11 Creating a Crosswalk of Vegetation Types and Fire Fuel Models for the National Park Service

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Abstract The US national fire danger rating System (NFDRS) generates daily estimates of fire potential throughout the United States. A key component of this system is the condition of live vegetation. Currently, there are no objective methods for determining vegetation condition. Inter-annual climatic variability causes the onset of spring green-up and fall leaf senescence to vary substantially from year-to-year. Therefore, methods used to assess live vegetation condition must be robust to these climatic changes. We present a system designed to integrate both remote sensing and surface weather-derived metrics of foliar greenness. This system provides two independent metrics that are meaningful representations of landscape level greenness responses and are suitable for use in verifying NFDRS greenup dates and greenness factors.

Keywords Phenology, fire danger rating, green-up dates, greenness factors, NDVI

11.1 Introduction

With more and more people moving into the wildland urban interface, wildfires have become an increasing concern for the National Park Service and other land-management agencies. According to the National Interagency Fire Center, almost 7 million acres and over 1,000 structures burned in 2004 (National Interagency Fire Center, 2005). This is nearly a 2-million-acre increase over the previous 10-year average and it came with an estimated $890-million-dollar fire-suppression price tag. These increases have generated expanded interest among fire managers and scientists developing more robust fire-behavior models. Key to the performance of these models is an accurate depiction of the spatial arrangement of fire fuel loads.

Current fire-behavior models (e.g., FARSITE) rely heavily on National Fire Fuel Laboratory (NFFL) fuel-classification procedures. These procedures, in turn,

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are based on litter (downed woody material), vegetation type, and overall vegetation structure (Anderson, 1982). Previous work in two national parks (Booker T. Washington National Monument and George Washington National Monument) found that there was a one-to-one relationship between vegetation type and NFFL fuel models for Mid-Atlantic Eastern United States forests (Devine, et al., 2003). This chapter expands those findings by further exploring this vegetation type-fuel model relationship in eight additional Northeastern national parks from East central Maine to SOUTH central Virginia. The national parks are listed below:

(1) Acadia National Park
(2) Appomattox Court House National Historical Park
(3) Colonial National Historical Park
(4) Fire Island National Seashore
(5) Fredericksburg and Spotsylvania County Battlefields Memorial National Military Park
(6) Petersburg National Battlefield
(7) Richmond National Battlefield Park
(8) Thomas Stone National Historic Site

This chapter focuses on the development of a comprehensive database that could be used to crosswalk formation-level vegetation maps to NFFL fuel-model maps. The process involved developing digital aerial photograph mosaics and using three-dimensional GIS procedures to combine these mosaics with vegetation information. This was followed by the development of techniques to produce complacent and available live fire-fuel-load maps. This chapter is divided into three sections describing the methods and results of the digital orthophoto mosaic production, the formation-level vegetation databases, and the fire fuel mapping.

11.2 Digital Orthophoto Mosaics

For this research we created digital orthophoto mosaics from color infrared, stereo pair 1:6,000-scale aerial photography with airborne global positioning system (GPS) and inertial mapping unit (IMU) data for eight national parks in the NPS Northeast Region. In the first step, the air photos were scanned at 600 dpi with 24-bit color depth on flatbed 11-x-17 scanners with transparency adapters. We found that these scanner settings resulted in manageable file sizes while maintaining a high level of detail.

During this multi-year research project we refined and improved our procedures. The final methodology included five basic steps:

(1) We imported scanned images of the air photos in tiff format to ERDAS' Imagine (.img) format (Erdas, 2004).

(2) We created a photo block in Leica's Photogrammetry Suite (LPS), using airborne GPS and IMU data and a digital elevation model from the United States Geological Survey (USGS, NED) (Leica, 2004).

(3) We triangulated each mosaic photo block with a root mean square error (RMSE) of less than 1. We then generated single frame orthophotos (one for each air photo) within Imagine.

(4) We exported the single frame orthophotos to Imagine .lan format and then imported the .lan files into ER Mapper's native (.ers) format (ER Mapper, 2004). An ER Mapper algorithm was created for color balancing, manual cutline creation, and final mosaicking.

(5) In ER Mapper we generated a band interleaved by line (.bil) image and header file for the final orthophoto mosaic. We imported the .bil image into Imagine .img format and compressed the .img image using MrSid software with a 20:1 target compression ratio (Lizardtech, 2001).

Figures 11.1 and 11.2 illustrate the visual improvements obtained with our final methodology using ER mapper for cutlines and color balancing. Figure 11.1 shows the Green Springs area of Colonial National Park. The left half of the image is the original mosaic and the right half shows the recreated mosaic. In the newer mosaic on the right, the red tint is substantially reduced, photo seamlines are nearly invisible, and the overall color balancing is much improved.

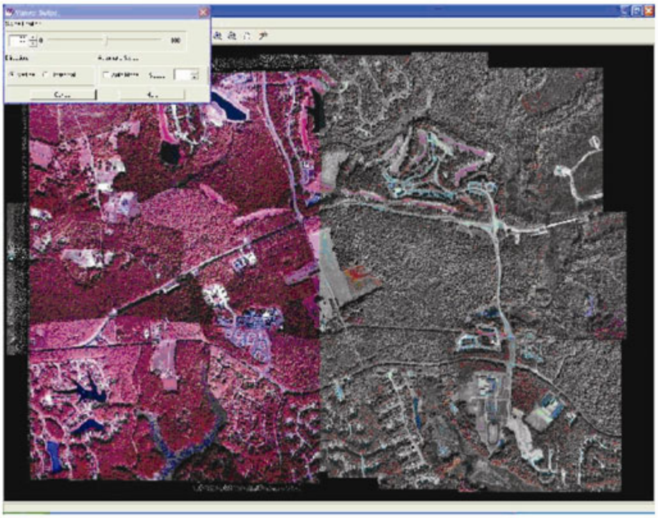

Figure 11.1 Imagine screenshot of initial (left half of image) and final (right half of image) mosaics of the Green Springs area of Colonial National Park

Figure 11.2 shows mosaics of the five forks area of Petersburg National Battlefield that illustrate similar improvements to those shown in Fig. 11.1. The mosaic created with the newer methodology using ER Mapper has better overall color balance, less noticeable seam lines, and less pronounced red tint.

The horizontal positional accuracy of each mosaic was then assessed following guidelines of the NBS/NPS vegetation mapping program (ESRI, NCGIA, and

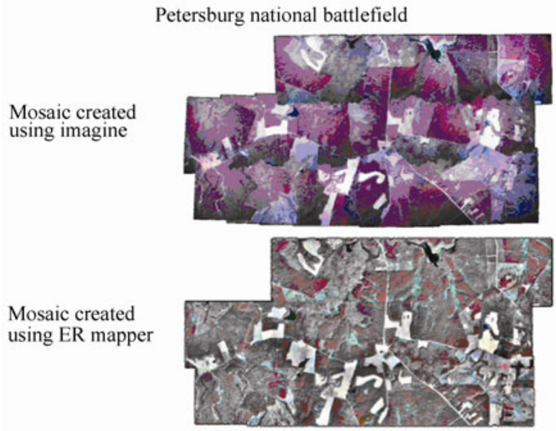

Figure 11.2 Initial and final mosaics of the five forks area of Petersburg National Battlefield

TNC, 1994). At least 20 well-defined positional accuracy ground control points were placed throughout all quadrants of the mosaic in ArcMap. Ground control points and zoomed in screenshots of each point were plotted on hard copy maps with the mosaic as a background. These maps and plots were used to locate the ground points in the field. For each ground-control point, field staff noted any alterations to the locations in the field and then recorded the coordinates with a Trimble Pro XR/XRS or GeoXT. Mapped ground-control points that were physically inaccessible were also noted. The coordinate data were collected with real-time GPS and post processed with differential correction using Trimble's Pathfinder Office software (Trimble, 2004).

Before positional accuracy was calculated, we excluded ground-control points identified by SAS's JMP program as outliers (SAS, 2004). Following USGS/NPS vegetation mapping guidelines, no more than 10 percent of the ground control points for any one mosaic were excluded. We then entered the field-collected GPS coordinates and the coordinates obtained from the mosaic viewed in ArcMap into a spreadsheet designed to calculate horizontal positional accuracy (in meters).

At the beginning of this project, the accepted method of calculating horizontal positional accuracy was based on Euclidean distance. Subsequently, a method based on root mean square error became the accepted procedure for assessing horizontal positional accuracy (FGDC, 1998b; Minnesota Governor's Council on Geographic Information and Minnesota Land Management Information Center, 1999). A positional accuracy handbook and a copy of the spreadsheet that contains the RMSE accuracy calculation formulas (horizontal.xls) can be downloaded from the Minnesota Department of Administration, Office of Geographic and Demographic analysis website (Minnesota Dept. of Administration, 2005).

Horizontal positional accuracy of the 15 mosaics[1] created for this project

[1] For some of the national parks involved in this research, we created two mosaics—a spring/leaf-off mosaic and a fall/leaf-on mosaic.

ranged from 0.815 – 1.580 meters. Thirteen of the 15 mosaics meet the class 1 national map accuracy standard (NMAS) of 1.5 meters or better for 1:6,000-scale photography and the other two mosaics failed to meet that standard by only 0.08 and 0.04 meters.

11.3 Formation-Level Vegetation Databases

The USGS and the NPS have standardized on the use of the hierarchal national vegetation classification system (NVCS) (FGDC, 1997) for their national vegetation characterization program. The formation-level is the lowest of the five physiognomic levels in the NVCS and it identifies ecological groupings of vegetation units with similar broadly defined environmental and physiognomic factors.

We created formation-level vegetation databases by interpreting the digital orthophoto mosaics for each park to delineate vegetation polygons to the formation-level defined in the NVCS. Table 11.1 displays the basic hierarchy of the system as well as some class examples.

Table 11.1 Hierarchy of the U.S. national vegetation classification (from Grossman et al., 1998)

	Level	Primary basic for classification	Example
Physiognomic	Class	Growth form and structure of vegetation	Woodland
	Subclass	Growth form characteristic, e.g., leaf phenology	Deciduous woodland
	Group	Leaf types, corresponding to climate	Cold-deciduous woodland
	Subgroup	Relative human impact (nature/ semi-natural, or cultural)	Natural/Semi-natural
	Formation	Additional physiognomic and environmental factors, including hydrology	Temporarily flooded Cold-deciduous Woodland
Floristic	Alliance	Dominant/diagnostic species of uppermost or dominant stratum	Populus deltoids Temporarily flooded Woodland Alliance
	Association	Additional dominant/diagnostic species from any strata	Populus deltoids – (Salix amygdaloides) / Salix exigua Woodland

Formation-level vegetation databases were created within ESRI's ArcMap using the orthophoto mosaics (both leaf-off and leaf-on, when available) as basemaps (ESRI). Photo interpreters viewing the mosaic(s) in two-dimensions delineated visible areas of homogeneous vegetation (i.e., vegetation polygons) using ArcMap's onscreen digitizing tools. Although the minimum mapping unit was 0.5 hectare, the photo interpreters were usually able to delineate polygons as small as 0.5 acre. After vegetation polygons were delineated for the entire park area, the photo interpreters created and populated three fields in the attribute table, entering a unique polygon identification number, the formation-level vegetation class code, and notes when they were unsure of the appropriate vegetation class code or could not assign a code. The photo interpreters relied on their experience to attribute the proper vegetation class. In some cases, digital raster graphics and existing spatial vegetation data were used to supplement the photo interpreters vegetation classification. The photo interpreters then examined each polygon in three-dimensions using Leica's Stereo Analyst software to verify the formation-level vegetation class code entered in the attribute table, and they entered a new or corrected code if appropriate (Leica, Stereo Analyst, 2003). Delineating the vegetation polygons in three dimensions is very time consuming. After considerable testing, the methodology was finalized to delineate in two-dimensions and perform validation and accuracy checks in three dimensions. This greatly increased productivity while conserving accuracy over a strictly three-dimensional approach. The final formation-level vegetation databases are archived in ESRI shapefile and geodatabase formats.

Sample field data were collected to assess the thematic accuracy of the formation-level vegetation databases at Booker T. Washington National Monument and George Washington National Monument.[1] These two databases were made up of 68 and 262 vegetation polygons and the final estimated thematic accuracy was 97% and 83%, respectively, based on field accuracy assessment data collected at 64 of the 68 polygons in the first park and at 96 of the 262 polygons in the other.

11.4 Fire Fuel Mapping

After each vegetation database was completed, we collected fire fuel load data at each of the 10 parks. Within each park the data-collection points were stratified by vegetation type to ensure that data would be collected for vegetation types for which we had little or no previous fire fuel data. The number of data-collection points per park ranged from 4 to 101, depending on the size of the park. At each point field crews measured downed woody debris using a modified Brown's transect line technique (Brown, 1974) developed by Shenandoah National Park (Carmichael and Cass, 2001) and an ocular estimation procedure (Burgan and Rothermel, 1984). Additional data that were collected include transect slope measurements, amounts of fine and coarse woody debris intersects, duff and litter depth measurements, canopy cover, average stand height, and height to live crown base (Smith, 2003). Sample forms used to record these data are included in Appendices A and B. On average, it took a two-person field crew 2 hours to take and record downed woody debris and Burgan/Rothermel measurements at each field location. Field plot photos were very helpful in crosswalking the vegetation to the fire fuel models. In future work we will take an additional field photo, looking up at the canopy, to help characterize canopy closure and crown bulk density.

[1] For the other parks, thematic accuracy assessment will be performed for alliance-level vegetation databases to be created in the future.

Analysis of the fire fuel load data included comparing the field data to standard NFFL fire fuel model values following Brown's procedures (1974). We found that fuel loads in the parks were consistently lower than fuel loads reported by Anderson (1982). This is undoubtedly because Anderson's work is based exclusively on data from the western United States, where vegetation and forest characteristics are different from those in the Eastern states. Therefore, we worked closely with NPS personnel to crosswalk vegetation to fire fuel models based on their experience and Anderson's narrative descriptions.

We produced final fire fuel load databases by assigning complacent and available live fuel fire fuel model values to each vegetation polygon. Distinguishing between complacent and available live fuel conditions is important because fire behavior is affected by seasonal differences in vegetation. The available live fuel model represents the fall period when previously unavailable fuels are available due to seasonal curing and drying of vegetation. For example, many shrub fields are considered to be a barrier to fire spread until a critical live fuel moisture threshold is reached. Figure 11.3 shows a completed complacent fire fuel map for the Western Front Unit of Petersburg National Battlefield.

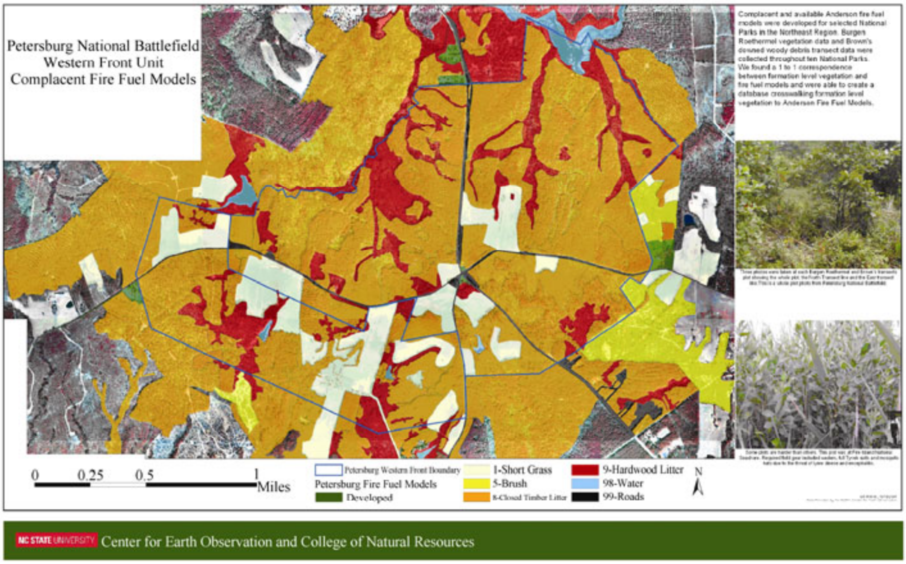

Figure 11.3 Complacent NFFL map of the Western Front of Petersburg National Battlefield

11.5 Discussion

As a result of this research, we have created a fairly comprehensive database of complacent and available fuel loads by vegetation type that could be used to easily crosswalk formation-level vegetation from other areas to NFFL fuel models without the need for the time consuming fire fieldwork (Appendix C). We also have a large database of Brown's and Burgan and Rothermel data that could be used to create custom fire fuel models for Eastern landscapes or, at the least, to generate numbers more useful in determining fire fuel models for national parks in the east. These data have become standard elements in the new fire behavior modeling program of the National Interagency Fire Center.

Based on our experience, we strongly recommend collecting airborne GPS and IMU data with aerial photography that will be used to create digital orthophoto mosaics. Use of these data, as opposed to external reference sources such as USGS digital orthophoto quadrangles (DOQQs), for ground control substantially reduces the time required to create the mosaics and increases their positional accuracy.

Table 11.2 compares the horizontal positional accuracy of four mosaics orthorectified with airborne GPS and IMU data with the positional accuracy of four mosaics orthorectified with DOQQs. The first four mosaics shown in Table 11.2 were orthorectified with airborne GPS and IMU data that were collected at the time the photography was acquired. The other four mosaics were orthorectified using external reference sources such as DOQQs and hand selected ground control points. The externally referenced DOQQS have a much poorer average accuracy. Additionally, the use of airborne GPS and IMU data substantially decreases the time needed to create an orthophoto mosaic because there is no need to place manual tie points or manual ground control points. Finally, airborne GPS/IMU data have been essential for creating mosaics in areas with little or no development, which describes many of our National Parks. When using DOQQs or other external reference sources, we must find recognizable, accurate landmarks throughout the entire area for control. With largely forested and/or uninhabited areas, this is often very difficult, if not impossible. The use of airborne GPS and IMU data eliminates this issue.

Table 11.2 Comparison of horizontal positional accuracy of mosaics orthorectified with airborne GPS and IMU data versus external reference source data

Park	Photography	Horizontal Positional Accuracy (m)	
		RMSE X	RMSE Y
Mosaics orthorectified with airborne GPS and IMU data:			
APCO	Leaf-on (Fall 2001)	0.859952	0.756570
GEWA-1	Leaf-on (Fall 2001)	1.068192	1.276164
GEWA-2	Leaf-off (Spring 2002)	0.826132	0.908170
HOFU	Leaf-off (Spring 2002)	1.188310	0.764670
Average		**0.985647**	**0.926392**
Mosaics orthorectified with external reference source data:			
PETE-MU	Leaf-off (Spring 1992)	1.624120	2.811615
PETE-FF	Leaf-off (Spring 1992)	1.885895	3.674856
VAFO	Leaf-on (Fall 1999)	1.184401	2.894345
APCO	Leaf-off (Fall 2000)	0.603000	2.415000
Average		**1.324354**	**2.948954**

Appendix A

Brown's Transects Field Data Collection Sheets

NCSU Vegetation Map Fuels Inventory Data Sheet

Plot ID: ________ District: __________ Date:___/___/___

Recorder (s): ________________________ Photo Numbers: _____________ Total # Taken:_____

Transect Lengths (ft): 0-0.25______ 0.25-1: ______ 1-3 ______ 3+r: ______

UTMs: ________________ e ________________ n ________________ +/-m

NORTH Compass

Direction ______

Slope ______%

0-0.25" (1-hr)	0.25-1" (10-hr)	1-3" (100-hr)	3+s (1000-hr)	3+r (1000-hr)		L	D	Note		L	D	Note
					1				25			
					5				30			
					10				35			
					15				40			
					20				45			

NOTES:

EAST Compass

Direction ______

Slope ______%

0-0.25" (1-hr)	0.25-1" (10-hr)	1-3" (100-hr)	3+s (1000-hr)	3+r (1000-hr)		L	D	Note		L	D	Note
					1				25			
					5				30			
					10				35			
					15				40			
					20				45			

NOTES:

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CANOPY COVER	
Overstory	
Can. Code:_____(%)	
Species	% Species

Canopy Codes: 1 = 0-20, 2 = 21-50, 3 = 51-80, and 4 = 81-100

HEIGHT TO LIVE CROWN BASE (FT) (SEE FIGURE 1)				
	Bottom	Base	Ht Lv Crwn	Notes
Canopy				

Height (**Ht Lv Crwn**)= **Bottom** of the live crown + **Base** of the tree
(% = Feet) and degrees actually = Feet

AVERAGE TREE HEIGHT (FT) (SEE FIGURE 2)				
	Top	Base	Height	Notes
Canopy Distance:_____				

Height = **Top** of the tree + **Base** of the tree *(distance is 100', 50', 66', or 33')

Formation for the plot area:___________

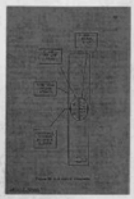


Figure 1

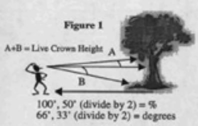
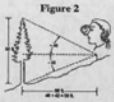


Figure 2



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Appendix B

Burgan Rothermel Field Data Collection Sheets

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Figure 9. Burgan and Rothermel Datasheet (front)

Fuel Data Entry Form
Shenandoah National Park

District:__________ Plot:__________

Recorders:__________ Date:__________

UTMs:__________e__________n__________+/-m

Grass Model Type 1. Dynamic
2. Static

Grass Type 1. Fine – colonial bent, poverty, oat grass
2. Medium – fescue, orchard, japanese bromegrass
3. Coarse – sedges and rushes
4. Very Coarse – sawgrass, tall oatgrass

Bulk Density Class (1-6)__________

Total Grass Load (0-30 tons/acre)__________ or Grass Depth (0-10 ft)__________

Dynamic Models enter maxium % that can be live (0-100%)__________

Static Models enter current % live (0-100%)__________

Percentage of area covered by grass (0-100%)__________

Shrub Shrub Type 1. Fine stem, thin leaves – Huckleberry, Gooseberry
2. Medium stem, thin leaves – Chiquapin, Alder, Spicebush
3. Medium stem, thick leaves – Ceanothus, Vaccinium
4. Densley packed fine stems and leaves – Spirea, Rubus
5. Thick stems and leaves – Mt. Laurel, Rhododendron

Bulk Density Class (1-6)__________

Total Shrub Load (0-80 tons/acre)__________ or Shrub Depth (0-10 ft)__________

Percentage of total shrub load in each size class. Enter as whole % (must tot. 100%)
1. 1-HR dead (0-1/4 inch) __________
2. 10-HR dead (1/4-1 inch) __________
3. 100-HR dead (1-3 inches) __________
4. Live leaves and twigs (0-1/4 inch) __________

Percentage of area covered by shrubs (0-100%) __________

Oils and Waxes Yes or No

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Figure 10. Burgan and Rothermel Datasheet (back)

Plot:__________ Date:__________

Litter Litter Source 1. Conifers
2. Hardwoods __________
3. Both but atleast 30% of lessor type

Needle length if conifers or both (1-2) __________
1. Medium/ Long
2. Short

Litter Compactness 1. Loose (freshly fallen) __________
2. Normal
3. Compact (older compressed)

Total litter load (0-100 tons/acre) __________
or
Litter Depth (0-5ft) (ft=cm/30.48) __________

Percentage of total litter load in each size class. Enter as whole % (must tot. 100%)
1. 1-HR (0-1/4 inch) __________
2. 10-HR (1/4-1 inch) __________
3. 100-HR (1-3 inches) __________

Percentage of area covered by litter (0-100%) __________

NOTES

Appendix C

Formation-Level Vegetation and Associated Fire Fuel Models

	Fire Fuel Model	
Formation-Level Vegetation Class	**Complacent**	**Available Live**
NVCS formation codes:		
I.A.4.N.a	8	9
I.A.8.C.x	8	9
I.A.8.N.b	8	9
I.A.8.N.c	8	9
I.B.2.N.a	9	9
I.B.2.N.d	9	9
I.B.2.N.e	9	9
I.B.2.N.g	9	9
I.C.3.N.a	8	9
I.C.3.N.b	8	9
I.C.3.N.d	8	9
II.A.4.N.a	8	9
II.A.4.N.b	8	9
II.A.4.N.f	8	9
II.B.2.N.a	9	9
II.B.2.N.f	9	9
III.A.2.N.a	5	6
III.A.2.N.f	5	5
III.A.2.N.g	5	5
III.B.2.N.a	5	6
III.B.2.N.d	5	5
III.B.2.N.e	6	6
III.B.2.N.f	5	5
III.B.2.N.g	6	6
III.B.2.N.h	1	1
IV.A.1.N.a	2	3

(Continued)

	Fire Fuel Model	
Formation-Level Vegetation Class	Complacent	Available Live
IV.A.1.N.b	5	5
IV.A.1.N.g	5	5
IV.B.2.N.a	5	5
V.A.5.N.c	1	1
V.A.5.C.x	1	1
V.A.5.N.c	1	1
V.A.5.N.e	1	1
V.A.5.N.k	1	1
V.A.5.N.l	1	1
V.A.5.N.n	1	1
V.A.7.C.a	1	2
V.B.2.N.d	1	3
V.B.2.N.g	1	3
V.C.2.N.a	1	3
VI.B.1.N.c	1	1
V.I.C.2.N.a	98[1]	98
VII.A.2.N.a	1	1
VII.C.2.N.d	98	98
VII.C.4.N.d	98	98
Water	98	98

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[1] 98 is a FARSITE code for water.

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