KANAWHA STATE FOREST, WV: WILDLAND FIRE FUEL LOAD ASSESSMENT AND GEOSPATIAL DISTRIBUTION

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Abstract.—Fire has become a major concern along the wildland-urban interface (WUI), and there is increased awareness that fires could result in serious damage to people and property in residential areas occurring in forested landscapes. Part of the long-term strategy the West Virginia Division of Forestry outlined in the 2010 West Virginia Statewide Forest Resource Assessment was to conduct a comprehensive monitoring program of wildland fire fuels. In an effort to predict and prevent catastrophic fire activity, identifying areas of the WUI that are at risk for wildfire is one of the initial steps in developing mitigation plans and priority levels. In early 2013, an extensive fuel sampling inventory was performed to quantify the fuel loading in the 9,388 acre Kanawha State Forest located 7 miles south of the state capitol, Charleston, WV. Results included fuel load volumes, a spatially distributed fuel load assessment model, and effects of site and vegetation characteristics. Data from the fuel sampling will be used in forthcoming evaluations that incorporate additional elements of fire hazard into a comprehensive fire risk assessment.

INTRODUCTION

In the last 150 years, fire in the area that is now Kanawha State Forest was predominately caused by industrial activities involving coal mining, logging, and the supporting railroad transportation networks. In 1908, over 1.7 million acres burned in West Virginia causing the state to pass the West Virginia Reform Law in 1909 which established the Division of Forestry and defined its focus as wildfire protection. In 1938, West Virginia purchased the first 6,705 acres of what is now the 9,388 acre Kanawha State Forest to serve as a recreation area to be developed by Civilian Conservation Corps and to provide forest fire protection for the area (West Virginia Division of Forestry 2009).

There are still widespread occurrences of uncontrolled wildfire in West Virginia, and the fire program mission of prevention, preparedness, and suppression remains the objective of the Division of Forestry. The large majority of wildfires are caused by debris burning and incendiary actions, and in the past 11 years there have been over 10,000 fires burning over 227,000 acres statewide (West Virginia Division of Forestry 2013a).

As part of the 2008 Farm bill mandate, West Virginia conducted the 2010 West Virginia Statewide Forest Resource Assessment, which included approximately 12 million forested acres statewide (West Virginia Division of Forestry 2010). One of the long-term strategies identified by the West Virginia Division of Forestry (WVDOF) was to locate and map all high risk fire areas in the state by 2015, providing information to make the necessary actions to successfully maintain the fire program mission.

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Wildland fire risk incorporates site-specific characteristics that both prevent and promote fire across a landscape, climatic conditions, as well as ignition variables. Kanawha County is historically among the counties with both the highest number of fires and the highest number of acres burned, and the vast majority of both are attributable to incendiary actions and other anthropogenic sources. As such, in the 2010 forest assessment, Kanawha County was identified as one of the 14 "hot" counties and a high priority area of wildfire concern based on a composite of fire occurrence, topography, and wildland-urban interface concerns (West Virginia Division of Forestry 2010).

Formal wildland-urban interface (WUI) definitions specify minimum structural density and vegetation levels, however the WUI is generally recognized as the area where housing and dense vegetation intermingle (Haight et al. 2004). Smoke levels are also a concern in the WUI from visibility reduction, public safety, and the health effects of breathing fine particulate matter. Among the other values at risk (VAR) in, or in close proximity to, Kanawha State Forest are heritage sites of historical importance, recreation resources, natural resource extraction infrastructure, and valuable timberland.

The major forest cover type in Kanawha State Forest is mixed mesophytic hardwoods, and eastern fuel types have not been as extensively modeled as western types. Several studies identify the existing fuel type shortcomings, especially in areas with ericaceous shrubs and timber litter. Suggested alternatives or customization as well as pictorial depictions (Brose 2009, Brose et al. 2009) are available to assist with determining appropriate local fuel types. Anderson's original 13 fuel types (Anderson 1982) have been improved upon by the 40 fuel type models identified by Scott and Burgan (2005), including an increase in the number of fuel types for high-humidity areas and types for forest litter and shrub understory. When using national tools such as the National Fire Danger Rating System and Wildland Fire Assessment System (West Virginia Division of Forestry 2013a, 2013b), certain fuel types used in the models may not accurately represent the specific local vegetation profile. Despite the increasing eastern fuel type resources and improvements, potentially inaccurate fuel type models used in some national tools can result in ambiguous or incorrect fire risk predictions unless careful interpretation is made.

In the absence of a large scale disturbance, fuel loading by seasonal pattern is a relatively static variable (Cooke et al. 2007). However, after two large disturbances in 2012, all previous fuel loading data were irrelevant. A high incidence of incendiary action and escaped debris fires, an undetermined volume of additional fuel loading from recent storms, potential local fuel type model differences, and proximity to the WUI necessitated fine-scale field data to be collected at Kanawha State Forest. Knowing current fuel loads and existing vegetation characteristics would enable WVDOF to make a more precise fire risk assessment than that from a national level analysis.

The objective of this project was to gather data to address the need to establish a general geospatial and quantitative assessment of potential wildfire fuel hazard areas in proximity to the WUI and VAR. Ignition causes and locations obtained from the WVDOF were mapped as part of the 2010 forest assessment. Together, fire hazards and ignition patterns can be used to determine fire risk, and mitigation and resource allocation can be concentrated in areas of greatest concern.

The urgency in determining fuel loading precluded conducting a full scale fire risk assessment that included climatic and topographic variables. Fuel load volume was the only component quantified by the data collected, with the intention that the baseline established by this study can provide more accurate data for future analyses and other management uses.

METHODS

Sampling

A sampling strategy was developed by the West Virginia University Appalachian Hardwood Center according to FIREMON protocol (Lutes et al. 2006). Data collection was done in January 2013 by the West Virginia Division of Forestry. Landform types were divided into three strata and grouped by ridgetops (RT), north, northeast, and east aspects (N, NE, E), and south, southwest, and west aspects (S, SW, W), in which 30 sample plots each were randomly distributed, totaling 90 plots. Northwest and southeast aspects were not selected for sample plot locations in this initial assessment because the fire hazard influence from fuel loading on these neutral topographic positions was expected to fall between high and low values of the other strata. The FIREMON fuel load (FL) method specifies sample measurements to be taken using the planar intercept technique. Measurements for 16 metrics were recorded, including 1-hour fuels (0- to 0.25-inch diameter), 10-hour fuels (>0.25- to 1-inch diameter), 100-hour fuels (>1- to 3-inch diameter), and 1000-hour fuels (>3-inch diameter), which were further separated into decay classes 1 (completely sound), 2 (moderate decay), and 3 (extensive decay) and weighed in tons per acre. Duff/litter profile depth and the litter component of total profile depth were measured. Litter defined the loose layer of mostly twigs, grasses, leaves and needles, and other debris that had not begun to decompose. Duff defined the organic layer below litter and above mineral soil in an advanced state of decomposition, inclusive of any root systems. Additionally, percentages of live and dead tree cover vertically projected to the ground, percentages of live and dead herbaceous cover vertically projected to the ground, and average tree and herbaceous heights were measured.

Analysis

Data Analysis

Plot data on fuel tonnage was calculated using equations described by Van Wagner (1968). Averages and totals were calculated on a per acre basis and identified by aspect, and a weighted averaging model was developed using eight fuel loading variables. Properties of each fuel type sample category were subjectively considered by their predicted effect on fire behavior (Scott and Burgan 2005) and were assigned weighted averages accordingly. Both 1-hour and 10-hour fuel readily reach ignition temperature and strongly determine fire behavior and spread (Anderson 1985) and were weighted 30 percent and 20 percent, respectively. Percentages of dead herbaceous cover and litter depth were weighted 7.5 percent and 5 percent, respectively, accounting for their ability to sustain fire combustion and spread by providing fuel bed continuity. Duff/litter depth, 100-hour, and 1000-hour fuels are attributed to extended flaming front and smoldering burn time and can strongly influence fire severity and effects (Lutes et al. 2006) and were assigned 20 percent, 10 percent, and 5 percent weights, respectively. Most 1000-hour fuel was blowdown from recent wind events and was still in decay class 1 and 2. Increased fire effects reflect the combustibility of sound or moderately decayed fuel compared to that of extensively decayed fuel. Dead tree cover was assigned 2.5 percent for its potential addition to fine fuel volumes and ladder fuels for an unlikely crown fire occurrence. SAS (SAS Institute Inc., Cary, NC) was used to perform statistical analyses used to develop a natural breaks algorithm to categorically quantify fuel load variables as a means to illustrate the distribution of fuels most influential on fire behavior and effects.

Spatial Analysis

Geospatial analysis was done by the WVDOF using ArcGIS 10.0 (Esri, Redlands, CA). All fuel load raster data were reclassified into high, medium, and low classes defined by natural breaks and were assigned values of 3, 2, and 1, respectively. Using the inverse distance weighting method, fuel load raster layers were derived using point sample data in Geostatistical Analyst, and values were interpolated within Kanawha Sate Forest boundaries. Raster analysis consisted of 9.84-square-foot grids, and using the Spatial Analyst Weighted Overlay tool, reclassified layers were assigned the corresponding weighted average influence.

Distribution of reclassified fuel load layers was overlaid with corresponding aspect location. Using spatial analyst tools, ridgetops were delineated with a 50 foot vertical buffer. The algorithm using weighted averages only incorporated fuel load volumes, not the effect aspect has on fuel load moisture levels and resulting fire behavior. However, for illustrative purposes, spatial distributions of the amalgamated fuel loading variables generated by the embedded weighted average algorithm were differentiated by aspect (Fig. 1).

Proximity of WUI areas to distribution of fuel loads in Kanawha State Forest was defined by overlay of raster data identifying structure locations and weighted model fuel load classes (Fig. 2).

RESULTS

Several results were influenced by the cyclical nature and disturbance-based conditions of the time when sampling was done in January 2013. Phenological stage influences litter volumes as well as herbaceous cover, and high levels of 1000-hour fuels were due to the significant volume of down woody debris from two large storm events in 2012, a derecho in June and Hurricane Sandy in October.

Total 1000-hour fuels across all sample strata averaged 20.1 tons per acre, with the N, NE, and E strata grouping having the highest average of 25.5 tons per acre. Across all strata, 100-hour fuels averaged 0.40 tons per acre and were about the same on the N, NE, and E grouping and RT strata, which averaged 0.46 and 0.45 tons per acre, respectively. Across all strata, 10-hour fuels averaged 0.96 tons per acre, averaging the highest with 1.1 tons per acre on N, NE, and E strata. The 1-hour fuels averaged 0.63 tons per acre across all strata with the highest averages of 0.7 on the RT strata. Duff/litter profile depth across all strata averaged 4.5 inches and was the highest with 4.7 inches on S, SW, and W strata. Litter depth component of total duff/litter profile depth across all strata averaged 2.8 inches, and averaged the highest on N, NE, and E strata with 3 inches. Percent dead tree cover across all strata measured 0.66 percent, averaging highest at 0.79 percent in the N, NE, and E strata. Percent dead herbaceous cover across all strata averaged 1.0 percent and averaged the highest at 1.3 percent on the RT strata (Table 1).

Within each stratum, the number of acres was further separated into low, medium, and high classes, and the percentage of acres that had fuel loading levels within each class is shown in Table 2. Fuel loading assessment across the Kanawha State Forest on all sampling strata included 3,214 acres categorized as low, 5,436 acres categorized as medium, and 738 acres categorized as high.

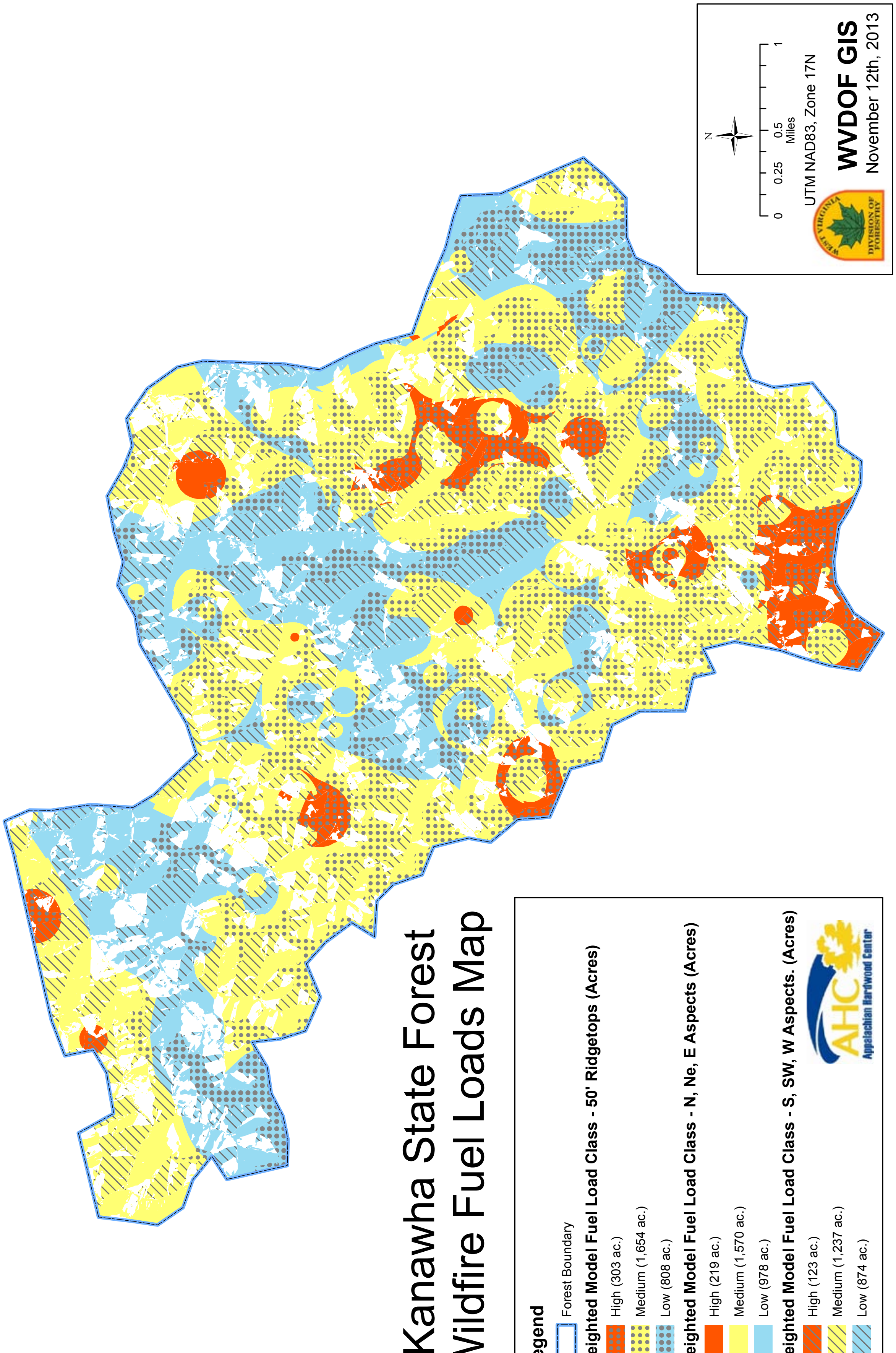

Figure 1.—Overlay of fuel load assessment map and sampling strata map.

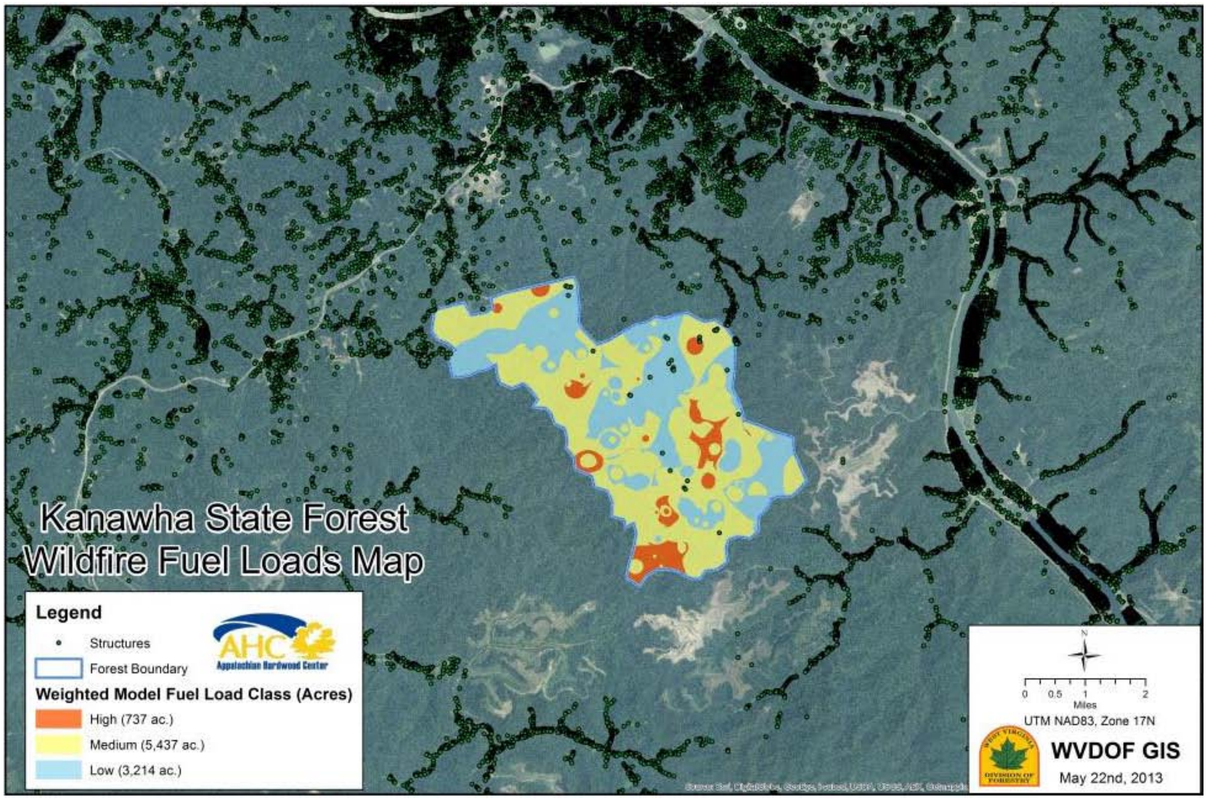

Figure 2.—Fuel load assessment in the wildland-urban interface context.

Table 1.—Fuel load sample averages by sampling strata, category and weighted model averaging for deriving fuel load assessment classes.

Fuel load category	Weighted average	Sample strata: All strata	N, NE, E	S, SW, W	Ridgetop
	%	*Average per acre*			
1000-hour (tons)	5	20.08	25.54	12.42	22.30
100-hour (tons)	10	0.40	0.46	0.29	0.45
10-hour (tons)	20	0.96	1.06	0.81	1.00
1-hour (tons)	30	0.63	0.63	0.56	0.70
Duff/litter profile (inches)	20	4.45	4.20	4.74	4.42
Litter depth (inches)	5	2.77	3.04	2.79	2.48
Dead tree cover (%)	2.5	0.66	0.79	0.58	0.62
Dead herbaceous cover (%)	7.5	1.00	1.24	0.42	1.33

Table 2.—Total acreage and percentage of acreage by fuel load assessment class and sampling strata

Sampling strata	Total acres	Load assessment class: Low	Medium	High
N, NE, E	2767	35%	57%	8%
S, SW, W	2234	39%	55%	6%
Ridgetop	2765	29%	60%	11%
NW, SE	1622	34%	60%	6%
All strata	9388	34%	58%	8%

The fuel loading averages were highest for five of the eight fuel load categories on N, NE, and E aspect strata grouping, perhaps attributable to higher site productivity and corresponding increased biomass on those topographic positions. Future sampling may indicate if faster decomposition rates on a more productive site equalizes the averages across aspects (Waldrop et al. 2013) and the rate at which that happens by fuel type category.

In areas with sloping terrain, fuel moisture content varied by aspect. South, west, and southwest aspects are exposed to increased solar radiation, resulting in decreased fuel moisture levels compared to other aspects with comparable canopy shading of fuels. Moisture levels are also influenced by topographic position with typically dry predispositions, such as ridgetops, within a limited elevation range (Lafon and Grissino-Mayer 2007). Because fuel moisture was not measured, a conservative fuel loading hazard rating would incorporate a fuel moisture condition significantly less than the specified moisture of extinction, defined as the dead fuel moisture at which a fire will not spread (Rothermel 1972).

DEVELOPMENT AND APPLICATION

The primary objective of this project was to establish a fuel load assessment from the sample dataset to augment current systems of fire risk analysis while maintaining enough flexibility for potential use in other capacities. In addition to modeling fire behavior and fire effects, this dataset can be used by management to develop fuel treatment prescriptions, estimate carbon storage, and assess wildlife habitat.

The data collected will be analyzed using FlamMap, a fire behavior mapping and analysis program that computes potential fire behavior characteristics over a landscape for constant weather and fuel moisture conditions. However, a sense of urgency to assess fire hazard before the spring 2013 window of West Virginia's bimodal fire season necessitated a preliminary model incorporating only fuel loading statistics to be reviewed in the interim. Subsequent developments to enhance this model will include additional inputs, facilitating comparisons with the results of the more robust FlamMap model.

Fuel moisture and climatic conditions including temperature, wind, precipitation, and humidity levels are integral in determining probability of ignition and fire behavior. However, because of their dynamic nature and temporal variability, they were not incorporated in this preliminary stage. Moisture levels available from weather data are a surrogate for the energy release component, which is an index of the potential heat release and fire intensity dependent on fuel moisture levels (Bradshaw 1984). West Virginia has 13 regional area weather stations (RAWS)[2] that can supplement fuel loading field data with climatic data to predict fire potential (Burgan 1998).

Two of the assessment tools the West Virginia Division of Forestry uses to identify wildfire danger levels statewide are the National Fire Danger Rating System and the Wildland Fire Assessment System (West Virginia Division of Forestry 2013a, 2013b). These types of products support analysis at a national and regional scale, but variability in fuels, weather, topography, and ignition sources

[2] Webster, B. 2010. Our role in the state. 16th Annual LEPC/SERC Conference; September 13-15; Pipestem State Park, Pipestem, WV.

contribute to the difficulty in applying the assessments at a local scale. Also, nationally mapped data layers used in these products often do not include local level resources or infrastructure, presenting management and planning challenges. Hindered by differing data standards, collection methods, and format, aggregation of local and national data is difficult (Calkin 2010).

Among the data gaps that the WVDOF identified in the 2010 forest assessment is the need for current and accurate fuel model maps. These have historically been produced by LANDFIRE, a nationwide interagency vegetation, fire, and fuel characteristics mapping program. In addition to LANDFIRE an increasing number of programs are available that model fire behavior, effects, fuels, smoke management, 75 of which are currently identified by the Missoula Fire Science Laboratory (U.S. Forest Service 2013). These models are invaluable to fire managers, however, most are complex and require familiarization with the functionality specific to each program and can require extensive training.

Complicating the use of the models is the lack of adequate fuel type descriptions of some eastern forests, particularly in the Appalachian region. Variable biophysical and topographical inputs dependent on specific conditions at the time and place of the risk assessment are another aspect that makes a general or national assessment difficult or even irrelevant. This is less of a concern in landscapes of relative homogeneity; however, unique characteristics of already inadequately described local fuel types necessitate a tailored model that can accommodate the site variability. Among unpredictable factors of fire intensity and severity in these variable conditions are residency time, spread rate and patterns, flame length, and their effects on fuel consumption and vegetation mortality (Rothermel 1972).

Several areas of future research and potential application include comparison between field gathered data and different national level datasets, and comparison of different national models using field collected data. Because field data is expensive and time consuming to collect, these comparisons can help to determine if there are significant differences between datasets when making risk assessments and can help to determine the level of accuracy that is lost by not collecting field data. Part of both prevention and preparedness on public lands is identifying areas of high wildfire risk that could benefit from mechanical fuels reduction and potentially the use of prescribed controlled burning in carefully considered areas. With field collected data from landscapes underrepresented by current fuel type models, the potential exists for the development of fuel models based on fire behavior in controlled experiments involving prescribed burns and documented wildland fire behavior. Collaboration opportunities have been identified with other state and federal agencies and nongovernment organizations that currently incorporate prescribed burns as part of their management plans. This includes participation in the Fire Learning Network which promotes the scientific basis of prescribed fire to restore and maintain fire-adapted ecosystems.

In addition to state and federal land, West Virginia has many individual and corporate forest landowners and interested parties that could benefit from fire risk assessments. Efforts to fulfill the preparedness aspect of WVDOF's fire plan also include outreach to private land and homeowners in the wildland-urban interface. Firewise communities and community wildfire protection plans are in place and are expanding to engage and provide guidance to homeowners on preparing and protecting their property from wildfire and minimizing potential damages. However, because of the combination of factors making fire risk assessment difficult, many proactive prevention and protection measures are not being identified or taken.

This project demonstrated the potential utility of geographic information system (GIS) raster modeling using field-collected fuel loading data, local knowledge of ignition distribution and historical fire occurrence data, and climatic data from local RAWS to develop a framework for empirical modeling and a composite index of local scale fire risk.

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