Sinlahekin Wildlife Area

Fuel Reduction and Fire Regime Restoration Plan

Appendices to

Volume 2: Ecology and Fire Behavior Analysis

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Appendix Analysis-A - Data and Program Descriptions

Contents of this Appendix

1. Data summary

This appendix describes files and software used in the SWA fuels analysis project, phase 2, analysis and development of prescriptions. Most of these are used with Arcview GIS software. Links to other types of files (spreadsheets, databases, fuel models, hard copy data and photography, etc.) are also described here (also see the Project Phase 1 report for descriptions of other files not used in Phase 2). The types of files and programs described here include software programs, Arcview extensions and scripts, algorithms developed specifically for this project, Arcview project files and Arcview data files. Data used only in phase 1 of this project is described in the 2003 report.

Files and computer program routines are described using shorthand notation. Subfolders are separated by a slash ("/"). The root folder is labeled "cd:/" to indicate that these files were transferred to the SWA Manager on a CD-ROM, at the completion of the project.

The folder cd:/fuelgis/arc contains project files and data layers used in 2004 phase II of the SWA fuels mapping project, some of which were developed during phase I of the project in 2003. The files listed below are grouped in categories related to their function within the entire analysis process of this project.

Metadata (data about data) files are for source data are contained on the computer and CD files within subfolders named *meta*. Folders with the name *versions* hold different versions of the parent folder. Folders with the name "*done*" hold data which has been processed, but is no longer used.

Version changes of processed data are indicated by appending version numbers to the file names, e.g., *roads-added3.shp*, *roads-added4.shp*, etc. Version numbers are frequently omitted in this report. An important file central to all analyses is the table of cover types for each stand. This table originally was called *cov_typ.shp* in Phase 1 of the project, and had evolved to *cov_typ4.shp* by the beginning of Phase 2. At the end of Phase 2, it was up to version *cov_typ8f.shp*.

Shapefiles are listed the first time with the ".shp" extension explicitly shown, and thereafter without the extension.

Grid files are listed here by the name of file folder, but not the accompanying INFO folder. Grid filenames do not exceed the 8 characters naming convention, therefore the names are more cryptic. A filename like *fbfm_oka*, might become *fbfm_ok2* after processing. Many of the filenames described below specify only the initial file names, not subsequent versions; however they can be uniquely identified by their folder names and the use of these version name-changing rules.

For this phase of the project, all GIS data files were reprojected into Universal Trans Mercator (UTM) Zone 11 North American Datum (NAD) 1983, in units of meters. Raster data cell resolution is 30 m for all input data, except for the 1998 7.5' digital orthophoto quads, which are 1 m. Grid files used as input for fuel modeling programs are co-registered and co-linear so that grid cells have identical border and corner cell coordinates. The orthophotos are also co-linear with the 30 m grids so that each 30 m grid cell exactly encloses a 30 X 30 matrix of orthophoto cells.

2. Software programs

Software used in phase 2 of the SWA fuels analysis project includes BEHAVE 2.0 (Andrews et al., 2003), FARSITE (Finney, 1998, Finney, 1996), and FlamMap 3.01 (Finney et al., 2003).

BEHAVE 2.0 and the other fire modeling programs accept a number of stand, fuel moisture and weather variables to run. The 13 standard Anderson (1982) fuel models are often used as the basis for the surface fire behavior models, using the following variables:

D1H: Dead 1-h Fuels (<1/4") ton/ac
D10H: Dead 10-h Fuels (0.25-1") ton /ac
D100H: Dead 100-h Fuels (1-3") ton /ac
LH: Live Herbaceous Fuel Load ton /ac
LW: Live Woody Fuel Load ton /ac
DSAV: 1-h Surface Area/Vol Ratio ft^2/ft^3
LHSAV: Live Herb Surface Area/Vol Ratio ft^2/ft^3
LWSAV: Live Woody Surface Area/Vol Ratio ft^2/ft^3
Fuel Bed Depth: Fuel Bed Depth (70% of avg stand ht) ft
Moisture of Extinction: Dead Fuel Moisture of Extinction (%)
DF Heat Cont: Dead Fuel Heat Content (BTU/lb)
LF Heat Cont: Live Fuel Heat Content (BTU/lb)

BEHAVE input parameters, their origin and output module usage include the following (Note: I/O refers to data used as input as well as output; some input variables that are also used secondary outputs to the modules for containment requirements and safety zones are not included in this table):

BEHAVE input parameter	**Origin of data**	**Output usage**
First Fuel Model	Default or custom parameters	surface fire behavior, ignition
Second Fuel Model	Used in two-fuel models	surface fire behavior, ignition
Overstory basal area	stand model	surface fire behavior
Mean cover height	stand model	spotting
Crown ratio	stand model	mortality
bark thickness	stand model	mortality (I/O)
Elevation	slope (from DEM)	RH
Aspect	slope (from DEM)	surface
Slope steepness	slope (from DEM)	surface
Fuel shading from sun	canopy cover	
Mean downwind cover ht	canopy cover	spotting
Mean tree ht	tree height layer	severity, mortality
Mortality Tree species	cover type	severity, mortality
Spot Tree species	cover type	spotting likelihood
tree diameter-at-breast height (DBH)	stand model	mortality, spotting
Ridge to valley elevation difference	Arcview Spatial Analyst & DEM	spotting
Ridge to valley horizontal difference	Arcview Spatial Analyst & DEM	spotting

Midflame wind speed	95th percentile weather	surface (I/O), scorch
20' wind speed	95th percentile weather	surface, spotting
Direction of wind vector from upslope	95th percentile weather	surface
Air temperature	95th percentile weather	scorch, ignition, RH
fuel shading	canopy cover	ignition

FARSITE, FLAMMAP: The following themes are used as input to a FARSITE or FlamMap “Landscape file”. All files are raster files except Initial Fuel Moisture which is a non-raster text file.

Theme, units (alternate units)	**Description**
Elevation, meters (feet)	Used for adiabatic adjustment of temperature and humidity; derived from the DEM.
Slope, degrees (percent)	Used for computing direct effects on fire spread; used with aspect, latitude, date and time for determining the angle of incident solar radiation; used to transfer spread rates and directions from surface to horizontal coordinates.
Aspect, degrees (categories)	See slope.
Fuel Model	A physical description of surface fuels used to determine surface fire behavior, given as one of 13 standard fire models or as custom models that match a specific type of ground, or that match conditions of extreme drought which change the modeled leaf moisture; given in weight per area by size class and dead or live categories; ratio of surface area to volume and bulk depth.
Crown Canopy Closure, percent cover (categories)	Average vertical projection of tree crown cover onto the ground; used to determine the shading of surface fuels that affects moisture and the wind reduction factor. Canopy cover is most accurately determined through photo-interpretation rather than satellite image modeling or ground-based determination.
* Stand Height, feet (meters, 10X meters, 10X feet)	Average height of the dominant tree layer; affects the wind profile above the terrain; used with canopy cover to determine the wind reduction factor, the starting position of firebrands, and the trajectory of falling embers.
* Crown Base Height, feet (meters, 10X meters, 10X feet)	Average height of the bottom of the tree crowns in the stand which must not exceed stand crown height in the raster inputs; used with surface fire intensity and foliar moisture content to determine the threshold for transition to crown fire.
* Crown Bulk Density, kg/m3 (10* kg/m3, lb/ft3, 10* lb/ft3)	The density of the tree crown biomass above the shrub layer; used to determine the threshold for achieving active crown fire and to compute crown fire spread.
** Initial Fuel Moisture, percent	Fuel Moisture for 1-hr, 10-hr, 100-hr, live herbaceous and live woody fuels.
* Duff Loading, tons/acre (mg/ha)	Quantitative measurement of duff depth and duff density. Values were obtained by multiplying the duff depth from stand exams

	times 9 tons/acre per inch of duff depth times the average percent forest overstory cover
* Coarse Fuel Loading, tons/acre (mg/ha)	Quantitative measurement of amount of coarse surface fuels (>3")

* Optional themes for crown fuel and post-frontal combustion.
** Required for FlamMap2, optional for FARSITE crown fuels and post-frontal combustion.

FARSITE and FlamMap model paramenters can be varied through ancillary files:

- Adjustment file (*.adj; local changes to fire spread rates)
- Custom Fuel Model file (*.fmd;)
- Weather file (*.wtr text file; daily observations; used to utilize the optional live and dead fuel moisture model)
  Temperature Fahrenheit (integer)
  Humidity Percentage (integer)
  Precipitation Inches X 100 (integer)
- Wind file (*.wnd text file).
  Wind Speed MPH, 20 foot open wind (integer)
  Wind Direction Azimuth Degrees (integer)
  Cloud Cover Percentage (integer)
- Vector shapefiles such as roads or streams to aid visualization

FlamMap creates raster maps of potential fire behavior characteristics over an entire landscape, including fireline intensity (FLI), rate-of-spread (ROS), flame length (FML) and crown fire activity (CFR), as well as and environmental conditions (dead fuel moistures, mid-flame wind speeds, & solar irradiance). These raster maps can be viewed in FlamMap or exported as ASCII Grid files for use in a GIS.

Default input parameters for SWA data into Flammap include: Wind direction 355 deg; 5 mph; canopy ht 60 ft, canopy base 5 ft, canopy bulk density 0.3 kg/m-3; foliar moisture content 100%; use fuel moisture conditioning *.*wtr*, *.*wnd* files; run from May 2 to May 4

3. Arcview extensions

A large number of the GIS procedures were performed with Arcview 3.2 with Spatial Analyst (© Environmental Systems Research Institute, ESRI) in conjunction with a number of other extensions. Arcview extensions, or "software dependencies", are additional software that work within the Arcview system, but which must be installed or enabled before the system can access their methods. An Arcview Script is similar to an extension, but must be compiled and run within a Script window. Many extensions and scripts are written by third party software developers. Most of the third-party extensions below are available in the public domain as online files; most are available at the ArcScripts web site of Environmental Systems Research Institute (http://arcscripts.esri.com/).

The following extensions were used in this project (when Extensions are expressly copyrighted this is noted and referenced by data and source, but others which did not include express copyrights are referenced only by author). They are provided on the

Phase 2 CD containing project data in the in the folder CD:/fuelgis/ancillary_files/Arcview_ extensions.

Arcview Utility Tools: This extension is © Minnesota Department of Natural Resources, 2001. It is a suite of tools for manipulating shapefiles. It is described at http://www.fws.gov/r9gisftp/avutil.pdf.

Clipgrid.ave (*grid-align2grid.ave*). This script was used to clip input grids to exactly match the extent and cell registration of the grid *base30*. The extension was written by Tom Van Niel and is available at the Arcscripts web page under the name of clipgrid.ave (not to be confused with a script of a similar name by Eugene Martin).

CRWR Raster: This extension by Francisco Olivera (1998) clips a grid by a selected polygon, however the output grid is shifted slightly to match the coordinate registration of the clipping polygons (the extension clipgrid.ave was used for a clipping routine that maintains the original grid coordinates).

DNR Garmin: This extension is © Minnesota Department of Natural Resources, 2001. It was used to download waypoints from the Garmin handheld GPS. The extension was downloaded from http://www.dnr.state.mn.us/mis/gis/tools/arcview/extensions.html.

***Fixjoin*.avx**. This extension attaches the fields from a join to a table permanently. It is available from the Arizona State University GIS website (unauthored) (http://www.asu.edu/gis/extensions/*Fixjoin*.zip).

Grid Enhancement Tools or "**Grid Tools**": This extension was written by Holger Schäeuble of the University of Tuebingen (1998). It is a comprehensive set of tools for manipulating grid files. This is an English translation of a German extension. It is available at http://www.uni-tuebingen.de/uni/egi/studium/projekte/schaeuble/sites/grid.htm and also at http://www.uni-tuebingen.de/uni/egi/studium/projekte/schaeuble/). It was used for resampling one grid into the cells of another geoferenced base grid, using the Combine command. It was also used for shifting grids in the x- and/or y-direction, and for computing zonal geometry.

Grid PIG (USGS, 2004): This extension was developed by the United States Geological Survey. It is a comprehensive set of tools for manipulating grid files. It is available at the U.S.G.S. Planetary GIS Web Server (http://webgis.wr.usgs.gov/arcview_scripts.htm).

Image Analysis Tools: This extension is © ESRI (1998) and ERDAS (2004). It is a comprehensive set of tools for manipulating images within Arcview. The extension is available at http://www.esri.com/software/arcview/extensions/imageext.html.

Image Tools (vsn 2.6). This extension is a suite of tools for manipulating images, written by Will Patterson (undated). It was used for conversion of tiff images to grids. A grayscale legend is built and included in the display when the process is complete. It is available at the ArcScripts website.

JPEG (JFIF) Image Support: This extension is © ESRI (1998). It is based in part on the work of the Independent JPEG Group, © 1991-1996 Thomas G. Lane. It allows viewing and manipulation of JPEG images within Arcview.

Memo Tools 5.0. This extension is a compilation of tools based on "MiniTools" by Stefanie Busch, with many additions, and bug fixes compiled and posted to the ArcScripts web site by "Harald". This comprehensive set of tools is used for manipulating tables and themes. Frequently-used operations include adding record numbers to tables and outputting a list of themes to a text file.

Mila Grid Utilities 1.4. This extension is a compilation of a number of other grid utilities from various authors. Tools include clip grid, clip grid in multiple grids, clip grid by polygon, zonal statistics, grid cell value extraction, which are described at the UCL-MILA GIS tools page at Université Catholique de Louvain (2003) at http://www.mila.ucl.ac.be/logistique/sig/sig-tools/.

Minnesota Department of Natural Resources (DNR) Projection Utility: This extension was developed for the Michigan DNR by Pacific Meridian Resources, September, 2000. It allows re-projection of shapefiles within ArcView. The NADCON extension must be installed before it can be used to shift from one datum to another. It is available at http://www.dnr.state.mn.us/mis/gis/tools/arcview/extensions.html.

NADCON: This extension was developed by the National Oceanographic and Atmospheric Administration (NOAA). The NADCON extension is an implementation of the NADCON program, which transforms the datum of shapefiles, e.g., from NAD 1927 to NAD 1983 or vice-versa. It is a dependency of many other reprojection utilities (e.g., Minnesota DNR Projection Utility) and must be enabled before using them. It is available at ftp://ftp.ngs.noaa.gov/pub/pcsoft/nadcon/.

Shademax ArcView Color Palettes. These palettes were installed for use in viewing elevation and hillshade themes as shaded relief. These were developed by Jim Mossman of Data Deja View (ddvgis@myalvista.com). The Wyoming Territory color palette series ddvelev5d.avl, was used.

Shape Enhancement Tools. This extension was written by Holger Schäeuble of the University of Tuebingen in 1998. It is a comprehensive set of tools for manipulating shapefiles. This is an English translation of a German extension, available at the Arcscripts website, available at http://www.uni-tuebingen.de/uni/egi/studium/projekte/schaeuble/sites/shape.htm. The German version is also available at http://www.uni-tuebingen.de/uni/egi/studium/projekte/schaeuble/sites/grid.htm and also at http://www.uni-tuebingen.de/uni/egi/studium/projekte/schaeuble/). The extension was used for several functions such as adding an ID number to shapefile polygons.

Spatial Analyst: This extension is commercially © ESRI (1998). It is an add-on extension that performs sophisticated spatial operations within Arcview.

Tiff 6.0: This extension is © ESRI (1998). It allows viewing of TIFF files as image themes. TIFF 6.0 image support includes GeoTIFF 1.0 tags for placing the image in the proper geographic space if present.

Transform Themes 1.11: This extension was written by William Huber (undated). It allows resizing and moving of Arcview vector themes. It is available at the ArcScripts website.

Vertex-edit script. This script will create a tool that can move polygon vertices to specified coordinates. It is available at the Arcscripts website (unauthored) and was modified for use in this project.

Vector Transformations 1.0: This extension is by Eugene Martin (2000), of CommEn Space. It is used to transform polygons within shapefiles. It is available at the ArcScripts website.

Wingdings TrueType font (cd:/fuelgis/ancillary_files/wingding.ttf): This font was used to display symbols in the Arcview Legend. It was chosen because it is available across a wide number of platforms. To be used, it should be installed in the

C:/WINDOWS/FONTS folder.

XTools: This extension contains a suite of useful tools by various authors for manipulating tables and shapefiles. It was developed, collected, and modified by Mike DeLaune (2003), Oregon Department of Forestry. It is available at the ArcScripts website or at the XTools website (http://www.odf.state.or.us/stateforests/sfgis).

4. Repeatedly used algorithms

a. Co-register a grid to the base30 grid (clips a grid by another grid): This procedure creates a new grid matching the resolution and extent of the standardized grid, *base30*, but with the cell values taken from those cells in the original file that overlap those in *base30*. Use *Grid Enhancement Tools - Combine*, select the *base30* grid, then select the target grid, and then click "*Cancel*" to indicate no more grids will be selected. The temporary grid created needs to have its *Value* field reclassified back to the original value with *Analysis - Reclassify*, using a *Lookup* command to select the original *Value* field.

b. Co-register FARSITE grids: Nine grids used as FARSITE input files were provided on CD by fire consultant Tom Lueschen and transferred into a folder called "oka": (*fbfm_oka, fbfm_n, canopy, slope, aspect, elevation, crbulk, crbase,* and *cr_ht*). They were originally provided as 30m raster grids. In order to maintain their original co-registration, the 9 grids were treated identically as follows. (1) Clip the grid using a version of *bigbox-clip.shp* within the original projection of State Plane North, NAD 1927; (2) reproject the result to UTM Zone 11 NAD 1983, and finally shift the grid 45 m west and 30 m north.

c. Load a legend file to fields in a joined table: After some operations such a *Combine Grids* command, legend files sometimes became unusable due to changed table attribute values used by the legend files. In these cases, legends can be re-created by joining the theme to a table containing the old legend fields. The *.vat table of the original grid can be joined to the new table by adding it as a table from the table menu. The tables are joined by their common fields and the *Fixjoin* extension is implemented to permanently save the joined tables, which can then be used to load the original legend that keys to the original field values.

d. Clip a polygon by another polygon. Use *XTools - Clip by Polygon* command.

e. Clip a grid by a polygon. Use *Grid PIG Tools - Clip Grid by Polygon* command.

f. Printout hard copy maps. For printing GIS displays and reports, an Hewlett-Packard cd1700ps PostScript printer was used, allowing paper sizes of up to 13" X 50". For 11 X 17 size printing (B size). It was found that a scale factor of 38,126 gave good resolution of individual trees from a 1-m orthophotos which would cover the entire SWA in just 5 separate B-size printouts.

g. Create a buffer zone around linear features. Buffering of linear features such as perennial streams was done using Minnesota DNR Arcview Tools.

h. Number polygons in shape files. Records were numbered with the command *Memo Tools - RecNo to Table*.

i. Clean up shapefiles. Shapefiles were cleaned in the following order using the Memo Tools menu: (1) *Clean-Functions - Find and delete Polygon Overlaps*, (2) *Clean-Functions - Find and fill Void Polygons*, (3) *Clean-Functions - Find and Explode Multipart polygons* (non-adjacent polygons), (4) Renumber records with field *RecNo to Table*, and (5) *Clean-Functions - Dissolve Sliver Polygons*. Steps 3 through 5 are then repeated until no more slivers are present in the table.

j. Impute grid values into overlaying polygons. The Analysis properties need to be set to the dimensions of the grid cells that will be averaged prior to using this method. Methow 1 is to calculate summary attributes for features using a grid theme, use the Arcview command *Summarize Zones*. Activate the feature theme on which to summarize the zones. From the Analysis menu, choose *Summarize Zones*. In the Summarize Zones dialog, choose the field *Recno*. Press OK. Choose the value grid theme defining the cell values to summarize within each zone defined by the zone theme. Press OK. Choose a statistic to chart from the dropdown list. With an integer value grid theme the choices are area, minimum, maximum, range, mean, standard deviation, sum, variety, majority, minority, and median. With a floating point value grid theme the choices are area, minimum, maximum, range, mean, standard deviation, and sum. Press OK. Summarize Zones computes a chart and a table, which can be linked back to the original shapefile.

Method 2. Open a polygon theme, and select the records to calculate grid overlap for (or select none to calculate overlap for all polygons), then make the polygon theme active. Use the MTools command *RecNo to Table* to number all of the fields. Use the MILA Grid Utilities command to calculate a new table containing the zonal statistics for the polygon table, by clicking the “Z” button on the toolbar, and then choosing the *RecNo* as the field to relate to. Then select the grid file and statistic to impute into the polygon file.

Following method 1 or 2, next edit the Answer table so that only the *RecNo* field and the field for the selected statistic is displayed, e.g., majority (the XTools Extension can delete multiple fields). Open Tables from the Project Window, and join the records in the Answer table with the polygon table with the *Table - Join* command, using the field *RecNo* as the joining field and making sure no records are selected. Make the join permanent with the *Fixjoin* button (“J” button). Test that the join worked by sorting the table by the joined field.

5. Arcview project files

The Arcview GIS is implemented through “Project files” (*.apr) that contain sets of Views, Tables, Charts and Print Layouts, within which are themes, or layers, that point to the different GIS GIS files on disk. File locations of the GIS themes are listed at thee end of this appendix). The project files are contained in the *cd:/fuelgis* folder. Project files have a 3-digit numerical code as part of the filename used to designate versions, e.g., swa-fuel-132-analysis.apr. Most of the completed GIS layers are stored in the *cd:/fuelgis/arc/1183/* subfolder, however where extensive sets of analytical procedures were performed, (such as the patch pattern analysis) these were stored in separate subfolders under the *cd:/fuelgis* folder.

Several projects were used for different parts of the SWA fuel mapping process. The main project for displaying data is *swa-fuel-nnn-analysis.apr*, where nnn represents a sequential version number for the file. The patch pattern canopy cover analysis used the project *pattern-analys-nnn.apr*. The plant community analysis files are in the project folder *cd:/fuelgis/analysis/arc1183/plantcom/*. A project used to determine the canopy cover outside the SWA as a prerequisite to the cover type classification was *cd:/fuelgis/analysis/arc1183/pattern/conif-cover-nnn.apr*. These project files are described in more detail in other appendices.

Many of the Arcview legend files (*.avl) are stored in the *cd:/fuelgis/arc/avl-lut/* folder, as well as in the folder for the data file (see Fig. App-A-7). When the legend files are contained in the same folder as the shapefile of the same name they will automatically load when the them is added to the view of a project. Alternative shapefiles and grid files need to manually loaded from the legend editor.

6. Background imagery

Digital elevation models (DEMs): DEM data is a raster data set used to determine generate elevation, aspect, and slope. The USGS Digital Elevation Model (DEM) data files are digital representations of cartographic information available in a raster format. DEMs consist of a sampled array of elevations for a number of ground positions at regularly spaced intervals. The DEM files were processed to generate elevation, aspect, slope and hillshade (shaded relief) files.

Shaded relief image (*elevshd.tif*): This is a 2-D shaded relief image of the DEM without z-coordinate data. It is used as a background image for aligning topographic features such as streams.

Digital Orthophotos: Orthophotos are digital raster scans of black-and-white images that are georeferenced to overlay onto 7.5' USGS quadrangles. The three Washington state orthophotos that cover the SWA boundary are Loomis, Blue Goat Mountain and Conconully East. These were downloaded from the Washington Geospatial Data Archive (http://wagda.lib.washington.edu) at a cell resolution of 1 m, and a production date of 1998. Surrounding orthophotos were used at a cell resolution of 2 m and a date of 1991. The orthophotos were the base layer used to delineate cover types.

Satellite images: Several images and formats were examined for this study to aid in the classification of cover type and structure. Two satellite images that were used in this project were:

ASTER imagery (*sinlahekin-n-2sep03-u11.tif, sinlahekin-s-22july02-u11.tif*): ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is an imaging instrument that is flying on Terra, a satellite launched in December 1999 as part of NASA's Earth Observing System (EOS). ASTER is a cooperative effort between NASA and Japan's Ministry of Economy, Trade and Industry (METI) and the Earth Remote Sensing Data Analysis Center (ERSDAC). The images are in multiple spectral bands. Three of these bands (one UV, one visible, and one IR, were combined into images which were registered to match that of the UTM Zone 11 NAD 1983 projection. For best separation of different vegetation and soil types, the images should be displayed in the order Red, Green, Blue = Bands 4, 3, 2.

NCGBE Landsat Multispectral Scanner (MSS) scene, July and August 1986 (*griz_reg*, *grz30*): This data was purchased as part of the NCGBE (North Cascades Grizzly Bear Evaluation) during a joint cooperative project of the Okanogan National Forest and WDFW. Portions of four Landsat scenes were purchased in the North Cascades study area. Four separate spectral bands represent green, red, and two bands of reflected infrared. The original file was geo-referenced to the Universal Transverse Mercator (UTM) map projection, zone 10, with a pixel size of 57 m. The raw Landsat data was used to fill in the vegetation classification in areas adjacent to the SWA not covered by the ASTER imagery.

7. Geographic alignment, layout and registration files

base30 (grid *base30*): This grid file is the base file used to register other grids used in the fuel and ecological models that collinear grids. It is a permanent integer grid in the UTM Zone 11 projection for the SWA, with a 30 meter cell size, 1350 rows and 750 columns. The boundary coordinates are the same as the line file, *Extent30m-clip.shp.* Boundaries in UTM Zone 11 NAD 1983 coordinates are left margin = 291,650; right margin = 314,150; bottom margin = 5,376,000; top margin = 5,416,500.

base2m (grid *base2m*): This file has 2m cells georeferenced to the *base30* grid. It was used in determining canopy cover to clip the 2m orthophotos to the extent of the *base30* grid.

Dissolved cover type polygons used for generating and clipping grids (files in the folder *cd:/fuelgis/arc/1183/cov/*). These shapefiles were used as clipping themes for grids. They were made from *Cov_Typ.shp* by "dissolving" multiple polygons of the selected classes into multi-part polygons, using the Arcview Geoprocessing Wizard. The descriptions are as follows:

- ***stands-dissolve3.shp***. This contains one class for all cover types dissolved together. It was made from the last version of the cover types shapefile created after version *cov_typ8i.shp*, with 2087 stands. It was used for generating print masks to show areas analyzed in project phase 2.
- ***cov_dissolve_all.shp***. This shapefile contains one class for all cover types dissolved together. This file was made from *Cov_typ4.shp*; it was archived after the boundary was modified in a later version of *Cov_typ.shp*.
- ***cov_dissolve_classes.shp***. This shapefile contains 13 classes, one for each of the 13 cover types. This file was made from *Cov_typ4.shp*; it was archived after the boundary was modified in a later version of *Cov_typ.shp*.
- ***cov_dissolve_ss&conif.shp***. This shapefile contains one class for both shrub-steppe as well as all coniferous types (cover type classes 5, 109, 110, 130, 160). This file was made from *Cov_typ4.shp*; it was archived after the boundary was modified in a later version of *Cov_typ.shp*.

Clipping and windowing polygons used for layouts and export scans (files in the folder *cd:/fuelgis/arc/1183/extent/*): A number of themes were used as clipping polygons and for aligning the display.

- ***Clipbox.shp*** was created to set the view extent for making multiple, overlapping screen captures of the Arcview Views (see Fig-App-A-7). It was archived after 2004.
- ***Bigbox-clip.shp*** was created to clip coverages and images over a 5 X 5 quad area surrounding the SWA (see Fig-App-A-8).
- ***Extent30m-clip.shp*** was used to clip files to the extent of the base 30m grid, used for most of the phase 2 analysis procedures (see Fig-App-A-8). The boundary coordinates of *extent30m-clip.shp* are the same as the grid *base30*.
- ***Display-window.shp*** was created for printing (see Fig-App-A-9). It has a rectangular hole in the center of a larger rectangle for use as a show-through print window. During printing this was used to blank out areas outside the print window. After creation, the table record order of *display-window.shp* was changed with the script *Table.SortPhysical.ave* to improve the display of outlined window edges.

Display-window2.shp was created to zoom to the extent of either of 2 equal-area rectangles for printing the SWA 11 X 17 paper (see Fig-App-A-10).

Display-window-4.shp was created to allow zoomed-in printouts (see Fig-App-A-11). This shapefile has 5 rectangular polygons that cover the SWA for zoomed-in printing on 11 X 17 paper.

Clip-outside-stands4.shp was created as a mask for printouts (see Fig-App-A-12). It was used to mask out areas outside the SWA stands, while leaving the stands transparent. It has a legend file that automatically loads a mask to whiteout areas outside the stands.

Bkg11x17.shp was created to center Views prior to printing (see Fig-App-A-13). It was used to zoom to the extent of the SWA within a rectangular portrait window. This shapefile is a rectangular polygon centered on and surrounding the stands analyzed in this project. Once the View was zoomed to this theme, the scale was then set to exactly 1:150,000, which was used for printing maps on many of the 11 X 17 tabloid printouts used as figures for the report.

Bkg11x17prn.shp was created to draw a black outline around a transparent print window surrounding the SWA on 11 X 17 printouts (see Fig-App-A-14).

Masks of the SWA boundary and SWA cover types were created from cov_typ.shp as needed to mask or reveal map objects of interest. These were created by placing transparent or opaque white features within legend files.

8. Topographic files

USGS elevation DEM resampled to 30m (grid *elev*; used as basis for FBM): The 10m elevation grid was resampled (nearest neighbor) to 30 m, followed by co-registration to the *base30* grid (see algorithms), to give values of 267-2040 meters. The elevation legend can be displayed in either of two ways: (1) using the legend *elevation.avl* or (2) as a shaded relief with legend *elevshade.avl* and shaded using *hillshade.avl* for the brightness values of the 10m hillshade.

USGS 10m elevation DEM (grid *elev10*): The elevation data was processed from USGS 1:24,000 scale 7.5-minute topographic quadrangle DEM data, interpolated from 10m contour intervals. It is available online from the University of Washington as DEM files with 10 m cells and elevation in meters in UTM Zone 11 NAD 1927 (http://wagda.lib.washington.edu). After extraction, the DEM files were imported into Arcview as grids with elevation in meters. These were mosaiced with Grid PIG beginning with the center quad. The 10m elevation grid was reprojected with Grid Projector to NAD 1983 (see Appendix B for a discussion of the problems involved in processing elevation grids).

Elevation contours (200 ft interval) (*contours-200ft-int-clip.shp, contours-200ft-int.shp*): The 10m elevation grid was used to calculate contours using a contour interval of 61 m (200 ft) and a base contour of 250 (which is just 6 m below the lowest base elevation of 256 m). The version with *clip* in the name is clipped to the *base30* extent for a neat line display.

Elevation (Geometronics) (grid *elev_oka*): This grid represents elevation (meters), generated from DEM files obtained from Geometronics Service Center in Salt Lake City, Utah. Okanogan National Forest stitched these quads together for one entire coverage. This grid was provided by fire consultant Tom Lueschen on a CD projected in State Plane North, NAD 1927, as a set of input files for FARSITE modeling on the

Okanogan National Forest. This grid and 8 others were co-registered identically (see algorithms). This grid was not used in favor of using USGS DEM data.

Aspect (USGS DEM resampled to 30m) (grid *aspect*) (used with the FBM): Aspect was generated from the 30m elevation grid, followed by truncation of decimal places to yield an integer grid. Aspect values of -1 were made positive by taking the absolute value ([Map Calculation Aspect].abs) to yield values of 0-359 degrees. For processing as a categorical file (used by some fire behavior models and in vegetation classification), the aspect grid was categorized into the following intervals contained in the field Value: 1=338-22 degrees (N), 2=23-67 degrees (NE), 3=68-112 degrees (E), 4=113-157 degrees (SE), 5=158-202 degrees (S), 6=203-247 degrees (SW), 7=248-292 degrees (W), 8=293-337 degrees (NW).

Aspect in 8 categories (USGS 30m, 8 cardinal directions) (grid *aspect8*): This grid of aspect was made by reclassifying the USGS 30 aspect grid into 9 categories as follows. The category "F", represents flat areas, calculated from records with the slope =0-2 % using the Arcview command *Table - Field - Calculate*.

Value	Aspect Degrees	Cardinal Aspect
0	flat	F
1	338-0, 0-22 deg	N
2	23-67 deg	NE
3	68-112 deg	E
4	113-157 deg	SE
5	158-202 deg	S
6	203-247 deg	SW
7	248-292 deg	W
8	293-337 deg	NW

Aspect (Geometronics) (grid *asp_oka*): Aspect (degrees, from 0 to 359), generated by Geometronics from the ELEVATION layer. This grid was provided by fire consultant Tom Lueschen on a CD in a projection of State Plane North, NAD 1927, as a set of input files for FARSITE modeling on the Okanogan National Forest. This grid and 8 others were co-registered identically (see algorithms). This grid was not used in favor of using USGS DEM data (see Appendix B for a discussion of the problems involved in processing elevation grids).

Slope (Geometronics) (grid *slo_oka*): Slope (degrees), generated from the Geometronics ELEVATION layer. This grid was provided by fire consultant Tom Lueschen on a CD in a projection of State Plane North, NAD 1927, as a set of input files for FARSITE modeling on the Okanogan National Forest. This grid and 8 others were co-registered identically (see algorithms). This grid was not used in favor of using USGS DEM data (see Appendix B for a discussion).

Slope degrees (USGS DEM resampled to 30m) (grid *slope*; used as the basis of the FBM): Slope was generated from the 30m elevation grid, followed by truncation of decimal places to yield an integer grid with values of 0-63 degrees. The USGS data required resampling (see Appendix B for a discussion of the problems involved in resampling slope grids).

Slope in 4 categories of degrees (UGSS 30m) (grid *slope4*): Slope4 was a temporary grid made by reclassifying the USGS 30 slope grid into 4 categories as follows: 1 (0-10 deg); 2 (11-30 deg); 3 (31-45 deg); 4 (46-63 deg).

Grid *Slope3* was made by reclassifying the USGS 30 slope grid into 3 categories:

slope category	Degrees slope	Percent slope

1	0-11	0-19 %
2	12-19	20-34 %
3	20-33	35-63 %

Grid *Slope5* was made by reclassifying the USGS 30 slope grid into 5 categories:

Slope Reclass Value	Degrees slope	Percent slope
0	0-2	0-4 %
5	3-11	5-19 %
20	12-19	20-34 %
35	20-33	35-66 %
67	34 - 63 (maximum in grid)	> 66

Aspect & slope combined (grid *asp_slo*): This grid was made by combining the grids from the USGS 30 categorical aspect grid with and the USGS slope grids.

Hillshade (grid *shd10*): The 10m elevation grid was used to calculate a corresponding 10m hillshade for viewing the elevation as a shaded relief. The hillshade was calculated with default values of azimuth 315 degrees, altitude 45 degrees and z-factor of 1. The legend for the hillshade brightness theme (*hillshade.avl*) uses 64 gray-scale intervals. The legend for the elevation theme (*elevshade.avl*) is the Shademax ArcView Color Palettes *ddvelev5d.avl*, and uses the hillshade advanced brightness theme values of 0 - 100.

9. Administrative and management units

Plot center locations (*plot-stands.shp*): Waypoints for the plot centers only, i.e., not for the stand exams, are stored in this file. Waypoints were established within stands wherever stand exams or eco-assessment plots were established. This layer is used to locate points visited on the ground in both 2003 and 2004, as an aid to developing the ecological model. See *waypts-subplots.shp* for a description of the waypoints for stand exams and see Appendix E for a copy of the plot form used in 2004.

Plots and stand exam locations (*waypts-subplots8.shp*): Waypoints for plots (*and the associated stand exams*) are stored in *waypts-subplots.shp*. Waypoints were established within stands wherever stand exams or eco-assessment plots were established. This layer is used to locate points visited on the ground in 2003, and to classify cover types.

Quadrangle boundaries (*waquad_u11_83.shp*): This data represents the boundaries of USGS 7.5 minute quadrangles for all of Washington.

SWA boundary (*wdfw-drg.shp, wdfw-dnr.shp*): There are different versions of the cadastral framework mapping the SWA boundary evaluated for use in this project. Unfortunately, the accuracy of the SWA boundary could not be resolved to the same level that is capable in the GIS. SWA boundary mapping involved extensive discussion with the SWA Manager, the Department of Natural Resources and Bureau of Land Management staff in charge of maintaining the cadastral framework.

Files with the name “wdfw-” mark the administrative boundary of the SWA that was used for the SWA boundary in phase 2 of this project. There are four versions of these files. Discrepancies were noted in the boundary depending on whether the boundary was digitized from Okanogan County parcel data, DNR ownership or the USGS DRG images. A final version named wdfw-edit3 was developed for printing that has orthogonal section lines which give it an improved appearance, if not more accuracy. The version called *wdfw-dnr.shp* was made by tracing the DNR public lands ownership (POCA) boundary lines. The version of the boundary made using Okanogan County parcel data called *wdfw-single.shp* was developed and used in the 2003 phase 1 of this project. The version one called *wdfw-drg.shp* was made by digitizing the boundaries of the SWA on the DRG images (digital raster graphics, a digital version of the USGS 7.5 minute topographic map) to attain the best fit of the boundary lines. Necessary edits to this boundary were made where it was felt that the boundary was incorrect, e.g., boundary lines crossing through houses. The version called *wdfw-edit3* was made by projecting wdfw-drg into decimal degrees and aligning all lines along orthogonally along section lines, and then projecting the edited file back into UTM Zone 11 NAD 1983. Extra vertices were removed using Shape Enhancement Tools - Remove Vertices command.

SWA boundary clipping polygons: In order to analyze treatment costs, it was necessary to clip the cover type file to match the SWA boundary. The file wdfw-w-o-mine.shp was created as a clipping polygon for the entire SWA. It only had a single multi-part polygon. This file was unioned with the shapefile of cover types and the field Owner was marked as either "WDFW" or "Other" depending on whether the stand was within the SWA boundary or not. A field Standnum was created to hold new stand numbers created after the union procedure, including stands both within the SWA, and stands outside the SWA boundary. The records were numbered after first sorting on the field Recno, which contained 85 duplicate records after the union procedure.

Public lands survey - DNR Township boundaries (*pls-twp.shp*): Townships were used to determine the extent of the analysis, and type of management that could occur on a given land area. The file contains township boundaries clipped from the Washington State Cadastral Framework Data provided under license by the Washington Department of Natural Resources (DNR) (http://framework.dnr.state.wa.us). None of the lines of these three cadastral coverages (see below) matched the others; all had approximately 10-20 meter discrepancies throughout their extent. Thus, there is no existing “correct” digital cadastral framework available for this area of Washington, and each of the different coverages must be considered in conjunction the others to determine a best fit for administrative boundaries.

Public lands survey - DNR section boundaries (*pls-sec.shp*): Sections were used to determine the extent of the analysis, and type of management that could occur on a given land area. The file is from Washington DNR - it delineates section boundaries within the townships. See note under Public lands survey - DNR townships.

Public lands survey - Okanogan County section boundaries (*pls_u11_83.shp*): This file contains section boundaries that originated from 1996 data provided by a contractor for Okanogan County. See note under Public lands survey - DNR townships.

Public lands ownerships (*pub_mgr.shp*): This layer represents all public lands in a single file made by merging the DNR *POCA* (ownership and Public Lands Survey with the *NDMPL* (Non-DNR-Major Public Lands) layers. These layers were provided under license from DNR; only the above clipped version is used. Each of the POCA and NDMPL layers were reduced in size by deleting extraneous fields, followed by merging into a single layer, which was then clipped with *bigbox.shp*.

Roads (*roads-clip2.shp*): This layer originated from the 2003 Phase 1 layer of roads that were manually digitized and edited (*roads-added3.shp*). It was then merged with the Okanogan County 1996 roads layer (*rd_w_ok5.shp*), and the Okanogan County 2002 roads layer (*ok_rds3.shp*), after these layers were edited for better registration and to remove duplicate lines. Edits to the Phase 1 roads layers are described briefly in this appendix under the *Phase 1 Themes* section. The merged roads layer was saved as *roads_merged.shp*, and then clipped to the extent of the *base30* grid with *extent30m-clip.shp*. The roads layer has a field Type, which is attributed to differentiate roads, trails, fences and irrigation canals ("Ditch") which were copied from other sources or manually digitized. Note that Washington DNR now has a detailed roads layer which can be downloaded for each county that would have been superior to the original files used in this project, however this became available too late to incorporate in this project.

Road buffers (*Rds-trails-dx-buff2.shp & Rds-trails-dx-buff.shp*): Road buffers were created to identify stands that could be treated with ground-based machinery. Road buffers are polygon files that have a border buffered around all roads and some drivable trails within the *base30* area. To generate this file, the roads and trails in roads-clip2.shp were each buffered using the Minnesota DNR Arcview Utility Tools. Two buffer distances used were 600 ft (0.1136 mi) and 900 ft (0.1705 mi), representing the reasonable maximum and extreme maximum distance for moving ground-based logging equipment beyond a road. The 600 and 900 m files were unioned for each of the files for roads and trails to generate file *rds-trails-buff3.shp*. In the attribute table of this file, the fields for the 2 distances to roads and trails were logically OR-d to generate a field "Label" giving the buffer distance to the nearest road or trail, in the following order of preference: rds<600, rds<900, trails<600, trails<900. For use in landscape views, the theme was unioned with an empty polygon having the same extent as *base30.shp*, and the result names as *rds-trails-dx-buff.shp*. All polygons within both the 900- and 600-foot buffer distances to either trails or roads were then merged into a single, multi-part polygon, so that there were only two types of polygons, labeled "inside" and "outside", the former representing all areas within 900 feet of a road or drivable trail. This file was named *rds-trails-dx-buff2.shp*. It was used as an overlay theme to select stands for ground-based treatments.

Towns (*towns.shp*): This is a point file depicting towns for use with presentation maps.

Fences and Pastures (*fence_u1183.shp, pasture_u1183.shp*): A line shapefile depicting fences was provided by Shelly Snyder of WDFW and reprojected from State Plane South NAD 1927. These were considered as possible fuel breaks. They were copied into the roads layer and attributed to differentiate them from fences.

10. Environmental features

Streams (*stream.shp*): The stream layer was downloaded under license from the Washington DOE ftp site. The streams were edited within the SWA boundary to match the denser shrub-tree layer of the orthophotos and/or the bank channels of the shaded relief made from the DEM (*elevshd.tif*) with a nominal error or ca. 5 meters. The layer was then clipped to the extent of the *base30* grid with *extent30m-clip.shp*.

Lakes (*lakes.shp*): The lakes layer was downloaded under license from the Washington Department of Ecology ftp site. After reprojection, it was shifted 120 feet eastward. It was then clipped to the extent of the *base30* grid with *extent30m-clip.shp*. A larger version of the lakes layer (*lakes-bigclip.shp*) is clipped to the larger area of *bigbox-clip.shp*.

11. Grid files used to develop cover types

North Cascades Grizzly Bear Habitat Evaluation (NCGBE) Level 1 Cover Types (composition) (grids *grzveg1, grzreg1*) (see Fig. App-A-1): North Cascades grizzly bear vegetation map (Almack et al, 1993), derived from a cooperative project between the Forest Service and Washington Department of Wildlife to map habitat using a 57m 1986 Landsat 4-band MSS image. The grid *grzveg1* is the Level 1 NCGBE vegetation classification which identifies 27 classes of vegetation cover. The *grz_reg* folder contains a regional clip of the grizzly bear data at 30 m resolution; the *grz30* folder contains the same files clipped and co-registered to the *base30* grid (see algorithms), with the original legend loaded back in. Registration compared to the orthophoto was good, approx 30-50 m (1-2 pixels).

North Cascades Grizzly Bear Habitat Evaluation (NCGBE) Level 2 (abundance) (grids *grzveg2, grzreg2*) (see Fig. App-A-2): The source and processing methods for this data are the same as in the NCGBE Level I classification described above. The Level 2 classification *grzveg2* grids contain 55 classes that define the vegetation cover abundance for each of the vegetation classes in the Level 1 map.

National Land Cover Database cover types for Washington (grid *NLCD*) (see Fig. App-A-3): NLCD data (MRLC, 2003) is derived from the early to mid-1990s Landsat Thematic Mapper satellite data from the USGS. The NLCD data is a 21-class land cover classification scheme applied consistently over the United States. The spatial resolution of the data is 30 meters. The original data format was 8 bit binary Geo-TIFF, provided online in Albers Conical Equal Area NAD 1983. After reprojection, the coverage was clipped and registered more accurately by shifting +90 meters east and -30 meters south with Grid PIG, prior to resampling into the grid file *base30*. The resultant *NLCD* grid was then co-registered to the *base30* grid (see algorithms), and the original legend loaded back in.

Northwest Habitat Institute (2001) (& Washington Department of Wildlife (WDFW) cover types for WA (grid *NHI*) (see Fig. App-A-4): This data was provided by the National Habitat Institute & WDFW. The original cell resolution was 25 m from a 1996 Landsat TM scene with 32 original classes. After reprojection, the coverage was clipped and registered more accurately by shifting -90 meters (west) with Grid PIG, prior to resampling into the grid file *base30*. The resultant *NHI* grid was then co-registered to the *base30* grid (see algorithms), and the original legend loaded back in.

Cover type grid converted from SWA stand polygons (grid *Cov_Typ4*): This grid was made by converting the stand polygons in *Cov_Typ4e.shp* into a grid file with 30m cells and registering it to the *base30* grid. This grid was superceded by the *ctswa30* grid, which covers the entire *base30* area in addition to the area within the SWA stands.

Mask of non-coniferous areas (grid *con_30_4*): This 30m grid identifies cells where coniferous cover is not assigned by definition of the cover type. It is partitioned into those areas outside the SWA stands boundary and those inside the SWA boundary. This file is necessary for maintaining the co-registration and collinearity of cells between subsequent grids built from the overstory coniferous canopy cover layer. The cell values of *con_30_4* defined as being without coniferous cover are: 1-Marsh & Swamp, 6-Agriculture, 9-Shrub Upland, 97-Developed, 98-Water, 99-Rock, 101-Deciduous Wet Forest and 102-Aspen. The remaining cells where coniferous canopy cover is intended to be determined were classified as 1. These had *Cov_Typ* values of:

5-Shrub steppe, 10-Canopy openings, 109-Coniferous riparian, 201-PIPO, 211-PSME-PIPO, 221-PSME montane and 231-ABLA-PICO.

Cover types for the base30 grid (grid *ctswa30*): The folder contains the most current version of *ctswa30*, with an appended letter to designate the latest version, i.e., ctswa30g; older versions were moved into a subfolder named /versions/. The *ctswa30* cover type classification is a refinement over other cover type and vegetation type classifications obtained for this project. This layer was developed in conjunction with the development of the canopy cover map; both were used together to determine areas of tree cover dominance and to differentiate shrub-steppe from areas of openings within forested zones. The *ctswa30* cover types mapped within the SWA stand boundary were derived from the *Cov_Typ4* grid, while the areas outside the SWA boundary were made by merging coincident cells from other data sources. Appendix D, steps 1-17, gives a description of the classification procedures, followed by a description of the clean-up and refinement process beginning with step 18.

Cover type from Utah State University (grid *usu_ct*): This cover type was developed for the Okanogan National Forest by Bio/West and Utah State University (Bio/West, Inc, 1999) from a 25 m 1997 Landsat TM grid, and projected into the Washington State Plane North projection, datum NAD 1927. There are two versions of this data set. One version was downloaded from the Regional Ecosystem Office link to Colville National Forest data (http://www.reo.gov/col/data_dictionary_grids/). An improved version of this data was provided on CD by fire consultant Tom Lueschen.

Usu_ct contains 27 vegetation classes and background (Agriculture, Burned Areas, Conifer/Deciduous Mixed, Deciduous, Douglas-fir, Douglas-fir/Grand fir, Dry Mixed Forest, Engelmann Spruce, Herbaceous, Lodgepole Pine, Lodgepole Pine/Western Larch, Low Canopy Closure Tree, Moist Mixed Forest, Mountain Hemlock, Pacific Silver Fir, Ponderosa Pine, Ponderosa Pine/Douglas-fir, Rock, Shrub, Snow, Subalpine Fir, Subalpine Forest Mix, Subalpine Larch, Urban, Water, Western Larch, Whitebark Pine, and Background). The grid was reprojected into UTM Zone 11 NAD 1983. After reprojection, the registration was compared to the orthophotos and judged fair. This was improved by shifting the grid 70 meters west and 30 meters north. This grid was not perfectly coregistered with the other Utah State University grids (size, canopy and structure), because the cell resolution of the source data was 25 meters, while the other grids had 30 m cells. This grid was resampled to 30 m, and aligned to be within approximately 5 m of the other Utah State University grids (size, canopy and structure) by shifting it 65 m west and 35 m north. The resultant *usu_ct* grid was then co-registered to the *base30* grid (see algorithms) and the original legend loaded back in through a table-join with the original (INFO) table (see algorithms at the beginning of this appendix).

12. Grid files used to develop canopy cover and stand structure

Canopy cover in 10% intervals (grid *cc_cov10*): This grid represents the coniferous canopy cover only for the area covering digitized SWA stands. It was calculated by patch-pattern analysis and resampled to 30m cell size. This grid is classified into 10 10% intervals of canopy created by reclassifying the values in the grid *cc_cov* in the same folder. Summary of the creation of *cc_cov*: The creation of *cc_cov* began with grid *shd_fact*, by summing the correction factors for shading in field *sum_shd* of *Cov_Typ4e.shp*, and then exporting this to an Excel Spreadsheet. The corrected value of coniferous canopy was then calculated in field *can* as the product of the corrected shading factor and the percent cover in the stand represented by the value in field *PctCan*. Prior to this calculation, *PctCan* values were copied into field *CC*, and then edited where they did not agree with field *Cov_Typ*. The records for cover types 5, 109, 110, 130, 160, were then selected and used to create the grid *cc_cov*. For subsequent analyses of cover type determination, grid *cc_cov* was resampled to 30m and registered to the *base30* grid, then renamed as *cc_cov10*.

Canopy cover filled in over non-data (grid *con_can3*): This is a 30m grid filled in to eliminate *No-Data* cells of non-coniferous cover types made by shrinking the perimeter of the grid against the favor of *No-Data* cells. The shrink operation created some anomalous cell patterns in non-coniferous areas outside the SWA boundary, which were judged to be insignificant for subsequent analyses within the SWA project area (see Appendix D, step 22).

Canopy cover with No Data cells eliminated (grid *con_can3b*) (This is formed by merging the grid *cc_cov10* as the first grid, with the base30 grid *mos_rcl6*, as described in Appendix D. This merge allows extending the refined canopy cover for the SWA stands to the extent of the *base30* grid).: This 30m grid has *No-Data* cells of non-coniferous cover types excluded through being clipped out by the grid file *con_area*.

Canopy cover from Okanogan National Forest (ONF) (grid *canopy*): This grid represents tree canopy cover (percent), in intervals of 0%, 1-19%, 20-39%, 40-59%, and 60-100%. This grid was provided by fire consultant Tom Lueschen on a CD in a projection of State Plane North, NAD 1927, as a set of input files for FARSITE modeling on the Okanogan National Forest. This grid and 8 others were co-registered identically (see algorithms).

Canopy height from ONF (grid *cr_ht*): This grid represents tree canopy height in feet. Non-forest types were assigned a zero. This grid was provided by fire consultant Tom Lueschen on a CD in a projection of State Plane North, NAD 1927, as a set of input files for FARSITE modeling on the Okanogan National Forest. This grid and 8 others were co-registered identically (see algorithms).

Canopy base (height) from ONF (grid *crbase*): This grid represents the distance between the base of a tree to the bottom of the live crown. This value represents the flame height necessary to enable the transition from surface to crown fire and accounts for ladder fuels. Non-forest types were assigned a zero value. This grid was provided by fire consultant Tom Lueschen on a CD in a projection of State Plane North, NAD 1927, as a set of input files for FARSITE modeling on the Okanogan National Forest. This grid and 8 others were co-registered identically (see algorithms).

Crown bulk density from ONF (grid *crbulk*): This grid represents tree crown bulk density (kg/m^3 * 100), the weight per unit volume of the crown, from the canopy base to the canopy height. The layer was multiplied by 100 to convert values into integers and save disk space [(kg/m^3) * 100], giving values of 0 to 28. Non-forest types were assigned a zero value. This grid was provided by fire consultant Tom Lueschen on a CD in a projection of State Plane North, NAD 1927, as a set of input files for FARSITE modeling on the Okanogan National Forest. This grid and 8 others were co-registered identically (see algorithms). The crown bulk density in this file correlated poorly with fuel model, canopy and cover type of the other USU files. The meta data says it was developed by modeling input from other stand characteristics, including the number of canopies, but the role of canopy number was not compared. Deciduous canopies were often scored with 0 in this model; perhaps because they are assumed to be shorter than 10 meters. The numbers in this grid file were generally much lower than in reviewed papers, which tended to fall in the range of .05 to 0.1 kg/m^3 for dense unlogged forests.

Canopy closure from ONF (grid *fmcc*): This is a grid of Fuel Model Canopy Closure in 5 increments developed by the Okanogan National Forest in 1989 and covering adjacent ownerships in the Okanogan Valley. The source file is a 50 m resolution grid developed from a 1983 Landsat scene and summarized into classes consisting of 5 canopy closures (1-10%, 11-30%, 31-50%, 51-70%, and >70%), and non-forested types of grass, shrub, agriculture, rock, snow and water. The registration after reprojection was poor to fair (ca. 50-100 m), and could not be corrected within the project time frame. Therefore this grid was used only for visual comparisons. The grid was co-registered to the *base30* grid (see algorithms) and the original legend loaded back in through a table-join with the original (INFO) table (see algorithms).

Canopy cover from Utah State Univ. (grid *usu_cc*) (see Fig. App-A-5): Canopy cover developed for Okanogan National Forest by BioWest and Utah State University (Bio/West, Inc, 1999) from a 25 m 1997 Landsat TM scene. The grid has 4 classes and background (1-19%, 20-39%, 40-59%, 60-100%). After reprojection, the registration to the orthophotos was good, but it was improved by shifting the grid 65 meters west and 30 meters north, prior to resampling into the grid file *base30*. After the grid was co-registered to the *base30* grid (see algorithms), the original legend was loaded back in through a table-join with the original (INFO) table (see algorithms).

DBH from Utah State Univ. (grid *usu_dbh*): Stem diameter at-breast-height classification developed for Okanogan National Forest by BioWest and Utah State University (Bio/West, Inc, 1999) from a 25m 1997 Landsat TM scene. The grid has 4 classes (1”-9.9”, 10”-19.9”, 20”+, and background). After reprojection, the registration to the orthophotos was good, but it was improved by shifting the grid 65 meters west and 30 meters north, prior to resampling into the grid file *base30*. The grid was then co-registered to the *base30* grid (see algorithms) and the original legend loaded back in through a table-join with the original (INFO) table (see algorithms).

Canopy number from Utah State Univ. (grid *usu_str*): This grid identifies the number of canopies in forested stands. It was developed for Okanogan National Forest by BioWest and Utah State University (Bio/West, Inc, 1999) from a 25m 1997 Landsat TM scene. The grid has 3 classes, classified into 1 = single-story; >1 = multi-story, or background. After reprojection, the registration to the orthophotos was good, but it was improved by shifting the grid 65 meters west and 30 meters north, prior to resampling into the grid file *base30*. The grid was then co-registered to the *base30* grid (see algorithms) and the original legend loaded back in through a table-join with the original (INFO) table (see algorithms).

13. Grid files used to develop 1m resolution canopy cover files

Canopy cover pattern analysis folder (cd:/fuelgis/analysis/arc1183/pattern/): This folder contains a number of temporary and permanent files used to develop and refine a canopy cover layer based on patch pattern analysis. See Appendix C for a description of the procedures and files used. Final products created from the patch pattern recognition process are described here.

Canopy openings type (grid *open_typ*): This is a 1m cell size grid that classifies the non-forested openings within a forested matrix by the size and distance from trees.

Canopy shade factor by aspect (grid *shd_fact*): This 1m resolution grid represents the combined grid values for tree density, canopy opening type, slope and aspect. It was produced by combining grid *tr_op* with grid *asp_slo*, and permanently joining all related fields. It contains a manually edited field *shade_fact*, used as a modifier factor for the percent of cells covered by just the horizontal projection of an average mature tree within the total projection of shadow and tree on an orthophoto at that aspect. The grid also contains a field *tree_fact*, that was added to *shade_fact*, as a modifier to vary the characteristics of shading for different types of canopies and openings. The summed factor was put into field *sum_shd*. The categories were as follows:

asp_slo	aspect category	slope category	Shade_fact
1	1-8 (N, 338-22 deg)	1 (0-10 deg)	35
21	1 (N, 338-22 deg)	2 (11-30 deg)	60
22	2 (NE, 23-67 deg)	"	45
23	3 (E, 68-112 deg)	"	27
24	4 (SE, 113-157 deg)	"	25
25	5 (S, 158-202 deg)	"	27
26	6 (SW, 203-247 deg)	"	45
27	7 (W, 248-292 deg)	"	60
28	8 (NW, 293-337 deg)	"	65
31	1 (N, 338-22 deg)	3-4 (31-63 deg)	60
32	2 (NE, 23-67 deg)	"	35
33	3 (E, 68-112 deg)	"	25
34	4 (SE, 113-157 deg)	"	20
35	5 (S, 158-202 deg)	"	25
36	6 (SW, 203-247 deg)	"	35
37	7 (W, 248-292 deg)	"	60
38	8 (NW, 293-337 deg)	"	70

Tree & canopy openings (grid *treeopen*): This is a 1m grid which depicts the combination of tree type with the mode of the adjacent type of opening associated with the canopy type.

In order to evaluate the metrics of tree patches, the values in grid *treeopen* needed to placed into 3 separate grids having only values of zero, or 1, the latter representing a value class from grid *treeopen*. The grids created were stored in the analysis/arc1183/pattern/treeopen/ folder, and weren't used within the main project file, except as values within *Cov_typ.shp*. The value 1 in each of these grid files represented the percent of cells in: even, medium patches, (value 101, grid *tree101*); percent of cells in even, thin patches (value 102, grid *tree102*); and percent of cells in dense patches of trees and shadows (values 103 or 104, grid *tree1034*).

Tree & canopy openings (trop30c, treeop30): These grids represents the tree and canopy openings classification resampled to 30m cell size. They contain the same values as the 1m grid treeopen.

Tree & canopy openings combined (grid *tr_op*): This is a 1m grid which depicts the combination of tree type with the mode of the adjacent type of opening associated with the canopy type. It contains values combined from grid *treeopen* for tree patch types and grid *open_typ* for canopy opening types as follows:

Tree class from treeopen	Opening type from open_typ
101 (even, medium patches)	0 (near-treeless areas)
101 (even, medium patches)	3 (canopy openings in even, thin patch matrix)
101 (even, medium patches)	4 (canopy openings in dense matrix)
102 (even, thin patches)	0 (near-treeless areas)
102 (even, thin patches)	3 (canopy openings in even, thin patch matrix)
102 (even, thin patches)	4 (canopy openings in dense matrix)
103 (dense shadow patches)	0 (near-treeless areas)
103 (dense shadow patches)	3 (canopy openings in even, thin patch matrix)
103 (dense shadow patches)	4 (canopy openings in dense matrix)
104 (dense tree patches)	0 (near-treeless areas)
104 (dense tree patches)	3 (canopy openings in even, thin patch matrix)
104 (dense tree patches)	4 (canopy openings in dense matrix)

14. Ecological model of SWA stands

Stand polygons for the SWA (*Cov_Typ4.shp* and versions): The shapefile *Cov_Typ4.shp* and its versions delineate stands of forested and non-forested types within and adjacent to the SWA. The naming convention for this file involves appending a number and optional letter after the name "*Cov_Typ*", e.g., *Cov_Typ4b.shp*, *Cov_Typ4c.shp*. This was done to simplify documentation and legend creation, while preserving archived versions. The primary feature of *Cov_Typ4.shp* was a field *Cov_Typ* representing land cover types used in this project. During phase 2 of this project, the original stands developed in *Cov_Typ.shp* were sub-categorized by dividing the polygons along the threshold values of key analytical criteria representing attributes of the stands, such as cover type, canopy density or slope.

After completion of Project Phase 1, *Cov_Typ4.shp* was shifted 20 m east and 8 m north from position of *Cov_Typ3.shp*, resulting in a more accurate registration. *Cov_Typ4.shp* was edited in 2004 using the ASTER imagery and field verification to refine the location of shrub uplands, open water, upland aspen stands and rock cliffs. In 2004, additional polygons were added to cover all versions of the SWA boundary (see the section on administrative themes for discussion).

A number of different legend files are available for working with the cover types: (1) the default legend, *Cov_Typ4.avl*, (2) *Cov_Typ4-13class.avl*, used for editing the cover types; (3) *Cov_Typ-display-non-conifer.avl*, used for displaying only the non-conifer map features for printouts.

Spatial data integrity was insured after each spatial operation by cleaning operations. During cleaning, referential data integrity was maintained using a unique number for each polygon stored in field *Recno*. The cleaning procedure was to number records with the Memo Tools command *RecNo to Table*, then remove polygon overlaps, fill in void polygons, dissolve sliver polygons and explode multipart polygons. Following the final edition of the cover types in *Cov_Typ4.shp*, the data was cleaned by dissolving polygons on *Cov_typ* initially resulted in dissolution of 25 polygons to create *Cov_Typ*6, using options of polygon size < 300 m^2, dissolve into largest adjacent polygon, and requiring that adjacent polygons share a common border. The dissolve operation found an additional 11 sliver polygons after exploding multipart polygons (*Cov_Typ*7).

14.a. Development of cover types

Cover types (field *Cov_Typ* in *Cov_typ.shp*). The cover type classification of *Cov_Typ4* was developed by sequential hierarchical division of the SWA area into successively smaller, more detailed regions, while maintaining a minimum polygon size of approximately 5 ac. The sequence for performing the classification followed the sequence: marshes, deciduous forest, openings, agriculture, 10-30% conifer, 30-60% conifer, 60-100% conifer, shrub-steppe, riparian conifer zone, rock talus, water, shrub uplands. The key to the cover types and upland conifer types is given in appendix D, and in phase 1 of this project.

Development of the cover types involved successive division into subcategories of the original cover types. Many of the sub-categories were structural categories or management procedures. The names and values of new categories of stand cover types were contained in new fields in Cov_typ.shp. Development of these subcategories are a main objective of phase 2 of the project described in this appendix and in appendix 1. A list of these sub-categories in the order created is given in the following list:

Cov_typ4 - original cover type designation using canopy density to partition coniferous cover types.

Treat_cat - treatment categories for coniferous and aspen stands partitioned by SWA ownership, stand structure, slope, north aspect, and proximity to roads.

Stand - merged values representing both coniferous and non-coniferous stands, from fields *treat_cat*, and *cov_typ4*, respectively.

Cov_fuel - merged values from field *stand*, subdivided into PIPO and PSME dominated stands.

B_u - Unit labels for controlled burning treatment areas (called “Burn Blocks”), subdivided into 10 total areas each covering approximately 10% of the SWA. Burn blocks were developed using spreadsheet *busum2-fig12c-12d.xls*. A subcategory of the burn blocks are “Burn Units” developed by a fuel specialist as sub-watershed scale controlled burn treatments. The labels for the burn units was originally contained in a field called *burn_unit* until the field *B_u* was developed, making that field obsolete.

Bu_ord - An abbreviated code for the Burn Blocks that allows sorting stands into 10 sets of hypothetical yearly controlled burns.

Burn_thin - combined treatment categories for controlled burns, ground-based treatments and helicopter-based treatments, as well as offbase stands outside the SWA.

Treat - this field is a further division of the treatment categories developed in field *burn_thin*, separating out coniferous stands not likely to need stem reduction, but still requiring pruning and raking prior to controlled burning treatments.

More detailed descriptions of these categories are described below and in appendix

1. Legend files using these fields are contained in folder *avl-lut*, with the same name as that of the field.

Cover types and plant associations from Dana Visalli (*types-visalli.shp*, and files in the folder *cd:/fuelgis/arc/spn27f_visalli/*): A file containing plant associations developed by Dana Visalli and botanists in 2004 was used to confirm the identify of PVTs and cover types developed for this project. Each plant association from the Visalli maps was merged into a single file, and polygon overlap was removed to produce a shapefile, *types-dv2.shp*, which was renamed as *types-visalli.shp*. There are 2 legend files for this file: one legend (*types-visalli.avl*) lists all of the features in field *Type* that were identified by the Visalli team, and one legend (*types-visalli-id.avl*) that only lists features in field *ID* that matched the cover types used in this project. The file was reprojected from State Plane North, NAD 1927 to UTM Zone 11, NAD 1983 for use in the comparison. A few minor changes were found in the comparison and corrected in file *Cov_Typ4.shp*.

14.b. Development of slope categories

Slope in field *Std_slo* of shapefile *Cov_typ.shp*. Slope of stands was coded in increments of 0-4%, 5-19%, 20-34%, 35-66% and >66%. Slopes were imputed into *Cov_Typ* by taking majority value of the slope category from the overlapping slope grid. There are 2 legend files for slope steepness in the *avl-lut* folder: *cov_typ-steep-slopes-35.avl* is used to outline stands slopes > 35% slope with a purple border and stipple them if they are north slopes; *cov_typ-steep-slopes-67.avl* is used to outline stands slopes > 67% slope with a bright blue border and stipple them if they are north slopes and *cov_typ-steep-slopes-35-67.avl* is used to stipple all four of these classes without outlines.

14.c. Development of PVT

Conifer categorization by potential vegetation type (PVT) (*Conif_Typ.shp*): These polygons were digitized manually to correct the conifer type classification for grid *ctswa30*. After confirmation of the classification by comparison with field data in *SWASUM.DB*, this shapefile was then incorporated into the attribute table of *Cov_Typ.shp* using a query to determine overlapping polygons within both shapefiles. *Conif_typ.shp* was then archived.

14.d. Development of TPA

Cover types and TPA (*Cov_Typ*8f.shp): *Cov_Typ8f.shp* was processed from *Cov_Typ4.shp*, in order to generate values representing the number of trees per acre and other stand characteristics. These values were constrained to lie within the range of the same values in the field exams.

The following stand attribute categories were used to hierarchically divide the stands in *Cov_Typ*8 into their respective categories for TPA calculations, based on the use of a sequential key to process if-then-else rules to process each stand's attributes in turn, as described here.

1. Use the fields *Cov_Typ4* and *Label* to separate out conifer stands in the following categories, then classify the stands in *Cov_Typ.shp* and *SWASUM.DB* by these

categories.
- 109 Riparian Conifer Zone
- 110 10-29% Conifer
- 130 30-59% Conifer
- 160 >59% Conifer

2. Use the fields *Conif_Typ* and *Conif_Zone* to divide the stands into the following conifer zones, and classify the stands in *Cov_Typ.shp* and *SWASUM.DB* by the following categories.
   - *Conif_Zone* = PIPO (Ponderosa pine); *Conif_Typ* = 201
   - *Conif_Zone* = PSME-PIPO (mixed Douglas-fir - ponderosa pine); *Conif_Typ* = 211
   - *Conif_Zone* = PSME-LAOC (montane Douglas-fir - western larch); *Conif_Typ* = 221

3a. Use the slope categories in the field *Std_Slo* to divide upland conifer into 3 slope categories as follows, then classify the stands in *Cov_Typ.shp* and *SWASUM.DB* into the following categories.
   - Gentle (*Std_Slo*= 0 or 5; slope = 0-19%)
   - Moderate (*Std_Slo*= 20; slope = 20-34%)
   - Steep (*Std_Slo*= 35 or 67; slope >34%)

3.b. Use the slope categories in the field *Std_Slo* to ensure that 109-Riparian Conifer Zone slopes are all >0 and 1-Marsh and Wetland slopes are all 20% or less:

4. Use the combined aspect and slope categories in the field *Std_Slope* to separate out steep, north-facing stands into a special category with N, NW or NE aspects and >34% slope. Add the following 2 categories to the field *Std_Slope*, in the stands in *Cov_Typ.shp* and in the stands in *SWASUM.DB*:
   - 35N Steep North
   - 67N Very Steep North

5. Use the field *Std_Toe* to separate out stands at the toe of slopes which are likely to have suppressed doghair stands, and mark the category *Std_Toe* = “Toe” in both *Cov_Typ.shp* and *SWASUM.DB*.

Cover types and TPA for additional pole stands digitized on screen (*Cov_Typ8i.shp*):

Cov_Typ8i.shp was processed from *Cov_Typ8f.shp*, in order to generate TPA values for additional pole stands identified by onscreen photo-interpretation. This file was the first file to include the field *Treat_cat*, used to classify stands into treatment categories based on structure and composition.

New pole stands were only identified for conifer stands not already determined to be pole stands. Existing pole stands were identified by the field *Std_toe* = "Toe" and labeled in field *Treat_cat* as "Pole". Existing non-pole coniferous stands were identified by field *Tpa_typ* not being blank and were labeled in field *Treat_cat* as "Con". Non-coniferous stands were labeled in field *Treat_cat* as "Noncon".

The procedure for identifying new pole stands was to visually inspect the View for stands with the following characteristics:

Coniferous cover type (*Tpa_typ* not blank)
AND Canopy cover >30% (*Cov_typ4_* <> "110")
AND NOT Riparian conifer (*Cov_typ4_* <> "109")
AND NOT in a stand with a plot located within it.
AND visually having an even-textured single canopy.

Newly identified pole stands were identified onscreen by scoring the field *Treat_cat* with “PoleID”, or for stands with > 67% slope, “PoleID-67”.

The data in *Cov_typ8f.shp* was copied as *Cov_typ8h.shp*. This file was linked to table *TPA.DBF* to load the correction factors for TPA for pole stands. The newly identified fields with *Treat_cat* = “PoleID” or “PoleID-67” were selected and the correction factors were multiplied by the existing TPA to yield corrected factors for TPA in fields *Tpacalc0, Tpacalc5, Tpacalc12, Tpacalc24*, and *Snagcalc*. The selection was then switched and the values for the rest of the records were transferred into the above fields (*Tpacalc0*, etc.) from the original TPA values without being changed.

Cov_typ8h.shp was archived, and copied as *Cov_typ8i.shp*. The fields for correction factors were deleted, and the new values were copied over the old fields. Then the new fields were deleted. Figure 8 shows pole stands identified in the SWA through both automated as well as photo-interpretation methods.

14.e. Stem density database (*SWASUM.DB*)

Table SWASUM.DB was used to hold the values for trees per acre (TPA) derived from the stand exams (plots, see Appendix E), after exporting the stand data from Access database *Plots-2003-12-16.mdb*, table *7Tree*. The table *SWASUM* was grouped and sorted by the categories in the field *Tpa_Typ* and then the records were copied into spreadsheet *TPA.XLS*. The values for TPA for the stands was averaged within each DBH category to yield mean values.

The records in *SWASUM* were classified based on the following key, which was used for the initial determination of categories of stands having a consistent cover of TPA in each of the 4 size categories of 0-5” DBH, 5-12” DBH, 12-24” DBH and >24” DBH. The field *Tpa_Typ* was edited with the following codes representing those categories using the following set of if-then-else calculations:

1. If *Cov_Typ4_*= “109 Riparian Conifer Zone”, THEN
   Tpa_Typ = “**Rip1**” [continue to step 3, appending new *Tpa_Typ* codes]
2. If *Std_Slo*pe = (“Steep North” or “Very Steep North”) THEN
   Tpa_Typ = *Tpa_Typ* + “**N-**” [continue to step 3, appending new *Tpa_Typ* codes]

After completion of steps 1 and 2, *Tpa_Typ* was classified by choosing one and only one of the following categories 3a to 3i. Then spreadsheet *TPA.XLS* was used to calculate the values for TPA as described in the spreadsheet, followed by calculation of the factor used to increase the TPA for suppressed pole stands with *Std_Toe* = “Toe” (step 4 below).

3a. If *Cov_Typ4_* = “110 10-29% Conifer” AND *Conif_Zone* = “PIPO” THEN
   Tpa_Typ = ... “**Cov110-PP**” Plots = 0049, 0101
   UNLESS *Std_Slo*pe = (“Steep North” or “Very Steep North”) THEN
   Tpa_Typ = “**N-Cov110-PP**” (NO PLOTS INTERSECTED)
3b. If *Cov_Typ4_*= “110 10-29% Conifer” AND *Conif_Zone* = “PSME-PIPO” THEN
   Tpa_Typ = ... “**Cov110-DP**” Plots = 0023, 0102, 0413, 0415, 0416
   UNLESS *Std_Slo*pe = (“Steep North” or “Very Steep North”) THEN
   Tpa_Typ = “**N-Cov110-DP**” (NO PLOTS INTERSECTED)
3c. If *Cov_Typ4_*= “110 10-29% Conifer” AND *Conif_Zone* = “PSME-LAOC” THEN
   Tpa_Typ = ... “**Cov110-DL**” (NO PLOTS INTERSECTED)
   UNLESS *Std_Slo*pe = (“Steep North” or “Very Steep North”) THEN
   Tpa_Typ = “**N-Cov110-DL**” (NO PLOTS INTERSECTED)

3d. If *Cov_Typ4_* = "130 30-59% AND *Conif_Zone* = "PIPO" THEN
Tpa_Typ = … "**Cov130-PP**" Plots = 0046, 0403, 0408, 0420
UNLESS *Std_Slo*pe = ("Steep North" or "Very Steep North") THEN
Tpa_Typ = "**N-Cov130-PP**" (NO PLOTS INTERSECTED)
3e. If *Cov_Typ4_* = "130 30-59% AND *Conif_Zone* = "PSME-PIPO" THEN
Tpa_Typ = … "**Cov130-DP**" Plots = 0011, 0019, 0057, 0404, 0407
UNLESS *Std_Slo*pe = ("Steep North" or "Very Steep North") THEN
Tpa_Typ = "**N-Cov130-DP**" (NO PLOTS INTERSECTED)
3f. If *Cov_Typ4_* = "130 30-59% AND *Conif_Zone* = "PSME-LAOC" THEN
Tpa_Typ = … "**Cov130-DL**" (NO PLOTS INTERSECTED)
UNLESS *Std_Slo*pe = ("Steep North" or "Very Steep North") THEN
Tpa_Typ = "**N-Cov130-DL**" (NO PLOTS INTERSECTED)
3g. If *Cov_Typ4_* = "160 60-100% AND *Conif_Zone* = "PIPO" THEN
Tpa_Typ = … "**Cov160-PP**" Plots = 0015, 0419
UNLESS *Std_Slo*pe = ("Steep North" or "Very Steep North") THEN
Tpa_Typ = "**N-Cov160-PP**" Plots = 0402
3h. If *Cov_Typ4_* = "160 60-100% AND *Conif_Zone* = "PSME-PIPO" THEN
Tpa_Typ = … "**Cov160-DP**" Plots = 0005, 0007, 0013, 0017, 0025, 0029, 0041, 0406, 0417, 0418
UNLESS *Std_Slo*pe = ("Steep North" or "Very Steep North") THEN
Tpa_Typ = "**N-Cov160-DP**" Plots = 0036 0055 0405
3i. If *Cov_Typ4_* = "160 60-100% AND *Conif_Zone* = "PSME-LAOC" THEN
Tpa_Typ = … "**Cov160-DL**" Plots = 0401
UNLESS *Std_Slo*pe = ("Steep North" or "Very Steep North") THEN
Tpa_Typ = "**N-Cov160-DL**" Plots = 0414
4. Evaluate stands with *Std_Toe* = "Toe" to determine a factor by which to modify stem density

14.f. Spreadsheets analyzing tree stems per acre (*TPA.XLS*)

Spreadsheet *TPA.XLS* was created to perform calculations on the corrected values developed in table *SWASUM.DB*. representing TPA in each of the 4 size categories of 0-5" DBH, 5-12" DBH, 12-24" DBH and >24" DBH. The table was used to compare the classified plot data with the GIS orthophotos, and to correct or annotate exceptions to the classification. The spreadsheet contains detailed notes describing the process, which proceeds from the leftmost tabbed spreadsheet through the rightmost. When complete, the values were transferred back into the GIS by linking to the field *Tpa_Typ* in shapefile *Cov_Typ8*.

Stem density calculations were based on known stem densities from field data for forested stands in the SWA, measured in four DBH classes of 0-5" DBH, 5-12" DBH, 12-24" DBH and >24" DBH.

The classification of stands with consistent values for TPA was coded in the data fields *Tpa_Typ*, which was used in association with field *Std_Toe* in *SWASUM* and *Cov_Typ*8.

A large number of associated tables were used to analyze the statistics associated with the values for stem density. These Paradox databases (data tables) and Excel spreadsheets are listed below in the order of processing (the list does not include descriptions of data summarized from other databases in the /fielddata/database/ folder for categories of fuel loadings, seedlings, saplings, or basal area):

- TREE03.DB - Export file from Access database *Plots-2003-12-16.mdb*, table *7Tree*
- TREE03B - Numbered TREE03.DB, sorted by *Waypt, Plotnum, Treesin*

(descending), *SeedSapTree, Treesp, NUM*.

- TREE03C - *TREE03B* table processed with *TRCOUNT*, seedlings and saplings data removed
- TRCOUNT.DB - Header subtracted from *TREE03.DB* giving count of trees in/out per plot
- TRSESAP.DB - Counts of seedlings and saplings subtracted from *TREE03.DB*
- SEED.DB - Seedlings subtracted from *TRSESAP.DB*
- SEEDLIV.DB - Counts of live seedlings subtracted from *SEED.DB*
- SEEDLIV2 - Calculate sum of seedlings for all species for each subplot
- SEEDLIV3 - Calculate sum of seedlings divided by 0.2 ac per subplot to get per-acre basis
- SEEDLIV4 - Join of *SEEDLIV3* with count of Waypts
- SEEDLIV5 - Sum of seedlings for all subplots for *SEEDLIV4*
- SEEDLIV6 - No. seedlings / no. subplots = no. seedlings / ac
- SAP.DB - Saplings subtracted from *TRSESAP.DB*
- SAPLIVE.DB - Counts of live saplings subtracted from *SAP.DB*
- SAPLIVE2 - Calculate sum of saplings for all species for each subplot
- SAPLIVE3 - Calculate sum of saplings divided by 0.2 ac per subplot to get per-acre basis
- SAPLIV4 - Join of *SAPLIV3* with count of Waypts
- SAPLIV5 - Sum of saplings for all subplots for *SAPLIV4*
- SAPLIV6 - No. saplings / no. subplots = no saplings / ac
- TRBAF.DB - Basal area counts just for live trees, numbered and sorted by plot number, species, DBH
- SNAGBAF.DB - Basal area counts just for dead trees
- BA.DB - Calculation of basal area for each stand exam
- TPA.DB - Summary table of TPA for each plot
- *TPA.XLS* - Calculations of TPA by stand category in *Std_Tpa*
- *SWASUM.DB* - Summary table of stand attributes
- *SWASUM* (modified) - contains *SWASUM* joined to *SAPLIV6* and *SEEDLIV6* to contain values of seedlings per ac (field *Seedpa*) and saplings per ac (field *Sappa*)

Spreadsheet *TPA.XLS* contained uncorrected TPA for each DBH category along with multiplication factors to be applied for stands marked as suppressed (i.e., having *Std_Toe* = “Toe”).

The following table gives values of *TPA.XLS* imported as *TPA.DBF* into Arcview and linked to the attribute table of *Cov_Typ.shp*.

	Trees per acre by DBH category					**Multiplication factor for suppressed stands**				
Tpa_Typ	**TPA0**	**TPA5**	**TPA12**	**TPA24**	**SPA (snags/ac)**	**TPF0**	**TPF5**	**TPF12**	**TPF24**	**SPF**
Cov110-DLDP	17	15	16	1	2	1.0	1.0	1.0	1.0	1.0
Cov110-PP	38	5	25	2	2	1.0	1.0	1.0	1.0	1.0
Cov130-DLDP	60	74	63	2	3	1.3	1.2	1.0	1.0	2.0
Cov130-PP	60	48	34	1	0	2.5	2.5	0.9	1.0	2.0
Cov160-DLDP	43	128	80	5	6	2.0	1.2	0.4	2.0	1.0

Cov160-PP	110	110	17	0	0	1.8	2.5	0.3	1.0	1.0
N-160	205	201	32	4	4	1.0	1.0	1.0	1.0	1.0
N-130	150	150	16	2	2	1.0	1.0	1.0	1.0	1.0
Rip	60	60	150	1	1	1.0	1.0	1.0	1.0	1.0

The main legend used for displaying the treatment categories was *cov_typ-treat-cats.avl*, and in addition, a second legend *cov_typ-treat-cats-legend.avl* was created to display treatment categories without separate features for north-facing, steep slopes, in order to simplify legend displays.

Spreadsheet treatments-all-tpa-by-bu.xls was created from shapefile cov_typ.shp to summarize the areas of stands by treatment. This data was not used, but rather was used to create a prune-rake treatment. The spreadsheet *treat-needed-fig15.xls* was used to create figure 15, showing treatment method by stand cover type.

14.g. Development of canopy cover

Canopy cover in field *can* of shapefile *treat.shp* (fields *cc_* and *pctcan*) - correction of canopy cover: During creation of treatment categories and recalculation of TPA in *cov_typ9f.shp*, the estimated average stand canopy cover was changed in some stands, due to a number of reasons including cutting and merging stands with mixed canopy cover, and changing the definition of canopy cover to include deciduous cover. The field *can* was created as the average overstory canopy cover for the stand in *treat.shp* that was linked to *cov_typ.shp* by field *Recno*. The value in *can* was modified by the photo-interpretation of deciduous canopy > 10 m for stand types 11 Aspen Upland, 12 Deciduous Wetland and 14 Shrub upland. In other stands where the classification of treatment category or cover type did not match the existing canopy in field cc_ or pct_can, the values for coniferous canopy cover were corrected, either using photo-interpretation of the orthophotos or via the sets of queries and field calculations given below:

01 Pole and 02 Mature & Pole
If cc_ > 59 then can = cc_
If cc_ < 60 and pct_can > 60 then can = pct_can
If cc_ < 60 and pct_can < 60 then can = 70

03 Mature Conifer Rocky
If cc_ > 59 then can = cc_
If cc_ < 60 then can = 75

04 Medium Conifer or 05 Medium Conifer & Shrub
If cc_ = 30 to 59 then can = cc_
If cc_ < 30 then can = 30
If cc_ > 59 then can = 59

06 Open Mature Conifer or 07 Open Conifer Steep North or 08 Open Conifer & Regen or 09 Open Conifer & Shrub
If cc_ < 30 then can = cc_
If cc_ > 29 then can = 29

10 Riparian Conifer
evaluate stand on orthophoto and evaluate canopy (deciduous + coniferous overstory).

11 Aspen Upland

evaluate stand on orthophoto and evaluate canopy (deciduous + coniferous overstory; the minimum aspen cover for the stand must equal 30% and the coniferous overstory must be less than 20%.

12 Deciduous Wetland
can = 60 (assumed all deciduous)

13 Marsh or 14 Shrub-steppe 16 Agriculture or 17 Developed or 19 Water
can = 0

15 Shrub Upland
If cc_ < 10 then can = 0
If cc_ > 9 then evaluate and attribute canopy using photo-interpretation (including deciduous overstory; conifer must be < 20% and aspen must be < 30%)

18 Rock & Cliff
evaluate and attribute canopy using photo-interpretation (canopy must be <50%)

14.h. Determination of basal area (BA)

Spreadsheet *bulk-ba-calcs.xls* was used to develop basal area (BA) calculations. The BA for average site trees on the SWA was modeled by averaging the total stem basal area within each of the dbh stem categories, each category of which was partitioned into bins of 2" diameter increments, and each assigned a percentage based on the expected stem frequency for each increment.

The BA for the 0-5" dbh class was determined as 0.0873 based on a 4" dbh site tree; the BA for the 5-12" class was determined as 0.4003 based on a 8.5" dbh site tree; the BA for the 12-24" class site tree was determined as 1.613 based on a 17" dbh site tree; and the BA for the 0-5" class site tree was determined as 3.8855 based on a 26.6" dbh site tree. The BA values were then joined to file cov_typ.shp.

The site tree BA was then used as a variable for the calculation of crown bulk density (CBD) within the spreadsheet bulk-ba-calcs.xls, using the above equations in conjunction with the values for TPA.

15. Files used to evaluate treatments, cover types and stand structure

15.a. Correction of misclassified stand attributes

Prior to determining treatment type, stand metrics were cross-validated against each other and used to make corrections to the values for TPA and canopy cover for stands with > 60% dense patches classified erroneously as <30% conifer; TPA values for closed-canopy stands (>75% canopy); TPA values for stands with medium canopies (30-75%). This is described next.

Misclassified stands with > 60% dense patches of trees and shadows classified erroneously as <30% conifer: Misclassified stands were identified within Arcview in Cov_typ.shp by identifying stands that were classed as < 30% conifer indicated by field Cov_typ4_ having a value of “110”, but having > 60% cover indicated by the value in field tr1034 for dense trees and shadows being > 60. Only stands on moderate slopes were evaluated, to prevent errors from hill shading. Stands on steep slopes were eliminated from the comparison using the following query: ([Std_Slope] <> "35N Steep North") and ([Std_Slope] <> "67N Very Steep North")

Upon inspecting these stands on orthophotos and from photographs, it was found that the coniferous canopy cover category of Cov_typ4_ was underestimated and the value in tr1034 was more accurate. These stands were corrected as follows.

Stands with Tr1034 <75 had the value of Cov_typ4_ changed to 130 (30-59% Conifer") and Tpa_typ changed to "Cov130-PP" or "Cov130-DL" depending on whether they were in PVT zone 201 or 211, respectively, for ponderosa pine or Douglas fir.

The TPA of these stands was also changed. The sets of existing TPA values were dependent on whether Conif_zone was "PIPO" or "PSME-PIPO". The TPA categories for "PIPO" stands were 38, 5, 25, 2 and 2, respectively for the dbh categories (0"-5" dbh, 5"-12" dbh, 12"-24" dbh, >24" dbh and snags / ac. >12" dbh and > 6' long). The values for PSME-PIPO stands were 17, 15, 16, 1 and 2, respectively. Both sets of values were changed to typical values for other stands of PSME-PIPO in the 30-59% canopy cover: 60, 74, 63, 2 and 3, respectively.

There were 3 misclassified stands with dense canopy cover (Tr1034 > 75). These were changed in Cov_typ4_ to "160 60-100% Conifer" and in Tpa_typ to "Cov160-PP" or "Cov160-DL", depending on whether they were in PVT zone 201 or 211, respectively, for ponderosa pine or Douglas fir. The TPA values for these stands were changed to that of typical PSME-PIPO stands with Tpa-typ "Cov160-DL" (Pole & Mature): 43, 128, 80, 5, and 6, respectively, for the same dbh categories listed above.

Corrected TPA values for closed-canopy stands (>75% canopy): Dense canopy stands were compared with the expected stem density based on patch metrics in field tr1034. The following queries were used to select the stands:

- Stands are non-riparian conifer ([Cov_typ4_] = 110) or ([Cov_typ4_] = 130) or ([Cov_typ4_] = 160)
- Stands are not pole types ([Treat_cat] <> "Con-Pole") and ([Treat_cat] <> "Con-PoleID")
- Stands are in the PSME-PIPO or PSME-LAOC zone ([Conif_typ] = 211 or ([Conif_typ] = 221)
- Stands have > 75% dense trees and shadows ([Tr1034] > 75)

Many of these stands have high numbers of pole trees, but they are not true pole stands. Most stands are dominated by trees in the largest dbh categories. Many of these stands are associated with rocky cliffs.

Inspection of orthophoto overlays revealed that the values for TPA in the pole classes were probably too low. A more realistic set of values for TPA was determined as follows:

The TPA categories of these stands were compared with the TPA of adjacent stands with plots in them. Plot 5 with 33% canopy cover was adjacent to a pole stand with 68% canopy cover and TPA values of 86, 154, 32, 10, and 6, respectively, for the same categories described above. The difference between these stands is a change for each dbh category, respectively, of 120%, 208%, 50%, 500% and 200%.

Plot 36 with 85% canopy was adjacent to a stand of mixed mature and pole trees with 91% canopy and TPA values of 205, 201, 32, 4, and 4, respectively, for the same TPA categories described above. The difference between these stands is a change for each dbh category, respectively, of 342%, 272%, 50%, 200%, and 200%.

Based on the above comparisons of TPA values for the two sets of stands, the TPA values for these stands were changed to the following: 145 TPA (0"-5" dbh), 178 TPA (5"-12" dbh), 32 TPA (12"-24" dbh), 7 TPA (>24" dbh), and 5 TPA (snags >12" dbh and > 6' long per acre).

Corrected TPA values for stands with medium canopies (30-75%): Medium canopy stands were compared with expected stem density based on patch metrics in field tr1034. The following queries were used to select medium canopy conifer stands:

- Stands are non-riparian conifer ([Cov_typ4_] = 110) or ([Cov_typ4_] = 130) or ([Cov_typ4_] = 160)
- Stands are not pole types ([Treat_cat] <> "Con-Pole") and ([Treat_cat] <> "Con-PoleID")
- Stands are in the PSME-PIPO or PSME-LAOC zone ([Conif_typ] = 211 or ([Conif_typ] = 221)
- Stands have <= 75% dense trees and shadows ([Tr1034] <= 75).
- Stands have >30% dense trees and shadows, or >20% dense trees and shadows and >6% even medium patches ([Tr1034] > 30) or ([Tr1034] > 20 and [Tr101] > 6)) .

Inspection of orthophoto overlays revealed that these stands had more openings than stands in the pole or mixed pole-mature treatment categories. Despite a highly variable canopy cover each of these stands had identical TPA values for each of the dbh categories. The values for TPA for the 5"-12" dbh category were changed based on the values for two stands in this category with plots in them: plots 19 and 57.

These plots had calculated canopy cover values of 62 and 45, respectively, and mean values for the dbh categories of 53 TPA (0"-5" dbh), 100 TPA (5"-12" dbh), 73 TPA (12"-24" dbh), 2 TPA (>24" dbh), and 6 TPA (snags >12" dbh and > 6' long per acre). These values were compared with the mean of the existing calculated values for this treatment category of 60, 74, 63, 2, and 3,for each of the same categories, respectively.

Of the actual TPA values, the calculated value of 100 for the TPA of 5"-12" dbh trees is furthest from the value of 74 TPA for that already calculated for the same dbh category. Therefore, the 5"-12" dbh category was changed from 74 TPA to 99 TPA for stands in this category. This number was 1 less than the minimum criterion that would have classed these as pole stands.

A minor additional change was made by to all stands with field Tpa_Typ = “Cov160-DL” and with field *Stand* = “01 Pole”. In these stands the Tpa for 24-36 in trees was changed from 10 to 3.

15.b. Attributes constrained prior to determination of treatment category

Identification of additional suppressed pole stands using on-screen photo-interpretation:

Pole stands were identified using onscreen photo-interpretation, adding to those already identified at slope breaks. The TPA values of these new pole stands were recalculated in Cov_Typ.shp, leaving the TPA values for previously identified pole stands unchanged.

The procedure for identifying new pole stands was to visually inspect the View* for stands with all of the following characteristics: coniferous cover >30%, but not classified as riparian conifer and not in a stand with a plot located within it, and having a visually even-textured, single canopy.

Newly identified pole stands were marked in the field Treat_cat with "Con-PoleID". The TPA was calculated by linking the TPA values for pole stands contained in table TPA.DBF, followed by multiplying the old TPA by the correction factors for each dbh category, to yield the corrected TPA for the selected stands. The selection was then switched and the values for the remainder of the records were transferred into the fields for corrected TPA without being changed. The old shapefile was archived as Cov_typ8f.shp and copied as Cov_typ8i.shp, so that temporary calculated fields could be deleted.

Identification of stands on steep, north slopes (Treat_cat = "Con-NS"): The following queries were used to identify stands on steep, north slopes:

- Stands are not riparian conifer ([Cov_typ4_] = 110) or ([Cov_typ4_] = 130) or ([Cov_typ4_] = 160)
- Stands are on steep, north slopes ([Std_Slope] = "35N Steep North") or ([Std_Slope] = "67N Very Steep North")

These stands typically have low productivity and high numbers of small stems. Along the slope dip there is higher runoff, but lingering late snowmelt tends to make these stands wetter overall. Stands have high wildlife values, greater diversity of plants, and higher numbers of snags. Stands are in a mixed severity fire regime, typically with longer fire intervals and hotter fires. Trees can attain great age particularly if they are on a rock outcrop. Many of these stands are suffering from understory competition exacerbated by fire suppression, but due to their inaccessibility, ground-based treatments may be impractical.

Stands on steep, north slopes were in different plant associations and had different TPA values than similar stands on other aspects and slopes. Even though steep, north-facing stands were sometimes grouped with stands on other slopes and aspects, it was important to maintain the distinction. Therefore the string "NS" (for "north slope") was retained for all these stands as a qualifier whenever these stands were grouped into other treatment categories.

Riparian Conifer Stands (Treat_cat = "Con-Rip"): Stands within the riparian conifer buffer (Cov_typ4_ = "109"), were marked in *Treat_cat* as "Con-Rip".

Aspen Uplands (Treat_cat = "Aspen Upland"). Aspen is a non-coniferous stand selected by querying *Label_* = "102 Aspen Upland" and marking *Treat_cat* as "Aspen Upland".

15.c. Queries used to develop stand treatment categories

Stand condition: Mixed Mature & Pole stems (*Treat_cat* = "Con-Mature-Pole" or "Con-NS-Mature-Pole"). These stands have a mixed overstory of larger, mature trees, as well as a second canopy of pole stems. Stands are similar to pole stands, except that they have a greater component of trees in the larger dbh classes.

- Stands are conifer ([Cov_typ4_] = 110) or ([Cov_typ4_] = 130) or ([Cov_typ4_] = 160)

- Stands are not pole types ([Treat_cat] <> "Con-Pole") and ([Treat_cat] <> "Con-PoleID")
- Stands have more than 100 TPA in the pole category, 5"-12" dbh ([Tpacorr5] > 99)
- Stands have more than 50% cover of dense trees and shadows ([Tr1034] > 50)

Stand condition: Mature Conifer Rocky (*Treat_cat* = "Con>75" or "Con-NS>75"; originally called "Medium Conifer with regeneration conifer").

- Stands are conifer ([Cov_typ4_] = 110) or ([Cov_typ4_] = 130) or ([Cov_typ4_] = 160)
- Stands are not pole types ([Treat_cat] <> "Con-Pole") and ([Treat_cat] <> "Con-PoleID" and ([Treat_cat] <> " Con-NS-Mature-Pole" and ([Treat_cat] <> "Con-Mature-Pole")
- Stands have more than 75% cover of dense trees and shadows ([Tr1034] > 75)

Stand condition: Open conifer Steep North (*Treat_cat* = "Con-NS>35"; originally called "Open conifer"**.** Only stands on north slopes with >35% slope remained in this category after processing subsequent queries, however open conifer stands were originally comprised of four subcategories, representing presence or not on north aspects and slopes >35% or <35%.

- Stands are classed as < 60% conifer ([Cov_typ4_] = 110) or ([Cov_typ4_] = 130)
- Stands are not pole types ([Treat_cat] <> "Con-Mature-Pole") and ([Treat_cat] <> "Con-NS-Mature-Pole") and ([Treat_cat] <> "Con-Pole") and ([Treat_cat] <> "Con-PoleID")
- Stands have less than 35% cover of dense trees and shadows ([Tr1034] < 35)

Stand condition: Open Mature Conifer & Herbaceous (*Treat_cat* = "Con-Open-Mature"). This treatment category is a sub-category of open conifer, containing conifer and steppe with large diameter open-grown conifers spaced widely throughout the stand and with a low amount of woody understory competition.

- Stands are already classed in the open-canopy conifer treatment type:
    - Stands are classed as < 60% conifer ([Cov_typ4_] = 110) or ([Cov_typ4_] = 130)
    - Stands are not pole types ([Treat_cat] <> "Con-Mature-Pole") and ([Treat_cat] <> "Con-NS-Mature-Pole") and ([Treat_cat] <> "Con-Pole") and ([Treat_cat] <> "Con-PoleID")
    - Stands have less than 35% cover of dense trees and shadows ([Tr1034] < 35)
- Stands are not on steep, north-facing slopes ([Std_Slope] <> "35N Steep North") and ([Std_Slope] <> "67N Very Steep North")

Two types of canopy structure are included in this category, the first one with more trees in dense shadowy patches, the second with more single large trees.

- ([Tr101] < 10) and ([Tr102] < 1.0)

or

- ([Tr101] > 10) and ([Tr102] < 2.0)

Stand condition: Open Conifer & Shrub (*Treat_cat* = "Con-SS-Ecotone" or "Con-NS>35-SS-Ecotone"). This treatment category is a sub-category of open conifer in the shrub-steppe ecotone modeled by stands having > 2% even, thin patches. It is mutually exclusive with the open-grown, mature treatment category, but does allow for stands on steep, north-facing slopes.

- Stands are already classed in the open-canopy conifer treatment type:
  - o Stands are classed as < 60% conifer ([Cov_typ4_] = 110) or ([Cov_typ4_] = 130)
  - o Stands are not pole types ([Treat_cat] <> "Con-Mature-Pole") and ([Treat_cat] <> "Con-NS-Mature-Pole") and ([Treat_cat] <> "Con-Pole") and ([Treat_cat] <> "Con-PoleID")
  - o Stands have less than 35% cover of dense trees and shadows ([Tr1034] < 35)
- Stands have more than 2% of even, thin patches ([Tr102] > 2.0)

For the above stands that were on steep, north-facing slopes ([Std_Slope] = "35N Steep North") or ([Std_Slope] = "67N Very Steep North"), Treat_cat was marked "Con-NS>35-SS-Ecotone", otherwise it was marked "Con-SS-Ecotone".

Stand condition: Open Conifer & Regeneration conifer (*Treat_cat* = "Con-Regen").

This treatment category is a sub-category of open conifer with invading regeneration conifer in the understory.

This category is separated from Open Conifer & Shrub (treat_cat = "Con-SS-Ecotone") by having even, thin patches (Tr102) of 0.9% - 2.0%, while Open Conifer & Shrub has twice as much area covered in even, thin patches (field Tr102 > 2.0). Both of these treatment categories have about the same amount of area in dense, shadow patches and also have more clumps of even, thin patches than that of open-grown open pine stands, however this category tends to have less area in both even, medium patches and even, thin patches.

Stands on steep, north slopes are excluded, due to the low productivity and higher soil moisture that would affect the successional pattern of the regeneration conifer component. This set of queries should be run after identifying and excluding the open-grown mature conifer treatment category, so that the first query in the set below can be used to exclude open-grown conifer stands from this set.

- Stands are not in the treatment category of open-grown mature conifer with low understory competition ([Treat_cat] <> "Con-Open-Mature")
- Stands are already classed in the open-canopy conifer treatment type:
  - o Stands are classed as < 60% conifer ([Cov_typ4_] = 110) or ([Cov_typ4_] = 130)
  - o Stands are not pole types ([Treat_cat] <> "Con-Mature-Pole") and ([Treat_cat] <> "Con-NS-Mature-Pole") and ([Treat_cat] <> "Con-Pole") and ([Treat_cat] <> "Con-PoleID")
  - o Stands have less than 35% cover of dense trees and shadows ([Tr1034] < 35)
- Stands are not on steep, north-facing slopes ([Std_Slope] <> "35N Steep North") and ([Std_Slope] <> "67N Very Steep North")

  Stands have between 0.9% and 2.0% of even, thin patches ([Tr102] > 0.9) and ([Tr102] <= 2.0)

Stand condition: Medium conifer cover (*Treat_cat* = "Con-Med" or "Con-NS-Med").

- Stands are conifer ([Cov_typ4_] = 110) or ([Cov_typ4_] = 130) or ([Cov_typ4_] =

160)
- Stands are not pole types ([Treat_cat] <> "Con-Mature-Pole") and ([Treat_cat] <> "Con-NS-Mature-Pole") and ([Treat_cat] <> "Con-Pole") and ([Treat_cat] <> "Con-PoleID")
- Stands have between 35% and 75% dense trees and shadows ([Tr1034] > 35) and ([Tr1034] < 75)

Stand condition: Medium Conifer & Shrub North (*Treat_cat* = "Con-Med-Regen"). This treatment category is a sub-category of medium-canopy conifer, having invading regeneration conifer modeled by the presence of > 2% even, thin patches.

- Stands are already classified in the medium canopy conifer treatment category:
  - Stands are conifer ([Cov_typ4_] = 110) or ([Cov_typ4_] = 130) or ([Cov_typ4_] = 160)
  - Stands are not pole types ([Treat_cat] <> "Con-Mature-Pole") and ([Treat_cat] <> "Con-NS-Mature-Pole") and ([Treat_cat] <> "Con-Pole") and ([Treat_cat] <> "Con-PoleID")
  - Stands have between 35% and 75% dense trees and shadows ([Tr1034] > 35) and ([Tr1034] < 75)
- Stands are not on steep, north-facing slopes ([Std_Slope] <> "35N Steep North") and ([Std_Slope] <> "67N Very Steep North")
- Stands have less than 60% cover of dense, trees and shadows ([Tr1034] < 60)

Stands have more than 2% of even, thin patches ([Tr102] > 2.0)

15.d. Analysis of treatment effects

In order to transform data from pre-treatment to post-treatment ecological conditions, a lookup database containing correlated factors related to stand structure was created called *treatment-factors-table2.xls*. This transformation table was also used to transform vector data into grid format. The data table *treatment-factors-table2.xls* was grouped by cover type in field *Stand*, allowing the table to be linked to the shapefile *cov_typ.shp*. The database was linked to *fuelgrd.dbf* as shapefile *fuelgrd.shp*.

Variables in the table were the post-treatment values following 3 possible treatments: after a controlled burn, after thinning or after thinning then burning. The following variables were assigned:

- the fraction of overstory stems remaining after each of the 3 treatments. Overstory stems were represented by values for trees per acre (TPA), in the 3 most important size classes of 0-5", 5-12", and 12-24". Other size classes were not considered significant in this procedure.
- the fraction of overstory canopy cover remaining after each of the 3 treatments.
- canopy crown base in feet for pretreatment stands and after each of the 3 treatments.
- crown bulk density (see under crown bulk density for those calculations)
- It was not necessary to change the canopy height, since following treatments, the height of overstory leave trees would remain the same.

Analyses of variables related to treatment was performed in a number of different spreadsheets. The chart in fig. 13 was created in spreadsheet *treatments-by-cover-by-10yr-fig13.xls*.

16. Stand structural cover type development

Structural cover types in field *cov_fuel* of shapefile *cov_typ.shp*. The structural cover type designation for SWA stands was developed in conjunction with the development of treatments, burn blocks and fire behavior modeling. The structural cover types are used in a number of tables and charts, such as *cov_fuel_acreages-fig16.xls*, which was used to determine the limiting acreage for the least common stand structures.

Structural cover types were hierarchically subdivided from the merged coniferous and non-coniferous stand categories contained in field stand of *cov_typ.shp*, by whether stands were PSME or PIPO dominated.

The assigned treatment categories in field *stand* were subdivided by the addition of for additional structural types to separate ponderosa pine (PIPO) from Douglas fir (PSME) dominated stands. The new stand structural attributes were placed in field cov_*fuel* and renumbered so that they would have the same sequence when converted to grid files. These cases were labeled as follows [by grid label, (shapefile label)]: 1 (101 Pole); 2 (102 Mature & Pole); 3 (103 Mature Conifer Rocky); 4 (104 Medium Conifer PIPO); 5 (105 Medium Conifer PSME); 6 (106 Medium Conifer & Shrub North); 7 (107 Open Mature Conifer PIPO); 8 (108 Open Mature Conifer PSME); 9 (109 Open Conifer Steep North); 10 (110 Open Conifer & Regen PIPO); 11 (111 Open Conifer & Regen PSME); 12 (112 Open Conifer & Shrub PIPO); 13 (113 Open Conifer & Shrub PSME); 14 (114 Riparian Conifer); 15 (115 Aspen Upland); 16 (116 Deciduous Wetland); 17 (117 Marsh & Swamp); 18 (118 Shrub-steppe); 19 (119 Shrub Upland); 20 (120 Agriculture); 21 (121 Developed); 22 (122 Rock & Cliff); 23 (123 Water).

For display purposes in Arcview, the field *stand* is used with the legend *stand*, to represent the stand structural cover types, even though this field does not differentiate between PIPO and PSME-dominated stands.

17. Fire behavior and fuel model development

17.a. Custom fuel models developed for the SWA

Fuel model spreadsheet (*plot-fuel-model.xls*). Fire behavior fuel models were developed in spreadsheet *plot-fuel-models-table16.xls*, based on the standard 13 fuel models (Anderson, 1982). Additional custom fuel models were developed within this spreadsheet by comparison with the FOFEM database, as well as with SWA field plot fuel load data. The fuel models determined for field plots are contained in the plot location database, *waypoints.shp*, field *FM2*.

Fuel model attributes were originally developed in table *plotfuel.db*, which were taken from the FOFEM database (Keane et al., undated). A spreadsheet *std-fuel-models.xls* was used to tabulate the fuel attributes for the standard Anderson (1982) fuel models. The data in table *plotfuel.db* and spreadsheet *std-fuel-models.xls* was then transferred to spreadsheet *plot-fuel-models-table16.xls* developed for the SWA stands. Data compiled in the spreadsheet includes dead 1-hour fuels (tons/ac), dead 10-hour fuels (tons/ac), dead 100-hour fuels (tons/ac), live herbaceous loads (tons/ac), live shrub (woody) loads (tons/ac), litter loads (tons/ac), duff loads (tons/ac), coarse woody debris >3" diameter (tons/ac), surface area to volume ratio of 1-hr fuels (per sq-ft), surface area to volume ratio of live herbaceous fuels (per sq-ft), surface area to volume ratio of live woody fuels (per sq-ft), fuel bed depth (ft), moisture of extinction (%), dead fuel heat content (BTU/lb), and live fuel heat content (BTU/lb).

The fuel model parameters are shown in the following table. Fuel loads are in tons/ac; moisture contents are in percent. 1h, 10h, 100h are dead fuel loads for 1-hr, 10-hr, and 100-hr fuels; Hrb is live herbaceous load; Shr is live woody load; SAV 1h, SAV Hrb and SAV Shr are the surface:area volume ratios; Fuel Dep is the fuel depth in feet; MX is the moisture of extinction. IFM 1h, IFM 10h, IFM 100h, IFM Hrb and IFM Shr are the initial fuel moisture contents of 1-hr, 10-hr, 100-hr, live herbaceous and live woody fuels; Duff TPA is the duff loading; CWD TPA is the coarse woody loading for sound wood only.

FM No.	Fuel Model	1r	10h	100h	Hrb	Shr	SAV 1hr	SAV Hrb	SAV Shr	Fuel Dep	MX	IFM 1h	IFM 10h	IFM 100h	IFM Hrb	IFM Shr	Duff TPA	CWD TPA
FM1	Grass	0.74	0.00	0.00	0.00	0.00	3500	1500	1500	1.00	15	4	7	8	60	90	0.0	
FM2	Grass/Brush	2.00	1.00	0.50	0.50	0.00	3000	1500	1500	1.00	15	4	7	8	60	90	0.0	
CM21	Open-Medium Timber/Rocky	0.10	0.30	0.10	0.10	0.30	2500	1500	1500	0.20	20	4	7	8	60	90		4.8
CM24	Shrub Upland (Savanna)	1.90	0.30	0.10	0.75	5.00	2500	1500	1500	1.50	20	4	7	8	60	90	0.0	
FM3	Tall Grass	3.01	0.00	0.00	0.00	0.00	1500	1500	1500	2.50	25	5	7	8	60	90		
CM34	Marsh/Swamp	1.01	1.00	1.00	4.01	2.00	2500	1500	1500	6.00	20	7	8	11	60	90	9.0	
CM41	Swamp (use CM34)	3.60	2.10	0.00	3.01	2.90	2500	1500	1500	6.00	20	7	8	11	60	90	9.0	
CM45	Deciduous	2.00	2.10	1.86	0.30	2.00	2500	1500	1500	4.00	20	7	8	11	60	90	10.0	3.8
FM5	Green Brush/Litter	1.00	0.50	0.00	0.00	2.00	2000	1500	1500	2.00	20	5	7	8	60	90	5.0	7.2
CM48	Grass/Brush/Forest Burned	0.01	0.01	0.01	0.20	3.00	2500	1500	1500	2.50	20	5	7	8	60	90	0.0	3.6
CM49	Grass/Brush/Forest Thinned	2.00	1.80	4.80	0.20	3.00	2500	1500	1500	2.50	20	5	7	8	60	90	9.0	9.5
CM50	Grass/Brush/Forest Untreated	1.00	0.90	2.40	0.20	3.00	2500	1500	1500	2.00	20	5	7	8	60	90	9.0	7.2
FM8	PSME/Litter	1.50	1.00	2.50	0.00	0.00	2000	1500	1500	0.20	20	5	7	8	60	90	10.0	6.3
FM9	PIPO/Litter	2.92	0.41	0.15	0.00	0.00	2500	1500	1500	0.20	20	5	7	8	60	90	6.8	2.9
CM18	PSME/Litter	0.40	1.40	2.50	0.20	0.35	2000	1500	1500	0.20	20	5	7	8	60	90	10.0	6.3
CM19	PIPO/Litter	0.20	1.50	1.20	0.00	0.00	2500	1500	1500	0.20	20	5	7	8	60	90	6.8	0.4
FM10	Mature Timber/Deadfall	3.01	2.00	5.01	0.00	2.00	2500	1500	1500	1.00	20	5	7	8	60	90	10.0	10.0
FM11	Med Timber/Light Slash	1.50	4.51	5.51	0.00	0.00	2500	1500	1500	1.00	20	5	7	8	60	90	5.0	13.5
CM15	OverMature Forest/Understory	1.50	2.00	3.50	0.20	2.00	2500	1500	1500	0.50	20	5	7	8	60	90	10.0	9.0

17.b. Grid files evaluated and rejected for fuel model attributes

Fuel model from Utah State University (grid *fbfm_oka*) (used as basis for FBM; see Fig. App-A-6): Fire behavior fuel model, classified into the standard 13 fire models: 1 = Short Grass, 2 = Grass/Timber, 5 = Brush, 6 = Dormant Brush, 8 = Short/needle Timber, 9 = Long/needle Timber, 10 = Mature Short/needle Timber, 97 = Snow & Ice, 98 = Water , 99 = Rock. This grid was provided by fire consultant Tom Lueschen on a CD in a projection of State Plane North, NAD 1927, as a set of input files for FARSITE modeling on the Okanogan National Forest. It was originally developed by Bio/West (1999). This grid and 8 others were co-registered identically (see algorithms). The grid was then co-registered to the *base30* grid (see algorithms) and the original legend loaded back in.

Fuel model from ONF (grid *fbfm_onf*): Fire behavior Fuel Model for Okanogan National Forest and adjacent areas. The source was a 30 m grid produced for the Okanogan and Colville National Forests and adjacent northern Washington prepared by BioWest in conjunction with Utah State University (Bio/West, Inc, 1999). That data was originally from a 25 meter cell resolution year 2000 vegetation classification, modified to 10 classes of: 1 Short Grass, 2 Grass/Timber, 5 Brush, 6 Dormant Brush, 8 Short needle Timber, 9 Long needle Timber, 10 Mature Timber, 97 Snow and Ice, 98 Water, and 99 Rock. After reprojection, the registration to the orthophotos was good, but it was improved by shifting 50 meters west and 40 meters north. The grid was then co-registered to the *base30* grid (see algorithms) and the original legend loaded back in through a table-join with the original (INFO) table (see algorithms).

Fuel model with north aspects from ONF (grid *fbfm_n*): Fire behavior fuel model, classified like the fbfm_oka grid, but with added categories representing the same fuel models on north aspects. This grid was provided by fire consultant Tom Lueschen on a CD in a projection of State Plane North, NAD 1927, as part of a set of input files for FARSITE modeling on the Okanogan National Forest. It was originally developed by Bio/West (1999). This grid and 8 others were co-registered identically (see algorithms) to that of the *base30* grid (see algorithms) and the original legend loaded back in.

17.c. Fire behavior modeling files

The grids used for the fire behavior model were originally developed to match the extent of a watershed-sized rectilinear grid named base30, but for the final analyses, a set of grids extending only to the edge of the delineated stands in *cov_typ.shp* were needed to incorporate the more accurate data developed only for the stands in the GIS for this project.

Several files were created to use as clipping files and to set the registration coordinates and cell size of the created grids. First, a grid file with 30 m cell size was created named base surrounding all the delineated stands in the GIS within a rectangle, and a shapefile named *baseclip.shp* was created that exactly enclosed this grid. The grid base was used to set the alignment, cell size and extent of a grid named stand, which was created by conversion from the *cov_typ.shp* shapefile for all delineated stands in the GIS. Grid stand had only a single value of 1 representing cells overlapping the delineated stands.

Using the above files to control registration, two main conversion methods were used to create the grids for the fire behavior model: (1) conversion of fields in the shapefile *cov_typ.shp* or shapefile *fuelgrd2.shp* using the grid *base* to set the registration of the created grid; or (2) grid-grid cell combinations of the grid *stand* with previously created grids having the larger extent of the *base30* grid. The grids resulting from grid-grid cell combination were then reclassified to set the value of the combined grid, and then clipped to the extent of *baseclip.shp* (using the software CRWR-Raster).

Elevation grid *elev*, with cell values in units of feet. This grid was used for fire behavior modeling input to FARSITE and FLAMMAP. It was created by grid-grid cell combination of grid *stand* with the USGS elevation grid *elev*.

Aspect grid *aspect*, with cell values in units of degrees. This grid was used for fire behavior modeling input to FARSITE and FLAMMAP. It was created by grid-grid cell combination of grid *stand* with the USGS aspect grid *aspect*.

Slope grid *slope*, with cell values in units of degrees. This grid was used for fire behavior modeling input to FARSITE and FLAMMAP. It was created by grid-grid cell combination of grid *stand* with the USGS slope grid *slope*.

Canopy Cover Density grid *cancov*, with cell values in units of percent canopy cover, from 0 to 92%. This grid was created by conversion of field *can*, in shapefile *cov_typ.shp* using the grid *base* to set the registration of the created grid.

Structural cover types grid *cov_fuel*, with 23 cell values corresponding to the structural cover types. This grid was created by conversion of field *cov_fuel*, in shapefile *cov_typ.shp* using the grid *base* to set the registration of the created grid.

Canopy base height, grid *cb*, with cell values corresponding to the canopy base height in feet. This grid was created by conversion of field *cb0*, in shapefile *fuelgrd2.*shp, using the grid *base* to set the registration of the created grid.

Canopy height, grid *ht*, with cell values corresponding to the canopy height in feet. This grid was created by conversion of field *cb0*, in shapefile *fuelgrd2.*shp, using the grid *base* to set the registration of the created grid.

Crown bulk, grid *crnbulk*, with cell values corresponding to the crown bulk density in units of kg/m^3, ranging from 0 to 44. This grid was created by conversion of field field *CBDm100* in shapefile *tpa-antilog.shp*, using the grid *base* to set the registration of the created grid. The values were then joined to *fuels.shp* via the stand record number field, *recno.*

CBD (in kg/m^3) was calculated in spreadsheet *bulk-ba-calcs.xls* and in shapefile *tpa-antilog.shp*. The procedure to derive CBD first involved exporting the data table for file *cov_typ.shp* to the spreadsheet. Basal area values for basal areas per tree per each dbh category was converted to a per acre basis, and then summed and converted to m^2/ha. Tree density in was converted from a per acre basis to stems/ha. The logarithm of basal area and tree density was then calculated.

CBD was modeled using the equations developed by Cruz et al. (2003) that derive CBD from basal area (in m^2/ha) and tree density (stems/ha)):

In ponderosa pine: CBD = exp[0.435 ln(basal area)) + (0.579 ln(tree density)] - 6.649

In Douglas-fir: CBD = exp[0.479 ln(basal area)) + ((0.625 ln(tree density)] - 7.38

Stands were divided into 3 groups corresponding to whether they were pine-dominated, Douglas-fir-dominated, or Non-forested. Stands in the pine group included pole stands (except not Mature & Pole); all structural cover types with PIPO in the name, Shrub-upland, and Aspen. All other stands were classified either as Douglas-fir (including Riparian conifer) or Non-forest.

The coefficients were added to the spreadsheet *bulk-ba-calcs.xls* corresponding with whether the stands were pine-dominated or Douglas fir dominated, and the CBD was then calculated, converted to an integer by multiplying by 100, and then imported into Arcview as shapefile *tpa-antilog.shp*, with the values for CBD held in field *CBDm100*. The values were then joined to *fuels.shp* via the stand record number field, *recno.* Non-forested types that had some coniferous canopy were attributed with CBD values by assignment as follows (in units of 100* kg/m^3): Aspen, Deciduous Wetland = 35; Rock & Cliff, Shrub Upland = 10; Marsh, Agriculture, Shrub-steppe, Water = 0.

The values for CBD were joined to *cov_typ.shp*, and also converted to grid *crnbulk* for use with the fire behavior model.

Duff (grid *duff*). Cells correspond to duff loading in tons/ac. This file was developed from the data assembled in spreadsheet plot-fuel-models-table16.xls, and transferred to file fuels.shp, by association with the field representing the fuel model, fm0. Values for duff loading were obtained by multiplying the duff depth from stand exams times 9 tons/acre per inch of duff depth times the average percent forest overstory cover.

Combined fuels shapefile fuels.shp. A shapefile was developed based on the stand numbers in field *Recno* to hold various fuel values, that couldn't simply be linked to the structural cover type. This was done in order to simplify the number of fields used in *cov_typ.shp*. The fuel values stored in this file were *recno*, owner, *treat* (treatment category), *cov_fuel* (structural cover type), *CBD_typ* (used in queries to develop fuel models), *can* (pre-treatment canopy cover density), *ba* (basal area in sq ft/ac), *fm0* (pre-treatment fuel model), *cdbm100* (pre-treatment crown bulk density), *duff* (duff loading, tons/ac).

FARSITE mild (May) weather text file, sinla-may1-5.wtr (details are in Appendix F). This is the mean of weather parameters used to represent mild burning conditions for May 1 to May 5, taken as the mean of 18 days of precipitation-free weather from 2006, May 1 00:00 to May 19 00:00, at the Oroville Weather station OVLW1, developed in spreadsheet *oroville-2006-weather.xls*, downloaded from the National Weather website, RAWS summaries for Washington weather (http://raws.wrh.noaa.gov/cgi-bin/roman/raws_ca_monitor.cgi?state=WA&rawsflag=2). This period includes within the average, the weather from two anomalously hot days with maximum temperatures of 98 and 97 degrees. Temperatures for this period ranged from 25 to 98 degrees F; RH ranged from 12-80%; the mean low temperature was 38 degrees F; the mean high was 69 degrees F; the mean low RH was 20% the mean high RH was 56%; the mean elevation was input as 800 feet. The same mean values were used for each day of the period from April 29 to May 5.

FARSITE 80th percentile (August) weather text file, sinla-aug80th.wtr (details are in Appendix F). This is the 80th percentile weather for August 15 to Aug 19, taken as the mean temperature and humidity during the 6 days with highest sustained wind speeds during the period of 30 days of precipitation-free weather from 2006, 7/31 00:40 to 8/29 23:40 at the Oroville Weather station OVLW1, developed in spreadsheet *oroville-2006-weather.xls*, downloaded from the National Weather website, RAWS summaries for Washington weather (http://raws.wrh.noaa.gov/cgi-bin/roman/raws_ca_monitor.cgi?state=WA&rawsflag=2). The temperatures and humidities used for the mean were not out ordinary for the entire 30-day period, and in fact the two temperatures on Aug 28 and 29 were above the 80th percentile highs. Temperatures for this period ranged from 49-98 degrees F; RH ranged from 15-55%; the mean low 80th percentile temperature was 58 degrees F; the mean high 80th percentile temperature was 86 degrees F; the mean low 80th percentile RH was 25% the mean high 80th percentile RH was 44%; the mean elevation was input as 800 feet. The same mean values were used for each day of the period from Aug 15 to Aug 19.

FARSITE mild (May) wind text file, sinla-may1-5.wnd (details are in Appendix F). This is the mean wind speed used to represent mild burning conditions for May 1 to May 5, taken as the mean of 18 days of precipitation-free weather from 2006, May 1 00:00 to May 19 00:00, at the Oroville Weather station OVLW1, developed in spreadsheet *oroville-2006-weather.xls*, downloaded from the National Weather website, RAWS summaries for Washington weather (http://raws.wrh.noaa.gov/cgi-bin/roman/raws_ca_monitor.cgi?state=WA&rawsflag=2). This period includes within the average, the weather from two anomalously hot days with maximum temperatures of 98 and 97 degrees. Wind speeds ranged from 5-10 mph during this period. This range of wind speeds was input for each hour of each day, for the five days spanning May 1 - May 5, , arranged in a diurnal rise-and-fall sequence that matched typical days.

FARSITE 80th percentile (August) wind text file, sinla-aug80th.wnd (details are in Appendix F). This is 80th percentile wind speed for August 15 to Aug 19, taken as the mean of the 6 days with highest sustained wind speeds during the period of 30 days of precipitation-free weather from 2006, 7/31 00:40 to 8/29 23:40 at the Oroville Weather station OVLW1, developed in spreadsheet *oroville-2006-weather.xls*, downloaded from the National Weather website, RAWS summaries for Washington weather (http://raws.wrh.noaa.gov/cgi-bin/roman/raws_ca_monitor.cgi?state=WA&rawsflag=2). Wind speeds ranged from 4-18 mph during this period, with a mean of 5-15 mph used for all 5 days in the weather file, arranged in a diurnal rise-and-fall sequence that matched typical 80th percentile days.

17.d. Flammap and FARSITE run files

Files for the pre-treatment inputs are contained in the root of folder *farsite/input*. The post-treatment input files for burn-only treatments are contained in folder *farsite/input/burn*; thinning only treatments are contained in folder *farsite/input/thin*; and combined burning and thinning treatments are contained in *farsite/input/burnthin*.

The "landscape file" for controlling Flammap inputs is contained within each input folder containing the names and units of fire behavior input files. The landscape file used by FARSITE version 4.0 and Flammap version 2 is named *sinla-1.lcp*. The landscape file used by both FARSITE version 4.1 and Flammap version 3 is named *sinla-2.lcp*. The landscape file includes inputs from *elev.asc* (ft), *slope.asc* (deg), *aspect.asc* (deg), *fuelmod2.asc* (class pointer to *sinla.fmd*), *cancov.asc* (canopy cover in % cover), *crnht.asc* (crown ht ft), *crnbase.asc* (ft), *crnbulk.asc* (crown bulk density ($kg \cdot m^{-3}$), *duff.asc* (tons/ac), *coarse.asc* (class pointer to *sinla-aug80th.cwd*).

Text-based project input files are *sinla.adj*, the fuel adjustment file; *sinla-aug80th.fms*, comtaining fuel moistures; sinla.fmd, the custom fuel models fuel characteristics; *sinla-aug80th.cwd*, the coarse woody profile; *sinla-aug80th.wth*, the weather file, and *sinla-aug80th.wnd*, the wind file.

Project files used by FARSITE and Flammap are *sinla-may.fpj*, for the May simulation, and *sinla-aug80th.fpj* for the August simulation. FARSITE bookmarks are *sinla-may.bmk*, for May, and *sinla-aug80th.bmk*, for August. The project file for Flammap version 3 is named *FlamMap3.fmp*.

The Flammap output values were imported into grid files, and then imputed into the attribute table of *effects.shp* as the mean of all grid values overlapping the stand. Variables of most interest were crown potential, rate-of-spread, heat/unit area, fireline intensity, and flame lengths for August and May, which were stored in effects.shp, respectively, in fields *crn, ros, heat, fli, flenaug* and *flenmay*.

18. Phase 1 Themes (not used in 2005)

2003 Project folder (*cd:/fuelgis/arc/1183/gis_2003/*): This folder contains 2003 project files and GIS data described in the final report for Phase 1 of this project. Some of these files were edited to build the clipped and georeferenced versions used in phase 2 of the project. Those are described below. Other Phase 1 files not used in 2004 are not described in this appendix. If files were used in Project Phase 2 without editing or correction, then they are described in the other sections of this appendix. The 2003 Phase 1 themes are linked from the Arcview View, *Phase 1 Themes*.

Roads - 1996 (*rd_w_ok5.shp*): This layer was originally developed by a GIS contracting firm for Okanogan County Planning Department. This layer contains roads, jeep trails and skid roads not shown on other layers that are useful for fire behavior modeling. In Phase 1 of this project this layer was called *rd_w_ok3.shp*. This layer was cleaned by deleting duplicate roads and improving the registration by shifting most of the roads outside the SWA boundary east by 24m. This roads layer was edited to insure there was no overlap with *roads-added3.shp*, before it was combined with that layer.

Roads - Okanogan County 2002 (*ok_rds3.shp*): This is the Okanogan County Planning Department road layer, downloaded in 2002. The roads that intersected the SWA boundary were edited to match the orthophotos as exactly as possibly (with an estimated error of 5m). This layer was edited to improve mapping accuracy and to insure there was no overlap with *roads-added3.shp*, and then it was combined with that layer.

Ownership - private (*oka_co_own.shp*): This file is the Okanogan County parcel layer used in phase 1 of this project as *shape1own2.shp*. It is provided here as a replacement for that file because it was found to be in the wrong projection, otherwise, it was not used in this phase of the project.

19. References for this section

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20. Images used in this section

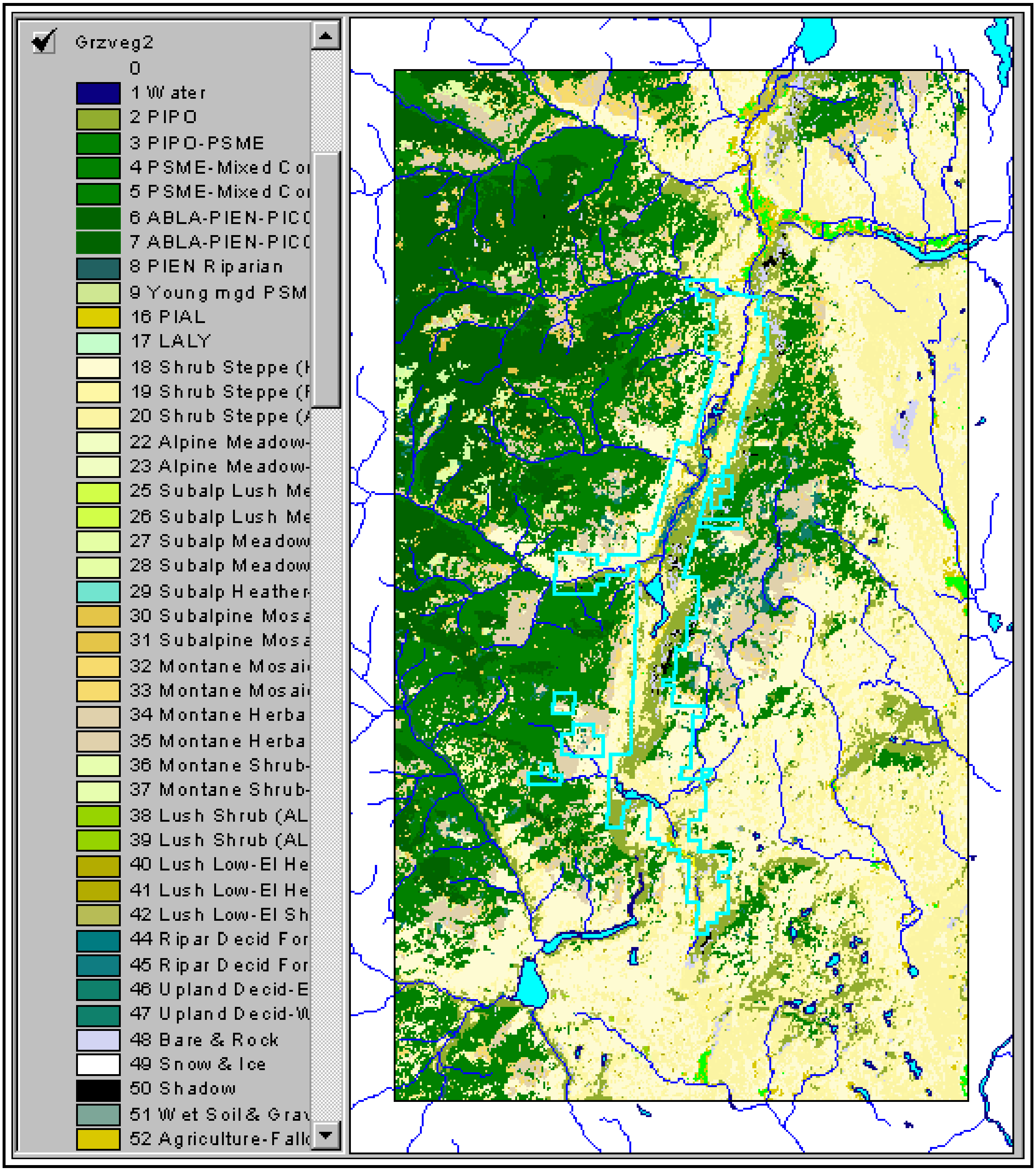


Figure Appendix-A-1. Grzveg2 - North Cascades Grizzly Bear Habitat Evaluation (NCGBE) Level 2 (abundance).

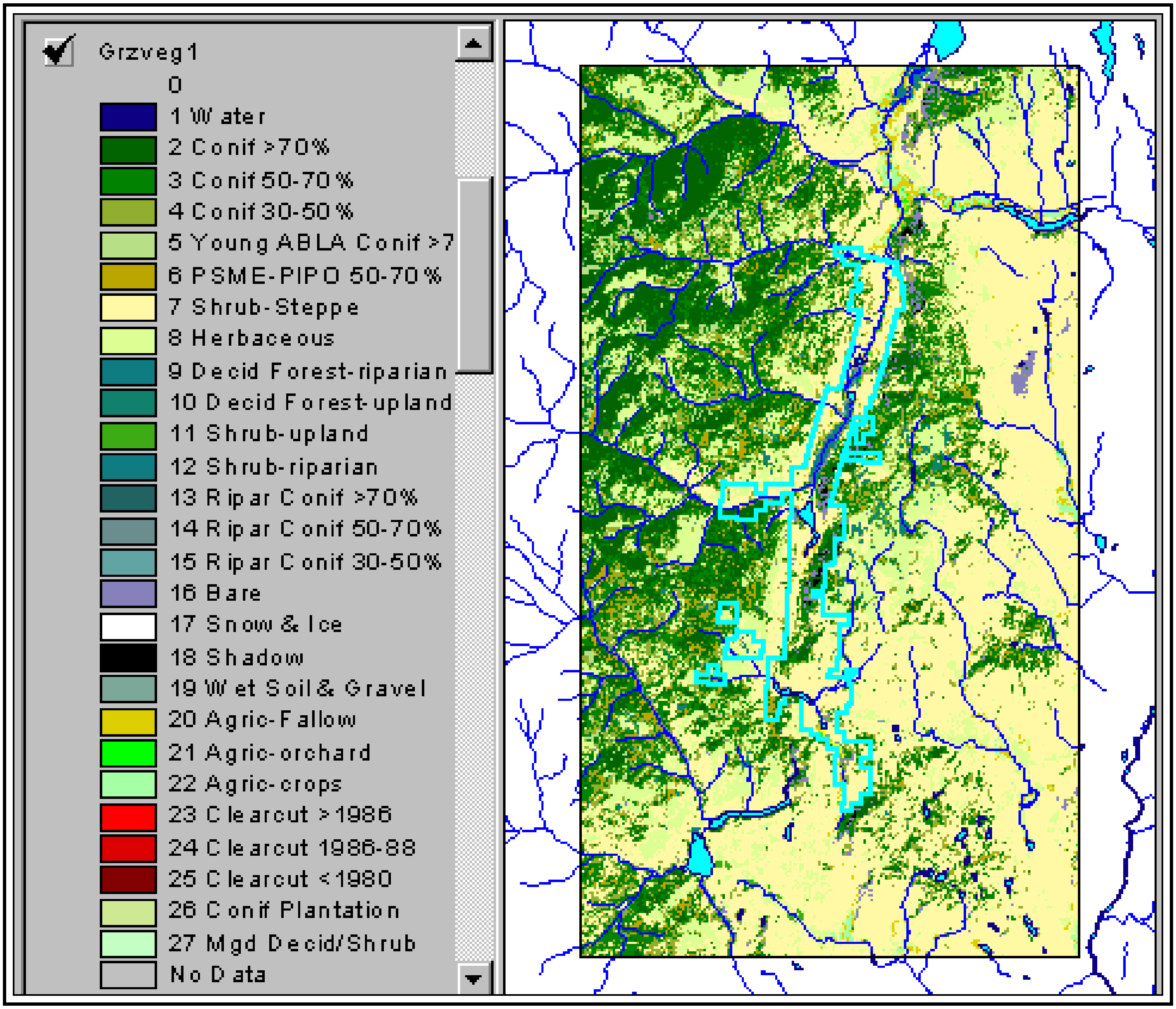


Figure Appendix-A-2. Grzveg1 - North Cascades Grizzly Bear Habitat Evaluation (NCGBE) Level 1 Cover Types (composition).

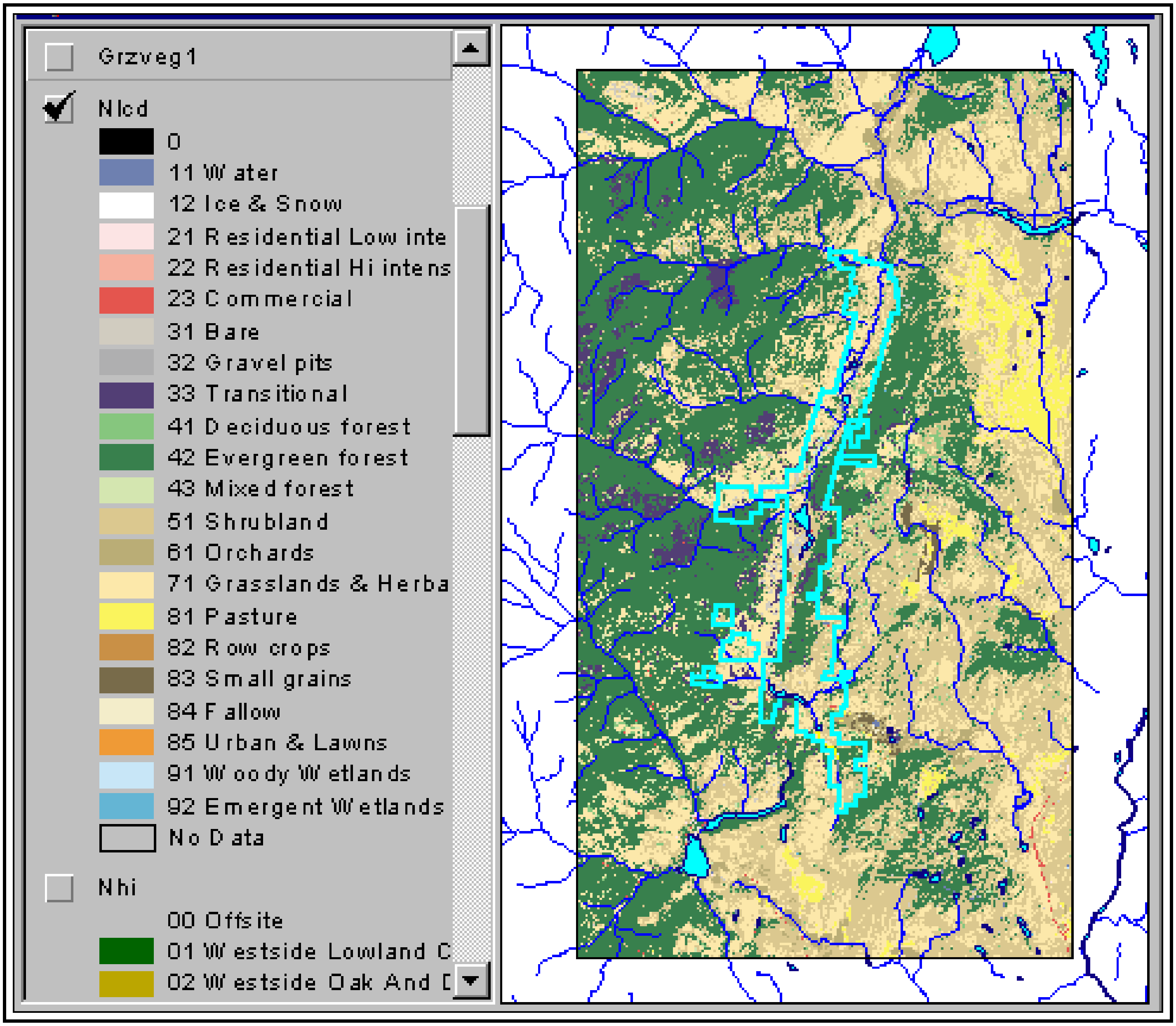


Figure Appendix-A-3. NLCD map - National Land Cover Database cover types for Washington.

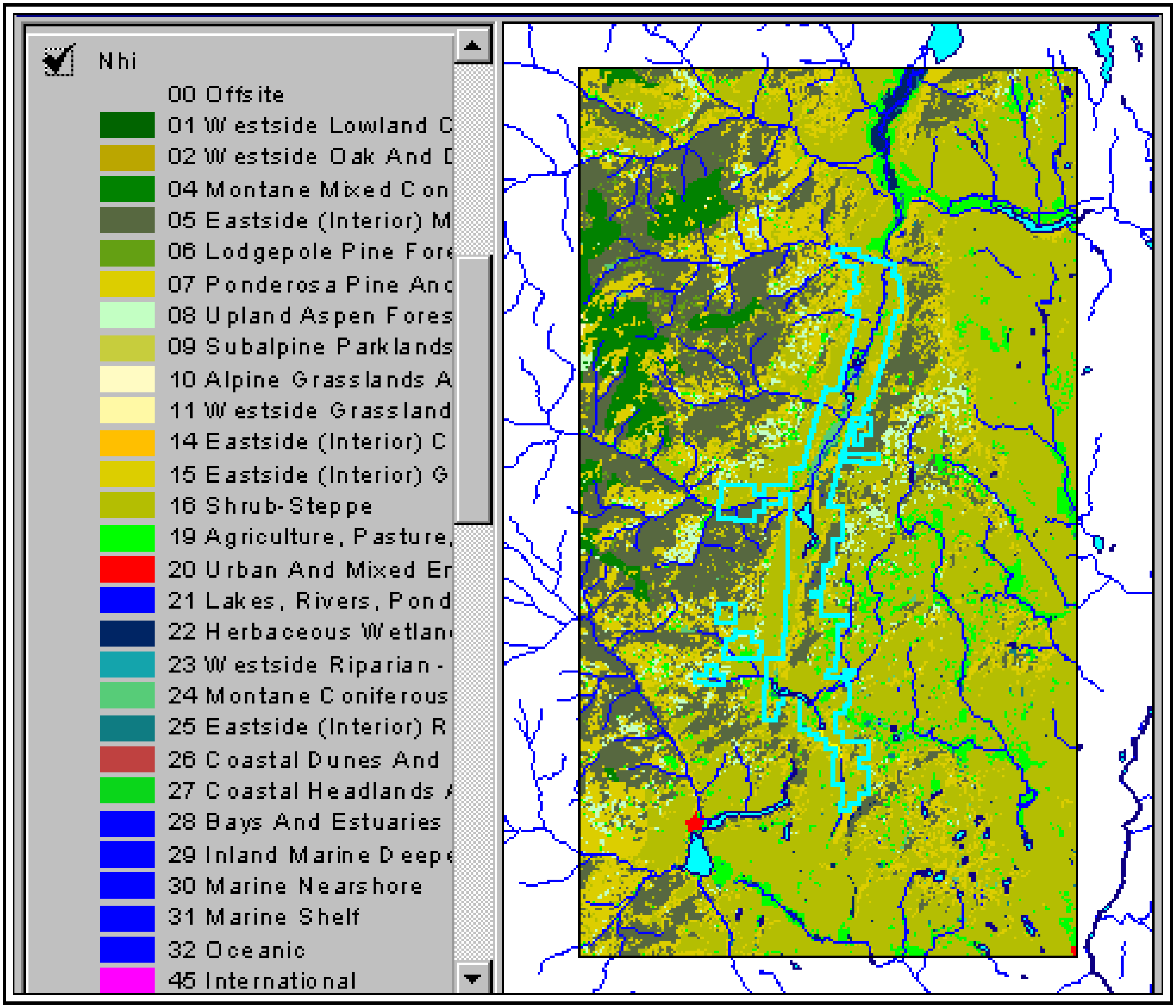


Figure Appendix-A-4. NHI map - Northwest Habitat Institute & Washington Department of Wildlife (WDFW) cover types.

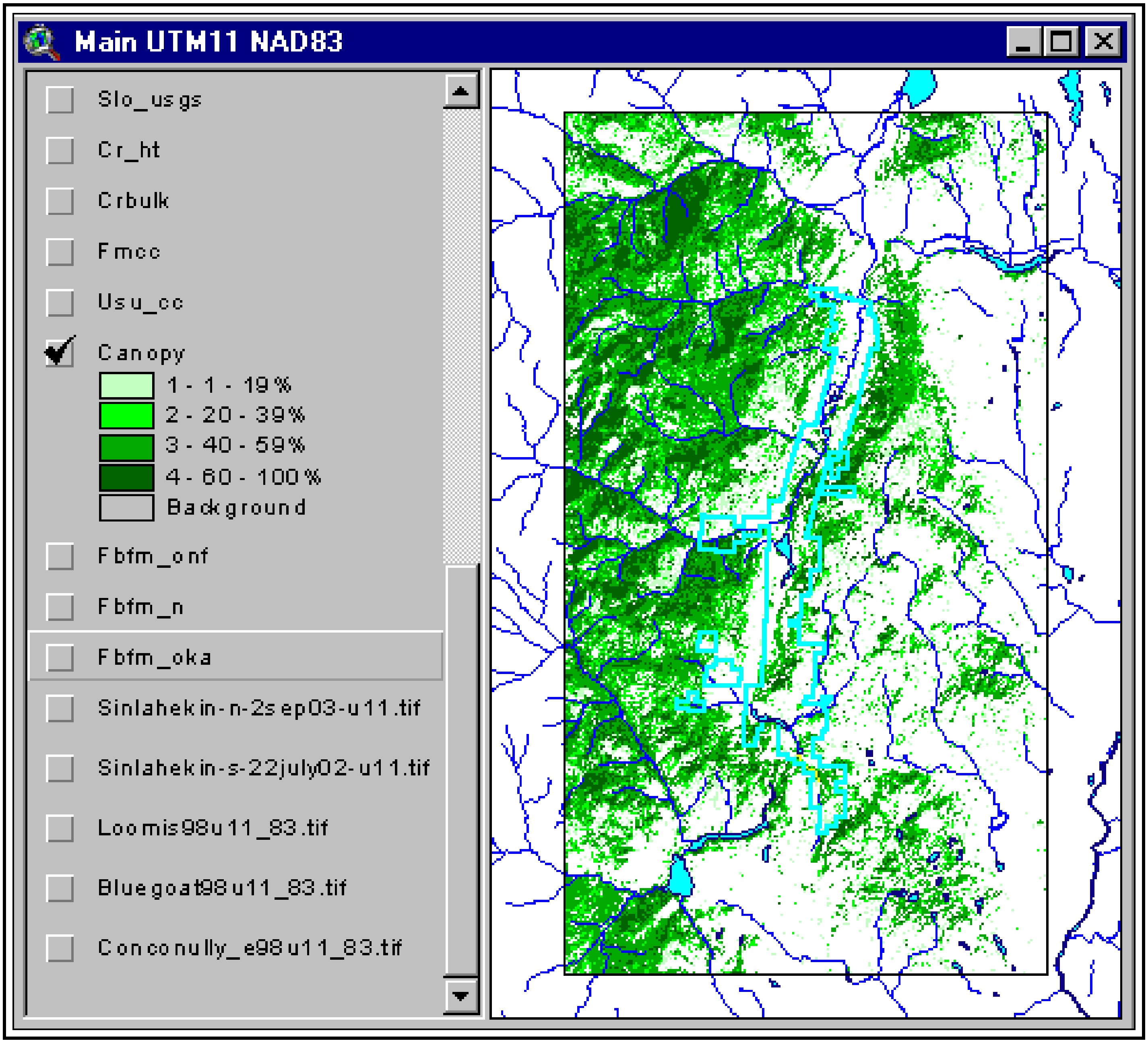


Figure Appendix-A-5. Canopy (usu_cc grid, produced by BioWest and Utah State University, most recent version provided by Okanogan National Forest).

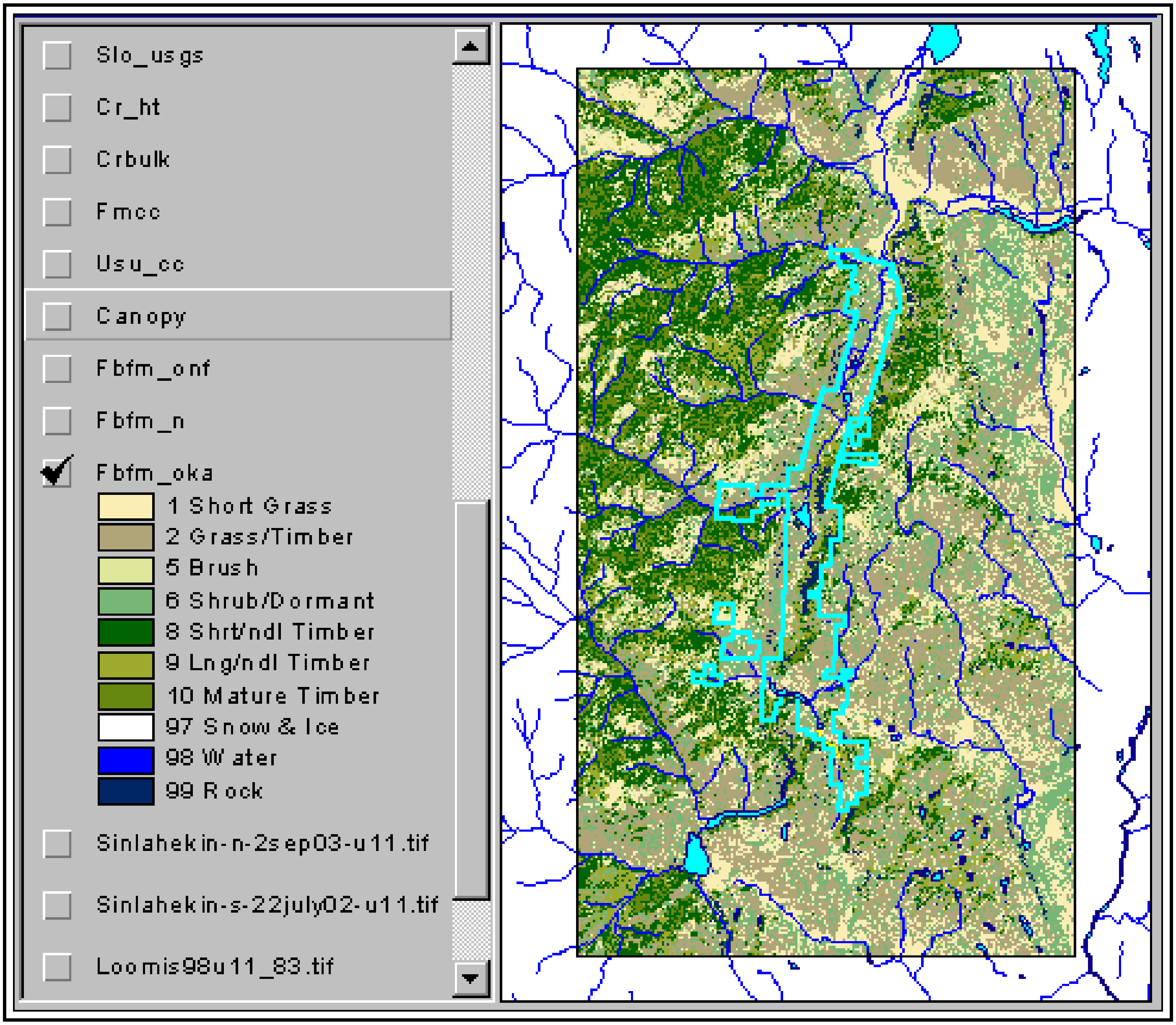


Figure Appendix-A-6. fbfm_oka - fuel model from Utah State and BioWest provided by Okanogan National Forest.

Arcview themes used as extents, clipping polygons and print masks.

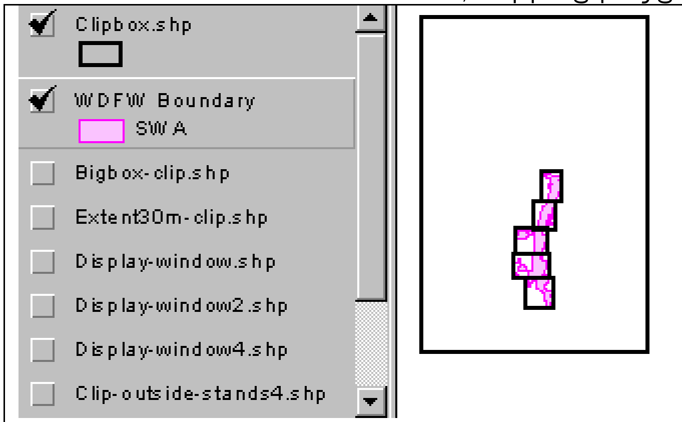


Fig. App-A-7. *Clipbox.shp* extent compared to the SWA boundary.

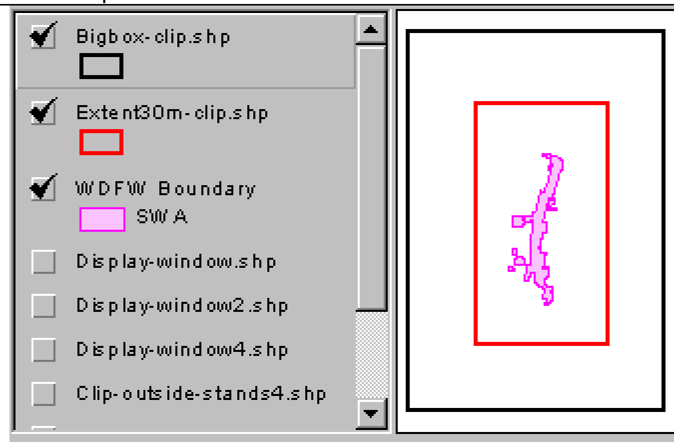


Fig. App-A-8. Extent of *Bigbox-clip.shp* and *Extent30m.shp*, compared to the SWA boundary.

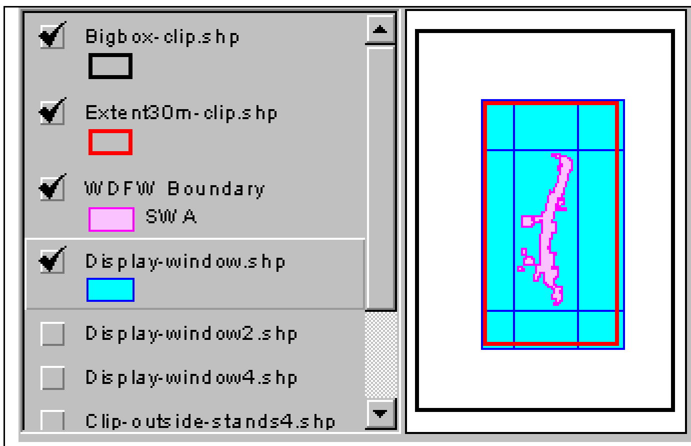


Fig. App-A-9. *Display-window.shp* extent compared to the SWA boundary.

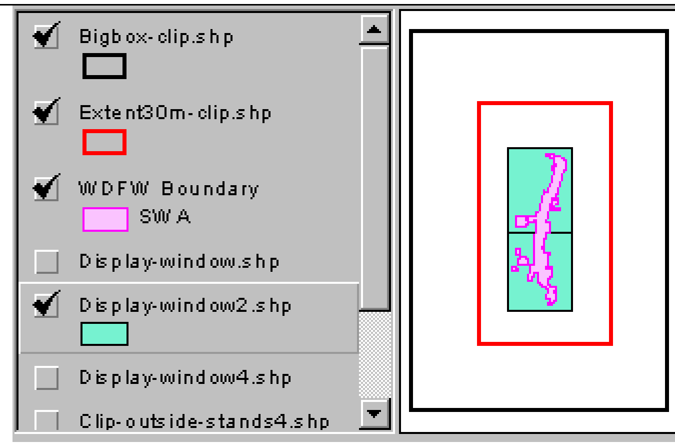


Fig. App-A-10. *Display-window2.shp* extent compared to the SWA boundary.

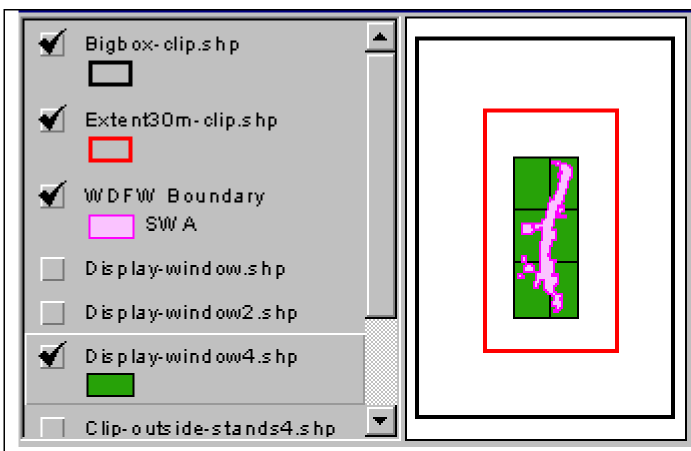


Fig. App-A-11. *Display-window4.shp* extent compared to the SWA boundary.

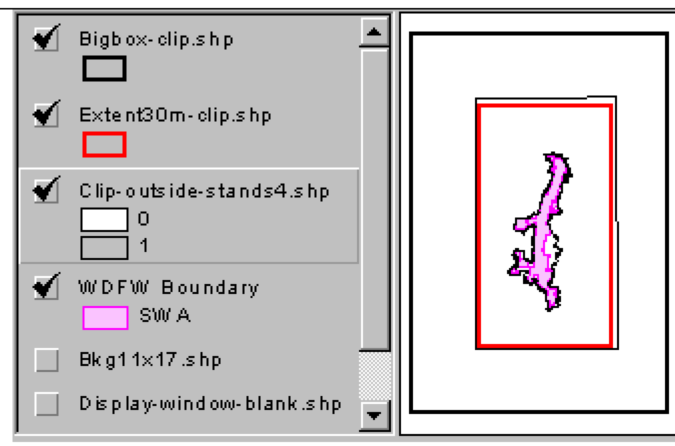


Fig. App-A-12. *Clip-outside-stands4.shp* extent compared to the SWA boundary.

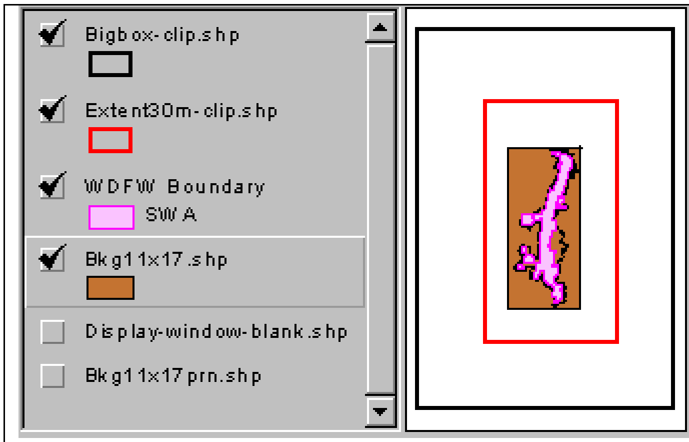


Fig. App-A-13. *Bkg11X17prn.shp* extent compared to the SWA boundary.

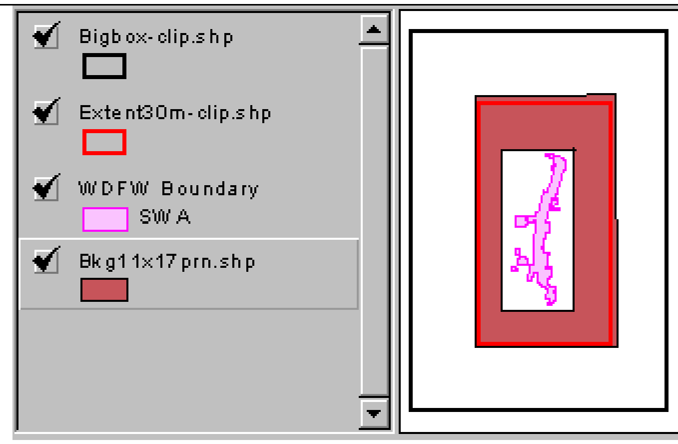
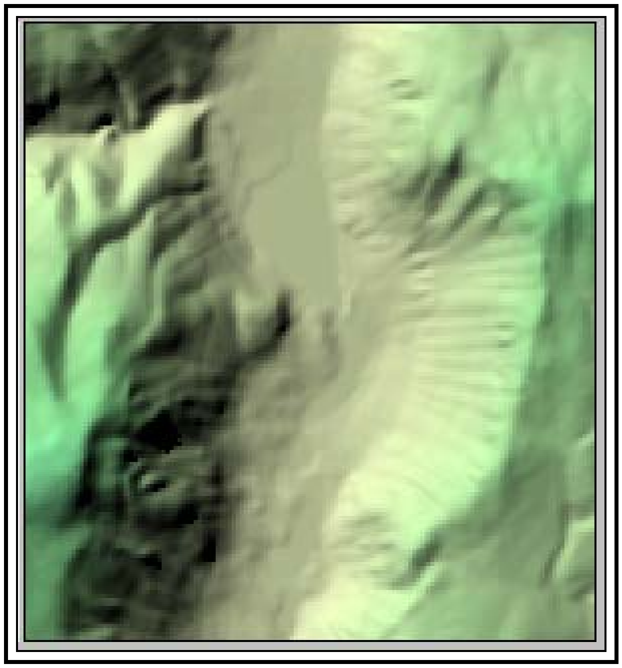


Fig. App-A-14. *Bkg11X17prn.shp* extent compared to the SWA boundary.

Appendix Analysis-B - Digital Elevation Data

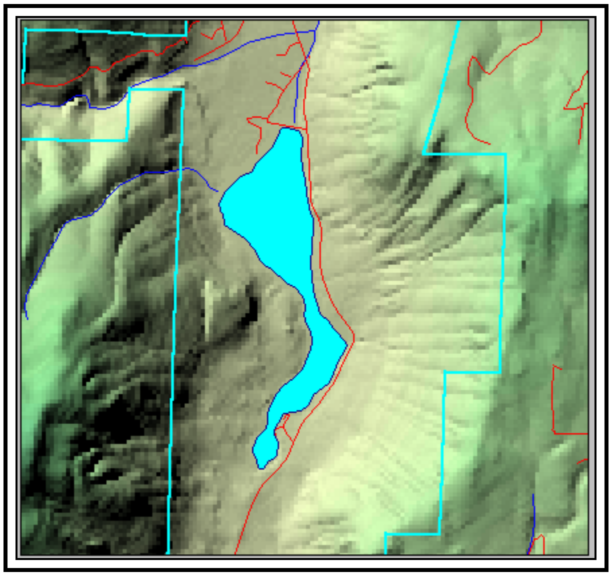
This appendix describes processes used to improve the digital elevation model (DEM) files used in the Sinlahekin Wildlife Area (SWA) fuels analysis project, phase 2, analysis and development of prescriptions.

The resolution of the Geometronics elevation data is shown below for shaded relief.



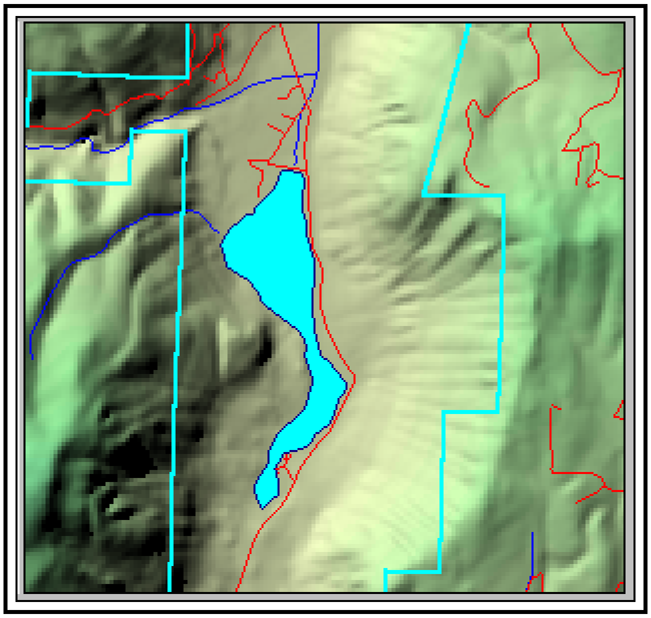
The Geometronics DEM file data was provided as a large file in Washington State Plane coordinates. Processing this file would have required numerous steps, each with a corresponding loss in resolution or accuracy, or creation of artifacts. Therefore elevation files were processed from the USGS digital elevation models (DEMs).

The resolution of the USGS 10 m DEM data for the same area is shown below.



The higher resolution is obvious from this image. But there is a trade-off in using higher-resolution elevation data to generate slope. This involves the creation of stair-stepped cell patterns, where the change in elevation is rapid between adjacent cells, such as those visible in the gullies east of Blue Lake. While this is not a major concern for the use of elevation data in fuel and ecological modeling, per se, it is a problem for slope, in which case steep differences between different pairs of adjacent cells can create incorrect values. A number of methods were tested for smoothing the elevation and slope. From these tests it was determined that slope and aspect would be calculated *after* resampling the elevation from 10m to 30m resolution, as described here and in the methods.

The 30m elevation grid is shown here as a shaded relief using a 30m hillshade calculation for the same area as that shown above.



The contrast pattern indicates that the accuracy and resolution of the USGS data was equivalent to the Geometronics data, and stair-step patterns were smoothed out adequately. The registration was also improved by 3-4 cells accuracy over the Geometronics data (ca. 100 m).

While both data sets originated with the USGS data, the algorithms used by Geometronics could be of wide benefit of to GIS specialists. However, we did not have access to these methods for this project, nor could the Geometronics file be re-projected without unacceptable creation of artifacts. The method described here was judged to be an acceptable workaround for producing slope data from USGS DEMs.

Appendix Analysis-C. Classification of structural canopy cover using patch pattern recognition of gray-scale orthophoto images

Background

A search of online software revealed no commercial pattern recognition programs were available for structural classification of digital orthophotography. Most available procedures for image classification begin with categorization by spectral wavelengths, however the resolution of remotely sensed data is too coarse for this to be applied to canopy structure.

Where high resolution data is available, several techniques are available for structural classification such as gray-level spatial dependency matrices, co-occurrence matrices or sum and difference histograms, however these methods do not account for variation in shape or size of patches, and they are computationally limited by the maximum size of raster convolution windows.

Several texture recognition algorithms exist for applications that exploit the rate of change in luminance as patch edges are crossed. Laws (1980) method (Dutra et al. (2000), has been used by the military for missile guidance systems. It uses a set of energy reduction filters on an image of varying resolution, followed by principal components transformation of the inverse sum of the combined filters for each resolution level and then classification to determine an optimum combination for each pattern. In addition to being computationally complex, this method is not widely available for a diverse set of applications; it would have to be hand-coded, and would require a supervised classification step to determine the optimum combination of filters.

Delibasis et al. (1977) and Undrill et al. (1977) used several advances in pattern detection. They use genetic algorithms to combine Fourier transformations of 32 X 32 pixel image training segments, augmented by energy minimization of boundary edges. This method is ultimately limited by grain resolution and computational requirements.

Fragstats 3.3 (McGarigal and Marks, 1995) gives a large number of patch statistics, but it is dependent on prior determination of the areas of interest from which to analyze patch metrics. Patch Analyst and its grid-based derivative Patch Analyst Grid (Rempel and Carr, 2003) are also predicated on the use of predetermined polygons of interest, with the exception of some relatively straightforward calculations of core/edge ratios.

Thus, the following patch pattern recognition method was developed for the SWA, with the objective of developing a coniferous canopy structural classification. This method is computationally straightforward and does not require a supervised classification step, other than determination of brightness level thresholds for identifying patches. The method uses the metrics of patch regions to determine the boundaries of areas with similar patch dispersion patterns, rather than delineating these regions and then determining their metrics. The process involves a sequence of computational steps to classify each of 6 patch patterns, which can be further combined to yield more complex patterns.

The procedures were tested and developed within the ArcView GIS environment (ESRI, 1998) on a small area of the Sinlahekin Wildlife Area (SWA), and then scaled to cover the entire area. Since the classification accuracy is dependent on the variation of luminance, the three different orthophotos covering the area were merged beforehand so that their contrast could be equalized across decision surfaces. Cover types not contributing to the coniferous canopy structural classification, e.g., deciduous stands, talus slopes, or wetlands, were masked out of the input raster grids before processing. Each of these determinations was done in a stepwise fashion, however an automated procedure could accomplish the same task in a reasonable amount of time.

The files for this analysis were stored in the folder *cd:\fuelgis\arc\analysis\pattern*

Desired Pattern Classification

There are several repeating patterns, or textures, that can be visually recognized in the image below, which was cropped from the digital orthophotography for the Sinlahekin Wildlife Area. The colors are dark where patches of trees and shadows occur and light in open areas. Areas representing stands of trees with similar growth and structural characteristics have been delineated manually within polygons by photo-interpretation. The type of information used by a photo-interpreter to draw these polygons relies heavily on the size and shape of patches and openings, and their distance and evenness of juxtaposition to each other (dispersion and interspersion).

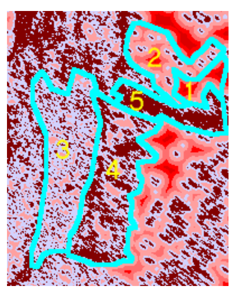


Figure App-C-1. Visible textures in the SWA canopy. The areas were categorized as follows: (1 and 2) near-treeless (shrub-steppe) areas; (3) a matrix of canopy openings and even, thin patches; (4) a matrix of canopy openings and dense patches; (5) large, dense patches.

The following procedures document an automated process for delineating these areas based on the metrics of patch distance and thickness that correlate with the underlying pattern of patches of trees and openings. A key procedure in this method is the use of *regions* of contiguous pixels of identical value, which can be labeled as a group and used for spatial calculations. Unfortunately ArcView is limited in its ability to compute statistics on large regions (referred to as "*zonal focus calculations*") and these limitations required some workaround procedures to overcome these limitations.

This entire procedure was first tested on a smaller area of the SWA of less than 1 square mile that was clipped out of the northern portion of the area. During this exploratory phase of development, several experiments were performed to determine the choice of algorithms. Where referenced in this report, these other experiments are briefly documented at the end of this report.

Create input grids

1a. Convert orthophoto image to grid *grd3*. The trial grid was created by converting the Loomis 1998 1 m resolution tiff USGS 7.5-minute digital orthophoto quadrangle into a grid. For processing the entire SWA, the quads were saved individually as **loom_grd**, **blue_grd** and **conc_grd**.

1b. Reclassifiy *grd3* to 16 classes in grid *grd3roi3*. The 256 brightness values of the input grids were reclassified into 16 equal-interval brightness values (see Experiment No. 1 for an analysis of the choice of classification method).

To lower computational demands required for processing the input grids for the 3 quads surrounding the SWA, the size of the input grids was reduced by clipping them to fit within the boundaries of the cover types delineated for the SWA analysis. The clipping polygon was generated from the map of stands of all cover types that was manually photo-delineated for the SWA, *cov_typ_4.shp*. The Arcview dissolve command was used to dissolve all multi-part polygons of this file to generate a stand map, *cov_dissolve_classes.shp*. The stand map was further dissolved to generate a single polygon covering the entire SWA, *cov_dissolve_all.shp*. The three quad grids were then mosaiced to create a temporary grid, which was then clipped by *cov_dissolve_all.shp*. The clipped grid was saved as *all256*, and then reclassified to 16 colors to create the grid *all16*.

To further improve the process of pattern recognition, the grid was clipped again to extract only features that contributed to the pattern of coniferous tree stands, while removing extraneous features of lakes, wetlands, talus, deciduous stands, developed areas and agricultural areas. The clipping polygon was made from *cov_dissolve_classes.shp* by dissolving together polygons of coniferous and shrub-steppe cover types 5, 109, 110, 130, 160, to create *cov_dissolve_ss&conif.shp*. This polygon was then used to clip the grid *all16* to generate the grid *sstr*.

1c. Region-group grid *sstr* to create determine the cell count of patches. The grid *sstr* was region-grouped orthogonally to yield 161,000 records containing 22,400 regions of the value *Count*. This is a memory intensive operation, requiring several minutes to yield a 30 MB output file from grid *sstr*. These divided into mutually exclusive sets of regions in 2 grids, so that the zonal thickness calculations could be completed on the smaller regions within a reasonable amount of computational time. Grid *grps* was created so that all values of count from 1-2999 were reclassified to a value of 1. Grid *grp3k* was created so that all values of count ≥ 3000 were reclassified to value of 1. After the zonal thickness calculation on grid *grps*, all cells in *grp3k* were reclassified to a value of 19, so that they could be merged without overlap into the zonal thickness grid *zonthk2*.

1d. Create the input grid *val2* for patch thickness calculations. Reclassify grid *sstr* brightness values 1-4 (trees & tree shadows) as value 1 and all other brightness values 5-

16 as “No Data” and name the output grid *val2*.

1.e. Create the input grid *rcl5* for mean neighborhood calculation of canopy openings. Reclassify grid *sstr* brightness values 1-4 (trees & tree shadows) as value 1, and brightness values 5-16 (openings) as value 0. Name the output grid *rcl4*. This reclassification was based on Experiment No. 2 to determine the optimum contrast breakpoint for separation of trees and shadows from background regions (openings).

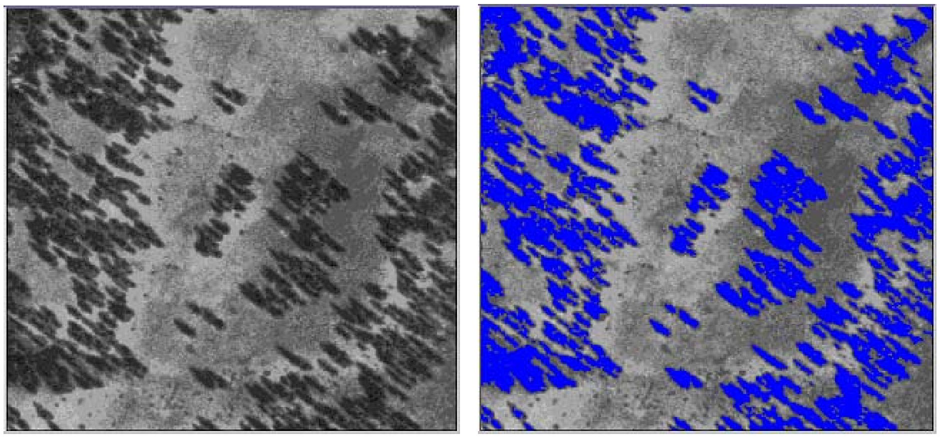


Figure App-C-2a, App-C-2b. The 2-value reclassification is illustrated before (left) and after (right) the reclassification. Openings are transparent so that the gray-scale input grid can be seen in the background.

The oblong shadows of the trees in the left-hand illustration are traced closely when overlain by grid *rcl4*. Misclassified stray pixels are uncommon. In comparison, two other reclassifications in the same region were less satisfactory (see Experiment No. 2, below).

1.f. Create the tree and shadow input grid, *tree3*. Reclassify grid *sstr* brightness values 1-3 (tree shadows) as value 103, brightness value 4 (trees) as value 104, and brightness values 5-15 (canopy openings in a dense patch matrix) as value 0. Name the output grid *tree3*. (See Experiment No. 2 to determine the optimum breakpoint between trees and openings).

Determine near-treeless (shrub-steppe) areas

2. Zone thickness. Grid *grps* was region-grouped orthogonally to create a temporary grid. This grid was used to calculate zonal thickness grid *zonthk* with values 0 to 17. This is a computationally intensive operation that took about 1 hour to finish processing grid *grps*.

The created grid was then reclassified to create a grid in which *No Data* values became 0 (openings) and all other cell values were incremented by one. This grid was then merged as the second grid with a reclassified version of grid *grd3k* in which all cell values equaled 19, to represent the largest regions. The output grid was named *zonthk2*, and had value 0 representing open areas, values 1-18 representing the regions of thickness of grid *grps*, and value 19 representing the large regions with count ≥ 3000 from grid *grp3k*. In order to reduce the size of the grid by reclassifying values of 0 lying outside the original extent of the analysis areas as *No Data*, the grid *zonthk2* was clipped by the original input grid *sstr*, using the script *grid-clip-by-grid.ave* to create grid *zonthk2b*.

The region thickness calculation (referred to in the *Grid Enhancement Tools* extension as *zonal focus thickness*) was the best of several different zonal calculations tested for determining the "density" of stands of trees. Cell counts have the disadvantage that large, linear stands that are similar in crown characteristics to single-tree stands become classified along with large, dense stands. On the other hand, the calculation of cell counts takes much less time. The choice of 3000 cells as the breakpoint for segregating regions into a separate grid *grp3k* was chosen to balance between the smallest count that would still reduce the thickness calculation times for the largest patches and the largest count that would permit stand densities to be calculated by thickness, rather than cell counts.

3.a. Calculate distance from openings. A distance grid was created from non-zero value cells in *zonthk2b* by opening its table and selecting all of the non-zero records, then running *Analysis - Find Distance* (Fig. App-C-3). A distance of 0 signifies areas with tree cover.

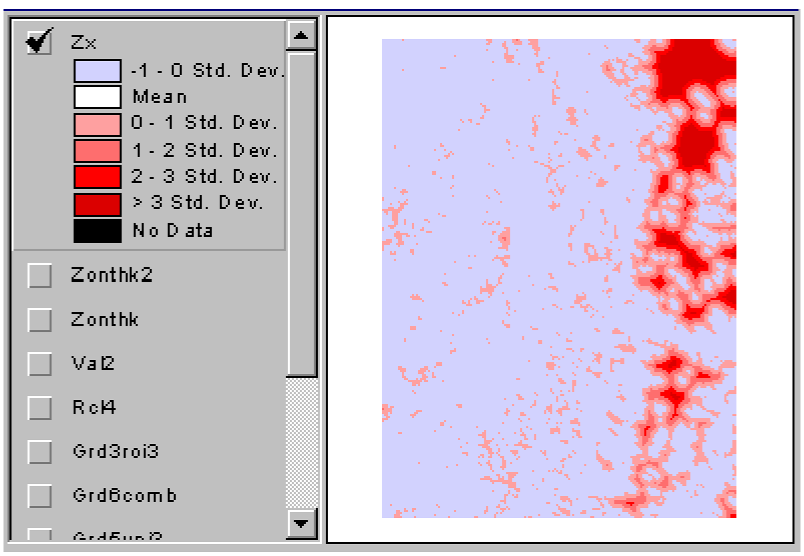


Figure App-C-3. Distance grid.

Fig. App-C-4 shows the treed areas overlaid onto the distance interval.

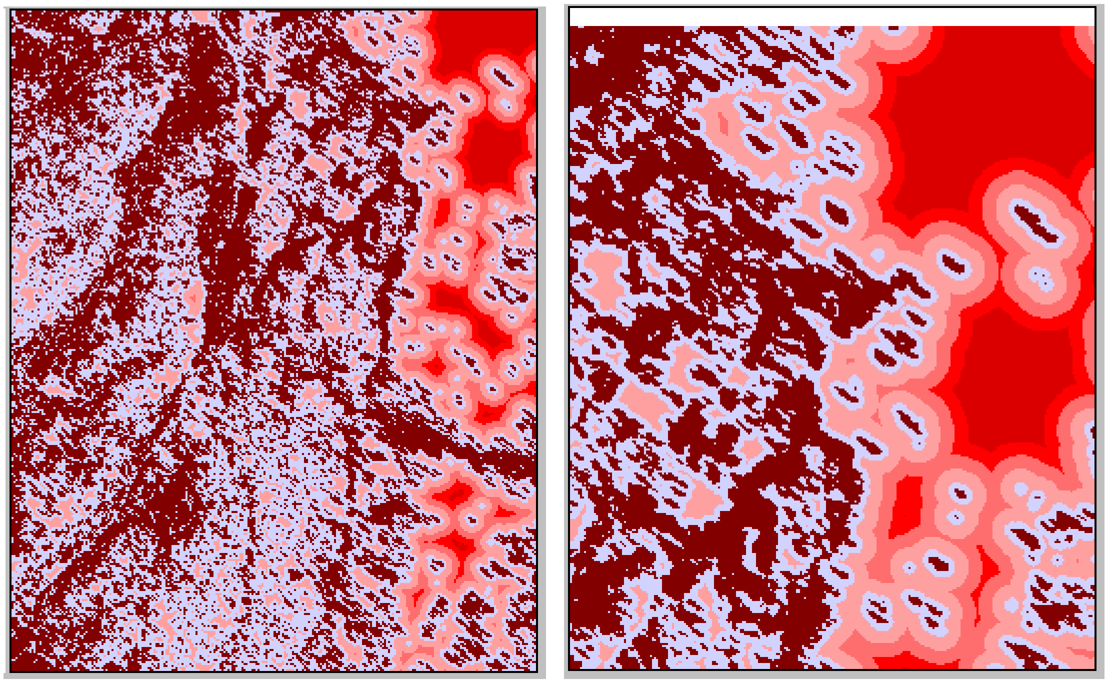


Figure App-C-4. Treed areas overlaid in brown onto the distance intervals in red. The image on the right is zoomed in to see the resolution at the level of individual trees.

3.b. Shrink open areas by 10 meters. Experiment No. 3 was performed to determine whether a classification of open areas into small and large regions of cells should be weighted against linear open areas versus more rounded openings. The test was made by shrinking the open areas once or twice and determining the breakpoint separating large and small areas. From the experiment, it was determined that a 10-cell shrinking operation on open regions would improve the classification by rejecting linear openings. Tests of the Arcview shrink command revealed it produced blocky orthogonal patterns in shrinking operations > 3 cells, therefore shrinking was performed using a distance calculation instead. A boundary shrinking operation was performed by reclassifying grid *zx* with an equal interval classification into 2 integer intervals. Values 0-9.999 were reclassified as *No Data*; values >10 were reclassified as 1. The resultant grid zxint1 has all cells of value 1 representing areas >10 m from tree patches.

3.c. Region-group to select largest open areas. Region Group grid *zxint1* orthogonally to create grid *zxint2*. Sort *zxint2* by count and select the largest regions (>=10,000 cells) and use this selection to create new grid *zx10*.

3.d. Calculate distance from outer boundary and expand perimeter by 12 meters. Create a distance grid from *zx10* by running *Analysis - Find Distance*. Expand the perimeter of *zx10* by 12 meters. This amount of region expansion was larger by 2 cells than the previous shrinking operation in order to erase any slivers, while at the same time avoiding extending the region into narrow peninsulas. To expand *zx10*, reclassify values 0-12 as 1 and all other values >12.0001 as *No Data*, and name this output grid *zxrest*. This grid represents the determination of area 1, near-treeless shrub-steppe (Fig. App-C-5).

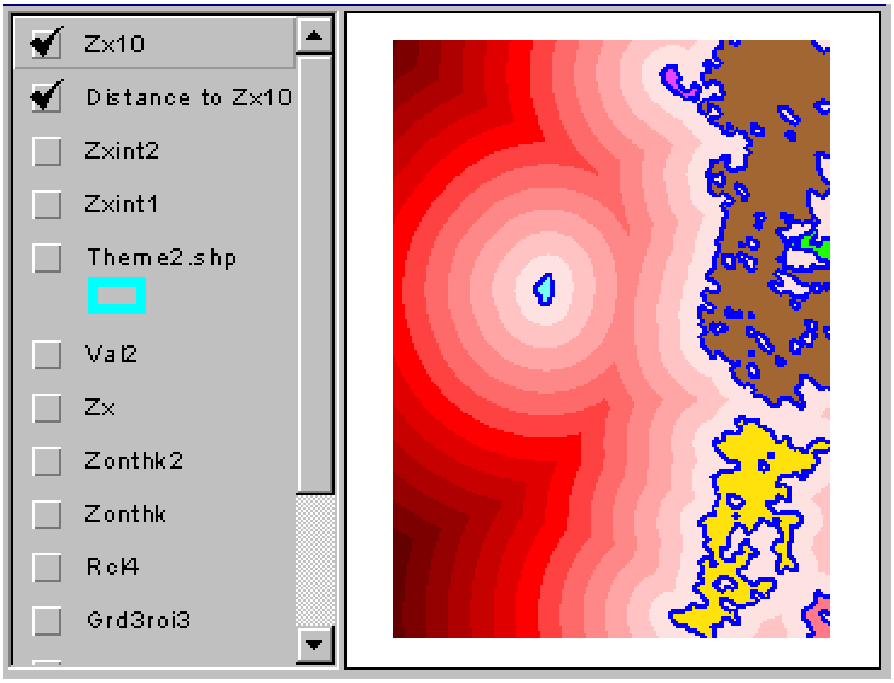


Figure App-C-5. Boundary cells which were added back to regions in *zx10* are shown in blue.

Delineate canopy openings adjacent to even, thin patches

To determine the boundaries of area number 3, representing a matrix of canopy openings and even, thin patches, required recognition of several patterns: thin patches with even spacing in the canopy openings. A number of procedures were tested for their ability to recognize this combination of criteria.

Patch analysis using the Patch Analysis Extension (Rempel and Carr, 2003) was performed on the grid *val2* to determine its utility for pattern analysis. The calculations were individually calculated within hexagonal grid areas. While the calculated metrics were useful, the grouping by hexagonal regions was unable to capture the spatial variation of linear patches. Therefore the Patch Analysis extension was not further used. See Experiment No. 4, for a description of Patch Analysis.

The concept for determination of the boundaries of canopy openings adjacent to even, thin patches, is described below. The algorithm was modeled after the manual photo-interpretion used to delineate the training polygons (Fig. App-C-6). To separate the 2 lower polygons required an algorithm able to simultaneously discriminate patch thickness and evenness of inter-patch distances, as shown in Fig. App-C-6 below.

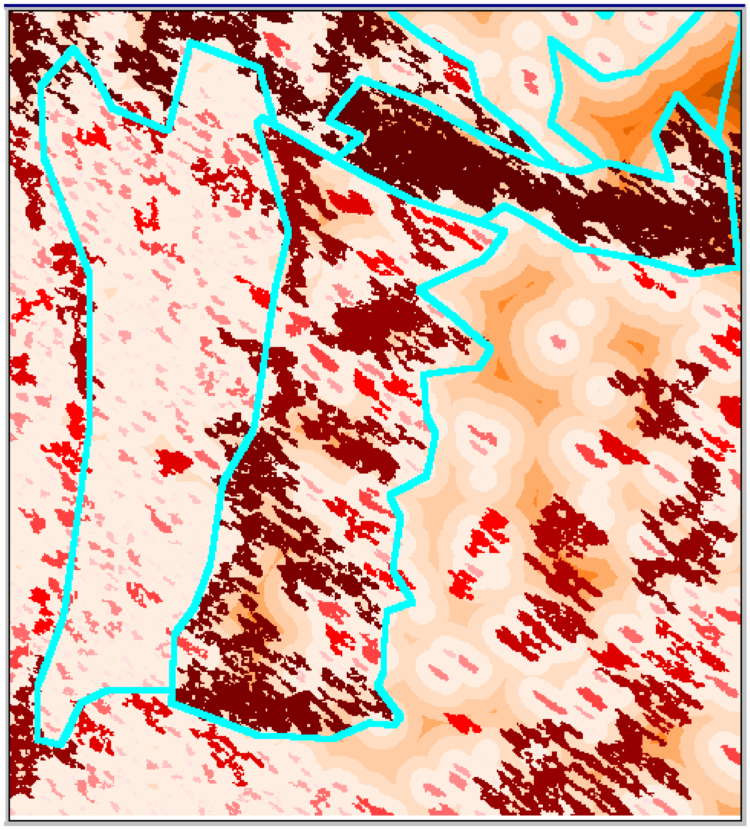


Figure App-C-6. Training polygons showing separation of regions by patch thickness and evenness of inter-patch distance. The left-hand polygon has smaller, more evenly spaced patches, and the right-hand polygon has larger patches, separated by openings of variable size.

The method chosen for the delineation of the matrix of canopy openings and even, thin patches consisted of classification of the patches by thickness, and classification of the evenness by ANDing (Unioning) the between-patch distance with a 7m neighborhood mean of canopy openings.

4.a. Neighborhood mean of canopy openings. From grid *rcl4*, representing trees and shadows as value 1 (brightness values 1-4), a *Neighborhood Analysis Mean* was calculated using a circle of radius 7 to generate a new grid that was then reclassified so that values of 0.5600 - 1.0 became *No Data* (trees) and values of 0-0.5599 became 1 (canopy openings). The result was named *rcl5*.

4.b. Reclassify even, thin patches (1-6 m thickness). The thickness grid *zonthk2b* was reclassified so that cell values of 0 and 7-19 became 0 and values 1-6 (thin patches) became 1. This grid was named *zonthk3*.

4.c. Calculate distances from even-thin patches. The reclassified grid of even, thin patches, *zonthk3*, was used to create a distance grid. The distance grid was reduced in size by clipping to the original input grid *sstr*, using the script *grid-clip-by-grid.ave*.

After experimenting with several reclassifications (see below), the distance grid was reclassified, and the output named *zondx2*. Values of 0-10 were reclassified as 3 (canopy openings) and values >10.00001 became *No Data*. The distance grid *zonthk3* is illustrated in Fig. App-C-7 below.

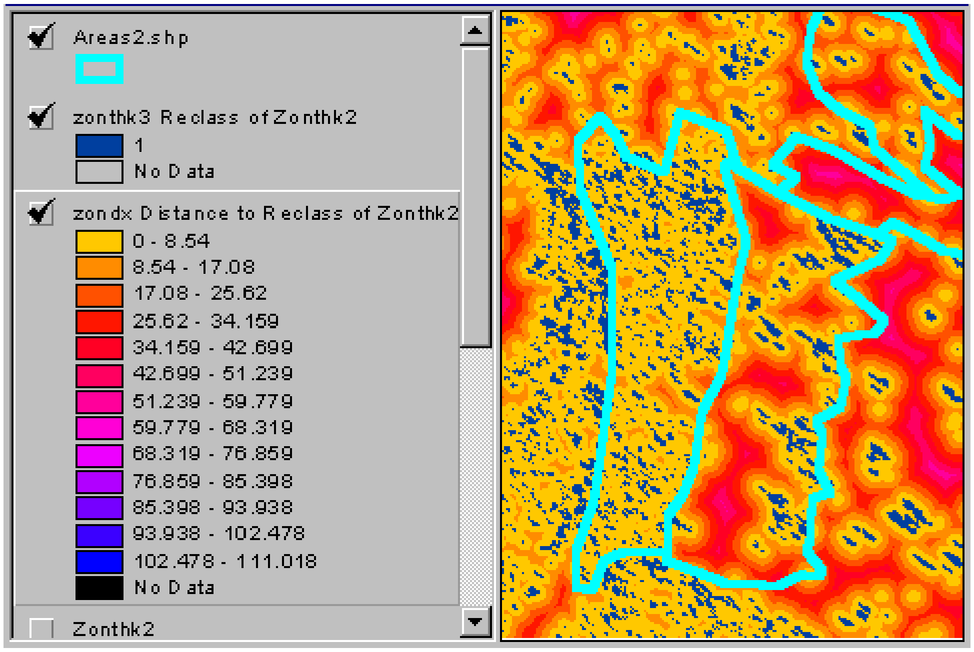


Figure App-C-7. The distance grid *zonthk3* is shown with training polygons in light blue, 1-6 m patches overlaid in dark blue, and distance from the 1-6m patches shown in an orange-to-red color ramp.

The overall pattern can now be described as large patches of trees surrounded by large open areas, and smaller patches of trees separated by small, relatively constant distances. The pattern recognition process should be able to generate a set of polygons that approximately follow the hand-drawn boundary of the hand-drawn blue polygons (Fig. App-C-8).

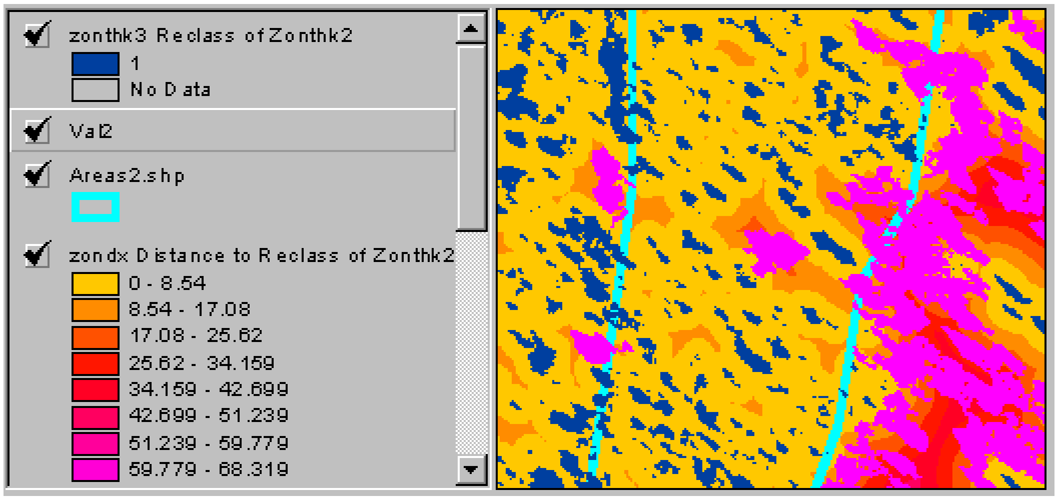


Figure App-C-8. Details showing the ability of the patch-pattern recognition process to approximately follow the blue training polygons, or even improve it by following the outlines of lacunae (peninsula of red coming into the center-right edge of the left blue polygon).

4.d. Union the neighborhood mean of canopy openings with the inter-patch distance of canopy openings. A new grid was created using map calculator in which the new cells had a value of 1 if the cell values in the input grids *zondx2* and *rcl5* were both 3. The union was used to strengthen the confidence in the delineation of canopy openings by requiring agreement between 2 different methods of determining openings in the thin, even patch matrix. Of the two methods, the neighborhood mean was probably the most accurate calculation, but also appeared to have more false positives. The distance grid had more false negatives resulting from misclassification of even, thin patches, but it did not have many false positives, since it was not a smoothed function. The resulting grid was region-grouped, and the largest regions selected (> 6000 cells, 551 of 11,824 classes) and used to create a final grid *zx3*, representing canopy openings adjacent to even, thin patches as value 3.

Merge all grids and finish the delineation of canopy openings and dense patches

5.a. Classify isolated trees ≥ 3 m thickness separately from even, thin trees. Select cells of *zonthk2b* ≥ 3 m thickness, and from this create a new grid, *rclss2*, in which the selected values are 101 and all other values (1-2) are *No data*. Use the script *grid-clipbygrid.ave* to clip the cells in this grid to the non-zero values of *zonthk3*, then merge the clipped grid as the first grid with *zonthk3*. Reclassify the values of this merged grid to match that of the two input grids (value 101 = patches ≥ 3m thick, value 102 = patches 1-2m thick, and all other values as *No Data*). Name this grid *zx102*.

5.a. Merge even thin patches, near-treeless regions and canopy openings and prepare mask. Prior to merging the grids, the cell values of the input files were classified as follows *zx102* cells were classed as value 101 (isolated trees) or 102 (even, thin patches); *zxrest* cells were classed as value 0 (near-treeless areas), and *zx3* cells were classed as value 3 (canopy openings).

These three grids were merged sequentially, to assign cell priority to the first grid in each merge operation. The merge sequence followed was to merge *zx102* with *zxrest*, and then to merge the result with *zx3*. This grid is named as *open4*. Grid *open4* was merged as the first grid with grid *tree3*. This final grid was named *treeopen*. The appearance of the final grid is shown in Fig. App-C-9.

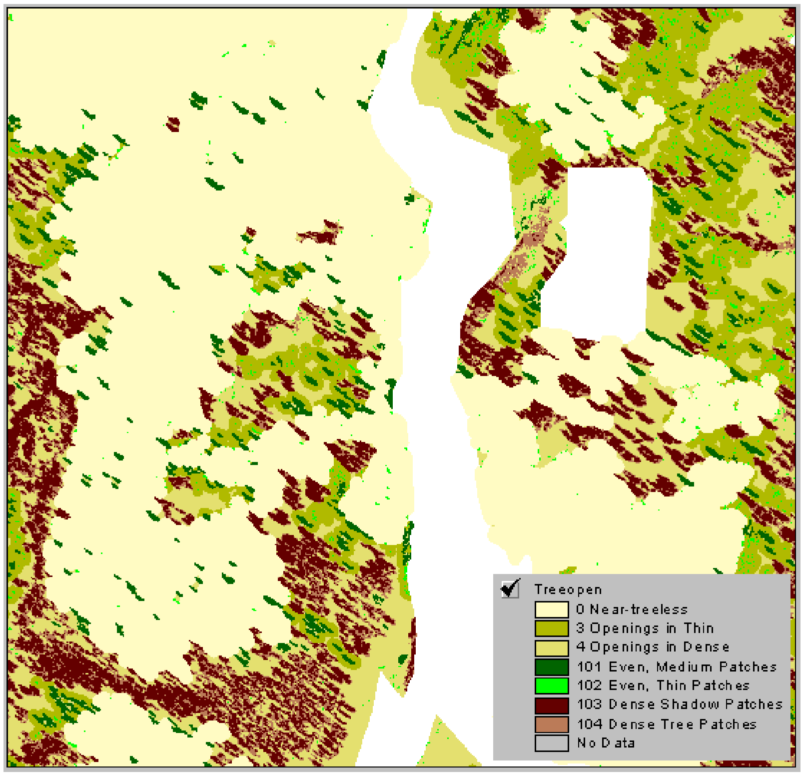


Figure App-C-9. Grid treeopen.

Use of the patch classification to develop a map of canopy structure

The goal of patch pattern recognition was to develop a patch classification that could be used to develop an accurate map of canopy structure.

The underlying assumption was that canopy structure could be modeled based on the characteristics of the patches and openings. To make this model work, it was necessary to add the attributes of other layers such as adjacent openings, aspect and slope as attributes of the patches themselves, or as attributes of polygons enclosing areas of patches of a similar type.

6.a. Add attributes to the manually digitized map of cover types. Use the *Shape Enhancement Tools - ID Number* command to add a field RecNo and assign unique numbers to the 730 stands in the SWA, containing 13 cover types.

6.b. Use *CRWR Raster* to calculate the mode of the type of opening (0 = near-treeless, 3 = canopy openings in even, thin matrix, 4 = canopy openings in dense matrix) from grid *treeopen* and add that value into the Open_type field of the polygon theme *cov_typ4d.shp*.

6.c. Create a new grid, *open_typ*, from shapefile *cov_typ4d.shp*, field *Open_type* with the analysis extent set the same as grid *treeopen* and the cell size set at 1m.

6.d. Combine grid *treeopen* tree types with grid *open_typ*, to generate a grid which depicts the combination of tree type with the mode of the adjacent type of opening associated with the canopy type. Grid *treeopen* tree types were reclassified as a temporary grid in order to omit the types of openings before performing the combine operation. Name the output grid *tr_op*. The following combinations are present:

Tree class from treeopen	**Opening type from open_typ**
101 (even, medium patches)	0 (near-treeless areas)
101 (even, medium patches)	3 (canopy openings in even, thin patch matrix)
101 (even, medium patches)	4 (canopy openings in dense matrix)
102 (even, thin patches)	0 (near-treeless areas)
102 (even, thin patches)	3 (canopy openings in even, thin patch matrix)
102 (even, thin patches)	4 (canopy openings in dense matrix)
103 (dense shadow patches)	0 (near-treeless areas)
103 (dense shadow patches)	3 (canopy openings in even, thin patch matrix)
103 (dense shadow patches)	4 (canopy openings in dense matrix)
104 (dense tree patches)	0 (near-treeless areas)
104 (dense tree patches)	3 (canopy openings in even, thin patch matrix)
104 (dense tree patches)	4 (canopy openings in dense matrix)

6.e. Combine grid *tr_op* with the 30m grid *asp_slo*, to create the grid *shd_fact*, with categories of aspect coded in the field *shade_fact* to represent the percent of cells covered by just the horizontal projection of an average single mature tree out of the sum of the number of cells of shadow and tree at that aspect. The aspect categories are as follows:

asp_slo	**aspect category**	**slope category**	**Shade_fact**
1	1-8 (N, 338-22 deg)	1 (0-10 deg)	35
21	1 (N, 338-22 deg)	2 (11-30 deg)	60
22	2 (NE, 23-67 deg)	"	45
23	3 (E, 68-112 deg)	"	27
24	4 (SE, 113-157 deg)	"	25
25	5 (S, 158-202 deg)	"	27
26	6 (SW, 203-247 deg)	"	45
27	7 (W, 248-292 deg)	"	60
28	8 (NW, 293-337 deg)	"	65
31	1 (N, 338-22 deg)	3-4 (31-63 deg)	60
32	2 (NE, 23-67 deg)	"	35
33	3 (E, 68-112 deg)	"	25
34	4 (SE, 113-157 deg)	"	20
35	5 (S, 158-202 deg)	"	25
36	6 (SW, 203-247 deg)	"	35
37	7 (W, 248-292 deg)	"	60
38	8 (NW, 293-337 deg)	"	70

6.f. From table view, permanently join all fields in *tr_op* and *asp_slo* that were deleted during the combine command. Edit the table to add a field *tree_fact*, that will be added to the field *shade_fact* as a modifier of the factor based on the types of trees. The values and rationale used for the field *tree_fact* are as follows:

Values of *tree_typ* of 101 (dense tree patches) that are in (*open_typ*) opening type 0 (near-treeless) or opening type 3 (thin) openings will have a value of *tree_fact* of 0. The rationale is that this is the actual tree, not the shadow, and no correction factor to the shade factor, *shade_fact*, should be applied.

Values of *tree_typ* of 101 (dense tree patches) that are in opening type (*open_typ*) 4 (dense matrix) will have a value of *tree_fact* that when added to *shade_fact* will halve the remainder (inverse addition). The rationale is that these are patches of medium-sized trees on the edges of small stands that have about half overlap with adjacent trees, that should not be counted as shadow.
These values are given in the following table:

shade_fact	**tree_fact**
20	40
24,25	37
27	36
30	35
35	32
45	22
60	20
65	17
70	15

All values of *tree_typ* of 102 (even thin, patches) were given a value of *tree_fact* that when added to *shade_fact* equals 50%. The rationale is that most of the thin patches are mixed shrubs and trees less than 10m (33 feet) tall, that do not cast a long shadow, nor comprise more than 50% of the cells indicating it is a canopy type.

Values of *tree_typ* of 103 (dense shadow patches) will have a value of *tree_fact* that when added to *shade_fact* will equal 95 if *shade_fact* > 50 and will equal 90 if *shade_fact* is < 50.

All values of *tree_typ* of 104 (dense tree patches) will have a value of *tree_fact* that when added to *shade_fact* equals 100. The rationale is that this is the actual tree, not the shadow, and no correction factor should be applied at all. Round all values of *sumshd* to the nearest multiple of 5.

6.g. Tabulate areas by rows of polygons of *cov_typ4d.shp*, field *RecNo*. and columns of grid *shd_fact*, field *sumshd*. Link the answer to table cov_typ4d.shp and export to an excel spreadsheet.

6.h. Within Excel, add the different fields representing different canopy characteristics together in the field *TotCanopy* with the following formula:
=.2*F3 +.25*G3 +.3*H3 +.35*I3 +.45*J3 +.5*K3 +.6*L3 +.65*M3 +.7*N3 +.8*O3 +.85*P3 +.9*Q3 +.95*R3 +S3

6.i. Calculate field *PctCan* as the percent of the total canopy out of the number of sq m in the polygon. Add this table back into Arcview and permanently join it to *cov_typ4e.shp*.

6.j. In table *cov_typ4e.shp*, fill the field *CC* with the value of *PctCan*, and edit this field wherever the value is outside the range of *cov_typ* values 110 (10-30%), 130 (30-60%), or 160 (> 60%), using the best estimated new value. Also edit CC wherever the value of the field *cov_typ* = 5 (shrub-steppe) or *cov_typ* = 109 (riparian conifer) and note all errors to correct in the next run as follows:

Stand RecNo	**Note**
639	looks like aspen
637	lots of shrub? w/ 20% conif
497	very small polygon
322	shrubland
316	stand deleted - it overlapped stand 400
730	riparian conifer may be marsh/swamp
594	riparian conifer break into left and right halves
689	riparian conifer - check whether to break - right arm may be marsh/swamp
534	needs to be split
664	needs to be split
694	split >60% conif from <60%
372	split >60% conif from <60%

Overall, the method was most useful for improving *cov_type* value 130, in which a number of the calculated values of coniferous canopy cover in *CC* were considered more correct.

6.k. Query cov_typ4e.shp to select polygons of coniferous and shrub-steppe cover types 5, 109, 110, 130, 160, and from the selection create a new grid, *cc_cov*, which is registered to the *base30* grid. Save the file as *cd:\fuelgis\1183\cov\grd30\cov_grd\cc_cov*.

Summary of the final steps in the creation of *cc_cov*: The creation of c*c_cov* began with *shd_fact*, by tabulating the summed correction factors for shading in field *sum_shd* into *cov_typ4e.shp*, exporting this to an Excel Spreadsheet, and summing all the grids to obtain a total calculated value for coniferous tree cover which is specified as the percentage of the total area in field *PctCan*. *PctCan* was copied into field *CC*, and edited where it did not agree with field *cov_typ*. The records for cover types 5, 109, 110, 130, 160, were then selected and used to create the grid *cc_cov*. In subsequent analyses for cover type determination, cc_cov was resampled to 30m and registered to the *base30* grid.

Results

A canopy cover map, *cc_cov*, was developed that models percent coniferous canopy cover within contiguous regions of 30m cells. The regions were comprised of stands delineated manually by photo-interpretation and having the same canopy cover and structure within the stand.

The height criteria for definition of tree cover in the *cc_cov* layer is still undetermined, however, the smallest patches sampled were 1-2m thick. From field studies in the area, the minimum height of this crown diameter class is about twice this height, or 2-4 m). However in order to produce enough shadow for the such thin patches to meet the brightness criteria for trees and shadows, it is likely that the mean height is at the higher end of this range, nominally 6m. The maximum height is related to the growth form of this size class, which for this area is < 10m. This height of tree was used as the definition of "overstory" trees in the SWA fuel mapping project.

Two correction factors were used to calculate the conifer density, one for the combined slope and aspect and one for the combined crown diameter-opening type. Although the slope and aspect correction factors were estimated for this project, this factor can be accurately calculated once the sun angle causing the tree shadows is determined from field surveys. Estimates of slope and aspect correction were made by assigning ratios of cells contained within the crown diameter circle to those lying on the shadowed side of the tree.

The crown diameter-opening type factor was a number which when inversely summed with the shade factor would produce a single correction factor which could be calculated using Arcview map calculator. The inversely summed correction factors were assigned as follows: dense tree patches were uncorrected (100%), dense tree patches adjacent to openings halved the original shade factor, even thin patches became 50%, dense shadow patches with a shade factor > 50% became 95% and dense shadow patches with a shade factor < 50% became 50%.

Estimates of error in determining the dense tree patches on slopes facing the sun are likely low, < 10%; all other areas are estimated to be < 30%. For the purposes of this project, shrub-steppe with scattered tree patches (which comprised half of the area) was defined to have less than 20% trees, so most of these cells would be correctly classified anyway as non-coniferous. The even, thin canopied areas and the dense areas near openings are estimated to have the greatest magnitude of overall error, ca. "20%. The overall error could be reduced to less than ca. 10% in all but the even-thin patches by accurately determining the combined slope and aspect correction factor with field work.

The new map of canopy cover, cc_cov, was compared with existing maps of canopy cover.

The calculated map of canopy cover, *cc_cov*, was compared with the *nlcd* grid of canopy cover, class 42, evergreen trees over 6m height > 25% cover. The count of coincident cells in *cc_cov* having values greater or equal to 25% was 26,282 out of 31,165 that overlapped. The count of coincident cells with values in *cc_cov* < 25 was 4,883. If the patch pattern analysis were 100% accurate, and the canopy heights are comparable, then this would indicate that the NLCD maps of type 42 evergreen cover, are about 16% misclassified.

The calculated map of canopy cover, *cc_cov*, was compared with the *usu_cc* grid of canopy cover produced by Okanogan National Forest from BioWest / Utah State University. When *cc_cov* was reclassified using similar intervals of 1-19%, 20-39%, 40-59%, and 60-100%, the coincidence of percent canopy cover could be compared (Fig. App-C-10; see Appendix D for the method of determining grid coincidence).

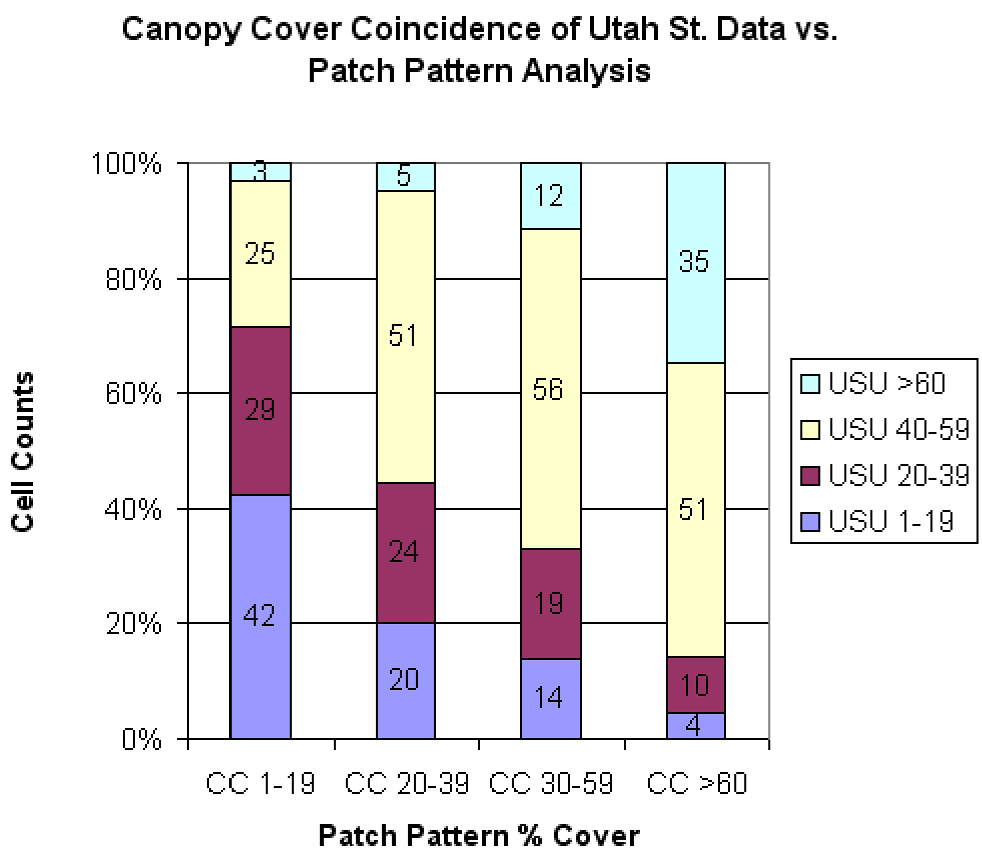


Figure App-C-10. The coincidence of percent canopy cover determined from patch-pattern recognition with that determined from the BioWest/Utah State University data is shown in the following chart.

The calculated map of canopy cover, *cc_cov*, was compared with the *canopy* grid of canopy cover developed by BioWest from a 25 m 1997 Landsat TM scene (REO, 2000), and containing 5 classes of canopy cover (1-19%, 20-39%, 40-59%, 60-100%, and background). When *cc_cov* was reclassified using the same intervals, the coincidence could be compared (Fig. App-C-11).

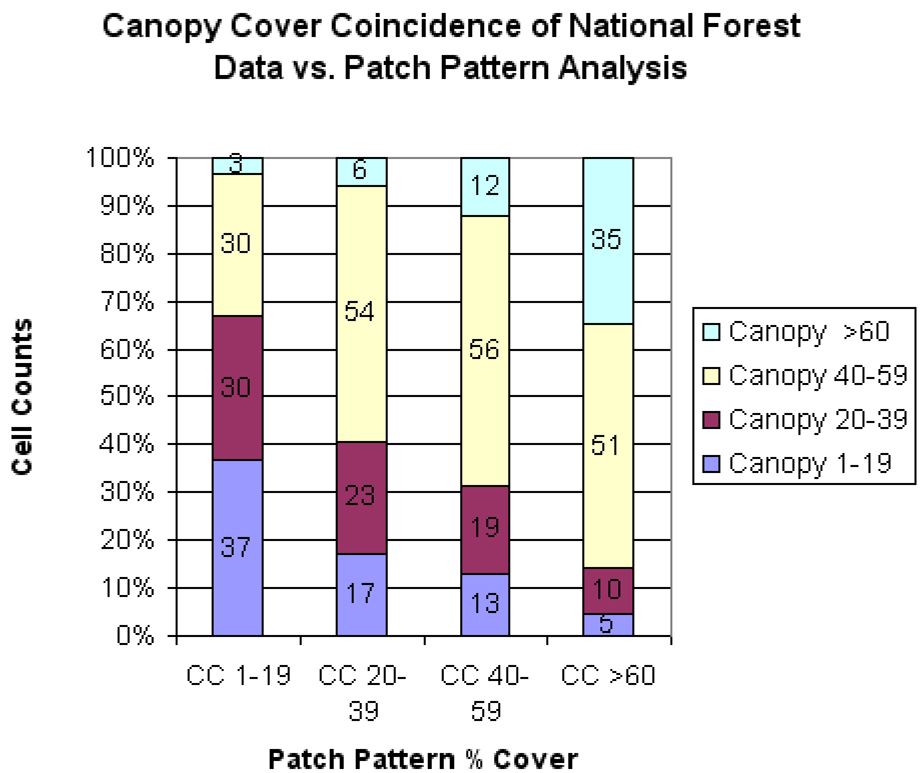


Figure App-C-11. The coincidence of percent canopy cover determined from patch-pattern recognition with that determined by BioWest from a 25 m 1997 Landsat TM scene (REO, 2000).

The calculated map of canopy cover, *cc_cov*, was compared with the *NCGBE* grid of canopy cover produced by the North Cascades Grizzly Bear Ecosystem Evaluation Project on the Okanogan National Forest, and containing 4 classes of canopy cover (1-29%, 30-49%, 50-69%, 70-100%), using the same classification intervals (Fig. App-C-11).

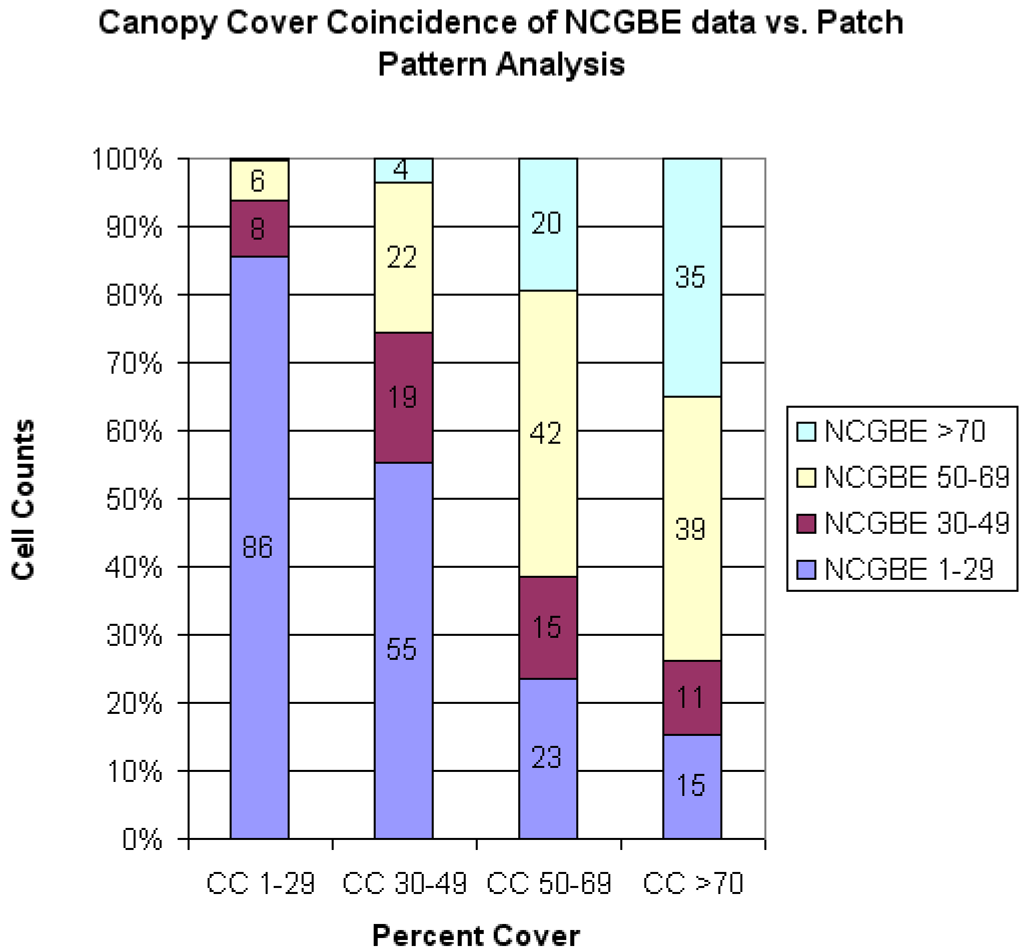


Figure App-C-11. The coincidence of percent canopy cover determined from patch-pattern recognition with that determined by the *NCGBE* grid of canopy cover produced by the North Cascades Grizzly Bear Ecosystem Evaluation Project on the Okanogan National Forest, and containing 4 classes of canopy cover (1-29%, 30-49%, 50-69%, 70-100%).

The calculated map of canopy cover, *cc_cov*, was compared with the NLCD data cover type 42, evergreen forest (75% of area covered with conifers > 6m tall). The height of the cc_cov layer is undefined, however the similar

From the above analyses it can be seen that the coincidence of the grid *canopy* (REO, 2000) has slightly better coincidence than the grid *usu_cc* from Utah State University. The coincidence of the Utah State data grid *canopy* is below 50% for the intervals of 1-19% and 20-39% canopy cover, but above 50% for the intervals 40-59% and >60% canopy cover. The coincidence of the National Forest version (grid *usu_cc*) of the original Utah State data is 5% lower in the 1-19% category (37%), 1% lower in the 20-39% category (24%), unchanged in the 40-59% category (56%), and unchanged in the >60% category (35%).

The coincidence of the *NCGBE* grid has different interval values from the Utah data so comparison is difficult. In comparison with the cc_cov grid, the *NCGBE* grid has 36% coincidence for the 1-29% canopy cover interval, 19% for the 30-49% canopy cover integral, 42% for the 50-69% canopy cover interval and 35% for the >70% canopy cover interval. These intervals are slightly lower than that of the Utah State grid *canopy*.

The discrepancies are larger than expected between the *cc_cov* canopy cover layer calculated by patch analysis and Utah State or NCGBE canopy estimations. One of the reasons for the low coincidence of the lower two intervals is that these are classified differently by patch analysis, Utah State and NCGBE. The patch analysis excluded non-coniferous canopy from all layers, but the other two maps calculated canopy for all cells classified as tree cover. But in the NCGBE trees are classified as cells having >30% trees. The classification is more complex in the Utah State data, but the algorithm apparently allows calculation of a tree canopy in cells not classified as a type of tree cover. This is acceptable, e.g., in areas where the classification is predominantly shrub-steppe, but has scattered trees making a canopy cover. Unfortunately the complete classification scheme for the Utah Data layer was not available, and the metadata that was available was a complex series of algorithms not readily comprehensible in human terms.

Neither the Utah nor the NCGBE layers are summarized within polygon themes; consequently their resolution can theoretically be as fine as that of the individual pixels (30m). Unfortunately, the accuracy of this fine-scale canopy classification is very poor for open areas, and only fair for denser canopies. The canopy cover data is shown overlaid by the regions of tree patches in Fig. App-C-12, App-C-13, and App-C-14, respectively, for the Utah State data, the NCGBE data and the patch pattern canopy cover classification.

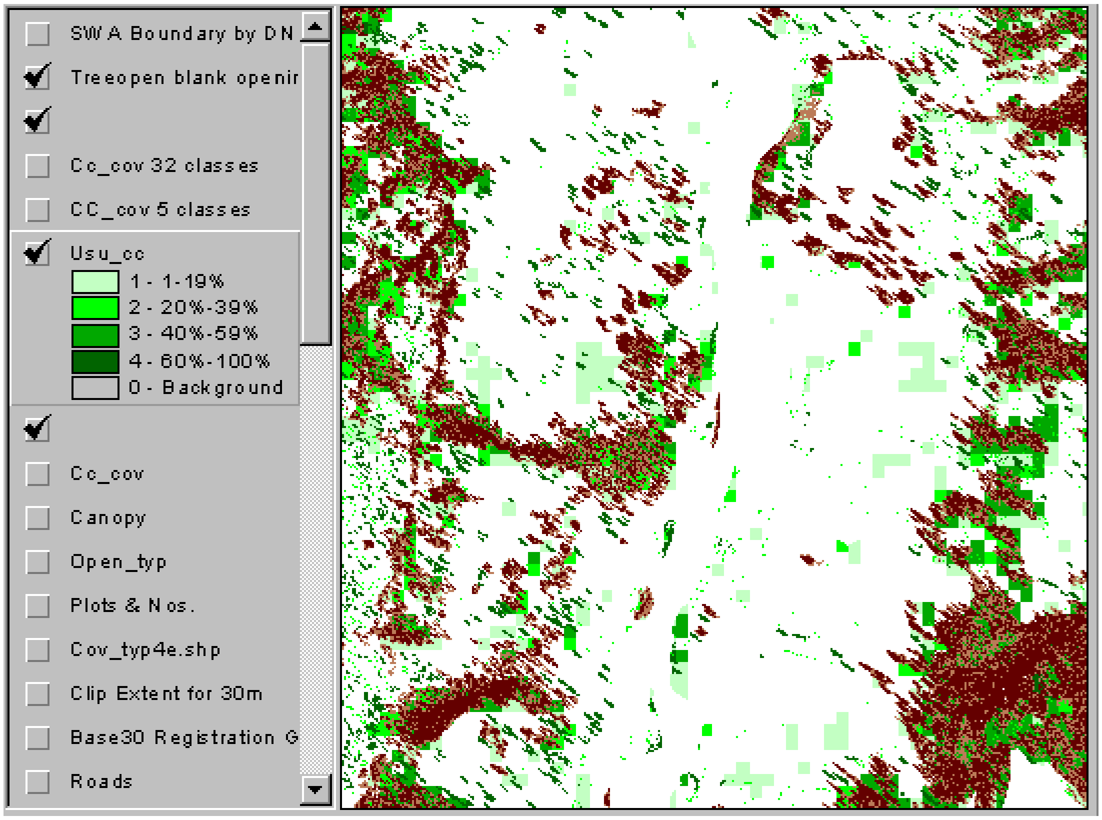


Figure App-C-12. The Utah State canopy cover data is shown overlaid by the regions of tree patches in brown and dark green.

The view clearly shows numerous stray cells representing or misrepresenting different canopy levels.

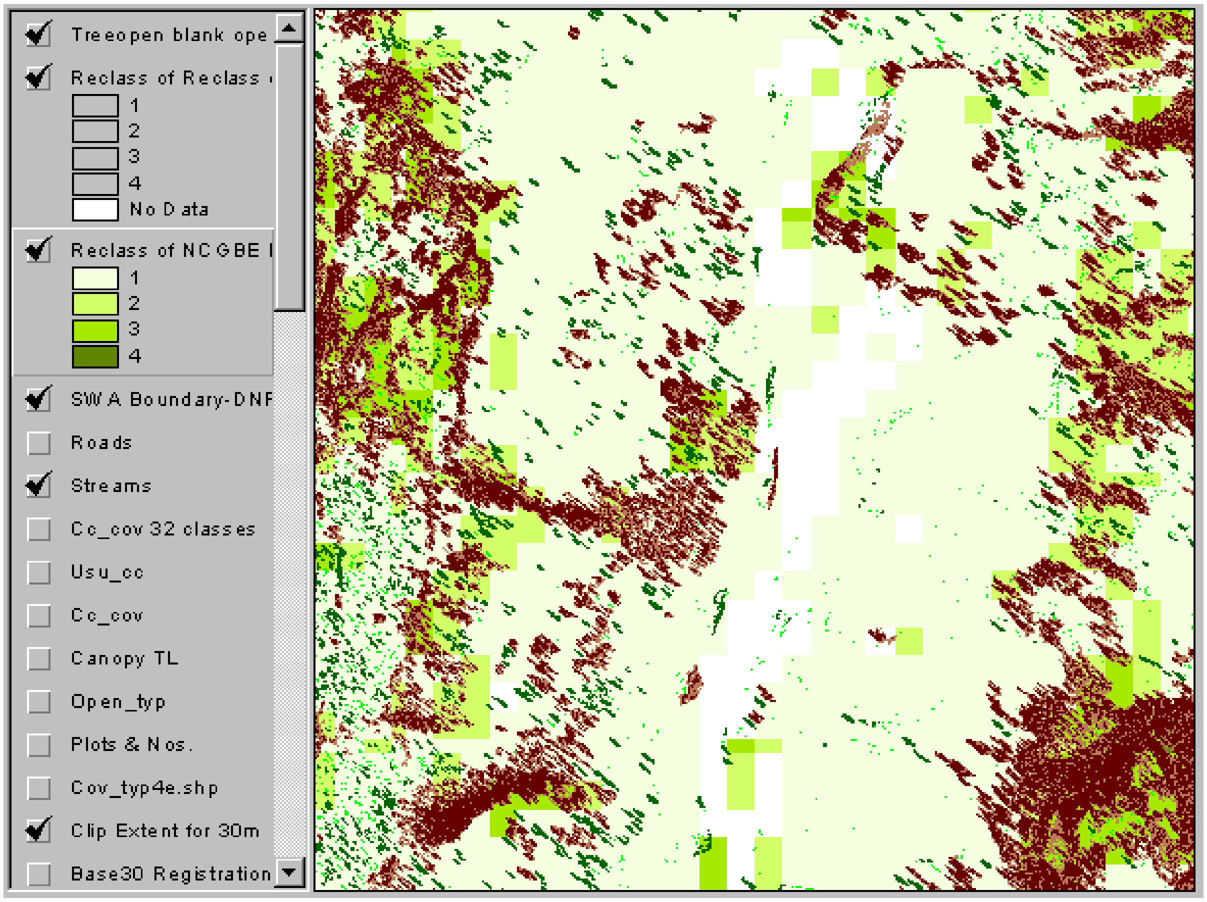


Figure App-C-13. The NCGBE canopy cover data is shown overlaid by the regions of tree patches in brown and dark green.

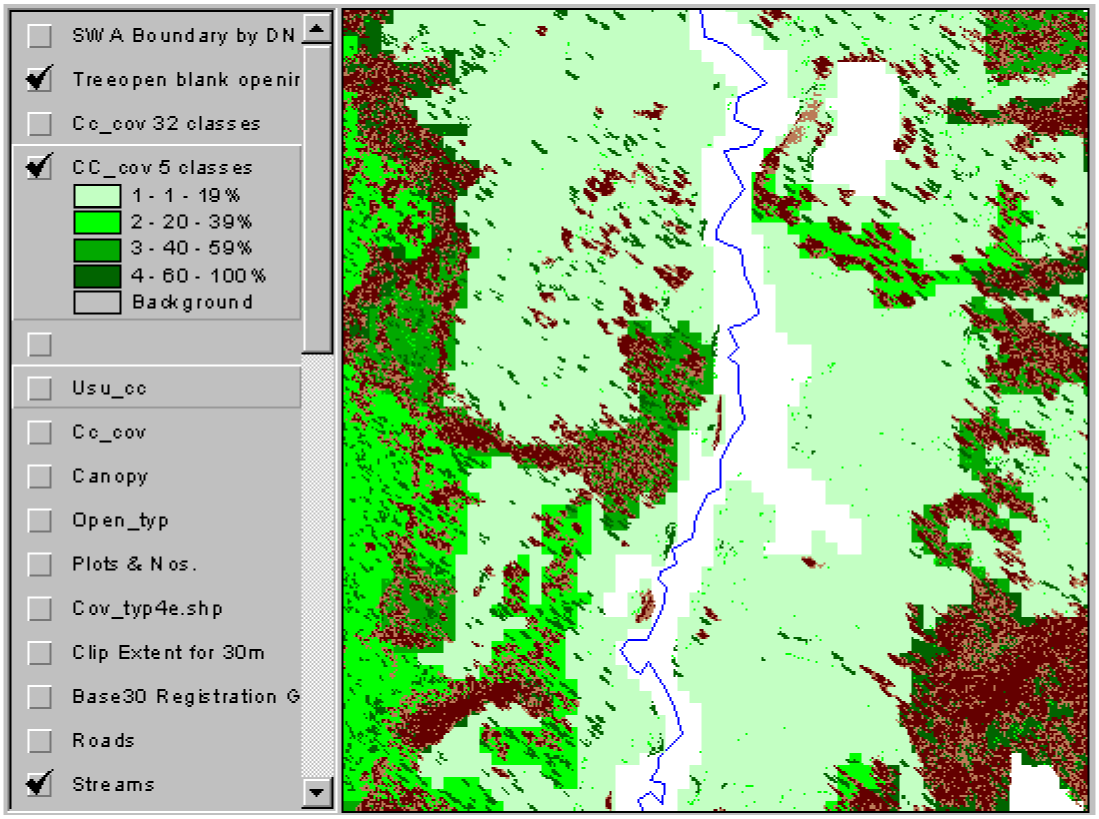


Figure App-C-14. The patch pattern canopy cover classification is shown overlaid by the regions of tree patches in brown and dark green.

The patch pattern canopy cover classification clearly has the best match of canopy to trees. Another advantage of using a patch pattern canopy determination is that the full range of cover intervals can be depicted at a precision of 1-2%, as shown in Fig. App-C-15.

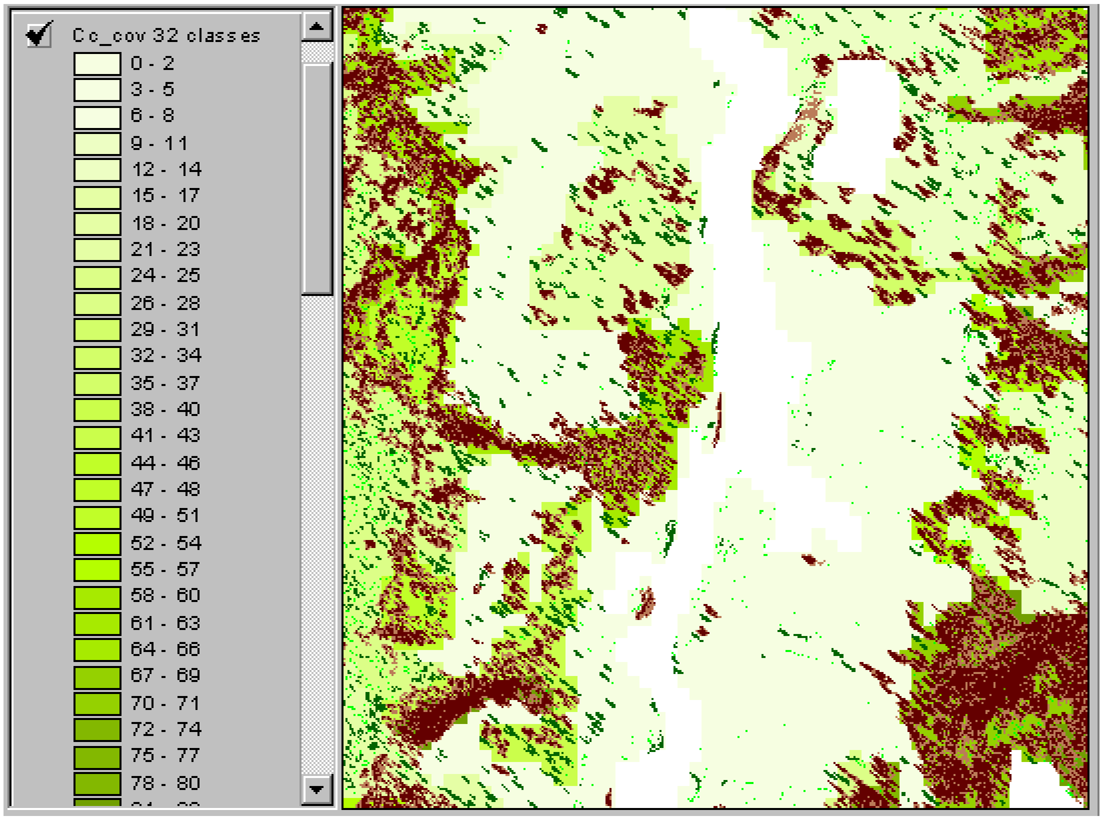


Figure App-C-15. The patch pattern canopy cover classification shown using a full range of cover intervals, at a precision of 1-2%,

Conclusion

Tree canopy cover calculated by patch pattern analysis matches the actual pattern of tree density better than that in any other available canopy layer.

The precision of the patch pattern tree cover was reduced to intervals of 10-29%, 30-59%, and >59% cover, so that the grid values could be imputed into the existing stand polygons using an averaging algorithm. Although it would be possible to calculate a finer resolution canopy cover grid by combining the values into 30m cells rather than averaging them into the polygons, this would be computationally intensive, and the cell values would form a jagged, stair-stepped pattern in passing over clumps of trees, as it is in the Utah and NCGBE data. Since this analysis determines management of the SWA by stands, it makes sense that the canopy cover be averaged by stands as well, rather than by individual 30m cells.

Overall, the use of patch pattern recognition has high potential for the creation of accurate canopy cover maps. This method of GIS modeling could become more utilitarian if some of the following considerations could be resolved. The method could be completely automated, and this would improve it immensely. There are computational limitations requiring scaled-down runs. We used a scratch drive which was wiped clean several times a day or whenever it exceeded 4 gigabytes. There will always be a need to manually filter out extraneous patterns, particularly dark areas which get grouped with tree shadows. There needs to be improved methods for calculating metrics on regions of identical cells (in ArcView, so-called “zonal focus” operations). Simple operations like grid buffering between core and boundary cells are unnecessarily cumbersome operations in ArcView and the program sometimes had to be aborted during calculations involving many classes of regions.

Further improvements in the accuracy of the patch pattern analysis could be made by incorporating field measurements of the shadow factors into the analysis process and running the program again.

Notes on algorithms used

Extensions used in this project are available in the public domain as online files; most are available at the ArcScripts web site of Environmental Systems Research Institute (http://arcscripts.esri.com/). Most of the following methods are dependent on having the Arcview Spatial Analyst extension (©, ESRI) enabled. Other frequently-used extensions are Grid PIG Tools (2004) and Grid Enhancement Tools (Schäeuble, 1998).

Average (mode) grid value onto a polygon was done with the *CRWR Raster*. The polygon theme must have a pre-existing field with unique values. After inputting the grid and polygon themes, the extension requests the polygon field name with the unique ID (called the “zone field”), then asks for a new field name to create and place grid values in, and finally asks whether to put the average or mode value into the record (called “most likely”).

Clipping a grid by another grid was done with the script *grid-clip-by-grid.ave* (*clipgrid.ave*), by Tom Van Niel (2004), rewritten from the original version by Eugene Martin of CommEn Space (http://www.commenspace.org). (Note that this script is different from the script of the same name also described here and rewritten by Tim Schaub). This script maintains the original coordinate registration of the input grid. It clips a grid by the non-zero values of a second, clipping grid.

Clipping a grid by a polygon theme was done with (1) *Grid PIG - Clip Grid With Polygon*; or (2) using the *CRWR Raster - Clip Grid by Polygon* command; or (3) with the script *clipgridalign.ave* (*ClipGrid.ave*). The latter (scripted) method was re-written by Tim Schaub (2004) from the original version by Eugene Martin of CommEn Space (http://www.commenspace.org). (Note that this script is different from the script of the same name also described here and rewritten by Tom Van Niel). This maintains the original coordinate registration of the input grid and allows feature selection within the clipping theme as well.

Combine grids was done with *Grid Enhancement Tools*.

Counts of cells in regions of a grid was done with *Grid Enhancement Tools - Region Group* command, using either the 4 orthogonal or all 8 nearest neighbors to label the regions and count the number of cells.

Dissolve polygons was done with the Arcview *Geoprocessing Wizard*. This command operates on either selected features, or if none are selected, then all features are processed.

Distance from cells was calculated by first selecting the cells of desired value to process and then using the Arcview command *Analysis - Find Distance*.

Image Conversion of tiff orthophoto images to *ArcInfo* grid format was done with the Arcview command *Convert to Grid*.

Merge multiple grids was done with *Grid Enhancement Tools*.
Reclassification of grid cell values was done with the Arcview command *Analysis - Reclassify*.
Region Grouping grid cells was done with *Grid Enhancement Tools - Group Region*, using either the 4 orthogonal or all 8 nearest neighbors to label the regions and count the number of cells.
Shrinking grids was done with *Grid Enhancement Tools - Expand/Shrink- Shrink*. This command produces blocky orthogonal patterns which was corrected by developing a distance- or buffer-based shrinking algorithm for this project.
Thickness of Zones (Regions) was calculated with *Grid Enhancement Tools - Zonal Geometry - Thickness*.
Unioning or ANDing grid layers was done with the Arcview *Map Calculator*.

Experiment No. 1. Test of low-variant regions as a measure of determining breakpoints for separation of trees and openings

a. Process the high-variance filter grid grd3roi3 -> grd4 -> grd5uni3. Grid *grd4* was created from *grd3roi3* using a 3 X 3 Neighborhood Statistics Range moving window and then displaying values 0-2 as low (red-orange) and values 3-11 as high (green). Grid *grd5uni3* was created from *grd4* by reclassifying higher range values to *No Data*. This generated a 1-class grid with value 1 representing cells with a 3 X 3 Neighborhood Statistics Range of 0-2.

b. Filter out cells of high variance: grd5uni3 -> grd6comb. This grid is a combination of a high-variance filter grid *grd5uni3* and the 16-class orthophoto *grd3roi*, as shown in Fig. App-C-16.

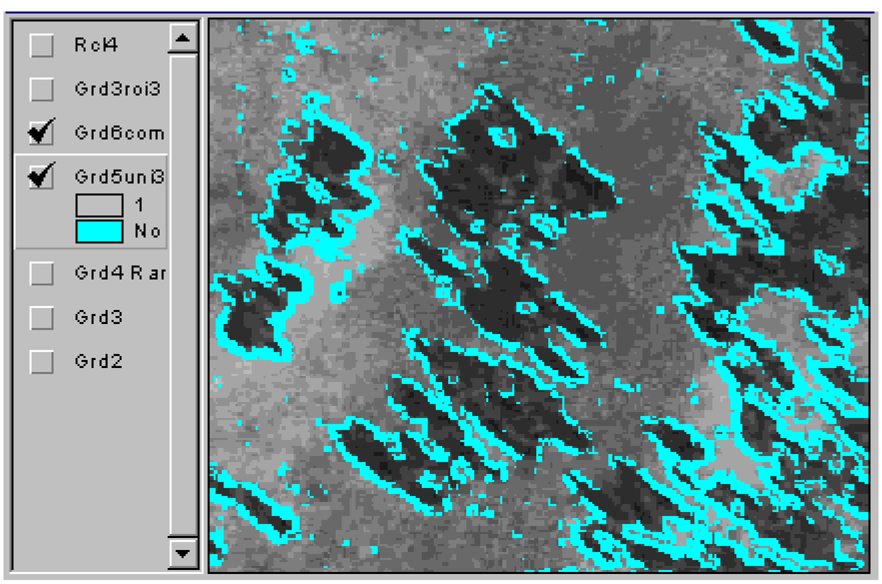


Figure App-C-16. Combination of the high-variance filter grid *grd5uni3* and the 16-class orthophoto *grd3roi*.

Neighborhood statistics were determined for the low-variance gray areas. From counts of the majority of nearest neighbors in a 3 X 3 matrix it was found that class 7 should be the breakpoint between dark and light areas. However reclassifications that classified dark areas as classes 1-7 or 1-6 or even 1-5 were all found to result in small, misclassified regions forming islands in the non-tree background. The reason for this counter-intuitive result may be due to a greater number of classes 5, 6, and 7 under the regions masked by the high-variance filter.

Experiment No. 2. Test to determine the optimum contrast breakpoint for separation of trees and shadows from background regions (openings)

Experiment No. 2 involved reclassification of *grd3roi3* to determine the optimum breakpoint for separating trees and shadows from openings. Two reclassifications were tested, both of which resulted in misclassifications of areas representing shadows or shrubs as trees (Fig. App-C-17).

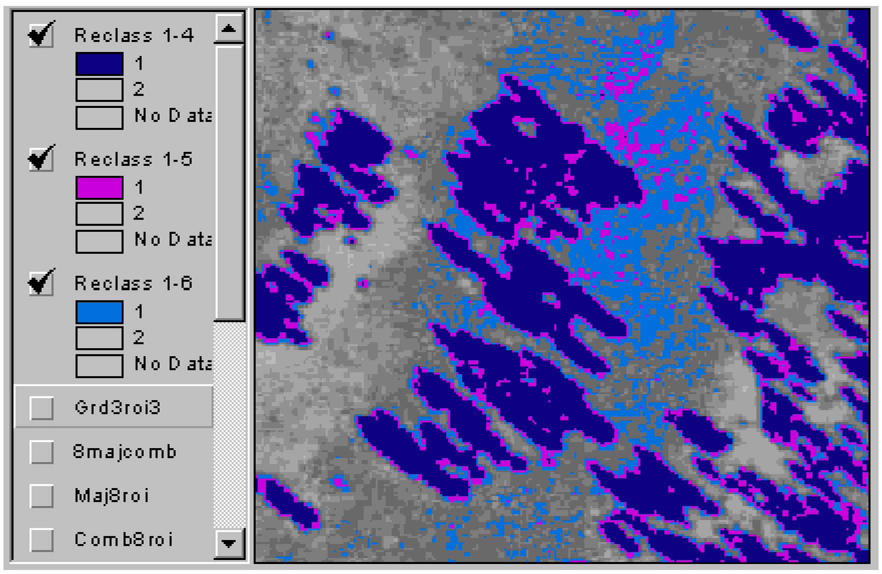


Figure App-C-17. In the following image two different reclassifications of *grd3roi3* are overlapped. Values 1-5 were reclassified to value 1 (purple) and values 1-6 were reclassified to value 1 (bright blue). Dark gray areas are misclassifications misrepresenting shadows or shrubs as trees.

Experiment No. 3. Test of methods used to select open areas by size criteria

An experiment was performed to determine whether a classification of open areas into small and large regions of cells should be weighted against linear open areas versus more rounded openings. The test was made by shrinking the open areas once or twice and determining the breakpoint separating large and small areas. The shrinking operation required use of a distance grid as a metric for shrinking to prevent unavoidable orthogonalization artifacts present in available shrinking and thinning algorithms. Two shrinking operations were performed; the first used a distance metric and the second used a zonal boundary shrink.

a. Distance shrink by 6 meters. The number of cells by which to shrink boundaries was determined by reclassifying grid *zx* by the standard deviation so that all cells with values greater than 6.068 were reclassified as value 1 and all other cells are classified as *No Data*. When overlaid onto *zon0*, the thickness classification of *zonthk2* resulted in a usable classification (Fig. App-C-18).

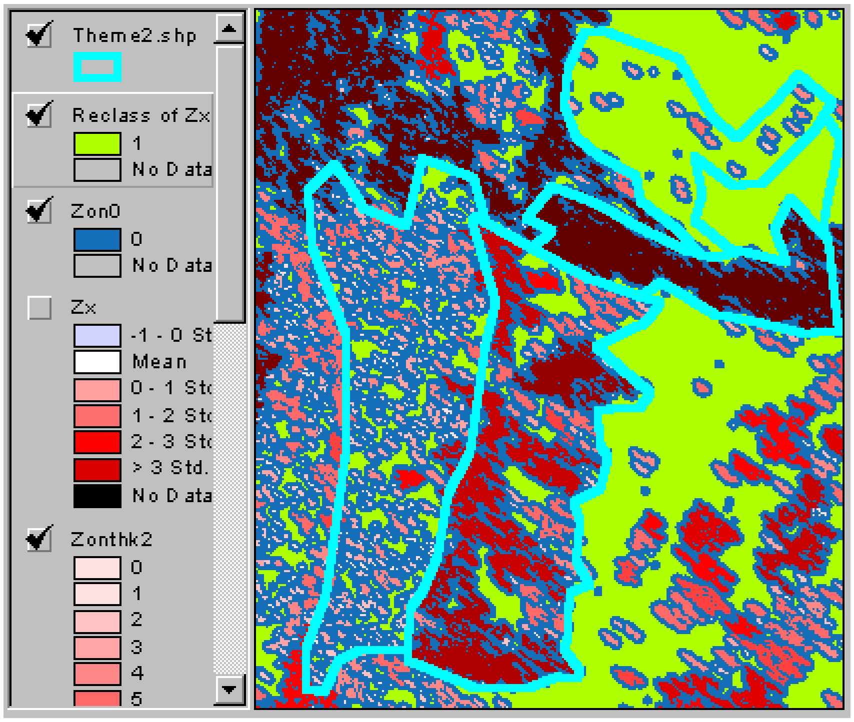


Figure App-C-18. The thickness classification of *zonthk2* overlaid on *zon0*, (blue polygons represent target texture classification regions as before).

b. Second zonal boundary shrink by another 4 meters. To possibly improve the classification, a second shrink operation by another 4 cells was performed on the results of the first shrink operation, using the *Grid Tools - Shrink* command.

Discussion. The breakpoint was determined for each of the shrunk regions using a region group. The table was then inspected, sorted by cell counts and displayed (Fig. App-C-19).

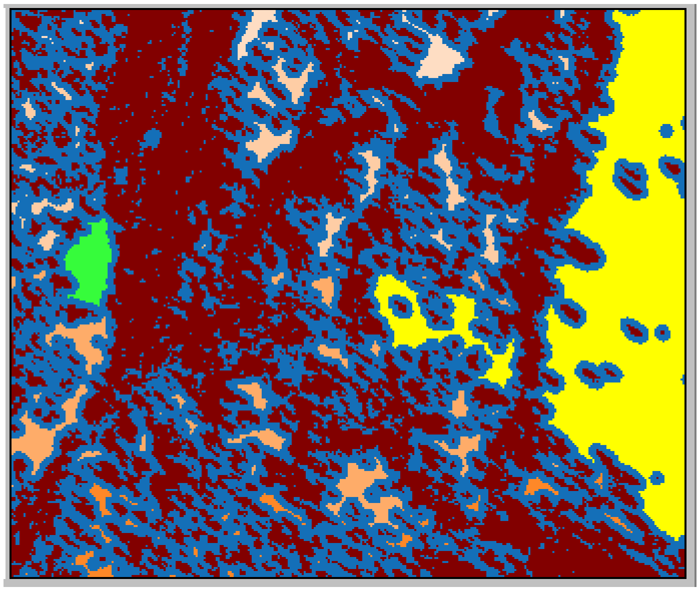


Figure App-C-19. The breakpoint determination of region shrinking. The first shrink is shown with yellow or green representing “large openings”. The second shrink operation resulted in reclassifying a new region (shown in green) as a new “large opening”.

In summary, a shrinking operation by ten cells on open regions was determined to improve the region classification by rejecting linear openings. This procedure was applied in fewer steps in the actual procedure used.

Experiment No. 4. Test of the utility of the Patch Analysis extension

Patch analysis was performed on the grid *val2* in which cells of value 1 represent patches of trees and shadows. Patch Grid was used to create an integer patch grid from this layer. This was displayed with 23 classes divided by natural breaks. The metrics of the patches were determined for 4 size categories as shown in the table below, with the patch sizes shown as the grid names in the chart heading.

Metrics of the patch grids for various patch sizes are given in the table below:

Patch Metric	grid pch0: Size <50 pixels	grid pch50: Size >=50 & <250	grid pch250: Size >=250 & <3000	grid pch3000: Size >3000 pixels
Class Area	21,798	51,005	79,677	47,812
No. of Patches	1968	482	123	13
Mean Patch Size	11.1	106	648	36,778
Median Patch Size	6	91	457	5061
Patch Size Coeff. of Variation	111	46.6	85.3	222.4
Patch Size Std. Dev.	12.3	49.3	551.6	81,796
Total Edge	30,894	35,310	37,642	142,498
Edge Density	1.41	0.69	0.47	0.30
Mean Patch Edge	15.7	73.3	306	10,961
Mean Shape Index	1.26	1.79	2.93	10.8
Area Weighted Mean Shape Index	1.46	1.86	3.54	31.0
Mean Perimeter-Area Ratio	2.37	0.74	0.50	0.36
Total Core Area	0.56*	2.84*	5.43*	37.68*
Core Area Density	40,462	13,861	4543	1353
Core Area Coeff of Var.	96.17	99.0	210.9	1747.3
Total Core Area Index	25.51	55.6	68.2	78.8
Shanon's Diversity Index	3.80	4.85	4.50	1.35
Shannon's Evenness Index	0.98	0.97	0.96	0.52

Note: core areas are separated from edge pixels by one pixel. Diversity indices are for the Landscape attribute Count. *'d values appear to be divided by 1000.

Discussion. An illustration of patches colored by size, showin in relation to the training polygons previously delineated. The patches appear to be roughly grouped into polygons, primarily by size, shape, and evenness of the inter-patch distances, but not by distance alone.

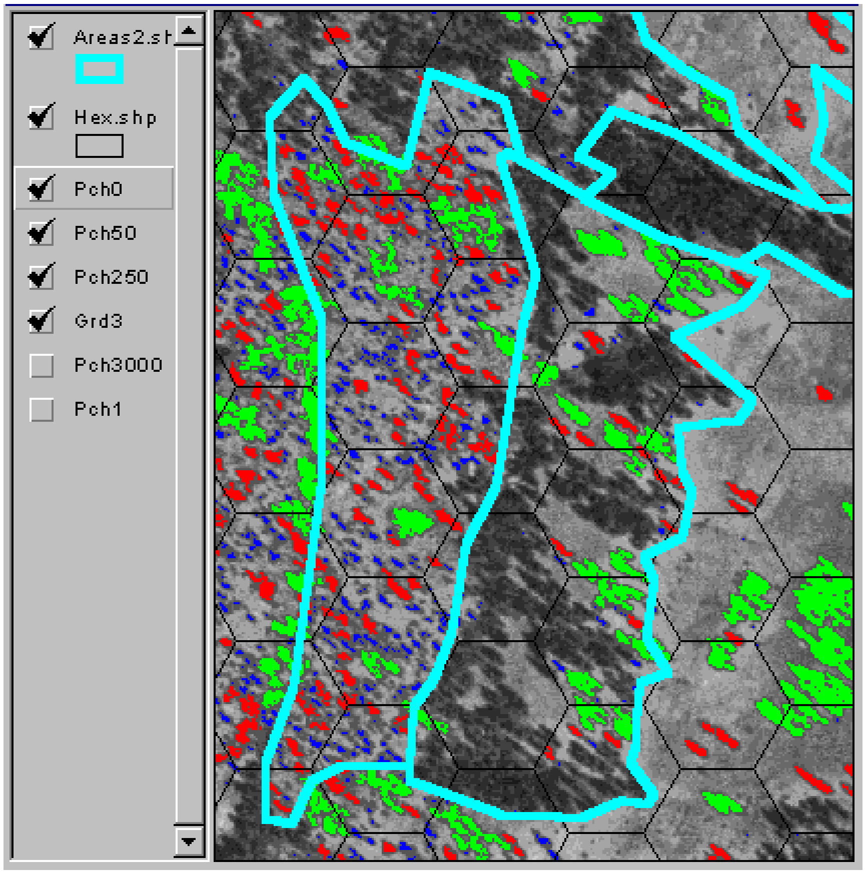


Figure App-C-20. An illustration of patches colored by size of 0-50 (blue), 50-250 (red), 250-3000 (green) and >3000 (black), in relation to the training area polygons (bright blue).

The 250-3000 cell class (green) appears to be a borderline case for the classification by size. To be separated from the right-hand polygon, the left-hand polygon needs to be classified by patch size and dispersion, giving it a definition as, "canopy openings within a matrix of even, thin patches".

Several alternatives for achieving an effective pattern recognition classification are possible. (1) design an algorithm that preserves the essential boundary of the two light-blue training area polygons, but re-classify the patches of size 250-3000 cells in a second step; (2) create a third class of polygons dominated by the 250-3000 cell patches; (3) classify all openings as a single type so that the polygon boundaries will be have more lacunae and can wiggle in and out of areas containing the 250-3000 cell polygons; (4) classify the openings rather than the patches, that would be defined as, "canopy openings in a matrix of dense patches".

Method 4 was chosen, however in practice, it was only necessary to classify canopy openings in even, thin patches, and allow the remainder to become "canopy openings in a matrix of dense patches”.

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Appendix Analysis-D. Cover type and plant association analysis

Background

The determination of cover type and plant association (potential natural vegetation, PNV) were conducted simultaneously for the SWA fuels mapping project. The cover type represents the dominant current vegetation growing on a site as given in the key in this section. Cover types are treated as successional stages within a plant association, and these were further grouped together into as few different types as possible, while still retaining sufficient information to run the fire behavior models.

It is more difficult to model PNV than cover type, because the remotely sensed satellite data is the primary source of data and this represents current vegetation. Thus, PNV was mapped from cover type, rather than what would seem to be the logical choice of the proceeding in the reverse order. PNV determination made following determination of the cover type is described in Appendix F, from which ecological characteristics, canopy structure, dominant species cover and fuel loadings were determined.

The determination of cover type involved two different levels of resolution, or minimum mapping size. Cover types were determined for the manually digitized stands surrounding the SWA through a combination of photo-interpretation and computational methods such as the patch pattern analysis described in Appendix C. For the area bounded by the manually digitized stands covering the SWA boundary, the minimum mapping unit was nominally 5 acres, or about 67 30m cells. The digitized stands representing cover types were coverted to grids with 30m cell sizes for input into the fuel and ecological models. No effort was made to systematically eliminate polygons smaller than the minimum mapping unit. Within the SWA boundary, the primary means of classifying data was *de novo* classification, using field data and analytical methods, combined with information from the other data layers where it was judged superior. The SWA layers were overlaid onto the entire analysis area so that they superceded data mapped at lower resolution or quality.

For the entire analysis area extending several miles beyond the SWA boundary and bounded by the extent of the *base30* grid, a lower level of resolution and classification accuracy was accepted, defined as the best data chosen from, or averaged between, the Utah State layers, the NCGBE layers, NHI data, NLCD data or *de novo* classifications. Since the analysis area extended beyond the SWA boundary, the affect of inaccurate classifications in these layers was indirect, but still important enough to warrant improvement in the quality of data. An example of an important indirect effect would be large changes in modeled fire spreading rates and intensities between areas mapped as grass, shrub or conifer. In both real or simulated situations, fires could travel at different spreading rates between different management areas.

The need to improve the existing classifications became apparent after inspection revealed grave data inaccuracies that would skew the fuel models. For instance, the patch pattern analysis (Appendix C) developed a layer of canopy cover that was judged to be the most accurate through independent verification by both photo-interpretation and computational means. When this canopy cover layer was compared with the Utah State data, of the four levels of canopy density > 20%, 2 had less than 50% coincidence, and 2 were barely over 50%. Other inaccuracies in the Utah State layer included violations of the hierarchical classification scheme required by fire modeling programs, for instance in having tree canopy densities of >40% in areas classified as shrub-dominated.

The cover type classifications described here are hierarchical-divisive, i.e., areas are successively divided into finer and finer units of cover type. Thus the procedures require that the order of processing be followed as described.

The determination of cover type required simultaneous determination of canopy cover, since most vegetative types were keyed by the percent canopy. Where it was used to determine cover type, canopy cover determination is also included among the procedures listed here. The patch pattern analysis method of determining canopy cover is documented in Appendix C. Some of those methods are used in a modified form in this section.

Cover types were determined for the manually digitized stands surrounding the SWA beginning in phase 1 of this project, using a combination of photo-interpretation and computational methods such as the patch pattern analysis described in Appendix C. These were determined for stand polygons prior to conversion to grids. The cover type definitions used for the digitized SWA stands is the same as that used for the *base30* grids, except that the canopy cover intervals were in increments of 10%.

The steps for determining canopy cover for the *base30* grid are also described in this section, since canopy cover was a prerequisite to cover type determination.

Determination of cover types for the SWA

Before the fuel and ecology models were developed, cover types were determined for the manually digitized stands surrounding the SWA beginning with on-screen photo-interpretation of the stand areas represented in the polygon file *cov_typ4.shp*.

The classification of *Cov_typ4* was developed by sequential hierarchical division of the SWA area into smaller and smaller regions representing different types of vegetation. The sequence for determining the cover of each of the following cover types should be done in the following sequence, which is modified from that actually used during this project: marshes, deciduous forest, agriculture, shrub-steppe, conifer types, riparian conifer zone, rock talus, water, shrub uplands. The sequential key to the cover types is as follows; each lead was evaluated in the sequence given below before the next lead was begun.

Cover Type Classification

0 - **Background**. This represents no data. It was only used during digital editing as a place holder for uncoded stands; after editing there were no 0-value polygons overlapping the SWA boundary.

1a. Water > 50%.

98 - Water. This is open water, ponds and lakes. Some seasonal lakes may not be included, as well as small ponds.

1b. Water < 50% ... 2.

2a. Rock and cliff > 50%.

99 - Rock & Cliff. Rocks and cliffs were digitized with the ASTER imagery.

2b. Rock and cliff < 50% ... 3.

3a. Developed > 1%.

97 - Developed. These are areas with yards, pavement, or buildings.

3b. Developed < 1% ...4.

4a. Agriculture > 50%.

6 - Agriculture. Agriculture includes fields, fallow fields orchards, and stand conversions with less than 10% conifer overstory.

4b. Agriculture < 50% ...5.

5a. Aquatic species > 50% OR area within 105.6 ft (0.02 mi) of a perennial stream.

6a. Deciduous or wetland vegetation > 50% and slope < 4%.

7a. Tree species < 50%; shrubs or herbs dominant

1 - Marshes & Swamps. This type includes both swamps (shrubby wetlands) and marshes (herbaceous dominated wetlands), with slopes less than 4%. This layer was created by buffering perennial streams to 0.02 mi (105.6 ft), and then intersecting with the National Wetlands Inventory layer. Polygons were edited and combined manually into larger areas, or reduced to smaller ones, where riparian vegetation appeared visible beyond the buffer limit. Some of the streams appear to be partially intermittent, and some upland areas are also wet. Areas with overlaid slope > 4% were keyed under Class 109, Riparian Conifer Zone.

7b. Tree species > 50%.

101 - Deciduous wetland forested bottomlands. This type includes tall shrub wetlands and swamps, aspen wetlands; cottonwood wetlands; Scouler willow or naturalized European white or golden willow wetlands.

6b. Slope > 4%, vegetation deciduous or coniferous.

109 - Riparian Zone (usually coniferous, sometimes with deciduous patches). The riparian conifer zone was not manually digitized. Instead it was modeled by segregating slopes > 4% out of all other wetland and riparian layers. The modeled riparian buffers were corrected within the SWA to exclude non riparian coniferous patches. Outside the SWA, the riparian conifer zone was created by extracting cells out the NCGBE grzveg1 Riparian Conifer Zone, types 13, 14, and 15. These cells were originally contained within a 114m wide buffer wherever coniferous overstory was adjacent to a stream, before being resampled for this project.

5b. Aquatic species < 50% AND distance > 105.6 ft (0.02 mi) from a perennial stream ...8.

8a. Conifer < 20% ... 9.

9a. Big sagebrush + bitterbrush + bunchgrasses + balsamroot > 40%; conifer generally < 10%, occasionally higher in localized patches of invading forest.

5 - Shrub-steppe (conifer 0%, 1-9% or 10-19%).
Shrub-steppe includes both typical examples such as sagebrush or bitterbrush dominated steppe, as well as natural grasslands, and other canopy openings, and recently burned areas with a significant herbaceous component. The canopy cover is specified as 0%, 1-10% or 11-20%. This lead can be further segregated in the field into any of the following dominant species and/or subdominant understory: mountain sagebrush, big sagebrush, three-tip sagebrush, bitterbrush, bluebunch wheatgrass, needlegrasses, balsamroot.

9b. Big sagebrush + bitterbrush + bunchgrasses + balsamroot < 40% ...9.

9a. Aspen > 30%.

102 - Aspen Upland. Aspen uplands were originally digitized from orthophotos, but additional stands were added with the use of ASTER imagery. There are misclassified areas where shrubs have been released following disturbance or irrigation.

9b. Aspen < 30% ... 10.

10a. Broad-leaved woody species + conifer < 10' tall > 50% of total vegetation.

11.a. Conifer cover > broad leaved

8 - Regenerating conifer.

11.b. Broad leaved cover > conifer

9 - Shrub Upland. This includes areas in which the predominant vegetation cover is shrubby and there is a dense understory of herbaceous plants covering the ground. Aspen is <30% and overstory conifers are <20%. This type includes recently burned or logged areas which have not yet recovered > 20% coniferous canopy. This type is often found at the margins of wetlands or aspen stands. These stands were determined using the ASTER imagery within the SWA. Outside the SWA this type was determined by combining class 3, Deciduous, from the grid usu_ct and class 11, Shrub upland, from the grid grzveg1. This type is underrepresented by the grzveg1 classification, although the classification is reasonable accurate. The usu_ct classification has fewer errors of omission, but more errors of commission, i.e., it includes some aspen stands as well. The misclassified shrub uplands derived from the Utah data are used without correction, inclusive of misclassified aspen stands.

10b. Other (montane mix, grassland, fallow, bare, etc).

10 - Montane Canopy Openings (conifer 0-9% or conifer 11-19%). These cover types were modeled using patch pattern analysis, but only for the area covered by SWA stands. It primarily represents pinegrass (*Calamagrostis rubescens*) openings, but also includes small patches of shrub-steppe, shrubby openings, regenerating conifer and mountain sagebrush.

8b. Upland Conifer > 20%.

Upland Coniferous Forest. The upland coniferous overstory canopy was classified several ways. See the subkey to Upland Coniferous Forests.

Subkey to Upland Coniferous Forests

For stands that key to upland conifer forests in the main key to cover types, the following key is used to classify the stand structurally and by topographic location.

1. Score the field Std_Slo in one of 5 steepness categories as follows, based on field data (rather than on digital DEM data).
   0 (0-4% slope)
   5 (5-19% slope)
   20 (20-34% slope)
   35 (35-66% slope)
   67 (>66% slope)
   If the stand has 2 or more slope categories, then include both, separated by a + sign
2. If the stand is north-facing (315-360 degrees or 0-45 deg) with >35% slope, the stand is considered "steep N-facing". Score the field Std_Slo as **35N**.
3. Determine the Conifer Zone as follows and score the fields Conif_Typ and Conif_Zone as follows.
   201 = PIPO (Ponderosa pine). PIPO is the only conifer species reproducing successfully on the site.
   211 = PSME-PIPO (mixed Douglas-fir - ponderosa pine). Mixed PIPO and PSME are the dominant conifers on the site, some LAOC may be present, but the site is dry by early summer. Understory plant diversity is low. These sites are totally incapable of supporting snow- and cold-tolerant species like subalpine fir, lodgepole or spruce even if there was a seed source.
   221 = PSME-LAOC (montane Douglas-fir - western larch). PSME or LAOC is the dominant conifer, PIPO is uncommon; sites are low to moderate productivity, cool, and moist into summer. Understory plant diversity is moderate to high. These sites could support occasional snow- and cold-tolerant species like subalpine fir, lodgepole or spruce if there was a seed source.
   231 = ABLA-PICO (Subalpine fir - lodgepole pine mix). This only occurs outside the area of the SWA boundary, but is included in the base30 area. In dry areas, PICO is the dominant conifer; ABLA may be present in the understory; sites are low-productivity, dry sandy soils. In wetter areas, PIEN is the dominant conifer, and ABLA and PICO are both present; the ground is moist into the summer and may be saturated.
4. Determine the canopy cover density in one of three classes and score this in the field Cov_Typ:
   110 = 10-29% conifer overstory

130 = 30-59% conifer overstory
160 = 60-100% conifer overstory.

The determination of stand density was done digitally using orthophoto images in Arcview (see Appendix). The determination of canopy density was refined using patch pattern analysis of the orthophoto images, to produce a grid file which was classified into four categories with intervals of 20%, so that the data conformed with the Utah State data. The determination of canopy density outside the boundary of the SWA used a simplified, less accurate, reclassification of orthophoto brightness images to estimate canopy within approximately 10% (see step 11 of Appendix D). This determination involved prior filtering out of most of the darkly shaded cells, however both systematic and non-systematic errors still remained after this process. Nonetheless, the classification of canopy density outside the SWA was still judged superior to the Utah State canopy cover determination.

5. Determine the stem density in the following classes and score this in the field Std_Stem.
6. Determine if the stand is suppressed (scored if the field Std_Toe = "Toe) and multiply the stem densities by the stem density factor.

1. Input files used to develop the cover type and canopy cover GIS layers for the *base30* area and SWA stands

The project files used to determine cover type are *cd:\fuelgis\research\research\plantcom\plant-comm.apr* and *cd:\fuelgis\arc\analysis\pattern\conif-cover-01zzz.apr*. The latter project file was used to determine the canopy cover outside the SWA as a prerequisite to the cover type classification. Grid files used in the cover type determination are stored in the folder *cd:\fuelgis\arc\analysis\plantcom\plantcom\ct_input1*, and grid files used in the canopy cover determination are stored in the folders *cd:\fuelgis\arc\analysis\pattern\patinput4* and *cd:\fuelgis\arc\analysis\pattern\patinput5\.*

The determination of shrub-steppe, conifer and riparian cover types was dependent on the prior determination of percent canopy cover (see Appendix C). The results of the patch pattern analysis indicated that that method had greater accuracy than the other canopy cover grid layers from either Utah State or the NCGBE. For this reason, the canopy cover was also re-calculated for the analysis area bounded by the *base30* grid for areas classified as conifer, shrub-steppe or riparian conifer. Due to the lengthy computational time involved for a complete patch pattern analysis, only the brightness and reclassification steps were used to develop a relatively crude canopy layer with a nominal precision of 10%. This determination was still judged to be more accurate than the other canopy layers, particularly in light areas.

The following files form the starting point for building the multiple-layer GIS for the SWA. They are used as a basis for generating all subsequent grid files used in fuel and ecological modeling, with the exception of the DEM data, the files used to generate the initial versions of canopy cover and cover type (in the *cd:\fuelgis\pattern* folder and the *cd:\fuelgis\plantcom* folder). As this data becomes outdated with the incorporation of new information, the project input grid files can be simply updated by modifying the following files.

a. Following editing, the shapefile *cov_typ4.shp* was converted to a 30m grid named *cov_typ4* with extent and registration identical to the *base30* grid. It was saved as *cd:\fuelgis\1183\cov\psigrd30\cov_typ4\cov_typ4*. To update this grid, it can be merged with subsequent changes made to the grids of cover type.

b. Mask files were used to identify regions where canopy cover, coniferous cover, or areas outside the SWA boundary are or are not assigned, by definition of the cover type. The masks are used to maintain the co-registration and colinearity of cells whenever grids are merged with overstory coniferous canopy or cover type layers.

One mask identifies regions of coniferous canopy, either within or outside the SWA stands area. Another mask identifies regions of combined deciduous and coniferous canopy.

Cell values where coniferous overstory canopy cover is not determined are 1-Marsh & Swamp, 6-Agriculture, 9-Shrub Upland, 97-Developed, 98-Water, 99-Rock, 101-Deciduous Wet Forest and 102-Aspen. Cells where coniferous canopy cover is meant to be determined are 5-Shrub steppe, 10-Canopy openings, 109-Coniferous riparian, 201-PIPO, 211-PSME-PIPO, 221-PSME montane and 231-ABLA-PICO.

The first version of the conifer cover mask was created in step 11.c as grid *naconswa*, which included only the SWA stands; a second version that extended the mask to the base30 area was created in step 21 named *con_area*. A third version partitioned coniferous stands into areas inside the SWA stands area or outside the area and was named *cd:fuelgis\1183\can\psigrd30\con_30_4*.

The procedure to create this was mask was to partition *cov_typ4* and *con_area* into 4 grids, then merge all of these into a single grid with 1 = non-conifer outside the SWA stands, 2 = non-conifer within the SWA stands, 3 = conifer outside the SWA stands, and 4 = conifer within the SWA stands.

c. A grid of coniferous canopy cover for the entire base30 grid is named *cd:\fuelgis\1183\can\psigrd30\con_can3*. This grid was filled in to eliminate *NoData* cells (classed as of value -1) by shrinking the grid against their favor. Although this produced some anomalous cell patterns in non-coniferous areas outside the SWA boundary, these were judged to be insignificant to analyses within the SWA project area (see step 21). If subsequent changes are made to these GIS layers, this file may be left unchanged. However grid con_can3 is a necessary input file for clipping by the grid *con_area* to form grid *cd:\fuelgis\1183\can\psigrd30\con_can3b*. Therefore to update *con_can3b* it will be necessary to clip *con_can3* with changed versions of *con_area*, followed by merging the result back into *con_can3b* and following the grid through subsequent processing steps until all the GIS layers are assembled together again.

2. Determination of the water cover type for the *base30* grid area

The procedure to determine the water cover type was as follows: Convert *lakes.shp* to a 30m grid georegistered to the *base30* grid. Classify the grid with class 1 = Water and all other cells = 0 and merge this as the second file with a reclass of grid *cov_typ4* in which Water, type 98 = 1 and all other types = 0. Save the file in folder *cd:\fuelgis\arc\analysis\plantcom\plantcom\ct_input1* as *water*.

3. Determination of the rock cover type for the *base30* grid area

The procedure to determine the rock cover type was as follows: Reclassify class 17, Rock, in the grid *usu_ct* to a 30m grid georegistered to the *base30* grid. Classify the grid with class 1 = Rock and all other cells = 0 and merge this as the second file with a reclass of grid *cov_typ4* in which Rock, type 99 = 1 and all other types = 0. Save the file in folder *cd:\fuelgis\arc\analysis\plantcom\plantcom\ct_input1* as *rock*.

4. Determination of the developed cover type for the *base30* grid area

The procedure to determine the developed cover type was as follows: Reclassify class 20, Urban, in the grid *nhi* to a 30m grid georegistered to the *base30* grid. Classify the grid with class 1 = Urban and all other cells = 0 and merge this as the second file with a reclass of grid *cov_typ4* in which Developed, type 97 = 1 and all other types = 0. Save the file in folder *cd:\fuelgis\arc\analysis\plantcom\plantcom\ct_input1* as *devel*.

5. Determination of the agriculture cover type for the *base30* grid area

The procedure to determine the agriculture cover type was as follows: Reclassify class 1, Agriculture, in the grid *usu_ct* to a 30m grid georegistered to the *base30* grid. Classify the grid with class 1 = Agriculture and all other cells = 0 and merge this as the second file with a reclass of grid *cov_typ4* in which Agriculture, type 6 = 1 and all other types = 0. Save the file in folder *cd:\fuelgis\arc\analysis\plantcom\plantcom\ct_input1* as *agric*.

6. Determination of the marshes and swamps cover types for the *base30* grid area

The procedure to determine the marsh & swamp cover type was as follows: Reclassify class 22, Herbaceous wetlands, in the grid *nhi* to a 30m grid georegistered to the *base30* grid. Classify the grid with class 1 = Herbaceous wetlands and all other cells = 0 and merge this as the second file with a reclass of grid *cov_typ4* in which Marsh & Swamp, type 1 = 1 and all other types = 0. Save the file in folder *cd:\fuelgis\arc\analysis\plantcom\plantcom\ct_input1* as *marsh*.

7. Determination of the deciduous wetland forest cover type for the *base30* grid area

The procedure to determine the wetland cover type was as follows: Reclassify class 91, Woody wetlands, in the grid *nlcd* to a 30m grid georegistered to the *base30* grid. Classify the grid with class 1 = Woody Wetlands and all other cells = 0 and merge this as the second file with a reclass of grid *cov_typ4* in which Deciduous Wet Forest, type 101 = 1 and all other types = 0. Save the file in folder *cd:\fuelgis\arc\analysis\plantcom\plantcom\ct_input1* as *decidwet*.

8. Determination of the riparian conifer zone cover type for the *base30* grid area

The procedure to determine the riparian conifer zone cover type was as follows: Reclassify classes 13, 14 and 15, Riparian conifer, in the grid *grzveg1* to a 30m grid georegistered to the *base30* grid. Classify the grid with class 1 = Riparian conifer and all other cells = 0 and merge this as the second file with a reclass of grid *cov_typ4* in which Riparian coniferous zone, type 109 = 1 and all other types = 0. Save the file in folder *cd:\fuelgis\arc\analysis\plantcom\plantcom\ct_input1* as *conripar*.

9. Determination of the aspen cover type for the *base30* grid area

The procedure to determine the aspen cover type was as follows: Reclassify class 10, Deciduous upland, in the grid *grzveg1* to a 30m grid georegistered to the *base30* grid. Classify the grid with class 1 = Deciduous upland and all other cells = 0 and merge this as the second file with a reclass of grid *cov_typ4* in which Aspen upland, type 102 = 1 and all other types = 0. Save the file in folder *cd:\fuelgis\arc\analysis\plantcom\plantcom\ct_input1* as *aspen*.

10. Determination of the shrub uplands cover type for the *base30* grid area

The procedure to determine the shrub uplands cover type was as follows: Reclassify class 3, Deciduous, in the grid *usu_ct* to a 30m grid georegistered to the *base30* grid. Classify the grid with class 1 = Deciduous upland and all other cells = 0. Reclassify class 11, Shrub upland, in the grid *grzveg1* to a 30m grid georegistered to the *base30* grid. Classify the grid with class 1 = Shrub upland and all other cells = 0. Use map calculator to OR these two grids together.

Merge the OR'ed grid above as the second file with a reclass of grid *cov_typ4* in which Shrub uplands, type 9 = 1 and all other types = 0. Save the grid as *cd:\fuelgis\arc\analysis\plantcom\plantcom\ct_input1\shub*.

The *usu_ct* classification includes most of the shrub uplands in class 3 (Deciduous), but this includes aspen as well (class 3 should be aspen in usu_ct, however about half of the time it actually represents shrub uplands; the shrub layer, type 18 is very poorly classified, and is unreliable). The grids of shrub uplands produced from the Utah data are understood to include these misclassified aspen stands.

11. Determination of the coniferous canopy cover level for the *base30* area

The coniferous forest types and shrub-steppe cover types required determination of the canopy cover level prior to classification. Canopy cover represents overstory (>10m ht) coniferous canopy cover and is assessed from 0 to 100% in ten 10% increments and 0, i.e., 0, 1-9%, 11-19%, etc. Canopy cover is only assessed for cover types of shrub-steppe, canopy openings, riparian conifer and conifer >20%.

The procedure used to determine the canopy cover for the *base30* grid was as follows. The project file containing the data and procedures is *cd:\fuelgis\arc\analysis\pattern\conif-cover01.apr*

a. Use map calculator to merge the non-coniferous layers created in steps 2-10 of this appendix. ([Shrub]) or ([Aspen]) or ([Decidwet]) or ([Marsh]) or ([Agric]) or ([Devel]) or ([Rock]) or ([Water]). Save this grid as *cd:\fuelgis\arc\analysis\plantcom\plantcom\ct_input1\notconif.*

b. Reclassify the *notconif* grid so that non-coniferous type 1 becomes type *NoData* and all other types become class 1. Resample the cell size to 2m. Name this grid *cd:\fuelgis\arc\analysis\pattern\patinput4\coniftyp*.

c. Create a mask that combines both the SWA stands and the non-coniferous areas using map calculator. Save the grid as *cd:\fuelgis\arc\analysis\plantcom\plantcom\naconswa*.

d. Convert the tif images of the quads overlapping the *base30* grid into grid files with 2m cell sizes. Use the script *grid-clip-by-grid.ave* to clip the orthophoto grids to the same extent and registration coordinates of a 2m cell grid *base2m* which is also registered to the extent of the *base30* grid.

e. Reclassify the quad grids into 2 classes with trees and shadows classed as 1 and all other values as *NoData* (openings). The different quads had different brightness values, so different reclassification intervals were used to obtain the best discrimination between trees and openings, as shown in Table App-D-1.

Table App-D-1. Classification intervals for USGS quads adjacent to the SWA.

Quad	Filename	Classification interval of trees and shadows
Aeneas Lk (2m)	aen84	0-84
Blue Goat Mt (1m)	blue16	0-63
Conconully E (1m)	conce16	0-63
Conconully W (2m)	concw135	0-135
Coxit Mt (2m)	cox135	0-135
Duncan Ridge (2m)	dunc135	0-135
Enterprise (2m)	ent79	0-127
Loomis (1m)	loom16	0-63
Riverside (2m)	riv89	0-127

Files were stored in the folder *cd:\fuelgis\arc\analysis\pattern\patinput4*.

f. Use the map calculator to AND grids *coniftyp* and each of the above quads of tree cover. Save the grids in the folder *cd:\fuelgis\arc\analysis\pattern\patinput4* with a "tr" prefix, e.g., *traen*, *trloom*, etc.

h. Some of the above grids overlapped the SWA stands and had to be clipped. This required the use of a mask of the SWA stands created by dissolving all the SWA stand polygons and converting the resultant file *cov_dissolve_all.shp* to a grid which then is aligned to the grid *base2m* with the script *clip-by-grid.ave*. The grid was saved as *cd:\fuelgis\arc\analysis\pattern\patinput4\covswa1m*. The cell size is 1m. Cells within the SWA stand boundary have a value of 1, cells outside the stands have a value of 0.

The mask grid of SWA stands was resampled to 30m and saved as *cd:\fuelgis\arc\analysis\pattern\patinput4\covswa30*.

Use map calculator to AND the *covswa1m* grid with the grids *trloom, trblue trconw, trcox* and *trcone*. Reclassify the result so that values of zero overlapping the SWA stands are classified as *NoData* and save the results in the folder *cd:\fuelgis\arc\analysis\pattern\patinput4* as *trloom3*, *trblue2*, *trconw2*, *trcox2*, and *trcone2*.

i. Set the analysis properties cell size to 30m and sum the above grids using a 15 X 15 block neighborhood statistic. (There was a problem in the second run of the neighborhood statistics routine. Arcview caused the output cell size to be 2m rather than 30m. To correct the problem, the 2m grids were nearest-neighbor resampled to 30m cell size). Save the created grids in the folder *cd:\fuelgis\arc\analysis\pattern\patinput5* as *trloom30, trblue30*, etc.

j. Mosaic the 30 m summary grids. Each 30m cell contains the count of the number of 2m pixels which were summed within it. The maximum value of a cell is 225 (30^2 / 2^2 = 900/4).

k. Reclassify the mosaiced grid as follows so that values falling within the original interval become classified as the target cell value. The shadow factor is a rough estimate of the inverse percentage of shadow contained within the combined cells representing trees and shadows. The shadow factor is assessed on a sliding scale so that it cannot exceed 100%, which accounts for overlapping trees at high densities. The file is saved as *cd:\fuelgis\arc\analysis\pattern\patinput5\mos_rcl*.

Table App-D-2. Reclassification values for grid *mos_rcl* determined from shadow factors.

Desired classification	Target cell value midpoint of % canopy cover)	No. 2m Cells / 30m cell	Shadow Factor	Factored Original Interval
0-10%	5	0-23	1.35	0-30
11-20%	15	24-45	1.30	31-59
21-30%	25	46-68	1.25	60-85
31-40%	35	69-90	1.20	86-108
41-50%	45	91-113	1.15	109-129
51-60%	55	114-135	1.15	130-155
61-70%	65	136-158	1.10	156-173
71-80%	75	158-180	1.05	174-189
81-90%	85	181-203	1.00	190-203
91-100	95	204-225	1.00	204-225

l. Reclassify *NoData* cells in *mos_rcl* as 0 and name the result as *cd:\fuelgis\arc\analysis\pattern\patinput5\mos_rcl*2.

m. (Steps m and n can be shortened to a single step by using grid *naconswa* to simultaneously exclude SWA stands and non-conifer stands). Combine the grid *mos_rcl2* with the grid *covswa1m* of stands overlapping the SWA and reclassify the values to restore the target value midpoints in the table above, with the addition of 0 values for treeless cells, and -1 to represent the SWA stand overlap. Rename the grid as *cd:\fuelgis\arc\analysis\pattern\patinput5\mosrcl3*.

n. Combine the grid *mos_rcl3* with the grid *notconif* of non-coniferous and non-shrub-steppe cells and reclassify the values to restore the target value midpoints in the table above, with the addition of 0 values for treeless cells, and -1 to represent the SWA stand overlap. Rename the file as *cd:\fuelgis\arc\analysis\pattern\patinput5\mosrcl4*.

The best match of the grid shrub-steppe regions was apparently that of the *nhi* classification.

The shrub-steppe regions (conifer < 20%) were misclassified most seriously in the region of the Aeneas quad, in areas that had greater ponderosa pine cover than indicated by the grid *mosrcl4*.

o. To correct this, the *nhi* type 7, Ponderosa pine, was classed as 25% conifer, and merged with *nacoswa* to mask out the SWA and non-conifer stands. This was then merged as the first grid with *mos_rcl4* to create *cd:\fuelgis\arc\analysis\pattern\patinput5\mos_rcl5* replacing values 0, 5, and 15 with value 25.

p. A second correction used the *nhi* type 5, Eastide Interior Mixed Conifer, and reclassified it as 35% conifer, then merged it with *nacoswa* to mask out the SWA and non-conifer stands. This was then merged as the first grid with *mos_rcl5* to create *cd:\fuelgis\arc\analysis\pattern\patinput5\mos_rcl6* with value 35 replacing values 0, 5, 15, and 25 in *mos_rcl5*, but only where there was overlap between these two classes of cells on the two different grids.

The grid *mos_rcl6* represents the final determination of canopy cover outside the SWA stands, for this section of the analysis.

12. Determination of the cover types for shrub-steppe and montane canopy openings within the SWA stands area

a. Reclassify grid cc_cov into 11 intervals of 0%, 1-9%, 11-19%, etc, and rename the grid as *cd:\fuelgis\research\1183\can\psigrd30\cc_cov10*.

b. Register the 1m grid *treeopen* created during the patch pattern analysis) to the extent of covswa1m using script clip-grid-by-grid.ave. Save this grid as *cd:\fuelgis\arc\analysis\plantcom\plantcom\swa_stands\treeopn1*.

c. Resample the 1m grid *treeopn1* to 30 m cell size and rename as *cd:\fuelgis\arc\analysis\plantcom\plantcom\swa_stands\treeop30*.

d. Clip this grid to the extent of *covswa30* to remove *NoData* cells outside the SWA boundary, and rename it as *cd:\fuelgis\arc\analysis\plantcom\plantcom\swa_stands\trop30c*.

e. Create cover type 5 - Shrub-steppe (conifer < 20%). Combine grids *trop30c* and *cc_cov10*. Select cell values where *trop30c* = 0 and *cc_cov10* = 0, 5 or 10 . Reclassify data values as 5 and rename this grid *cd:\fuelgis\arc\analysis\plantcom\plantcom\swa_stands\ss*.

Create a sectond grid *ss2* in the same folder which just contains values of the grid cov_typ4 = 5 (shrub-steppe) or 0. This will be used later on.

f. Create cover type 10 - Montane Canopy Openings (conifer < 20%). Combine grids *trop30c* and *cc_cov10*. Select cell values where *trop30c* = 3 or 4 and *cc_cov10* = 0, 5 or 10. Reclassify data values as 10 and rename this grid *cd:\fuelgis\arc\analysis\plantcom\plantcom\swa_stands\can_open*

g. h, i. Create cover types for conifer cover types 110, 130 and 160 as above and store in the same folder.

13. Determination of the coniferous canopy cover for the SWA stands area

Follow step 12a and from grid *cc_cov10*, select cells of value 25-95 and use the selection to create a new grid representing conifer cover named *cd:\fuelgis\arc\analysis\plantcom\plantcom\swa_stands\conswa*.

14. Merge the shrub-steppe and canopy openings for the base30 area and SWA stands

Region-group the base30 registered grid *s_steppe*, and then calculate the zonal thickness, and reclassify the result so that values < 100 become 10 (canopy openings) and values ≥ 100 become 5 (shrub-steppe). Merge the SWA stands grid *can_open* as the first grid, then the SWA stands grid *ss* as the second grid and then merge the result with the reclassed thickness grid made from *s_steppe* as the third grid. Name the resultant grid *cd:\fuelgis\arc\analysis\plantcom\plantcom\merged\ss_open*.

15. Merge the coniferous canopy cover for the base30 area and SWA stands

Merge the SWA stands grid *cc_cov10* as the first grid with the base30 grid *mos_rcl6*, and name the result as *cd:\fuelgis\arc\analysis\plantcom\merged\con_can*.

16. Merge the different cover types

a. Merge grids one by one in the following order, after reclassifying data cell values to the target cover type code. Following each merge operation, first-merged grids are reclassified to have *NoData* Values for non-data, second-merged grids to have a value of 0 for non-data:
98 Water + 97 Devel + 99 Rock + 6 Agric + -> to101
5 & 10 Ss_open + to101 -> tempgrid
101 decidwet + tempgrid -> to102
1 marsh + tempgrid2 -> tempgrid3
109 conripar + tempgrid3 -> tempgrid4
tempgrid4 + 9 shrub upland + 102 aspen -> to102

It was noted that the merging of grid *ss_open* into the SWA stands area replaced some open pine regions with shrub-steppe. This results in a technical misclassification (although it may be more correct on the ground). Misclassifications are cleaned up in a final step further on.

17.a. Experiment to determine a method for using map coincidence for determining PNV

In order to generate maps of potential natural vegetation (PNV), it was necessary to determine which data from different sources was the most accurate. The method described here, coincidence mapping, was designed to compare different overlapping vegetation grids by determining the cover type of every cell in all of the grids. Each cell of each input grid was evaluated by AND-ing the overlap and by OR-ing the overlap, and the resulting two grids were used to define the minimum and maximum extent of that cover type. The procedure involves creating a “coincidence layer” with values to represent the overlap where all overlapping grid cells are in agreement, followed by a determination of the percent of each grid that matches this coincidence layer. Steps 17.b and 17.c. below complete the generation of maps of cover types using coincidence mapping.

From each of the following cover type grids, new grids were created representing only ponderosa pine as value 1 all other cells as 0. The grids were added together with Map calculator and the result in each non-zero cell added to 10 (so that values were 0, 11, 12, and 13 representing respectively, no, 1, 2 or 3 grids with original overlapping cells of value 1).

Table App-D-3. Grid files used for ponderosa pine cover type map coincidence.

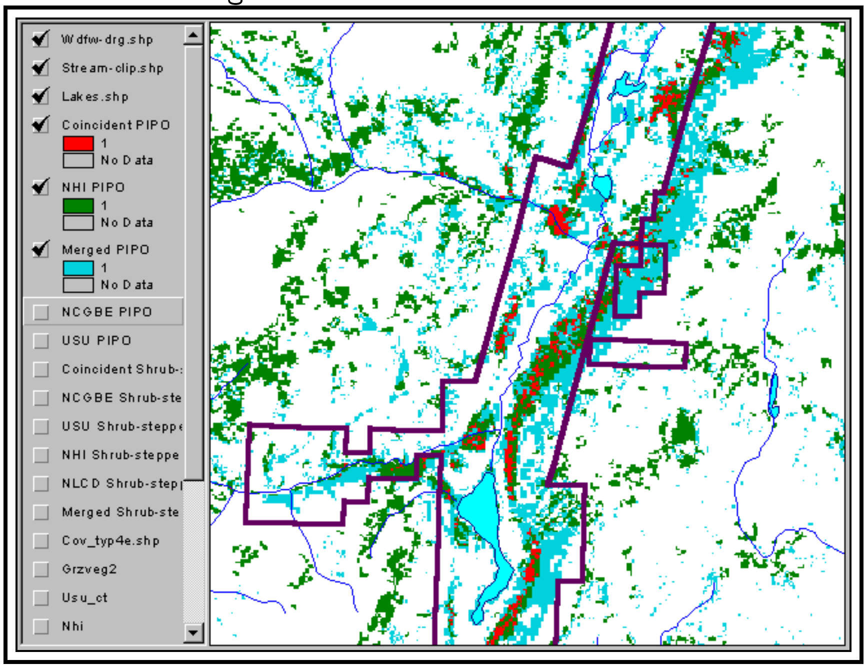
Data source	PIPO types used	PSME-PIPO types not used	PSME types not used	Output file
Grzveg2	2 PIPO	3 PIPO-PSME	4 PSME-Mixed conif E	grzpipo1
Usu_ct	15 PIPO	16 PIPO-PSME	4 PSME, 25 Dry mixed forest, 27 western larch	usupipo1
NHI	7 PIPO	5 Eastside interior mixed conifer	04 Montane mixed conifer	nhipipo1

Table App-D-4. The amount of coincidence for each of the layers with the merge of all of these layers, calculated using Analysis -Tabulate Areas, with the following results.

Layer	Ponderosa pine coincidence with merged
NCGBE (Grizzly Bear Habitat Study)	65,888 / 236,486 (28%)
Utah State Univ / BioWest	109,721 / 236,486 (46%)
NHI	137,333 / 236,486 (58%)

The number of cells in which all grid cells had coincident values (i.e., they were classified identically) were calculated as 10,982 cells or 5% of the merged ponderosa pine layer.

The highest coincidence with the merged ponderosa pine layer was that of the NHI data, depicted below in green, with the coincidence of all layers overlaid in red, and the remaining non-coincident merged PIPO cells in blue.



Because of this low level of coincidence in this case, multiple values were used to rate the degree of coincidence in developing a map of PNV zones.

The following reclassifications were used to derive other coincidence layers:

PSME-PIPO

Data source	PSME-PIPO types used	PSME types not used	Output file
Grzveg2	3 PIPO-PSME	4 PSME-Mixed conif E	grz03
Usu_ct	16 PIPO-PSME	4 PSME, 25 Dry mixed forest, 27 western larch	usu16
NHI	5 Eastside interior mixed conifer	04 Montane mixed conifer	nhimont

PSME-upper montane

Data source	PSME-Upper montane	Output file
Grzveg2	4 PSME-Mixed conif E	grzmont
Usu_ct	4 PSME, 25 Dry mixed forest, 27 western larch	usumont
NHI	5 Eastside interior mixed conifer	nhi5mix

PICO-ABLA mix

Data	PSME-Upper montane	Output file

source		
Grzveg2	6 - ABLA-PIEN-PICO E	grzabla
Usu_ct	21 - Subalpine forest mix, 8 - Lodgepole pine	usuabla
NHI	4 Eastside montane mix	nhi4mont

17.b. Determination of forest PNV zones

This procedure was done as a preliminary to the next step in order to generate a grid of plant zones for the SWA.

a. Determine the map coincidence for ponderosa pine (PIPO) cover as grid file *pipo* (for each coincidence determination (see step 17.a., above, for a description of how map coincidence was used in determining PNV forest zones for the base30 area).
b. Determine map coincidence for PSME-PIPO as grid *psmepipo*.
c. Determine map coincidence for PSME-montane as grid *psmemont*.
d. Determine map coincidence for ABLA-PICO mix as grid *abla*.
e. Classify *abla* value 3 as 231, *psmemont* value 3 as 221, *psmepipo* value 3 as 211 and *pipo* value 3 as 201 and add these together with Map Calculator. Reclassify values of 0 as *NoData*.
f. Classify *abla* value 2 as 231, *psmemont* value 2 as 221, *psmepipo* value 2 as 211 and *pipo* value 2 as 201. Use Map Calculator to add *psmemont* as the first grid with *pipo*, then reclassify 0 values in this grid to *NoData*. Next add *abla* as the first grid with *psmepipo*. Finally, merge the last created grid (*abla+psmepipo*) as the first grid with the first created grid (*pipo+psmemont*). Leave values of 0 as 0.
g. Merge the grid created in step e as the first grid with the grid created in step f. Name this grid as *cd:\fuelgis\arc\analysis\plantcom\coincidence\mrg_3_2*.
h. Classify *abla* value 1 as 231, *psmemont* value 1 as 221, *psmepipo* value 1 as 211 and *pipo* value 1 as 201. Merge grid *mgr_3_2* (after first reclassifying values of 0 to *NoData*) in turn with each of the above grids in the order *psmemont, abla, psmepipo*, and *pipo*. Name the grid as *cd:\fuelgis\arc\analysis\plantcom\coincidence\mrgzone*.

17.c. Clean up gaps containing *NoData*

Before completion of the cover types, it is necessary to clean the data.

a. Run a 15 X 15 majority filter on *mgrzone*, and a second 15 X 15 majority filter on the majority filter. Reclass *mgrzone* value 0 as *No-Data* and merge it with the first majority filter, then reclass value 0 as *NoData* again, and merge it with the second majority filter. Rename this as *cd:\fuelgis\arc\analysis\plantcom\coincidence\mrgzone2*. Continue to remove additional stray pixels.

b. Merge *mrgzone2* as the second grid with the grid *to102* and save as grid *to231*. Run a 7 X 7 nearest neighbor majority filter analysis and combine these cells with 0 values of the *to231* grid to get all remaining *NoData* cells either coded correctly or if in regions not filled in by the 7 X 7 majority filter, then still coded as *No-Data*. Reclassify all remaining *NoData* Cells of this to type 211 (PSME-PIPO) and merge this back into the cells of the *to231* grid that are still blank. Rename the result *cd:\fuelgis\arc\analysis\plantcom\merged\to232*.

k.To fill in the few remaining stray single *NoData* Cells, do a 9 X 9 Nearest Nieghbor Majority filter, then expand all zones of all cell values by 2 cells and add this back into grid *to232* and name the grid *to231*. Rename the output file as grid *cd:\fuelgis\arc\analysis\plantcom\merged\ct_swa30*.

18. Clean up the merge of external data sources

a. The merge was cleaned up by replacing cells in the *to102* grid with a grid *nss_ncon* of correctly identified cells from grid *cov_typ4* of value 1, 6, 9, 97, 99, 101, 102, and 109. Name this grid *cd:\fuelgis\arc\analysis\plantcom\merged\to102b*.

b. Grid *to102b* was then cleaned up by replacing *NoData* cells in the *to102b* grid with *grid ss2* with value 5, and setting the result to have a Null values of 0. Name this grid *to102b*.

c. Grid *to102b* was then overlapped to replace misclassified cells in grid *ct_swa*. Rename the result as *cd:\fuelgis\arc\analysis\plantcom\merged\ctswa30b*.

19. Correct shrub-steppe misclassified as conifer and PSME-PIPO misclassified as PIPO

a. Reclass *cc_cov10* values 5, 15 as value 1, other values as *NoData*. Combine this grid with *ctswa30b*. From the result, select all cells where *ctswa30b* = 201, 211, 221, or 231, which are misclassified as conifer that should be shrub-steppe or openings. Reclassify these cells as value 10, and merge them back into *ctswa30b* and rename the result *cd:\fuelgis\arc\analysis\plantcom\merged\ctswa30c*.

Correct conifer misclassified as shrub-steppe in the SWA stands. Reclass *cc_cov10* values 25 - 95 as value 1, other values as *NoData*. Combine this grid with *ctswa30c*.

Select all cell values where *ctswa30b* = 5 or 10 (misclassified as shrub-steppe or openings when it should be conifer) and reclassify these values as value 211, PSME-PIPO, then merge them back into grid *ctswa30c* and rename the result as *cd:\fuelgis\arc\analysis\plantcom\merged\ctswa30d*.

From the last operation, replace misclassified PSME-PIPO that should be PIPO. by expanding the zones of PIPO by 1 cell at the expense of PSME-PIPO cells.

Expand the zones of PIPO, 201 in grid *ctswa30d* by 1 cell. Combine the result with *ctswa30d*. Select cells of *ctswa30d* value 211 that became value 201 during the expand operation, and convert the selection to a new grid. Reclassify the result as value 201 and merge this back into grid *ctswa30d* and rename the result *cd:\fuelgis\arc\analysis\plantcom\merged\ctswa30e*.

This operation was so successful at blocking up the cells and removing stray pixels that it was performed in the reverse direction, in order to expand PSME-PIPO cell values of

211 at the expense of PIPO-PSME value, 201. The result was named *cd:\fuelgis\arc\analysis\plantcom\merged\ctswa30f*.

20. Cleanup expanded region borders

Examination of the grid *ctswa30f* revealed that 1-pixel changes had occurred to the borders of regions at the boundary of the coniferous/non-coniferous interface, where cells grew or shrank from their original locations in grid *cov_typ4*. This operation was performed to restore those changes to their original classification.

a. Combine *ctswa30f* with the *cov_typ4* grid. Select misclassified cells of value 1, 6, 9, 97, 98, 99, 101, 102, and 109 and convert these to a grid. Reclassify original values so that misclassified *cov_typ4* cells are changed as follows:
Original value 5 stays as 5
Original value 110 becomes value 10 (canopy openings)
Original value 130 becomes value 201 (PIPO)
Original value 160 becomes value 211 (PSME-PIPO)

The grid *ctswa30g* is stored in the folder *cd:\fuelgis\1183\cov\psigrd30\ctswa30*. This folder has a subfolder, \versions\, where the cover type grids are moved to as they become updated.

The overall data quality of this grid is better than the cover types mapped by any of the other external layers, partly since it is a product of all of them. The PSME-PIPO and PIPO types are mostly correct within the SWA stands area. Outside the SWA boundary, the cover grid still contains a large number of misclassified cells of PSME-PIPO that should be PIPO or PSME-montane. The ABLA and PSME-montane classes appear to have better classification accuracy, however misclassified openings occur near ABLA and PSME-montane due to assumptions in filling in with the majority filters.

b. A polygon file mask, *cd:\fuelgis\1183\cov\conif_typ.shp*, was created to clean remaining misclassified conifer type cells, by generalizing them to match the stand boundaries and dissolving the stand boundaries to group them further still. The mask was converted to a grid and georegistered to *base30*, the combined with *ctswa30g*. For each combination that is the new cover type 201, 211 or 221, combine these with ctswa30g and reclassify the misclassified tree types as 201, 211 or 221, respectively. Merge all of the grids and rename the new grid *ctswa30h*. This has the effect of eliminating most of the noise within stands, which is not likely to represent an accurate data classification.

21. Create a mask file of coniferous types

a. Create a permanent file used to identify cells as coniferous canopy or not for use in procedures which require canopy cover. The grid *con_area* in the folder *cd:fuelgis\1183\can\psigrd30* was created from grid *ctswa30g*. The cell values where coniferous overstory canopy cover was not determined were classified as 0. These are 1 Marsh & Swamp, 6 Agriculture, 9 Shrub Upland, 97 Developed, 98 Water, 99 Rock, 101 Deciduous Wet Forest and 102 aspen.

The other cells where coniferous canopy cover is explicitly mapped by the *ctswa30* grid were classified as 1. These are 5 Shrub steppe, 10 Canopy openings, 109 coniferous riparian, 201 PIPO, 211, PSME-PIPO, 221 PSME montane and 231 ABLA-PICO.

b. Remove *con_can* cells of value -1. Shrink grid *con_can* value -1 by 9 cells. Reclass the shrink to reclassify cells of value -1 to value *NoData*, clip the grid by *con_area* 0-values and perform a mean filter with a 7 X 7 window, then reclass this to the original integer values, clip it by the *con_area* 0-values again, and merge it as the first grid into *con_can* and rename the result *con_can2*.

c. Remove the remaining regions of cells of value -1 from *con_can2* as follows. Make a clipping grid from cells of value -1. Shrink value -1 by 9 cells. Clip the shrink with the clipping grid and merge the clip back into the original grid *con_can2*, then rename the product *con_can3*.

Save this grid as it can be used to regenerate a background canopy grid for future changes.

d. Use the *con_area* grid to clip the grid *con_can3* and rename the result as grid *con_can3b*.

Appendix Analysis-E. 2004 Field Data

This appendix information about field data, including brief descriptions of data collected during 2004, a description of the procedure for merging 2003 and 2004 data, and a sample 2004 plot form. Additional data collection procedures are included with the plot form documentation, and in phase 1 of the report.

Merging 2003 and 2004 data

The attribution of cover types in file *Cov_typ* required consistency in the definitions used for 2003 and 2004 field data. The field data was summarized in a Paradox summary table named *SWASUM.DB*. Some of the data in SWASUM.DB was summarized from mean values within categories of fuel loadings, seedlings or saplings, and basal area. The raw data from these files is contained in subfolders of the /fielddata/database/ folder. In 2004, additional field visits were made to collect additional data on fuel loads, and to verify the accuracy of the cover type classification.

The 2004 field plot data was not added to the set of original field plot data. Instead, selected fields from the 2003 and 2004 data tables were merged as needed. Procedures for merging the 2004 data with the 2003 database file, *Plots-2003-12-16.mdb*, are given below:

1. Summarize snag overstory categories 5-12", 12-24" and >24" into a single category that is the greater of either the first two categories or the first plus the second category.
2. Transfer the values of 2003 records from the field *HerbGram* (live herbaceous <6’) to the field *HerbPct* and from the field *Wood<6* (live woody shrubs <6') to the field *ShrubPct*.
3. Transfer the total canopy cover from the Species table of the 2003 records, field *TreePct*, to field *Can>6*.
4. Transfer values for overstory canopy coverage from the Species table of the 2003 records rounded to the nearest 5.
5. Transfer the values of species percent cover for each category of tree, shrub, and herb from the first two records in the 2003 database for each of those categories. Only two records from each category are contained in table *SWASUM*, so some data is lost in this process. In cases where the first two plants include an artificial plant group (e.g., “*GRASS*”) or where there is a near-tie in plant cover between the abundance of the second and third records, the record used was the one most indicative of the plant association. For example, if the first record was AMAL=5%, the second was OTHER=1% and the third was SYAL=0% (trace), then SYAL=0% was used in preference to OTHER=1% as the attribute for the second plant cover value.
6. Transfer the values of 2003 records for grass cover from the Species table to the field *GramOnly*. Estimates of species cover were increased slightly (nominally, 5-20%), if there were many unknown species, or lowered in the case of obvious recording errors where the total abundance for all herbaceous plants was lower than for an individual plant.

7. Estimate 2003 values for dead woody cover <6' and dead herbaceous <6' from photos.
8. Merge the tables.
9. Fill in blank values for the 2004 records using Arcview queries and displays of the topographic layers, orthophotos and field exams locations.
10. Change the field *Asp* (aspect) from numerical degrees to cardinal coordinates, e.g., N, S, W, and E. Further divisions of the octants was allowed, e.g., SSE.
11. Score the field *Std_Slo* in *SWASUM* in one of 5 steepness categories as follows: 0=0-4%, 5=5-19%, 20=20-34%, 35=35-66% and 67=>67%. The values for *Std_Slo* in table *SWASUM* are based on field data, while the values of *Std_Slo* in the table *Cov_typ* are derived by transferring the values from a grid file of slope, reclassified into the above categories (see Appendix A and below under aspect and slope).
12. If the slope of the stand is >35% and the aspect of the stand is northerly, i.e., lying predominantly between 315 and 360 degrees or 0 and 45 azimuth (Asp=NW, NNW, N, NNE, or NE), then score the value in Std_Slo as 35N.
13. Enter the values for 2004 fuel loads.

2004 plot form variables collected

This section describes the procedures for data collection used in 2004.

<u>Crown fuels</u>

- Canopy Cover (%). This is an estimate of the percent canopy cover of the highest stratum that contains at least 10 percent crown cover. This is a modified canopy cover estimate derived from the Nature-Serve canopy determination which estimates canopy above 2m regardless of the species group or highest stratum height. This value is used to estimate crown bulk density for crown fire spread modeling. Be sure the estimate cover as percent vertically projected canopy cover and includes cover for all species.
- Stand Height (ft). Estimate the height of the highest stratum that contains at least 10 percent crown cover. This value is used to model crown fire spread.
- Canopy Fuel Base Height (ft). This is the lowest point above the ground at which there is a sufficient amount of canopy fuel to propagate a fire vertically into the canopy. Canopy fuel base height is a stand level measurement that provides an index for crown fire initiation and should account for dense dead vertical fuels (e.g., lichens, needle-drape, dense dead branches) that could provide a conduit for entrance of a surface fire into the crown.

<u>"Woody" and "non-woody" vegetative fuels</u>

- % cover of live woody species.
- % cover of dead woody species.
- average height of live and dead woody species.
- % cover of live herbaceous + graminoid species.
- % cover of dead herbaceous species.
- % cover of graminoid species only.

- average height of live and dead herbaceous species.

Canopy characterization

- percent cover of all overstory conifers (> 30’)
- percent cover of all medium sized conifers (10-30’)
- percent cover of all short conifers (0 - 10’)
- percent cover of all overstory woody species (> 30’)
- percent cover of all medium woody species (10-30’)
- percent cover of all short woody species (0-10’)

Dominant species

- name of commonest tree species in the overstory
- total % cover of this species
- % cover of this species in the overstory only (> 30’ height)
- name of 2nd-commonest overstory tree species
- total % cover of this species
- % cover of this species in the overstory only (> 30’ height)
- name of commonest woody broadleaf species
- % cover of commonest woody broadleaf species
- name of 2^{nd}-commonest woody broadleaf species
- % cover of 2^{nd}-commonest woody broadleaf species
- name of commonest herbaceous or graminoid species
- % cover of commonest herbaceous or graminoid species
- name of 2^{nd}-commonest herbaceous or graminoid species
- % cover of 2^{nd}-commonest herbaceous or graminoid species

Bare ground characterization

Duff - litter & bare ground characterization

- Duff/litter. “Litter” is the loose layer made up of twigs, dead grasses, recently fallen leaves, needles where the individual pieces are still identifiable and little altered by decomposition. The “duff” layer lies below the litter layer and above the mineral soil. It is made up of litter material that has decomposed to the point that the individual pieces are no longer identifiable. The “duff/litter profile” is a cross-section that extends vertically from the top of the mineral soil to the top of the litter layer.
- % of bare ground not obscured by vegetation or litter, visible from 5’ height.

Fuels characterization

Dead and Down Woody Debris (DWD), sampled along a 75-foot transect tape

- tons/ac 1-hr fuels (FWD 0-0.25")
- tons/ac 10-hr fuels (FWD 0.25-1")
- tons/ac 100-hr fuels (FWD 1-3")
- tons/ac of 1000-hr fuels coarse woody debris (CWD, >3" thick & > 3’ long).

Plot # 0 4 _ _ | **Observer** ______________________________ **Date** _ _ _ _ - _ _ - _ _

Location: ______________________________ | **Wpt #** _____ **Wpt Acc** ____m

______________________________ | **Photo #s** ______________

______________________________ | ______________

Site Description and Notes: ______________________________ | **Cover Type**: ______________

______________________________ | **PNV**: ______________

____

Tot Canopy >6'	%	(Sp. is 'NA' if 0, otherwise 0=trace)	Tot % Cover		
Conifer >30' (non-exclusive)	%	1° tree species:	%		
Conifer 6-30' (")	%	2° tree species:	%		
Broadlf >30' (")	%	1° shrub species:	%		
Broadlf 6-30' (")	%	2° shrub species:	%		
<6' Live Woody	%	1° herb species:	%		
<6' Dead Woody	%	2° herb species:	%		BAF=
<6' Live herb + graminoid	%	Stems 0-5" (**Dom sp**. _______ **Cond**: ___)	spcng'	or tpa	In=
<6' Live graminoid only	%	Stems 5-12" (**Dom sp**. _______ **Cond**: ___)	spcng'	or tpa	In=
<6' Dead herb + gram	%	Stems 12-24" (**Dom sp**. _______ **Cond**: ___)	spcng'	or tpa	In=
Bare <3" dia in stand @ 5' ht	%	Stems >24" (**Dom sp**. _______ **Cond**: ___)	spcng'	or tpa	In=
Rock >3" dia in stand @ 5' ht	%	Snags >12" X 6' ht	spcng'	or tpa	

Avg Ht' Canopy >6': _____ **Base ht'**: _____ **Crown ratio%**: ____ **Ht' live+dead woody <6'**: _____ **Ht' Live herb+gram <6'**: ____

Tsect# / azimuth from cntr	|	|	|	|	|	|	|	|
% Slope (if > 20%)								
FWD <1/4" counts @15-21'								
FWD 1/4"-1" counts @15-21'								
FWD 1"-3" counts @15-30'								
>1 reading: Duff+Litter depth" / Litt% of	|	|	|	|	|	|	|	|

CWD >3" @15-75'

TSect #	|	|	|	|	|	|	|	|	|	|	|
Dia | Decay	|	|	|	|	|	|	|	|	|	|	|
TSect #	|	|	|	|	|	|	|	|	|	|	|
Dia | Decay	|	|	|	|	|	|	|	|	|	|	|
TSect #	|	|	|	|	|	|	|	|	|	|	|
Dia | Decay	|	|	|	|	|	|	|	|	|	|	|

Canopy is >6' w/>10%cov **Trees**=PIPO, PSME, PICO, LAOC, POTR, POTR2, ALIN, BEOC, SAAL, ROPS, ULSI
TPA/Spacing:209'=1; 147'=2; 93'=5; 66'=10; 47'=20; 30'=50; 21'=100; 15'=200; 10'=500; 6.6=1K; 4.6'=2K; 3'=5K; 2.1'=10K
Ac=43560sqft=.405ha | =150X290', 175X249' | =209'sq, 235.5'dia | 0.1 ac=74.5'dia | 0.01 ac=23.6'dia
0.001 ac=7.45'dia | m=3.28'=39.37" | ft=0.3048m
Tree spacing is for stems > 10' tall; avg cond (up to 2) of: Crowded=unshaded, Suppressed=shaded, Moderate, Vigorous
Fuels 1-hr<1/4" 10-hr=1/4-1" 100-hr=1-3" 1000-hr=>3" **Fuel Transects** are 6' ht; sampled up to 100 pcs FWD
Decay 1=bark intact 2=some bark gone 3=most bark gone 4=unsound 5= all rotten

Appendix Analysis-F. Using Fire behavior modeling programs for the SWA Fuel Reduction Plan

The following procedures and files were used in modeling fire behavior on the SWA using the software FARSITE and Flammap by Mark Finney (2003, 2001, 1998, 1996). In this file, files and buttons are italicized and default parameters are highlighted in green; optional parameters used in only limited circumstances are highlighted in yellow; parameters varied depending on circumstances are highlighted in blue.

FARSITE: Quick start instructions
Before starting, be sure all input files are in the same folder, e.g., *farsite/input*. Then start the FARSITE executable module. Click *Input - Bookmarks* and load *sinla-may.bmk*, or create a new landscape file.

Landscape file creation

If a landscape file is not already created Select *Input - Landscape Utilities - Generate Landscape File* and make the following settings:

Latitude = 49
Distance units = meters
Elevation ASCII = *elev.asc* (feet)
Slope ASCII = *slope.asc* (degrees)
Aspect ASCII = *aspect.asc* (degrees)
Fuel Model ASCII = *fuelmod.asc* (categorical values)
Canopy Cover ASCII = *cancov.asc* (%)
Crown height = grid *ht*, with values of 0, 30, 50, 60, 70, 90 feet
Crown base = grid *crnbase*, with values of 0, 2, 3, 5, 10, 20 feet
Crown bulk = grid *cb*, with values of 0, 2, 4, 5, 7 and units of 100* kg/m^3
Coarse woody theme = grid *coarse*, linking to the Coarse woody profile text file
Description = a reminder of why the Landscape file was built.

Click the *Save File* button to save the Landscape file (*SINLA-1.LCP*), and also click *Bookmarks - Save Bookmarks* (*sinla-may.BMK*).

Example set up procedure for a burn simulations:

There are two sets of fire weather conditions set up to run in Farsite. One set of files is set up for simulated controlled burning on May 2 from 8am to midnight, and the other is setup to run on August 17 from 8am to midnight, to represent 80th percentile fire weather conditions. The following example is for May.

Click Input - Bookmarks and load *sinla-may.bmk*
Click the *Input - Project Inputs* (*sinla-may.FPJ*)
Confirm that the following have been loaded:

Landscape file (*SINLA-1.LCP*)
Adjustment Factors file (*SINLA.ADJ*).
Initial Fuel Moistures file (*sinla-may1.fms*; all values are 1.0)
Skip Loading the Conversions file

Custom Fuel Models file (*sinla.fmd*)
Weather file(s) (*sinla-may1-5.wtr*)
Wind file(s) (*sinla-may1-5.wnd*)

Optional:

Click the *Attached Vector Files* button and load any Arcview shapefiles.
Load the Burn Period file (**.BPD*)
Load the Coarse Woody Profiles (*sinla-may1-5.CWD*)

After any changes be sure to click the *Save Project* button (*sinla-may.FPJ*).
and the button *Bookmarks - Save Bookmarks* (*sinla-may.BMK*)

Display the landscape

Click Simulate - Initiate/Terminate or click the  button. The *Landscape* and *FARSITE Simulation Legend* windows will appear in random colors. To also display any of the attached shapefiles, click the 2D check box for them in the *Simulation Legend* window. To change the colors of the Legend, right-click in the *Visible Theme* window to and from the *Choose Color Ramp* dialog box, set up a new color scheme or load a pre-exisiting color file, e.g., *SINLA-ELEVATION01.CLR, sinla-fuelmod.clr*.

Set Model Parameters and Duration

Right-Click Model - Parameters. Default units should be acceptable:

Time Step = 30 min. The maximum time that the conditions at a given point are assumed constant so that the position of the fire front can be projected. The range should be between 5 and 120 minutes.

Visible Steps = 2 hrs. This is the screen redraw rate for the fire front.

Permieter Resolution = 60 m. This is the resolution that determines the maximum distance between points used to define the fire perimeter. Using a perimeter resolution that is several times longer than the raster resolution would allow the fire to skip-over variations in fuels or topography that have a finer scale, for example if FARSITE is used to simulate large, 30,000 ha fires at a resolution of 30 m. Perimeter resolution should logically be no more than about twice the raster resolution (30 m).

Distance Resolution = 30 m. This is the maximum projected spread distance from any perimeter point that cannot be exceeded in a time step before new fuels, weather, and topography data are used to compute a new spreading rate.

Units = Metric.

Import an Ignition

Click *Simulate - Modify Map - Import Ignition file* (*sinla-may-perim-5-pt.shp*), or locate a new ignition location.

Locate an Ignition

To locate a single point ignition select the *Simulate - Modify Map - Locate* Ignition(s) command or click the  button. The status bar will show you are in the IGNITION

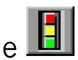
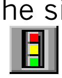
MODE and the cursor will be a drip torch when inside the landscape window. Move the drip torch cursor into the landscape window, and first left-click the mouse, then right-click without moving your mouse and a small white "+" will show on the landscape to depict the point of ignition. Click the button to exit the IGNITION MODE and the status bar will change back to NULL MODE. To locate multiple ignitions, click the cursor.

To save a set of ignitions before starting a burn, click *Simulate - Modify Map - Export Current Fire Perimeters.*

<u>Import an Ignition</u>

Click *Output - Current Time* and *Output - Elapsed Time* to follow the progress of the simulation.

<u>Start a simulation</u>

To start a simulation, click *Simulate - Start/Restart* or click the  button. A progress dialog box appears showing the status of the fuel moisture calculations and the status bar indicates SIMULATION RUNNING. As a default FARSITE will first calculate all the fuel moistures for the entire simulation. Do not attempt to suspend the simulation during the fuel moisture calculations.
As the simulation progresses, click the Simulate - Suspend /Resume command or click the  button to toggle the simulation to suspend or resume.

<u>To save the fire perimeter</u>

Click Simulate - Modify Map - Export Current Map Perimeters

To change parameters, it may be necessary to first click *Simulate - Reset* to allow recalculation of the fuel moistures, but it will be necessary to re-import the ignition points and re-set the duration.

Procedures for setting up and using FARSITE

<u>Model - Fire Behavior Options</u>
Enable Crownfire = No. This option enables a surface fire to make the transition to some form of crown fire depending on the crown fuel conditions and surface fire behavior. Selecting this option does not force a crown fire, but allows the *FARSITE* model to determine if transition occurs
Link Crown Density & Cover = No. This option forces the simulation to use the crown cover attributes for each cell to modify the crown bulk density values for that cell. DO NOT select this option if your crown bulk density theme in your Landscape (.LCP) File contains site specific crown bulk densities that are already representing actual variability of crown fuels.
Embers from Torching Trees = No. If the crown fire calculations are enabled, embers may be lofted by torching trees. Embers of a given size class are lofted and their contact points with the landscape are computed by iterating their descent through a modeled wind field.

Enable Spot Fire Growth = No. This option will enable a variable percentage of embers that land on receptive fuel to ignite new fires. The simulation will grow each of these as new point ignitions.

Ignition Frequency (%) = 5%. The slider changes the percentage of live embers that cause ignitions. This setting is NOT equivalent to a calculated Probability of Ignition. Simulations takes too long for most purposes with the many spot fires started when the ignition frequency is near 100%. In most situations the ignition frequency should be set at less than 10%.

Ignition Delay (mins) = 0. The Ignition Delay time is simply the time between a ember landing and when it begins a spot fire.

NWNS Backing ROS = On. This option forces the use of the No-Wind No-Slope (NWNS) rate of spread for the spread rate of backing fires (Rothermel 1983). This has been proposed as a solution to problems of fire area with increasing wind speed if the origin of fires assumed to coincide with the rear focus of an ellipse (Bilgili and Methven 1990); if not selected, the backing spread rate is computed as a product of elliptical dimensions

Expansion Correction = (grayed out). This option attempts to eliminate illogical expansions of the fire perimeter at each time step. These illogical expansions are caused by small local concavities involving a series of three perimeter points; the orientation off these points forces them to cross over previously burned areas. Enabling this option will not affect the fire shape at the scale of the whole fire, but will affect some localized concave portions of the perimeter. These operations also increase the processing time for the simulation.

Fire Level Distance Checking = On. Distance checking compares the advance of the simulated fire perimeter to the values of the Distance and Perimeter Resolutions set in the "Parameters" dialog box. If the simulated fire reaches either the Distance or Perimeter Resolution within a time step, *FARSITE* recalculates the fire behavior characteristics. This prevents fast simulated fires from skipping over changes in the landscape. The two choices in the *Fire Behavior Options* dialog box are to compare either the maximum spread of an individual fire or the maximum spread of all simulation fires.

Simulation-Level Distance Checking is required if the simulation includes post-frontal combustion. FARSITE won't let you select the *Fire-Level Distance Checking* radio button if the *Simulate Post-Frontal Combustion* checkbox is selected in the *Post-Frontal Calculations* dialog box.

Model - Fire Acceleration

Acceleration = OFF. Fire acceleration is defined as the rate of increase in spread rate/fire line intensity from a given source. Fire acceleration from a point source fire will be slower than from a line fire. A point fire is one with a perimeter length shorter than the threshold for transition to a line fire.

Load/Save Fire Acceleration (.ACL) File. All acceleration definitions can be saved and retrieved as a binary Fire Acceleration (**.ACL*) file. This file can only be created or edited by using the *Model - Fire Acceleration* command.

Fuel Model. This button allows fuel types to be applied to fuel model numbers. For each fuel model that you select with the slider, click once on the appropriate fuel type buttons on the lower left of the dialog box (Grass, Shrub, Timber, Slash, and Default).

Notice that previously defined values for these fuel types now appear in the constant and 90% equilibrium box.

Fuel Types. This button defines the fuel type for fire acceleration, which can be adjusted for point and line source acceleration constants until the user is satisfied with the 90% equilibrium time for that constant and fuel type. *Default* values can also be defined in this same way.

Model - Post-Frontal Combustion

Simulate Post-Frontal Combustion = Off. The Post-Frontal Combustion model simulates both flaming and smoldering fire activity behind the flaming front. This allows calculations of heat flux and emissions so that impacts such as smoke production and soil heating can be simulated. Post-Frontal Combustion requires two optional raster themes: *Duff loading* and *Coarse Woody Debris*. Like some other themes these can be entered as constants across the entire landscape. The Post-Frontal Calculations are very intensive and will increase the run time of the simulation several times. Simulation-Level distance checking is required and will be automatically selected if the simulation includes post-frontal combustion. To simplify fire behavior modeling for the SWA stands, post-frontal combustion modeling was done with crown fire enabled, spotting off, ember lofting off, and NWNS backing behavior on. When the Post-Frontal Combustion model is selected the simulated fire displayed in the Landscape window is changed to show fire activity behind the flaming front.

Never Combine Surface and CWD fuels - use this option when surface fuels are already included in the Course Woody Profile file;

Always Combine Surface and CWD fuels - use this option when the surface fuels are NOT included in the Course Woody Profile file;

Use Surface Fuels when CWD absent - use this option when the surface fuels in the fuel Model are the best information available.

Calculation Precision = Normal. High precision gives a slightly longer computation time and more precise solutions.

Model - Dead Fuel Moisture

This command displays the *Fuel Moisture Options* dialog box which controls three options in the FARSITE dead fuel moisture model: (1) It allows a Fuel Moisture Map (**.FMM*) File to be saved and reloaded; (2) it controls when a Fuel Moisture Map is calculated; and (3) it sets the resolution of the calculated Fuel Moisture Map. Whether calculating a Fuel Moisture Map or not, the moistures do not need to be recalculated for repeated simulations unless modifications are made to the Weather (**.WTR*) or Initial Fuel Moisture (**.FMS*) Files, the duration settings (*Simulate - Duration*), or the options for dead fuel moisture (*Model - Dead Fuel Moisture*).

Pre-Calculate Fuel Moisture Map = On. This is the default option and is used for most simulations. Use this option for when you have a relatively short simulation and a definite duration ending time. Pre-Calculating involves a long computational period before the first time step, but the calculation of the simulation is relatively fast.

Calculate Moisture Map As Needed = Off. This option can be useful when testing or calibrating long simulations by evaluating the first time steps and you are unsure how long you will let the simulation run. It is also useful when you want a simulation to end when it reaches a pre identified point on the landscape and don't have a good idea of how long the simulation needs to run.

Simulate - Options

OFF = Reset Duration at Restart - removes duration parameters on restart

OFF = Restore Ignitions at Restart - restores ignitions and barriers on restart

ON = Rotation Sensitive Ignition Patterns (all ignitions will produce outward burning fires)

OFF = Display Fire Growth as Completed - Clearing this check box will display growth of all fires simultaneously by delaying drawing until a time step is completed.

ON = Adjust Ignition Spread Rates - Selecting this check box allows setting the current rate of spread when setting polygon or line ignitions. This affects the starting value of spread rate for fire acceleration in the subsequent time step.

Clearing this check box gives polygon or line ignitions a default initial spread rate at 100% of the equilibrium ROS.

ON = Preserve All Inactive Enclaves (When a simulated fire burns around a rock or lake it create a inactive enclave (inward burning fire). If a simulation has very many of these inactive enclaves, *FARSITE* will spend a lot of time on them, even though they are not contributing to the simulated fire behavior. Selecting this option will remove these inactive enclaves and speed up the simulation. However these enclaves will then be included in the fire area statistics.)

1 = Number of Simulation Threads

Simulate - Duration

Setting the duration is required for every *FARSITE* simulation - the start and stop times of a simulation. Weather (.WTR) and Wind (.WND) Files must be loaded before the duration can be set.

Use Conditioning Period for Fuel Moistures = Yes OR No. This was originally set to Yes, but changed to No, after the final report was submitted and reviewed. Selecting this starts with values in the Initial Fuel Moisture (**.FMS*) File and calculates fuel moistures across the landscape based on elevation, aspect, slope, and shading before the Starting Time of the simulation. Weather and wind streams are required in the Weather (**.WTR*) and Wind (**.WND*) Files for the conditioning period. Also weather data is needed for a minimum of one day before the start of the conditioning period.

If the Use Conditioning Period for Fuel Moistures check box is cleared, *FARSITE* begins the simulation with every point on the landscape using fuel moistures from the Initial Fuel Moistures (.FMS) File. Fuel moistures are then adjusted for topography and shading during the simulation, eventually equilibrating to the local environment.

Selecting the Use Conditioning Period for Fuel Moistures check box will display the earliest day available in the Weather (.WTR) File to begin the conditioning period. Conditioning periods are for whole days only. Conditioning begins at 0000 hrs. on the day specified, the dialog box will not accept hours and minutes input.

Starting and Ending Times. Times are simply set with the appropriate spin boxes. If zero is displayed in any of the text boxes, clicking the up or down arrows will insert the earliest available value. Minutes are optional.

For the SWA May simulation, Start at 5/2 at 0800 and end at 5/2/2300

Canopy characteristics

Additional canopy characteristics can be controlled beyond just those in the canopy grids, by clicking Input - Canopy Characteristics and modifying the following options:

Foliar Moisture = 80 - 100%. See the discussion by Agee (2002). Foliar moisture is different from live fuel moisture. It ranges widely, even on a diurnal basis and is lowest in the spring. It is highest in riparian areas. In the Teanaway watershed of Washington, Agee found that old foliage varied from 85% in June to 116% in September, while new foliage varied from 236% to 149% during the same period. Arboreal lichens that contribute up to 30% of the dry biomass of the crown foliage only varied between 6 and 18%.
Species expected to torch = Douglas fir.
Shade tolerance of torching trees = Moderate.
Units English.
Diameter = 30 cm (10 in), the default.

Selecting Output Files
Output filenames must be set before running a simulation. *Select Output - Export and Output* to bring up the Export and Output Options dialog box.
Units = Metric.
Output Units = Metric.
Vector output format = Check Select ASCII and .
Arcview Shapefile Name. Click this box to navigate to the output folder location and specify the output filename.
Visible Steps Only. With this box checked a file of the visible perimeters will be created as the simulation progresses. Perimeters can be saved as lines or as Polygons.
Raster Files. This check box designates the raster output file locations, resolution and format. Raster outputs will only cover the area within the simulated fire perimeter. The Time of Arrival (hrs) check box is automatically selected whenever raster output files are selected, the others are optional. The file names will be output with the default extensions, so for import into Arcview, the extensions can be changed to **.asc*. Clicking Start - Restart the first time clears these file names, so the file names need to be specified as the very last step before running a simulation. Select *Create Log File(s)* to help document the FARSITE options and features used in creating the output files.

Reports
Click the Table button (

) to see the results of a simulation. Right-click in the Area Table window to bring up output options and select Save Data To File to specify an output filename for a report. To view the results of a simulation within FARSITE< first remove the simulation perimeters, by clicking *Simulation - Initiate/Terminate*.

Files used with FARSITE

Input files are stored in the directory CD:\fuelgis\arc\farsite\input. Output files are stored in CD:\fuelgis\arc\farsite\output

Five raster files are required for FARSITE dynamic fire behavior modeling:
1. Elevation theme *elev*, with values of 428 - 1395 feet.
2. Slope theme *slope*, with values of 0-63 degrees.
3. Aspect theme *aspect*, with values of 0-359 degrees.

4. Fuel Model theme *fuelmod*, with standard fuel models 1 (Grass), 2 (Grass/Brush), 8 (Timber/Compact litter), 9 (Timber/Loose litter) and custom models 15 (Overmature Forest/Understory), 21 (Forest/Rocky), 24 (Shrub Savannah), 34 (Marsh/Swamp), 45 (Deciduous), 48 (Grass/Brush/Forest Burned), 49 (Grass/Brush/Forest Thinned), 50 (Grass/Brush/Forest Untreated), 98 (Water), 99 (Rock & Developed)
5. Canopy theme *cancov*, with values of 0-92 % overstory cover.

Optional raster input files used are:

6. Crown height theme *ht*, with values of 0, 30, 50, 60, 70, 90 feet
7. Crown base theme *crnbase*, with values of 0, 2, 3, 5, 10, 20 feet
8. Crown bulk theme *cb*, with values of 0, 2, 4, 5, 7 and units of 100* kg/m^3
9. Coarse woody theme *coarse* with values that point to values in the Coarse Woody Profile text file (**.cwd*)

Each grid file needs to be converted to an ascii input format for FARSITE, using the Arcview command *File - Export Data Source*. Choose the ASCII file type, then browse to the grid file to export and click OK, then browse to the output folder and give the ascii file a name.

Custom Fuel Model text file

To access the custom fuel models (*.fmd) File, click the *Custom Models* button from *Input - Project Inputs*.

The following values are arranged on each row for each numbered custom fuel model in the fuel model input file:
FMod 1H 10H 100H LiveH LiveW 1HSAV HSAV WSAV FDep XtMoist DHt LHt
e.g.,
15 1.500 2.000 3.500 0.200 2.000 2000 1800 1500 0.500 14 8000 8000
21 0.100 0.300 0.100 0.100 0.300 2000 1800 1600 0.200 28 8000 8000
24 1.900 0.300 0.100 0.750 7.100 2000 1800 1600 1.500 14 8000 8000
34 1.010 1.000 1.000 4.010 2.000 2000 1800 1500 6.000 14 8000 8000
45 2.000 2.100 1.860 0.300 2.000 2000 1800 1600 4.000 20 8000 8000
48 0.010 0.010 0.010 0.200 3.000 2000 1800 1500 2.500 20 8000 8000
49 2.000 1.800 4.800 0.200 3.000 2000 1800 1500 2.500 20 8000 8000
50 1.000 0.900 2.400 0.200 3.000 2000 1800 1500 2.000 20 8000 8000

Fuel Moisture text file

Fuel moisture files are saved in ASCII format with the extension **.fms*, so that the file can be edited with a text editor. Each record lists the fuel model and 5 fuel moisture parameters, using a space-delimited format to separate data items. The data items are as follows:
FuelMod 1Hour 10Hour 100Hour LiveH LiveW

Fuel moistures for each category are in percent (integers), and may exceed 100. LiveH and LiveW indicate "live woody" and "live herbaceous" fuels. Unlike dead fuels, live fuel moistures remain constant throughout the simulation.

SWA IFM values developed

open fuel models and the brush models (01, 02, 21, 24) used very low 1-hr fuel IFM, low 10-hr and 100-hr IFMs, 2/3 cured live herbaceous IFM and 1/3 cured live shrub IFM, e.g., for FM1 in May, used:
01 4 7 9 90 120
For the same fuel Models in 80th percentile August conditions for FM1 used:
01 4 7 8 60 90

The treated brush models (48, 49) used low dead fuel IFMs, 2/3 cured live herbaceous IFM and 1/3 cured live shrub IFMs for August, and the same values for the live fuels for the May condition, e.g., for FM 48 in May, used:
48 6 7 9 90 120
For the same fuel Models in 80th percentile August conditions for FM48 used:
48 5 7 8 60 90

wet fuel models (34, 41) used moderate dead fuel IFM values and 1/3 cured live fuels, e.g., for FM 34 in May, used:
34 12 13 14 90 120
For the same fuel Models in 80th percentile August conditions for FM34 used:
34 9 10 11 90 120

The shaded, untreated brush, and deciduous fuel models (05, 08, 09, 10, 11, 12, 13, 15, 41, 50) used moderate dead fuels IFM values and 1/3 cured live fuels, e.g., for FM 5 in May, used:
05 9 10 11 90 120
For the same fuel Models in 80th percentile August conditions for FM5 used:
05 6 7 8 60 90

Weather text file

Each record has the following information
Month Day Precip Hour1 Hour2 Temp1 Temp2 Humid1 Humid2 Elevation rt1 rt2
e.g.,
ENGLISH
05 01 00 0500 1500 40 80 15 20 1500
05 02 00 0500 1500 40 80 15 20 1500
05 03 00 0500 1500 40 80 15 20 1500
05 04 00 0500 1500 40 80 15 20 1500
05 05 00 0500 1500 40 80 15 20 1500

where:
- Precipitation is the daily rain amount specified in hundredths of an inch or millimeters (integer).

- Hour1 corresponds to the hour at which the minimum temperature was recorded (0-2400).
- Hour2 corresponds to the hour at which the maximum temperature was recorded (0-2400).
- Temperatures (Temp1 is minimum; Temp2 is maximum) are in degrees Fahrenheit or Celsius (integer).
- Humidities (Humid1 is maximum; Humid2 is minimum) are in percent, 0 to 99 (integer).
- Elevation is in feet or meters above sea level. NOTE: these units (feet or meters) do not have to be the same as the landscape elevation theme (integer).
- Precipitation Duration is entered with the beginning (rt1) and ending (rt2) times (0-2400) of the daily rain amount. Only one time period per day is allowed.

<u>Wind text file</u>

Each record has this information
Month Day Hour Speed Direction CloudCover
e.g., for May 1:
ENGLISH
05 01 0000 01 355 00
...
05 01 2300 01 355 00

- Hour is specified as 0-2400, to the nearest minute (integer).
- Speed is either the 20ft windspeed specified in miles per hour or the 10m windspeed in kilometers per hour (integer)
- Direction is specified in degrees, clockwise from north (0-360), (integer). A "-1" in the direction field indicates the winds to be up slope, similarly downslope winds can be specified with a "-2".
- CloudCover is specified as a percentage, 0 to 100 (integer).

<u>Coarse Woody Debris text file</u>
The file must be in the space delimited format shown below, and have profile numbers between 1 and 99. *FARSITE* 4.0 allows coarse woody profile inputs in English or metric units. The units are selected by inserting the word ENGLISH or METRIC as the first line of the Course Woody Profile (.CWD) File. The file can contain multiple lines per profile, with each line representing a fuel size class and each profile is separated by a header.

The header is two lines, the first starting with the word "MODEL" and then the model number (integer) and a brief description of the model (with no spaces). The second line starts with the word "DEPTH" and the depth of the profile (decimal) in feet or centimeters, measured as the vertical distance from the bottom of the litter layer to the highest intersected dead particle for 3 partitions of the 3 ft sampling plane.sampling

The data format of a coarse woody file is as follows:
SizeClass Loading HeatContent S/R Moist

Definitions:

SizeClass - The representative size of the class based on surface to volume ratio. (i.e.; for the 3" to 6" size class the representative size is 4.75, for the 6" to 10" class it is

8.25, for the 3” to 9” size class it is 6.25 it is A decimal data type, the units are inches or centimeters.

Loading - Fuel loading of the class (decimal), units are tons/acre or kilograms/hectare

HeatContent - Heat content of the class (integer), units are BTU/lb or joules/kilogram

S/R - Sound or rotten is defined by the density of the fuel (lb/ft3, or kg/m3). Typical values are 32 lb/ft3 for sound fuel and 19 lb/ft3 for rotten.

Moist - Moisture content of the size class in percent (integer).

For the SWA, CWD fractions were calculated for two intervals of CWD size class - the 3-9 in range represented by an average 6.25 in size class, and the >9 in size range represented by an average 15.8 in diameter size class. Bed depth was figured from plot photos and reference to FOFEM or to fuel plot photo series; generally, unless there were visible logs, the plots were given a bed depth of 0.1. Loads were calculated by reference to plot photos, plot data, FOFEM and the photo series. The S/R ratio was divided 90S:10R for both size classes; moisture was set for the August profile using the FARSITE Ashley data, and later adjusting the data to higher moistures for the May data.

After the models were developed, the CWD moistures were set using FOFEM values of 30% for spring-moderate, and 12% for summer dry sound wood, and 15% for the summer rotten 15.8-in+ classes.

After the models were developed as described below, the CWD profiles were redistributed using the FARSITE CWD calculator, and the results were saved as *sinla-may1-5.CWD*. and *sinla-aug80th.CWD*.

Fuel models without CWD were the open fuel models (01, 02, 03, 24, 98, 99).

Untreated brush (FM50 and FM5) were assigned as follows:

```
MODEL 50 CWD
DEPTH 0.10
  6.250  4.50  8000  32 30
  6.250  0.50  8000  19 30
 15.800  2.70  8000  32 30
 15.800  0.30  8000  19 30
```

The treated brush models (48, 49) were based on FM 50. For post-burn fuel model 48, burning was assumed to be about 50% efficient. Fuel depths stayed the same; fuel loads halved, rotten or not.

```
MODEL 48 CWD
DEPTH 0.05
  6.250  2.25  8000  32 30
  6.250  0.25  8000  19 30
 15.800  1.35  8000  32 30
 15.800  0.15  8000  19 30
```

For post-thin fuel model 49, thinning was assumed to be moderately effecient, but have little effect on existing loads. Fuel depths stayed the same. Fuel loads of the sound 6.35-in class (all in the 4-inch class after redistributing the profile) increased 50%. All remaining classes stayed the same, rotten or sound.

```
MODEL 49 CWD
DEPTH 0.15
```

6.250 6.75 8000 32 30
6.250 0.50 8000 19 30
15.800 2.70 8000 32 30
15.800 0.30 8000 19 30

Wet fuel models (34, 41) were averaged together from plots 1 and 2. There were scattered trees in plot 1 that contributed to CWD, but plot 2 without trees had no 9”+ material. Therefore, the average load of 9”+ material set to 0 and was added to the 6.25” category. Depths were set high, to 2 feet, due to the 6’ shrub layer contributing to CWD.

MODEL 34 CWD
DEPTH 2.00
6.250 2.70 8000 32 30
6.250 0.30 8000 19 30
15.800 0.00 8000 32 30
15.800 0.00 8000 19 30

Fuel model 15 (0vermature/Shrub) was developed from plots 36, 49 and 57, the latter two of which eventually ended up becoming fuel models 9 and 8, respectively. The depth and CWD amounts was based on averages in the plot data and photos.

MODEL 15 CWD_overmat_shr
DEPTH 0.200
6.250 4.50 8000 32 30
6.250 0.50 8000 19 30
15.800 4.50 8000 32 30
15.800 0.50 8000 19 30

Models 10 and 11 were similar to model 15, with values from the photo series substituted where it improved the model. The fraction of rotten CWD was higher in FM10, lower in FM11.

MODEL 10 CWD_mat_deadfall
DEPTH 0.200
6.250 2.50 8000 32 30
6.250 2.50 8000 19 30
15.800 7.50 8000 32 30
15.800 7.50 8000 19 30
MODEL 11 CWD_tim_slash
DEPTH 0.200
6.250 5.30 8000 32 30
6.250 0.70 8000 19 30
15.800 8.20 8000 32 30
15.800 1.10 8000 19 30

FM 8 was developed from plot 57 and Int-97 p. 23.

MODEL 8 CWD_psme_litter
DEPTH 0.200
6.250 3.60 8000 32 30
6.250 0.40 8000 19 30
15.800 2.70 8000 32 30

15.800 0.30 8000 19 30

FM9 was developed primarily from the SWA plots, as these indicated we had lower CWD loadings than in the photo series, and the FOFEM tables.

MODEL 9 CWD_pipo_litter
DEPTH 0.100
 6.250 1.20 8000 32 30
 6.250 0.20 8000 19 30
15.800 1.50 8000 32 30
15.800 0.20 8000 19 30

FM 21 was developed based on a PSME forest like FM8, without the surface fuels, but with some deadfall in jackpot fuel caches. Bed depth was made very low. The 6.25-in class was reduced by 25% and the 15.8-in class remained the same. Rot was 10%.

MODEL 21 CWD_medium_rocky
DEPTH 0.05
 6.250 2.50 8000 32 30
 6.250 0.20 8000 19 30
15.800 2.70 8000 32 30
15.800 0.30 8000 19 30

FM 45 (deciduous) was developed based on the plot data. Fuel bed depth was 1 ft, rot was 50%. Moisture was high.

MODEL 45 CWD_aspen
DEPTH 2.00
 6.250 2.90 8000 32 30
 6.250 2.90 8000 19 30
15.800 0.90 8000 32 30
15.800 0.90 8000 19 30

References for this section

Agee, James K.; Clinton Wright; Nathan Williamson; Mark Huff. 2002. Foliar moisture content of Pacific Northwest vegetation and its relation to wildland fire behavior. Forest Ecology and Management 167:57-66.

(INT-97) Fischer, William (1981) Photo guide for appraising downed woody fuels in Montana forests. USDA Forest Service Gen. Tech. Report INT-97, Intermountain Forest and Range Experiment Station, Ogden, UT.

(PNW-105) Maxwell, Wayne, and Franklin Ward (1980). Photo series for quantifying natural forest residues in common vegetation types of the Pacific Northwest. USDA Forest Service Gen. Tech. Report PNW-105, PNW Forest and Range Experiment Station, Portland, OR.

Appendix Analysis-G: Annotation - Technical Information added after publication in December 2006

This appendix documents technical information developed after publication of the Sinlahekin Wildlife Area Plan.

Data Dictionary for the file Cov_typ.shp (covering versions up to Cov_typ9g.shp). Cov_typ9g and Cov_typ9h have the same record numbers in field Recno. Cov_typ9b has two named versions - one for helicopter treatments and one for ground-based treatments. It is a reduced set of data, containing only loggable stands.

Cov_typ9b.shp	Cov_typ9g.shp	Cov_typ9h.shp	
Shape	Shape	Shape	Polygon (all records) Arcview default
Recno (may not correspond to Cov_typ9g, Cov_typ9h)	Recno	Recno	Unique record number for each of 2,469 polygons, overlapping slightly beyond the SWA boundary
Standnum			Stand numbers used for labeling maps
Cov_typ4_	Cov_typ4_	Cov_typ4_	Main classification for polygons, including non-forested.
Label			Text label corresponding to Cov_typ4
Owner	Owner	Owner	WDFW Other
Conif_typ	Conif_typ	Conif_typ	201=PIPO 211=PSME 221=PSME-LAOC
Conif_zone			Text label corresponding to Conif_typ
Std_asp	Std_asp	Std_asp	Cardinal aspect
Can	Can	Can	Corrected canopy cover
CC			Calculated or evaluated canopy cover
Pctcan			Calculated or evaluated canopy cover
Std_slo	Std_slo	Std_slo	Slope in increments of: 0 = 0 to 5% 5 = 5 to 20 % 20 = 20 to 35 % 35 = 35 - 67 % 67 = >67%
Std_slope	Std_slope	Std_slope	Text label of slope with “North” appended for North aspects only
Std_toe	Std_toe	Std_toe	“Toe” or blank to indicate whether stand is at toe of slope
Treat_cat		Treat_cat	Treatment categories for coniferous and aspen stands partitioned by SWA ownership, stand structure, slope, north aspect, and proximity to roads (see text for documentation): Con-Mature-Pole Con-Med Con-Med-Regen Con-NS-Mature-Pole Con-NS-Med Con-NS>35 Con-NS>35-SS-Ecotone Con-NS>75

			Con-Open-Mature Con-Pole Con-PoleID Con-Regen Con-Rip Con-SS-Ecotone Con>75 Non-con Aspen Non-con Decid Wet Non-forest
	Treat		This field is a further division of the treatment categories field Treat_cat, developed using field *burn_thin*, separating out coniferous stands not likely to need stem reduction, but still requiring pruning and raking prior to controlled burning treatments: 999 Water Ground Aspen Ground Conif Prep & Burn Ground Conif Ripar Ground Conif Thin Ground Decid Heli Aspen Heli Conif Prep & Burn Heli Conif Ripar Heli Conif Thin Nonforest Offbase Steep Aspen Steep Conif Steep Conif Ripar Steep Nonforest
Tpa_type	Tpa_type	Tpa_type	Trees per acre (total, the sum of the DBH classes below)
Tpacorr0	Tpacorr0	Tpacorr0	TPA of 0-5-inch DBH trees
Tpacorr5	Tpacorr5	Tpacorr5	TPA of 5-12-inch DBH trees
Tpacorr12	Tpacorr12	Tpacorr12	TPA of 12-24-inch DBH trees
Tpacorr24	Tpacorr24	Tpacorr24	TPA of trees >24 inches DBH
Spacorr	Spacorr		Snags per acre
Buff_in			Loggable capability based on accessibility: HELI<67 = Helicopter logging Ground-based = Ground-based logging (<35% slope and within ¼ mi of a road)
	Stand	Stand	Merged values representing both coniferous and non-coniferous stands, from fields *treat_cat*, and *cov_typ4*, respectively: 01 Pole 02 Mature & Pole 03 Mature Conifer Rocky 04 Medium Conifer 05 Medium Conifer & Shrub North 06 Open Mature Conifer 07 Open Conifer Steep North 08 Open Conifer & Regen 09 Open Conifer & Shrub 10 Riparian Conifer 11 Aspen Upland 12 Deciduous Wetland 13 Marsh 14 Shrub-Steppe

			15 Shrub Upland 16 Agriculture 17 Developed 18 Rock & Cliff 19 Water
	Cov_fuel	Cov_fuel	Merged values from field *stand*, subdivided into PIPO and PSME dominated stands: 101 Pole 102 Mature & Pole 103 Mature Conifer Rocky 104 Medium Conifer PIPO 105 Medium Conifer PSME 106 Medium Conifer & Shrub North 107 Open Mature Conifer PIPO 108 Open Mature Conifer PSME 109 Open Conifer Steep North 110 Open Conifer & Regen PIPO 111 Open Conifer & Regen PSME 112 Open Conifer & Shrub PIPO 113 Open Conifer & Shrub PSME 114 Riparian Conifer 115 Aspen Upland 116 Deciduous Wetland 117 Marsh 118 Shrub-Steppe 119 Shrub Upland 120 Agriculture 121 Developed 122 Rock & Cliff 123 Water
	B_u	B_u	Unit labels for controlled burning treatment areas (called "Burn Blocks"), subdivided into 10 total areas each covering approximately 10% of the SWA. Burn blocks were developed using spreadsheet *busum2-fig12c-12d.xls*. A subcategory of the burn blocks are "Burn Units" developed by a fuel specialist as sub-watershed scale controlled burn treatments. The labels for the burn units was originally contained in a field called *burn_unit* until the field *B_u* was developed, making that field obsolete
	Bu_ord	Bu_ord	An abbreviated code for the Burn Blocks that allows sorting stands into 10 sets of hypothetical yearly controlled burns
	Burn_thin	Burn_thin	Combined treatment categories for controlled burns, ground-based treatments and helicopter-based treatments, as well as offbase stands outside the SWA: 999 Water Burn & Ground Burn & Heli Burn Only Burn Only Forest Steep Burn Only Non-forest Steep Offbase
		Ba	Basal area calculated by summing all the basal areas for each diameter class
	Ba0		Basal area of 0-5-inch DBH trees
	Ba5		Basal area of 5-12-inch DBH trees
	Ba12		Basal area of 12-24-inch DBH trees
	Ba24		Basal area of trees >24 inches DBH
Tr101	Tr101	Tr101	
Tr102	Tr102	Tr102	

Tr1034	Tr1034	Tr1034	
		Priority	Field used to prioritize treatments for Figure Analysis-14: Hi-Flame Hi-Flame-Non-SWA Hi-Thin Hi-Thin-Non-SWA
		Priorhab	Field used to prioritize treatments for aspen stands: Hi-Decid Hi-Decid-Non-SWA
		Cbdm100	Canopy bulk density
		Flen_pri	Flame length under standard evaluating conditions
		Fmcust	Custom fuel models
		Fmstd	Standard Fuel models
		Acres	Acres