AN ANALYSIS OF THE NORTH RAINIER ELK HERD AREA, WASHINGTON: CHANGE DETECTION AND HABITAT MODELING WITH REMOTE SENSING AND GIS

By

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Dedication

Dedicated to Cassidy Benton.

Acknowledgements

First and foremost I would like to thank my wife Tabby for her support during this process. Without her essentially doing everything while I focused on school, this would not have been possible. I would also like to thank my thesis committee, Dr. Travis Longcore, Dr. Flora Paganelli and Dr. John Wilson, for their constant support through this whole process.

Special thanks must also be given to the authors/creators of the Westside Elk Nutrition and Habitat Use Models who created a very exciting method of analyzing elk habitat and to Michelle Tirhi who helped set me on the path to this project in more ways than one.

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Abstract The North Rainier Elk Herd (NREH) is one of ten designated herds in Washington State, all managed by the Washington Department of Fish and Wildlife (WDFW). To aid in the management of the herd, the WDFW has decided to implement a spatial ecosystem analysis. This thesis partially undertakes this analysis through the use of a suite of software tools, the Westside Elk Nutrition and Habitat Use Models (WENHUM). This model analyzes four covariates that have a strong correlation to elk habitat selection: dietary digestible energy (DDE); distance to roads open to the public; mean slope; and distance to cover-forage edge and returns areas of likely elk habitation or use. This thesis includes an update of the base vegetation layer from 2006 data to 2011, a series of clear cuts were identified as areas of change and fed into the WENHUM models. The addition of these clear cuts created improvements in the higher quality DDE levels and when the updated data is compared to the original, predictions of elk use are higher. The presence of open or closed roads was simulated by creating an area of possible closures, selecting candidate roads within that area and then modeling them as either “all open” or “all closed”. The simulation of the road closures produced increases in the higher levels of predicted use.

Chapter 1: Background

The North Rainier Elk Herd (NREH), as one of the ten designated herds in Washington State, is managed by the Washington Department of Fish and Wildlife (WDFW). Although primarily managed by the WDFW, other interested stakeholders include the Muckleshoot Indian Tribe (MIT) and government and private landowners within the herd area boundary, including the Washington Departments of Transportation (WSDOT) and Natural Resources (WDNR) and the Hancock Timber Resource Group. The WDFW describes the NREH as an important state resource that provides recreational, cultural and aesthetic values to the public. The NREH is also valued highly by the Native American people of the area for ceremonial and subsistence uses (Spencer 2002).

Elk (*Cervus elaphus*) are herbivores and consequently closely associated with the plants they eat. This basic concept predates the early GIS modeling of elk habitat that in turn is the foundation for the work in this thesis. In some of the early attempts to demonstrate the relationship between elk and plants, individual animals showed a preference for areas that are higher in quality when the habitat is heterogeneous (Stephens and Krebs 1986; Collins et al. 1978; Weins 1976; Martinka 1969). To further establish a relationship between elk and the food they eat regardless of the environment, Kufeld (1973) looked at the value of specific plant species as studied in previous work. He aggregated several studies surrounding diet and preferences of Rocky Mountain elk (*Cervus elaphus subspecies???*). This work was conducted with the knowledge that previous studies had mostly been centered on specific locations throughout the Rocky Mountains of the western U.S. and Canada. Kufeld (1973) was able to categorize the plant species and rank them by the intensity at which elk sought them. Some plants may be ranked higher or lower because of limited availability or because of differences in palatability (Kufeld 1973).

Not only do elk prefer areas associated with higher quality forage, productivity of herds (i.e. health of females during parturition and calf survival) is strongly related to time of the year and quality/quantity of available forage. The times leading up to and during pregnancy greatly influence birth rates and cow and calf survival. As early as 1958, Swank (1958) found a strong correlation between the quality and quantity of available forage and the productivity of deer herds, a species with a similar life history. Poor forage also has been found to adversely affect Rocky Mountain cow elk in Wyoming through stress and weight loss limiting the survival of calves (Thorne et al. 1976). Feeding trials on 30 captive female elk confirmed that a reduction in quality of dietary digestible energy during the summer months affected reproductive functions, with even just moderate reductions in DDE resulting in delayed estrus (Cook et al. 2001). Furthermore, lactating female elk can be used as a quality indicator to link nutrition and habitat selection because they have been found to have energy requirements 2–3 times the level found during times when not lactating (Robbins, as cited in Beck et al. 2006).

Another basic component of the relationship between elk and their environment is the idea that food is not the only factor in how elk choose their location. In 1979, a study found a link between the sizing and spacing of forest stands and openings, habitat quality and road densities with elk usage of the areas (Thomas et al., as cited in Wisdom et al. 1986), which in turn led to the widespread use of cover-forage ratios and road-densities as indicators of elk habitat quality. The weakness of this method was that it required several assumptions: that areas of forage and cover were of adequate size; forage quality was not limiting; and that thermal cover needs were met (Witmer and DeCalesta 1985). It was apparent then that more specific indices of the sizes and spacing of forage and cover, habitat quality, and the effects of human disturbances were needed (Witmer and DeCalesta 1985). Shortly thereafter, a model was created that evaluated four criteria: sizing and spacing of forage and cover; density of roads open to motor vehicles; cover quality; and forage quality (Wisdom et al. 1986) that was an important influence in the creation of the WENHUM.

With this much knowledge of the relationships between elk and their environment it was only a matter of time before geographic information systems (GIS) were applied to the study of elk. In 1997, existing digital land-cover data were used to evaluate elk habitat in Illinois to facilitate the reintroduction of the eastern subspecies of elk (*Cervus elaphus canadensis,* Van Deelen et al., 1997). Bian and West (1997) used GIS modeling to study elk, created a logistic regression model to measure the observed calving grounds with other habitat variables such as dietary and other needs. GIS was used to implement the model and predict other elk calving grounds throughout the grasslands in the study.

This thesis will use the knowledge of the relationship between elk and their environment through the use of the Westside Elk Nutrition and Habitat Use Models (WENHUM) to analyze the habitat within the study area. The WENHUM is a suite of software tools that model elk habitat and nutrition that were developed by a consortium of scientists from state, federal and private entities. It uses a base vegetation layer to calculate four covariates, variables that may have an influence on the outcome, that form the basis of the habitat use predictions. First will be an update of the base vegetation layer that serves as an important factor for the subsequent toolboxes contained within the WENHUM. Next the four covariates will be calculated.

During the process there will be a detailed account of the use of the WENHUM including errors contained within some of the models. The result of this thesis will be the predicted use by elk for the study area as well as other outputs created along the way including DDE data, an assessment of the available nutrition.

Chapter 2: Study Area

The study area is the Carbon River watershed (as established by the National Hydrography Dataset; NHD, WA Department of Ecology, 2012) with the addition of a 2.5 km buffer (Figure 1). A buffer is added to account for the effects of roads and vegetation that are adjacent but on the outside of the study area. The distance of 2.5 km was chosen for this analysis as an estimation of the effects of the surrounding environment. The site is in the western portion of Washington State and located almost entirely within Pierce County, covers 924 km^2 and overlaps the northwest corner of Mount Rainier National Park (199 km^2). The major waterway is the Carbon River, which is in turn fed by Voight's Creek and South Prairie Creek. The landscape is dominated by its highest peak, Mt. Rainier, a solitary peak at a height of 4,394 m. The lowest point in the study area is 27 meters and runs along the Carbon River as it in turn feeds into the Puyallup River which runs into Puget Sound. The two largest population centers, Orting and Buckley have a combined population of 11,333 (U.S. Census Bureau 2012; City of Buckley 2012).

The climate of the area is cool with relatively dry summers and mild, wet and cloudy winters. Sunny days per month average 4–8 in winter, 8–15 in spring and fall and 15–20 in the summer (Western Regional Climate Center 2013). The dominant trees found within the study area include western hemlock (*Tsuga heterophylla*), Pacific Fir (*Abies amabilis*) and Mountain Hemlock (*Tsuga mertensiana*).

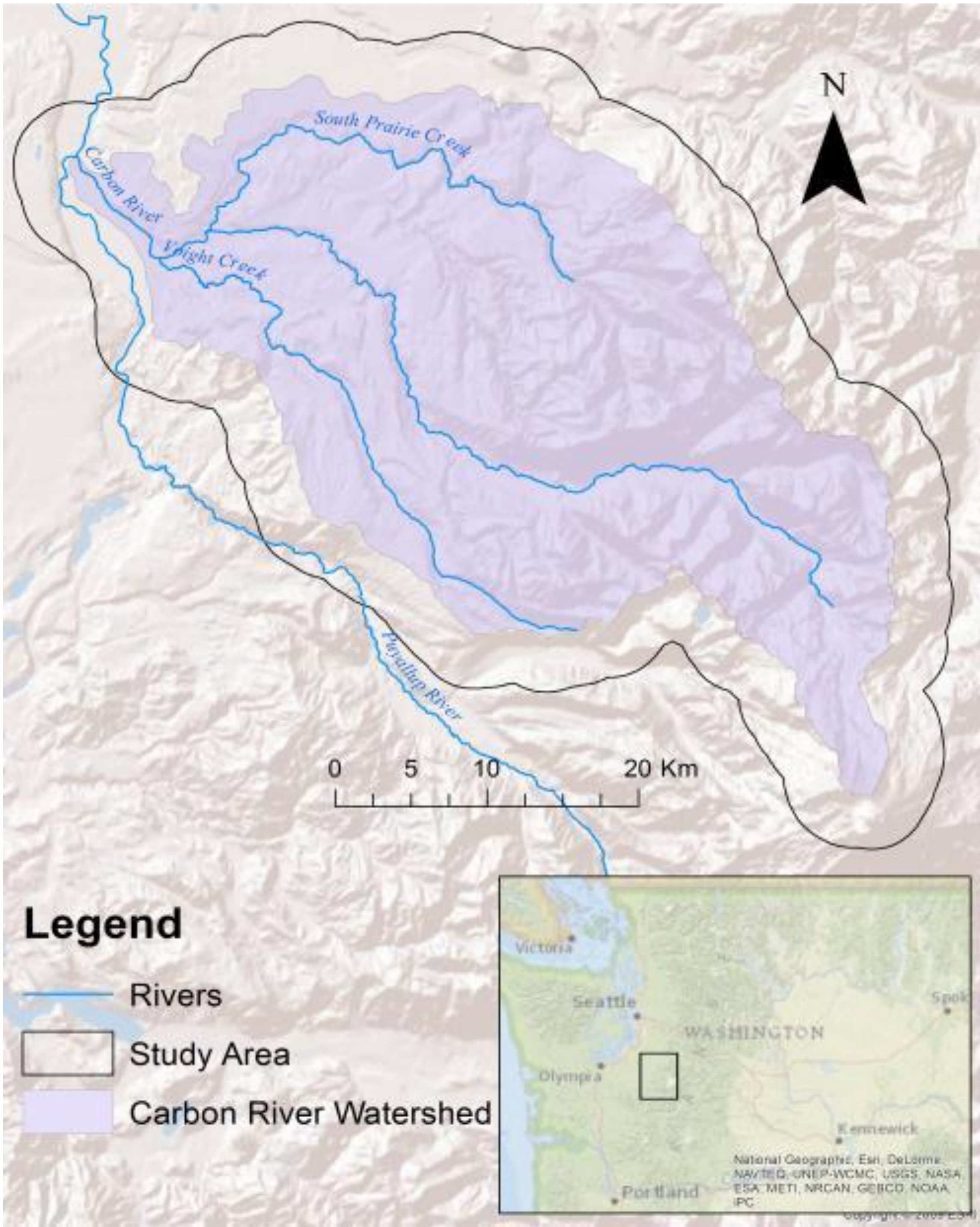

Figure 1: Study area map showing the Carbon River watershed and the major streams: Puyallup River, Carbon River, Voight's Creek, and South Prairie Creek.

Chapter 3: Methods

The WENHUM is composed of four toolboxes: “Update Base Veg Toolbox”; “Elk Covariate Toolbox”; “Elk Nutrition Toolbox”; and “Elk Use Toolbox” (Figure 2). The toolboxes and models analyze elk nutrition and habitat use specifically in western Washington and Oregon. Each of the toolboxes contains one or more models which are used to identify the four covariates that have consistently provided the most support for observed patterns of elk movements which in turn are used in the identification of the predicted habitat use(Boyd et al. 2011):

- elk dietary digestible energy (DDE; higher DDE, higher predicted elk use);
- distance to roads (farther from roads, higher use);
- percent slope (flatter slopes, higher use); and
- distance to cover/forage (closer to edge, higher use).

A modified or updated vegetation layer is a product of the first of the four toolboxes, “Base Veg Update Toolbox”. The base vegetation layer is an important part of the remaining tools, it is the basis for some the assumptions about the habitat. Second, the “Elk Nutrition Toolbox” calculates DDE for the study area using the base vegetation layer. Third, the “Elk Covariate Toolbox”, establishes the remaining three covariates needed to run the fourth tool, the “Elk Use Toolbox”. The “Elk Use Toolbox” creates a map that shows the predicted probability of elk using an area.

The use of the WENHUM is the main focus of this thesis and a major component of being able to use the WENHUM is the use of an up-to-date vegetation layer. Vegetation data were originally compiled from National Agriculture Imagery Program (NAIP) images taken circa 2006. NAIP imagery is a product of the Farm Service Agency (FSA) in an effort to collect the imagery for the entire conterminous United States at a 1-meter resolution. The imagery used for this thesis is captured at a spatial resolution of 1 meter (NAIP products prior to 2008 vary) from an aircraft platform in three bands: Red; Green; and Blue (natural color; USDA 2009). It is a raster with 1 m by 1 m pixels.

The first step in the analysis was to determine the study area. I originally planned to analyze the entire NREH area comprising 7,144 km^2 (9,131 km^2 with a 4 km buffer). I soon realized that the size of the area was excessive; the magnitude of the image files associated with that area were unmanageable and processing times on available equipment were prohibitive. A decision was then made to work with a portion of the NREH area. The wider area can easily be analyzed in separate sections using the data and clarification to the WENHUM methods developed in this thesis.

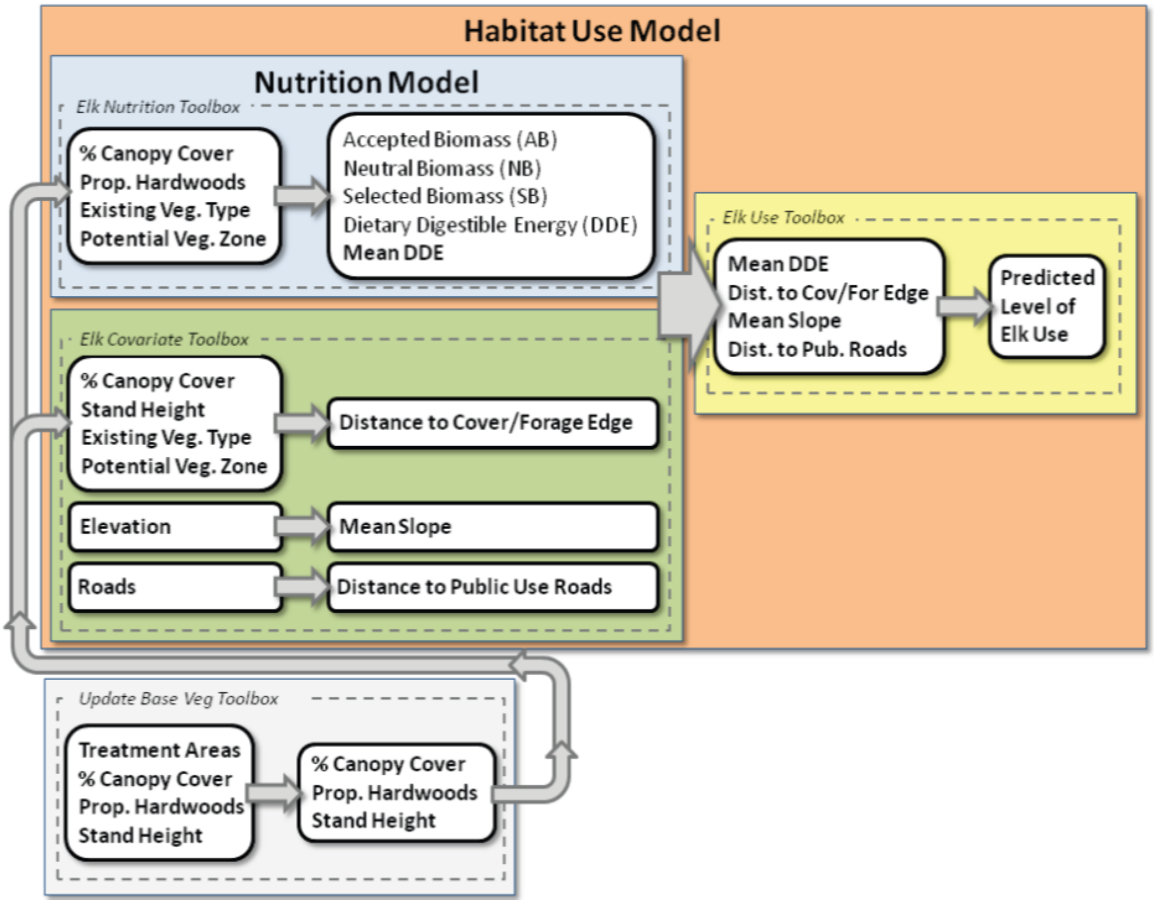

Figure 2: Overview of the analysis toolboxes within the WENHUM, showing importance of vegetation layer to subsequent analyses (Boyd et al., 2011).

The area chosen was the Carbon River Watershed, as established by the National Hydrography Dataset (NHD; WA Department of Ecology, 2012). This area was chosen because it is within the original study area and it is known to contain elk (personal observation). Any areas that could be designated as uninhabitable by elk prior to any analysis (e.g. city, residential, and other urbanized areas) were left in the study area to judge the ability of the WENHUM to recognize them as unsuitable.

The first step in the use of the WENHUM was to update the available vegetation layer using the "Update Base Veg Toolbox" (Figure 3). The layer provided with the WENHUM, referred to as "gnn_2006" (gnn = gradient nearest neighbor), is defined by Boyd et al. (2011) as "… a modeling method that incorporates multivariate statistics and imputation to produce a variety of vegetation maps, based on ground data and mapped (explanatory) data. For elk nutrition and habitat use modeling, we used key fields from the March 2010 release of the GNN species-size model, developed for Northwest Forest Plan Effectiveness Monitoring."

The data consist of many fields including: HW100 – the proportion of stems in the dominant canopy layer that are considered hard wood tree species multiplied by 100; STNDHGT – stand height in meters; CANCOV – canopy cover, percent of all live trees; and Elk_Hab_Ma – a field that defines whether vegetation provides elk habitat or not (using modeled values). The layer is based on data established in 2006 and was updated to 2011.

Initially I evaluated the use of a supervised classification to derive the vegetation layer update but due to technical difficulties arising from the constraints and limitations of available hardware, software and geospatial data, a "heads-up" approach was used. A heads-up approach is a common approach defined by the use of an image, typically a satellite image or orthophotograph displayed as a basemap, and then features such as buildings or parcels are scanned visually and drawn on top (Esri 2013).

The heads-up digitizing process was undertaken in ArcMap with the same NAIP imagery used in the creation of the vegetation layer, the most current available from 2011. Polygons were hand drawn around areas where significant change had occurred. The first step was to create a new feature class polygon layer, referred to as the vegetation update polygon layer, which was used as a parameter in the “Update Base Veg Toolbox”. An edit session was started using the “Create Features” toolset to digitize polygons. The study area was subdivided into NHD sub-watersheds and each unit was carefully scanned by eye, using the swipe function to switch between the 2006 (Figure 4) and 2011 (Figure 5) images quickly, searching for significant change. When an area of change was found (Figures 6 and 7) a polygon was drawn around it and saved as the change areas polygon layer (Figure 8).

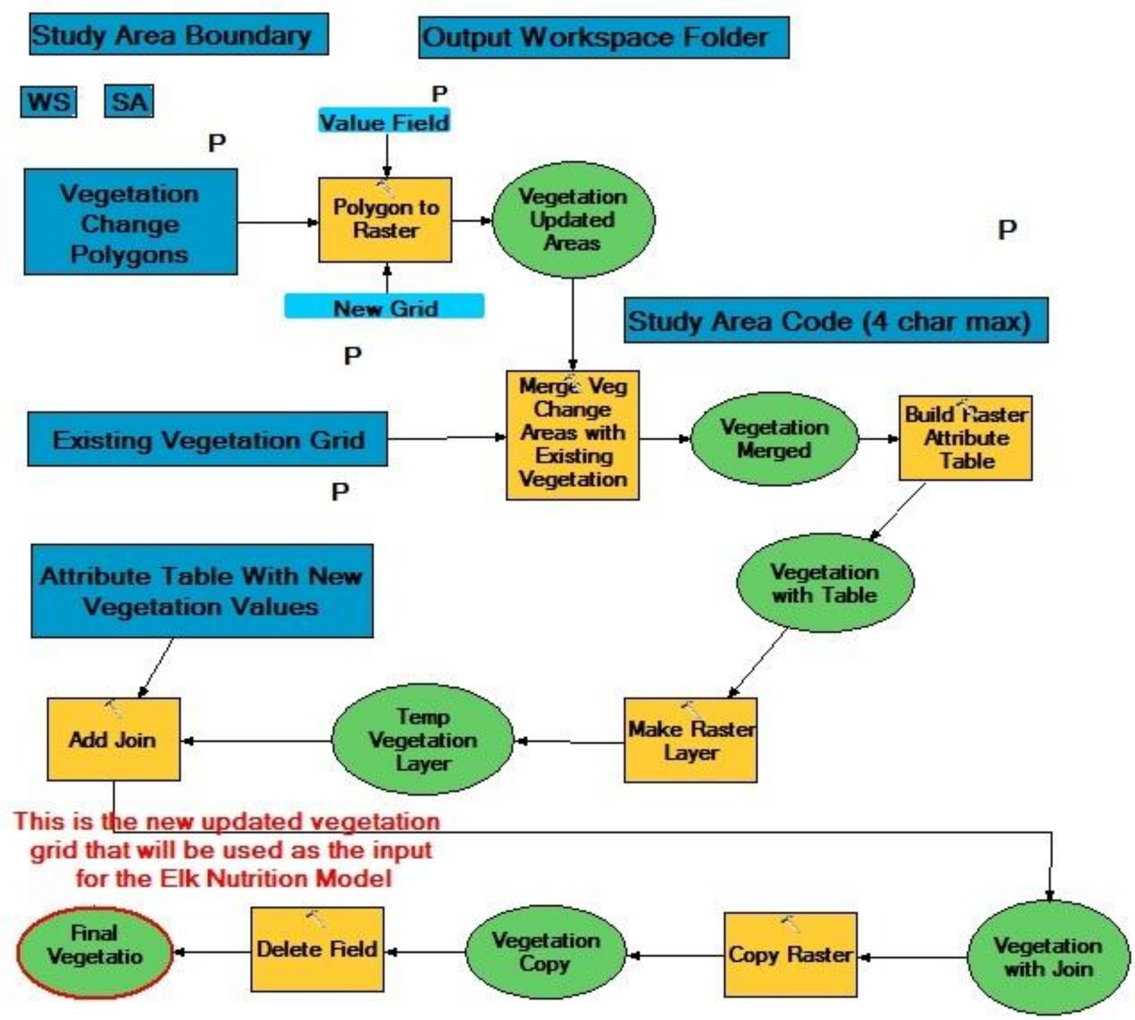

Figure 3: The "Update Base Veg Toolbox" that was used to update the vegetation layer.

Figure 4: NAIP imagery from 2006 that was used to create the original vegetation layer.

Figure 5: NAIP imagery from 2011 that was used to update the vegetation layer in the WENHUM.

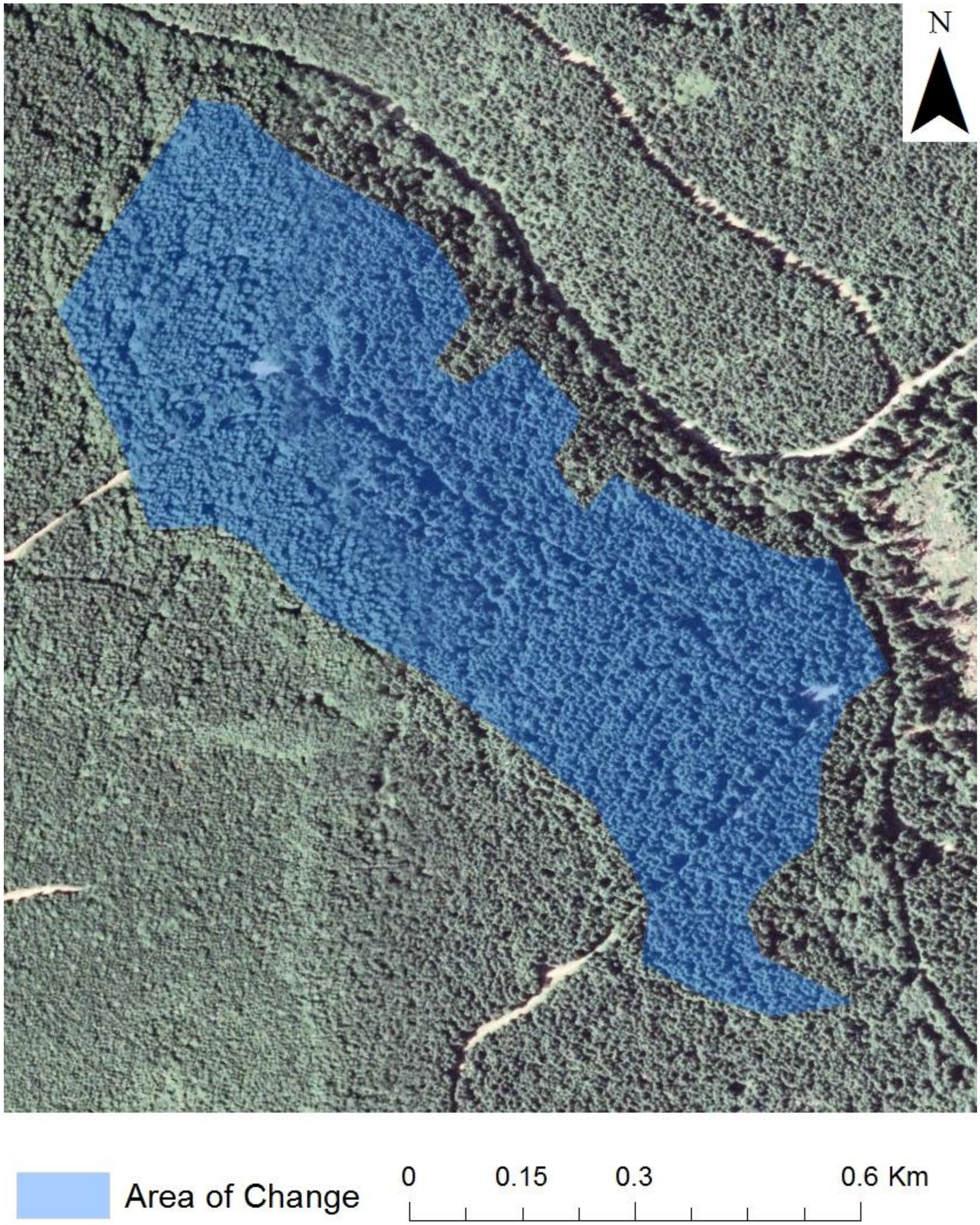

Figure 6: Detail of a forested area circa 2006, prior to clear cutting. The polygon represents the extent of the change that was found and is a portion of the change areas polygon layer.

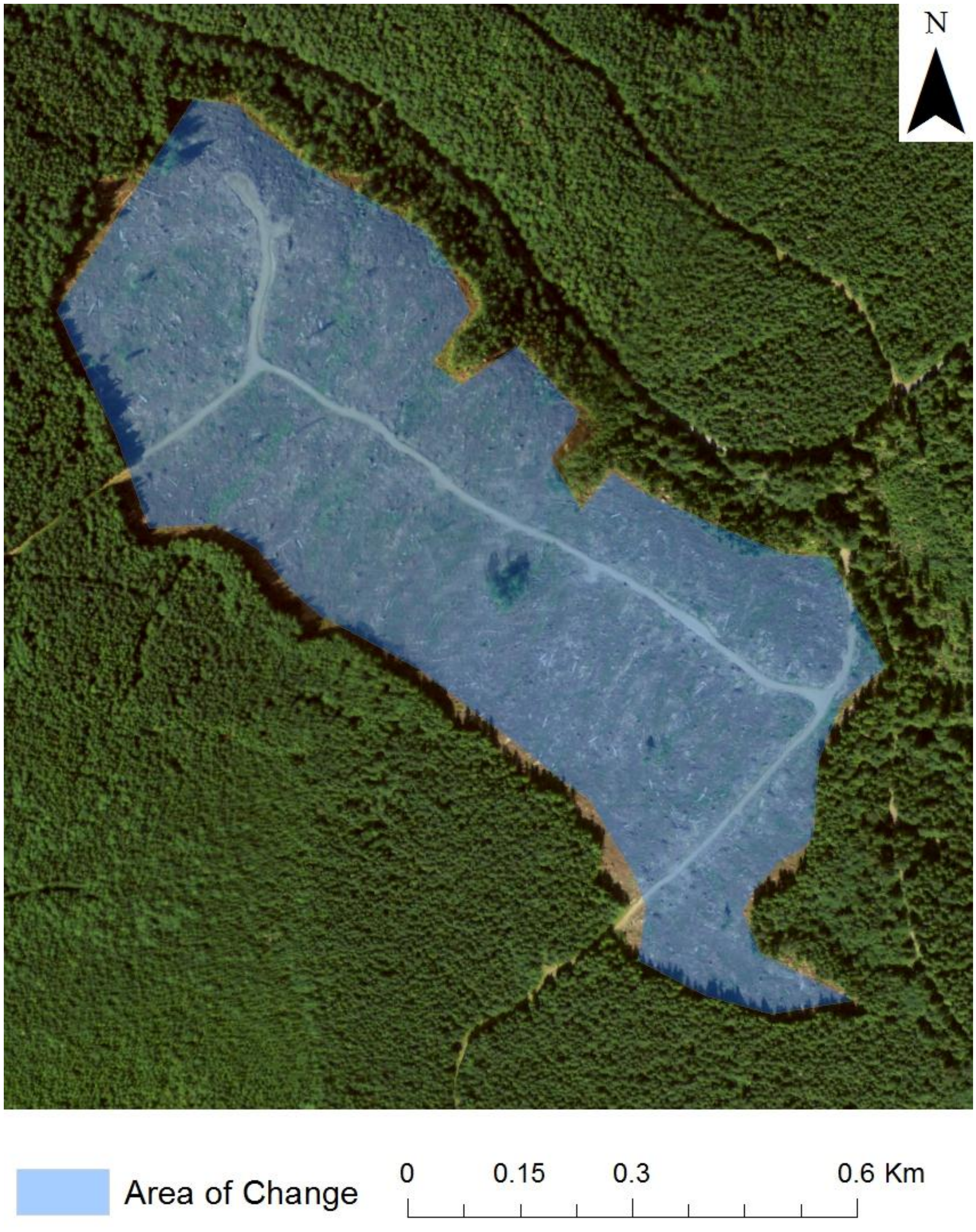

Figure 7: Detail of a changed area circa 2011, after clear cutting. The polygon represents the extent of the change that was found and is a portion of the change areas polygon layer.

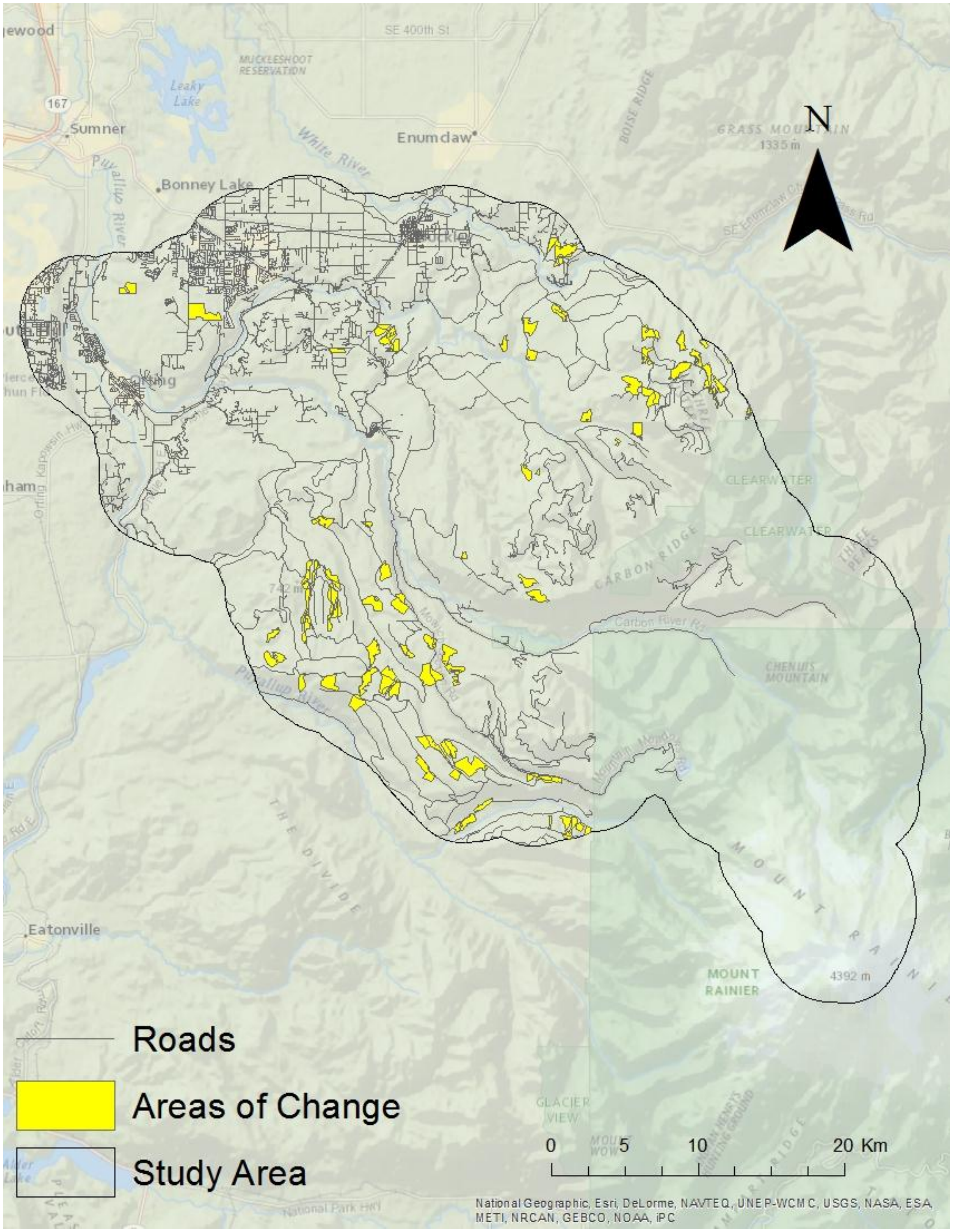

Figure 8: The areas of change found within the study area.

When all 72 areas of change were found within the study area, the attribute table for each was edited using the "Update Base Veg Toolbox" by updating the following fields in Table 1.

Table 1: Description of fields added to the changed areas polygon attribute table to be used in the vegetation update toolbox.

Field Name	Description
Value	A long integer data type, this is what the toolbox will look for when creating a grid from the polygon layer.
HW	Proportion of hard woods, 0 - 10
CANCOV	Percent canopy cover, 0 - 100
STANDHGT	Height of stand (meters), ≥1

The value field within the attribute table for the changed areas polygon layer is an arbitrary number indicating each unique combination of values for the fields related to hardwoods proportions, canopy cover, and stand height. This is the field that was used in the join process in the update.

Next, the attribute table from the existing vegetation grid was modified to include the values from the changed areas. The entries here matched the "Value" field in the update polygon layer and because all areas of change were considered identical, there was only a single entry. Then all of the appropriate data is entered as parameters in the model provided in the "Update Base Veg Toolbox".

Before the “Update Base Veg Toolbox” could be run it had to be edited in an edit session within ArcMap 10.1 Model Builder (Esri 2012a) because it was not producing the desired results. The user guidelines stated that the newly updated vegetation layer would be output as a layer titled “new_veg” when it actually had retained a title designated from the step “Copy Raster” titled “temp_view_CopyRaster”. Once it was determined that this was the layer that was desired, the title applied at this step was edited to “new_veg”.

The next model is the Elk Nutrition Model (Figure 9); this model creates one of the four covariates, mean DDE as well as “raw” DDE estimates. The raw DDE output of the nutrition model can be used alone to assess the nutritional values available to elk. The model uses a series of equations (Tables 2 and 3) to calculate the biomass of available forage in two vegetation series in three regions in western Washington and western Oregon: Nooksack; Willapa Hills; and Springfield (Figure 10). The two vegetation series are TSME-ABAM (mountain hemlock [*Tsuga mertensiana*] / Pacific silver fir [*Abies amabilis*]) and THSE (western hemlock [*Tsuga heterophylla*]).

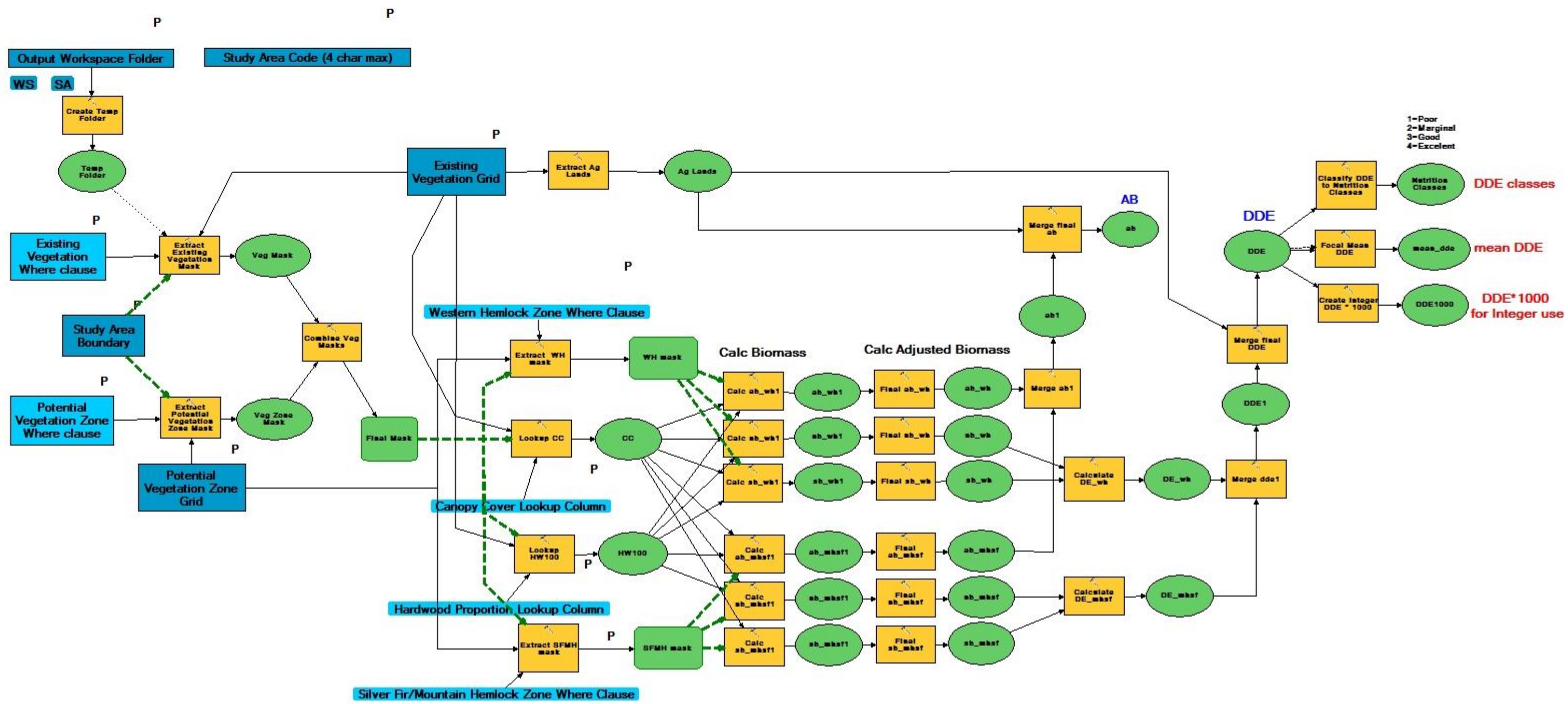

Figure 9: Schematic showing the nutrition data model in the Nooksack region, as provided in the “Elk Nutrition Toolbox”. A zoomed-in, segmented view is in the appendix (Figures A1 – A4)

Table 2: Equations used to predict biomass (kg/ha) of three forage classes based on stand and forest overstory conditions in three forest zones and three study areas[a] in western Oregon and Washington (Boyd et al. 2011).

TSME & ABAM[b] habitats, all seasons, all study areas

$AB^{c} = 657.6 – 11.28(CC) + 0.0458(CC^2) + 553.06(HW)$

$NB = 527.8 – 6.09(CC) + 590.49(HW)$

$SB = 1/(0.00833 + 0.00062(CC))$

TSHE habitats, all seasons, by study area

$AB_{Nk} = 707.3 – 13.93(CC) + 0.0731(CC^2) + 383.17(HW)$

$AB_{WH} = 707.3 – 6.28(CC) - 0.0154(CC^2) + 383.17(HW)$

$AB_{Sp} = 490.5 – 11.70(CC) + 0.0731(CC^2) + 383.17(HW)$

$NB_{Nk} = 671.8 – 16.91(CC) + 0.1092(CC^2) + 268.13(HW)$

$NB_{WH} = 477.4 – 3.90(CC) – 0.0151(CC^2) + 268.13(HW)$

$NB_{Sp} = 308.5 – 7.59(CC) + 0.0473(CC^2) + 268.13(HW)$

$SB_{Nk} = 80.1 – 0.66(CC) + 99.83(HW)$

$SB_{WH} = 212.6 – 2.20(CC) + 99.83(HW)$

$SB_{Sp} = 166.2 – 1.68(CC) + 99.83(HW)$

[a] The 3 study areas are Nooksack (Nk, northern Cascades near Mount Baker), Willapa Hills (WH, coastal foothills west of Centralia, WA), and Springfield (Sp, central Cascades, west of Springfield, OR).

[b] Habitat codes are: TSME = *Tsuga mertensiana* forest series, ABAM = *Abies amabilis* forest series, TSHE = *Tsuga heterophylla* forest series.

[c] Forage class codes (equation variable names) are: NB = biomass (kg/ha) of neutral plant species (those plants that elk neither significantly avoided nor selected), SB = biomass (kg/ha) of selected plant species (those plant species that elk significantly selected), and AB = biomass (kg/ha) of accepted species (SB and NB combined). Predictor variable codes are: CC = canopy cover (%) of all live trees; HW = proportion of stems in dominant canopy layer that are hardwood tree species (e.g., red and other alders, big leaf maple, and paper birch).

The study area is divided nearly down the middle by the boundary line between the Nooksack and Willapa Hills regions (Figure 11). I first attempted to split the study area into two halves for the elk nutrition model runs to obtain individual results for both the Nooksack and Willapa Hills sets of equations. From those results it became apparent that there were inconsistencies that were not biologically realistic. For example, this approach resulted in abrupt changes in calculated DDE along the boundary. Areas that were adjacent had different DDE values when in reality, or when viewed on the ground, they should not have. On the ground there would be differences of course but they would not follow this artificial boundary line (Figure 12). The differences were attributed to the equations that were used to predict biomass within the two regions.

Table 3: Final equations to predict dietary digestible energy (DDE) for elk based on abundance (kg/ha) of two forage classes in different habitats and 3 study areas[a] in western Oregon and Washington (from Table 2, Boyd et al. 2011).

TSME & ABAM[b] habitats, all seasons, all study areas
DDE = 2.44 + 0.000889(NB) [c] + 0.00308(SB) - 0.00000546(SBNB)
TSHE habitats, all seasons, by study area
DDE_{Nk} = 2.362 + 0.00108(NB) + 0.000504(SB) – 0.00000361(SBNB)
DDE_{WH} = 2.278 + 0.00062(NB) + 0.00120(SB) – 0.00000172(SBNB)
DDE_{Sp} = 2.300 + 0.00108(NB) + 0.00129(SB) – 0.00000418(SBNB)

[a] The 3 study areas are Nooksack (Nk, northern Cascades near Mount Baker), Willapa Hills (WH, coastal foothills west of Centralia, WA), and Springfield (Sp, central Cascades west of Springfield, OR).

[b] Habitat codes are: TSME = *Tsuga mertensiana* forest series, ABAM = *Abies amabilis* forest series, TSHE = *Tsuga heterophylla* forest series.

[c] Forage class codes (equation variable names) are: NB = biomass (kg/ha) of neutral plant species (those plants that elk neither significantly avoided nor selected), SB = biomass (kg/ha) of selected plant species (those plant species that elk significantly selected), and SBNB = the interaction of SB x NB (i.e., the product of SB and NB).

Figure 10: Map showing modeling regions for the WENHUM. Displayed here are the Nooksack, Willapa Hills and Springfield regions. These regions are used for assigning the correct nutrition model equations (Table 2) to the study area.

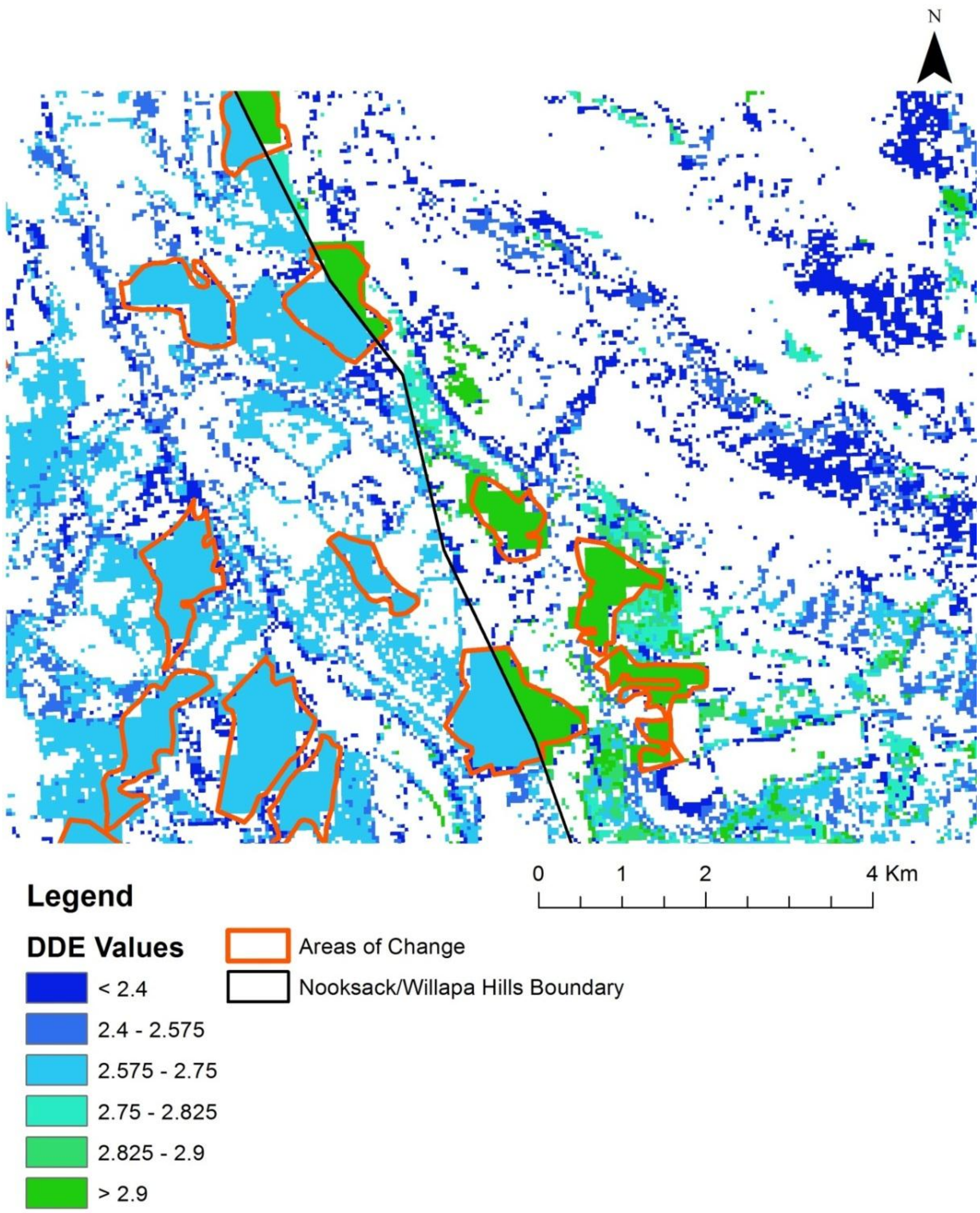

Figure 11: Map showing the differences between the Nooksack and the Willapa Hills models. The differences that are evident along the boundary line do not appear to follow any natural cause.

I then decided that because the portion of the study area that falls under the Nooksack region was larger, that I would use the Nooksack Region model. At a minimum, this approach ensures that the habitat suitability estimates will be consistent within the study area, and could be repeated with the other region's model if needed in the future.

While running the nutrition model for the Nooksack region, I found further errors in the WENHUM model. Some of the outputs were not being saved to the designated output folder. I then opened model in an edit session in ArcMap (Esri 2012a) and scanned the outputs from several of the tools to verify labels and permanency. Permanency refers to the option for an output that allows it to be designated as "intermediate," which means that it is created and used for the next step but is deleted at the end of the model run. Several of the outputs were erroneously marked as intermediate, particularly the raw DDE output along with others that were not a part of this analysis.

The three remaining covariates: distance to roads open to the public; mean slope; and distance to cover/forage edges were generated with the "Elk Covariates Toolbox" (Figure 12). This model required five different inputs:

1. Vegetation Grid
2. Study Area Boundary
3. Roads Data (Figure 13)
4. PNV (potential natural vegetation) Zones (Figure 14)
5. DEM Grid (Figure 15)

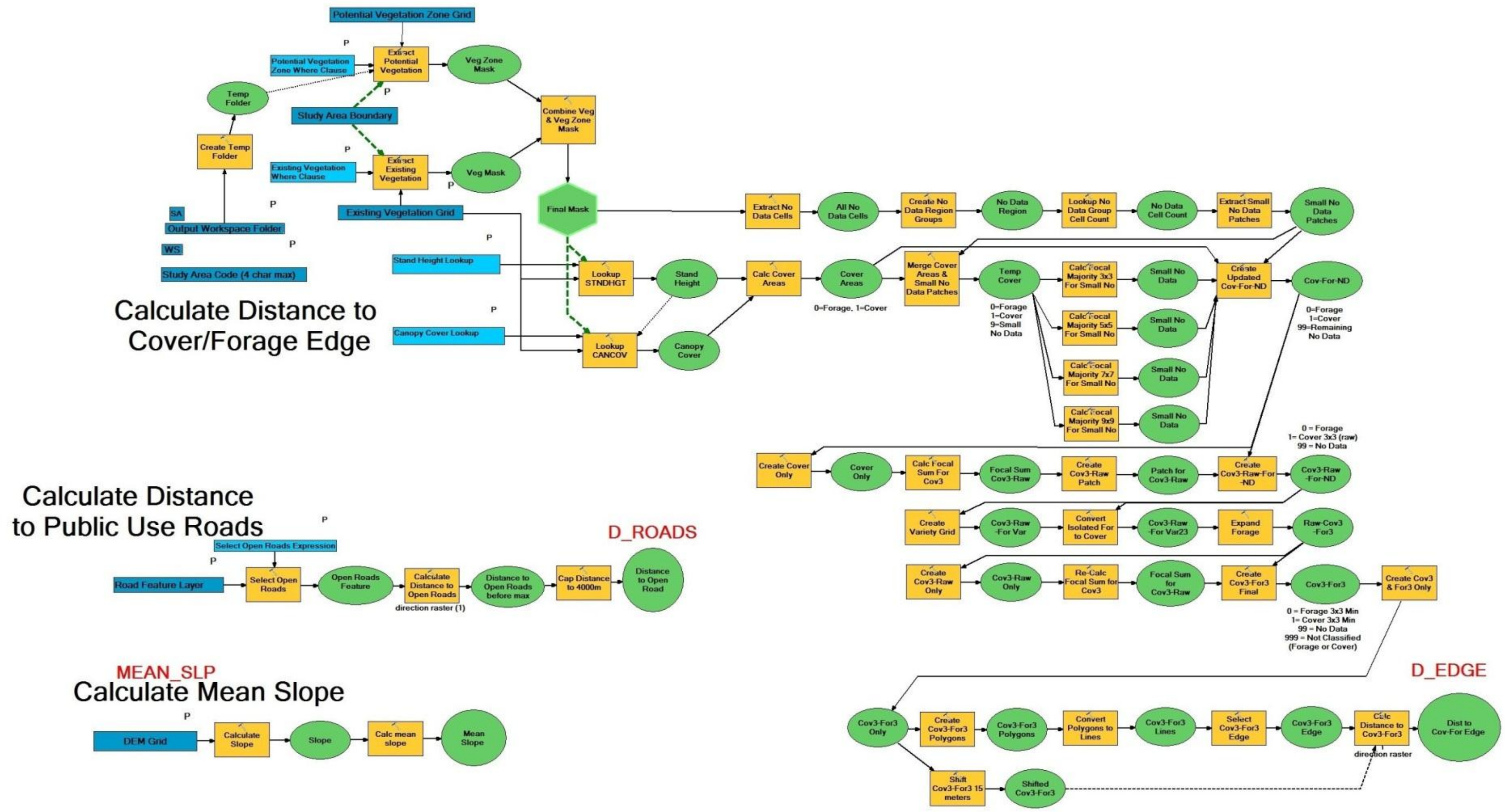

Figure 12: This is the model provided in the “Elk Covariates Toolbox”. A segmented and zoomed-in view is in the appendix (Figures A5 – A11).

The road data were downloaded from the Washington Office of Financial Management's website in the form of TIGER/line data from the U.S. Census Bureau (WOFM 2012). To allow its use in the model, a field titled "Open" was added. This field would be the designation of whether or not the roads were open to public use. Because data were not available on the status of roads as open or closed, I conducted a sensitivity analysis to show the range of variation in model results from having potentially closed roads modeled as both all-open or all-closed.

To determine which roads would be modeled as potentially opened and closed, an area of likely closures was determined. To accomplish this, land ownership and land use data were evaluated to determine which of these areas were most likely to have closures. I decided that land owned by the U.S. Forest Service (USFS), the Washington Department of Natural Resources (WDNR) and other areas designated as "timberland" by the WDNR were the most likely to be closed (Figure 13). Once a polygon indicating the area was created, the roads within that area were narrowed down further to roads with no names and USFS roads labeled as "National Forest Development Roads" as the closure candidates. The models were then run to show all roads either opened or closed to illustrate the effect.

To calculate the distance to roads open to public use, the model separates all of the roads into either open or closed. It then calculates the distance of each pixel to the nearest open road in meters.

The method of calculating the distance to cover forage relies on the designation of pixels into cover, forage or nodata cells. The isolated nodata cells (< 2x2) are then eliminated by assigning them to either cover or forage based on the surrounding cells. Cover areas with canopy cover

≥40% and stand height > 2 m, are defined as areas occupying at least a 3x3 cell area and then the smaller areas are redefined as forage. Forage is defined as areas that are 3x3 or greater with smaller areas defined as "not classified." To calculate the distances to cover/forage edges, the model determines the boundary lines between the cover and forage areas and calculates the distance in meters of pixels to the boundary lines.

The vegetation grids are the original and the updated vegetation layers. The PNV is a layer provided with the WENHUM (Figure 14) and is used in the calculation of distance to cover forage edge. The mean slope is calculated for a 350-meter radius circle around each pixel from a slope grid derived from the DEM (Figure 15).

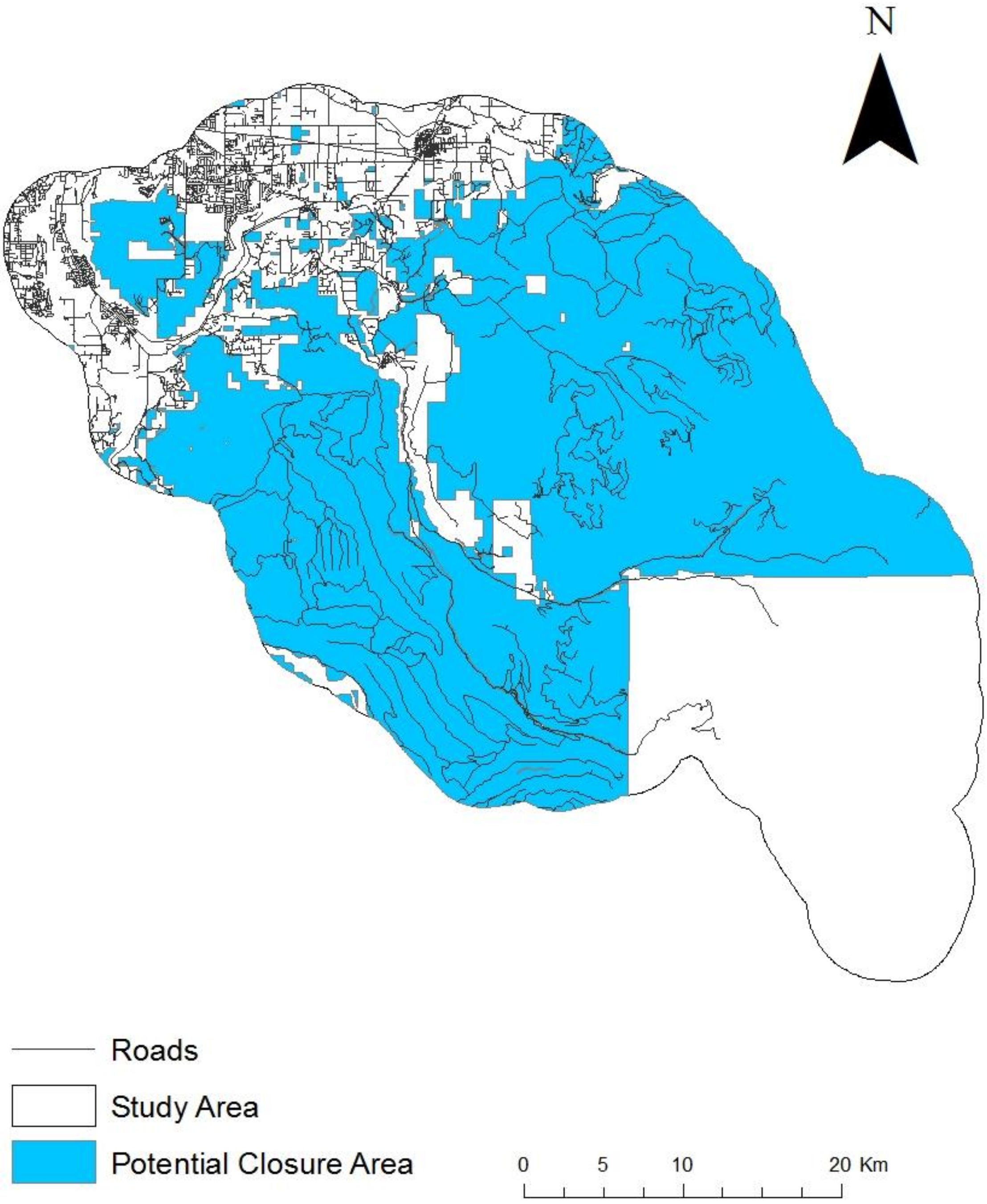

Figure 13: Map showing the roads as well as the area designated as containing potential closures.

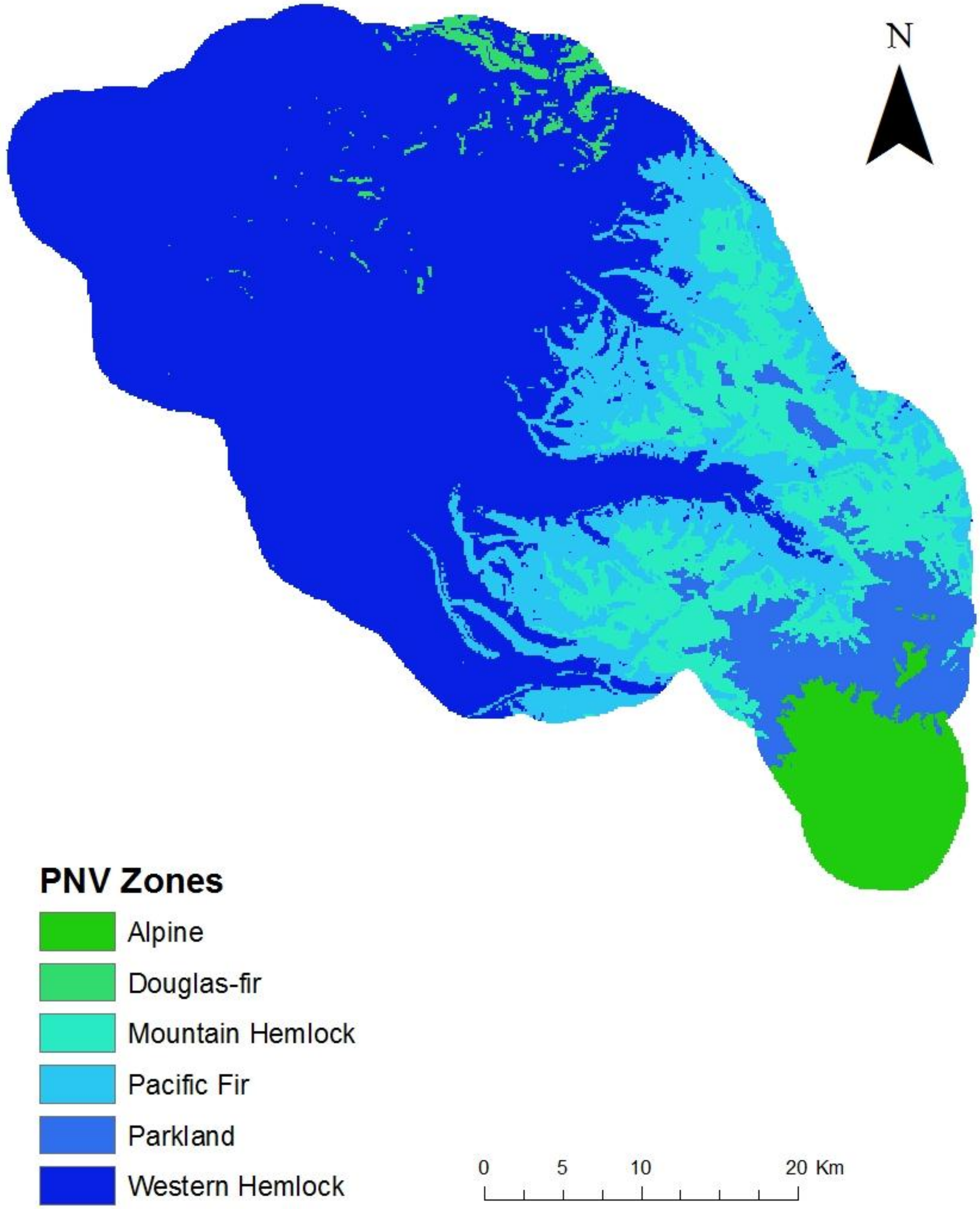

Figure 14: Map showing the Potential Natural Vegetation zones used in the application of the nutrition equation in the “Elk Covariates Toolbox”.

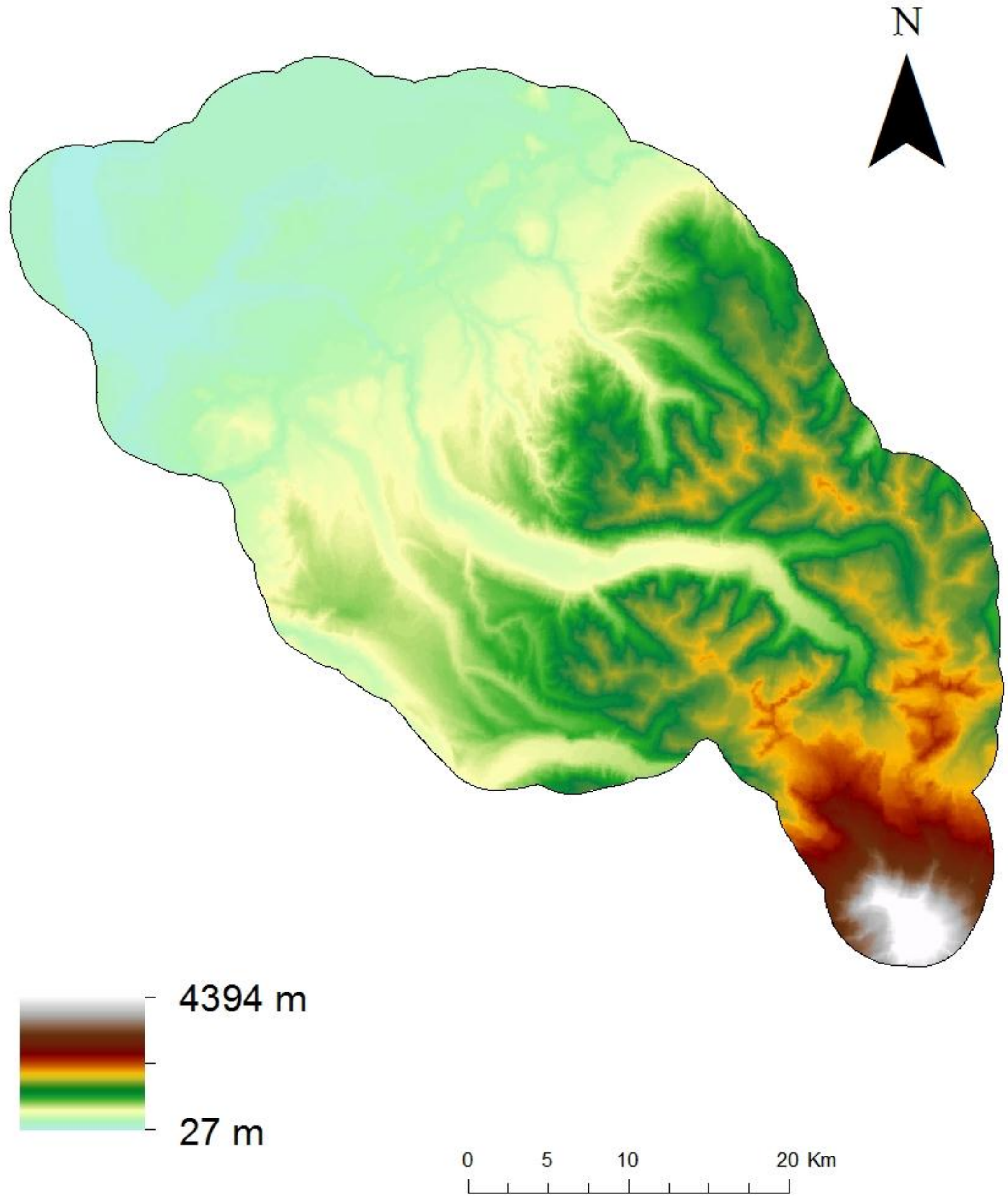

Figure 15: Topography of the study area as characterized by a 30 m x 30 m resolution Digital Elevation Model provided in the WENHUM.

The final toolbox used was the “Elk Use Toolbox” (Figure 16) that took the four covariates and used them within a single equation to create a single grid that predicts the likelihood that elk will use the habitat. The equation is:

$$Y = -27.7565 + (8.63746 * X_1) + \left(\frac{0.24788}{1000 * X_2}\right) - \left(\frac{0.67417}{1000 * X_3}\right) - (0.04372 * X_4)$$

where: Y = predicted elk use; X_1 = mean DDE; X_2 = distance to open public roads (meters); X_3 = distance to cover/forage edge (meters); X_4 = mean slope.

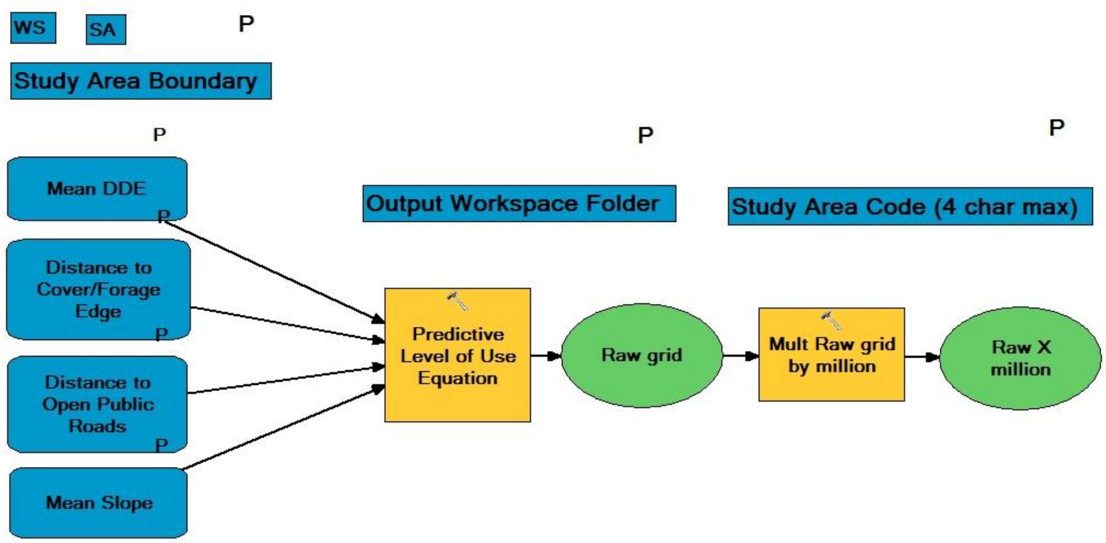

Figure 16: Schematic showing the predictive habitat use model in the “Elk Use Toolbox” of the WENHUM.

Chapter 4: Results

The “Update Base Veg Toolbox” produces a new vegetation grid that can either represent real changes over time as an update of the base vegetation layer or simulated changes to model proposed management actions. This analysis updated the original to reflect the changes to the forest structure during the period 2006 - 2011. The actual vegetation grid is not used on its own as an analysis tool but as an input into the other models.

The primary output from the Elk Nutrition model is the information pertaining to dietary digestible energy (DDE), which is output in multiple forms. The two that we are concerned with are DDE (measured in kcal/g) and mean-DDE. The values in the DDE output were originally summarized by Cook et al. (2004) into four categories (Table 4).

Table 4: Original DDE classification table proposed by Cook et al. (2004).

Description	DDE (kcal/g of food)
Excellent	> 2.90
Good	2.75 – 2.90
Marginal	2.40 – 2.75
Poor	< 2.40

One problem with the summary provided by Cook et al. (2004) is that nearly all of the DDE levels within the WENHUM modeling areas are below the excellent and good categories. Boyd et al. (2011) later created another classification scheme that uses six classes defined by the percentage of pixels that fall within each class (Table 5).

Table 5: DDE divided into six classes (Boyd et al. 2011).

Class	**Description**	**DDE**
1	Poor	< 2.40
2	Low-Marginal	≥ 2.40 to < 2.575
3	High-Marginal	≥ 2.575 to < 2.75
4	Low-Good	≥ 2.75 to < 2.825
5	High-Good	≥ 2.825 to < 2.90
6	Excellent	≥ 2.90

When viewing the results from the “Elk Nutrition Toolbox” (Figures 17 and 18) it is easy to see that there is essentially no change from 2006 to 2011 except in the designated change areas. In the change areas, where the change was clear cutting, the elk habitat has improved the DDE to the sixth class. There is a 2.25% increase in the total area of DDE class 6 (Figure 19) representing a significant increase in the amount of the most desirable DDE category.

Also evident is that the two lowest DDE classes, “poor” and “low-marginal”, have decreased and the remaining middle classes, “high-marginal”, “low-good”, and “high-good”, have remained nearly unchanged (Figure 19).

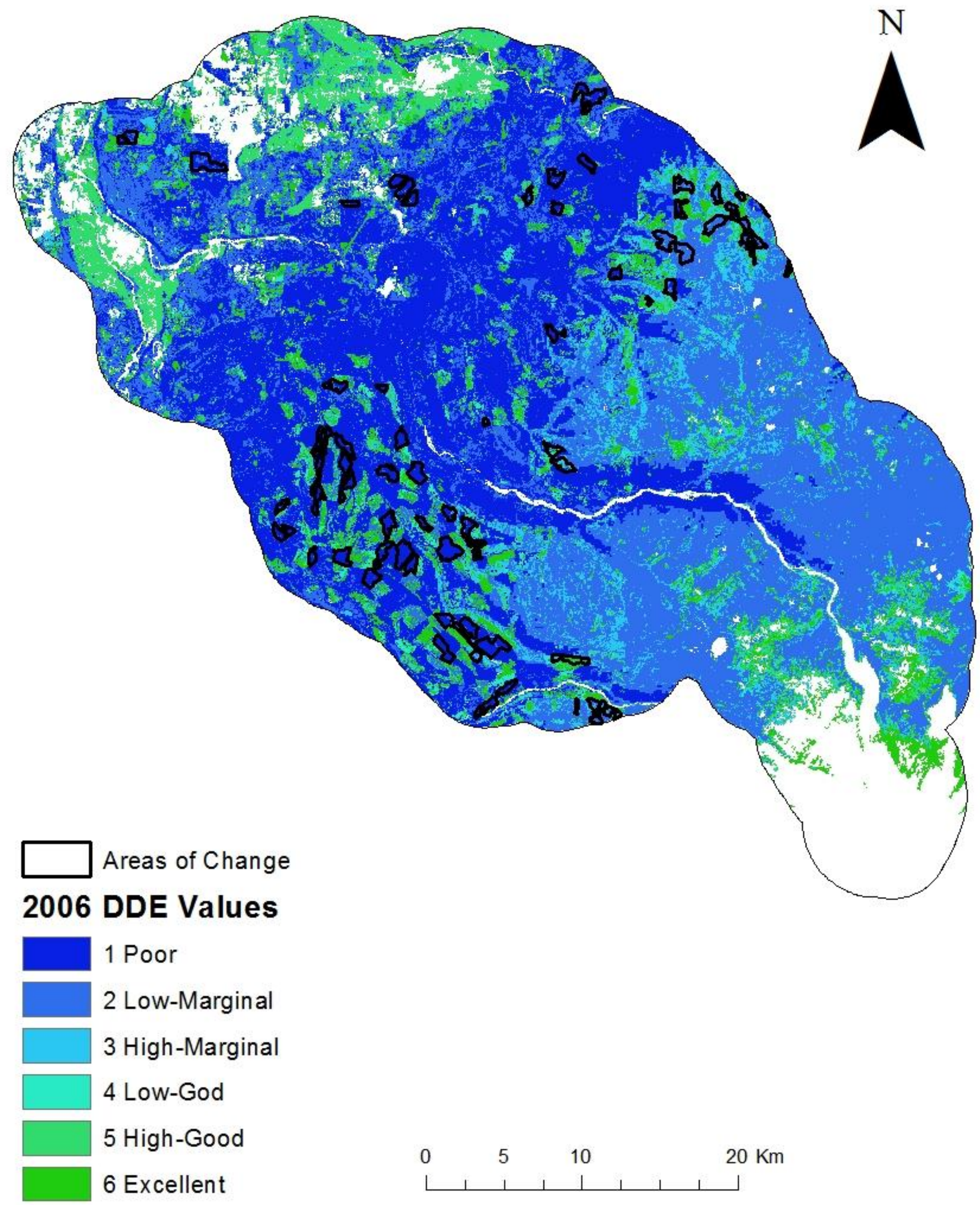

Figure 17: Raw DDE values for 2006 with change areas outlined in black. Values

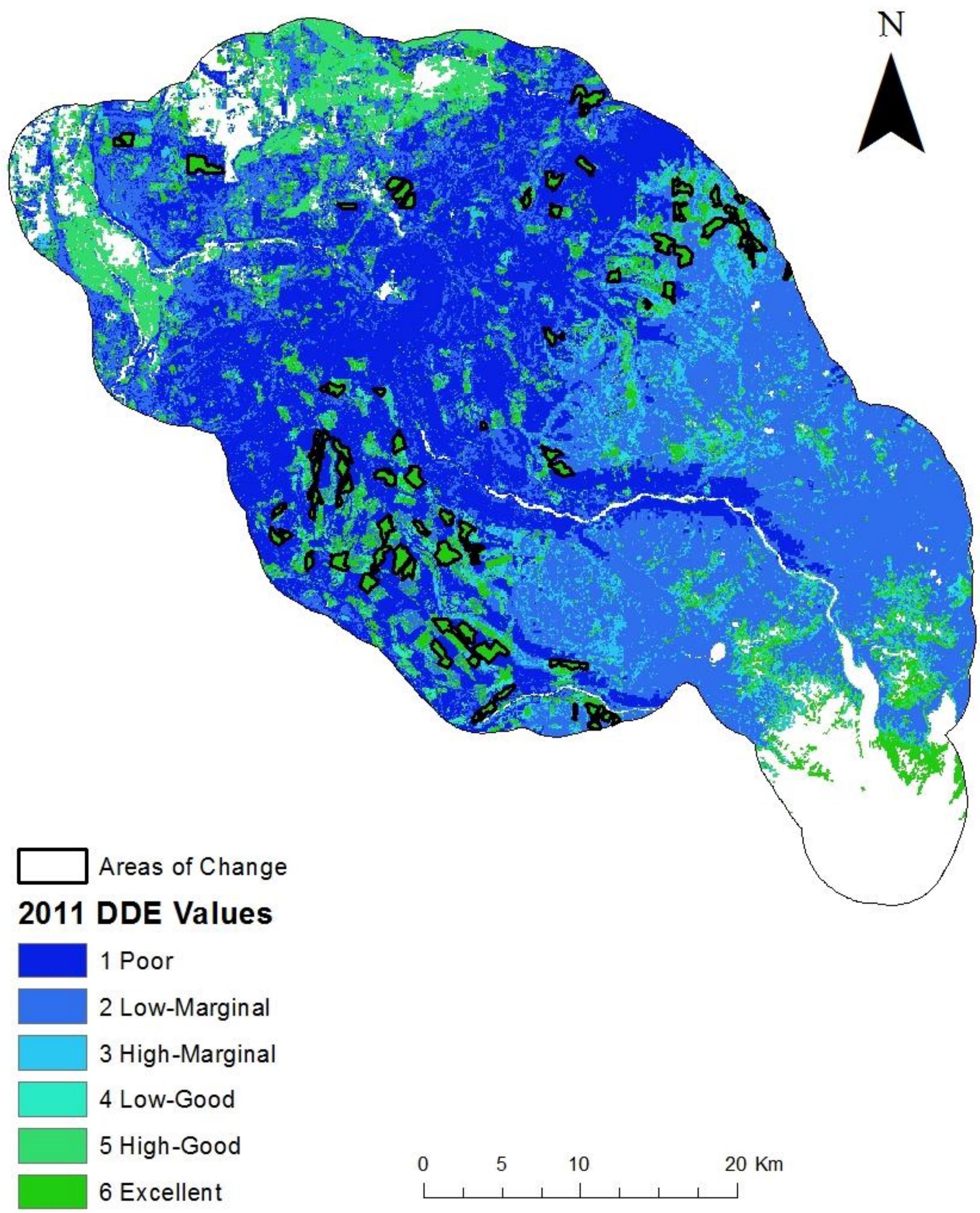

Figure 18: Raw DDE values for 2011 with change areas outlined in black. It is visible here that the color within the outlines is representative of category 6. Most of the DDE values in the change areas have values of 6.

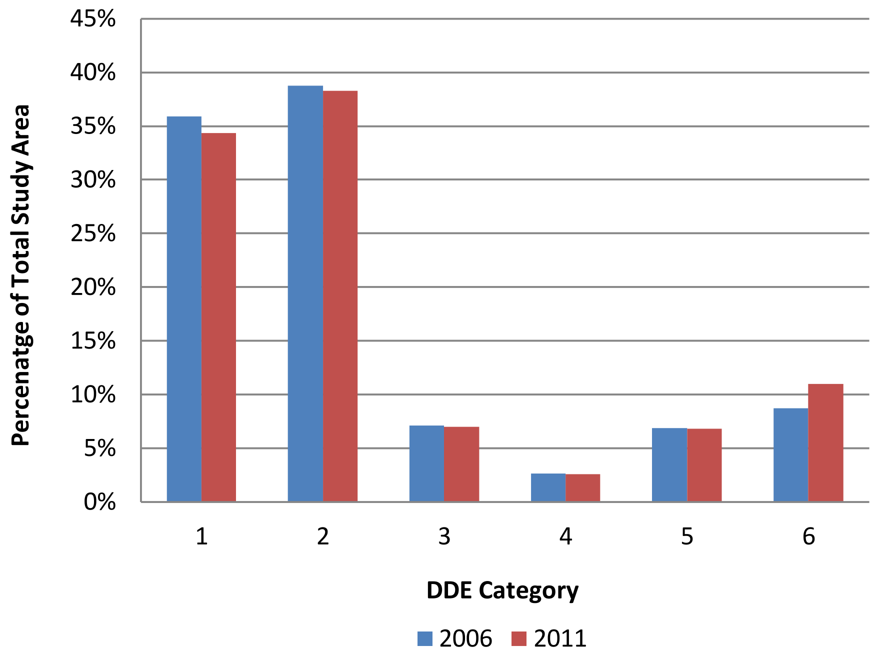

Figure 19: Change in percentage for each class of DDE for the years 2006 and 2011.

The “Elk Covariate Toolbox” produced the following outputs:

- distance to cover/forage edge
    - 2006 (Figure 20)
    - 2011 (Figure 21);
- distance to the nearest road open to public use
    - all candidate roads modeled as “open” (Figure 22)
    - all candidate roads modeled as “closed” (Figure 23);
- and mean slope (Figure 24).

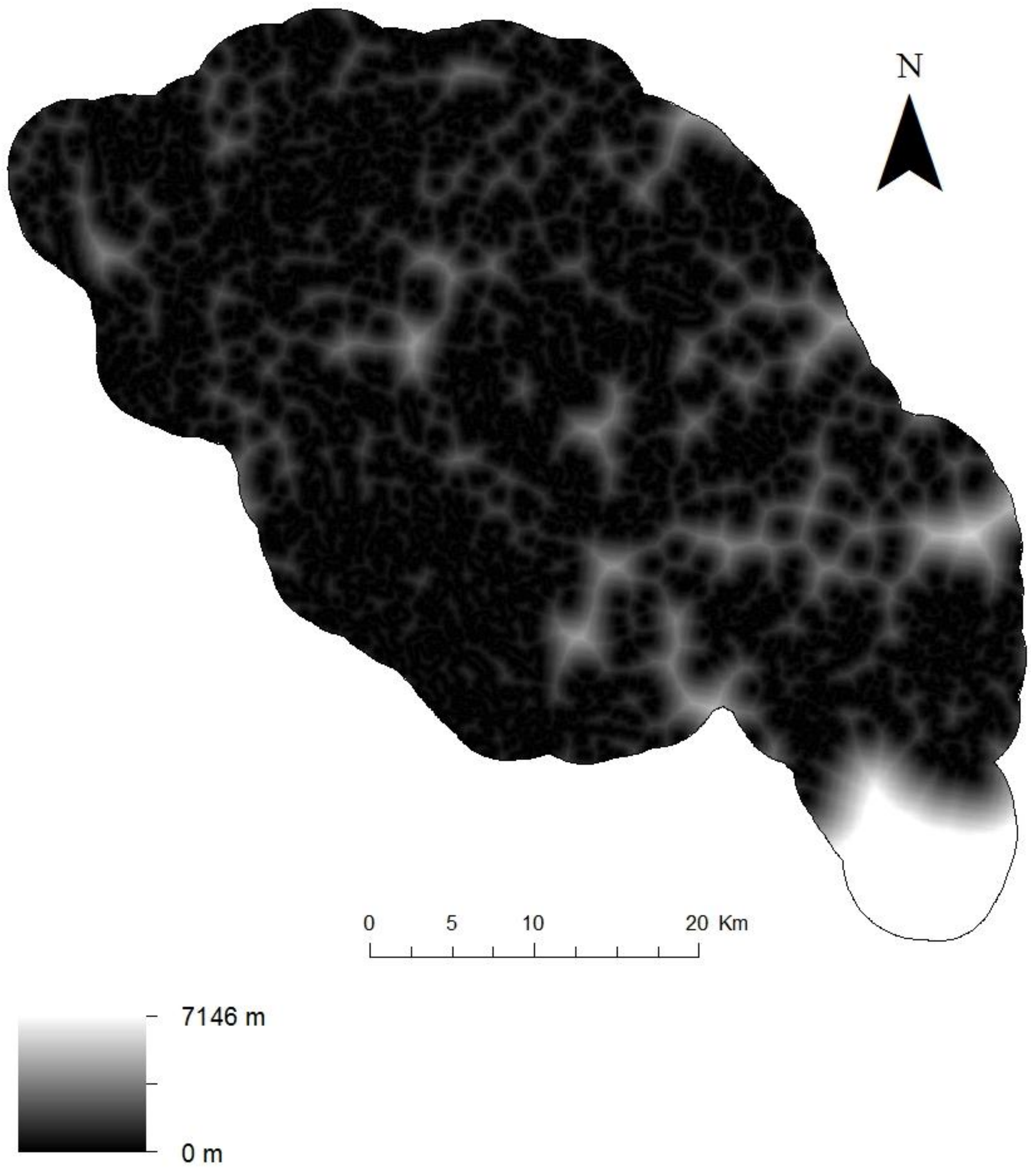

Figure 20: Distance to the edge of cover and forage for 2006, using the original vegetation layer.

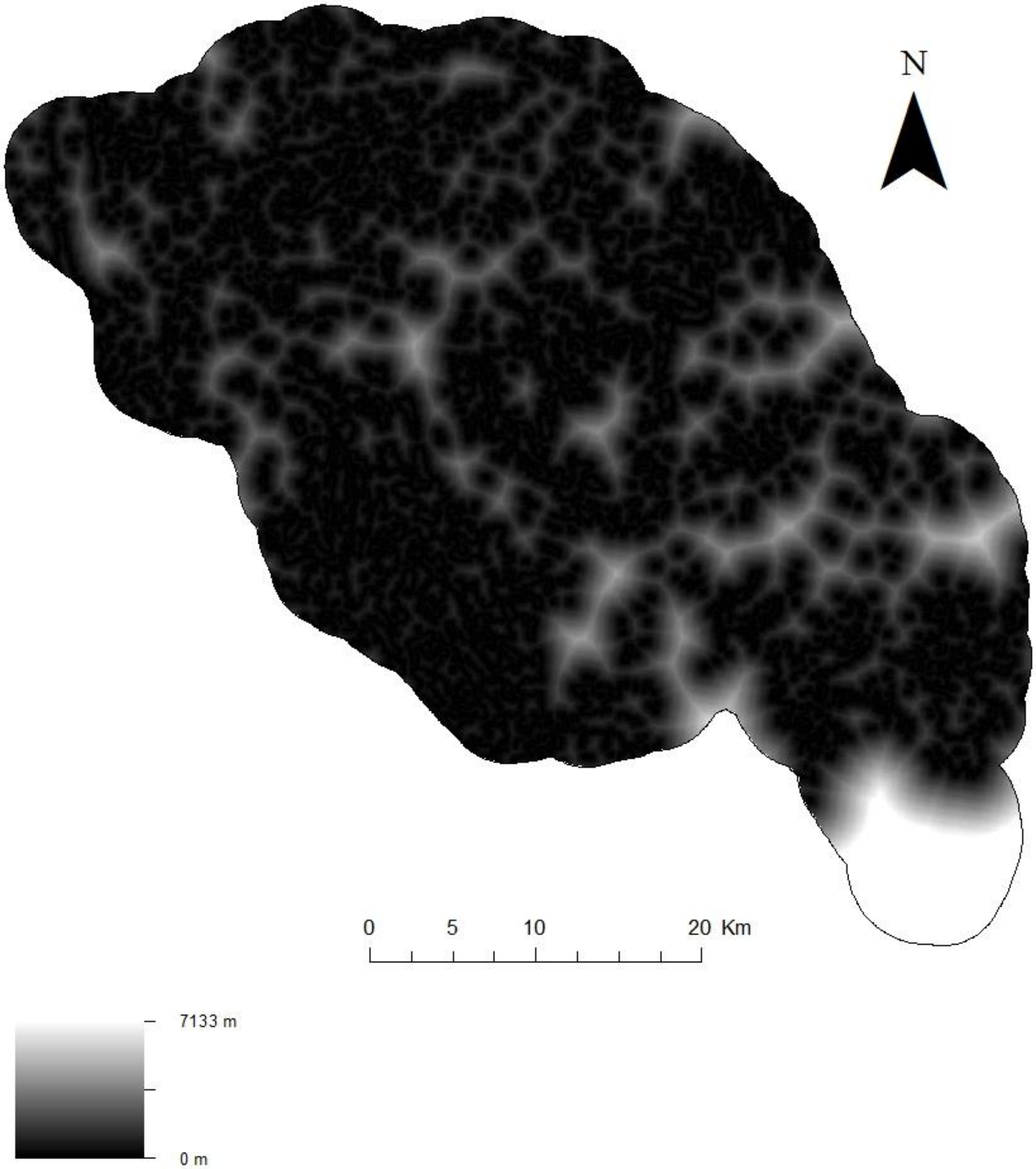

Figure 21: Distance to the edge of cover and forage for 2011, using updated vegetation layer.

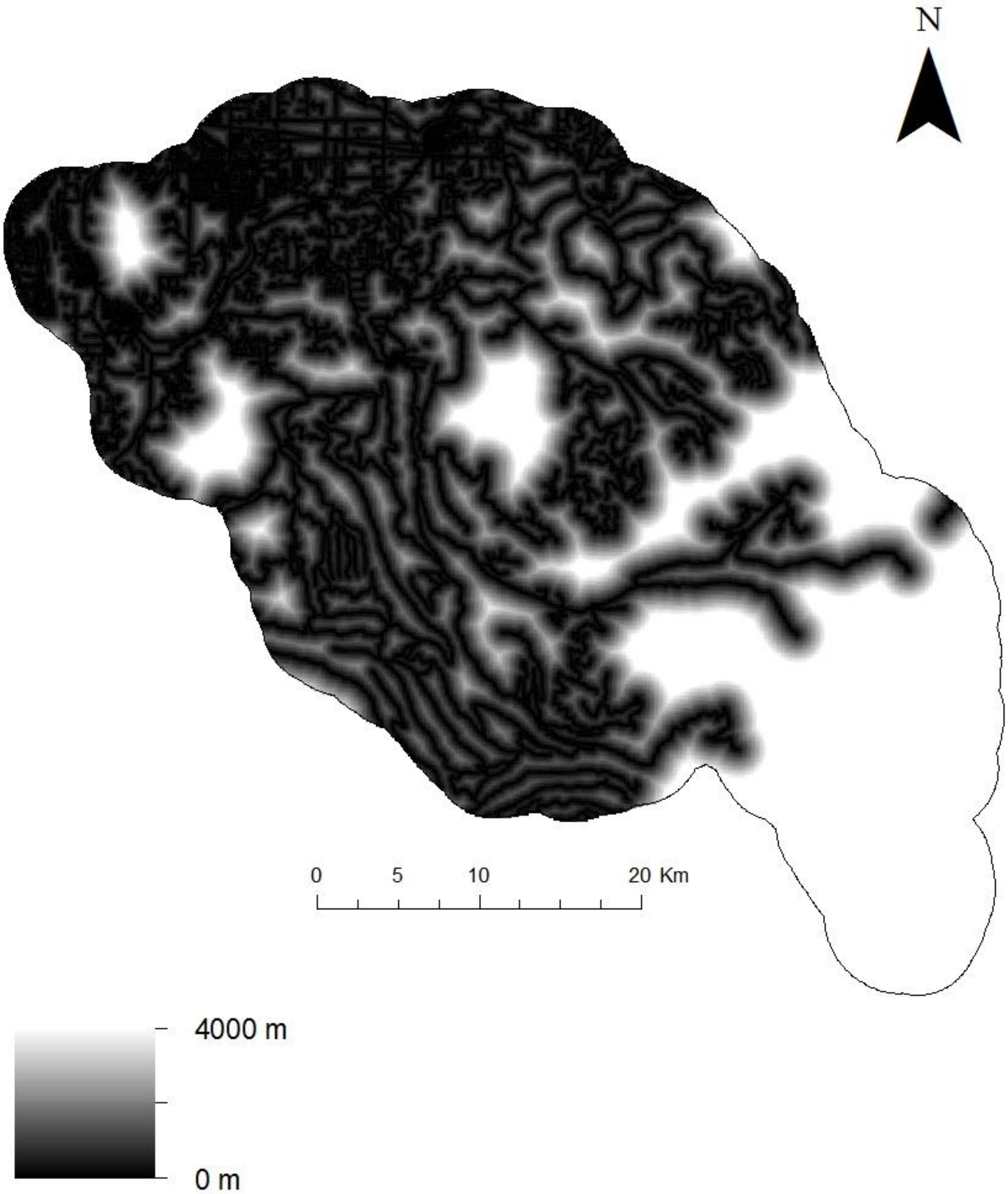

Figure 22: Distance to open roads with all candidate roads listed as open.

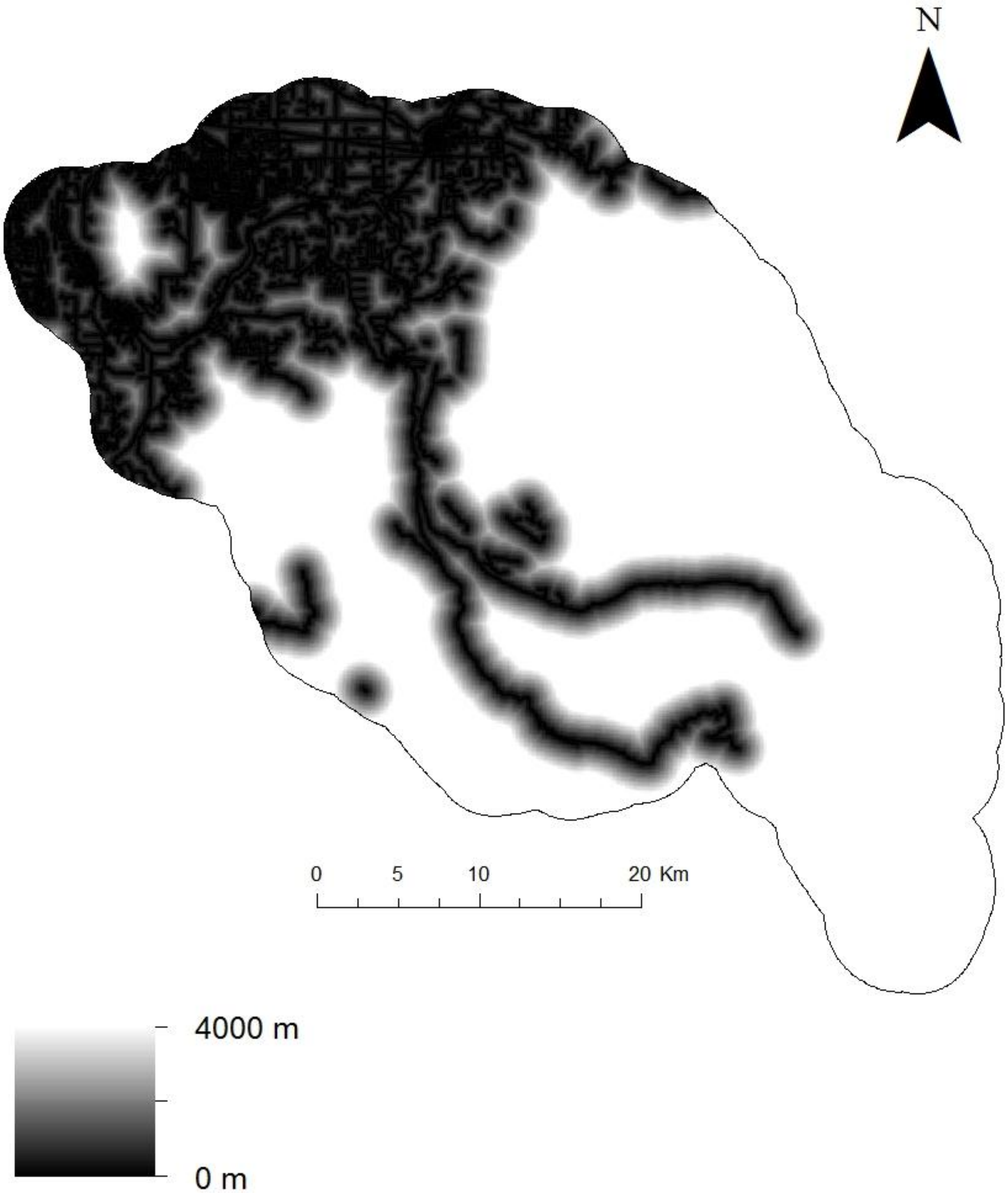

Figure 23: Distance to open roads with all candidate roads listed as all closed.

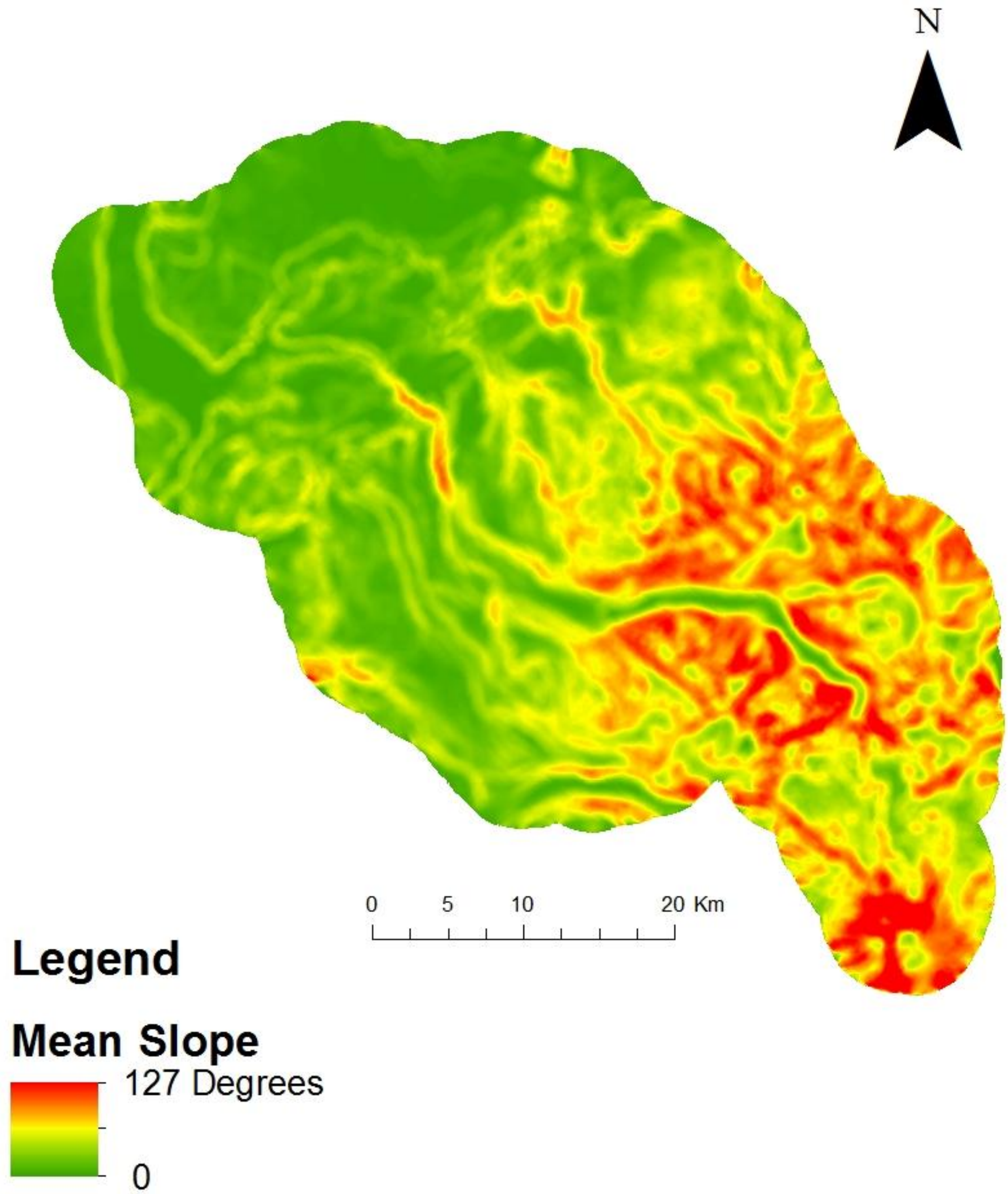

Figure 24: Mean slope for study area, calculated for a 350 m radius circle around each pixel from a slope grid derived from the DEM.

The output from the "Elk Use Toolbox" for example, Boyd et al. (2011) caution that the results for any given pixel are not standardized and that the number values can vary substantially from analysis to analysis, they are an index where the higher the number the higher the predicted use. For this reason, all results have been classified identically to support comparisons. The classification used is Geometrical, described by Esri as "a scheme that creates class breaks based on class intervals that have a geometrical series. The algorithm creates geometric intervals by minimizing the sum of squares of the number of elements in each class. This ensures that each class range has approximately the same number of values with each class and that the change between intervals is fairly consistent" (Esri 2012b). By using this method we can ensure that the study area is divided into equal regions for each use level, as recommended by Boyd et al. (2011).

When viewing the comparative maps (Figure 25) it is easy to see the effect of the open and closed roads. The areas of higher use increase in the region where roads have been modeled to be closed (Figure 25-A and 25-D). In 2006 and 2011 all of the predicted use categories increased with the exception of the lowest category and category 6 in 2006 which remained static at 0.006% (Figures 26 and 27). This data illustrates the importance of the road data, having accurate data of road closures/openings can be have an effect on the use probability; the amount of the effect is dependent on the density and number of closures.

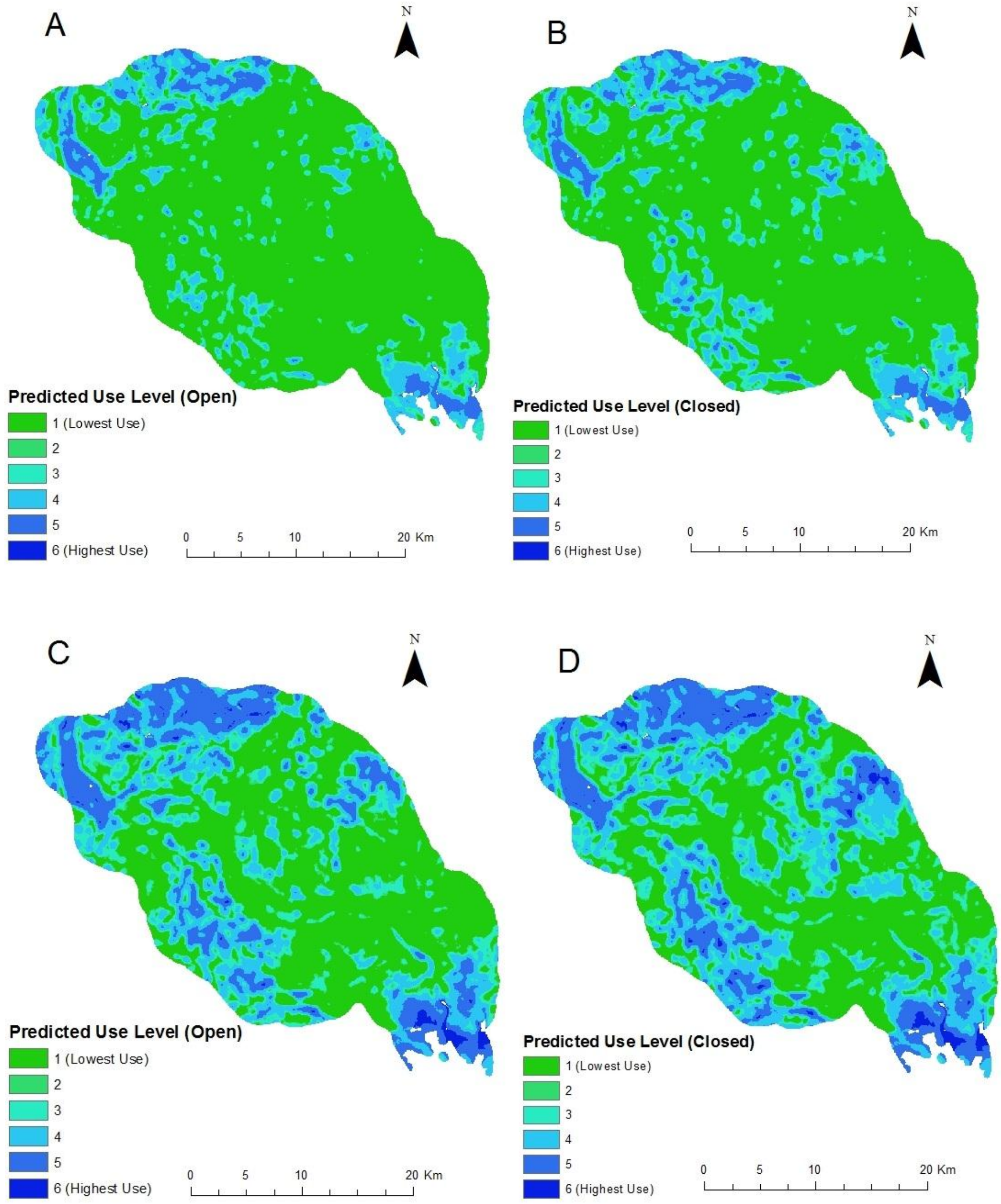

Figure 25: Comparison of the predicted use results for 2006 and 2011: (a) with all roads open in 2006; (b) with all roads closed 2006; (c) with all roads open 2011; and (d) all roads closed 2011.

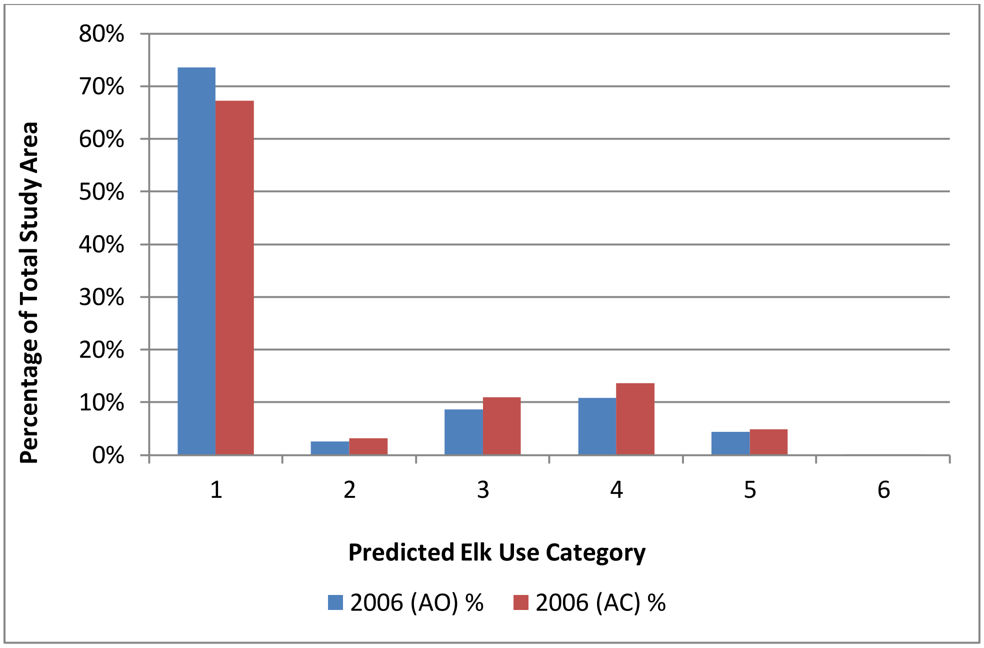

Figure 26: Changes in percentages of each elk use categories for 2006, both with potential road closures modeled as “all open” (AO) and “all closed” (AC).

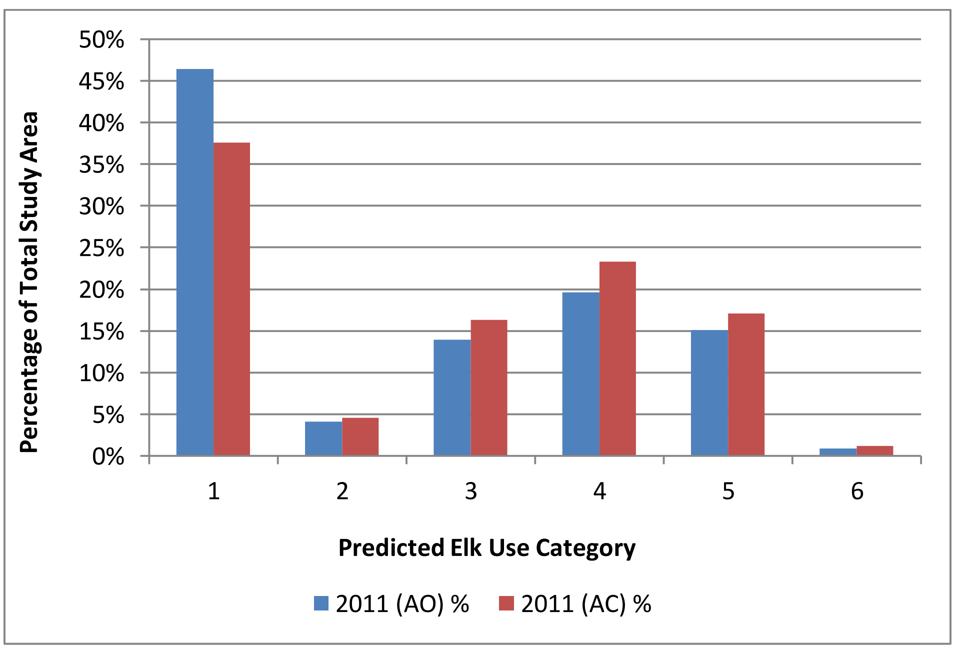

Figure 27: Changes in percentages for each of the elk use categories for 2011, both with potential road closures modeled as “all open” (AO) and “all closed” (AC).

Chapter 5: Discussion and Conclusions

Analyses show that at least in the short term that clear cuts can provide improved habitat for elk, as shown by the increase in total habitat between 2006 and 2011.

The DDE showed an increase in the more desirable categories, particularly in category six ("excellent") between 2006 and 2011. This resulted from clear cuts providing an increase in available forage. Benefits from the clear cuts will likely decrease as the size of individual clear cuts increases because this will increase the distance to cover/forage edges. In addition to this, as time passes since the time of the clear cut, DDE and associated predicted use will decrease as the stand height increases and the other variables change as well.

At the onset of the study it was decided to leave in urbanized areas that were clearly not elk habitat and to judge the ability of WENHUM to classify them. It is evident in that while the models use proximity to open roads as an important covariate, exceptional habitat must exist in those areas since they labeled as "high" in terms of predicted habitat use (Figure 28). Given that the WENHUM predicts habitat based on proximity to open roads, and all roads in that area are classed as open, the amount of high predicted use is surprising. The model does not take into account human population densities or urbanization and this analysis shows that (Figure 28). In the map it shows how in the northwest portion of the study area there is a high concentration of roads open to the public but also a high predicted elk use, which does not actually occur. Therefore, areas that can be deemed to be uninhabitable by elk prior to any analysis should be removed at the onset to minimize these kinds of problems.

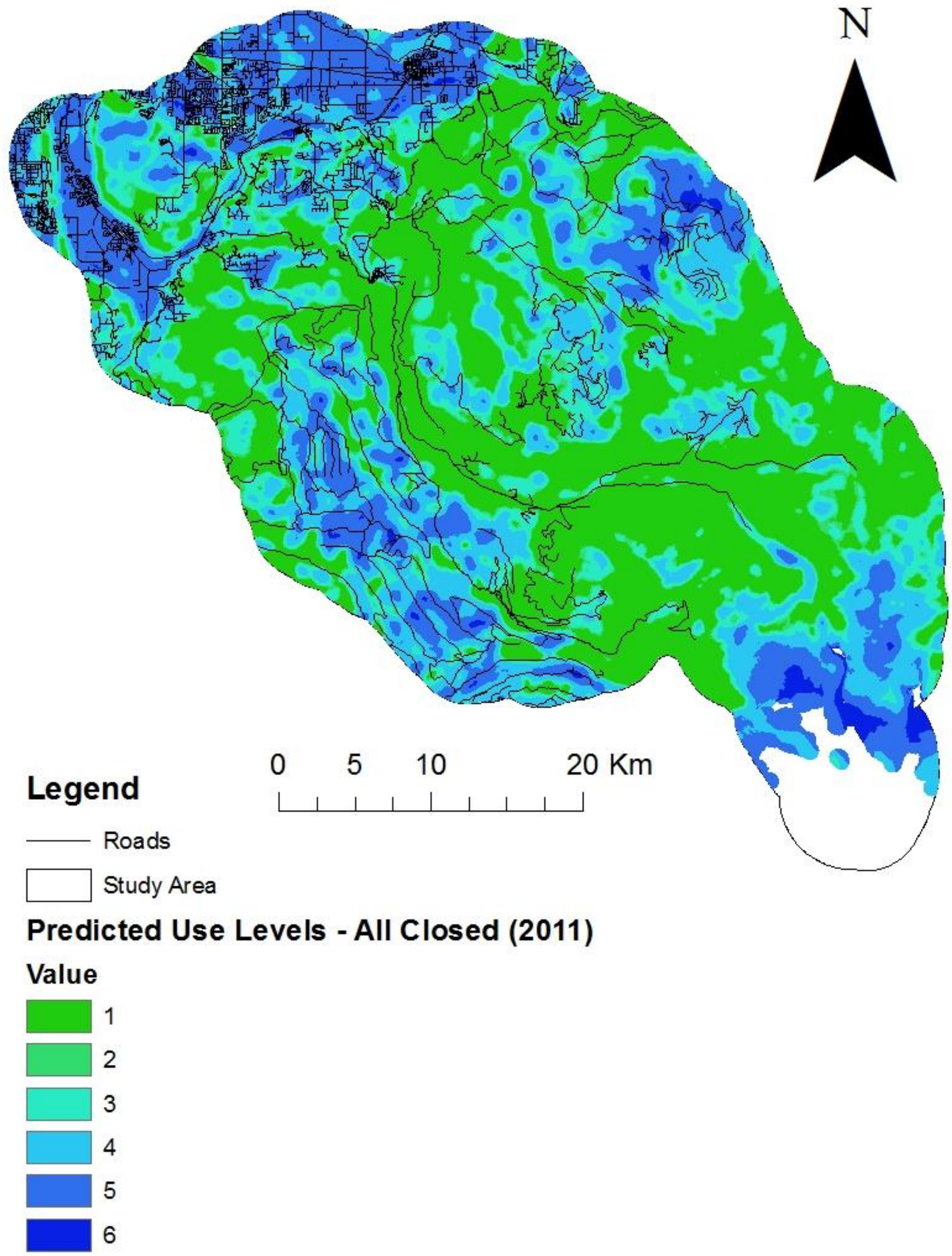

Figure 28: Map showing roads and 2011 predicted use with all candidate roads modeled as closed to public use. In the northwestern portion of the map, a high density of roads and a high predicted use occur together, these two conditions are in reality mutually exclusive.

I encountered challenges in the use of the WENHUM (new table). In some instances, models were not producing the results stated in the manual, results that were required as input for the next step. The models had to be edited so that all the appropriate results were not designated as “intermediate” or were named in a way so that the desired result was known (Table 6).

Table 6: Description of the editing required for toolboxes in the WENHUM.

Model	Problem	Solution
“Update Base Veg Toolbox”	Newly created base vegetation layer Incorrectly named.	Edited title for the output raster dataset in the “Copy Raster” tool within the model.
“Elk Nutrition Toolbox”	Outputs not being saved to designated folders.	Removed “intermediate” designation from several required outputs .

Based on the results of this analysis I think that it is safe to say that the WENHUM can be used to evaluate the much larger NREH area. Although it would be wise to break it down into sections to be combined at different points to produce whole maps. Caution should be taken with the study area and its overlap of the modeling regions.

In response to the initial attempt of conducting a classification and change analysis, it is my opinion that it is possible but would require an immense amount of computing/processing time that may make it prohibitive in most cases. There was also an anticipated issue with creating the change areas polygons following the change detection. The results were likely to be too granulated and not formable into clean, easy to use polygons. It should also be noted that judging by the results obtained here using the “heads-up digitization” of the change area polygons, it may not be necessary.

The WENHUM created by Boyd et al. (2011) are a fascinating way to view and to model elk habitat. There is an even greater amount of detail that can be used to study an area especially when taking into account forestry practices other than clear cutting. In situations where there has been more thinning or selective cutting a thorough and more detailed analysis of an area would be required. Caution should be taken as the size of the study area increases, finite detail on forest stands and road closures will be increasingly more difficult.

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Appendix

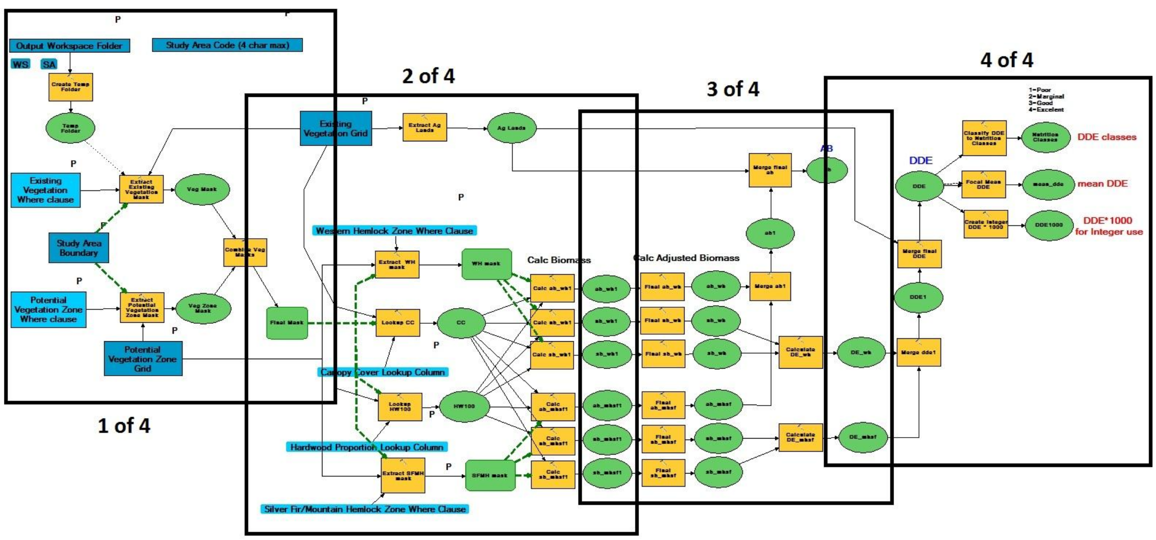

Figure A 1: An overview of the subsections that follow (Figures A2 – A5) for the Nooksack version of the "Elk Nutrition Toolbox" model.

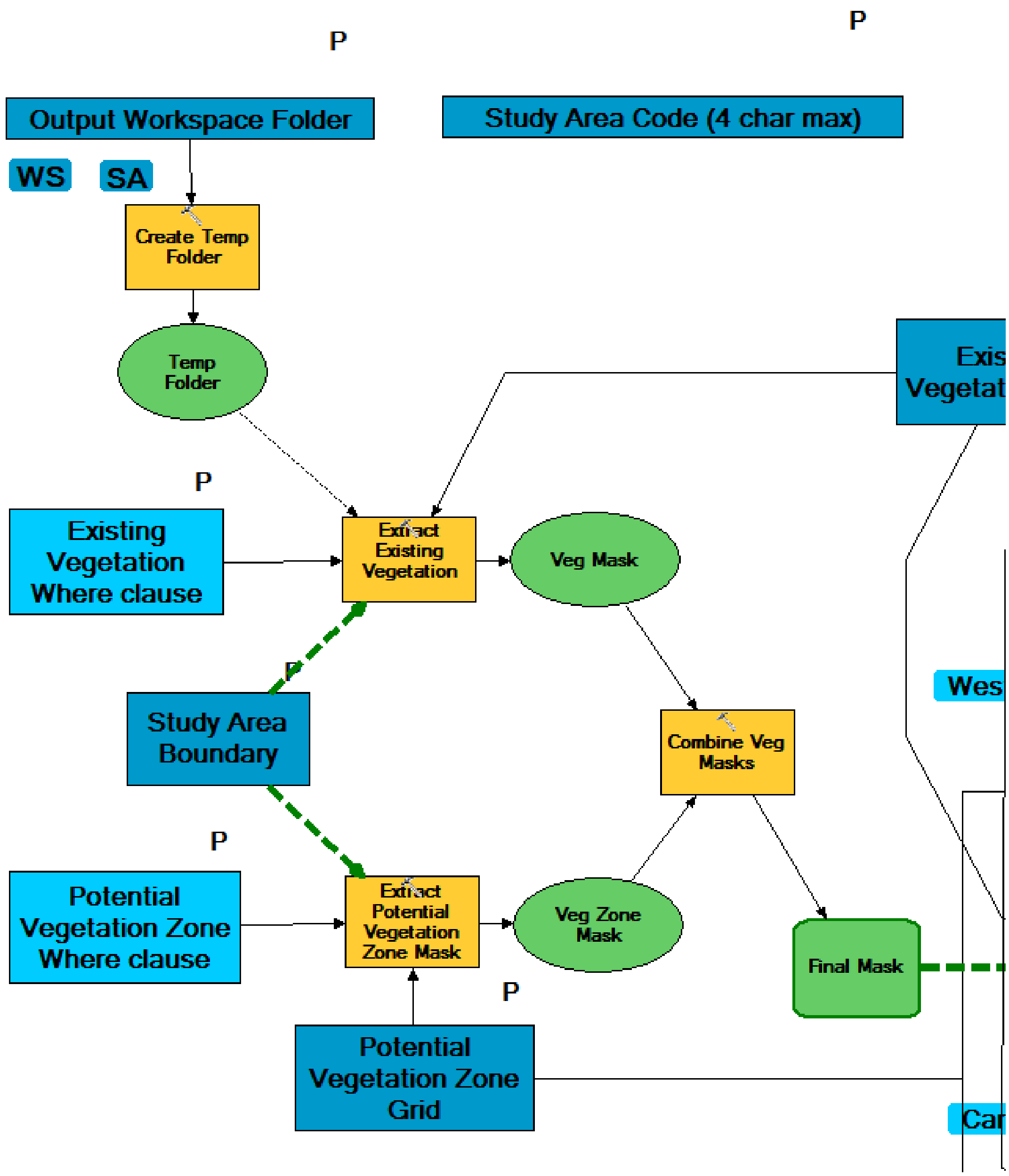

Figure A 2: A close-up view of a portion of the nutrition model for the Nooksack Region (1 of 4).

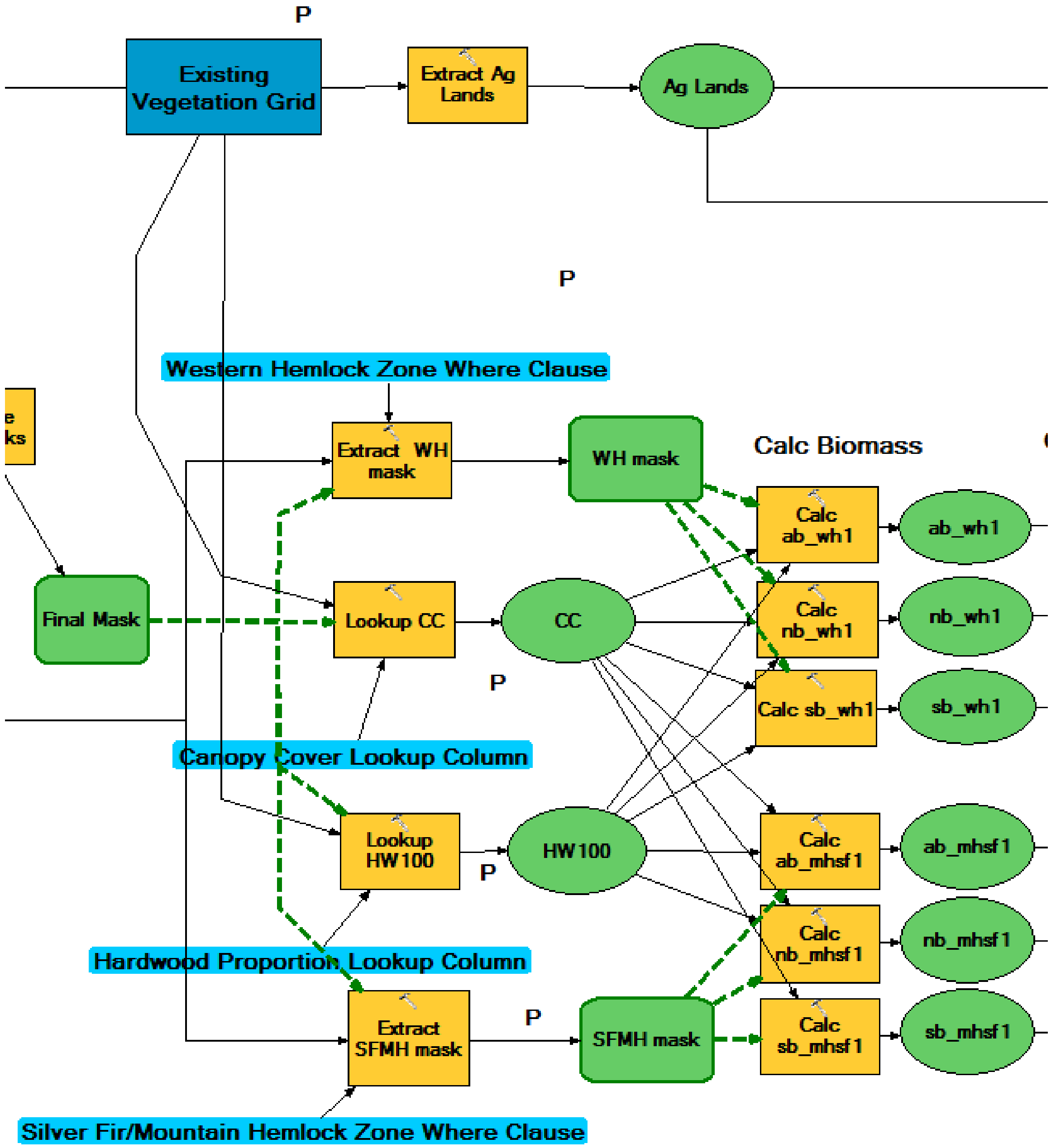

Figure A 3: A close-up view of a portion of the nutrition model for the Nooksack Region (2 of 4).

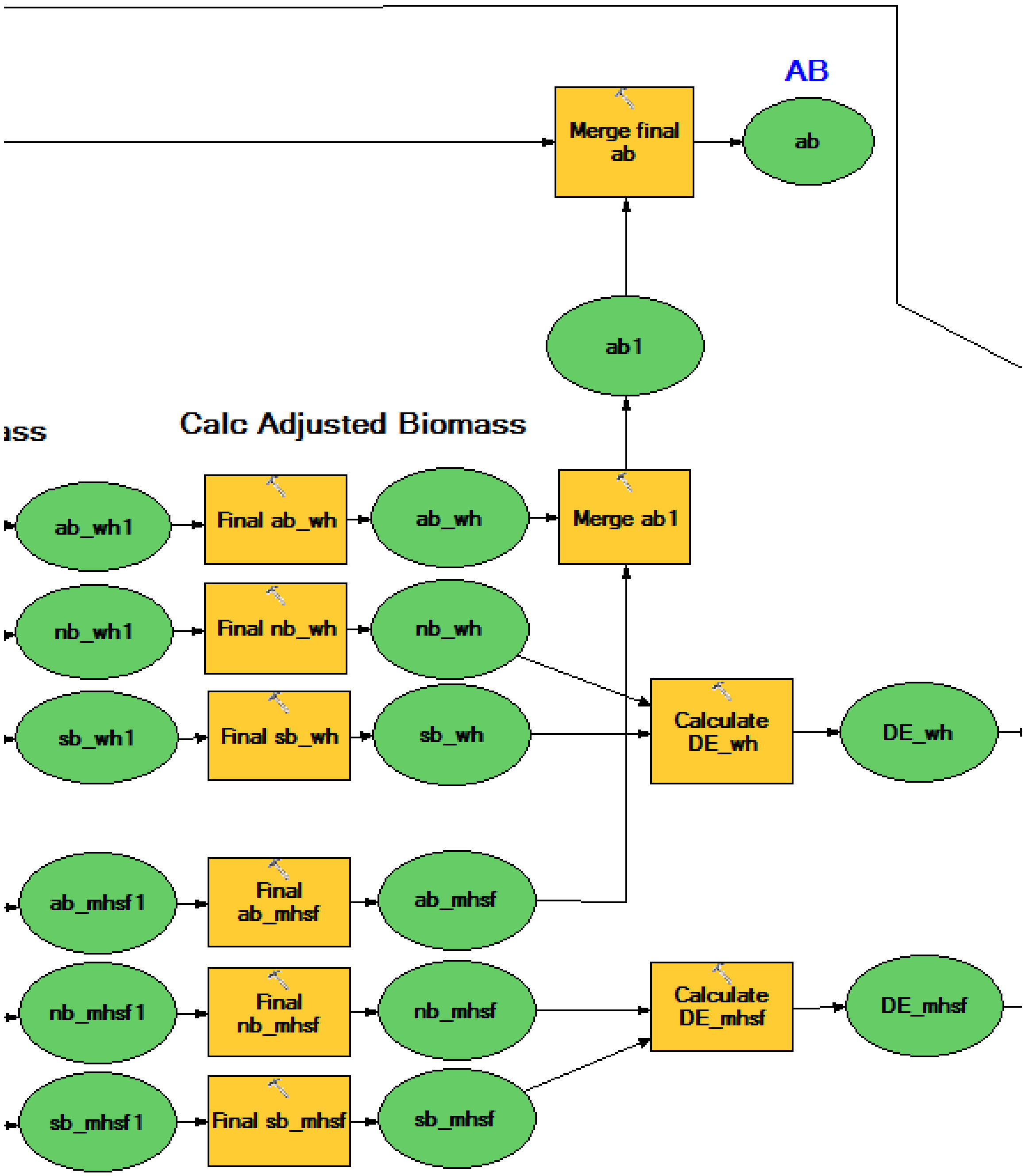

Figure A 4: A close-up view of a portion of the nutrition model for the Nooksack Region (3 of 4).

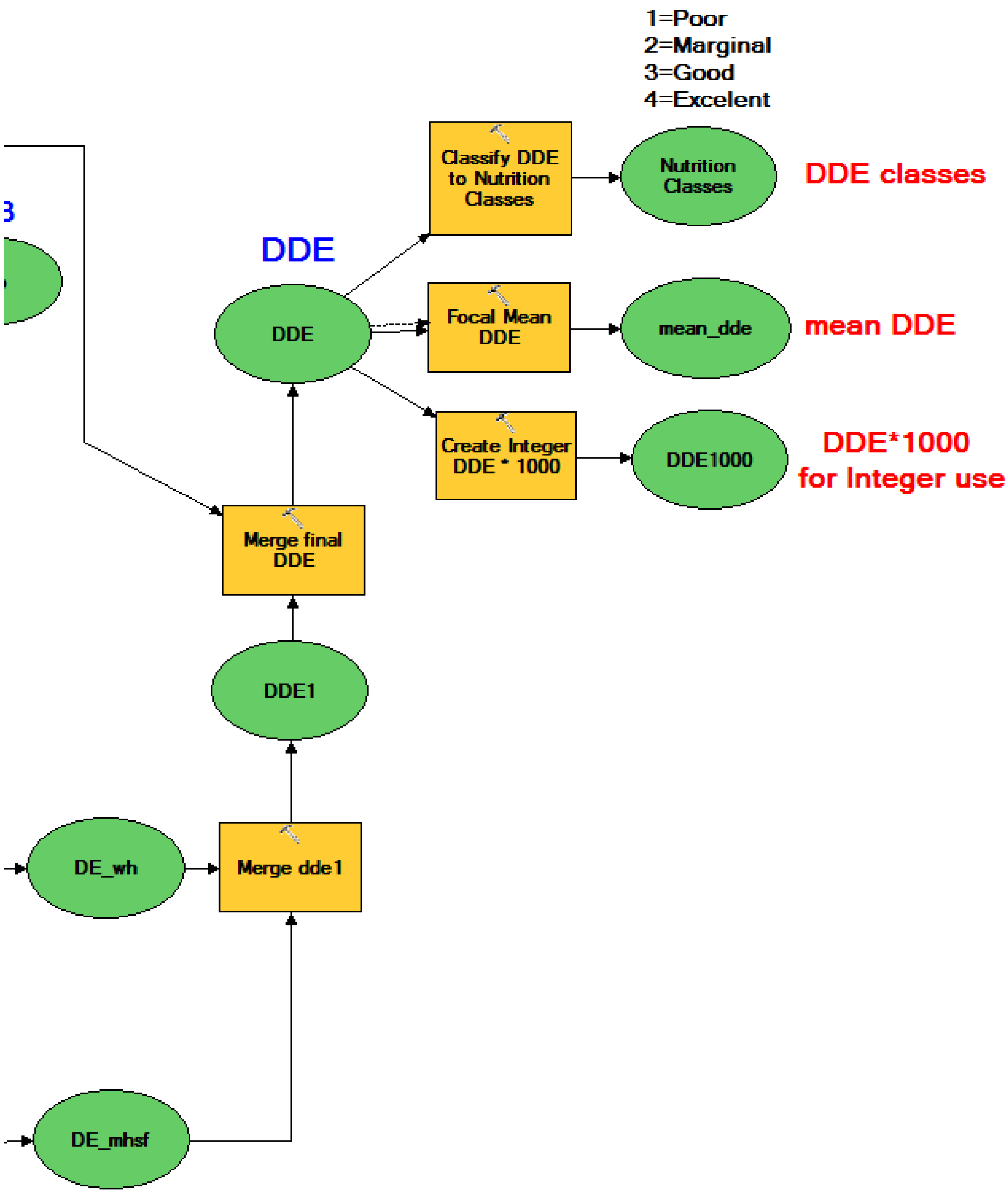

Figure A 5: A close-up view of a portion of the nutrition model for the Nooksack Region (4 of 4).

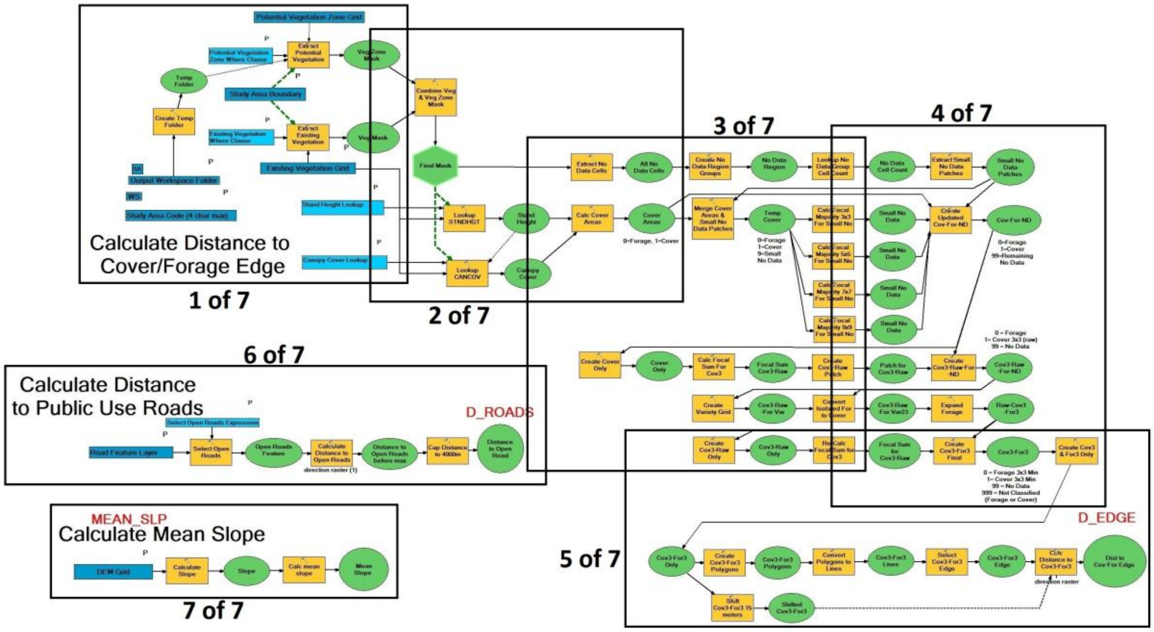

Figure A 6: An overview of the subsections that follow (Figures A7 – A13) for the “Elk Covariates Toolbox”.

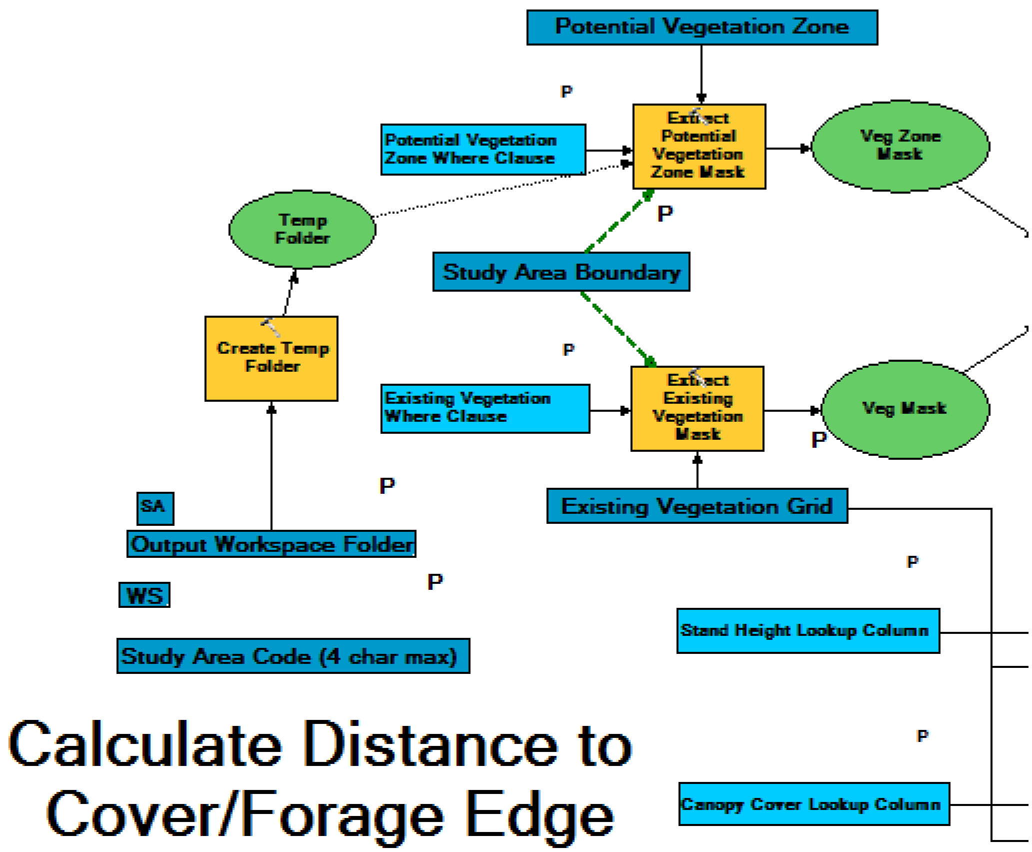

Figure A 7: A close up view of the Elk covariates model (1 of 7), the portion that calculates the distance to cover/forage edges.

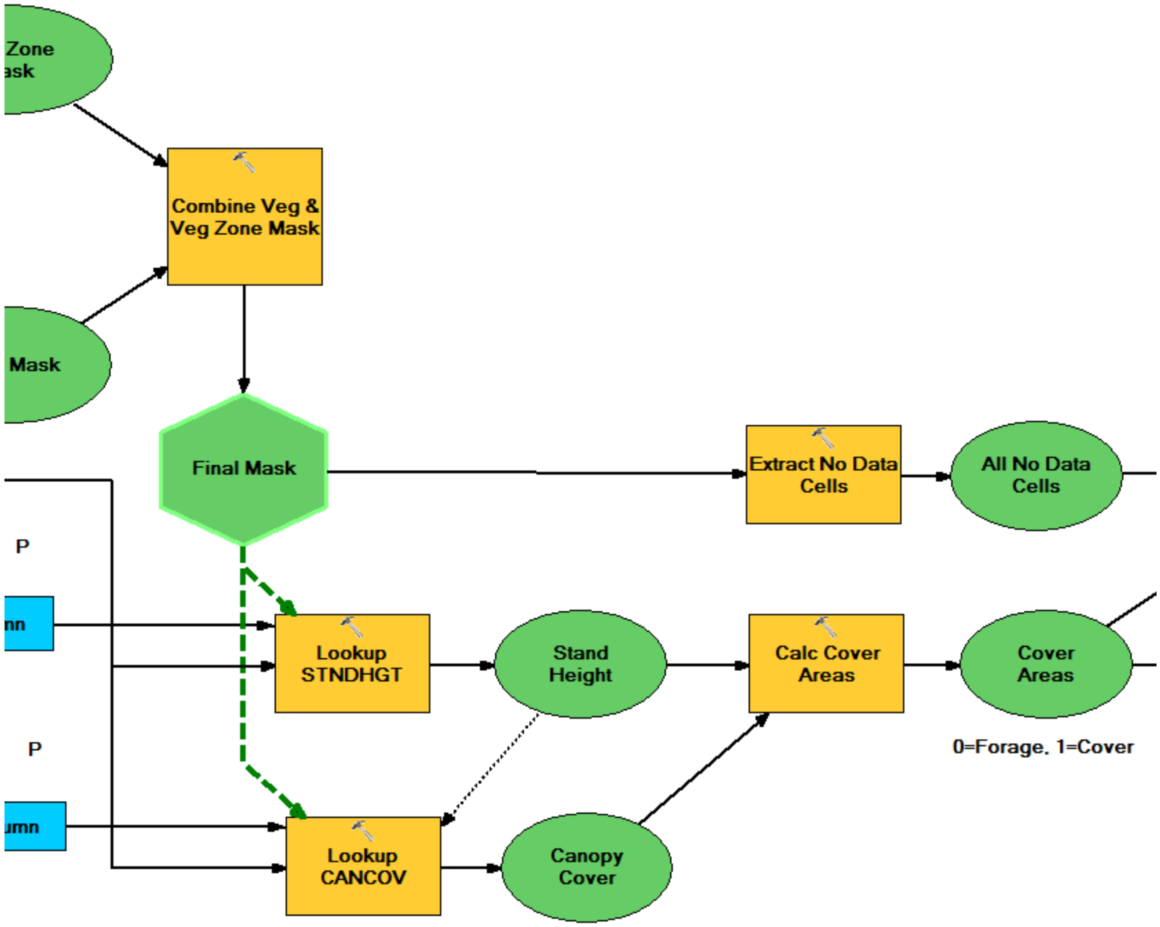

Figure A 8: A close up view of Elk covariates model (2 of 7), the continuation of the portion that calculates the distance to cover/forage edges.

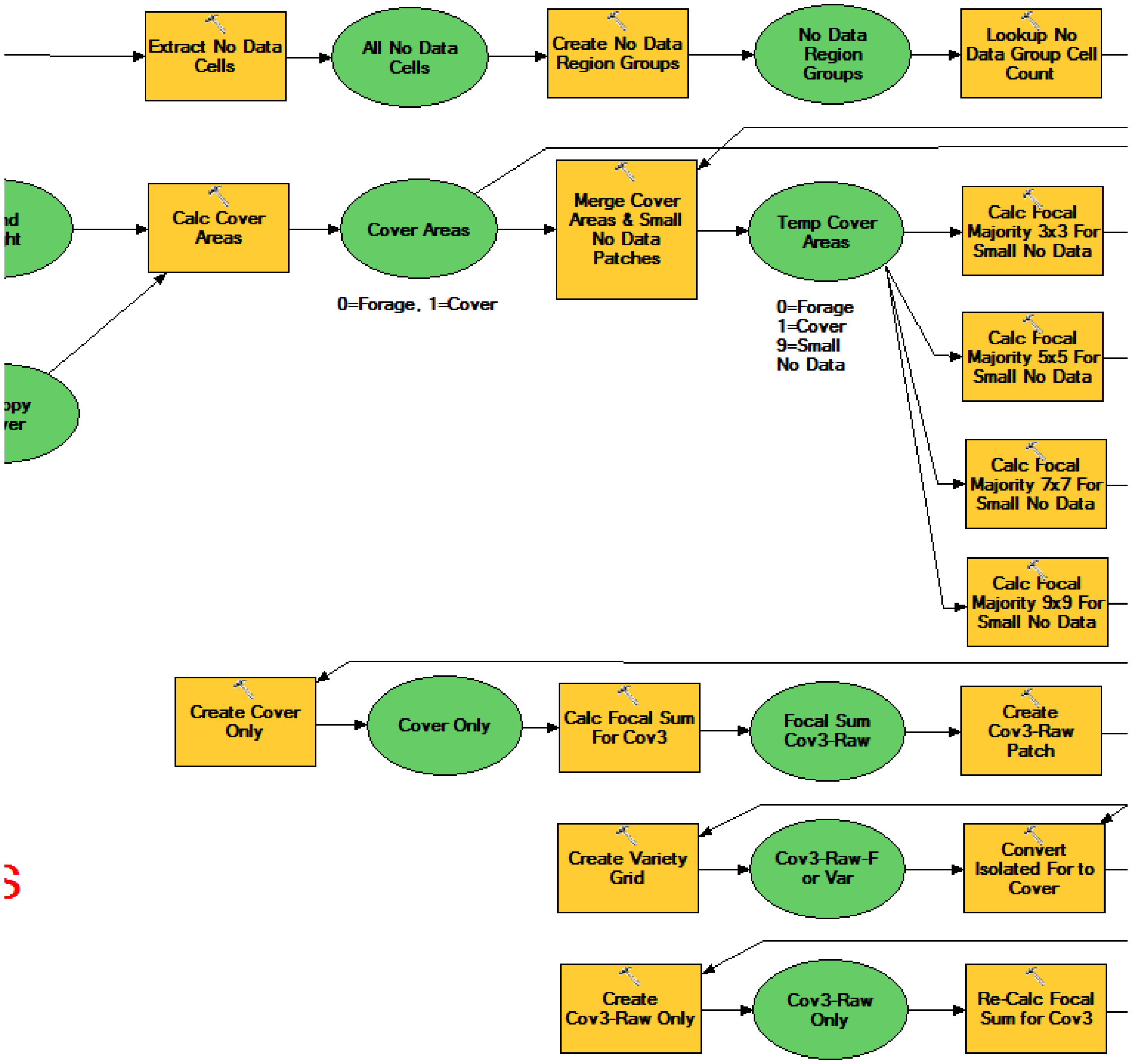

Figure A 9: A close up view of the Elk covariates model (3 of 7), the continuation of the portion that calculates the distance to cover/forage edges.

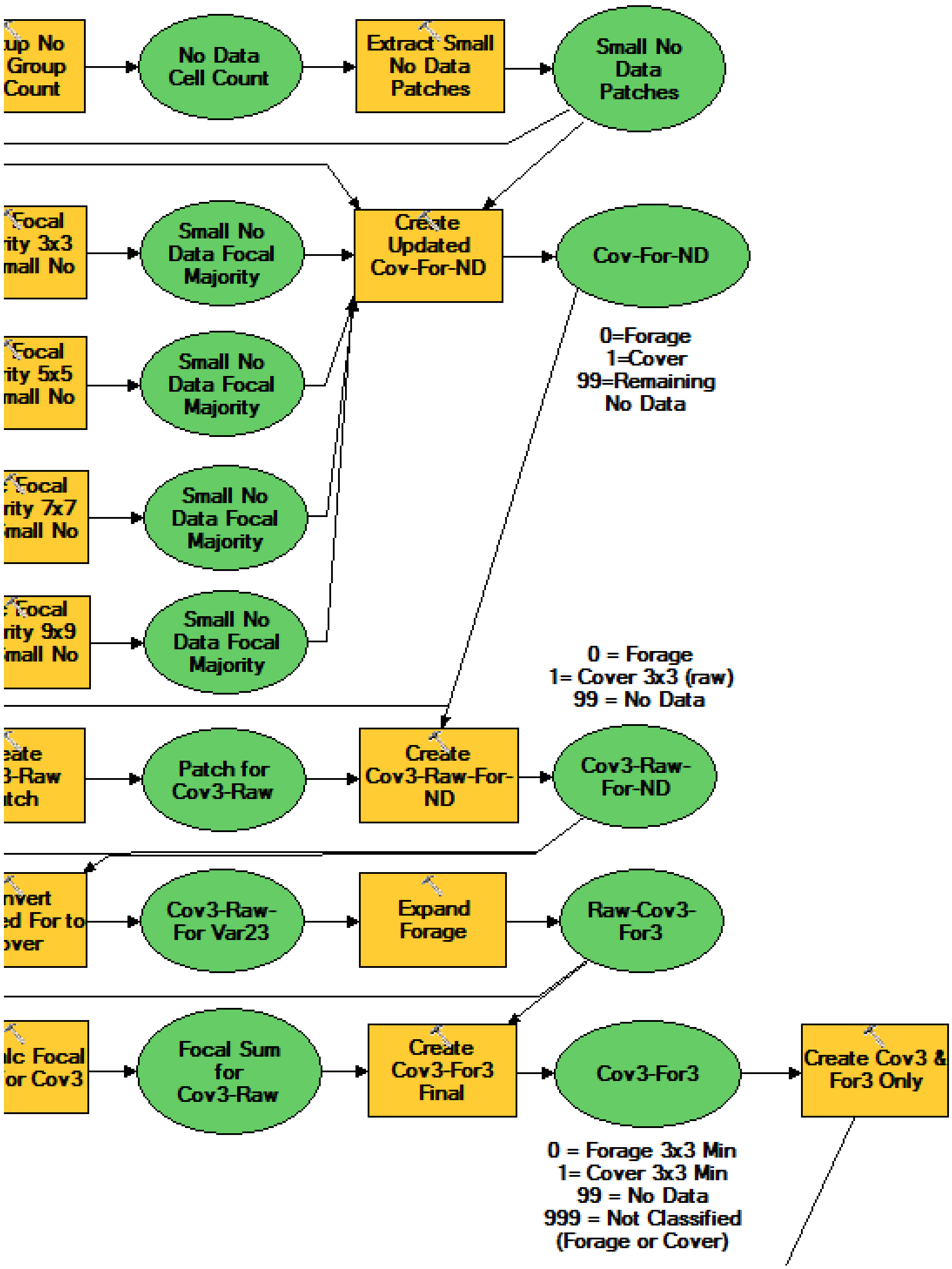

Figure A 10: A close up view of the Elk covariates model (4 of 7), the continuation of the portion that calculates the distance to cover/forage edges.

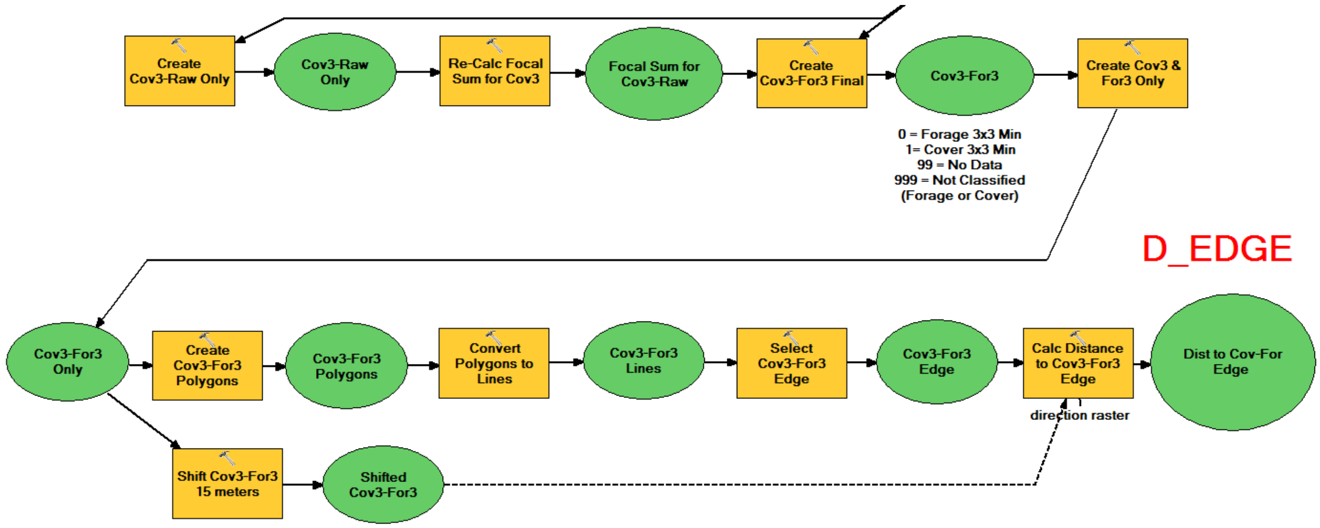

Figure A 11: A close up view of the Elk covariates model (5 of 7), the continuation of the portion that calculates the distance to cover/forage edges.

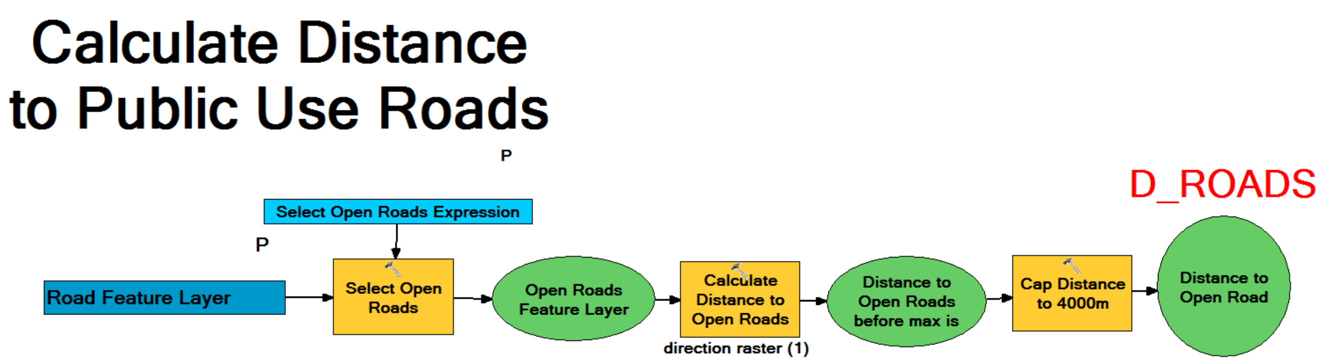

Figure A 12: A close up view of the Elk covariates model (6 of 7), the portion that calculates the distance to roads open to the public.

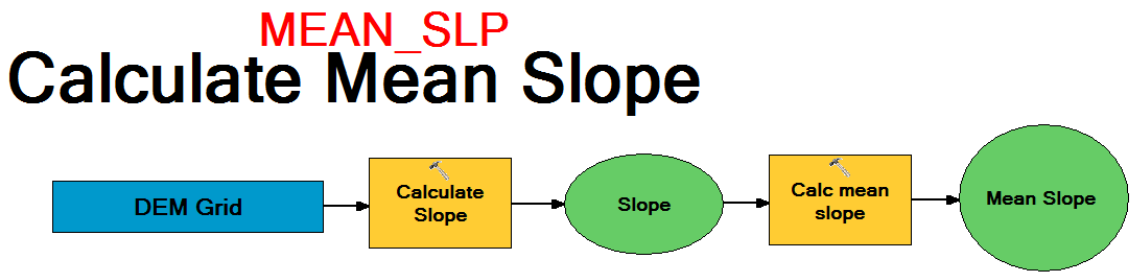

Figure A 13: A close up view of the Elk covariates model (7 of 7), portion of that calculates the mean slope.