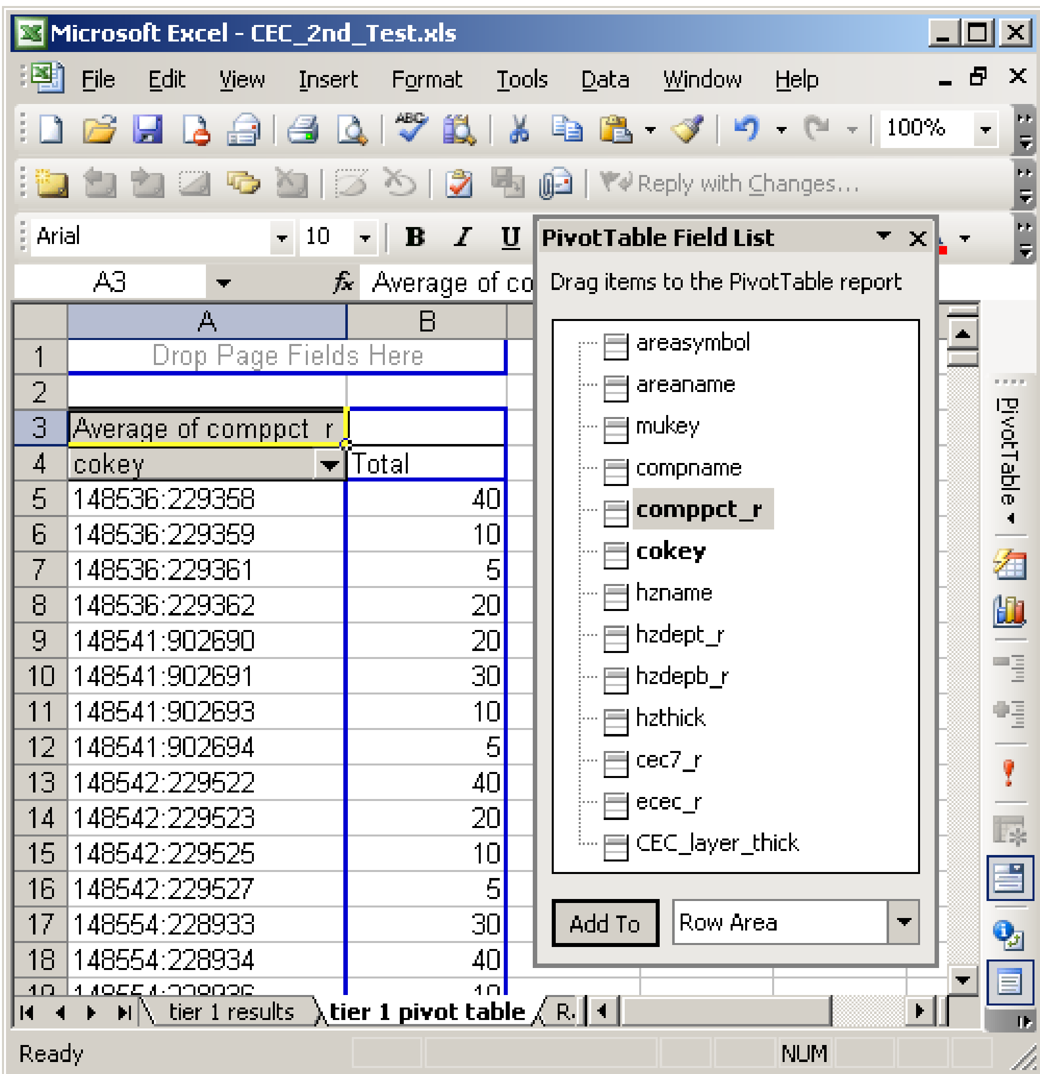
Using the average function, we aggregate the horizon level data to the component level for insertion as follows:

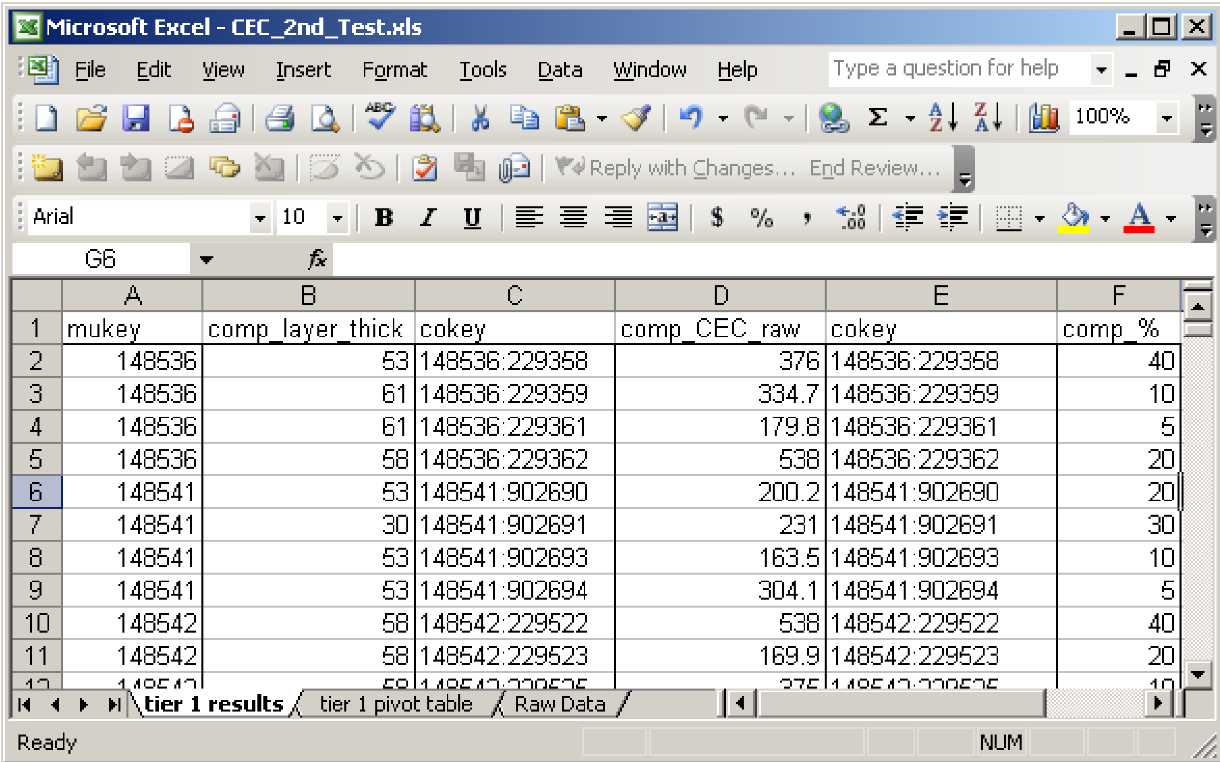


- Return to “tire 1 pivot table” worksheet and drag/drop the contents of cell **A3** to empty cell **C5** so as to delete the previous column field.

- Drag/drop “**comppct_r**” into cell **B5** and new results appear in column B. Note: make sure the label in **A3** reads “Average of comppct_r” and not anything else. If the wrong label appears, double-click on this cell (A3) and change the selection in the resultant Pivot Table Field dialog window under Summarize by: to **Average** and click **OK** (see screen image above).

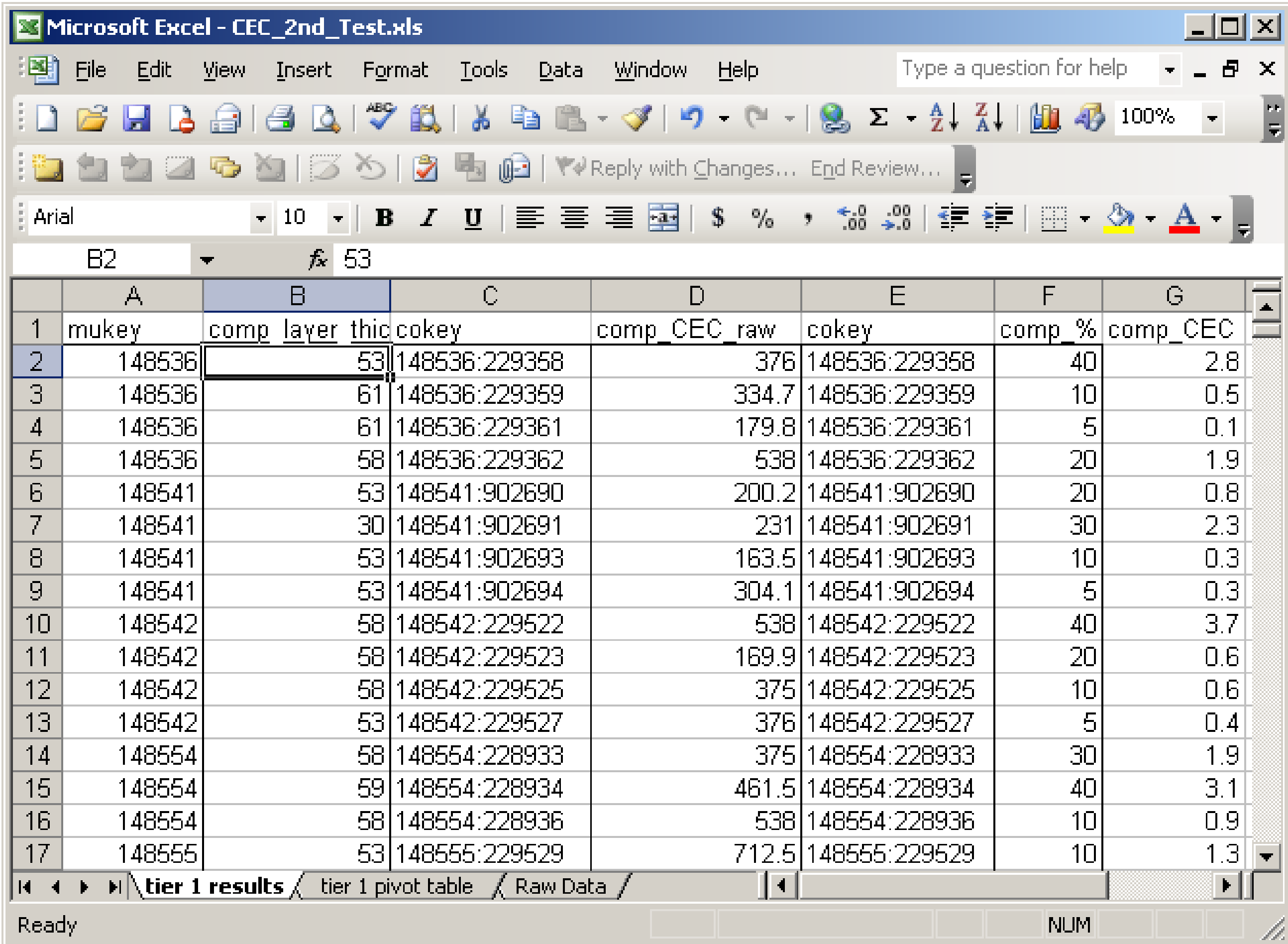
- Copy the resulting two columns of data into the “tier 1 results” worksheet, placing it in the **5th** column labeled “**cokey**” and the **6th** column labeled “**comp_%**”.





	A	B	C	D	E	F
1	mukey	comp_layer_thick	cokey	comp_CEC_raw	cokey	comp_%
2	148536	53	148536:229358	376	148536:229358	40
3	148536	61	148536:229359	334.7	148536:229359	10
4	148536	61	148536:229361	179.8	148536:229361	5
5	148536	58	148536:229362	538	148536:229362	20
6	148541	53	148541:902690	200.2	148541:902690	20
7	148541	30	148541:902691	231	148541:902691	30
8	148541	53	148541:902693	163.5	148541:902693	10
9	148541	53	148541:902694	304.1	148541:902694	5
10	148542	58	148542:229522	538	148542:229522	40
11	148542	58	148542:229523	169.9	148542:229523	20

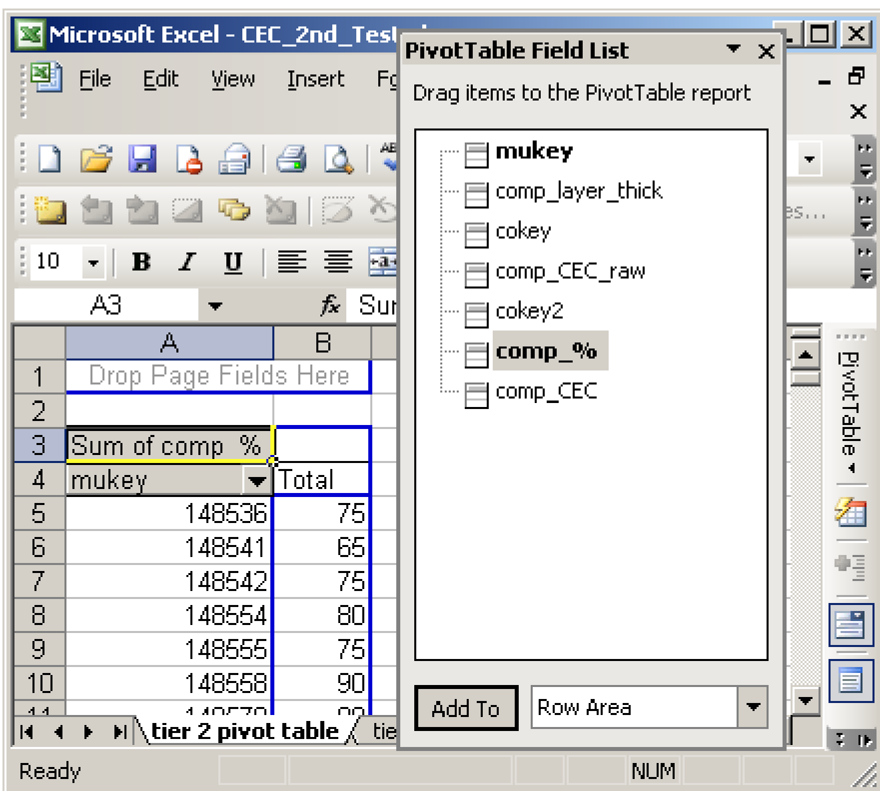
- Next, we create a 7th column labeled “**comp_CEC**” in the “tier 1 results” worksheet using the formula: = d2*(f2/100)/b2 (comp_CEC_raw X (comp_%/100) / comp_lyr_thick). The results are shown in the screen capture on the next page.



	A	B	C	D	E	F	G
1	mukey	comp_layer_thic	cokey	comp_CEC_raw	cokey	comp_%	comp_CEC
2	148536	53	148536:229358	376	148536:229358	40	2.8
3	148536	61	148536:229359	334.7	148536:229359	10	0.5
4	148536	61	148536:229361	179.8	148536:229361	5	0.1
5	148536	58	148536:229362	538	148536:229362	20	1.9
6	148541	53	148541:902690	200.2	148541:902690	20	0.8
7	148541	30	148541:902691	231	148541:902691	30	2.3
8	148541	53	148541:902693	163.5	148541:902693	10	0.3
9	148541	53	148541:902694	304.1	148541:902694	5	0.3
10	148542	58	148542:229522	538	148542:229522	40	3.7
11	148542	58	148542:229523	169.9	148542:229523	20	0.6
12	148542	58	148542:229525	375	148542:229525	10	0.6
13	148542	53	148542:229527	376	148542:229527	5	0.4
14	148554	58	148554:228933	375	148554:228933	30	1.9
15	148554	59	148554:228934	461.5	148554:228934	40	3.1
16	148554	58	148554:228936	538	148554:228936	10	0.9
17	148555	53	148555:229529	712.5	148555:229529	10	1.3

At this point we enter the next phase by creating a “tier 2 pivot table” worksheet from all seven columns highlighted in the “tier 1 results” worksheet. The purpose of this second phase is to subtotal map unit composition (mu_comp) and raw map unit CEC (mu_CEC_raw). The resulting mu_comp and mu_CEC_raw fields will be run through a formula to obtain the final goal of map unit weighted CEC to a depth of 61cm (24 inches).

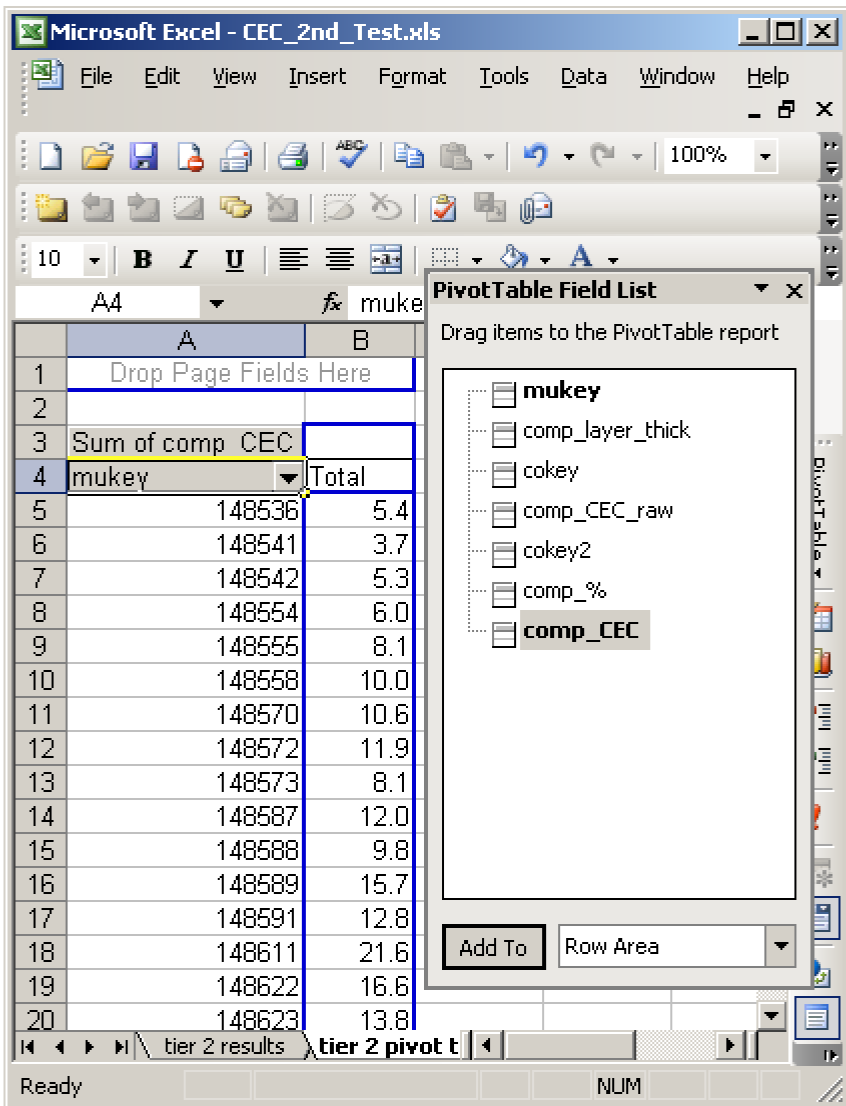
- Drag/drop row field “**mukey**” into cell **A4** and drag/drop column field “**comp_%**” into cell **B5**.
- If the label in cell **A3** does not read “Sum of comp_%”, double-click the wrong heading in cell **A3** and a Pivot Table Field dialog window appears.
- Select Summarize by: **Sum** and click **OK** to correct this mistake.
- Insert a new worksheet labeled “**tier 2 results**”.
- Copy the two columns of data starting at row 5 from the “tier 2 pivot table” worksheet into the first two columns of the “tier 2 results” worksheet starting at row 2 and label these columns “**mukey**” and “**mu_comp**” respectively in row 1.

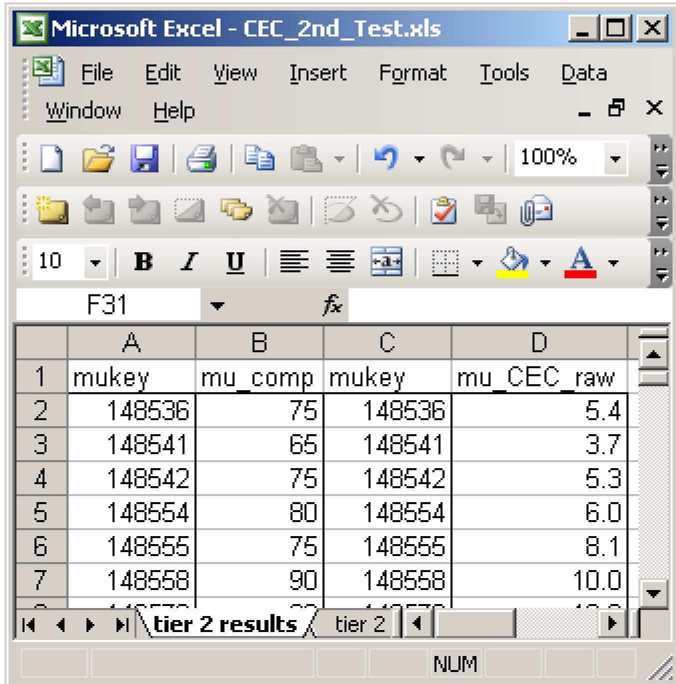


- Return to the “tier 2 pivot table” worksheet and drag/drop the contents of cell **A3** to empty cell **C5** so as to delete the previous column field.

- Drag/drop “**comp_CEC**” into cell **B5** and new results appear in column B. Note: make sure the label in **A3** reads “Sum of comp_CEC” and not anything else. If the wrong label appears, double-click on this cell (A3) and change the selection in the resultant Pivot Table Field dialog window under Summarize by: to **Sum** and click **OK**.

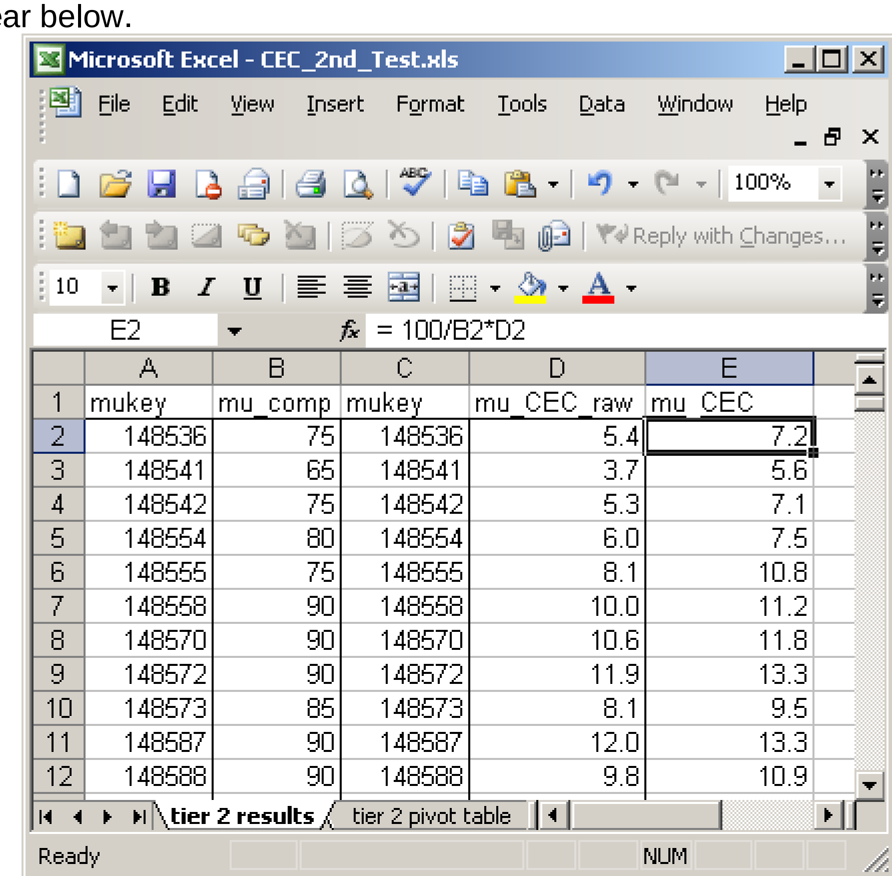
- Copy the two columns of data starting at row 5 from the “tier 2 pivot table” worksheet into the 3rd and 4th columns of the “tier 2 results” worksheet starting at row 2 and label these columns “**mukey**” and “**mu_CEC_raw**” respectively in row 1. The results are shown in the screen grab on the next page.





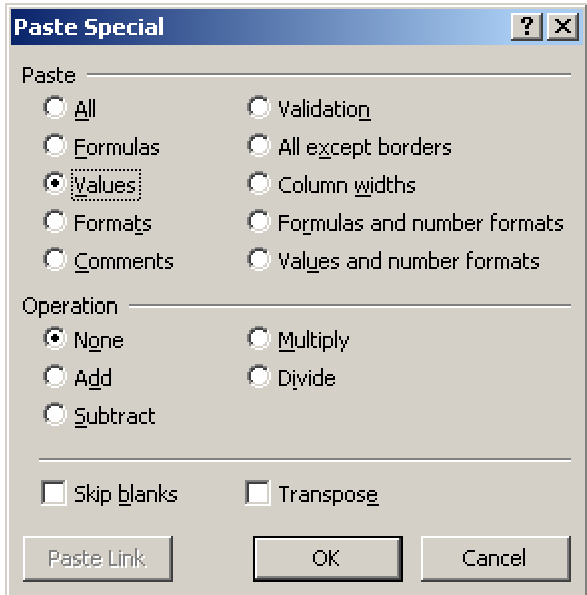
	A	B	C	D
1	mukey	mu_comp	mukey	mu_CEC_raw
2	148536	75	148536	5.4
3	148541	65	148541	3.7
4	148542	75	148542	5.3
5	148554	80	148554	6.0
6	148555	75	148555	8.1
7	148558	90	148558	10.0

- Create a 5th column labeled "**mu_CEC**" and populate that column with the formula: = 100/B2*D2 (100/mu_comp X mu_CEC_raw). This calculation adjusts "mu_CEC" for the percent of the map unit represented in the data. The results appear below.



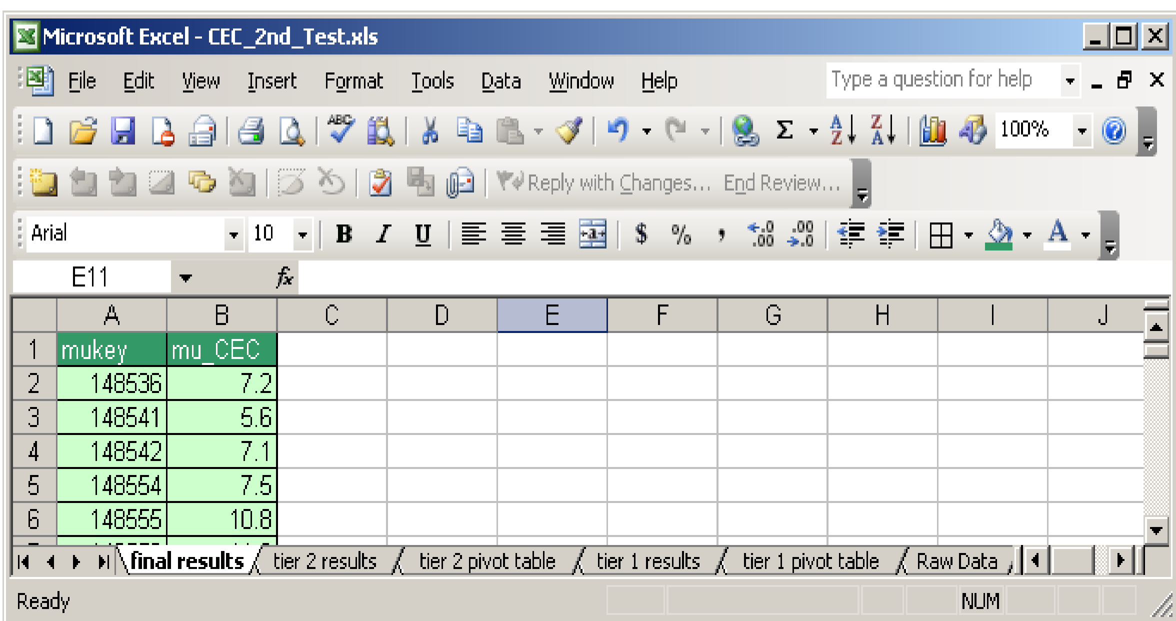
	A	B	C	D	E
1	mukey	mu_comp	mukey	mu_CEC_raw	mu_CEC
2	148536	75	148536	5.4	7.2
3	148541	65	148541	3.7	5.6
4	148542	75	148542	5.3	7.1
5	148554	80	148554	6.0	7.5
6	148555	75	148555	8.1	10.8
7	148558	90	148558	10.0	11.2
8	148570	90	148570	10.6	11.8
9	148572	90	148572	11.9	13.3
10	148573	85	148573	8.1	9.5
11	148587	90	148587	12.0	13.3
12	148588	90	148588	9.8	10.9

One final step is to copy these results into another worksheet. Most others have calculated fields which are sensitive to being moved etc…



Using **copy/paste special** into the next right empty column, being sure to click the radio button for “values” as noted above.

I then add a new worksheet, name it “**final results**”, copy this new, value based column of **mu_CEC** values along with the “**mukey**” column. This is the data that will be accessed in the context of the spatial data for analysis etc…



The result is a single CEC value identified by “mukey”, weighted within soil components to a depth of 61cm (24 inches) and across components within the map unit and finally balanced against the soil portion of the map unit for later analysis use.

Appendix G

List of converted NRCS soil-woodland field records by county and plot number ranges
November 13, 2007

List of converted NRCS soil-woodland field records by county and plot number ranges dated November 13, 2007

County Code	County Name	Order of Importance	Plot Numbers	Location data Entered (Who)?
01	Beaverhead	7	1	YES (Barb)
03	Big Horn	28	None	
05	Blaine	15	1 - 10	
07	Broadwater	23	1 - 6	
09	Carbon	18	1 - 32	
11	Carter	13	1 – 62 =>1 - 34	YES (Hans)
			35 – 62	YES (Sonia)
13	Cascade		1 - 19	
15	Chouteau	16	1 – 52	YES (Sonia)
17	Custer		1 – 6	YES (Barb)
23	**Deer Lodge**	test (24)	1 – 48	YES (Sonia)
25			1 - 3	
27	**Fergus**	test (19)	1 - 86	
29	Flathead	6	1 – 32	YES (Hans)
31	Gallatin	17	15 – 96	YES (Barb)
35			1 - 31	
37	Golden Valley	29	None	
39	Granite	10	1 – 122 => 103 – 122	YES (Barb)
41	Hill	25	1 - 17	
43	Jefferson	20	1 - 18	
45			1 - 36	
47	**Lake**	test (12)	1 – 14	YES (Hans)
			15 - 204	YES (Hans)
49	Lewis & Clark	8	1 – 50,	YES (Hans)
			51 – 149	YES (Hans)
51			1 – 7	
53	Lincoln	4	1 – 18	YES (Barb)
55			1	
57	Madison	21	301 – 408	YES (Rob)
59	Meagher	22	1 – 10	
61	Mineral	3	1 – 3	YES (Hans)
63	Missoula	1	1 – 117	YES (Sonia)
			118 – 252	YES (Hans)
			259 – 299	YES (Hans)
65	Musselshell	30	1 – 7	
69			1 – 7	
71	Phillips	26	1 – 3	
75	Powder River	9	1 – 45 => 1 – 43	YES (Hans)
77	Powell	5	1 – 156	YES (Rob)
81	Ravalli	2	1 – 42	YES (Hans)
85			1 – 6	
87	Rosebud	31	1 – 27	YES (Rob)

89	**Sanders**	test (11)	1 – 186	YES (Sonia)
			214 – 468	YES (Sonia)
			500 – 575	YES (Sonia)
93	Silver Bow	32	1 – 11	
95	Stillwater	27	1 – 6	
97	Sweet Grass	33	1 – 36	YES (Barb)
99			1 – 26	
101	Toole	14	1 – 6	

TOTAL # of records completed: **2267**

Appendix H

REAP Data Extraction Operations

REAP Data Extraction Operations

- Launch “all_Counties.mxd” (located in …/database subdirectory) in ArcMap.

- Add new county REAP raster layer, e.g. reap_flathead & build pyramids when asked by ArcGIS software (click **YES** in pop-up window)

- Open **ArcToolbox**.

- Click on **Spatial Analyst Tools** to expand the items tree.

- Click on **Extraction** to expand the items tree.

- Double click on **Extract Values to Points** and the Extraction dialog window appears:

  For the **Input point features** select the previous county map layer named “Extract_reap_ravalli”
  For the **Input raster** select “reap_flathead” (current county name)
  For the **Output point features** type “Extract_reap_flathead.shp”
  Click **OK** and another dialog box appears indicating execution progress.
  Click **Close** when execution has been successfully completed

- Right-click on newly created output point map layer name and select **Open Attribute Table**.

- Move horizontal scroll bar over to far right of the table and see that new column labeled **RASTERVALU** has been added to the table. Note: A value of -9999 indicates a null, i.e. no data.

- Click on **Selection/Select by Attributes…** and a dialog window appears:

  For **Input layer** select “Extract_reap_flathead” and create a new selection in the lower text box as follows **“RASTERVALU” > 0** and click **OK**. All the records with positive values are highlighted in cyan.

- Right-click on the **REAP** column label & select **Field Calculator…**

- Double-click on the field name **RASTERVALU** and click **OK** to initiate the requested computation. All the values in the **RASTERVALU** column of the selected records are added to the existing **REAP** column.

- Verify the transfer and then right-click on the **RASTERVALU** column label and select **Delete Field** and click **YES** to confirm this operation.

- Click on **Selection/Clear Selected Features** to remove highlighting from records.

Appendix I

Determining Culmination of Mean Annual Increment

Determining Culmination of Mean Annual Increment

Kelsey Milner
3/6/2008
Modified by Hans Zuuring on 6/12/2008

Introduction

Potential productivity of forest land is defined as the culmination of mean annual increment (CMAI) of a fully stocked, even aged stand. For this project, the units of CMAI are Net Scribner Board Feet per acre per year.

The estimate of CMAI is determined in two steps. First, the Site Index (SI) is predicted for every 5-acre piece of forest land using the Soil/Site models developed by Milner and Zuuring. This model was built from field data collected by Milner (1984), field data from a DOR sponsored effort (2006), and data collected by the SCS over many years. The model predicts SI (height of dominant and co-dominant trees at 50 years of age at breast height) for given inputs of slope, aspect, elevation, precipitation, soil water holding capacity, and pH. Details of this model's derivation and validation are given in a separate document.

Second, the predicted SI is used in a growth and yield model (Forest Projection and Planning System – FPS) to grow fully stocked, even-aged plantations to the point of CMAI. The remainder of this paper describes the procedures used in this second step.

The FPS Model

The Forest Projection and Planning System (**FPS**) is a set of software used by industrial, tribal, state, and county organizations throughout the Inland and Pacific NW regions. Owned by the Forest Biometrics Research Institute, FPS has become the most widely used and referenced G&Y system in the West. Specifically, it has been calibrated for forest land and species in Montana.

The model grows individual trees of a species based on SI, growing space, and tree vigor. Trees die as competition increases beyond specified thresholds of stand density. Competition is a function of growing space, which changes over time as trees grow. Growing space also depends on how clumpy a stand is. Trees in clumps grow more slowly than trees in openings. Thus a clumpy stand will have less growth on a per acre basis than a stand with uniform spacing among trees. The ability to incorporate stand clumpiness in G&Y estimates is unique to the FPS model and provides a way to accommodate stockability limitations found in some forest types (like dry DF and PP habitat types).

Determining CMAI

Our approach is to use FPS to simulate G&Y of fully stocked, even-aged stands, of a specified species or species mix, from year zero to the point of CMAI in BF/ac/yr. The simulations must use even-aged stands as CMAI is not defined for multi-aged conditions. The results will be an estimate of potential productivity that may or may not be achieved under actual management.

The basic steps are as follows:

1. Create input plantations for the FPS model. I recommend we use a mixture of Douglas-fir and ponderosa pine as these are the most common commercial species.

2. Project these plantations forward for **150** years for each 5-foot site index class from **35**’ to **95**’ (13 classes) crossed with clumpiness factors between **0.4** and **0.9** (6 levels). The FPS model calculates CMAI for each simulation. This produces **78** (13 X 6) estimates of CMAI arrayed by SI and Clumpiness factors.

3. Develop a cross-walk between habitat types (or environmental variables) and the stockability factors published in Pfister’s habitat type manual. Because the stockability factors in the habitat manual have essentially the same meaning as the FPS clumpiness factor, I propose to use the published stockability factors directly in FPS to adjust yields on very hot and dry sites. Thus if a location has a Clumpiness of 0.5, the estimate of potential productivity will be approximately 50% of the potential for that SI level.

4. The estimates of CMAI can then be mapped at the resolution used for applying the underlying soil/site model to the actual landscape.

Step 3 was modified by the development of a stocking factor equation that was a function of precipitation. The stockability factors were obtained from Pfister’s Montana Habitat type Manual (1977). A stocking factor was subsequent applied to CMAI75 so as to reduce it when the annual precipitation was between 10 and 18 inches. This resulted in a reduction in timber yield on very hot and dry sites.

Appendix J

SAS Program to build SOIL/SITE models
Using CIC, DOR & FIRELAB GIS data

```
 ***************************************************************************;
********** SAS PROGRAM TO BUILD SOIL/SITE MODELS FOR DOR PROJECT **********;
****                  Uses CIC, DOR & FIRELAB GIS DATA                 ***;
***************************************************************************;

* DEFINE INPUT DATA SET FROM CHAMPION ;
FILENAME SIDATA 'C:\DATA\CIC\841.DAT';
* DEFINE OUTPUT DATA SET CONTAINING FINAL MODELING DATA;
PROC EXPORT DATA=MODEL1
     OUTTABLE = "MODELDATA"
       DBMS = ACCESS97
       REPLACE;
       DATABASE = "C:\DATA\DOR\ALLDATA.MDB";

* IMPORT DOR LOCATION DATA  *;
PROC IMPORT OUT= WORK.location
            DATATABLE= "location"
            DBMS=ACCESS REPLACE;
     DATABASE="C:\Data\DOR\Copy of DOR_Data.mdb";
     SCANMEMO=YES;
     USEDATE=NO;
     SCANTIME=YES;
* IMPORT DOR TREE DATA  *;
PROC IMPORT OUT= WORK.TREE
            DATATABLE= "TREE"
            DBMS=ACCESS REPLACE;
     DATABASE="C:\Data\DOR\Copy of DOR_Data.mdb"; *the copy has been updated
to include calculated SI;
     SCANMEMO=YES;
     USEDATE=NO;
     SCANTIME=YES;
***    IMPORT FIRELAB DATA WITH ADDITIONAL SITE/CLIMATE VARIABLES FOR CIC
SAMPLE SITES ****;
PROC IMPORT OUT= WORK.Z19CIC
            DATATABLE= "841Z19"
            DBMS=ACCESS REPLACE;
     DATABASE="C:\Data\DOR\FIRELAB_DATA.mdb"; *the copy has been updated to
include calculated SI;
     SCANMEMO=YES;
     USEDATE=NO;
     SCANTIME=YES;
***    IMPORT FIRELAB DATA WITH ADDITIONAL SITE/CLIMATE VARIABLES FOR DOR
SAMPLE SITES ****;
PROC IMPORT OUT= WORK.Z19DOR
            DATATABLE= "DORZ19"
            DBMS=ACCESS REPLACE;
     DATABASE="C:\Data\DOR\FIRELAB_DATA.mdb"; *the copy has been updated to
include calculated SI;
     SCANMEMO=YES;
     USEDATE=NO;
     SCANTIME=YES;
***    IMPORT ZUURINGS SOILS DATA AND XY DATA   ********************;
PROC IMPORT OUT= WORK.ZUURING
            DATATABLE= "ALLPOINTS"
            DBMS=ACCESS REPLACE;
     DATABASE="C:\Data\DOR\ALLPTS.mdb";
     SCANMEMO=YES;
```

```
     USEDATE=NO;
     SCANTIME=YES;
********************************************************************;
**** READ IN DOR LOCATION DATA                                    **;
********************************************************************;
DATA ONE; SET LOCATION;
  IF FLAG=5 THEN DELETE; *These locations do not have GIS data;
*****************************************************;
********* READ IN DOR TREE DATA    *********************;
*****************************************************;
DATA TWO (KEEP=LOC_ID SP SI DBH HT BH_AGE DHRATIO); SET TREE;
LOC_ID=LOCATION;
  IF FLAG=5 THEN DELETE;
  IF STATUS EQ 'S' OR STATUS EQ ' ' OR STATUS EQ 'S?' ;  *SITE TREES ONLY;
  IF SP EQ 'DF' OR SP EQ 'PP' OR SP EQ 'WL' OR SP EQ 'LP';
  IF LOC_ID=276 AND TREE=1 THEN DELETE;    *BAD DATA;
  IF LOC_ID=246 AND TREE=8 THEN DELETE;    *BAD DATA;
  SI=CALCSI;
  IF SI < 20 THEN DELETE;            *NUMEROUS TREES WITH SI=0 OR MISSING;
  DHRATIO=DBH/HT;
PROC SORT DATA=TWO; BY SP;
/*PROC PLOT DATA=TWO; BY SP;
   PLOT HT*(BH_AGE DBH);
   PLOT SI*BH_AGE;*/
*************************************************************************;
************ CALCULATE MEAN SI BY DOR LOCATION AND SPECIES **************;
PROC SORT DATA=TWO; BY LOC_ID SP;
PROC MEANS DATA=TWO NOPRINT; BY LOC_ID SP;
  VAR SI;
 OUTPUT OUT=QUAL MEAN=MSI STD=STDSI MAX=MAXSI MIN=MINSI;
DATA QUAL2; SET QUAL;
   IF _FREQ_ GE 2; * AT LEAST TWO SITE TREES REQUIRED;
   IF MSI GT 0;     * MEAN SI MUST BE NON-ZERO;
************** CALCULATE MEAN AND VARIANCE OF MSI BY SPECIES ***********;
PROC SORT DATA=QUAL2; BY SP;
PROC MEANS DATA=QUAL2; BY SP;
  VAR MSI;
******************* ATTACH MSI TO LOCATIONS **************************;
PROC SORT DATA=QUAL2; BY LOC_ID;
PROC SORT DATA=ONE; BY LOC_ID;
DATA TEST;
MERGE QUAL2(IN=IN1) ONE(IN=IN2); BY LOC_ID;
 IF IN1 & IN2;
 IF SP EQ 'DF' OR SP EQ 'PP' OR SP EQ 'WL' OR SP EQ 'LP';
*******************************************************************;
*******************  READ IN 841 DATA *****************************;
*******************************************************************;
DATA SITE (KEEP=OWNSHP PLTNO SLP ASP ELEV HAB PRECIP PM GMT
               ASH)                             /*HZN1 HZN2 HZN3 HZN4 HZN5 HZN6
HZN7 I SND1
                                                SLT1 CLY1 FRGS1 DPTH1 REACT1
BDRCK SND2 SLT2
                                                CLY2 FRGS2 DPTH2 REACT2 SND3 SLT3
CLY3 FRGS3
                                                DPTH3 REACT3)*/
     TREES(KEEP= RECTYP TRETYP OWNSHP PLTNO TRNO SP HT CRWN D6 BAF SI HG
              HEART RADG RNG1 DOB1 DIB1 RNG2 DOB2 DIB2);
```

```
INFILE SIDATA;
INPUT RECTYP 6 @;
IF RECTYP=1 THEN DO;
     INPUT OWNSHP $ 1-2 PLTNO 3-5 SLP 7-8 ASP 9-11 ELEV 12-13 HAB 14-16
           PRECIP 17-18 PM 19 GMT 20 ASH 21-22; /* HZN1 23-24 HZN2 25-26
           HZN3 27-28 HZN4 29-30 HZN5 31-32 HZN6 33-34 HZN7 35-36
           SND1 37-38 SLT1 39-40 CLY1 41-42 FRGS1 43-44 DPTH1 45-46
           REACT1 47 DPTH2 56-57 BDRCK 70-71 @;
              I=1;  * COUNT NUMBER OF HORIZONS MEASURED;
              IF DPTH2 NE . THEN DO;
                 INPUT SND2 48-49 SLT2 50-51 CLY2 52-53 FRGS2 54-55
                       REACT2 58 DPTH3 67-68 @;
                       I=2;  * COUNT NO. OF HORIZONS MEASURED;
                 IF DPTH3 NE . THEN DO;
                    INPUT SND3 59-60 SLT3 61-62 CLY3 63-64 FRGS3 65-66
                          REACT3 69 @;
                          I=3;  * COUNT NO. HORIZONS;
                    IF BDRCK EQ . THEN DPTH3=60-DPTH2-DPTH1;
                 END;
                 IF BDRCK EQ . THEN DPTH2=60-DPTH1;
              END;
              IF BDRCK EQ . AND DPTH2 EQ . THEN DPTH1=60;
           INPUT;*/
           OUTPUT SITE;
        END;
IF RECTYP=2 OR RECTYP=3 THEN DO;
           INPUT OWNSHP $ 1-2 PLTNO 3-5 TRNO 7-8 SP 9 HT 10-13 .1
               CRWN 14-16 D6 17-19 .1 BAF 20-22 SI 23-26 .1 HG 27-29 .1
                 HEART 30-32 .1 RADG 33-34 RNG1 35-37 DOB1 38-40
                 DIB1 41-43  RNG2 44-46 DOB2 47-49  DIB2 50-52 @;
            TRETYP=1;    * SITE TREE;
            OUTPUT TREES;  *INCLUDES ALL SI TREE RECORDS;
END;
******** CALCULATE MEAN SI FOR EACH PLOT BY SP ********;
DATA SINDX(KEEP=PLTNO SP SI);
  SET TREES;  IF SP=1 OR SP=2 OR SP=3 OR SP=5;
PROC SORT DATA=SINDX; BY PLTNO SP;
PROC MEANS DATA=SINDX NOPRINT; BY PLTNO SP;
  VAR SI;
 OUTPUT OUT=QUALS MEAN=MSI STD=STDSI MAX=MAXSI MIN=MINSI;
DATA QUALS2; SET QUALS;
   IF _FREQ_ GE 2; * AT LEAST TWO SITE TREES REQUIRED;
   IF MSI GT 0;     * MEAN SI MUST BE NON-ZERO;
********** ATTACH MSI TO PLOT LOCATIONS ****************;
PROC SORT DATA=QUALS2; BY PLTNO;
PROC SORT DATA=SITE; BY PLTNO;
DATA COMBO;
MERGE QUALS2(IN=IN1) SITE(IN=IN2); BY PLTNO;
 IF IN1 & IN2;
************ GET MEAN AND VARIANCE OF MSI BY SPECIES ACROSS LOCATIONS
********;
PROC SORT DATA=COMBO; BY SP;
PROC MEANS DATA=COMBO; BY SP;
     VAR MSI;
******** COMBINE DOR AND 841 DATA ***************;
DATA DOR (DROP=SP) ; SET TEST;
   SLP=FIELD_SLOPE;
```

```
   ASP=FIELD_ASPECT;
   ELEV=GIS_ELEV*3.28;
   PRECIP=GIS_PRECIP/2.54;
   SOURCE=1;
   SPECIES=SP;
*PROC PRINT DATA=DOR;
DATA CICDATA (DROP=SP) ; SET COMBO;

   LOC_ID=PLTNO*1000;
   SOURCE=2;
   ELEV=100*ELEV;
   IF SP=1 THEN SPECIES = 'PP';
   IF SP=2 THEN SPECIES = 'DF';
   IF SP=3 THEN SPECIES = 'WL';
   IF SP=5 THEN SPECIES = 'LP';
DATA COMBINE; SET DOR CICDATA;
   IF ASP=0 THEN ASP=360;
   IF SLP=0 THEN SLP=5;
   ELEV=ELEV/100;        * CONVERT TO HUNDREDS;
   ASPRAD=ASP*.01745;    * CONVERT DEGREES TO RADIANS FOR SAS;
   X1=(ELEV)**2;
   *STRESS=(GIS_HEAT)/GIS_PRECIP;
   COSASP=COS(ASPRAD);
   SINASP=SIN(ASPRAD);
   SL=SLP/100;
   ASPSLP1=COSASP*SL; ASPSLP2=SINASP*SL;
   ASPSLP=(ASPSLP1 + ASPSLP2);
   RASLP=1/ASPSLP;
   SLSQ=SL**2;
   INT1=PRECIP/ELEV;
   INT2=PRECIP*ELEV;
   INT3=(PRECIP/ELEV)*ASPSLP2;
   INT4=(PRECIP/ELEV)*(ASPSLP1+ASPSLP2);
   TELEV=ELEV+1;
*************************************************************************;
****** ADD GIS AND MODELED DATA FROM FIRELAB   *************************;
*************************************************************************;
DATA FIRELAB; SET Z19DOR(IN=IN1) Z19CIC(IN=IN2);
   IF IN1 THEN LOC_ID = POINTS_ID;
   IF IN2 THEN LOC_ID = 1000*POINTS_ID;
*PROC PRINT DATA=FIRELAB;
PROC SORT DATA=COMBINE; BY LOC_ID;
PROC SORT DATA=FIRELAB; BY LOC_ID;
DATA FINAL; MERGE COMBINE(IN=IN1) FIRELAB(IN=IN2); BY LOC_ID;
     IF IN1 & IN2;
*PROC PRINT DATA=FINAL;
*/;
DATA FINAL; SET COMBINE;
**********************************************************************;
*********** CALCULATE MEAN SI RATIOS AMONG SPECIES ******************;
**********************************************************************;
*;
*********** DEFINE DATA SETS & FORM RATIOS OF DF TO OTHER SPECIES *****;
DATA DF;
   SET COMBINE; IF SPECIES='DF'; DFSI=MSI;
DATA LP;
   SET COMBINE; IF SPECIES='LP'; LPSI=MSI;
```

```
DATA PP;
   SET COMBINE; IF SPECIES='PP'; PPSI=MSI;
DATA WL;
   SET COMBINE; IF SPECIES='WL'; WLSI=MSI;
PROC SORT DATA=DF; BY LOC_ID;
PROC SORT DATA=LP; BY LOC_ID;
PROC SORT DATA=PP; BY LOC_ID;
PROC SORT DATA=WL; BY LOC_ID;
DATA DFDF; SET DF; BY LOC_ID;
   RATIO=1.0;
DATA DFPP; MERGE DF(IN=IN1) PP(IN=IN2); BY LOC_ID; IF IN1 & IN2;
   RATIO=DFSI/PPSI;
DATA DFWL; MERGE DF(IN=IN1) WL(IN=IN2); BY LOC_ID; IF IN1 & IN2;
   RATIO=DFSI/WLSI;
DATA DFLP; MERGE DF(IN=IN1) LP(IN=IN2); BY LOC_ID; IF IN1 & IN2;
   RATIO=DFSI/LPSI;
****************************************************************************;
*********** LOOK AT HOW RATIOS VARY BY SITE CHARACTERISTICS ****************;
****************************************************************************;
DATA RATIOS; SET DFPP DFWL DFLP; IF RATIO LE 1.2;
      V1=COS(ASPRAD)*SLP;
        V2=SIN(ASPRAD)*SLP;
        V3=LOG(TELEV)*SLP*COS(ASPRAD);
        V4=LOG(TELEV)*SLP*SIN(ASPRAD);
        V5=(ELEV**2)*SLP*COS(ASPRAD);
        V6=(ELEV**2)*SLP*SIN(ASPRAD);
        V7=ELEV;
        V8=ELEV**2;
        V9=LOG(TELEV)*SLP;
        V10=V8*SLP;
PROC SORT DATA=RATIOS; BY SPECIES;
/*PROC PLOT DATA=RATIOS; *BY SPECIES;
    PLOT RATIO*(PRECIP ELEV ASP COSASP SINASP)= SPECIES;
PROC REG DATA=RATIOS; BY SPECIES;
   MODEL RATIO=ELEV PRECIP COSASP / SELECTION=NONE;*/
**************** NOW CALCULATE MEAN RATIOS BY SPECIES ***************;
PROC MEANS DATA=DFDF NOPRINT;           * NOTE ALL RATIOS ARE = 1.0 FOR DF;
  VAR RATIO; ID SPECIES;
  OUTPUT OUT =RATDFDF MEAN=MRAT STD=STDRAT MAX=MAXRAT MIN=MINRAT;
PROC MEANS DATA=DFPP NOPRINT;
  VAR RATIO; ID SPECIES;
 OUTPUT OUT=RATDFPP MEAN=MRAT STD=STDRAT MAX=MAXRAT MIN=MINRAT;
PROC MEANS DATA=DFLP NOPRINT;
  VAR RATIO; ID SPECIES;
 OUTPUT OUT=RATDFLP MEAN=MRAT STD=STDRAT MAX=MAXRAT MIN=MINRAT;
PROC MEANS DATA=DFWL NOPRINT;
  VAR RATIO; ID SPECIES;
 OUTPUT OUT=RATDFWL MEAN=MRAT STD=STDRAT MAX=MAXRAT MIN=MINRAT;
**************** NOW APPLY CONVERSION RATIOS
**************************************;
DATA MRATIOS; SET RATDFDF RATDFPP RATDFLP RATDFWL;
PROC SORT DATA=FINAL; BY SPECIES;
PROC SORT DATA=MRATIOS; BY SPECIES;
*PROC PRINT DATA=MRATIOS;
*PROC PRINT DATA=RATDFPP;
*PROC PRINT DATA=RATDFWL;
*PROC PRINT DATA=RATDFLP;
```

```
DATA CONVERT; MERGE FINAL (IN=IN1) MRATIOS (IN=IN2); BY SPECIES;
      IF IN1 & IN2;
        DFSI=MRAT*MSI;
PROC SORT DATA=CONVERT; BY LOC_ID;
PROC MEANS DATA=CONVERT NOPRINT; BY LOC_ID;
  VAR DFSI;
  OUTPUT OUT=DFSITE MEAN=MDFSI STD=STDDFSI MAX=MAXDFSI MIN=MINDFSI;
DATA LOOK; SET DFSITE; *IF LOC_ID GE 1000;
*PROC PRINT DATA=LOOK;
***************************************************************************;
*********** MERGE DFSITE WITH ZUURING'S ALLPTS DATA **********************;
***************************************************************************;
PROC SORT DATA=DFSITE; BY LOC_ID;
DATA ZUURING2; SET ZUURING;
LOC_ID=PLOTID; IF SOURCE = '841' THEN LOC_ID=1000*PLOTID;
PROC SORT DATA=ZUURING2; BY LOC_ID;
DATA MODEL1; MERGE DFSITE(IN=IN1) ZUURING2(IN=IN2); BY LOC_ID; IF IN1 & IN2;
*PROC PRINT DATA=MODEL1;
***************************************************************************;
********** BUILD SOIL/SITE EQUATIONS USING DF SI *************************;
***************************************************************************;
DATA MODEL; SET MODEL1; *IF SOURCE = '841';
    X1=TAVE*REAP*PAR;
      X1SQ=X1**2;
      X2=PAR*REAP*TAVE*AWS;
      X3=X1/ELEV30;
      X3SQ=X3**2;
      X4=X2/ELEV30;
      X5=AWS*REAP;
      X6=1/AWS;
      X8=TAVE*PAR/REAP;
      AWST = 10;
      IF AWS >= 10 THEN AWST = AWS;
      BARET = 10;
      IF BARE_ >=10 THEN BARET = BARE_;

*PROC PLOT DATA=MODEL;
*   PLOT MDFSI*(X1 X2 X3 X4 AWS AWST X5 X6 MU_CEC BARE_ BARET MU_PH);
*(ELEV30 REAP PAR DDAY TAVE SLP30 ASP30 MUKEY AWS MU_PH MU_CEC BARE_);
PROC REG DATA=MODEL;
*MODEL MDFSI = X1 X1SQ X2 X3 X3SQ X4 X5 X6 X7 ELEV30 REAP PAR DDAY TAVE SLP30
ASP30 MUKEY AWS MU_PH MU_CEC BARE_/ SELECTION=STEPWISE;
MODEL MDFSI = X3 MU_PH MU_CEC BARE_ AWST ELEV30/ SELECTION=MAXR;
OUTPUT OUT=RESIDS
R=RESID
P=PRED;
PROC PLOT DATA=RESIDS;
   PLOT MDFSI*PRED; *=SOURCE;
PROC REG DATA=RESIDS;
   MODEL MDFSI = PRED;
***************************************************************************;
*** TEST MODEL FROM ONE SOURCE ON DATA FROM OTHER SOURCE ******************;
**************************************************************************;
*********** COEFFICIENTS ESTIMATED FROM 841 DATA ************;
/*DATA VALIDATE; SET MODEL;
   B0 = 56.523; B1=.28809; B2=-2.7371; B3=-.22798; B4=1.7069; B5=-.00736;
   PDFSI = B0 + B1*X3 + B2*MU_PH + B3*BARE_ + B4*AWST + B5*ELEV30; */
```

```
*****    COEFFICIENTS ESTIMATED FROM DOR DATA     ******************;
/*DATA VALIDATE; SET MODEL;
   B0=77.67494; B1=.17458; B2=-5.3434; B3=-.25826; B4=-.22021; B5=.70753;
B6=-.0003157;
   PDFSI = B0 + B1*X3 + B2*MU_PH + B3*MU_CEC + B4*BARE_ + B5*AWST +
B6*ELEV30;
PROC PLOT DATA=VALIDATE;
  PLOT MDFSI*PDFSI;
PROC REG DATA=VALIDATE;
  MODEL MDFSI = PDFSI;*/
RUN;
```