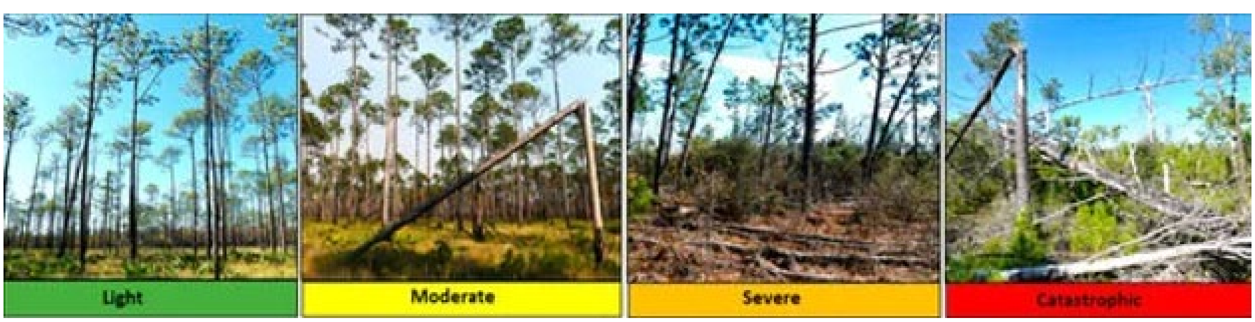
Fuels and Fire Management Considerations for Hurricane Helene Damaged Areas

Executive Summary

Hurricane Helene has caused significant disruption to forested landscapes, resulting in widespread debris accumulation and altered fuel structure across the southeast particularly in the Southern Appalachians of southwest Virginia, western North Carolina, northeast Tennessee, northeast Georgia as well as the Piedmont of South Carolina, central Georgia and north Florida. The storm's high winds broke or toppled trees, and created extensive blowdown zones, transitioning fuel conditions from lighter models, such as grass and leaf litter, to heavy slash and debris typical of Fuel Models 12, 13, SB2, and SB3. This shift in fuel types presents substantial challenges for wildfire suppression efforts. The increased resistance to control, difficult access, and elevated potential for extreme fire behavior necessitates strategic adaptation of suppression tactics. The storm's aftermath has also introduced the need to reconcile older fire line production rates with the Scott and Burgan 40 fuel models used for modern fire behavior predictions, as the line production data for these newer models remains undeveloped. This report explores these challenges, provides practical insights for resource deployment, and outlines strategies for managing this complex landscape. The effects of Helene will be felt for some time. In a 2005 risk assessment for Hurricane Katrina, it was reported by the Mississippi Forestry Commission that debris from Hurricane Camille which struck in 1969 was still preventing access to certain areas.

This document provides fuel loading and modeling guidance, fire behavior expectations, and fire management considerations for both wildfire response and prescribed fire implementation for each of the hurricane damage severity categories described below:

Damage Severity	**% of overstory altered/damaged**
Catastrophic	>50%
Severe	34-50%
Moderate	26-33%
Light	<25%



Finally, general recommendations are provided as to how to estimate fuel loading and fire line production rates in hurricane damaged areas based on previous experience in the Southern Area and the best available science.

Catastrophic Damage

Physical Characteristics and Visual Cues

Catastrophic storm damage is characterized by an overwhelming alteration of the forest landscape, with more than 50% of the timber affected. Visual indicators of this level of destruction include widespread fallen trees, broken tops, and a landscape that appears "jack-strawed," where large amounts of woody debris are haphazardly scattered across the ground. This category results in an almost complete removal of the forest canopy, exposing the ground to direct sunlight and drastically altering the microclimate. The absence of canopy significantly reduces shading, allowing greater solar radiation to reach the forest floor. This exposure accelerates the drying process of fine fuels such as small twigs, pine needles, and leaf litter. The fallen debris ranges in size from small branches to large-diameter trees, significantly increasing the depth and complexity of the fuel bed. Based on preliminary analysis, most of the catastrophic damage appears to be on southern and southeastern aspects at elevations above 3500'. There are many exceptions including instances of catastrophic damage in drainage bottoms and bordering water bodies.

The damage can vary by tree species, as hardwoods tend to uproot while pines are more likely to snap mid-trunk. This creates a mix of uprooted stumps, splintered trunks, and fallen trees, contributing to hazardous and unstable ground conditions. Over time, fine and coarse woody debris from the broken canopy should settle, creating a thick fuel layer subject to prolonged drying periods with exposure to sunlight and wind. In addition, much of the material is elevated, not in contact with moisture in the soil, and surrounded by air flow. Drying times could be amplified where fuels are suspended and on southern aspects.

Fine fuel generated by a mature overstory will now be limited. The fine fuel currently mixed in the debris of totally blown down areas may compact and decompose prior to the larger fuels becoming available. However, the effects of new herbaceous growth are uncertain. Increased sun exposure and warmth this summer, may stimulate resprouts and a flush of herbaceous understory that acts as a heat sink to moderate fire behavior, however once these fuels cure it could be a combustible mix with fine cured fuel woven into elevated coarse woody debris.

Fuel Modeling Guidance, Fuel Loading, and Expected Fire Behavior

In areas impacted by catastrophic damage, currently assigned fuel models need to be significantly modified due to the accumulation of debris. Pre-storm fuel models such as FM9 (hardwood litter) could be converted into slash blowdown or even shrub fuel models such as SH3 or SH8 to more accurately represent increased rates of spread and flame lengths. This shift reflects a significant increase in fine fuels combined with coarse woody debris in a suspended deep fuel bed arrangement. Large fuels (1000-hour) dominate the fuel composition, but likely won't contribute to fire spread for some time. Fire spread will initially rely on smaller, fast-drying fuels but transition to involve the larger fuels as they dry over time. In one to three years, fuel models SB2 and SB3 may become representative as large fuels become available and the significance of fine fuels lessens. In the most extreme conditions, SB4 could be used. Fire behavior modeling should use unshaded conditions and a high wind adjustment factor due to the lack of obstructions.

Since the storm occurred in late September, significant soil and fuel moisture from the storm and moderate weather conditions this winter have limited wildfire occurrence and overall fire behavior. Observations of fire behavior this winter in the damaged areas indicated moderate fire behavior not unlike what is observed in undamaged areas, likely due to the abundant post-storm soil and fuel moisture. Of critical concern moving into spring is the relative drying of these fuels especially the larger fuels. Information reported by fire managers suggests that site prep burns in the Southern Appalachians, designed to consume logging slash typically achieve desirable results 2–3 years after timber harvest. Logging slash is often churned into the soil and compacted by logging equipment which extends the time needed for drying. Where the hurricane debris remains lofty and uncompacted, drying and combustibility can occur within 1 to 2 years. Fire Managers with experience in hurricane fuels note that the availability of heavy fuels to burn once reached is not slow but relatively quick, like a switch flipping on.

The drying rates of woody debris are strongly influenced by whether the material is suspended above the ground or in direct contact with it. Suspended debris, such as fallen branches that rest above the forest floor, dries quickly due to increased air circulation and sunlight exposure. In contrast, debris in contact with the ground retains moisture longer because of poor air circulation and absorption of water from the soil. This ground-level material decomposes faster in humid environments, further reducing its immediate flammability, but it can contribute to prolonged smoldering fires under the right conditions.

Tree species and environmental conditions also play a critical role in shaping fuel composition and behavior. Pines, for instance, dry faster and become flammable more quickly than hardwoods, which have denser wood and decompose more slowly. In humid climates, such as the Southern Appalachians, the high levels of fungal and microbial activity accelerate the decomposition of downed material, particularly fine and medium debris. Conversely, in drier environments, fine and medium fuels persist longer, increasing the duration of fire risk. The intensity of the damage also affects the fuel profile. Severe or catastrophically damaged areas may have a higher percentage of large 1000-hour fuels, while lower-intensity damage generates more fine and medium debris. Slope and aspect further influence drying rates, with south-facing slopes and steeper terrains drying faster due to increased sunlight and drainage, while shaded areas retain moisture for longer.

Figure 1 Roan Mountain post Hurricane Helene. Illustrating catastrophic damage

Fire Management Considerations

Wildfire Response:

Catastrophic Storm damage zones present significant challenges for wildfire suppression. The volume of downed woody debris makes access difficult, limiting the effectiveness of smaller equipment such as Type 3 dozers. Instead, larger Type 1 and 2 dozers are necessary to navigate and clear debris. Of course, complex terrain in the Southern Appalachians severely limits where larger dozers can be utilized, and thus indirect attack is often the only strategic option. Dozers used in tandem with engines or other water handling equipment will improve line holding ability substantially. Aerial resources play critical roles in containing fires, particularly in areas where ground access is severely restricted. The heavy fuel loads demand wider control lines to prevent spotting, and mop-up operations are extended due to the high volume of large fuels that can smolder for weeks.

In the short-term (i.e. this spring), we can expect fire behavior to include rapid ignition , higher flame lengths, and intense heat production due to increased 1-to-100-hour fuel loadings. Long-term fire behavior (1–3 years post-storm) reflects the drying of larger 1,000-hour fuels, resulting in longer burn durations and resistance to control. Fires in catastrophic damage zones, particularly under conditions of low humidity and high wind, have a high potential for large incidents requiring complex incident management teams, substantial out of area resources, and numerous aviation assets.

Given the instability of standing dead trees and large amounts of overhead debris, firefighter safety is a top concern. Pre-response planning should include hazard tree assessments and the identification of potential safety zones and escape routes. Firefighters working in the debris must climb over and around the fallen trees presenting an exposure to hazard beyond what tis encountered normally.

Access limitations also greatly influence tactics and strategies. The heavy fuel loads and "jack-strawed" conditions severely restrict entry, necessitating indirect strategies such as the use of containment lines along roads, more open areas, or natural features. Indirect strategies will result in larger and more complex fires than usual. This shift in approach highlights the operational difficulties associated with catastrophic damage zones.

Prescribed Fire Implementation:

Prescribed fire in catastrophic damage zones is inherently risky but can be an effective tool for fuel reduction if implemented strategically. Implementing prescribed fire sooner rather than later, before larger fuels become fully dried and available to burn, can reduce future fire complexity. Burning now, targeting only the fine woody debris and smaller fuels, could create strategic fuel breaks and reduce fuel continuity. This approach minimizes the risk of high intensity burns and helps prepare the area for subsequent burns as larger fuels dry and decay.

Containment of prescribed fire projects must be carefully planned before implementation. The burn unit boundaries may need updating to account for changes in the fuel loading and landscape. Previously reliable natural holding features such as creeks and drainages could be compromised by debris that acts as a “bridge” of fuel allowing fire to spread across. Remaining standing trees where branches were torn, twisted or broken off will become cigar like and ignite, potentially spotting across control/containment lines. Fire fighters are not necessarily programmed to look at branches for stubble holding embers etc.

Plan for a longer duration commitment for prescribed burning projects in the hurricane debris. As ignitions proceed, large debris on the ground will impede movement of low intensity fire. The fire will eventually weave through and around the ends of logs to consume most of the available fuel. However, ignition periods will be longer, leading to smoke production later in the day combined with increased smoke production from the additional fuels. As larger fuels gradually become available, they will partially consume resulting in residual smoke production and containment risk. Smoke production can be reduced by carefully selecting days when larger fuels are holding moisture and will not consume. Doing this limit smoke production to rapidly consuming fine fuels.

Some of the containment risk can be mitigated with a pairing of mechanical treatment followed by prescribed burning. Standing and broken tress along planned boundaries could be removed or felled by heavy equipment. Cleared roads could serve as an alternate to natural features which may no longer hold fire. UAS teams could provide detailed imagery of fuel loading and arrangement to plan projects with the best information possible.

Figure 2 Pre and post prescribed burn in Hurricane Hugo debris.

The timing of prescribed burns is critical. Within the first year, fine surface fuels may carry fire effectively, but controlled burns must be carefully planned to avoid unintended escalation. Burning during periods of higher humidity or lower temperatures can help moderate fire intensity and limit the risk of escape. Pre-burn treatments, such as creating and reinforcing firebreaks, are essential to maintaining control and ensuring safety.

There is a compelling case for summer burning, during periods of adequate soil and fuel moisture, on sites that no longer have overstory. The open sites are exposed to drier conditions than the surrounding woodlands presenting an opportunity to burn the debris fields with minimal risk of escape into adjacent shaded stands where the intact overstory shelters the surface fuels.

In summary, catastrophic storm damage fundamentally transforms the forest environment, creating a hazardous and dynamic fire regime. Effective fire management requires a thorough understanding of fuel transitions, fire behavior dynamics, and the operational challenges posed by extensive debris and altered canopy conditions. Early prescribed fire implementation can play a key role in mitigating future risks by reducing fine fuels and creating defensible spaces for future fuels management projects.

Severe Damage

Physical Characteristics and Visual Cues

Severe storm damage is marked by significant disruption to the forest stand, with 34–50% of the timber affected. This level of damage results in extensive treefall and breakage, though less pervasive than in catastrophic damage zones. The canopy is substantially fragmented, creating patches of open exposure to sunlight interspersed with partial cover. Visual cues include large areas of downed trees and branches, many with broken tops and exposed root systems. Hardwoods in these areas are more likely to topple with their roots, while pines tend to snap. This pattern creates a mix of horizontal and vertical fuel arrangements that complicate fire behavior predictions.

The fragmented canopy allows increased solar radiation to penetrate the forest floor, accelerating the drying of surface fuels. Fine woody debris, suspended leaves, and pine needles accumulate quickly, deepening the fuel bed. While large-diameter fuels (1000-hour) are present, their density is lower compared to catastrophic zones. However, the arrangement of fuels remains highly variable, often forming concentrated jackpots of combustible material.

Fuel Modeling Guidance, Fuel Loading, and Expected Fire Behavior

In severe damage areas, the combination of surface litter, fine woody debris, and partially suspended fuels leads to a highly volatile fire environment. The fragmentation of the canopy increases exposure to wind and sunlight, which, combined with the high availability of fine fuels, promotes rapid drying and ignition potential.

Pre-storm fuel models such as FM9 (hardwood litter) could transition to models like FM 12 or 13, indicating moderate to heavy slash. SB3 or a shrub fuel model could be used as well depending on the amount of overstory remaining. Areas with fewer wind obstructions could be best represented by shrub models which tend to have higher rates of spread and flame lengths than a more moderate model like SB2 which might best represent areas with more overstory and wind obstructions remaining.

Short-term fire behavior (i.e. this spring) features rapid ignition of fine fuels and moderate to intense flame lengths. Fires are expected to spread quickly under moderate wind conditions, with potential spotting in areas of concentrated debris. As larger fuels continue to dry, the intensity and duration of fires may increase, requiring extended mop-up times.

By 6–24 months post-storm, heavy fuels begin to contribute more significantly to fire behavior. Fires in these areas may transition to higher intensity due to the drying and ignition of coarse woody debris. This creates challenges for containment and suppression, as control lines must be wider and constructed with greater effort.

Fire Management Considerations

Wildfire Response:

Severe damage zones present moderate-to-high challenges for fire suppression. The variable fuel distribution complicates access, requiring diverse strategies and resource types. Type 3 dozers may struggle in areas with heavy fuel concentrations, while Type 1 and 2 dozers, engines, and aerial resources are better suited to the task depending on the complexity of the terrain. The fragmentation of the canopy can increase wind exposure at the surface level, leading to rapid fire spread and making direct suppression more challenging.

Indirect strategies, such as establishing containment lines along roads, natural features, or previously cleared areas, may be necessary in heavily impacted zones. Safety remains a critical concern, particularly regarding the instability of standing dead trees and overhead hazards. Suppression strategies should include pre-response planning to identify potential safety zones, escape routes, and high-priority areas for protection.

Prescribed Fire Implementation:

Prescribed burning in severe damage areas offers opportunities to reduce fine fuel loads and mitigate future fire risks. Implementing prescribed fire within the first-year post-storm can target fine woody debris and surface fuels before larger fuels fully dry. These burns help create fuel breaks and reduce fire intensity in subsequent years.

Like catastrophically damaged areas, prescribed burns in severe damage zones require careful planning and timing. Burning during favorable conditions, such as higher humidity and lower wind speeds, minimizes the risk of high-intensity fire behavior. Firebreaks must be reinforced to account for spotting potential and the presence of dense debris. Mechanical treatments, such as the removal of heavy fuel concentrations, may be necessary before burning to ensure safe and effective operations.

In summary, severe damage zones represent a transitional fire environment with significant challenges and opportunities. Fire managers must adapt strategies to account for variable fuel distributions, altered microclimates, and the drying timeline of larger fuels. Early intervention through prescribed fire and pre-planned suppression tactics can help mitigate risks and improve long-term outcomes for fire management.

Moderate Damage

Physical Characteristics and Visual Cues

Moderate storm damage affects 26–33% of the forest stand, resulting in noticeable but less obvious disruption compared to severe and catastrophic zones. This category is characterized by scattered treefall and broken tops, with more intact canopy coverage than in higher severity zones. The fragmented canopy allows sunlight to filter through in patches, creating localized variability.

Hardwood trees often blow over with their roots exposed, while pines are more likely to snap, leaving standing trunks intermixed with fallen debris.

The fuel bed consists of increased fine woody debris and leaf litter, along with some coarse woody material. The debris is distributed unevenly, forming patches of concentrated fuels (fuel jackpots) surrounded by areas of lighter loading. The overall depth and complexity of the fuel bed increase, although the arrangement remains less dense and chaotic than in severe or catastrophic zones. Surface fuels dry more quickly in exposed areas, contributing to variability in fire potential within the damaged area.

Figure 3 Hurricane damage on the Kisatchie National Forest

Fuel Modeling Guidance, Fuel Loading, and Expected Fire Behavior

In moderate damage zones, pre-storm fuel models such as FM9 (hardwood litter) transition to models like FM11 (light slash) or SB1. This shift reflects a moderate increase in fine fuels and some coarse woody debris. The fragmented canopy allows more sunlight and wind to reach the forest floor, accelerating the drying of surface fuels and increasing ignition potential. The partially intact overstory will continue to generate fine fuels.

Short-term fire behavior (i.e. this spring) features moderate flame lengths and fire intensities, driven by the ignition of fine fuels and litter. Fires in these areas are more likely to exhibit moderate fire behavior under light wind conditions but can have higher rates of spread with moderate winds and dry conditions.

Over the longer term (6–24 months), as larger fuels dry and integrate into the fuel bed, fire intensity may increase. While flame lengths and heat output remain lower than in severe or catastrophic zones, the variability of fuel loading and microclimates can lead to unpredictable fire behavior.

Fire Management Considerations

Wildfire Response:

Moderate damage zones present fewer access and operational challenges than severe or catastrophic areas, but fire managers must still account for increased fuel loads and variable fire behavior. Type 3 dozers and engines are generally sufficient for suppression efforts, although localized jackpots of heavy fuels may require additional resources or specialized equipment. The presence of partially standing dead trees creates overhead hazards, necessitating heightened situational awareness and pre-response planning.

Direct attack strategies are feasible in many areas, but firefighters must be prepared to adjust tactics in response to changing fire behavior, particularly in areas with concentrated fuel loads. Mop-up operations may require additional time in patches of heavier debris to ensure complete extinguishment.

Of special concern is the variability in the moderate damage zones. A strategy may be developed based on open ground visible on one side of the stand only to find denser debris fields once implementation has begun requiring alterations to the plan after resources are engaged. Thorough scouting during initial attack , aviation resources, and pre-season familiarization can mitigate these situations.

Prescribed Fire Implementation:

Moderate damage zones are well-suited for prescribed fire as a tool to manage fuel loads and promote ecological recovery. Burning within the first-year post-storm can effectively target fine woody debris and surface fuels, reducing future fire intensity. Prescribed burns should be planned during periods of favorable weather conditions, such as higher humidity and low to moderate wind speeds, to minimize risks and ensure controllable fire behavior. Special emphasis should be placed on having additional holding and contingency resources in these areas.

Firebreaks should be established and reinforced in areas with heavier fuel concentrations to limit the risk of spotting and fire escape. Managers should also monitor the drying of larger fuels over time and adapt prescribed fire plans accordingly to address evolving fuel conditions.

In summary, moderate storm damage zones offer opportunities for proactive fire management through prescribed fire and adaptive suppression strategies. While these areas are less challenging than severe or catastrophic zones, the variability in fuel loading and fire behavior requires careful planning and execution to achieve management objectives.

Light Damage

Physical Characteristics and Visual Cues

Light storm damage affects less than 25% of the forest stand, resulting in minimal disruption to the landscape. This category is characterized by scattered minor treefall and broken branches, with much of the canopy remaining intact. Visual indicators include isolated pockets of downed limbs and occasional toppled trees, often localized in specific areas rather than widespread. The forest retains much of its pre-storm structure, with surface fuels such as leaves, pine needles, and small branches showing moderate increases in accumulation.

The fuel bed depth increases slightly due to the deposition of fine woody debris, but the distribution remains relatively uniform across the area. Canopy openings are small and scattered, leading to limited increases in sunlight and wind exposure at the forest floor. As a result, surface fuel drying occurs more gradually compared to areas with higher damage severity.

Fuel Modeling Guidance, Fuel Loading, and Expected Fire Behavior

In light damage zones, pre-storm fuel models such as FM9 (hardwood litter) experience minimal changes, with slight increases in the 1-hour, 10-hour, and 100-hour fuel classes. These areas retain a relatively low fire hazard compared to moderate, severe, or catastrophic zones. Unlike more severely altered stands, the more intact overstory will continue to generate fine fuels in the years to come.

Short-term fire behavior (i.e. this spring) is generally limited to low-intensity surface fires, with flame lengths and rates of spread remaining modest. Fires are likely to exhibit creeping or smoldering behavior, particularly in areas with limited wind exposure. Over time, as fine fuels dry and accumulate further, fire potential may increase slightly, but overall behavior remains manageable.

Fire Management Considerations

Wildfire Response:

Light damage zones are the least challenging for fire suppression and present minimal operational obstacles. Firefighters can use direct attack methods with high confidence in achieving containment, as fuel loads remain low, and access is rarely restricted. Type 3 dozers and engines are sufficient for most suppression efforts, and mop-up operations are typically straightforward.
The primary concern in light damage zones is ensuring that localized jackpots of fine fuels do not become ignition points for larger fires under extreme conditions. Fire managers should focus on rapid detection and response to prevent the spread of small ignitions.

Prescribed Fire Implementation:

Prescribed fire in light damage zones serves as a proactive tool for maintaining fuel loads and promoting ecological health. Burning within the first-year post-storm can address fine fuel accumulations and reduce potential hotspots. Prescribed burns in these areas are relatively low risk, as fire behavior is predictable and controllable under typical weather conditions.

Managers should still monitor localized fuel concentrations and adjust burn plans accordingly to ensure even fuel reduction. Firebreaks are less critical in light damage zones but should be implemented where necessary to prevent unintended fire spread.

In summary, light storm damage zones offer favorable conditions for fire management, with minimal increases in fuel loads and low-intensity fire behavior. Proactive prescribed fire use and rapid response to ignitions can effectively mitigate risks and maintain forest health with limited operational challenges.

Estimating Post-Hurricane Fuel Loading

When comparing the fuel loading information from different sources it's necessary to review the collection methods to ensure that an accurate comparison can be made. Comparing pre-hurricane fuel loading from one photo series to post-hurricane fuel loading collected in a different location using different methods could also be confounded by variables other than storm damage, especially comparing pine to hardwood stands. Though potentially imperfect, the data can be used for rapid rough estimates with future verification and to identify trends that deserve further attention. The following sources contain information relevant to the Hurricane Helene damaged areas.

The Stereo Photo Series for Quantifying Natural Fuels Photo Series Interactive Dashboard includes a volume focused on post-hurricane fuels in the southeastern US: Volume XII: Post-Hurricane Fuels in Forests of the Southeastern United States. Photo Series volumes VI and VIa contain examples of pre-hurricane fuel loading mostly in the coastal plain. Included in Volume VIa are 7 sampling sites in hardwood stands located in Tennessee and north Georgia. In the Stereo Photo Series for Quantifying Natural Fuels, Volume XII: Post-Hurricane Fuels in Forests of the Southeastern US, data was collected from 20 plots. The data for this project was collected in coastal plain areas of Florida, Texas, and Mississippi. Woody material was weighed by diameter size classes. On average for the 20 plots collected post-storm, 2.7% of debris by weight was 1 inch (1- and 10-hour fuel) and below, 8.6% was between 1 and 3 inches (100-hour fuel), and 89% was over 3 inches in diameter (1000- hour fuel). Including woody material, litter, and duff the average fuel loading across all plots was 47.3 tons per acre with litter/ duff making up 9.4% of the total. This volume provides detailed fuel loading by type and size class. Additionally, fuel loading information has been collected from undisturbed locations in the southern Appalachians the data collected for this volume is from coastal plain sites that are predominately pine dominated. provides or an understanding of the total biomass and canopy fuel loading of the pre-hurricane forest can assist with estimating post-hurricane fuel loading. The overstory canopy now on the ground could be considered part of the fuel bed.

In 2019, the Southern Research Station published a guide for undisturbed sites in the Southern Appalachians: Photo Guide for Estimating Fuel Loading in the Southern Appalachian Mountains The Photo Guide for Estimating Fuel Loading in the Southern Appalachian Mountains GTR SRS-241 (2019) was created from 705 research plots using Brown's transects. The woody fuel loading data for 74 plots collected from 12 combinations of aspect and elevation was averaged together to produce a baseline fuel loading of 7.6 tons per acre of dead fuel approximately 4.5% 1-hour fuel, 12 % 10-hour, 31 % 100-hour fuel, and 52% 1000-hour fuel. Or 17% fine woody debris (1- and 10-hour fuel) and 83% coarse woody debris (100- and 1000-hour fuel). These plots were collected on undisturbed sites with no storm damage.

A rough estimate of fuel loading using the total biomass and the Photo Guide for Estimating Fuel Loading in the Southern Appalachian Mountains percentage of trees blown down a rough estimate of fuel that includes 1000-hour fuel. Adding the estimated canopy fuel loading to the pre-storm fuel loading provides an estimate of the fuel available to burn soon after the storm. Factors influencing Appalachian Biomass:

- Elevation: Higher elevations tend to have lower biomass due to harsher growing conditions.
- Aspect: North facing slopes may have higher biomass due to reduced water stress.
- Forest type: Hardwood forests generally have higher biomass than coniferous forests.
- Stand age: Older, mature stands typically hold more biomass than younger stand

On all, but the least disturbed sites, the total biomass of forests in the southern Appalachians ranges from 80 to 150 tons per acre or about 115 tons per acre. It has also been estimated that 40% of fallen forest debris becomes available to burn at some point. The rest of the material falling to the forest floor decays or is otherwise unavailable to burn. For example, fuels over 3 inches in diameter are not included in fire behavior fuel models and don't contribute much to fire spread except under the most extreme conditions. Logs over 8 to 9 inches in diameter will hold moisture for many years and may decay prior to becoming dry enough to burn. Using these numbers and the percentage of overstory damage, the post storm fuel loading can be roughly estimated. Making all these assumptions and maintaining the same distribution of fuel size classes results in the table below.

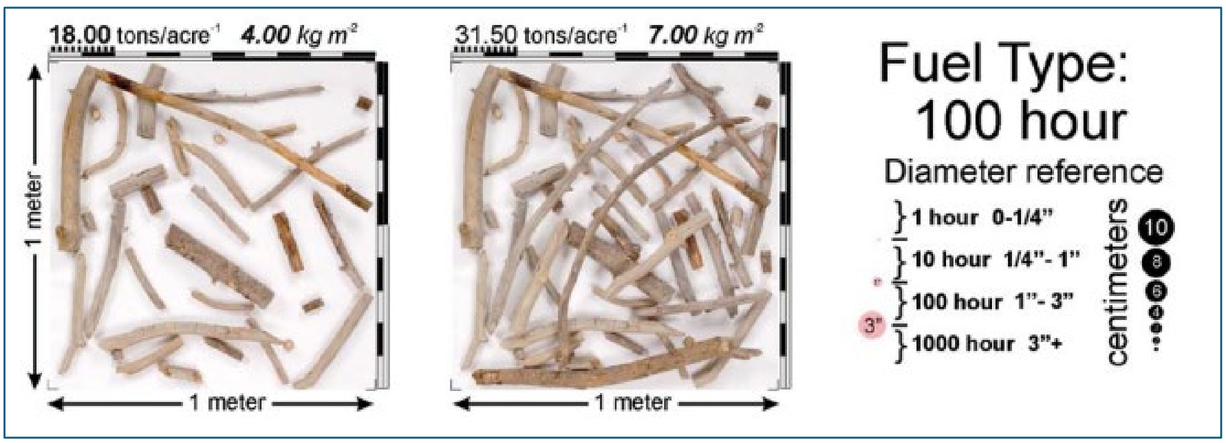
		Percentage of Overstory Broken or Blown Down									
Fuel Size Class	Base	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
1-hour tons/acre	0.3	0.5	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4
10-hour tons/acre	0.9	1.5	2.0	2.6	3.1	3.7	4.2	4.8	5.3	5.9	6.4
100-hour tons/acre	2.3	3.8	5.2	6.6	8.1	9.5	10.9	12.3	13.8	15.2	16.6
1000-hour tons/acre	3.9	6.3	8.7	11.1	13.5	15.9	18.3	20.7	23.1	25.5	27.9
Total Fuel Loading	7.6	12.2	16.8	21.4	26.0	30.6	35.2	39.8	44.4	49.0	53.6

Following Hurricane Hugo in 1993, the Southern Research Station published a document containing fuel loading and an analysis of post-hurricane prescribed burning: Photo Series for Estimating Post-Hurricane Residues and Fire Behavior in Southern Pines Following Hurricane Hugo, fuel plot data collected in southern pine stands was grouped into light (12 to 17 tons per acre), moderate (19 to 22 tons per acre), and heavy (29 to 36 tons per acre) fuel loading categories. The sampling included dead woody material 3 inches and below including litter, duff, and live vegetation. After a prescribed burn, the post burn data indicated almost no reduction in fuels larger than 3 inches while 78% of litter, duff, live vegetation, and woody material smaller than 3 inches was consumed by the prescribed burn.

Canopy fuel loading can be estimated using LANDFIRE data: LANDFIRE viewer A formula using canopy characteristics could be used to roughly estimate the amount of fine woody debris added by hurricane damage.

- Canopy Fuel Loading (CFL) = canopy bulk density (CBD) x [canopy height (CH) – canopy base height (CBH)] x canopy cover (CC)
- All inputs using metric, kg/m^3 for CBD or meters for CH, CBH. Canopy cover is the percentage of the surface shaded by the canopy, convert to decimal in the equation.
- Conversion – CFL x 4.25 = tons per acre
- Tons per acre x percentage of canopy on the ground could be added to pre-hurricane fuel loading estimates of fine woody debris (FWD)

The photo fuel loading series is an accurate method of estimating fuel loading using photographs of weighed fuels. An estimate is calculated by combining the weight of each type of fuel based on the specified loading. This sampling method can be implemented with less experienced personnel. Below is an example of how the system works. https://www.firelab.org/project/photoload-visually-estimating-fuel-loading.



While these data sets are not an apples-to-apples comparison, they do show some important trends. Fine woody debris (FWD) makes up 17% of total woody debris for pre-storm data collected in the mountains. Pre-storm data from the coastal plain indicates that FWD makes up 73% of total fuel loading while post-storm, FWD makes up only 8% of total fuel loading. Clearly, hurricanes result in a major shift in fuel loading as these storms can create significantly more heavy debris than fine fuel The chart above provides an excellent tool to estimate fuel loading changes post-storm based on fuel size class and damage severity. Having a solid understanding of post-Helene fuel loading is critical information for fire managers as they consider the impacts of fuel loading on fire behavior and smoke management.

Practical Interpretation of Fireline Production Guide

The increase in fuel loading caused by hurricane damage has significantly altered the fuel models across the affected landscape. What were previously Fuel Model 9 (pine and hardwood litter) have transitioned to slash blowdown models, including Models 12 and 13, characterized by heavy debris and increased resistance to control. These changes in fuel characteristics will directly impact wildfire suppression strategies and the effectiveness of the current resource allocation.

The NWCG line production rates were produced using the original 13 fuel models described by Anderson (1982). The CONTAIN model in Behave Plus is based on the line production rates by resources type and kind. NWCG_2021_FireLineProductionRates.pdf Fire managers must use the available data to build an expectation of performance for the resources available to them. Line production rates for the 40 Scott and Bergan fuel models can be deduced based on the characteristics of each fuel model. For example, the obvious similarities between fuel model 13 and SB4 could be used to make informed decisions about resource capabilities when suppressing a fire or planning for contingency resources on a prescribed burn in areas represented by fuel model SB4.

Using Fuel Models for Fire Behavior vs. Line Production Rates

Typically, the same fuel models are used for both fire behavior modeling and fire line production rate estimates. However, the dynamic nature of hurricane-damaged fuels introduces a significant divergence between these two applications:

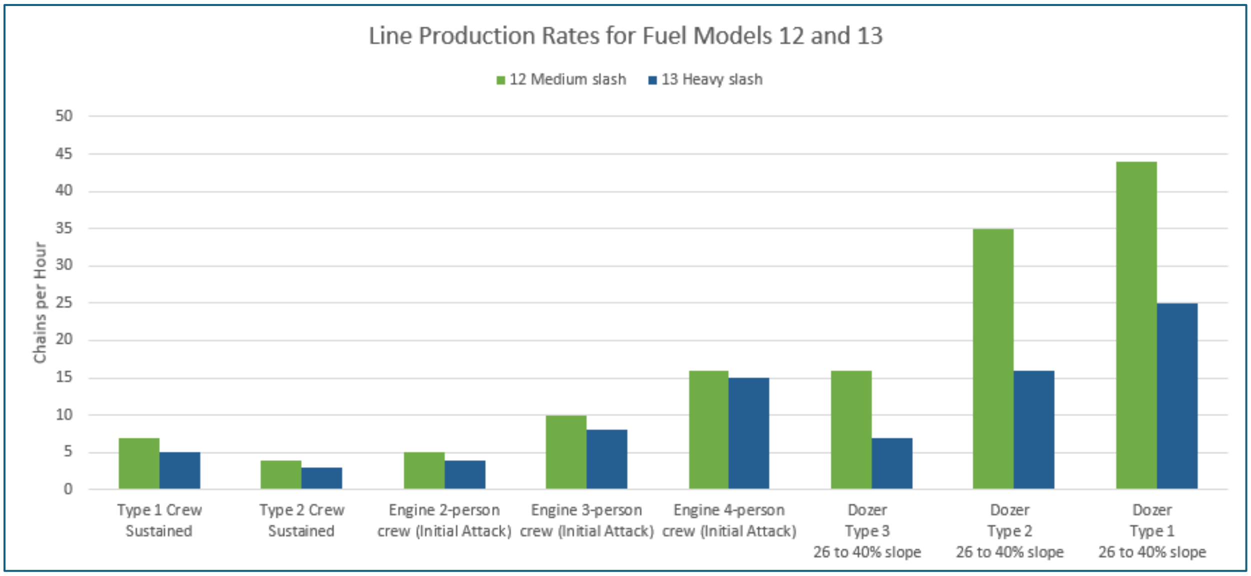
Fire Behavior Modeling: As the damaged fuels dry over time, larger debris may begin to contribute to fire behavior, increasing rates of spread and fire intensity. This process evolves, requiring adjustments in modeling assumptions as fuel availability changes.

Line Production Rates: Even when larger debris is not actively burning, its sheer volume will significantly slow fire line production. Fire managers must account for this distinction when planning suppression strategies, as traditional assumptions about fuel models may not apply uniformly.

The line production guide differentiates between initial attack rates and sustained rates to reflect the different phases of firefighting and the varying conditions under which fire lines are constructed.

Initial attack rates represent the productivity of resources when speed is critical to contain the fire before it grows significantly. Crews work with high intensity, often creating temporary or "scratch" or wet lines to quickly slow the fire's spread prioritizing speed over durability, without fully clearing or strengthening the fire line.

Sustained rates reflect the productivity of resources during extended operations, where fire lines are strengthened and made more durable for long-term containment. Crews work methodically to widen, reinforce, and secure fire lines, often incorporating additional defensive measures such as burnout operations or mop-up. Productivity is lower than during initial attack because of the more labor-intensive nature of sustained operations. Most tables in the guide are for sustained line building.



Impacts on Fire Suppression Response

Firefighters working in hardwood leave litter typically utilize **backpack blowers** to remove light fuels by blowing debris away to expose bare ground, creating fire lines much faster than traditional methods that rely solely on rakes and shovels. The increase in line production rate with blowers has not been thoroughly evaluated. However, in coordination with chainsaw operators and hand tools, blowers significantly enhance, possibly doubling, the line construction capabilities of both hand crews and engine crews. In areas dominated by heavy hurricane debris, blowers may have limited effectiveness. Large logs, heavy branches, and compacted fuel beds obstruct their use, forcing crews to rely more heavily on chainsaws and hand tools, which slows production.

UTVs equipped with water tanks (typically under 100 gallons) and pumps have become common in wildfire suppression. These vehicles improve mobility by transporting firefighters, tools, fuel, and small amounts of water directly to the fire line. Dense debris fields and large fallen trees may limit UTV access to the fire line, reducing their utility in these scenarios and requiring additional efforts to clear paths for their operation.

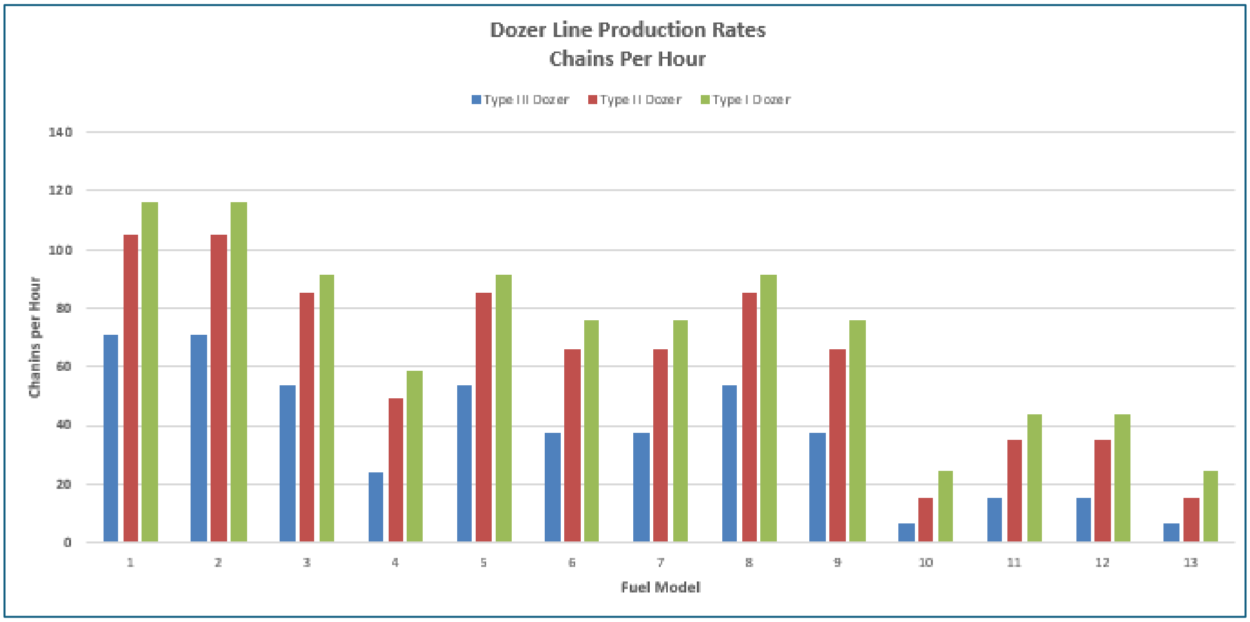
*The impact of UTVs and Backpack blowers are not reflected in the NWCG line production rates guidebook.

Engine crews remain a key component of initial attack operations, and their production rates (initial attack) are less impacted by heavy debris than other resources. Adding an additional firefighter to each engine crew increases productivity by at least 40% in most fuel models and up to 100% in medium and heavy slash (Fuel Models 12 and 13). An engine staffed with 5 people is capable of 20 chains/ hour in heavy slash, a production rate that rivals a type II dozer in the same fuel. These gains represent initial attack rates and assume that water is continuously available, requiring tenders to support engines during extended operations. Describing the line production rate for engine crews as faster than LPR for hand crews can be misleading. During initial attack the engine crews are not building line through the debris, they are knocking the fire down. But it's important to highlight that water can be used to stop fire spread without having to move the debris.

Holding the line will require widening and more thoroughly removing the debris. Additionally, engines may face challenges accessing areas with dense blowdown, reducing their ability to position effectively along the fire line and advance hose lays into the debris fields.

Hand crews, including type 1 and type 2IA crews, are adaptable resources and often employ tools like backpack blowers, chainsaws, and UTVs to increase efficiency. Heavy slash and blowdown significantly slow their productivity, as more time is required to clear large debris by hand. In Fuel Models 12 and 13, production rates for hand crews can drop by as much as 70% compared to lighter fuels.

Dozers remain critical for constructing fire lines in heavy fuels but face steep declines in production rates as fuel loading increases. Larger dozers (Type I) maintain moderate productivity in heavy fuels (10–20 chains/hour) and are better equipped to handle dense debris. Smaller dozers (Type III) struggle significantly, with production rates dropping to 3–8 chains/hour in heavy slash.



Blasting fire lines with explosives is an uncommon but highly effective option in areas of heavy debris and blowdown. Explosives crews can construct fire lines much faster than hand crews in conditions with dense debris. For example, a 7-person explosives crew can achieve up to 120 chains in heavy slash over a 10-hour shift, compared to 45 chains by a 20-person hand crew. Blasting requires specialized training, additional safety precautions, and advance planning, making it most suitable for pre-identified problem areas.

Other types of **Heavy Equipment** should be considered for constructing fire line in the storm damaged areas. Excavators, front end loaders, and logging equipment are designed to move large material. They will be invaluable to install strategic fire breaks and construct indirect and contingency lines during suppression efforts.

Aviation assets will be a key resource for fire fighters in the coming years, possibly decades. Using aerial observation platforms including UAS, helicopters, and planes will prevent having to send firefighters on foot into debris fields for scouting missions. The increased fire intensity from the heavy fuel loading makes water dropping aircraft a necessity to slow spread in inaccessible areas. Having type 1 helicopters during initial attack will provide responders an advantage when attempting to suppress fires in the heavy debris. The concentrated volume of water from a type 1 is needed to penetrate the piles of fallen trees. Light helicopters don't drop enough water to accomplish this efficiently. For the same reason, retardant use may be complicated by fire burning underneath retardant coated fuels on the surface of debris piles.

Conclusion

The shift to heavier fuel models caused by hurricane-altered landscapes requires strategic adaptation in fire suppression efforts and in prescribed fire planning and execution. By upgrading equipment and enhancing crew capabilities, fire managers can mitigate the productivity loss associated with increased resistance to control. Recognizing the evolving relationship between fire behavior and line production rates will further enable fire managers to tailor suppression and prescribed fire contingency tactics effectively to these challenging conditions. During suppression and contingency actions, mixed resources can complement and enhance one another so that the sum line production rate of the group is greater than its parts. This aspect of line construction is even more important in storm debris.

Author's Note

Information for this report was compiled from the linked documents and several unpublished hurricane risk assessments written by R8 FAM staff over the past several decades and a fuels impact assessment report created following the December 2000 ice storm damage in Arkansas. Much of the narrative is anecdotal or speculative, based on personal conversations with fire managers around the southern area who have worked in hurricane debris. This report is intended to serve as a practical decision aid and starting point in situations where there is no proven or tested data. The information should be verified by observation. Hurricane damage to forests in the coastal plain is unfortunately a common occurrence with major storm damage events happening in every southern coastal state during the past 20 years. However, the impacts from Hurricane Helene are unique in the severity and extent of damage to hardwood dominated stands in complex terrain.

For more information contact David Quisenberry - david.quisenberry@usda.gov