NIST GCR 18-018

Structures Ignited by Virginia WUI Fires 2/2015 – 2/2017

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Prepared for
U.S. Department of Commerce
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Abstract

This report documents twenty-one structures that were ignited or significantly damaged by burning wildland vegetation in Virginia over a two-year period starting in 2015. The structures included all of those that would have been lost except for the intervention of local fire departments or the Virginia Department of Forestry to suppress the fires. The objective of the study was to supply data to the National Institute of Standards and Technology (NIST) from wildland-urban interface (WUI) fire sites where structures were ignited, including incident date, structure location, type of wildland vegetation that spread fire to the structure, and the first material ignited. Most of the incidents involved storage or utility buildings that were typically located away from residences where landscaped ground cover abutted a forested area on private property. Many of the structures ignited had wood or wood based exterior finish materials. Exterior finishes were burned and, in many cases burned through allowing fire to spread to the interior. In most cases, the fire was spread to the structure through leaves on the ground. In those incidents, ground leaf and tree litter cover sufficient to spread fire and ignite the structures was estimated to be between 8 cm and 13 cm (3 in and 5 in) deep. Video from the 2016 Chalet Village WUI community fire (near Gatlinburg, Tennessee) showed that the same ignition mechanism played a role in the ignition of structures in that community.

Key words

Wildland-urban interface (WUI) fires; Virginia; ground cover fires; structure ignition.

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1. Introduction

Wildland-Urban Interface (WUI) fires are fires that involve fire spread through an intermix of vegetative and structure fuels distributed in a community or on the landscape [1]. The total burden of WUI fires is estimated at about $14 billion annually [1]. The WUI fire problem appears to rapidly be getting worse in terms of structures lost and acres burned [1]. If unchecked, the WUI fire burden will likely double over the next decade [1].

The wildland-urban interface research efforts of the Fire Research Division at the National Institute of Standards and Technology (NIST) are directed toward improving the resistance to ignition of isolated structures in large area rural properties and closely spaced structures in residential communities when subject to wildland-urban interface fires. NIST has investigated major WUI fires in California [2], Texas [3] and Colorado [4]. These investigations of major fire events have contributed substantially to the understanding of WUI fire spread in communities and WUI firefighting.

Although there is a lot that can be learned from major WUI fires that destroy communities, the more frequent smaller fires that damage or destroy one or more structures on a single property can also contribute to the understanding of WUI fire spread and ignition of structures. In fact, investigations of smaller fire events can contribute more details with less uncertainty about fire spread, first material ignited on a structure and fire department response. Also, smaller fire incidents require less resources and time to thoroughly investigate. Considering these advantages, NIST funded this study of WUI fires that damaged structures in the state of Virginia. Additionally, this study contributed data and observations relevant to eastern U.S. WUI fires that are studied less than fires in the western U.S.

This study can be regarded as a foundational research to determine from structures ignited or significantly damaged by WUI fires, the exterior materials that are susceptible to ignition by burning vegetation, and the characteristics of the fire spread from the ignition point to the structure. This study was primarily one of reporting observations made at fire sites by experts guided by a standardized form for data collection. Fire sites were visited within a few days after firefighter response. The data collected after the fires were enhanced by information reported by foresters and others who observed the fires.

Over a period of two years, twenty-one structures that were ignited or significantly damaged but not destroyed by WUI fires in Virginia were studied. Observations and information collected from these fire incidents indicated that ground fire spread in eastern U.S. WUI fuels, such as dry dead leaves, can be significant threats to structures. Results of this study can help to provide direction to science-based development of standard test methods for building materials and structure design to reduce the likelihood of structure ignition from WUI fires. Reducing ignitions is the best course of action to reduce the negative impact of the WUI fire problem [1].

Information from each site was collected in a standardized format adapted from WUI 1 [3] as implemented on electronic tablets by NIST for data entry for the investigations of large fires. This data entry form was adapted for use in Virginia and implemented in paper form for use in the field. Later, data were transferred to electronic format as a table shown in Appendix A. This information was supplemented by photographs of the structures and fire sites.

Beyond the minimum data set required by NIST (the location of the structure, the first material ignited on the structure, the WUI fuel that spread fire to the structure, and photographs of the damage), effort was invested to understand the fire initiating events, the fire spread, and the intervention by local fire departments, the Virginia Department of Forestry, and defensive actions by others to suppress the fire. This report contains an overview of data collected at the fire site and discussion of the fire incident including photographs for each of the 21 fire damaged structures studied.

Identifying information for people and properties is not reported to protect the privacy of those involved in the fire incidents studied.

2. Method

The intention of this study was to document the WUI fire and material ignited on structures in the state of Virginia from February 2015 to February 2017. Structures destroyed by fire were not included as it was unlikely that the first material ignited by the burning vegetation could be determined with certainty. All the structures included in the study were ignited and saved or significantly damaged by fire and likely to have ignited except for the intervention of owners, neighbors, the local fire department and/or the Virginia Department of Forestry (VDOF).

Monday through Thursday of every week the Virginia Department of Forestry posts on its public website (http://dof.virginia.gov/fire/sit-rep.htm) fire incident information from its six regional offices. This includes weather conditions relevant to fire ignition and spread, the number of fires and area burned since the last report, and the number of homes and other structures damaged or protected from fire.

If a home or other structure was reported online as being damaged by a fire responded to by VDOF, the identified regional office was contacted to gather more information about the fire event and to identify the forester that responded to the fire. The forester was contacted to learn as much about the incident as possible. Many times, structures that were initially listed in the online report as damaged were eventually found to be total losses. In other cases, it was learned that the home or structure listed was the original source of the fire that spread to the wildland. These cases were not investigated. Those that remained fell into the scope of the study. These were structures that were significantly damaged or ignited by fire that spread to the structure through wildland or forest fuels, no matter the original fire source. The forester was usually able to supply contact information for the property owner.

The property owner was contacted, and arrangements were made to gain access to the site for documenting the fire damage and providing specific information requested by NIST. Typically, the fire site was visited within 2-4 days after the fire depending upon the time needed to contact owners and/or forester and plan for access to the property. A two-person team visited each site to assess the fire incident and collect data. The team consisted of a professional engineer with formal education and experience in fire dynamics and a former firefighter/assistant fire marshal. As requested by NIST, the primary data collected on site were: (1) the GPS coordinates of the building ignited, (2) the material on the building that was ignited, (3) the WUI fuels that spread fire to the building and (4) pictures of the site and damaged building.

Typically, the source of fire was an open-air trash or debris burn, burning accumulated leaves, or a tree contacting powerlines. In the cases of trash, debris or leaves burning, the fire was attended. The person who was attending the burn was a reliable source of information about the fire. In some cases, residents or others shared photographs and/or video of the fire and first responder activity. This helped greatly in eliminating uncertainties in understanding and documenting the incident.

The forester who responded to a fire submits a report with Virginia Department of Forestry (VDOF). VDOF provided information from the forester's report on each fire included in the study. Information from the forester's report included: the general and specific causes of the fire, fire weather, and a statement of the forester from the investigation of the incident. Fire weather included: date and time of the observation, wind speed and direction, the air temperature and relative humidity, Cumulative Severity Index (CSI), and the Fire Danger Class Day. The latter two quantities are not commonly encountered and require further explanation. The Virginia Department of Forestry provides the following information about the CSI [5]:

> The Cumulative Severity Index (CSI) or Keetch-Byram Drought Index (KBDI) is a continuous reference scale for estimating the dryness of the soil and duff layers. This system is based primarily on recent rainfall patterns.
>
> The CSI, specifically developed to equate the effects of drought with potential fire activities, is the most widely used system by fire managers in the southeastern United States. This mathematical system for relating current and recent weather conditions to potential or expected fire behavior results in a drought index number ranging from 0 to 800. This number accurately describes the amount of moisture that is missing; a rating of 0 defines a point of no moisture deficiency and 800 defines the maximum drought possible.
>
> Prolonged droughts (high CSI) influence fire intensity since more fuel is available for combustion (i.e. fuels have a lower moisture content). In addition, dry organic material in the soil can lead to increased difficulty in fire suppression. High values of the CSI are an indication that conditions are favorable for the occurrence and spread of wildfires, but drought is not by itself a prerequisite for wildfires. Other weather factors,

such as wind, temperature, relative humidity and atmospheric stability, play a major role in determining the actual fire danger.

These CSI numbers correlate with potential fire behavior:

- 0 - 200 Soil and fuel have a high moisture content. Most fuels will not readily ignite or burn. However, with sufficient sunlight and wind, cured grasses and some light surface fuels will burn in spots and patches.

- 200 - 400 Fuels more readily burn, and fire can move across an area with no “gaps.” Heavier fuels do not readily ignite and burn. Smoldering and the resulting smoke to carry into and possibly through the night.

- 400 - 600 Fire intensity significantly increases. Fire readily burns in all directions exposing mineral soils in some locations. Larger fuels may burn or smolder for several days creating possible smoke and control problems.

- 600 - 800 Fire burns to mineral soil. Stumps will burn to the end of underground roots and spotting will be a major problem. Fires will burn through the night and heavier fuels will actively burn and contribute to fire intensity.

There are five classifications of Fire Danger Class Day -- 1 to 5. Low to Extreme respectively. The Virginia Department of Forestry provides the following information about Fire Danger Class Day [6]:

> Fire danger is the probability of a fire to start, the rate of spread and intensity of its burn. This probability is influenced by fuel type, fuel moisture, amount of fuel, and slope of the land area. Another important influence is weather, particularly wind and relative humidity.

- Class Day 1 -- LOW

  Fires do not readily start.

  Fires that do start spread slowly with low resistance to control.

- Class Day 2 -- MODERATE

Fires can start from most accidental causes, but the number of starts is generally low.
Fires burn at moderate intensities; heavy fuel concentrations will burn hot.

- Class Day 3 -- HIGH

Fires start easily from most causes.
Control of fires can become difficult if initial attack not initiated promptly, especially in heavy fuels.

- Class Day 4 – VERY HIGH

Fires start readily and spread quickly.
Resistance to control is high, as is the potential for large fires.
Fire behavior is often erratic, “blow up” potential is high.

- Class Day 5 -- EXTREME

Severe fire conditions, potential for fire disaster is high.
Direct attack of fires is virtually impossible, fires often escape initial attack.
Fire behavior is erratic, “blow ups” may be expected.
Resistance to control is high, fires not usually controlled until burning subsides.

For its major fire investigations, NIST developed the NIST WUI Data Collection Methodology that was implemented by an electronic tablet-based data collection program (WUI 1) for use in documenting damage to structures from WUI fires. This was the first standardized approach to collect basic WUI community fire incident data at a national level [3]. Use of this format was requested by NIST. Although the tablet form of this data collection program was not used for this study, a paper form of the tablet application with a few modifications was used to collect data in the field. Data recorded in the field were transferred to an electronic format and supplemented with pictures from the site. Appendix A shows the structure of this data collection format.

A method was needed to identify sides of buildings that were damaged by wildland fire and to help explain the fire incident details in text and photos. The method and terminology chosen in this report to designate the sides of buildings follow the guidelines and common terminology used in the Incident Command System (ICS). The National Incident Management System (NIMS) uses the ICS as a standard incident management organization for the management of all major incidents. NIMS is intended to provide a comprehensive national framework for incident managers and responders [7].

The identification of building sides uses the ICS letter designation for each side. The four sides are labeled A, B, C and D. In general, the front of the building or street access side is designated as side A. In a clockwise rotation, the building side to the left of side A is side B. Continuing clockwise, the rear of the building is side C and the side to the right of side A is side D. Figure 1 shows a plan view example of the Incident Command Systems recommended side of building designations.

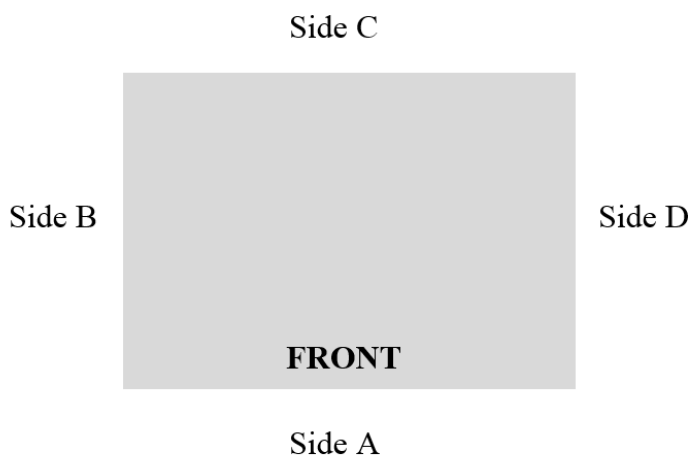

Fig. 1. Plan view of the Incident Command System designations for the sides of buildings.

3. Structures Ignited and Damaged

This section provides a summary of the data from the fire incident sites that are part of this study. A narrative of each fire incident is presented with selected pictures. Primary data requested by NIST is presented in tabular form for each incident. Table 1 presents a summary of primary data for each structure included in this study.

Table 1: Summary data for structures ignited or damaged by WUI fires in Virginia

#	Incident Date	Nearby Town/City	ZIP Code	Wildland Fuel	Material Ignited or Damaged
1	2-15-15	Charlottesville	22902	Leaves	Oriented Strand Board
2	3-31-15	Earlysville	22936	Leaves	Wood board siding
3	5-4-15	Ripplemead	24150	Leaves	T1-11 plywood siding
4	11-16-15	Monroe	24574	Leaves	Wood column
5	11-24-15	Kenbridge	23944	Leaves	Wood joist and floor sheeting
6	11-24-15	Kenbridge	23944	Leaves	Interior combustible contents
7	3-1-16	Earlysville	22936	Pine needles Leaves	Wood board siding
8	3-1-16	Cedar-Bluff	24609	Leaves Grass	Fiberboard siding
9	3-8-16	Axton	24054	Grass	Vinyl siding
10	3-31-16	Hayes	23072	Grass	Vinyl siding
11	3-31-16	Hayes	23072	Firebrands	Plywood siding
12	4-20-16	Churchville	24421	Leaves	Glass fiber panels
13	10-24-16	Naruna	24576	Leaves	Wood door
14	11-11-16	Scottsville	24590	Leaves	T1-11 plywood siding
15	11-14-16	Cedar Bluff	24609	Leaves	Metal siding damaged

16	11-14-16	Cedar Bluff	24609	Leaves Grass	Metal siding damaged
17	11-26-16	Middleburg	20117	Leaves	T1-11 plywood siding
18	11-22-16	Green Bay	23942	Leaves	Wood board siding
19	1-13-17	Stanley	22851	Leaves	Oriented Strand Board
20	1-26-17	Prospect	23960	Leaves Pine needles Grass	Cedar shake siding
21	1-26-17	Prospect	23960	Leaves Pine needles Grass	Cedar shake siding

Description of wildland fuels listed in Table 1:

Firebrand: a burning ember from a vegetation fire that is carried by the wind.

Grass: low growing plants with very thin leaves growing together on the ground surface in large numbers or clusters.

Leaves: light, thin, dry, dead plant material fallen from deciduous trees to the ground that predominantly make up a combustible surface layer. In a treed area, there may be a small number of twigs intermixed.

Pine needles: long slender shaped leaves fallen from a pine tree.

Description of materials ignited or damaged listed in Table 1:

Cedar shake siding: tapered wood shingles made from split cedar wood logs.

Fiberboard siding: manufactured sheet product made with compressed wood fibers used for an exterior weather barrier.

Glass fiber panel: a corrugated panel manufactured with glass matting and resins.

Metal siding: a thin gauge metal panel used for an exterior weather barrier.

Oriented Strand Board: a wood product used in construction made with wood chips and adhesives compressed in layers of specific orientations.

Plywood siding: a wood sheet product used for an exterior weather barrier.

T1-11 plywood siding: a vertically grooved wood sheet used as an exterior weather barrier.

Vinyl siding: strips of plastic panels used as an exterior weather barrier.

Wood board siding: wide wood boards (lumber) placed vertically on the exterior of a building for an exterior weather barrier.

Wood column: a round or square wood structural element supporting a building load.

The fire sites included in the study were determined by fire events. All fires that fit within the scope of the study were visited and data recorded. The fires and structures ignited or significantly damaged occurred widely over the state of Virginia. Figure 2 shows the locations of the structures included in the study with numbers keyed to Table 1 and the detailed incident descriptions in this section. As fires occurred over the entire state, a wide variety of WUI environments were encountered including sites dominated by deciduous forests, native and invasive grasses, and landscaped lawns.

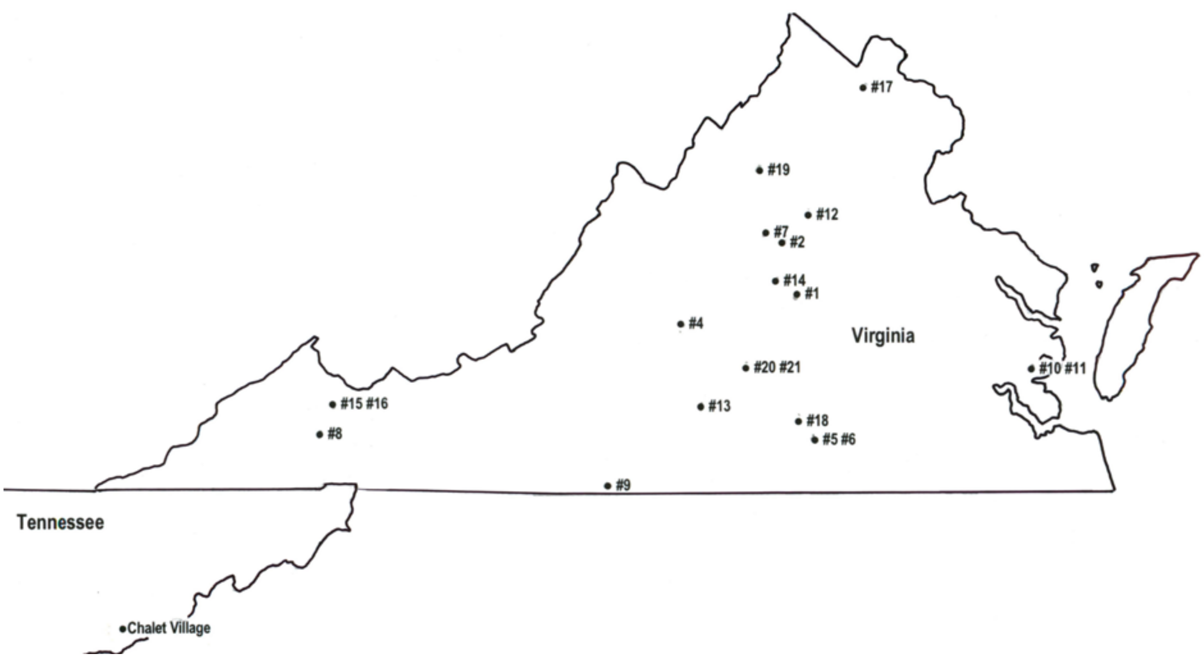

Fig. 2. Locations of structures ignited or damaged by WUI fires in Virginia included in this study.

Each of the fire incidents and 21 structures included in this study are summarized below. Selected pictures are included to provide better understanding of the structure, materials ignited or damaged by the fire, and the surrounding WUI environment to support discussion of the study results.

3.1. Structure #1 Charlottesville, Virginia

Incident date	2-15-2015
Structure location	ZIP Code 22902
Wildland fuel	Leaves
Material ignited	Oriented Strand Board

Incident description

The Virginia Department of Forestry Incident Commander determined the fire was caused by a green tree outside the Right-of-Way (ROW) falling because of high winds onto the power line, causing it to short and start the ROW and adjacent woods on fire. The reported fire weather observations at 10:53 AM: wind direction NW, wind speed 8 m/s (18 mph), air temperature -8.9 °C (16 °F) and relative humidity 27 %. It was a Class 2 fire day. The Cumulative Severity Index (CSI) was not reported.

Sparks from a tree contact with the power line ignited a surface fire in leaves. The surface fire was wind-driven through the woods, reaching the utility storage building located near the woods edge. Soon after the fire event the site received several inches of snowfall, so the site observations of burn patterns and surface fuels were limited because of snow pack.

There were likely leaf accumulations against the building and among the many items stored outside next to the side C exterior wall. It is likely that fire reached the accumulations of leaves, deforming the vinyl siding on the building exposing the oriented strand board (OSB) sheeting to direct flame contact. The OSB ignited along the bottom edge. The wind intensified fire spread up the entire side C wall and damaged the gambrel roof shingles.

Firefighters from Albemarle County, East Rivanna VFD and Lake Monticello Fire/Rescue worked to control the woodland fire and save the burning building. The first item damaged on this building was the vinyl siding along the base of the side C wall. The OSB ignited and burned the entire exterior wall of side C. The deepest char in the OSB sheets occurred near the center of the building wall.

Fig. S1-1. Photo provided by the owner shows the path the fire took through the woodland toward the utility building in the distance on the right.

Fig. S1-2. Photo provided by the owner shows a close-up of the burn pattern on the ground where the surface fire approached and passed the utility building. The metal items in the photo were next to the utility building on side C.

Fig. S1-3. Photo provided by the owner shows fire damage to the utility building on side C. Surface fire burning in leaves reached the structure, deforming the vinyl siding and igniting the OSB sheeting.

3.2. Structure #2 Earlysville, Virginia

Incident date	3-31-15
Structure location	ZIP Code 22936
Wildland fuel	Leaves
Material ignited	Wood board siding

Incident description

The Virginia Department of Forestry Incident Commander reported that the fire appears to have started as a result of a spark escaping the chimney of the outdoor wood-fired boiler. He stated the Albemarle County Fire Marshal checked the chimney the day of the fire and there was no spark arrester in place and no other source of ignition in the area the fire started. The reported fire weather observations at 2:00 PM: wind direction S, wind speed 9.8 m/s (22 mph), air temperature 20.6 °C (69 °F) and relative humidity 23 %. It was a class 2 fire day and the Cumulative Severity Index (CSI) was 6.

It was very likely that embers emitted from the boiler ignited surface fuels of leaves near the unit. The wind direction and speed rapidly spread the surface fire deeper into woodland away from the residence and boiler. However, as the fire approached the utility building, it spread much slower backing against the wind.

The owner called 911 and was beating out the backing fire moving toward the utility building with a shovel when he heard sirens. He left briefly to guide firefighters to the scene. Upon his return with the firefighters the utility building was on fire on its side B.

The first item damaged was the wood board siding on side B of the wood framed utility building. The boards were ignited as the surface fire burning in leaves reached the base of the side B wall. The fire continued to burn in the accumulations of leaves and among the many items stored against the building.

The fire spread up the entire exterior side B wall surface bottom to top. Fire damaged the exterior wall and corners of side B, the side B roof overhangs, soffits and ignited the rolled roofing material under the top layer of standing seam metal roofing. The fire made entry through the gaps in the wood board siding.

Firefighters from Earlysville VFD saved the burning building and helped to control the spreading woodland fire. The Virginia Department of Forestry responded with a dozer and placed a containment line around the perimeter of the fire area.

Fig. S2-1. Photo shows the damaged side A of the utility building. The blackened area on the left side of the photo is the damaged wall of side B.

Fig. S2-2. Photo shows the surface fire's path of travel from near the boiler to the utility building. The wind speed was 9.8 m/s (22 mph) from the south, blowing from the right to the left in this photo.

Fig. S2-3. Photo of damaged wood board siding on side B.

Fig. S2-4. Photo shows close-up view of damage to the bottom edge of wood board siding on side B. Deeper char damage was present along the weathered bottom edge of the wood board siding.

Fig. S2-5. Photo shows points of entry along the top wall plate of the side B wall. Fire entered through gaps in the wood board siding.

3.3. Structure #3 Ripplemead, Virginia

Incident date	5-4-15
Structure location	ZIP Code 24150
Wildland fuel	Leaves
Material ignited	T1-11 plywood siding

Incident description

The Virginia Department of Forestry Incident Commander determined the fire started around 9:30 AM along the north side of the roadway in dry leaves. The source of ignition was unknown. The reported fire weather observations at 1:30 PM: wind direction SW, wind speed 2.2 m/s (5 mph), air temperature 23.3 °C (74 °F) and relative humidity 27 %. It was a class 2 day and the Cumulative Severity Index (CSI) was 50.

The fire spread from the north side of the roadway into woodland understory burning in leaves. The surface fire continued northeast slightly upgrade driven by a 2.2 m/s (5 mph) SW wind along the woodlands' edge reaching side C of the pole building garage. The garage had accumulations of leaves as well as other combustible items stored against it.

The first item damaged on the garage was its exterior T1-11 plywood siding along its bottom edge. Ignition occurred in two locations. The greater damage and likely first ignition occurred on side D where there were two ignition points within 1.8 m (6 ft) of the side C, D corner. The second ignition location with lesser damage occurred on side B, 16 cm (6 in) from the side B, C corner. The fire on side D was the location the owner first saw his garage burning as he defended other property.

Firefighters from the Blacksburg VFD, Newport VFD, Pembroke VFD and the Virginia Department of Forestry responded and extinguished the fire, saving the garage and preventing damage inside the garage. The fire burned a total of 2.5 acres of woodland before it was contained and extinguished.

Fig. S3-1. Photo showing an overview of the detached garage building sides C and D.

Fig. S3-2. Photo shows close-up view of fire damage to exterior T1-11 siding on side D near the corner with side C. The bottom edge of the exterior siding was the item first ignited by a creeping surface fire burning in leaves reaching the base of the building. Other combustibles ignited next to the building contributed to the large blackened area.

Fig. S3-3. Photo shows fire damage to T1-11 siding on side B near the corner with side C. A creeping surface fire burning in leaves reaching the base of the building ignited the bottom edge of the exterior siding.

3.4. Structure #4 Monroe, Virginia

Incident date	11-16-15
Structure location	ZIP Code 24574
Wildland fuel	Leaves
Material ignited	Wood column

Incident description

The Virginia Department of Forestry Incident Commander determined the fire was caused by the homeowner burning brush when an ember landed in adjacent hardwood timber fuels and ignited. The reported fire weather observations at 1:45 PM: wind direction NE, wind speed 1.8 m/s (4 mph), air temperature 17.8 °C (64 °F) and relative humidity 36 %. It was a class 3 fire day and the Cumulative Severity Index (CSI) was 58.

The owner stated he was burning a 2.4 m (8 ft) high pile of construction debris (boards) and brush in his burn pit. The fire escaped to the woods across the driveway west of the burn pit. The owner found a burning stick in the woods he thought had been ejected as the pile in his burn pit collapsed. The burning stick had ignited leaves and he attempted to stomp the fire out. Unsuccessful, he began hauling water in the loader bucket of his farm tractor to extinguish it. While trying to extinguish the leaves across the driveway west of the pit he noticed the fire had escaped east of the pit. The escaped fire burned from the pit upslope in continuous light fuels of leaves, grass and dry brush. The structure damaged was just 31 m (102 ft) upslope northeast of the burn pit.

The surface fire reached the structure at the SE corner, igniting the first structural column at the corner of sides C and D and entering the building at that point. Column ignitions continued by direct flame contact at ground level to all 5 structural support columns of the open 3.7 m (12 ft) by 9.1 m (30 ft) pole structure.

The first item damaged was the structural support column located at the corner of sides C and D. This column was a 15 cm (6 in) diameter locust log (debarked) set in a dug posthole. The support column was ignited at ground level by direct flame contact from a surface fire in accumulated leaves. There was a 17 cm (7 in) depression in the backfill at the base of the column where the soil had compacted or was left unfilled and likely contained extra leaf accumulation.

Firefighters from Amherst VFD, Pedlar VFD and the Virginia Department of Forestry took actions to save the structure and control the spreading woodland fire.

Fig. S4-1. Photo shows the burn pit, where the owner was burning debris, located below the damaged building. Fire escaped to the east (right side of the photo) and burned uphill 31 m (102 ft) to the pole building to the left of the backhoe.

Fig. S4-2. Photo shows the burned area on side D where the surface fire entered the open pole structure near the corner with side C.

Fig. S4-3. Photo shows the column that was the first building component damaged. This column was a 15 cm (6 in) diameter locust log (debarked) set in a dug posthole at the corner of sides C and D.

3.5. Structure #5 Kenbridge, Virginia

Incident date	11-24-15
Structure location	ZIP Code 23944
Wildland fuel	Leaves
Material ignited	Wood joist and floor sheeting

Incident description

The Virginia Department of Forestry Incident Commander determined the fire was caused by the resident burning trash and the wind blew embers into the woods, spreading the fire. The reported fire weather observations at 8:00 AM: wind direction W, wind speed 3.6 m/s (8 mph), air temperature 12.8 °C (55 °F) and relative humidity 23 %. It was a class 2 fire day and the Cumulative Severity Index was 9.

A trash burn barrel was being used to burn a large amount of used notebook papers unattended. The wind speed was estimated to be 9 m/s (20 mph) at the time of the fire. Embers blown from the burn barrel into nearby leaves caused a surface fire that spread in the layer of leaves, damaging two structures (structure #5 and #6) on the property.

Fire damaged structure #5 was a manufactured utility storage building. The floor system was made with wood joists on skids and wood sheeting for the interior floor deck. The exterior walls and roof were metal framed with medal siding. The surface fire burning in leaves ignited the open wood floor joists and floor sheeting under the building. The fire extended into the interior of the building from the underside at the exterior wall on side B near the corner with side A.

The first items damaged were the wood floor sheeting and floor support structure. The combustible floor assembly was open under the structure and exposed to direct flame contact from a surface fire burning in accumulated leaves. The combustible floor materials in the first three joist spaces sustained charring damage on the underside of the floor assembly.

Firefighters from the Kenbridge VFD and the Virginia Department of Forestry responded and extinguished building and woodland surface fires.

Fig. S5-1. Photo shows overall view of the damaged building from the side A, B corner. Heat damage occurred from burning leaves along the base of the building and from the ignition of the underside of the wood floor joists and wood floor sheeting. The wood floor sheeting burned through and interior contents were ignited, causing more heat damage to the metal wall siding.

Fig. S5-2. Photo shows a close-up of the exterior damage on side B near the corner with side A. This is the area of most damage to the underside of the building and where the fire made entry into the building.

Fig. S5-3. Photo looking under the structure at ground level shows charring to the underside of floor sheeting and floor support structure. Post-fire leaf accumulation is present in the open area under the building.

Fig. S5-4. Photo shows interior floor damage and burn pattern on the side B interior wall near the corner with side A. Burned interior contents were removed by firefighters.

Fig. S5-5. Photo shows a close-up view of the location where the fire made entry into the building. A sample of the most damaged floor sheeting is shown at this location where the fire made entry. The sample was broken out by firefighters during extinguishment and overhaul operations.

3.6. Structure #6 Kenbridge, Virginia

Incident date	11-24-15
Structure location	ZIP Code 23944
Wildland fuel	Leaves
Material ignited	Interior combustible contents

Incident description

The Virginia Department of Forestry Incident Commander determined the fire was caused by the resident burning trash and the wind blew embers into the woods spreading the fire. The reported fire weather observations at 8:00 AM: wind direction W, wind speed 3.6 m/s (8 mph), air temperature 12.8 °C (55 °F) and relative humidity 23 %. It was a class 2 fire day and the Cumulative Severity Index was 9.

A trash burn barrel was being used to burn a large amount of used notebook papers unattended. The wind speed was estimated to be 9 m/s (20 mph) at the time of the fire. Embers blown from the burn barrel into nearby leaves caused a surface fire that spread in the layer of leaves, damaging two structures (structure #5 and #6) on the property.

Fire damaged structure #6 was a corrugated metal utility storage building. The non-combustible building was not ignited by the surface fire but did sustain heat damage caused by the surface fire burning in leaves accumulated against the building. The fire breached the building through openings at the base of the building where the gravel floor materials had eroded. Interior combustibles were ignited and caused additional heat damage to the structure.

The first items ignited were the interior combustible contents stored against the inside corner of the C and D walls.

Firefighters from the Kenbridge VFD and the Virginia Department of Forestry responded and extinguished the structure’s contents and the woodland surface fires.

Fig. S6-1. Photo shows an overall view of building side A. The burn barrel (fire cause) can be seen at the center left of the photo.

Fig. S6-2. Photo shows the heat damage to the C, D corner where the surface fire burned to the structure and made entry.

Fig. S6-3. Photo shows the erosion in floor materials on the exterior of side C at the corner with side D. This is where the surface fire made entry and ignited interior combustibles.

Fig. S6-4. Photo shows a close-up view of eroded floor openings at base of low burn pattern on the interior of the side C wall. This is where the surface fire of burning leaves entered the steel building, igniting interior combustibles.

Fig. S6-5. Photo shows the burn pattern on side C interior wall at the corner with side D.

3.7. Structure #7 Earlysville, Virginia

Incident date	3-1-16
Structure location	ZIP Code 22936
Wildland fuel	Pine needles and leaves
Material ignited	Wood board siding

Incident description

Upon his arrival, the Virginia Department of Forestry Incident Commander found the roadside fire under control by local firefighters. He conducted an investigation but was unable to determine the cause. The reported fire weather observations at 1:53 PM: wind direction S, wind speed 4.5 m/s (10 mph), air temperature 20.6 °C (69 °F) and relative humidity 22 %. It was a class 3 fire day. The Cumulative Severity Index (CSI) was not reported.

A surface fire of unknown origin burned 21.3 m (70 ft) along a roadway parallel to a farm fence in pine needles, leaves.

The fire-damaged structure was a recently constructed agricultural shed used as a run-in shelter for livestock (horses). The wood framed shed was enclosed on 3 sides with vertical wood board siding. The shed’s side B wall was incorporated in the parallel fence next to the roadway.

The surface fire burned in accumulations of pine needles and leaves to the base of the side B wall. The wood board siding had direct flame contact and ignited along the bottom edge. The fire made entry, burning between vertical spaces in the wood board siding along the bottom edge of the side B wall. The first item damaged was wood board siding through direct flame contact with a surface fire burning in pine needles and leaves.

Albemarle County Fire and Earlysville VFD responded and extinguished the burning shed and roadside surface fire. Virginia Department of Forestry conducted an investigation.

Fig. S7-1. Photo shows an overall view of the livestock run-in shed from the side A, D corner.

Fig. S7-2. Photo shows burn pattern on the ground leading to the shed on side B with the fire damage at the bottom edge of the wood board siding.

Fig. S7-3. Photo shows close-up view of exterior damage where the surface fire ignited the wood board siding and made entry.

3.8. Structure #8 Cedar-Bluff, Virginia

Incident date	3-1-16
Structure location	ZIP Code 24609
Wildland fuel	Leaves and grass
Material ignited	Fiberboard siding

Incident description

The Virginia Department of Forestry Incident Commander reported the cause of this fire to be a trash burn. The fire burned approximately 1 acre of the owner's land and damaged an outbuilding. The reported fire weather observations at 10:53 AM: wind direction SW, wind speed 4.9 m/s (11 mph), air temperature 18.3 °C (65 °F) and relative humidity 39 %. It was a class 3 day and the Cumulative Severity Index (CSI) was 14.

The resident was burning trash in a rock circle designated for that purpose. The fire escaped into nearby leaves and dry warm season grasses burning in all directions. The surface fire reached the base of side C of the utility building 56.2 m (184.5 ft) southeast of the rock circle.

The fire-damaged structure was a utility building that provided general storage for household items and maintenance equipment. The wood framed utility building had an overall size, including the deck, of 3 m x 5.2 m (10 ft x 17 ft). A surface fire burning in leaves and grass burned to the base of the building, igniting the bottom edge of the wood fiberboard siding on side C. Fire extended into the building's wood framing.

The first item damaged was the exterior wood fiberboard siding panel on side C. The surface fire made direct flame contact, igniting the siding at two points along the bottom edge. The ignition point on the right of side C caused deep charring into the building's wood framing.

Firefighters from the Belfast-Rosedale VFD responded and extinguished the utility building and surface fire on the owner's property. Firefighters opened the exterior walls of the utility building on sides C and D, removing the fiberboard siding during their overhaul operations.

Fig. S8-1. Photo shows close-up view of the trash burn pit (rock circle) and the burned area leading to the damaged utility building 56.2 m (184.5 ft) away (Building sides C and D shown).

Fig. S8-2. Photo shows the view of side C where firefighters removed the fiberboard siding during fire suppression and overhaul operations. Fire damage to the sill plate can be seen at the lower right of the photo.

Fig. S8-3. Photo shows a view of the side C siding, placed in original position, showing damage at bottom edge.

3.9. Structure #9 Axton, Virginia

Incident date	3-8-16
Structure location	ZIP Code 24054
Wildland fuel	Grass
Material ignited	Vinyl siding

Incident description

The Virginia Department of Forestry Incident Commander determined the fire was caused by the owner burning a pile of trash beside his mobile home. The wind caused the open burning fire to escape and spread into the adjacent woods. The reported fire weather observation at 12:30 PM: wind direction S, wind speed 4.47 m/s (10 mph), air temperature 21.1 °C (70 °F) and relative humidity 30 %. It was a class 3 fire day and the Cumulative Severity Index (CSI) was 25.

The owner started a fire to burn trash in an open area of his yard. The fire escaped and spread in dry warm season grasses, brush, leaves and pine needles. The surface fire burned in dry grass to the base of the mobile home, damaging the vinyl siding on sides C and D.

The first item damaged on the mobile home was vinyl siding. Vertical vinyl siding was damaged for a distance of 4 m (13 ft) on side C near the corner with side D. The surface fire burning in dry grass had deformed the vinyl siding along the damaged area near the ground. Other combustible items including a discarded refrigerator door and baby crib mattress were on the ground next to the mobile home in the damaged area. These items ignited and were a source of sustained heat that charred the vinyl siding and contributed to the heat damage of the vinyl siding.

Firefighters from the Axton VFD and the VDOF IC were in the area when this fire was dispatched. They arrived to find the fire had already burned about 0.25 acre of woodland and the grass fire had reached the mobile home. Firefighters extinguished the fire and very likely saved the mobile home.

Fig. S9-1. Photo shows an overview of side C and fire damage.

Fig. S9-2. Photo shows an overview of fire burn pattern in grassy area from side C of the mobile home. The trash burn spot where the surface fire started is located at the top of the hill in the center of the photo.

Fig. S9-3. Photo shows a close-up view of damaged vinyl siding on side C.

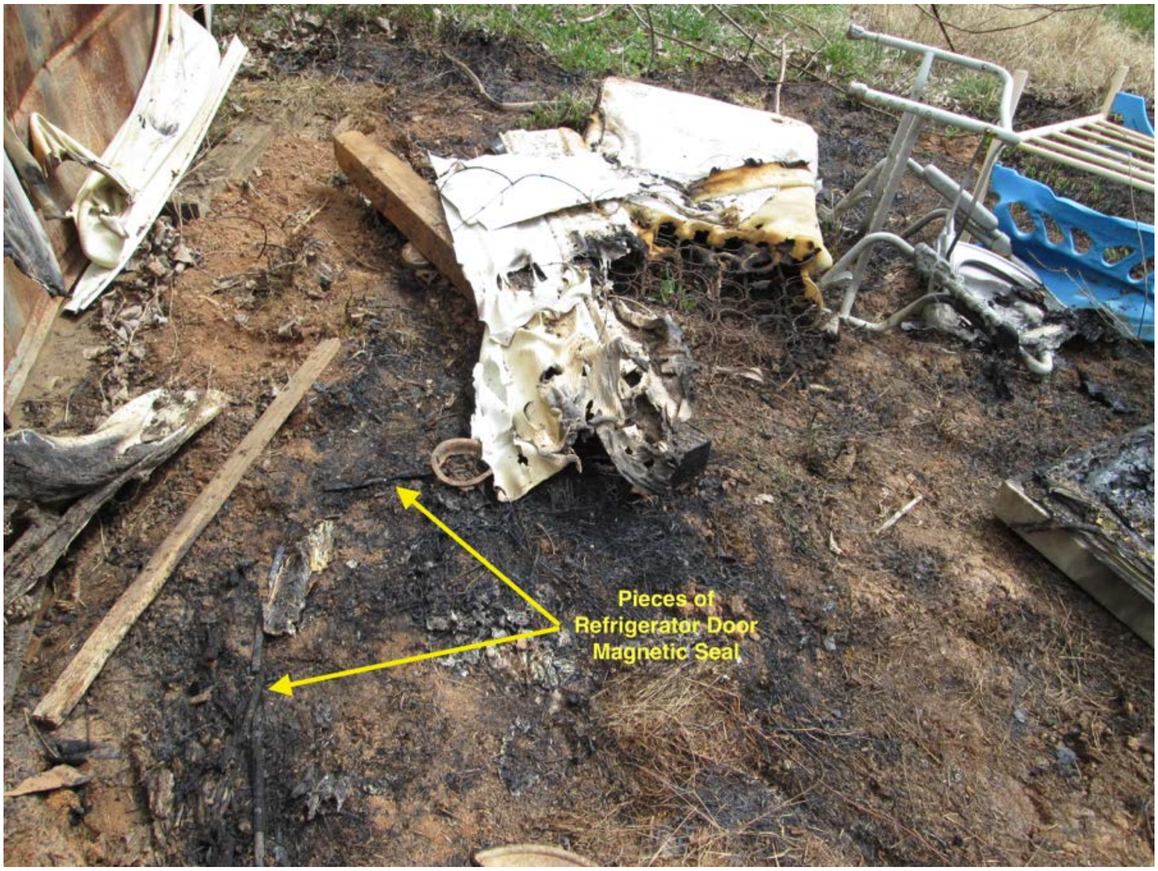

Fig. S9-4. Photo shows a close-up view of the ground burn pattern on side C. The remains of the refrigerator door magnetic seal indicate the location of refrigerator door at time of fire.

Fig. S9-5. Photo shows a close-up view of the burn pattern in grass to the mobile home side D at corner of side C and damaged vinyl siding.

3.10. Structure #10 Hayes, Virginia

Incident date	3-31-16
Structure location	ZIP Code 23072
Wildland fuel	Grass
Material ignited	Vinyl siding

Incident description

The Virginia Department of Forestry Incident Commander the fire cause was incendiary. The area of origin was along the west side of the community's access road. The fire spread northeast. The reported fire weather observations at 3:15 PM: wind direction SW, wind speed 1.34 m/s (3 mph) gusting to 5.36 m/s (12 mph), air temperature 24.4 °C (76 °F) and relative humidity 49 %. It was a class 3 fire day and the Cumulative Severity Index was 161.

The wildland fire burned intensely in tidewater marshland fuels. The fuels are characterized as a heavy cover of easily ignited fuels of brush, swamp grass, invasive Phragmites reeds 1.8 m to 2.75 m (6 ft to 9 ft) tall and scattered clusters of pine trees. The wind was blowing the fire from the SW, approaching at a 45° angle toward side B of the residence. The wildland fuels burned intensely within 8.53 m (28 ft) of side B of the residence, stopping at the edge of the recently mowed yard.

The first item damaged was the horizontal vinyl siding on side B of the residence. Radiant heat caused extensive distortion and buckling of the vinyl materials but did not ignite the structure. Minor radiant heat damage occurred to the vinyl siding on side C near the corner with side B.

Firefighters defended and saved this residence. The firefighters were positioned on the road in front of this and three other nearby residences being defended. Abington's Engine 31 and a brush truck were positioned in the driveway directly in front of this residence. Firefighters used hose lines to protect the buildings, themselves and their apparatus from what they described as incredible heat. Firefighters from Abingdon Volunteer Fire Company, Gloucester Volunteer Fire and Rescue, James City County Fire

Department, York County Fire Department and the Virginia Department of Forestry worked to control this incident saving several structures.

Fig. S10-1. Photo shows an overview of side B showing the damaged building weather protected with plastic sheeting. The wildfire burned to the edge of the recently mowed yard within 8.53 m (28 ft) of side B. The residence was defended by firefighters positioned in front of side A.

Fig. S10-2. Photo provided by the VDOF Incident Commander showing the damaged vinyl siding on side B.

Fig. S10-3. Photo shows a close-up view of minor heat damage to vinyl siding on side C near the corner with side B.

Fig. S10-4. Photo shows marshland fuels of invasive Phragmites reeds 1.8 m to 2.75 m (6 ft to 9 ft) tall. Fire spread was stopped by firefighters positioned in this driveway in front of side A.

Fig. S10-5. Photo shows a view of burned area looking SW from the rear deck on side C of the residence. This was the direction the wildfire approached the residence.

3.11. Structure #11 Hayes, Virginia

Incident date	3-31-16
Structure location	ZIP Code 23072
Wildland fuel	Firebrands
Material ignited	Plywood siding

Incident description

The Virginia Department of Forestry Incident Commander determined the fire cause was incendiary. The area of origin was along the west side of the community's access road. The fire spread northeast. The reported fire weather observations at 3:15 PM: wind direction SW, wind speed 1.34 m/s (3 mph) gusting to 5.36 m/s (12 mph), air temperature 24.4 °C (76 °F) and relative humidity 49 %. It was a class 3 fire day and the Cumulative Severity Index was 161.

The wildland fire burned intensely in tidewater marshland fuels. These fuels are characterized as a heavy cover of easily ignited fuels of brush, swamp grass, invasive Phragmites reeds 1.8 m to 2.75 m (6 ft to 9 ft) tall and scattered clusters of pine trees. The wind was blowing the fire from the SW, approaching at a 45° angle toward side B of the damaged structure. The wildland fuels burned up to the back edge of the mowed yard.

The damaged structure was a wood framed utility building. The building was in the mowed yard area to the left of the residence. The utility building's exterior materials were weathered and deteriorating.

The first item damaged was the exterior plywood siding. As reported by firefighters, flying firebrands ignited the plywood siding on side B. The ignition occurred along the horizontal joint between two sheets of plywood. A horizontal wooden trim board also covered this joint. The plywood siding and trim board in place near the fire damage shows significant weathering creating loose jagged edges receptive to catching flying firebrands. Fire burned through the plywood siding entering the building at the top inside corner of the side A and B walls.

Firefighters were actively protecting this and other buildings along the community's access road. Firefighters quickly extinguished the utility building once they became aware it had ignited. Firefighters and apparatus from Abingdon Volunteer Fire Company, Gloucester Volunteer Fire and Rescue, James City County Fire Department, York County Fire Department and the Virginia Department of Forestry worked to control this incident and saved several buildings.

Fig. S11-1. Photo shows an overview of the utility building side A, B corner with fire damaged area indicated by arrow.

Fig. S11-2. Photo shows a close-up view of the fire damaged area.

Fig. S11-3. Photo shows a close-up view of the inside of the utility building where fire burned through and made entry. This is the top inside corner of the side A, B walls.

Fig. S11-4. The plywood siding and trim board of the utility building in place near the fire damage shows significant signs of weathering creating loose jagged edges receptive to catching flying firebrands.

Fig. S11-5. Photo shows wildland fire area looking SW. This was the direction from which the fire approached the damaged utility building.

3.12. Structure #12 Churchville, Virginia

Incident date	4-20-16
Structure location	ZIP Code 24421
Wildland fuel	Leaves
Material ignited	Glass fiber panels

Incident description

The Virginia Department of Forestry Incident Commander (IC) on the fire walked the property with us and thought the fire may have originated from the carport that was damaged. The IC advised that there was an electrical outlet on the side where the fire was, and it is possible there was an electrical problem, which caused the wire to catch fire, resulting in the brush fire. The reported fire weather observations at 2:30 PM: wind direction E, wind speed 1.82 m/s (6 mph), air temperature 18.9 °C (66 °F) and relative humidity 19 %. It was a class 3 fire day and the Cumulative Severity Index was 167.

The damaged structure was a 5.58 m x 6.4 m (18 ft x 21 ft) metal-framed carport. The carport stored an ATV 4-wheeler, yard equipment and other items. The carport was located 56.7 m (186 ft) south of side D of the main residence at the end of a gravel access road. The structure's glass fiber wall panels ignited and burned. The metal roofing sustained heat damage from the burning siding panels.

After walking the fire scene with the IC, the property was walked with the homeowner, who reported the fire. The homeowner's account of the fire differed from the IC. The homeowner described the fire as advancing to the carport and towards his other buildings from a location near his neighbor's shed. According to the homeowner, the surface fire burned downslope about 69 m (225 ft) from the area where the fire originated to the carport. The carport's glass fiber wall panels were ignited by direct flame contact with the surface fire burning in leaves.

The first item damaged was glass fiber siding. The corrugated glass fiber wall panels attached to metal framing were ignited at the ground level by a surface fire burning in leave accumulations along the side B wall of the carport. The surface fire made direct flame contact with the lower glass fiber panels on side B. The panels were ignited and burned along the length of the side B wall.

Firefighters from Churchville VFD, Mt. Solon Volunteer Fire/Rescue, Swoope VFD, and the Virginia Department of Forestry responded and extinguished the carport and woodland fires.

Fig. S12-1. Photo shows an overview of carport side A. Fire damage to the building can be seen on side B.

Fig. S12-2. Photo showing fire damage and roof to wall transition with corrugated metal.

Fig. S12-3. Photo shows a close-up view of the wall side at the B and C corner where the surface fire ignited glass-fiber wall panels.

Fig. S12-4. Photo shows a close-up view of burned leaves next to wall on side B, as viewed from the interior of the carport.

Fig. S12-5. Photo showing the interior fire damage to the carport caused by the burning glass fiber wall panels. The Incident Commander thought the electrical outlet box and wiring seen on wall support column (center of photo) was a suspect cause of the fire.

3.13. Structure #13 Naruna, Virginia

Incident date	10-24-16
Structure location	ZIP Code 24576
Wildland fuel	Leaves
Material ignited	Wood door

Incident description

The Virginia Department of Forestry Incident Commander (IC) determined the fire was caused by burning trash along the wood line with no control measures in place. The reported fire weather observations at 3:30 PM: wind direction W, wind speed 3.1 m/s (7 mph), air temperature 22.2 °C (72 °F) and relative humidity 31 %. It was a class 1 fire day and the Cumulative Severity Index was 383.

Fire escaped from an open trash burn into woodland fuels. The fire crept along the woodland surface, burning in leaves until it reached side B of the abandoned home. The abandoned home was surrounded with heavy vegetation up to and against the building. The IC advised that discarded combustibles lying at the open doorway of the abandoned home were ignited. The combustibles at the doorway with the burning leaves were sufficient to ignite the wood door that was swung open into the interior.

The first item damaged on the building was the side B entry door. The door was constructed with a wooden frame with upper and lower plywood panels. The lower plywood panel and frame sustained the fire damage. The creeping surface fire reached the side B doorway, igniting combustibles that lay in the doorway. The combination of leaves and other combustibles in the doorway ignited the wooden door.

Firefighters arrived and extinguished the fire in the building very soon after the door ignition occurred. Firefighters from Brookneal VFD and the Virginia Department of Forestry responded and worked to save the abandoned home and control the spreading woodland fire.

Fig. S13-1. Photo shows the view of the abandoned home side B. The creeping surface fire burned in leaves under thick vegetation to the entrance door on side B.

Fig. S13-2. Photo shows fire-damaged door on side B and combustible materials pulled from the interior by firefighters during overhaul operations.

Fig. S13-3. Photo shows a close-up view of the burn pattern in the leaves leading to the front doorstep on side B. The debris placed in front of the door by firefighters during overhaul seen in Figure S13-2 were removed for this photo.

Fig. S13-4. Photo shows an overview of the damaged door on side B. The Incident Commander reported that the surface fire ignited combustibles lying in the open doorway. The burning combustibles in the doorway combined with leaves ignited the wood door's lower frame and panel.

Fig. S13-5. Photo shows a close-up view of lower door panel damage and sample of panel being collected.

3.14. Structure #14 Scottsville, Virginia

Incident date	11-11-16
Structure location	ZIP Code 24590
Wildland fuel	Leaves
Material ignited	T1-11 plywood siding

Incident description

The Virginia Department of Forestry's Incident Commander (IC) determined the fire cause was burning debris (leaves). The fire escaped the burn pile and damaged the garage, a junked car, and burned on to an adjoining property. The reported fire weather observations at 1:00 PM: wind direction W, wind speed 2.7 m/s (6 mph), air temperature 18.3 °C (65 °F) and relative humidity 38 %. It was a class 1 fire day and the Cumulative Severity Index was 435.

The fire-damaged structure was a building used for storage and maintenance. The land surrounding the structure was well-kept with an open understory beneath tall trees. Much of the open ground area was covered in a layer of fall leaves 5 cm to 13 cm (2 in to 5 in) in depth.

The owner had been burning leaves in an open area next to his building for several days. The fire escaped and a surface fire burning in leaves reached the structure along the B and C sides. T1-11 exterior wood siding was ignited on its lower edge at several spots along the bottom of the exterior wall.

The first item damaged was wood T1-11 siding. Ignition occurred from direct flame contact with a surface fire burning in a layer of leaves. Fire had penetrated the building exterior and was burning in the interior in the open wood framing cavity space of the exterior wall. Charring was observed on the back face of the T1-11 siding. A 15.24 cm x 10.16 cm (6 in x 4 in) hole was burned through from the exterior to the interior. The pine lumber sill plate double 5 cm x 10 cm (double 2 in x 4 in) was charred to a depth of 0.63 cm (0.25 in).

Firefighters from Fluvanna Co. VFD, Fork Union Fire Company, Scottsville VFD, and the Virginia Department of Forestry responded and extinguished the building and surface fires.

Fig. S14-1. Photo shows sides B and C of the building (fire damage located along the foundation wall on each side).

Fig. S14-2. Photo shows where two spots ignited on the side C exterior wall. The larger damaged spot on the left penetrated to the interior of the building. The smaller and lower spot burned through but encountered the wood sill plate and did not penetrate to the building interior.

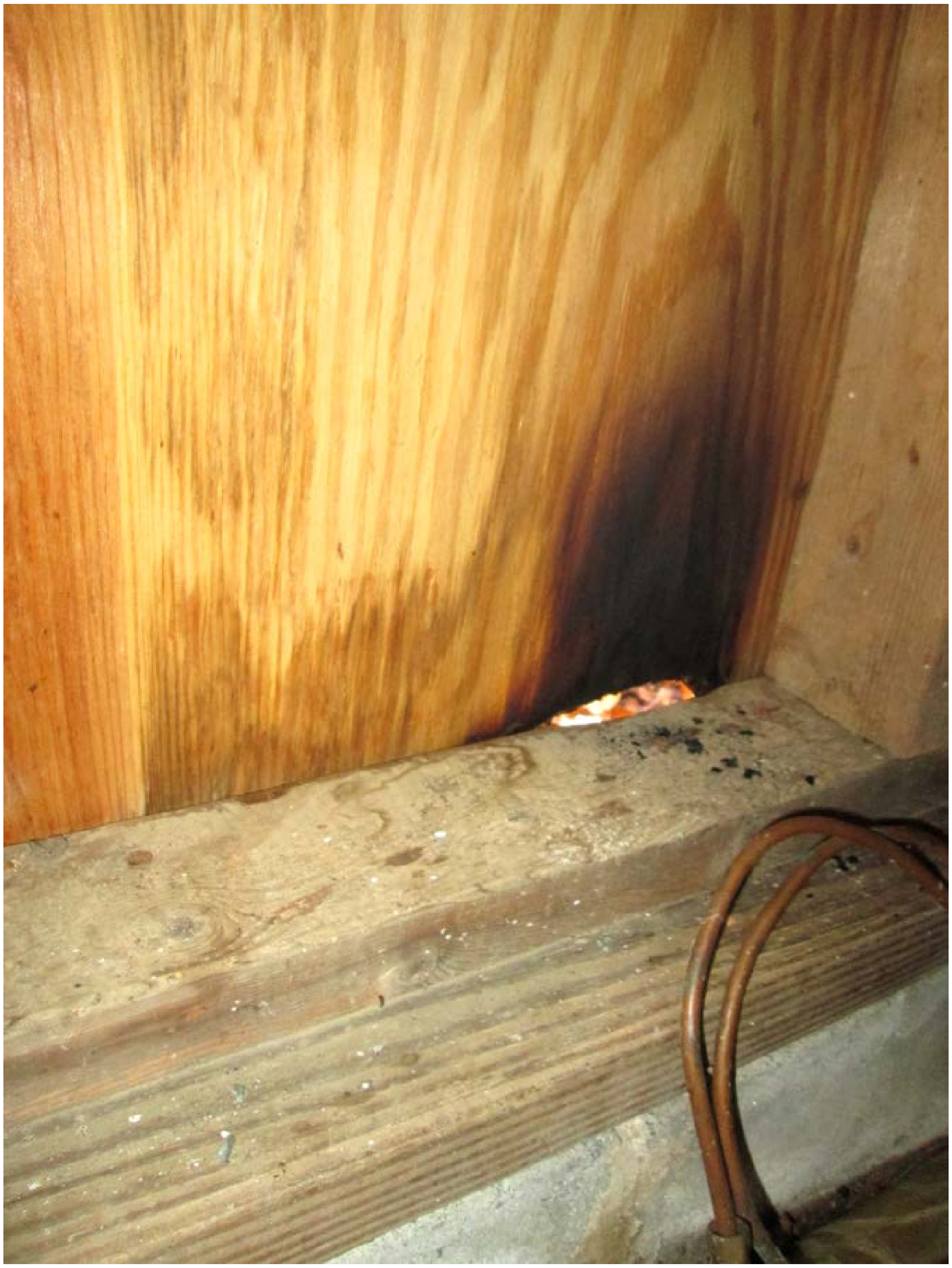

Fig. S14-3. Photo shows damage to interior wall cavity in area where fire penetrated to the interior of the building.

3.15. Structure #15 Cedar Bluff, Virginia

Incident date	11-14-16
Structure location	ZIP Code 24609
Wildland fuel	Leaves
Material ignited	Metal siding damaged

Incident description

The Department of Forestry's Incident Commander (IC) and Fire Investigator determined fire cause was incendiary. The IC reported the fire started as a brush fire near a barn/storage building and moved to the structure before his arrival. The reported fire weather observations at 1:25 PM: wind direction W, wind speed 0.9 m/s (2 mph), air temperature 16.1 °C (61 °F) and the relative humidity 29 %. It was a class 3 fire day and the Cumulative Severity Index 554.

The neighbor became aware a fire was burning on adjacent properties. When he investigated, he witnessed two distinct fires. One was burning in a pile of stumps and one in a pile of tires separated by approximately 200 ft with some fire burning between in the brush. His wife called 911 and he took videos of the fire soon after he discovered it. There was significant destruction and damage to other structures clustered close together on this property, but only the damaged fixed mobile structure is the focus of this report.

Information gathered from the witnesses, videos and burn patterns on the scene indicate the surface fire spread from the stump pile, burning in leaves to damage the fixed mobile structure on its side C near the corner with side D. The fire made contact and damaged the metal siding and ignited contents of a storage compartment built into side C of the fixed mobile structure.

The first item damaged was the exterior metal siding on side C at the corner with side D of the fixed mobile structure and ignition of the contents of storage compartment at that location.

Firefighters from Bandy VFD, Baptist Valley VFD, Richards VFD, Tazewell Co. VFD and the Virginia Department of Forestry responded to this incident. Firefighters used hose lines to actively suppress the fire and protect all the structures that were being damaged by radiant heat from the burning shop/storage building. Firefighters also suppressed the woodland fire.

Fig. S15-1. Photo shows side A of the fixed mobile structure (no fire damage).

Fig. S15-2. Photo shows the damage to side C of the fixed mobile structure and to the storage compartment contents at the corner with side D.

Fig. S15-3. Photo shows surface fire burn pattern leading to the fixed mobile structure's side C damage.

3.16. Structure #16, Cedar Bluff, Virginia

Incident date	11-14-16
Structure location	ZIP Code 24609
Wildland fuel	Leaves and grass
Material ignited	Metal siding damaged

Incident description

The Department of Forestry's Incident Commander (IC) and Fire Investigator determined fire cause was incendiary. The IC reported the fire started as a brush fire near a barn/storage building and moved to the structure before his arrival. The reported fire weather observations at 1:25 PM: wind direction W, wind speed 0.9 m/s (2 mph), air temperature 16.1 °C (61 °F) and the relative humidity 29 %. It was a class 3 fire day and the Cumulative Severity Index was 554.

The neighbor became aware a fire was burning on adjacent properties. When he investigated, he witnessed two distinct fires. One fire was burning in a pile of stumps on his neighbor's property that ultimately damaged several buildings (see structure #15 Cedar Bluff, VA 24609). The second fire was burning in a pile of tires next to an unoccupied mobile home on his father's property. The fire involving the mobile home is the focus of this report.

The burning tires were about 8.7 m (25 ft) away from side D of the mobile home. The neighbor saw that the fire had spread from the tire pile and was burning only a few feet from the mobile home on side C. He attempted to stomp out the fire where it was only a few feet away. The surface fire burning in leaves and dry grass did reach the base of the mobile home's metal skirting on side C.

The first materials damaged on the mobile home was a section of metal exterior siding on side C and the inner insulation materials it concealed. A section of metal siding was found on the ground at the site of the damage. The metal siding had sustained heat damage from the inside and the interior wall insulation it had covered was blackened and burned. It is uncertain how the surface fire reached the height needed to ignite the inner concealed wall insulation materials 76.2 cm (30 in) above the ground level. It appeared firefighters had removed a section of siding for fire overhaul operations.

Firefighters from Bandy VFD, Baptist Valley VFD, Richards VFD, Tazewell Co. VFD and the Virginia Department of Forestry responded to this incident.

Fig. S16-1. Photo shows the damaged side C of the mobile home.

Fig. S16-2. Close-up of damaged area on side C. A section of metal siding was removed for what looked like overhaul by firefighters. The section of metal siding was on the ground with the blackened interior side facing up.

Fig. S16-3. Photo shows fire damage close-up with a ruler showing height of damaged area starting 76.2 cm (30 in) above the ground.

Fig. S16-4. Photo shows surface fire burn pattern from the tire pile (steel wheel rims center right) leading towards the point of damage on the mobile home side C.

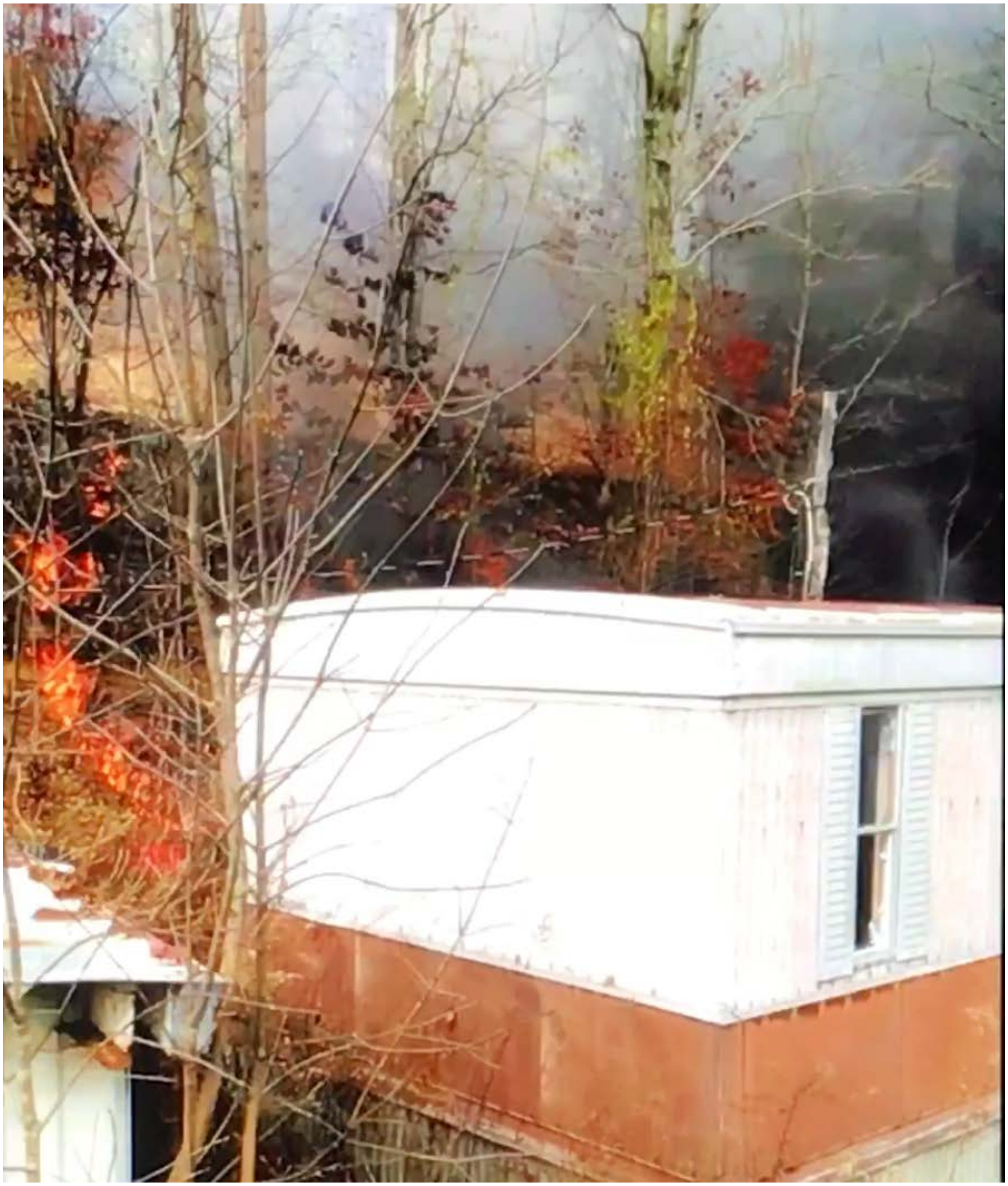

Fig. S16-5. Photo from cell phone video showing black smoke from the tire pile burning (right) and small surface fire burning (left) on the hillside opposite side C of the mobile home. The surface fire is moving away from the tire pile.

3.17. Structure #17 Middleburg, Virginia

Incident date	11-20-16
Structure location	ZIP Code 20117
Wildland fuel	Leaves
Material ignited	T1-11 plywood siding

Incident description

The Virginia Department of Forestry Incident Commander determined the cause of the fire was a tree touching a power line. A total of 2 acres burned and one utility shed was damaged. The reported fire weather observed at 5:40 PM: wind direction W, wind speed 15.64 m/s (35 mph), air temperature 6.11 °C (43 °F) and relative humidity 48 %. It was a class 2 fire day and the Cumulative Severity Index was 349.

The fire started around 2:00 PM when windy conditions broke a treetop that fell onto an overhead power line. The power line ignited the branches that sparked surface fire in leaves along the power line right-of-way. The right-of-way passed through the steep woodland of mature trees down grade from the damaged structure.

The damaged structure was a one-story wood frame utility building measuring 4.93 m x 4.95 m (16 ft 2.5 in wide and 16 ft 3 in long). The exterior walls were finished with wood T1-11 siding 1.4 cm (5/8 in) thick. The building was located uphill from the power line right of way along the edge of the landscaped yard and the woodland.

The first material damaged was wood T1-11 siding. The wood siding was ignited by a surface fire burning in a layer of leaves 5 cm to 13 cm (3 in to 5 in) deep. The surface fire was spreading uphill backing against the wind when it reached side B of the utility building. The fire made entry by burning through T1-11 siding in the area where the initial ignitions occurred.

Firefighters from Aldie VFD, Hamilton VFD, Leesburg VFD, Loudoun County Fire and Rescue, Middleburg VFD, Philomont VFD, Round Hill VFD and the Virginia Department of Forestry responded and extinguished the burning utility building and woodland fire.

Fig. S17-1. Photo shows side A of the utility building (no damage).

Fig. S17-2. Photo of the utility building on side B where the surface fire ignited the T1-11 siding, damaging the building. Sections of decayed but burned firewood can be seen scattered downhill in this picture. The decayed remains of a wood pile were about 1.8 m (6 ft) away from the side B wall.

Fig. S17-3. Photo shows the damaged exterior on side B.

Fig. S17-4. Photo of the interior of side B wall opposite figure 17-3 shows the fire damage to the interior of the building. This was the area of fire entry.

Fig. S17-5. Photo shows the burn pattern leading to side B of the utility building. The surface fire burning leaves spread uphill, backing against a west wind reaching and igniting the utility building.

3.18. Structure #18 Green Bay, Virginia

Incident date	11-22-16
Structure location	ZIP Code 23942
Wildland fuel	Leaves
Material ignited	Wood board siding

Incident description

The Virginia Department of Forestry Incident Commander on the fire determined the fire cause to be debris burning. He reported the resident was burning leaves in the yard and the wind blew embers into material behind the shop, igniting the debris and building. The reported fire weather observations at 8:00 AM: wind direction W, wind speed 3.6 m/s (8 mph), air temperature 12.2 °C (54 °F) and the relative humidity was 20 %. It was a class 2 fire day and the Cumulative Severity Index was 264.

The tenant on the farm had left a pile of burning leaves in an area of mature trees unattended. The wind caused the fire to escape his firebreak and spread into an adjacent layer of leaves. The resulting surface fire spread downwind 23 m (75 ft) reaching the shop building on side B. The fire burned along the side B wall in a 0.30 m (1 ft) deep layer of accumulated leaves, igniting the building wood board siding, tires and other combustibles along the wall. The tenant witnessed the building burning soon after ignition and took defensive actions with a water sprayer.

The shop building was originally a pole barn measuring 9.75 m x 12.19 m (32 ft x 40 ft). The building had a bump out 1.8 m x 1.8 m (6 ft x 6 ft) storage room addition attached to the side B wall. The side B wall was enclosed with various materials including boards, corrugated sheet metal, asphalt rolled roofing and 3-tab shingles. With the helpful information recounted by the tenant, the observed lowest point of burn, the deepest charring and heaviest damaged materials, we were able to determine the likely location of the first damaged area. It was at the inside corner of the bump storage room along the side B wall.

The first item of the building damaged was wood board siding. We are not certain of the first material ignited by the burning leaves because of the damage to the building and the presence of volatile combustibles including paints, thinners, glues, oils and tires stored in the first damaged area that also burned during the fire.

Firefighters from the Meherrin VFD, Victoria Fire and Rescue and the Virginia Department of Forestry responded to this incident. Firefighters extinguished the shop building and the surface fire.

Fig. S18-1. Photo shows side A of the damaged shop building.

Fig. S18-2. Photo shows the damage to building side B caused by the surface fire.

Fig. S18-3. Photo of the exterior of side B in the area where the tenant said the fire had reached and ignited the building. The lowest burn is at the first ignition point shown. This was also the inside corner where the bump out storage room connected to the side B wall. The storage room contained volatile combustibles including paints, thinners, glues and oils. Tires were also stored near the inside corner. A heat damaged steel wheel can be seen next to the first ignition arrow.

Fig. S18-4. Photo shows the interior fire damage to the side B wall opposite the exterior damage shown in figure S18-3. The lowest burned material is at the first ignition point indicated by the arrow.

Fig. S18-5. Photo shows the area of the intentional burn and its proximity to the fire damaged shop building. The burn pattern is almost covered by new leaf fall.

3.19. Structure #19 Stanley, Virginia

Incident date	1-13-17
Structure location	ZIP Code 22851
Wildland fuel	Leaves
Material ignited	Oriented Strand Board

Incident description

The Virginia Department of Forestry's Incident Commander determined the fire was the result of a fire escaped from a burn barrel that was not properly extinguished and left unattended. The fire spread, destroying one building and damaging two others. The reported weather observations at 1:00 PM: wind direction NW, wind speed 2.2 m/s (5 mph), air temperature 16.7 °C (62 °F) and relative humidity 50 %. It was a class 1 fire day and the Cumulative Severity Index was 245.

Embers escaped from an unattended trash burn barrel and started a surface fire in leaves. The surface fire spread north up the steep woodland slope and along the edge of the yard at the wood line. The first structure ignited and destroyed was the larger 3.65 m x 9.75 m (12 ft x 32 ft) storage shed. It was about 2 m (6 ft) south (left) of the burn barrel. Radiant heat from the large shed burning damaged the vinyl siding on sides C and D of the residence 5.2 m (15 ft) away. The surface fire spread along the edge of the yard/woodland to the north (right) of the burn barrel reaching and igniting a smaller 2.5 m x 2.92 m (8 ft 3 in x 9 ft 7 in) storage shed. The smaller building was saved by firefighters and is the focus of this report.

The burn pattern on the ground led to side C of the small shed, which had the most exterior damage and burn through, indicating the location of first ignition. The oriented strand board (OSB) siding on side C was the material first ignited by direct flame contact from burning leaves. Sides B and D also showed signs of ignitions. Side B had ignition of its railroad tie foundation materials. Side D also had an exterior ignition of railroad tie foundation materials and wood siding.

Firefighters from the Stanley VFD, Luray VFD and the Virginia Department of Forestry responded and protected the residence from further damage and saved the small shed. Defensive action was also taken by the neighbor. He was first to notice smoke from the fire and knocked on the door to alert the homeowner to call 911. He tried to save the homeowner's valuable property in the large burning storage shed but could not because of the smoke and heat. He used a garden hose to defend the residence until firefighters arrived, likely saving the residence from destruction. He suffered first-degree burns to his face. All these heroic things he did while barefoot and in his pajamas.

Fig. S19-1. Photo looking north showing burn barrels (the barrel on left was the point of origin) and the surface fire burn pattern leading to the damaged small shed.

Fig. S19-2. Photo shows the fire damaged to the small shed at the side B, C corner. The OSB on side C was the first material ignited by a surface fire burning in leaves reaching the base of the side C wall. A second ignition by burning leaves occurred to the railroad tie foundation on side B.

Fig. S19-3. Photo shows the third site of damage to siding and railroad tie foundation near the side D, C corner.

Fig. S19-4. Photo shows an interior view of the damage to the side C wall. The OSB sheeting is burned through along the base of side C. Railroad ties used for landscape retention can be seen through the burned out OSB.

Fig. S19-5. Photo (looking south) shows fire area south of the trash barrel. This was the direction the wind was blowing toward. The trash barrel point of origin, surface fire burn pattern, remains of the large shed and damaged residence are shown.

3.20. Structure #20 Prospect, Virginia

Incident date	1-26-17
Structure location	ZIP Code 23960
Wildland fuel	Leaves, pine needles and grass
Material ignited	Cedar shake siding

Incident description

The Virginia Department of Forestry Incident Commander determined the fire was caused by a downed power line igniting grass. The fire burned 2.5 acres and damaged three unoccupied buildings in Virginia's Featherfin Wildlife Management Area. The reported fire weather observations at 3:00 PM: wind direction W, wind speed 11.2 m/s (25 mph), air temperature 15.5 °C (60 °F) and relative humidity 30 %. It was a class 2 fire day and the Cumulative Severity Index was 12.

The fire started around 2:00 PM in dry grasses along the utility right of way. Windy conditions 11.2 m/s (25 mph) with higher gusts had blown down two trees into overhead power lines. The wind driven surface fire moved from the utility right of way into open fields of wildlife habitat vegetation on the west side of the cabin compound. The surface fire reached the cabins, spreading in dry grass and a layer of accumulated leaves, pine needles and dry grass up to the base of the two cabins. The largest cabin, Cabin #1, is the focus of this report.

Cabin #1 was a one-story log home measuring overall 12 m (39 ft 6 in) wide on side A and 16.66 m (54 ft 8 in) long on side B. The cabin had various exterior materials covering the logs. Fire damage occurred in three places. The first ignition and most damage occurred on side A where the surface fire ignited wood cedar shake siding. The cedar shakes burned out along the base of the exterior wall, allowing fire entry into the concealed floor joist space. Fire also burned up the exterior wall to the open soffit where the firefighters stopped it, saving the structure. Two other exterior wall ignitions occurred along the bottom edge of wood board and baton siding on side C and D as the surface fire burned around the cabin.

The first item damaged was the cedar shake siding along the base of the side A wall. It was ignited by direct flame contact from a surface fire burning in leaves, pine needles and grass.

Firefighters from Prospect VFD, Darlington Heights VFD, Hampden-Sydney VFD, Pamplin VFD, Toga VFD and the Virginia Department of Forestry responded and extinguished the cabins and one agricultural structure, saving all buildings from destruction.

Fig. S20-1. Photo shows side A fire damage. The cedar shake siding was ignited by direct flame contact from a surface fire burning to the base of the wall in leaves, pine needles and grass.

Fig. S20-2. Photo shows a close-up view of damage to the side A wall at its base. Cedar shake siding covered the exterior of the log wall.

Fig. S20-3. Photo shows the damage to the joist space under the floor where the fire made entry.

Fig. S20-4. Photo shows the fire damage to base of board and batten wood siding on side C.   This was the second wall ignition on Cabin #1. Fire made entry into the joist space and ignited the wood porch floorboards.

Fig. S20-5. Photo shows minor fire damage to base of wood board and batten siding on side D.

3.21. Structure #21 Prospect, Virginia

Incident date	1-26-17
Structure location	ZIP Code 23960
Wildland fuel	Leaves, pine needles and grass
Material ignited	Cedar shake siding

Incident description

The Virginia Department of Forestry Incident Commander determined the fire was caused by a downed power line igniting grass. The fire burned 2.5 acres and damaged 3 unoccupied buildings in Virginia's Featherfin Wildlife Management Area. The reported fire weather observations at 3:00 PM: wind direction W, wind speed 11.2 m/s (25 mph), air temperature 15.5 °C (60 °F) and relative humidity 30 %. It was a class 2 fire day and the Cumulative Severity Index was 12.

The fire started around 2:00 PM in dry grasses along the utility right of way. Windy conditions 11.2 m/s (25 mph) and gusting higher had blown down two trees into overhead power lines. The wind driven surface fire moved from the utility right of way into open fields of wildlife habitat vegetation on the west side of the cabin compound. The surface fire reached the cabins, spreading in dry grass and a layer of leaves, pine needles and grass up to the base of two cabins. The smallest cabin, Cabin #2 is the focus of this report.

Cabin #2 was a one-story log home measuring overall 15.24 m (50 ft 8 in) wide on side A and 15.24 m (50 ft 8 in) long on side B. The cabin had various wood exterior materials covering the logs. Fire damage to Cabin #2 occurred on sides A and D. A surface fire burning in leaves, pine needles and grass burned along the ground to the base of the exterior walls, igniting cedar shake siding on sides A and D. The first ignition occurred on side A at the corner with side D. This was the point of first ignition as indicated by the deepest charring in the logs where the shingles had been attached. This was also the location where the fire made entry through joints in the log wall construction at the corner of sides A and D. The surface fire also ignited the cedar shake siding in two other places along the base of the side D exterior wall.

The first item damaged was the cedar shake siding along the base of the side A wall at the corner with side D. It was ignited by direct flame contact from a surface fire burning in leaves, pine needles and grass.

Firefighters from Prospect VFD, Darlington Heights VFD, Hampden-Sydney VFD, Pamplin VFD, Toga VFD and the Virginia Department of Forestry responded and extinguished the cabins and one agricultural structure, saving all buildings from destruction.

Fig. S21-1. Overall view of Cabin #2 from side A, D corner. Fire damage is visible on the side A exterior wall at the corner with side D.

Fig. S21-2. Photo shows the fire damage on side A of Cabin #2. Surface fire ignited the cedar shakes at the base of the side A wall at the corner with side D.

Fig. S21-3. Photo shows a view of fire damage on side D. Here two areas of ignition can be seen along the bottom edge of the shingled wall.

Fig. S21-4. Close-up photo shows fire damaged cedar shake siding at the base of the side D wall.

Fig. S21-5. Photo shows a close-up view of the deepest char at base of the corner of side A with side D. The fire made entry at the side A, D corner through gaps at the joints in the log wall construction.

Fig. S21-6. Photo shows a close-up view inside Cabin #2 of the base of the corner of side A with side D where the fire penetrated the structure through gaps at the joints in the log wall construction.

4. Discussion of Results

4.1. Structures Included in Study

In this study, there was an opportunity to investigate 21 incidents where burning WUI vegetation ignited or substantially damaged structures in Virginia. The fires were taken as they occurred where each satisfied two criteria. The first was that the structure was ignited or significantly damaged by fire that spread to or near the structure through vegetation, no matter the source of ignition. The second was that the structure survived, usually saved by the intervention of fire departments, the Virginia Department of Forestry, and/or defensive actions by others. These two requirements were restrictive. There were many more structures ignited and lost in WUI fires during the two-year duration of this study. Even though the loss of structures that were destroyed would have contributed to the understanding of WUI fire incidents, it would have been unlikely to determine the first item / material ignited, which was a primary piece of information requested by NIST.

In many of the investigated incidents, fire spread from forested areas to structures that were located near the edge of landscaped areas. In many cases, intentional and attended open air burning by residents of trash or leaves escaped confinement and ignited other ground cover, spreading the fire to structures. Attended fires were extremely valuable to the study, as reliable information was available from people who observed the entire event. This served to eliminate uncertainties in documenting the event.

4.2. Ignition of Structures

All post-fire evidence indicated that of the 21 structures studied, 15[1] were ignited by fire spread through ground layers of leaves or leaves mixed with other vegetation. As all the structures were studied after the fire, it was impossible to measure conditions existing at the time of ignition. To improve upon the estimates of quantities such as leaf layer depth sufficient to ignite the exteriors of structures, controlled ignition experiments are required. Such studies are part of the recommendations for additional research needed included in this report (see Sec. 6, Additional Research Needs).

In cases where the fire was attended, measurements of leaf ground cover were made in areas where a witness indicated leaf cover was typical of that adjacent to the structure at

[1] Structures #1, #2, #3, #4, #5, #7, #8, #12, #13, #14, #17, #18, #19, #20, #21

the time of the fire. These were the most reliable estimates of leaf layer depth. In cases where the fire was unattended, measurements were made in the area surrounding the structure. The important result from the study is that large accumulation of leaves in piles with great depth did not appear to be necessary to ignite structures. Typical ground leaf cover depths of nominally 10 cm appears to be sufficient. In only one case, Structure #18, did the witness to the fire report that there was a large accumulation of leaves next to the structures intermixed with containers, tires and other stored materials.

The layer depth of leaves measured at the fire site was the best available estimate of conditions that may have existed at the time of the fire. Measurements were consistently in the range of 5 cm to 13 cm (2 in to 5 in). The measurement itself has significant uncertainty as layers of leaves had an irregular surface and tend to fill in small irregular ground features, both of which may affect the measured depth.

The following photographs indicate the general uncertainty in determining the layer depth as the leaves create an irregular surface. Figure 3 shows measurement in leaf layers remote from the ignited structure but indicated by owners to be typical of that adjacent to the structure at the time of the fire. Figures 4 and 5 show two measurements near a structure that was ignited. These photographs indicate the natural variations that can occur at different positions. What is clear from the data collected at many of the sites is that the depth of a layer of leaves sufficient to ignite structures with wood or wood product exteriors was relatively small and common.

Fig. 3. Depth of leaves in area indicated by owners as existed around the structures on the day of the fires, Structure #4 (left) 4 in (10 cm), Structure #13 (right) 2 in (5 cm).

Fig. 4. Structure #5: Depth of leaves in area indicated by owner as existed around structure on the day of the fire, 2 in (5 cm) left and 3 in (8 cm) right.

Fig. 5. Structure #14: Depth of leaves along undamaged side A indicated by owner as existed around the structure on the day of the fire, 2 in (5 cm) left and 4 in to 5 in (10 cm to 13 cm) right.

For several of the structures studied, the ignition scenario was complicated by the presence of other combustibles near the structure such as plastic wheelbarrows, all-terrain vehicles (ATVs), hand tools, and plastic containers. These may or may not have played a role in ignition of the structure, but they were damaged by the fire. These extraneous pieces of hardware complicate the determination of the ignition of the structure, introducing uncertainties. These uncertainties can be eliminated by conducting controlled tests designed to study the burning of relatively thin layers of leaves and the ability of the fire to ignite structures (see Sec. 6 on Additional Research Needed).

As part of the annual growth cycle, deciduous trees grow a canopy of leaves from spring through summer. In the fall, that entire mass tree canopy foliage is deposited on the ground, creating an extensive layer of dead, dry, thin, lightweight WUI fuel. Furthermore, as everyone who has property or lives adjacent to property with deciduous trees knows, wind can easily move leaves around. The fire that damaged structure #1 was carried by leaves from the adjacent stand of trees and blown onto the lawn area surrounding the storage shed, see Fig. S1-2. As observed in this study, it is not necessary to have large accumulations of leaves near structures to ignite combustible exteriors. Typical leaf ground cover found extensively throughout Virginia was sufficient to ignite structures both in the fall and spring.

The dead vegetation ground layer made up of thin, lightweight and often dry individual leaves is easily ignited by spotting. Individual burning leaves that are blown by the wind serve as additional sources of spotting that can advance the fire. Burning leaves that are picked-up by the wind or tumbled on the ground are embers that advance the fire as a type of firebrand. In this study, wind carried burning leaves across a fire break to generate spot fires in other leaves. For example, the fire having escaped from the confined burn area spread to and ignited structure #18.

Even in the absence of wind, fire spreading in leaves covering the ground can be very rapid. The fire that damaged structure #4 was attended. The initial spot fire in leaves was observed and immediately responded to by the owner. Even though he took immediate action, he was unable to control the fire that spread to the structure.

4.3. Gatlinburg, Tennessee WUI Fire

Even though this study dealt with fire incidents that ignited or damaged structures on single properties or small areas, what was learned about fire spread and the potential to ignite structures by ground fires in leaves has application for understanding major WUI fires. During the period of this study, there was a major loss WUI fire in and around Gatlinburg, Tennessee at the end of November 2016. Gatlinburg is located about 60 miles south of the Virginia border, so this is just outside the boundary limits for this study and was not investigated. Information from web posting and local news reports showed evidence that fire spread through ground layers of leaves aided by windy conditions. A reporter described the unusually fast downhill spread of the fire as, "… the two pressures of wind and blowing dry leaves sent the blaze downhill, with flaming leaves sparking the fire's spread." [10] A video [11] of one evacuation down the mountain roads of the Chalet Village community located west of Gatlinburg during the fires provides some visuals of the fire that show the ground fires in leaves. Figure 6 is a still frame from the video and shows the view as the vehicle approaches what appears to be a wind-driven upslope fire. Firebrands are being blown across the roadway from the right. Figure 7 shows the view from the right-side window as the vehicle passes by the fire shown on the right in Fig. 6. At the lower edge of the still image (Fig. 7), the leaf cover on the ground can be seen clearly.

Fig. 6. Vehicle drives towards hillside fire. Upslope wind drives burning leaves across roadway. Still frame from video [11].

Fig. 7. Vehicle drives by the upslope ground fire on right in Figure 6. A ground cover of leaves is shown clearly in the lower right of this still frame from video [11].

It was likely that the ground fire played an important role in the ignition of structures. Many of the Chalet Village resort cabins and chalets were built on properties that were heavily wooded with deciduous trees. Figure 8 is a still frame taken from the video [11] that shows a ground fire, in leaves and tree litter, threatening a structure on the right in the frame. Afterwards, this structure was found to be destroyed by fire [12].

Fig. 8. A ground fire, in leaves and tree litter, approaches structure as the vehicle passes. Still frame from video [11].

This study indicated that leaf cover over the ground can be an important factor in WUI fire spot ignition, fire spread, and ignition of structures. Fallen leaves are dead vegetation that is thin, lightweight and generally dry on the top layer. As a thin light-weight material, it is quick to respond to changes in humidity. In the case of structure #19, there were recent rains, but the top of the leaf layer was sufficiently dry that burning debris from the burn barrel ignited the leaves. Depending on weather, leaves persist as an easily ignited fuel on the ground for months. Even after rain, wind can dry out the top layer of leaves and move them around to inundate areas that are not treed. Understanding the role played by ground covers of leaves in spreading WUI fires and igniting structures is important to evaluating WUI fire hazards and educating residents of WUI communities about the threats of this common WUI fire fuel.

5. Preliminary Methodology to Enable Individual States to Generate WUI Fire Loss Data

5.1. Data Collection for This Study

The data collected in this study was from a joint effort of foresters of the Virginia Department of Forestry (VDOF) and Home Safety Foundation investigators. Structures that were damaged or destroyed in WUI fires that were responded to by VDOF were recorded. The first responsibility of the foresters, wildland firefighters and local fire departments that respond to the fire incidents is to control and extinguish fires. In the incidents recorded as part of this study, contact with the forester was critical in making decisions about responding a few days after the fire to document the structures damaged by fire for NIST. The foresters, being one of the first responders to incidents involving the wildland, have early knowledge of the fire. The forester documents for the VDOF report on the fire incident, structures threatened, damaged and destroyed by the fire. Destroyed structures were not included in this study because the initial material ignited would not be determinable without a reliable witness to the incident and some residual material at the site.

VDOF foresters, in their role as a fire investigator, assess the loss to all structures damaged or destroyed by fires that also involve the wildland. This information is part of the formal structure of the reports on fire incidents. As the structures involved in a fire are individually assessed, there is an opportunity to augment the forester's reporting with data that would be useful to NIST. From this study, a reduced set of data for NIST would include: the structure location, the structure type, the WUI fuel that spread the fire to the structure, the part of the structure ignited, the exterior material ignited (or indicate that the structure was ignited by firebrands penetrating the exterior), and a relevant picture of the damage and surroundings. Only some of the data are collected as part of the present VDOF incident report. For example, structure locations are not individually geo-located, but the fire location is identified with an accuracy sufficient for a State or National database. Generally, this location is close to the origin of the fire.

5.2. USDA Forest Service Data Collection

Annually each state supplies to the U.S. Department of Agriculture Forest Service a summary report of data from forest and wildland fires that occurred. States provide varying amounts of detail in their reports, but all supply a minimum specified set of data. This minimum includes identifying information for the fire, its location, ignition factors, and the final burned area. Accounting for the fate of structures that may be involved in the fire is not part of the minimum required data set.

A comprehensive online database system has been developed to assist states in entering relevant data for wildland fire incidents and utilizing the information. This online fire statistics system is known as FIRESTAT [13]. The database accommodates information on all factors dealing with the fire incident, its management, resources used, expenses and losses including the fate of structures. One thing that the database does not presently accommodate is pictures.

5.3. Future Data Collection by Foresters

After the completion of the field data collection for this study a meeting was held with NIST, the Virginia Department of Forestry and the Home Safety Foundation to discuss findings and explore ways in which the minimum data set collected in this study could be accomplished by foresters as part of the normal fire investigations. The likelihood that this data collection also could be accomplished by foresters in other states was explored. The minimum data set collected during this study was the location of the structure ignited or damaged, the material ignited, the wildland fuel that spread fire to the structure and a picture of the damaged structure. It was noted that the foresters in Virginia are being issued smart phones that could easily utilize an application to collect the minimum data set and more. Using the camera feature on phones or tablets it is also practical to include pictures. Using the experience with post fire data collection applications like WUI 1 [3] and working with national organizations, such as the National Wildland Coordinating Group (NWCG) or the National Association of State Foresters, it is likely that applications can be developed to enable any state forester to generate useful WUI fire loss data using handheld electronic devices.

6. Additional Research Needed

Large areas of the eastern United States WUI are dominated by deciduous tree forests. In the annual cycle of growth these trees drop the entire canopy of leaves onto the ground. These leaves build into a layer of dead vegetation that is lightweight, thin and often dry fuel. Ground cover of leaves deposited every fall in deciduous tree forests are a fire spread hazard in the WUI. Despite the large deciduous forest area of the eastern U.S., this WUI fuel type and its potential to damage and destroy structures has not been studied significantly. In a recent workshop report on structure ignition in WUI fires [8] the only mention of leaves as a pathway for fire spread was the ability of accumulated leaves and needles in gutters to ignite roofing assemblies. The results of this study show that a layer of dead leaves covering the ground is a fuel that can spread fire and ignite structures in the WUI.

During the period of this study, there was a major WUI fire (Chimney Top 2 Fire) near Gatlinburg, Tennessee. The fire was responsible for 14 deaths and 191 injuries, and damaged or destroyed more than 2,400 structures [9]. Investigation of the structures lost in this major eastern WUI fire was beyond the scope of this study, but as shown in Figure 2, Gatlinburg, Tennessee is only 60 miles south of the Virginia border. Video from the conflagration in the Chalet Village [9] located just west of Gatlinburg showed clearly that ground fires spreading in fall leaves played a role in the destruction of the resort cabins and chalets. The cases documented in this study point to the importance of dead leaves ground cover as a principle fuel source for spread of fire in WUI areas in the eastern U.S. and therefore worthy of additional study to quantify the hazard and support models of the fire dynamics.

A key finding from this study for the many cases where fire spread through dead leaves on the ground to ignite structures was the consistency of the layer thickness of the leaves – generally 8 cm to 13 cm (3 in to 5 in) near the structure. This result is supported by measurements made in areas not burned that were close to the ignited structures or in areas in which residents indicated that the ground cover was like that which existed before the fire. To verify and better understand the ignition of structures by layers of leaves, experiments need to be conducted under controlled conditions where fire spread, and structure ignition can be observed under differing weather and leaf layer conditions. Even without an effort to quantify heat transfer rates and gather other data important to modeling the fire spread and structure ignition, being able to replicate the ignition of structures under conditions that as far as practical duplicate the condition for the fires investigated in this study would add significantly to the confidence that the findings in this report are accurate.

Wind-blown firebrand-initiated ground fires spread throughout Chalet Village igniting structures. Ignition of leaves by firebrands needs to be studied under various fuel and environmental condition by controlled experiments in order to create the foundation data upon which models of the ignition can be created and assessed. The generation of firebrands by WUI vegetation and structure fires have been studied [14,15]. The role of firebrands in the direct ignition of structures has also been investigated [16,17]. To complement these studies, particularly with significance to eastern U.S. WUI fires, the role of firebrands in the initiation of fire in leaf covered ground of WUI communities needs to be understood.

Fire spread in a layer of dead leaves on the ground has not been studied sufficiently to model the ability of burning leaves to ignite structures. Given ignition, fire spread rate is important in determining whether available resources can gain control of fire. A comprehensive experimental study of fire spread rates with different leaf types and under various fuel depths, fuel moisture, wind and slope conditions would be required to support fire spread rate quantification and modeling. The fire dynamics of leaves as fuel has the extra feature that at some wind speed the leaves can be picked up by the wind and carried over distances of meters. Burning leaves blown by the wind spread fire by spotting. It is likely that fire spread in the Gatlinburg fire, which spread under high wind conditions, exhibited this phenomenon. This unique aspect of fire spread in ground layers of dead leaves needs to be understood to support accurate modeling of the fire spread.

Heat transfer rates to structures from a burning ground layer of dead leaves need to be measured to support an ignition model. The sensitivity of ignition to the duration and intensity of the fire exposure can be examined experimentally for selected exterior building materials. Primary exterior siding materials encountered in this study were wood boards, vinyl siding covered OSB, and T1-11 plywood.

In the studies described above, it is critical to involve fire modelers to help define the measurements that will be needed to incorporate the phenomena of fire spread in ground cover of leaves and ignition of structures by contact with the flames. Fire spread in a ground layers of leaves is a complicated process to model because the fuel layer of leaves consists of a collection of dry thin and lightweight fuel elements (a dead leaf) that readily ignite but can tumble or be picked-up by the wind to carry the fire in spots over distances of meters. In this case, even though the leaves are on the ground, burning leaves exhibit characteristics of short range firebrands and may be thought of as “ground brands”. Understanding and modeling the dynamics of fire spread for a layer of dead dry leaves on the ground with wind and the ability of burning leaves to ignite structures are open problems in WUI fire modeling.

There is a need to understand how a fire in leaves that have fallen to the ground and formed a layer of fuel in forested areas may impact WUI communities. Even well-kept landscaped areas surrounding homes and other buildings in the WUI can be inundated with leaves on windy days. Leaves can provide a path for fire to reach and ignite structures. Fires in fallen leaves are characteristics of WUI fires in the eastern U.S. where deciduous forests are common. Even small stands of deciduous trees yield extensive leaf cover on the ground. Further research is needed to understand this WUI fire hazard.

References

[1] Hamins, A., Averill, J.,Bryner, N., Gann, R., Butry, D., Davis, R., Amon, F., Gilman, J., Maranghides, A., Mell, W., Madrzykowski, D., Manzello, S., Yang, J., Bundy, M., Reducing the Risk of Fire in Buildings and Communities: A Strategic Roadmap to Guide and Prioritize Research, National Institute of Standards and Technology Special Publication 1130, 171 p., April 2012.

[2] Maranghides, A. and Mell, W.E., Case Study of a Community Affected by the Witch and Guejito Fires, National Institute of Standards and Technology Technical Note 1635, 60 p., April 2009.

[3] Maranghides, A., Mell, W., Ridenour, K., McNamara, D., Initial Reconnaissance of the 2011 Wildland-Urban Interface Fires in Amarillo, Texas, National Institute of Standards and Technology Technical Note 1708, 38 p., July 2011.

[4] Maranghides, A., McNamara, D., Vihnanek, R., Restaino, J., Leland, C., A Case Study of a Community Affected by the Waldo Fire – Event Timeline and Defensive Actions, National Institute of Standards and Technology Technical Note 1910, 213 p., November 2015.

[5] "KBDI/CSI: Introduction." Wildfire and Fire Safety, KBSI/CSi: Introduction, Virginia Department of Forestry, published November 25, 2014, http://dof.virginia.gov/fire/kbdi.htm, March 11, 2017.

[6] "Fire Danger Rating and Weather." Fire and Forest Protection, Virginia Department of Forestry, Fire and Forest Protection, Fire Danger and Weather, published November 25, 2014, http://dof.virginia.gov/fire/danger-rating.htm, March 11, 2017.

[7] NIMS-Incident Command System for the Fire Service, Second Edition, First Printing, Federal Emergency Management Agency, October 2005.

[8] Manzello, S.L., Quarles, S.L., Summary of the Workshop on Structure Ignition in Wildland-Urban Interface (WUI) Fires, National Institute of Standards and Technology, Special Publication 1198, 82 p., September 2015.

[9] Jacobs, Don, "Park didn't heed Gatlinburg firestorm 'call to action' " Knoxville News Sentinel, Dec. 30, 2016. Web accessed Mar. 25, 2017, http://www.knoxnews.com/story/news/local/2016/12/30/park-didnt-heed-gatlinburg-firestorm-call-action/95797456/

[10] Pappas, Stephanie, "Gatlinburg Burning: How a Tennessee Wildfire Spread So Fast", Live Science, Planet Earth, November 29, 2016, Web accessed March 31, 2017, http://www.livescience.com/57015-how-tennessee-wildfire-spread-so-fast.html

[11] Luciano, Michael, "Chalet Village Fire Gatlinburg Amazing 'Escape from Hell' Full Length Video by Michael Luciano," YouTube, December 1, 2016. Web accessed March 31, 2017, https://www.youtube.com/watch?v=cI2sgyoiL1o

[12] Personal communication with Michael Luciano, Gatlinburg, Tennessee

[13] Forest Service: Fire Statistics System (FIRESTAT) User guide for the Individual Wildland Fire Report, FS-5100-29, May 16, 2016, Web accessed April 26, 2017, fam.nwcg.gov/fam-web/firestat/FIRESTATUserGuide.pdf

[14] Manzello, S. L., Maranghides, A., Mell, W.E., Cleary, T.G., Yang, J.C., "Firebrand Production from Burning Vegetation," Forest Ecology and Management 234S (2006) S119

[15] Suzuki, S, Manzello, S.L., Hayashi, Y., "The Size and Mass Distribution of Firebrands Collected from Ignited Building Components Exposed to Wind," Proceedings of the Combustion Institute, Volume 34, Issue 2, 2013, Pages 2479-2485

[16] Manzello, S.L., Suzuki, S., Hayashi, Y., Summary of Full-scale Experiments to Determine Vulnerabilities of Building Components to Ignition by Firebrand Showers, NIST Special Publication (NIST SP) 1126, January 2, 2012.

[17] Manzello, S.L., Suzuki, S., Nii, D., "Full-scale Experimental Investigation to Quantify Building Component Ignition Vulnerability from Mulch Beds Attacked by Firebrand Showers," Fire Technology, Volume 53, Issue 2, March 2017, pp. 535-551.

Appendix A: Data Form

The following data form was used to document information collected at burn sites for each structure studied. This data collection form was adapted from the NIST WUI 1.0 tablet data application.

Structure #__, Virginia (ZIP Code)

1	VIRGINIA WUI DAMAGE ASSESSMENT FORM		
2	1. INCIDENT & FIELD DATA COLLECTOR INFORMATION		
3		Form Sequence Number	
4		Incident Name	
5		Incident Start Date	
6		Recording Date	
7		Time Recorded	
8		First Name	
9		Last Name	
10		Contact Phone	
11		Camera Name	
12		GPS Name	

13	2. SITE INFORMATION		
14		Street Number	
15		Street Pre-Direction	
16		Street Name	
17		Street Type (RD, ST)	
18		Unit Number	
19		City	
20		State	
21		Zip	
22		Site Assessment Method (X all that apply)	
23		Walked Built Property	
24		Accessed Interior	
25		Street Access	
26		Aerial Assessment	
27		Historical Records	
28		Spoke with Forestry Official	
29		Spoke with Fire Department	
30		Spoke with Owner	
31		Spoke with Other	

32		Structure GPS	
33		Latitude (Degree Minutes)	
34		Longitude (Degree, Minutes)	
35		Way Point #	

36	3. STRUCTURE DAMAGE INFORMATION		
37		Date Structure Damaged	
38		Image Numbers	
39		Structure Use Category (X that applies)	
40		Residential	
41		Business/Commercial	
42		Industrial	
43		Agricultural	
44		Structure Type: (X that applies)	
45		Single Family Residence	
46		Multi-Family Residence (apartment Complex)	
47		Manufactured Home	
48		Fixed Mobile Structure (mobile home Used as Residence)	
49		Other	
50		Extent of Damage: (X that applies)	
51		Destroyed	
52		Damaged	
53		No Damage	
54		Not Determined	
55		Defensive Actions: (X that applies)	
56		No sign of Defensive Action	
57		Protected	
58		Saved	
59		Defensive action sign(s)	
60		Not Determined	
61	STRUCTURE BUILDING COMPONENT DAMAGE/DESTRUCTION		
62		Roof Cover: (X all that apply)	Comments and Image #s
63		Asphalt Shingles	
64		Clay Tile	
65		Tar	
66		Multiple Layers	
67		Metal	
68		Wood	
69		Other	
70		Not Determined	

71		Roof Edge: (X all that apply)	Comments and Image #s
72		Mortar	
73		Bird Stops	
74		Other	
75		Not Determined	
76		Gutter (X all that apply)	Comments and Image #s
77		Vinyl	
78		Metal	
79		Other	
80		Not Determined	
81		Soffit/Eave Material (X all that apply)	Comments and Image #s
82		Heavy Timber	
83		Light Timber/Framing	
84		Metal	
85		Plywood	
86		Cement Fiber	
87		Stucco	
88		Vinyl	
89		Composite	
90		Other	
91		Not Determined	
92		Siding: (X all that apply)	Comments and Image #s
93		Cement Fiber	
94		Wood	
95		Stucco/Brick/Rock Cement	
96		Metal	
97		Vinyl	
98		Other	
99		Not Determined	
100		Window Frame (X all that apply)	Comments and Image #s
101		Wood	
102		Metal	
103		Vinyl/Plastics	
104		Other	
105		Not Determined	
106		Window Pane (X all that apply)	Comments and Image #s
107		Single	
108		Double	
109		Triple	
110		Other	
111		Not Determined	

112		Shutter (X all that apply)	Comments and Image #s
113		Vinyl	
114		Wood	
115		Metal	
116		Fiberglass	
117		Other	
118		Not Determined	
119		Vents (X all that apply)	Comments and Image #s
120		Metal	
121		Vinyl/Plastics	
122		Wood	
123		Other	
124		Not Determined	
125		Skylight Frame (X all that apply)	Comments and Image #s
126		Metal	
127		Vinyl/Plastics	
128		Wood	
129		Other	
130		Not Determined	
131		Doors (X all that apply)	Comments and Image #s
132		Wood	
133		Metal	
134		Vinyl	
135		Composite	
136		Other	
137		Not Determined	
138		Garage Doors (X all that apply)	Comments and Image #s
139		Wood	
140		Metal	
141		Vinyl	
142		Composite	
143		Other	
144		Not Determined	
145		Foundation Material (X all that apply)	Comments and Image #s
146		Treated Wood	
147		Other Wood	
148		Concrete	
149		Steel	
150		Brick	
151		Other	
152		Not Determined	

153		Foundation Covering Material (X all that apply)	Comments and Image #s
154		Painted Wood	
155		Stained Wood	
156		Other Wood	
157		Concrete	
158		Steel	
159		Brick	
160		Other	
161		Not Enclosed	
162		Not Determined	

163	4. FIRST ITEM DAMAGED		
164	*Use First item damaged sub-form for multiple fire damage locations.*		
165		Structure Building Component	Comments and Image #s
166		Roof	
167		Roof Edge	
168		Gutter	
169		Soffit/Eave	
170		Siding	
171		Doors	
172		Window Frame	
173		Window Pane	
174		Shutter	
175		Vents	
176		Skylights Frame	
177		Skylights Pane	
178		Garage Doors	
179		Foundation Material	
180		Foundation Covering	
181		Foundation Window	
182		Other	
183		Structure Attachments (X)	Comments and Image #s
184		Deck	
185		Pergola	
186		Porch	
187		Fence	
188		Retaining Wall	
189		Car Port	
190		Playground Equipment	
191		Other	

192		Damage Source (X)	Comments and Image #s
193		Direct Flame Contact	
194		Embers	
195		Solely Radiation	
196		Not determined	

197	5. POINT OF ENTRY LOCATION		
198	*Use first item ignited sub-form for multiple points of entry.*		
199		Building Component (X)	Comments and Image #s
200		Roof	
201		Roof Edge	
202		Gutter	
203		Soffit/Eave	
204		Siding	
205		Doors	
206		Window Frame	
207		Window Pane	
208		Shutter	
209		Vents	
210		Skylights Frame	
211		Skylights Pane	
212		Garage Doors	
213		Foundation Material	
214		Foundation Covering	
215		Foundation Window	
216		Other	

217	6. DEFENSIVE ACTION INFORMATION		
218	*Record any pertinent comments regarding defensive actions and the source of the information. Use defensive action sub-form for multiple defensive action sources.*		
219		Defensive Action Comments	Comments and Image #s
220		First Name	
221		Last Name	
222		Contact Phone Number	
223		Contact Email	

224	7. MULTIPLE COMBUSTIBLE DAMAGE/DESTROYED INFORMATION		
225	*Use if more than one item damaged/destroyed.*		
226		Combustible Item (X)	Comments and Image #s Distance from Structure (m)
227		Deck	
228		Pergola	
229		Porch	
230		Stairs	
231		Fence	
232		Retaining Wall	
233		Car Port	
234		Playground Equipment	
235		Other	

236	8. INFORMATION FROM VDOF INCIDENT REPORTS		
237		General Cause	
238		Specific Cause	
239		Fire Weather	
240		Date of Observation	
241		Time of Observation	
242		Cumulative Severity Index (CSI)	
243		Class Day	
244		Wind Direction	
245		Wind Speed	
246		Temperature	
247		Relative Humidity	
248		VDOF Investigation Results	Comments and Image #s
249			
250			

251	9. ADDITIONAL INFORMATION		
252	*Record any additional pertinent information about the structure or surrounding area.*		
253			Comments and Image #s
254			
255			