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SPATIAL PATTERNS AND PHYSICAL FACTORS OF SMOKEJUMPER UTILIZATION SINCE 2004

By

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Thesis

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Spatial Patterns and Physical Factors of Smokejumper Utilization since 2004

Chairperson: Dr. Carl Seielstad

Abstract:

This research examines patterns of aerial smokejumper usage in the United States. I assess landscape and environmental factors of their deployment using a detailed nine-year record of smokejumper activity in combination with terrain, fuels, and transportation network data. Specifically, the research seeks to identify commonalities in location (proximity), terrain, fuels, fire occurrence, and accessibility of smokejumper actions that inform current usage and identify opportunities for improved utilization. Terrain parameters (steep, rugged, inaccessible) of the western U.S. were classified and a baseline travel time grid was created (30 meter resolution). Fires in which smokejumpers responded were compared with all fires that occurred (Fire Program Analysis Fire Occurrence Database) on the same landscape during the same time period. Most (96%) aerial smokejumper actions (2004-2012) in the western U.S. and Alaska were recovered from the Smokejumper Master Action Database and used in this analysis. Results reveal differences between incidents in which smokejumpers were used when compared with total fire load. In the context of total fire load smokejumpers are dispatched to fires in steeper (+117%), rougher (+100%), and higher terrain (+51%). Additional analysis reveals that smokejumpers are utilized further from roads (+375%), on landscapes that are harder to access on foot (+473%), and on incidents that are proximal to bases where jumpers are stationed (-33%). The identified patterns in smokejumper utilization provide a systematic assessment that helps explain where and how smokejumpers are currently being used. The research also quantified the occurrence of steep, rugged, and inaccessible terrain across the western U.S. and showed that more than half of the western U.S is within a 20 minute walk of the nearest road and 83 percent is within one hour. The most remote location based on Euclidean distance is in the Thorofare Basin of Yellowstone NP (21.5 miles). Based on hiking time, the most difficult to reach location is near Halfway Creek between Fish Lake and Moose Creek in the Selway-Bitterroot Wilderness (29 hours). The travel-time results have utility beyond smokejumping in the areas of wildlife management, recreation, and search and rescue. This study provides the groundwork and takes an initial step toward the culminating goal of improving the efficacy of the U.S smokejumper program and the wildland fire community as a whole.

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1. INTRODUCTION

Understanding patterns of smokejumper use is significant to a smokejumper organization working to improve effectiveness and to the agencies responsible for efficient delivery of firefighting capacity. Ironically, little is known about smokejumper utilization nationally because there has never been a comprehensive quantitative assessment of smokejumper actions despite meticulous record-keeping by each individual base. Development of a web-accessible multi-agency Smokejumper Master Action database in 2004 has enabled analysis of nine years of smokejumper activity in the context of physical factors such as distance from base, proximity to roads, terrain, and fuels. Few firefighter organizations exist with the extensive amount of data available in the Smokejumper Master Action and analysis of these data is overdue. The results from this research represent the first comprehensive analyses describing the use of parachute-delivered firefighters.

The smokejumper program can trace its roots to suppression-centric focus of fire management that emerged at the start of the 20th Century. The beginning of organized wildfire suppression in the United States (U.S.) was marked by the federal government's actions to engage fire in Yellowstone National Park in 1886 (Pyne, 1982). Shortly thereafter, the fires of 1910 greatly influenced a young U. S Forest Service (USFS) organization that viewed fire as the enemy to forestry. Before the middle of the 20th century, most forest managers believed forest fires to be detrimental to forest and human health (Pyne, 1982). Following several more years of severe wildfire activity in the West, fire suppression became the nationwide management response to all wildfires. This policy has remained largely intact through the 20th century (Busenberg, 2004). The USFS instituted the "10 AM Policy" in 1931, where the objective was to prevent all human caused fires, and contain any fire that started by 10a.m the following day, regardless of its location, using all necessary or available resources (Stuart, 1932).

Aggressive initial attack remains the backbone of wildfire suppression in the U.S. and it has been this way since the advent of modern firefighting in the early 20th century. The National Wildland Fire Coordinating Group (NWCG) defines Initial Attack (IA) as “a preplanned response to a wildfire given the wildfire’s potential.” In other words, IA is the practice of attempting to put fires out quickly when they are small. Planning deployment of suppression resources via ground (engines, hand crews, heavy equipment) or aerially (smokejumpers, helitack, air tankers) to implement suppression strategies is a complex process (Calkin et al., 2011). Fire managers need the ability to identify, in real time, the likelihood that wildfire will affect valuable developed and natural resources. These determinations help guide where and when aggressive initial attack is required to protect values.

Planning for effective initial attack is essential to a wide variety of forest fire management activities including strategic planning, pre-suppression planning, initial attack dispatching and the selection of tactics. In an effort to reduce response time and fatigue accrued from driving and hiking to remote wildfires, the practice of using aircraft to support firefighting began in California in 1917 with fixed wing fire patrol (USFS, 1980). In December 1935 The Aerial Fire Control Project was established to test the use of water and chemical filled bombs, marking the beginning of air tanker use for fire suppression in the USFS (USFS, 1980). Shortly thereafter, the smokejumper program began, predicated on three primary factors: 1) speed, 2) range, 3) payload. Aircraft and parachutes were first used for delivering firefighters to fires on July 12, 1940 on the Nez Perce National Forest. Seven years later, on August 5, 1947, rotor wing aircraft (helicopters) were used to support fire suppression, changing forever how wildland fires were fought (Dudley and Greenhoe, 1998). Wildfire suppression became increasingly effective following World War II, when surplus aircraft and human power were converted from military operations to civilian use (DeWilde and Chapin III, 2006). The First World War II airtankers fitted with water tanks appeared in 1956. The use of retardant and water drops for fire suppression soon followed. Aerial resources continued to evolve and in May 1959, The U.S. Bureau of Land Management (BLM) activated its first smokejumper base in Fairbanks, Alaska. In 1986 the BLM opened another base at the National Interagency Fire Center (NIFC) in Boise, ID (BLM website). Currently, nine smokejumper programs are active in the western U.S. and Alaska: seven USFS and two BLM.

In sum, the use of initial attack wildland firefighting resources delivered by ground and air has been an important facet of land management since the creation of the USFS in 1905. The management decisions following each new fire ignition have become increasingly complex. Previous analyses of wildfire and climate change have suggested that area burned and number of fires that escape initial attack suppression will increase dramatically (Torn and Fried, 1992; Hirsch et al., 1998, Fried et al., 2006; Fried et al., 2008) in the West and the agencies responsible for initial attack on wildland fire continue to seek quantitative information to guide decisions regarding amount, type and configuration of IA resources (Fried et al., 2006). According to Williams and Hyde (2009), 98% of all fires were successfully suppressed in Initial Attack stage (e.g., an Incident Management Team was not ordered) between the years 2000 and 2008, although, the wildfires that do escape account for the majority of total acres burned (95%) as well as suppression costs (85%). Thus, keeping fires small in places they are not desired is, and will continue to be, a growing consideration in fire management. Typically, two primary factors are assessed in each IA decision: 1) how is the incident going to be managed (strategy); 2) What resources are going to be deployed (staffing). Factors driving these decisions can be grouped into human, logistical, and physical elements (Figure 1). An example of a human factor is a decision maker with smokejumping experience who might use smokejumpers preferentially because of his/her familiarity with them. More frequent smokejumper use on fires closer to bases is an example of a logistical factor. Preferred smokejumper use in rough terrain is an example of a physical factor. Only a small number of these factors are believed to be significant and measurable due to complexity of human nature and the difficulty in quantifying it. This thesis will consequently focus on the physical factors determining aerial smokejumper usage.

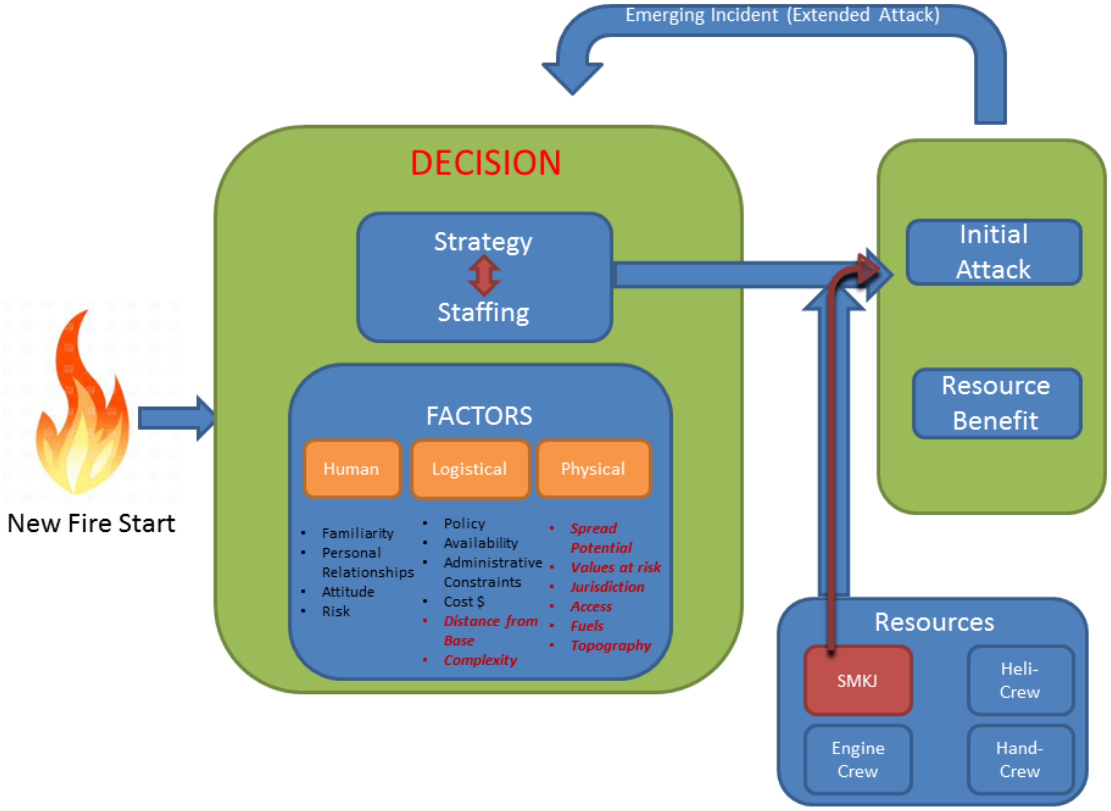


Figure 1. Given a new fire or change in existing fire, fire managers face two primary decisions. 1) How is the incident going to be managed (Strategy). 2) What resources are going to be deployed (Staffing). Factors that drive these decisions can be grouped into human, logistical, and physical elements. The bold-highlighted (red) factors are believed to be significant and measurable. There are two general options for new starts. Attempt aggressive suppression (e.g. Initial Attack Fire), or allow for fire to burn on the landscape (e.g. Resource Benefit Fire). The human resources that can be deployed depend on the factors listed. Although this phenomenon is undocumented, conventional wisdom relating to selection of smokejumpers would suggest complexity, difficult terrain, remote location, and potential for rapid fire spread. Fires that resist control are then reconsidered into the decision making process.

Following a century of increased wildland fire size, occurrence, and intensity (Climate Central, 2012; Odion et al., 2004; Westerling et al., 2006) ample smokejumper usage data is available for analysis. The fire season of 2012 marked the 9th year that records have been collected in the Smokejumper Master Action Database (SMA). The compiled smokejumper utilization data allows for access of all smokejumper records in this time period. A primary consideration of the research is to produce standardized tools and products that aid in the wildland fire decision-making process and are accessible to fire managers. Proper utilization of a dwindling resource pool is, and will continue to be, critical in resource and fire management.

1.1 Goals and Objectives

The overarching goal of this research is to quantify current smokejumper usage in the conterminous United States and Alaska and to compare this use with data from all fires occurring in the same areas. By combining a nine-year record of smokejumper actions with data describing location, proximity, terrain, fuels, vegetation and all fire occurrence, this project intends to describe smokejumper activity in the context of major environmental factors. The purpose of this work is threefold: **1)** to identify patterns of smokejumper usage in terms of physical factors; **2)** to relate these patterns to total fire load; **3)** to produce standardized tools and products that aide in additional analyses and decision making.

Specific objectives of this work include:

1. Update and clean the Smokejumper Master Action Database.
2. Summarize smokejumper actions in terms of total jumps, load size, distance from base, aircraft type, fire complexity, and mission.

3. Quantify and map steep and rugged terrain.
4. Define accessibility in terms of distance from road and travel time.
5. Attribute smokejumper actions and all fires with terrain and accessibility data.
6. Compare attributes of smokejumper fires to all fires.
7. Relate spatial patterns of jumper usage to physical factors.

Smokejumpers are used in a variety of ways and are transported by both ground and fixed wing aircraft. This study focuses solely on the aerial usage of smokejumpers and all further discussion of smokejumper usage is for actions in which transportation of jumpers was by fixed wing aircraft and parachute.

This thesis is organized in six chapters. Following this introduction (Chapter 1), the research background makes up Chapter 2, the study methods comprise Chapter 3, research results encompass Chapter 4, a discussion section comprises Chapter 5, and conclusions and future work are found in Chapter 6.

2. BACKGROUND

Investigating physical factors that may affect smokejumper utilization requires a background and understanding of landscape characteristics (topography, fuels, and accessibility) and how they relate to both fire occurrence and firefighter movement. Additionally, it is important to describe the smokejumper program's lengthy history and current mission.

2.1 The Smokejumper Program

The United States Smokejumper program has had a significant impact on fire management since the beginning of the 20th century (ADFF, 2008). The U.S. Forest Service interest in aerial fire control began soon after the First World War ended when Chief Forester Henry S. Graves contacted the Chief of the Army Air Corps proposing the military's guidance in aerial platforms (USFS, 1980). The USFS began experimenting with aerial photography in 1925, and by 1929 many remote fires had cargo exclusively supplied by aircraft and parachute (USFS, 1980; Maclean, 1992). Following the "Great Fire of 1910" and several years of severe wildfire activity thereafter, the USFS instituted the "10 AM Policy" in 1931, where the objective was to prevent all human-caused fires, and contain any fire that started by 10 a.m. the following day, regardless of its location (Stuart, 1932; Dale, 2006). The 10 a.m. policy's emphasis on response times to new fires promoted examination of new approaches to access remote areas more quickly. T.V. Pearson of the USFS Intermountain Region (R-4) was the first to propose and initiate the idea of parachuting aerial firefighters to improve initial attack times to fires in remote locations in 1934, but the project was deemed too hazardous and impractical (USFS, 1980; USFS, 2008). In 1935, the Washington Office founded the California based Aerial Fire Control Experiment Project.

The project initially focused on the use of water and chemical bombs, but by 1939 all efforts were concentrated into parachute jumping (USFS, 1980; USFS, 2008). David P. Godwin moved the experimental project to Winthrop, Washington. Approximately 58 test jumps under a 30 foot Eagle Parachute main canopy were made by professional parachutists into varying terrain between 2,000 and 6,800 ft., marking the beginning of the smokejumper program (USFS, 1980; Dick, 1984; USFS, 2008).

Figure 2. (1941) Smokejumping has continued to evolve in an effort to remain efficient, safe, and more effective in their role in natural resource management (Forest History Society).

In 1940, two small crews of smokejumpers were established; one in Winthrop, WA and one at Moose Creek Ranger District in Idaho. On July 12, 1940, Rufus Robinson and Earl Cooley made the first parachute jumps over a forest fire on Martin Creek on the Nez Perce National Forest. Nine total fires were jumped in two regions in 1940 (USFS, 1980; Maclean, 1992; USFS, 2008). In 1941 all parachute operations were moved to Missoula, MT in an effort to save budgets and consolidate forces to areas with less roads and more wilderness (USFS, 1980). The initiation of the Second World War in 1942 severely hampered manpower, but by 1944 The Smokejumper Project was officially adopted by the USFS, and was no longer considered to be in trial stages (USFS, 1980; USFS, 2008) (Figure 2). In an effort to be a safer, more effective tool for land managers, the smokejumping program continued to evolve throughout the years (Huntington and

Golik, 1998). In 1945, a 28-foot flat circular canopy manufactured by Irvin Parachute Company was implemented by the USFS and used until 1954, when the FS-2 replaced it. Two years later the FS-5a, a 32-foot parachute, was placed into service and flown exclusively until 1970 (NIFC).

August 5, 1949 marked the first major tragedy in the smokejumper program. Twelve smokejumpers and a District guard were overrun by flame on Helena Forest's Mann Gulch Fire (USFS, 1980; Maclean, 1992; USFS, 2008). The tragedy was not found to be smokejumper related and the program continued to expand under President Dwight D. Eisenhower's direction. It was not until June 3, 1970, following 31 years of operation that the first smokejumper fatality associated with parachute jumping occurred on a fire jump in northern California (Huntington and Golik, 1998).

The smokejumper program grew significantly throughout the 1950s. By 1959, nine permanent smokejumper bases were found throughout the west in MT, ID, WA, CA, OR, and AK (USFS, 1980). In May 1959, The U.S. of Bureau of Land Management activated its first smokejumper base in Fairbanks, Alaska and by 1986 the BLM opened another base at the National Interagency Fire Center (NIFC) in Boise, ID (BLM History). Smokejumper numbers peaked in the late 1960s and throughout the 1970s, where on average total jumpers were between 400-450 (USFS, 1980). The USFS moved to the FS-10, a 35-foot parabolic canopy in 1970 until it was replaced by the FS-12 in 1982. In the late 1970s, the USFS began consolidating bases. Some smaller bases were closed, while the remainder were deemed either regional core bases or satellite bases.

Beginning in 1977, the BLM program started investigating the potential of the RAM Air (square) parachute, and by 1990 full implementation of the system by the BLM had occurred (BLM). In

1995 the FS-14 parachute, available in three sizes, was put into the service by the USFS and is still currently the primary canopy used by all USFS bases outside of Region 1. The USFS initiated the Region 1 RAM-Air program in 2008 in an effort to explore and evaluate other canopies and deployment systems (USFS, 2009). As of 2013, 46 smokejumpers in Region 1 are currently testing the BLM drogue deployed RAM-Air system (USFS, 2013). The future direction of the USFS parachute program has yet to be determined.

Table 1. Current configuration of U.S. smokejumper program (USFS, BLM).

Smokejumper Base	Personnel	Agency	Region
Missoula, MT	76	USFS	R-1
Grangeville, ID	30	USFS	R-1
West Yellowstone, MT	30	USFS	R-1
McCall, ID	70	USFS	R-4
Winthrop, WA	35	USFS	R-6
Redmond, OR	50	USFS	R-6
Redding, CA	40	USFS	R-5
Fairbanks, AK	65	BLM	Alaska
Boise, ID	80	BLM	Great Basin

Currently there are approximately 350-400 smokejumpers (BLM; USFS) dispersed among nine permanent smokejumper bases in the western U.S.: 7 USFS (Missoula, MT, West Yellowstone, MT, Grangeville, ID, McCall, ID, Winthrop, WA, Redmond, OR, and Redding, CA) and 2 BLM (Fairbanks, AK and Boise, ID) (Table 1). In the last ten years, smokejumpers have been dispatched from 38 additional airports throughout the western U.S. for fire jump missions.

2.2 Fighting Fire in Alaska

Organized wildland fire suppression in the Territory of Alaska began almost 60 years after the emergence of the first federal effort in the contiguous US. The Alaska Fire Control Service (AFS) was established in 1939 (Pyne, 1982). Alaska is vast, remote, and consists of a very diverse topography, which in turn limits the number of drivable roads and largely the ability for organized fire suppression. Roads, firebreaks, lookout towers, and rural ranger stations that provide local access to most areas in the contiguous states are notably absent in Alaska. Current and historical fire policy in Alaska focuses suppression efforts on a small proportion of the fire-prone region (DeWilde and Chapin III, 2006). Fire control in Alaska would not be feasible without aircraft, thus AFS evolved with a strong link to aviation. Planes, and later helicopters, continue to be the only efficient means of transportation to the remote locations where the vast majority of large fires occur (Todd and Jewkes, 2006). In 1949 the Alaska division acquired its first plane to transport men, supplies, and serve as an aerial detection platform. Helicopters joined the aviation scene in 1951 (Todd and Jewkes, 2006). It was not until 1959 that the BLM Division of Forestry established the first smokejumper force in the state (USFS, 1980). The smokejumper experiment was deemed successful in quickly addressing remote fires in inaccessible terrain (Todd and Jewkes, 2006).

2.3 Smokejumper Mission

Historical literature and video (USDA, 1948; Dick, 1984; Maclean, 1992; Pyne, 1996) promote the notion that the smokejumper program was created to put out small fires in remote, rugged locations more quickly and efficiently than on foot. Seventy-four years after the initiation of the program the stated smokejumper mission remains largely unchanged: efficiently delivering firefighters to initial attack incidents based on range, payload, and speed (Maclean, 1992; ADFF, 2008; USFS, 2011; BLM, 2008) (Figure 3). The current interagency smokejumper mission statement (USFS, 2011) reads:

> **Mission Statement:** Smokejumpers primary mission is initial attack. While most effective at providing rapid initial response, smokejumpers are well equipped to respond to extended attack incidents and short-term critical need missions on large fires. Smokejumpers are normally configured by planeload, with each load ranging from 2 to 20 smokejumpers depending on aircraft type and smokejumper availability. Smokejumpers may be configured as crews (hand crew, engine crew, or helitack crew), as wildland fire use modules, or as single-resource overhead for Incident Command System positions.

Yet, there is considerable speculation among the wildland fire community regarding how smokejumpers are actually being used in present day fire management. A recent USFS management study of the Aerial Delivery of Firefighters (USFS, 2008) suggests that smokejumper operations are a rapid response and support tool that provide overhead and highly skilled operational personnel (on all fires) including emerging fires, wildland fire use, and long duration fires. Smokejumpers are now being relied upon for quick and accurate situational assessment, management insight, command structure and tactical actions, fire leadership, as well as logistical support of extended operations (USFS, 2008). Leadership in the USFS

Figure 3. (1960) The smokejumper program was created to put out small fires in remote, rugged, locations more quickly and efficiently than on foot. (Forest History Society).

Washington Office have plans and a vision of shifting their focus from rapid suppression of mostly small fires in inaccessible terrain to preferentially dispatching smokejumpers to more complex emerging incidents closer to the wildland urban interface (WUI) (T. Harbour personal communication, June 2014).

It should be mentioned that smokejumpers are utilized for forest management practices in a variety of ways, often outside the realm of fire suppression. Although annual use is fluid, staffing fires by means of aircraft and parachute only accounts for roughly one-third of jumper utilization. Prescribed burning and fuels treatments, ground response, overhead assignments, instruction, training, and manufacturing account for the bulk of the remaining use (USFS, 2010).

2.4 Defining Landscape Characteristics

To properly analyze where and why smokejumpers are currently aerially deployed, it is necessary to understand an array of elements including terrain, fuels, and accessibility. Fire behavior and spread is attributable to three main factors: fuels, weather, and topography (Agee, 1993; Baker, 2009). Conventional wisdom relating to smokejumper utilization suggests that smokejumpers are preferentially deployed on incidents with high management complexity, difficult terrain, remote locations, and potential for rapid fire spread.

2.4.1 Topography/Terrain

Topography is the most constant of the three legs of the fire behavior triangle (Agee, 1993) and is an essential factor in fire behavior in mountainous terrain. Physiographical effects on fire occurrence and behavior are strongly correlated to the local and regional topography. Slope, aspect and elevation all play a significant role in fire behavior (Rothermel, 1972; Agee, 1993; Finney and Andrews, 1999; Baker, 2009) and spread potential (Ryan, 1981; Finney, 2006), which in turn determines staffing and strategy for an incident. Topographic features are generally easy to identify from the field, air, and map and thus are important factors in staffing decisions.

Slope. Wildfires in steep terrain are difficult to engage and manage (Figure 4). In most cases, steepness in slope correlates directly with rate of spread (Rothermel, 1972; Baker, 2009; Linn et al. 2010). Historical research (Barrows, 1951) suggests as slope increases, a higher percentage of fires reach a large size. Steeper slopes not only create a dryer environment from effects of increased runoff and higher insolation, but they enhance heat transfer in an uphill direction (Baker, 2009). Radiation and convection on steep slopes allow for preheating of fuels and increased direct flame contact (Rothermel, 1972; Agee, 1993). However, research (Rollins et al. 2002) between fire frequency and slope steepness has showed no significant relationship

Figure 4. Topography is a significant and measurable factor influencing the selection of smokejumpers because it influences fire behavior, accessibility, and complexity of an incident (USFS).

and very steep slopes may have reduced ignitions due to the lack of available fuels (Barrows et al. 1976). Slope position also influences fire rate of spread greatly with fires lower on the slope exhibiting greater potential for spread than those closer to ridgetops.

Aspect. Fire ignition and spread characteristics vary greatly depending on aspect. Differences in topography cause local variations in climate. These changes influence the character of the ecosystem and the flammability of fuels. The aspect of terrain dictates solar radiation, evapotranspiration, and humidity of the environment. Steep south and southwest slopes receive higher solar radiation and are generally a drier environment, thus likely to have more and larger fires. Historical research (Barrows, 1951) found that large fire potential is roughly 2.5 times greater on south or southwest aspects than on north slopes. Increased evapotranspiration leads to earlier snowmelt and sparser vegetation on these slopes. Steep north and northeast aspects tend to be the most sheltered and mesic and the last to become available to burn (Agee, 1993; Baker, 2009).

Elevation. Elevation is a key contributor to both fire spread and occurrence. Elevation of terrain influences dominant species and temperature. As elevation increases, air temperature and length of fire season decrease; while precipitation, humidity, and fuel loadings all increase (Ryan and Reinhardt, 1988; Baker, 2009). Elevation has been found to be a significant environmental gradient in regards to the distribution of major vegetation zones (Zobel et al. 1976). Some vegetative ecosystems are much more prone to ignition and carrying fire. The bulk of all fires in the western US have been historically in the middle elevations (1,000-2,000m). Large fires are least common at high elevations (Baker, 2009). Fire seasons are shortest at high elevations where lower average temperatures limit growing season. Extended spring runoff and earlier significant fall weather events lead to a more substantial snowpack that limits fuel available to burn (Agee, 1993).

2.4.2 Fuels

Fuel is the material of primary concern to fire control. Fuels are an essential facet of land management in a range of disciplines including recreation, fire suppression, restoration treatments, watershed hydrology, and wildlife habitat. They are the dependent factor in the environment and need to be managed appropriately. Changing weather patterns, insects and disease, harvest and fire suppression have led to transformations in fuel loading, fire regimes, and the character of the landscape in many locations (Reinhardt et al. 2008). Potential for extreme fire behavior and growth are common to certain fuel types.

There are many ways to classify fuels. This study uses fuel models to characterize landscapes. Fuel models are intended to facilitate prediction of how a landscape will burn and what the primary carrier of fire will be (Scott and Burgan, 2005). Rothermel introduced the notion of fuel models in 1972 with his mathematical work in trying to model fire behavior (Rothermel, 1972). The most common fuel models were developed by Albini (Albini, 1976) and published by Anderson (Anderson, 1982). Anderson's original 13 standard fire behavior fuel models ultimately represent distinct fuel loading and fuel types. The fuel models are broken down into four discrete fuel types: grass, brush, timber litter, and slash.

2.4.3 Accessibility

Distance from nearest road. Location **(**proximity) to ground access is significant in the decision process of staffing fires. A direct correlation exists between fire distance from nearest road and total time elapsed between discovery and arrival of resources. Distance from road limits what resources may be available to manage an incident in a timely manner. Current conventional wisdom believes that staffing and strategy change the further the proximity between access and incident. In a time where current research suggests increased global temperatures and fire activity (Westerling et al. 2006; Climate Central, 2012), fire managers have largely increased their focus on travel time and staffing fires as quickly as possible (T. Harbour personal communication, 2014). Aerial delivery of firefighters, (smokejumper and helitack/rappel operations), continue to be utilized to reach remote fires quickly (NIFC, 2013).

Distance from base dispatched. Optimizing the distribution of resources is a key to successfully managing wildfire (Martin-FernÁndez et al. 2002; Ntaimo et al. 2013). Fire containment and suppression strongly depend on the decisions made during the initial response. Location (proximity) of an incident in respect to fire resources may impact fire manager's tactical and staffing decisions (Fried et al. 2006). Cost increases and efficiency decreases the further proximal distance an incident is from the nearest firefighting resources (ADFF, 2008). The current dispersion of aerial delivered firefighters across the western US is not optimal in regards to successful initial attack (ADFF, 2008).

Ruggedness. Landscape ruggedness is an important measure of landscape surface, and the accessibility of the incident. Rough terrain can be defined as: 'topographically uneven, broken, or rocky and steep. Terrain that is difficult to travel through or penetrate' (Sappington et al. 2007). Although "rough" terrain can vary greatly depending on geographic location as well as a myriad of other environmental factors, fires occurring in rough terrain make staffing decisions for fire managers challenging. Safety, accessibility, and fire potential are all serious concerns when suppressing fires in rough terrain. Small fires occurring in rough environments may quickly become complex to manage and/or suppress. Experienced resources, such as hotshot crews or smokejumpers, are trained to suppress incidents in “rough” terrain.

3. METHODS

This chapter describes the methods of data collection and analysis used to characterize spatial patterns and physical factors of aerial smokejumpers actions throughout the conterminous US. I will: 1) explain each of the datasets used and how they were acquired and cleaned; 2) describe how the landscape was characterized in terms of terrain and fuels; and 3) explain how proximity and accessibility were defined and measured.

3.1 Study Area

In an effort to capture landscapes in which smokejumpers may realistically be used, the study area for this research was selected based upon historical smokejumper usage. However, it is important to understand smokejumper usage is not static and continues to expand into areas where jumpers have not traditionally been utilized. US smokejumpers are used throughout the world providing overhead, leadership, and training on a broad spectrum of natural incidents. Aerial delivery by means of fixed wing aircraft and parachute primarily occur on federal and state lands throughout the western US. A contiguous unit boundary was created containing area of all 14 states that have aerially utilized smokejumpers in the last 10 years (Figure 5). These states include Arizona, California, Colorado, Idaho, Montana, North Dakota, New Mexico, Nevada, Oregon, South Dakota, Texas, Utah, Washington, and Wyoming.

10 Mile Buffer. A second study site was examined to further constrict the total landscape to area similar to what has been utilized historically by smokejumpers. This process allowed analysis of terrain nearest where smokejumpers are being dispatched. Using ArcGIS software, a 10 mile radius buffer was placed around each fire from the Smokejumper Master Action Database. This step removed 141,007 wildfires from the original study area (western U.S.) that occur in and around cities, suburbs, and infrastructure where smokejumpers have not been historically used.

Alaska. Due to unique physical characteristics, smokejumper usage in Alaska was examined separately from the western U.S. Alaska continues to live with a limited transportation road system, few logging roads, and very few firebreaks. Unlike most of the contiguous US, aerial resources continue to be one of the few modes of transportation to reach remote fires (Todd and Jewkes, 2006). Thus, hiking times were not modeled and calculated for the state of Alaska. All 565 fire jump records for AK (SMA) from 2004-2012 were analyzed in three categories and compared to a complete record of 4,609 wildfires (FPA FOD) from the same time period.

3.2 Data

3.2.1 The Smokejumper Master Action Database

Tracking of personnel has always been a challenging task within the smokejumper program due to the unique sharing of individual smokejumpers between bases and incidents in response to fire activity and changing resource needs. In 2003, the University of Montana’s National Center for Landscape Fire Analysis (FireCenter) developed a web-enabled, centralized, multi-agency database to track all smokejumper activity (FireCenter, 2013). Prior to the creation of the database, each smokejumper base independently tracked the actions of its personnel individually, originally with paper records and more recently with individual MS Access databases developed within the smokejumper community and customized by each base. The current Smokejumper Master Action collectively tracks individual actions from all bases.

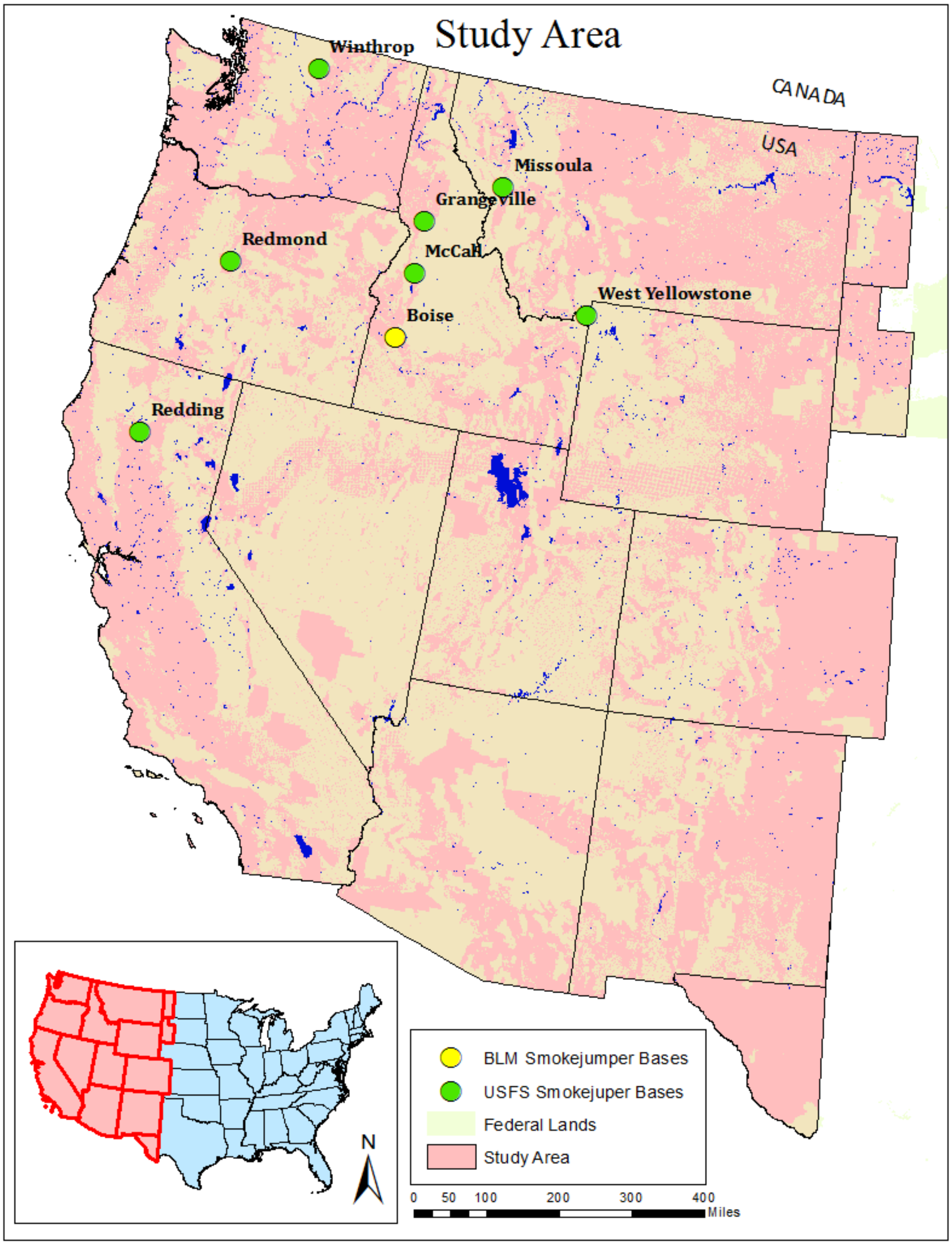


Figure 5. Location of study area in the contiguous U.S. Home smokejumper bases (circles) are labeled and colored by governing agency: green (USFS), yellow (BLM).

For every incident, records are logged to include fire location, size, date, incident name, base dispatched from, state, spotters, pilots, mission type, fire type, and number of personnel (Appendix A). This system allows smokejumper managers the ability to compile summary statistics for year-end reports and to store records from each year, thus creating a historical archive of national smokejumper data. The smokejumper program itself is exclusively responsible for the administration, maintenance, and improvement of the application and its development (FireCenter, 2013). Most recent updates have focused on increasing incident information tracked in the database focused on collecting more comprehensive data on the fires being jumped and the parachutes being used.

For this study, Smokejumper records from all 7 USFS and 2 BLM bases (4,797 actions) were obtained from the Smokejumper Master Action Database (SMA) to analyze trends in aerial use between 2004 and 2012. The records were further broken into 2 databases: conterminous US (4,232) and Alaska (565). Additionally, 212,583 fire records from the FPA Fire Occurrence Database (FOD) described below (Short, 2014) were used to update incidents with missing or erroneous entries.

3.2.2 The Fire Program Analysis System Fire Occurrence Database

The FPA Fire-Occurrence Database (FPA FOD) is the most complete standardized source of fire occurrence data available in the United States. The FPA FOD includes more than 1.67 million wildfire occurrence records from all 50 states between the years 1992-2012. Since 1998, the FPA FOD database agrees with published national reports for area burned and total fire occurrence 99.9% of the time (Short, 2014). Each wildfire in the database has values for at least the following fields: location, incident name, discovery date, and final size (Appendix B)

Records are available from all federal, non-federal (state and local), and interagency systems (Short, 2014) (Appendix C). Although fire records from all 50 states have been collected, acquisition for the western U.S. is the most accurate and complete (Short, 2014). For this study, fire occurrence data was obtained from the FPA FOD (Short, 2014). All federal, state, and local fire records have been compiled and archived into a single database for public use. Points were extracted from database applications and projected spatially for viewing and analysis purposes.

3.2.3 Fuels

This research used 2012 LANDFIRE fuels data for examining patterns of smokejumper usage as well as for creating a friction surface input in the travel time model used to determine accessibility of incidents. In 2002 a coarse-scale assessment of mapping fuels and vegetation in Utah, Montana, and Idaho began called the LANDFIRE project (Rollins, 2009; Ryan and Opperman, 2013). The LANDFIRE project (Schmidt et al. 2002) has produced data for many applications in fire and land management planning since 2009. The LANDFIRE project provides consistent comprehensive geospatial data coverage of the conterminous US, Alaska and Hawaii at a 30 meter resolution on vegetation, fuels, and terrain. The LANDFIRE dataset has been institutionalized as the primary data source for modeling and conducting landscape analysis (Ryan and Opperman, 2013). All geo-spatial fuels data for this project were acquired from the LANDFIRE project (http://www.landfire.gov). LANDFIRE fuels data were selected because they provide consistent coverage of all wildlands in the study area across agencies/ownerships at 30m spatial resolution.

3.2.4 Terrain

Geo-spatial topographic data for this project were acquired from the USGS. One-third arc-second 10 m resolution Digital Elevation Model's (DEMs) were attained and stitched together for the entire study area. Overall, 457 unique DEMs were used to develop terrain data for the study area.

3.2.5 Boundaries and Roads

Spatial data were acquired from trusted federal, state, and private entities. In an effort to find the most current, accurate data available, multiple layers were downloaded and compared for accuracy and completeness using GIS, maps, Google Earth and personal experience/knowledge.

Jurisdictional Boundaries. Federal administration boundary shape files were downloaded from the Wildland Fire Decision Support System (WFDSS, 2013) (http://wfdss.usgs.gov) data downloads page. All boundaries came from the same source to provide consistency. BIA, BLM and USFS data were produced in 2011, while NPS, USFWS, and designated wilderness areas were made in 2013. State land shapefiles were acquired at the individual state level. I was unable to find or obtain access to a source that provided consistent or comprehensive coverage, thus there is considerable discrepancy in currency, accuracy, and comprehensiveness of the individual files.

Roads. Acquisition of public road data was demanding and time consuming. Although primary public roads layers (highways and interstates) can be found with relative ease, spatial compilations of secondary road systems (all other drivable roads) are more difficult to acquire. Complete (primary and secondary) public roads layers are generally compiled at a state level. For this study, roads data were taken from individual state or BLM geographic information clearinghouses (57%) when available (Table 2). Some states either failed to provide those GIS services or the data were incomplete or inaccurate. US Census Bureau TIGER/line data were used in these instances (43%).

Table 2. Road sources used to create network for distance to nearest road calculations and source grid input for travel time model primarily came from state, agency, and TIGER clearinghouses.

State	Year	Source
AZ	2011	TIGER Primary-Secondary roads, TIGER county roads by county
CA	2011	TIGER Local roads, TIGER Major roads
CO	2011	Colorado Department of Transportation: Highways, Major roads, Local roads
ID	2011	Idaho Geospatial Data Clearinghouse Road centerline transportation layer Idaho
MT	2011	Montana State Library Transportation Framework Layer
ND	2011	TIGER statewide centerline
NM	2011	TIGER Primary-Secondary roads, TIGER county roads by county
NV	2011	Tiger Centerlines by county
OR	2011	BLM Oregon State Office GTRN_PUB_ROADS_ARC
SD	2011	State of South Dakota Department of Transportation by county
TX	2011	Texas Strategic Mapping Program, Texas Natural Resources Information System
UT	2011	Utah Automated Geographic Reference Center State Geographic Information Database
WA	2011	BLM Oregon State Office GTRN_PUB_ROADS_ARC
WY	2011	TIGER state wide centerline

3.3 Database Cleaning

Spreadsheet and database applications were used to extract all records in which smokejumpers were operationally deployed on fire incidents using fixed wing aircraft and parachute. Complete and accurate record keeping of the SMA proved to be an issue. In an effort to clean and standardize the SMA, many changes were made. The major data quality issues encountered can be summarized as follows. In 2004, BLM bases (FBX, BOI) entered most, but not all smokejumper actions. The SMA did not make Latitude and Longitude fields a requirement until 2005 at which point users were still able to circumvent entering correct information by entering 0’s. Roughly 16% of fire entries had no description of location (latitude/longitude). Another 12% were missing information on incident name, date, type, or size. Smokejumper entries with missing or erroneous fields were cross-referenced with the USFS FOD database to validate accuracy and completion. SMA entries missing spatial information and that were not found in the FOD (4%), were deleted. Spatial location coordinates are entered into the SMA using degrees-decimal-minutes format. However, GIS applications require spatial records to be in decimal degrees to accurately display and analyze. All records had geographic coordinates converted using the formula:

$$\text{decimal degrees} = (\text{seconds}/3600) + (\text{minutes}/60) + \text{degrees}$$

Next, all base layers (vector and raster) were spatially projected into USA Contiguous Albers Equal Area Conic coordinate system. A shapefile of the conterminous US (WFDSS, 2013) was generated to match the study area. All fires from the FPA FOD that did not fall into the study area (1.46 million) were clipped and deleted from the database.

Thirty- meter resolution LANDFIRE data was used to display areas of water within the study area. Incidents with coordinates that fell in FBFM 98 (Water) were either relocated (SMA), or deleted (FPA FOD). 6 fires (<1%) from the SMA database were moved to a location nearest their current point that did not lie in water. 1,694 fires (<1%) from the FOD database that landed in water were deleted from the study.

Depending on the fire and its complexity, more than one load of smokejumpers may have been dispatched. Every subsequent planeload of smokejumpers that arrived on the same incident was considered a "reinforcement load." Following the first planeload, each succeeding mission was renamed in the order it was dispatched. For example, the first load would have an incident name of Deer Fire, followed by Deer Fire Load 2, Deer Fire Load 3, etc. Location information for each subsequent load was updated to the latitude and longitude of the first mission.

3.4 Geoprocessing

Geographic Information Systems (GIS) was used heavily in this project. Spatial information, analysis, and visual display was completed using ArcGIS 10.0 (ERIS, 2010), ERDAS Imagine® 2013 (ERDAS, 2013), R, and Python software.

Geographic Coordinates. All project base layers contain a North American 1983 datum and were spatially projected into USA Contiguous Albers Equal Area Conic coordinate system. This conic projection best preserved shape, area, direction, and distance for the conterminous US (Snyder, 1987; ESRI, 2010). Fires that occurred in Alaska were projected into NAD 1983 Alaska Albers coordinate system and plotted.

Road Networks. Integration and manipulation of the most up to date road networks was a lengthy process. Polyline road layers were obtained at a state level and then merged together to create one large network for the entire study area. Memory and size limitations during analysis required the road network to be converted from polyline to 30m raster. Finally, all roads were clipped to the study area boundaries and roads that fell outside the boundaries were deleted from analysis.

Physical Analysis. Using spatial tools in ArcGIS, physical characteristics such as elevation, slope, aspect, fuel model and ruggedness were analyzed. Proximal analysis, Euclidean distance from road, distance from base dispatched, and distance from nearest base were calculated for all points in both SMA and FPO databases. Flight time (hrs.) to each incident was also computed using baseline aircraft performance (cruise speed and range) from the current smokejumper fleet (USFS, 2011). Hiking time models were determined using GIS and multi-paradigm programming and modeling (Python, 2013) and are discussed in further detail in following.

3.5 Objectifying Steep, Rugged, and Inaccessible Terrain

'Steep, rugged, inaccessible terrain' is widely used terminology in wildfire reporting. Fire managers invoke it to explain difficulties in control efforts, to justify the deployment or non-deployment of resources and personnel, and to validate decisions not to take direct action on incidents they might otherwise suppress. The frequent use of this phrase to justify so many different decisions led me to consider what defined steep, rugged, inaccessible terrain and where it was located. Parameters were created (using subject matter experts along with current and historical research and models) to define 'steep, rugged, and inaccessible.' Collectively, these layers provided an objective, spatially-explicit characterization of steep, rugged, inaccessible terrain, which in turn was summarized by an administrative unit to reveal patterns of occurrence. Below I explain the steps taken to objectify each of the following criterions.

3.5.1 Steep

The USGS 1/3 arc second (10-meter) national DEM was used to calculate slope, elevation, and aspect for the study area. 'Steep' terrain was defined from the slope layer as >40% (21.80 degrees). Selection of 40% slope was based on several sources: the USDA National Trail

Classification System which defines the steepest grade allowed in current trail design as 40%, in lengths up to 200 feet and not exceeding 10% of the total trail length (USFS trails, 2006), a primer for timber and harvesting describing topographic limitations for ground based systems (Greulich et al. 1999), wildlife habitat related research (McNay et al., 2006; Sappington et al., 2007) and two studies that tested slope as a contributor to human route selection (Kinsella-Shaw et al., 1992; Pingel, 2010). Using spatial analysis tools available in ArcGIS and Imagine, slopes over 40% were selected, analyzed and mapped on state and federal landscapes at the jurisdictional boundary level.

3.5.2 Rugged

To measure ruggedness, I used the Vector Ruggedness Measure (VRM) model developed and implemented by Sappington et al. (2007). 'Rugged' was calculated from USGS 1/3 arc-second 10 m resolution DEM's using the VRM in a 3x3 neighborhood.

$$\text{VRM}=1\text{-}x=\frac{\sqrt{(\sum_{i=1}^{n} xi)^2+(\sum_{i=1}^{n} yi)^2+(\sum_{i=1}^{n} zi)^2}}{\text{n}}$$

where: $x = \sin(\alpha) * \sin(\beta)$, $y = \sin(\alpha) * \cos(\beta)$, $z = \cos(\alpha)$

$\alpha = slope, \beta = aspect,$ computed with a 3×3 grid cell neighborhood.

VRM ranges from 0 (flat) to 1 (most rugged)

VRM estimates the degree of terrain ruggedness by calculating the dispersion of vectors orthogonal to the land surface (Olson et al. 2008). Unlike most methods of modeling landscape ruggedness where results are strongly correlated with slope, VRM is based on a 3 dimensional vector dispersion method (Hobson, 1972) that is less correlated with slope (Sappington et al., 2007). Calculation of VRM for this project was measured using a GIS tool created by Sappington et al. (2007) that results in a dimensionless ruggedness number that ranges from 0 (flat) to 1 (most rugged) where values of natural terrain are rarely >0.2. VRM's greater than 0.006 (85th percentile) were classified as 'rugged' through visual comparison with aerial photography over known rugged locations in MT, ID, WA, UT, and CA. Spatial analysis was completed throughout the study area and terrain with a VRM greater than 0.006 was selected, analyzed, and mapped.

3.5.3 Inaccessible

'Inaccessible' was determined by calculating hiking times from the nearest road using a Pathdistance Model which implements Naismith's Rule, with Langmuir's correction (Fritz & Carter, 1999) and will be discussed in further detail below. Points >2 hours from nearest road were deemed inaccessible. Distance, slope, ground cover (LANDFIRE Fuel Model), and barriers (slope >40°; large rivers and lakes) were considered. Best available primary and secondary roads layers (2011) were used. Friction underfoot is a vital input to hiking speeds in mountainous terrain. Dead and down woody debris (FM10), chaparral and thick brush (FM4-7), and slash (FM11-13) may severely slow or alter walking speeds. Anderson's 13 fire behavior fuel models were used to slow down the model outputs in order to get an accurate estimate of how long it will take to reach any given point in the study area. Although LANDFIRE fuel data were used for fire behavior inputs, fuel models also give a consistent estimate of friction underfoot at a landscape level and results show a clear effect on total hiking time (Figure 6).

3.5.3.1 Travel (Hiking) Time Model

Travel time of the western US is modeled based on a GIS implementation of Naismith's rule, with Langmuir's correction. The travel time model was originally developed by Carver and Fritz (1999). The model used in this research was based on the same principal calculations used by Carver and Fritz, though several input alterations were made to fit project needs. The travel time model output depicts the fastest route it would take a person to walk to every pixel in the study area from the nearest road (source grid). The model requires the following inputs: source grid (road layer), cost grid (LANDFIRE fuels data, barriers), surface grid and vertical factor grid (DEM), and a horizontal factor/aspect grid (DEM, Naismith algorithm). Distance, terrain, land cover, and natural barriers are used to delineate the relative time it takes to walk to a point location from the nearest motorized access (road).

Calculation of Pathdistance. The path distance model creates an output raster in which each cell is assigned the accumulative cost from the cheapest source cell. The objective of the path distance tool is for each cell location in the analysis to determine the least cost path to reach the cell from the least costly source. Every cell has an impedance value associated with it. The impedance is derived from the costs that have been assigned and from the horizontal and vertical direction of movement (ESRI, 2014). The cost to travel is dependent on spatial orientation and how the cells are connected. Adjacent cost, perpendicular cost, and diagonal cost are all added to create an accumulative cost distance. The processing that occurs in path distance is similar to that of other cost distance algorithms (ESRI, 2014). All programming script was written and processing was performed in Python (Appendix D).

1. The source (road) cells are identified
2. The cost to travel to each neighbor that adjoin a source cell is determined
3. Each of the neighbor cells is listed from least costly to most costly
4. The cell location with the least cost is removed from the list
5. The least accumulative cost to each of the neighbors of the cell that was removed from the list is determined
6. This process is repeated until all cells on the raster have been assigned an accumulative cost.

Each cell will need to determine the least accumulative cost path from a source (roads layer), the source that allows for the least cost path, and the least cost path itself. The algorithm used to calculate the total cost of travel from cell a to cell b depends on if that travel is perpendicular or diagonal (ESRI, 2014).

Perpendicular:

$$\text{Cost\_distance} = (((\mathit{Cost\_Surface}(a) * \mathit{Horizontal\_factor}(a)) + (\mathit{Cost\_surface}(b) * \mathit{Horizontal\_factor}(b)))/2) * \mathit{Surface\_distance}(ab) * \mathit{Vertical\_factor}(ab)$$

Diagonal:

$$\text{Cost\_distance} = (((\mathit{Cost\_Surface}(a) * \mathit{Horizontal\_factor}(a)) + (\mathit{Cost\_surface}(b) * \mathit{Horizontal\_factor}(b)))/2) * 1.414214 * \mathit{Surface\_distance}(ab) * \mathit{Vertical\_factor}(ab)$$

Accumulative cost distance:

$$\text{Accum\_cost\_distance} = a1 + (((\mathit{Cost\_Surface}(b) * \mathit{Horizontal\_factor}(b)) + (\mathit{Cost\_surface}(c) * \mathit{Horizontal\_factor}(c))/2) * \mathit{Surface\_distance}(bc) * \mathit{Vertical\_factor}(bc)$$

- where: a1 is the total cost of travel from cell a to cell b

Naismith's Rule. William Naismith, a Scottish Mountaineer, devised the hiking rule in 1892 in an effort to help plan hiking expeditions (Naismith, 1892). The basic rule calculates a rough estimate of how long it will take to walk a route, including ascents. The rule states: allow 1 hour for every 5 kilometers (3.1 mi.) forward, plus 1 hour for every 600 meters (2,000 ft.) of ascent. Naismith's rule assumes the person is a fit and healthy individual and does not make allowances for "heavy" loads, adverse weather conditions, or navigational skills. The rule does not account for delays or extended breaks. Naismith was considered an optimist and in practice Naismith's rule is most often considered the minimum time necessary to complete the route (Thompson, 2010).

Langmuir's Correction. Several alterations to Naismith's rule have been made to make it much more applicable in the field. In 1984, E. Langmuir used Naismith's rule with an additional correction to develop an alternative algorithm for predicting hiking time in mountainous terrain (Langmuir, 1984) (Table 3). Langmuir's correction recognizes the need to slow speeds with increased slope both ascending and descending. Shorter steps taken and/or reduction of slope angle create increased path length from zig-zagging (Fritz and Carver, 1998). The correction assumes:

3 a walking speed of 5.0 km/h with 30 minutes added for every 300m ascent

4 10 minutes are subtracted for every 300m of descent for slopes between 0 degrees and 12 degrees

5 10 minutes are added when the slopes are greater than 12 degrees for both ascent and descent

Studies (Carver and Fritz, 2000; Carver and Wrightham, 2003; Carver et al. 2012; Tricker et al., 2013; Doherty et al., 2014) have found this modification to be applicable to reasonably fit hikers under typical terrain and weather conditions.

Road Network. The source grid (road network) is a crucial element of the model. The best available road networks (2013) were used. Only primary and secondary (drivable) roads were considered.

Topography. The model takes into account vertical and horizontal factors that determine the difficulty of moving from one raster cell to another (Table 3). Slope and aspect are two main factors that determine the angle at which terrain is crossed. These features are known as the horizontal and vertical relative angles and are used to determine the total relative slope and height that are gained and lost to complete a route (Tricker et al., 2013). These values are input into the model using a lookup table function.

Table 3. Naismith's rule expressed in the vertical relative moving angle (VRMA) field. (Carver & Fritz, 1999).

VRMA (Degrees)	Vertical Factor (seconds/meter)
-40	2.4
-30	1.87
-20	1.45
-12	0.29
-11	0.33
-10	0.37
-9	0.44
-8	0.47
-6	0.51
-5	0.72
0	0.72
10	1.78
20	2.9
30	4.19
40	5.75

Cost. Speed over ground is largely affected by vegetation type, fuel cover, and routes of least resistance. LANDFIRE's 30-meter resolution Anderson's classic fuel behavior models data were used in the model in an effort to give a more accurate depiction of travel time in mountainous terrain. In addition to the classic 13 fuel models mentioned previously, LANDFIRE added urban, snow/ice, agriculture, water, and barren classifications to the dataset. Using previous studies (Tricker et al., 2013) and subject matter experts, impedance values were assigned to each of the fuel model classes using ArcGIS spatial tools and a new spatial cost layer was produced (Table 4). Amending base cost surfaces and conditions underfoot allow the PathDistance tool to correctly yield realistic hiking time outputs.

Table 4. Impedance values shown signify the walking speed assigned to each fuel model.

Fuel Model		**Impedance (mph)**	**(km/h)**	**m/s**
1) Short Grass		3.10686	4.999994	1.388888
2)Timber Grass and Understory		2	3.21868	0.894078
3)Tall Grass		2	3.21868	0.894078
4)Chaparral		1.24	1.995582	0.554329
5)Brush		1.24	1.995582	0.554329
6)Dormant Brush		1.24	1.995582	0.554329
7)Southern Rough		1.24	1.995582	0.554329
8)Closed Timber Litter		2	3.21868	0.894078
9)Hardwood Litter		2	3.21868	0.894078
10)Timber Understory		1	1.60934	0.447039
11)Light Slash		0.75	1.207005	0.335279
12)Medium Slash		0.5	0.80467	0.22352
13)Heavy Slash		0.25	0.402335	0.11176
Urban		3	4.82802	1.341118
Snow/Ice		2	3.21868	0.894078
Agriculture		3	4.82802	1.341118
Barren		3.10686	4.999994	1.388888
Slope>40 degrees		10000	10000	10000
Lakes		10000	10000	10000

Natural Barriers. Barriers to movement were taken into consideration in the travel time model. Steep terrain with slopes over 40 degrees were deemed impassable on foot and coded null for model inputs. Major bodies of water such as rivers, canals, and lakes that showed up on 30-meter LANDFIRE data were also considered impenetrable on foot and their respective raster values were coded null in the model. Coding raster input values as “null” forces the model to seek a path around cells and implicates walking around the natural obstacle.

3.6 Data Analysis

Smokejumper actions data were analyzed and summarized for temporal trends both holistically and by each individual base. Statistical analysis was performed to determine the significance and magnitude of trends, and to assess the variance between the two datasets. Due to the fact that complete populations were available for analysis, no statistical hypothesis testing of means or variances was employed.

4. RESULTS

4.1 Data Quality

Spreadsheet and database applications were used to extract all 4,478 records from the SMA in which smokejumpers were operationally deployed to fire incidents using fixed wing aircraft and parachute. A query of the FPA FOD yielded 207,974 fire records for the same study area. An unknown portion of BLM smokejumper actions were reported missing from the study during 2004. Roughly 45% off all SMA entries required cleaning and updating. Sixteen percent of all smokejumper records were entered without a description of location (latitude/longitude). Another 12% were missing information on incident name, size, date, type, or load size. Smokejumper entries with missing or erroneous fields were cross-referenced with the USFS FOD database to validate accuracy and completion. SMA entries missing spatial information and that were also not found in the FOD (4%), were deleted. It is important to note that 10% of all smokejumper dispatches were reinforcement loads thus, 3,812 separate fires were actually jumped (Figure 6). Multiple planeloads to the same incident were all updated with the same location from the first load to jump the incident. Duplicate entries (~1%) were deleted from the database. Roughly 2,015 SMA entries were cleaned or updated and a total of 245 (~5%) were not used in this analysis.

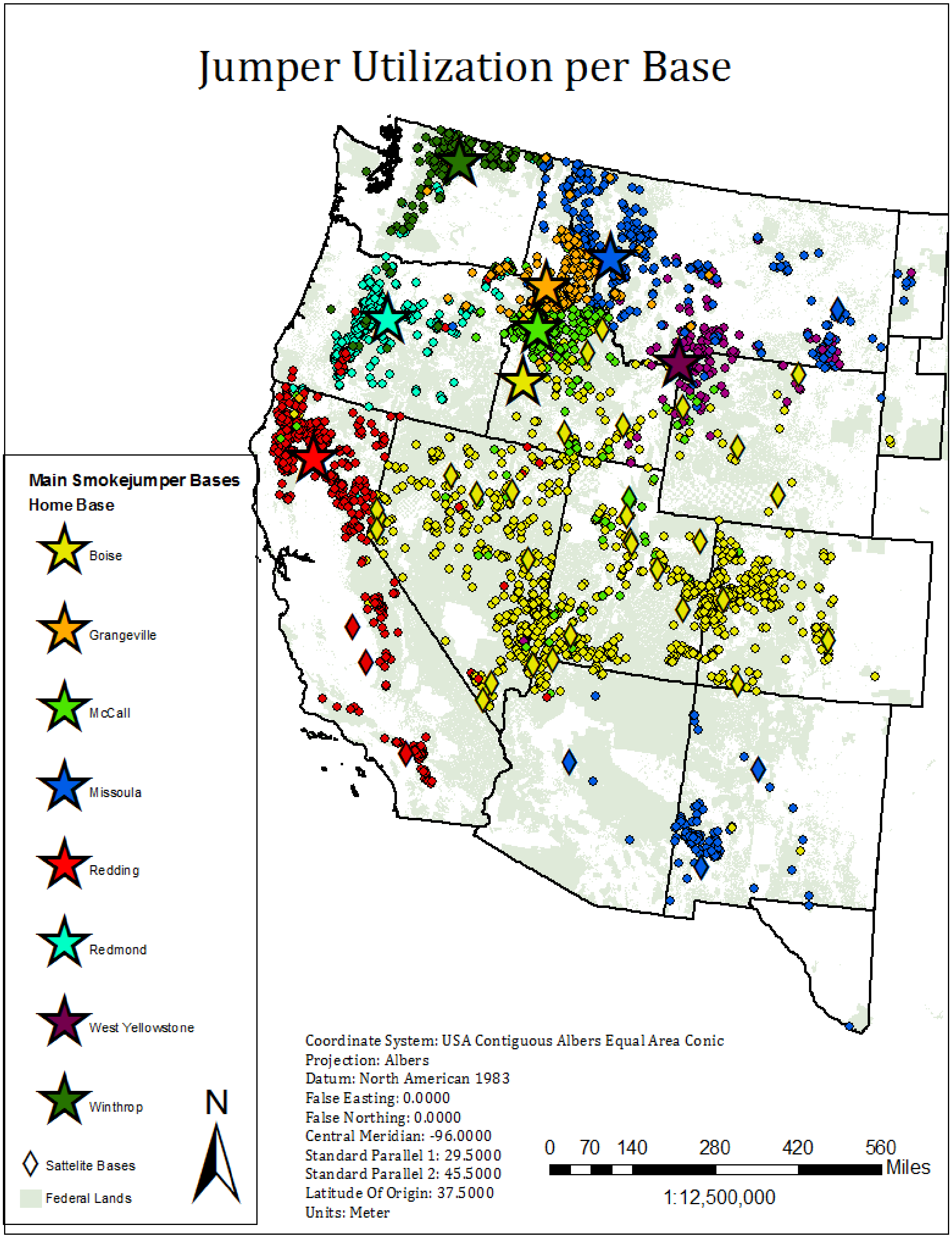


Figure 6. Smokejumper utilization shown at the base level. Sattelite bases (diamond) and jumper missions (circles) are colored in respect to the home base in which they belong.

4.2 Summary of Actions

U.S. Smokejumpers aerially responded to 4,232 fire incidents in 15 states from 2004-2012. Nine main bases and 43 satellite bases/airports were used to deploy smokejumpers during that time. More than 18,995 individual jumps were made on 3,667 fires from bases in the contiguous U.S.

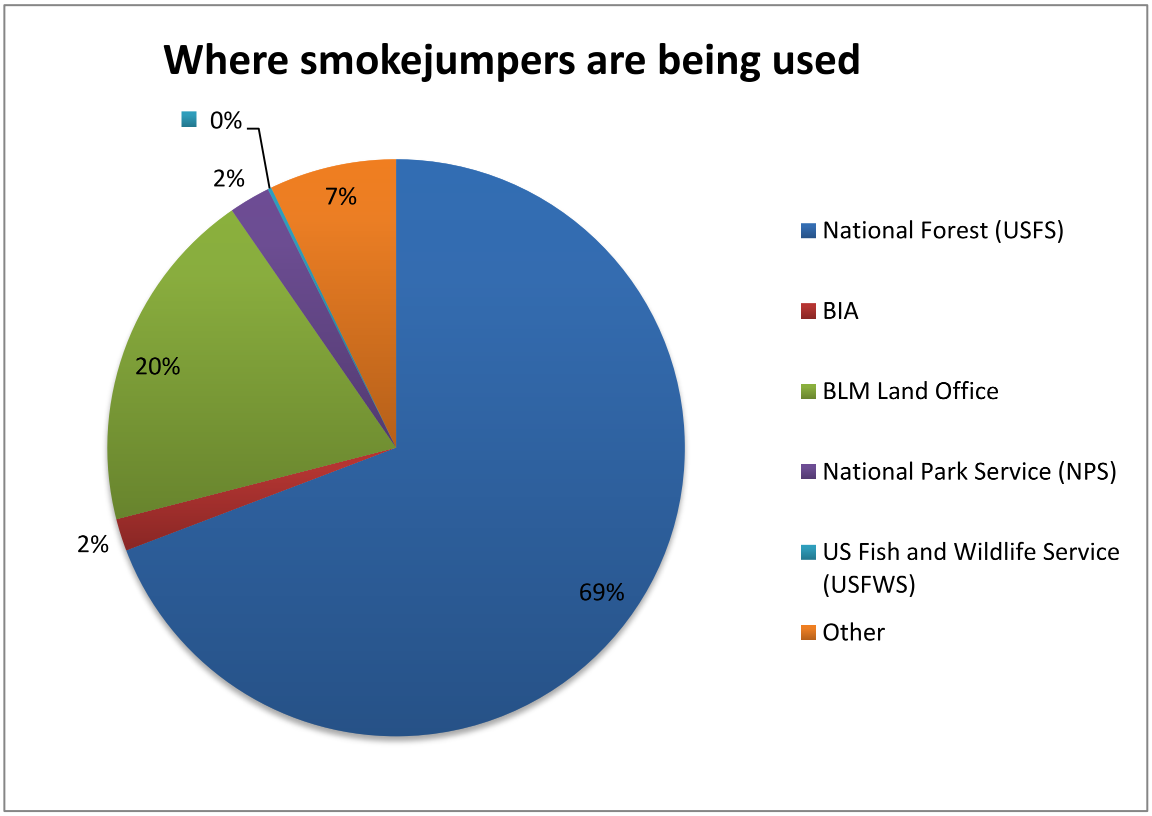


Figure 7. Percentage of smokejumper use by agency jurisdiction.

Furthermore, 3,515 smokejumpers were dispatched to another 565 fires in Alaska. Jumpers were dispatched to 3,629 fires on 552 separate federal jurisdictional units and 52 fires on state managed lands in the western U.S. Most smokejumper usage was on National Forests (69%) or lands managed by the BLM (20%). Seventy-one USFS Forests, 248 USFS Ranger Districts, 45 BLM districts, 17 BIA Agencies, 15 National Parks, 3 USFWS refuges, and 122 designated wilderness areas used smokejumpers (Figure 7). Average first and last jump dates for all bases were May 8 and October 7, respectively. Fiscal years 2006, 2007, and 2012 were the busiest seasons for a smokejumper organization that averaged 470 missions per year (Figure 8). Five different fixed wing aircraft platforms were used for smokejumper operations: De Havilland Twin Otter (36%), Shorts C-23 Sherpa (22%), Dornier 228-202 (18%), CASA 212-212-200 Aviocar (16%), and Douglas DC-3TP (8%). Smokejumpers were dispatched 98% of the time for

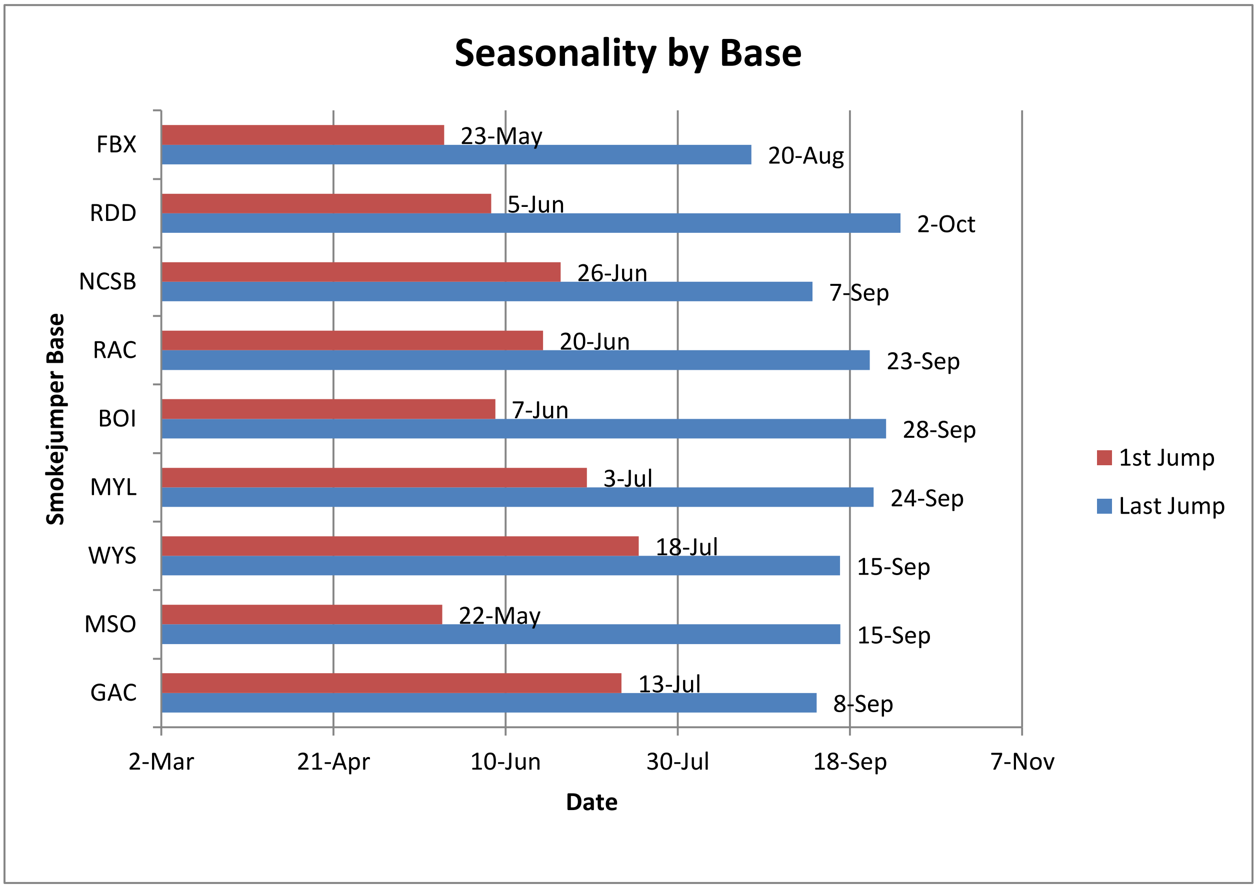
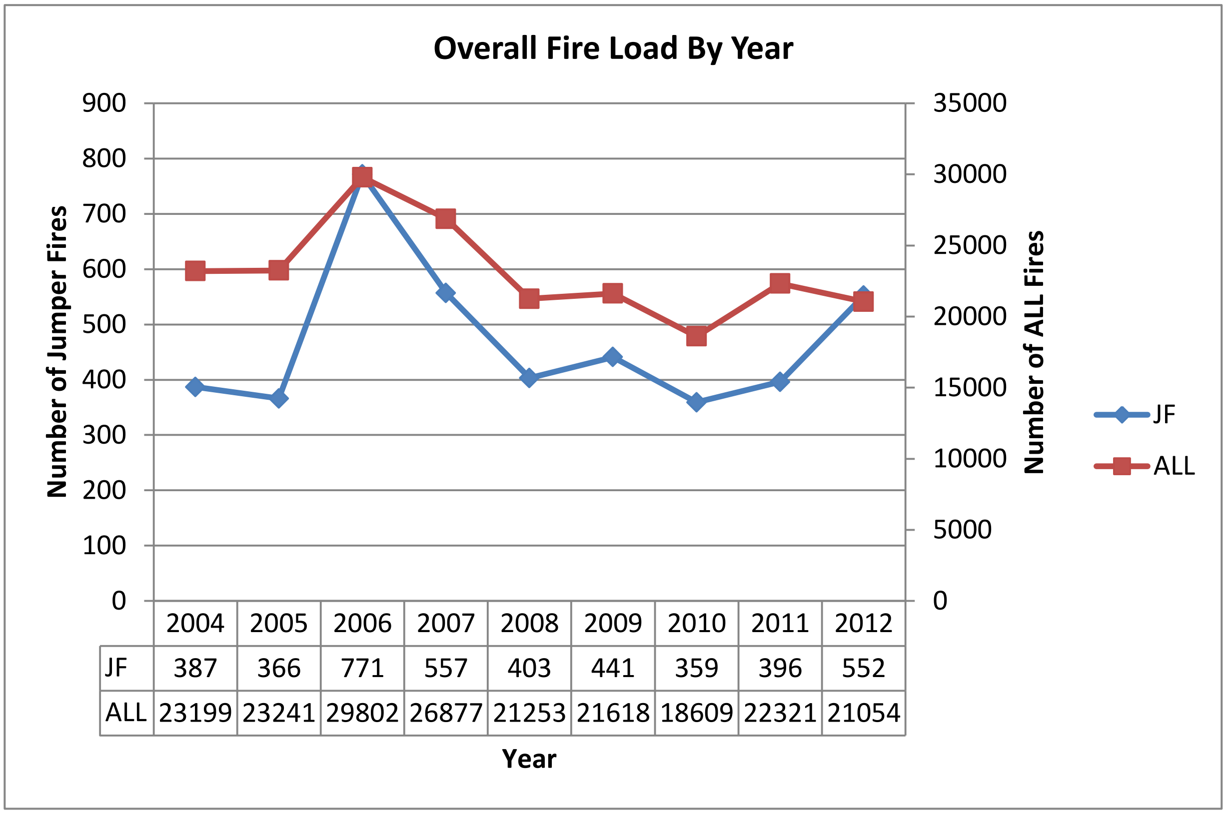


Figure 8. Average first and last operational jump by home base.

fire suppression purposes and 2% for rescue and miscellaneous AK missions, of those 90% were for Initial Attack. Eighty-one percent of all smokejumper missions were responding to Type 4 and Type 5 incidents. Ten percent of all smokejumper actions were reinforcement loads to incidents that had one or more loads of smokejumpers already on the ground.

4.2.1 Activity by Base

Activity at smokejumper bases in the U.S. typically trend with overall fire load (Figure 9). 2012 was the only year where there was not a general correlation between total fire load and smokejumper usage. That season showed a modest decrease in all fires (~6%) and a sharp increase in smokejumper usage (28%), perhaps related to a pre-season letter to fire managers



	2004	2005	2006	2007	2008	2009	2010	2011	2012
JF	387	366	771	557	403	441	359	396	552
ALL	23199	23241	29802	26877	21253	21618	18609	22321	21054

Figure 9. Comparison of total fire activity by year. Smokejumper missions (blue) and all fires (red).

from Deputy Chief, State and Private Forestry James Hubbard requesting aggressive initial attack to minimize suppression costs (Hubbard, 2012). Thus, fires that would have traditionally been allowed to burn in remote areas were suppressed in 2012. In relation to total fire load, smokejumpers in the contiguous U.S. were used most frequently in 2006 (2.59% of all fires) and 2012 (2.62%). On average, smokejumpers were used on roughly 2% of all recorded fires in the western U.S.

Base Breakdown. Roughly 400 smokejumpers staffed 9 bases in the western U.S., and Alaska during the period of record. Each individual base varies by size (personnel) and operational seasonality. Thus, base-by-base activity and use characteristics fluctuate (Table 5).

Table 5. 9-year averages for each base. Complexity reported as number of Type 1, 2, ,3, 4, 5 fires.

Base	**1st Jump**	**Last Jump**	**# of Missions**	**# of Fires**	**# of Jumpers out the Door**	**Avg. # of Jumpers/Load**	**# of Reinforcement Loads**	**Complexity**
BOI	7-Jun	28-Sep	114.1	105.8	582.3	5	8.3	**1**-2, **2**-7, **3**-212, **4**-461, **5**-345
AK	23-May	20-Aug	62.8	50.8	393.9	6.1	12	**1**-4, **2**-36, **3**-133, **4**-292, **5**-100
MSO	22-May	15-Sep	59.2	55.9	345.7	6	3.3	1-3, **2**-13, **3**-96, **4**-212, **5**-209
GAC	13-Jul	8-Sep	30.7	28.7	148.2	4.7	2	**1**-1, **2**-3, **3**-44, **4**-78, **5**-150
WYS	18-Jul	15-Sep	22.7	19.4	123	5.3	3.2	**1**-4, **2**-9, **3**-41, **4**-80, **5**-70
NCSB	26-Jun	7-Sep	28.8	25.4	136.3	5	3.3	**1**-4, **2**-5, **3**-14, **4**-96, **5**-140
RAC	20-Jun	23-Sep	51	47.7	239.9	5	3.3	**1**-2, **2**-2, **3**-29, **4**-171, **5**-255
RDD	5-Jun	2-Oct	55.4	52	285.9	5.2	3.4	**1**-11, **2**-8, **3**-52, **4**-165, **5**-263
MYL	3-Jul	24-Sep	45.6	42.6	249.2	5.6	3	**1**-4, **2**-7, **3**-67, **4**-124, **5**-209

Boise. Overall, Boise smokejumpers made the most individual jumps (5,241) and were dispatched to the highest number of fires (1,027) from the greatest number bases/airports (31). Four percent of Boise smokejumper fire missions were dispatched from the home base in Boise, ID. Thirty percent of all Boise-administered actions were dispatched from Grand Junction, CO, a well-used satellite base. The average date of the first and last jumps out of respective Boise bases was June 7, and September 28 (Table 6).

Table 6. Boise smokejumper actions expressed annually.

	1st Jump	Last Jump	# of Missions	# of Fires	# of Jumpers out the door	Avg # of Jumpers per load	# of Reinforcement Loads
BOI							
2004	19-Jun	15-Sep	14	14	54	3.9	0
2005	3-Jun	22-Sep	120	109	658	5.5	11
2006	3-May	6-Oct	251	240	1267	5	11
2007	15-May	19-Sep	129	116	697	5	13
2008	19-Jun	1-Oct	100	93	511	5.1	7
2009	7-Jul	28-Sep	84	80	346	4.1	4
2010	19-Jun	2-Oct	65	61	338	5.2	4
2011	8-Jun	2-Oct	110	102	575	5.2	8
2012	2-Jun	11-Oct	154	137	795	5.2	17
Total	3-May	11-Oct	1027	944	5241	5.1	Load 2=71, 3=8, 4=4
Average	7-Jun	28-Sep	114.1	105.8	582.3	5	8.3

Eighty-two percent of Boise smokejumper fire missions were flown in Twin Otter aircraft. 2006 was the busiest season in which 251 missions were completed, more than twice the seasonal average (114). Ninety-four percent of Boise missions were for initial attack and more than 21% of the fires responded to were Type 3 and above, the second highest average complexity of any base. More than 8% of all dispatches were reinforcement loads. The average number of jumpers used per fire was 4.95.

Alaska. Alaska smokejumpers carried the second highest load with 3,545 individual jumpers responding to 565 incidents from seven bases. Seventy-six percent of all missions were dispatched from the main base in Fairbanks followed by Galena (15%) and McGrath (7%). On average, fire season is earlier within Alaska, where 93% of their activity occurred between April and July. The first fire jump generally occurred on May 23, and last jump averaged August 20, the earliest of all bases. Most missions were flown on the CASA 212 (68%) and the Dornier (31%) aircraft. Alaska smokejumpers average 63 missions per year. 2010 was the busiest season on record with more than 167 missions recorded (Table 7).

Table 7. Alaska smokejumper actions expressed annually.

	1st Jump	Last Jump	# of Missions	# of Fires	# of Jumpers out the door	Avg # of Jumpers per load	# of Reinforcement Loads
FBX							
2004	25-Jun	27-Jul	36	31	137	3.8	5
2005	17-Jun	19-Aug	33	29	199	6	4
2006	22-May	1-Aug	28	24	186	6.6	4
2007	4-May	6-Sep	80	68	541	6.8	12
2008	20-May	6-Sep	29	25	173	6	4
2009	11-May	12-Aug	94	73	617	6.6	21
2010	27-Apr	28-Sep	167	124	1083	6.5	43
2011	20-May	1-Aug	50	40	316	6.3	10
2012	30-May	21-Aug	48	43	293	6.1	5
Total	4-May	28-Sep	565	453	3545	6.3	Load 2=78, 3=27, 4=4, 5=3
Average	23-May	20-Aug	62.8	50.8	393.9	6.1	12

Eighty-four percent of all actions were for initial attack, the lowest of all nine programs. Thirty-one percent of use was directed toward larger and more complex fires (Type 1, 2, 3). Furthermore, 20% of all dispatches were reinforcement loads, more than double the average of all bases. Alaska smokejumpers averaged more firefighters per incident than any other respective base, (6.075).

Missoula. 3,111 smokejumpers responded to 533 incidents out of Missoula and its satellite bases in Silver City, NM and Miles City, MT. July was the busiest month for the Missoula smokejumpers when 38% of all actions took place. However, it's important to note that 20% of Missoula's activity for the month of July occurred in Silver City. On average, the first jump occurred on May 22 and the last jump on September 15. The majority of all missions were flown out of the Sherpa (34%), DC-3TP (32%), and the Twin Otter (23%). It is also important to note Missoula has the last active DC-3TP in the U.S. smokejumper fleet. This in turn will create conceivable implications in Missoula smokejumper actions in the future when the DC-3TP is put out of commission. Fiscal years 2006 (91), 2007 (92), and 2012 (97) were the busiest seasons for Missoula smokejumpers where the average number of missions was 59. Roughly 90% of all dispatches were utilized for initial attack, and more than 79% of all fires that were jumped were small (Type 4, 5) upon arrival. An average load of 5.99 smokejumpers responded per incident (Table 8).

Table 8. Missoula Smokejumper actions expressed annually.

	1st Jump	Last Jump	# of Missions	# of Fires	# of Jumpers out the door	Avg # of Jumpers per load	# of Reinforcement Loads
MSO							
2004	5-May	20-Aug	66	57	294	4.5	9
2005	1-Jun	7-Sep	43	42	262	6.1	1
2006	17-May	7-Oct	91	90	575	6.3	1
2007	18-May	19-Sep	92	89	539	5.9	3
2008	19-Jun	8-Sep	25	24	199	8	1
2009	12-May	27-Sep	32	32	167	5.2	0
2010	30-May	27-Aug	24	22	149	6.2	2
2011	12-May	3-Oct	63	57	416	6.6	6
2012	27-May	21-Sep	97	90	510	5.3	7
Total	5-May	7-Oct	533	494	3111	5.8	Load 2=33, 3=5, 4=1
Average	22-May	15-Sep	59.2	55.9	345.7	6	3.3

Grangeville. The Grangeville smokejumpers delivered 1,334 individuals to 276 incidents. On average, the first jump out of Grangeville took place on July 13 and the last jump occurred on September 8th. 2006 was the busiest year with 58 fire missions followed by 2007 (41) and 2012 (40) respectively. August was the busiest month where more than 61% of the fire load occurred. The Twin Otter was used almost exclusively (96%) for all missions. Ninety-eight percent of all actions were suppression driven and 91% of those were initial attack of primarily (83%) small (Type 4, 5) fires. The average number of jumpers per incident was the lowest of all respective bases at 4.69 (Table 9).

Table 9. Grangeville smokjeumper actions expressed annually.

	1st Jump	Last Jump	# of Missions	# of Fires	# of Jumpers out the door	Avg # of Jumpers per load	# of Reinforcement Loads
GAC							
2004	29-Jun	20-Aug	28	27	115	4.1	1
2005	31-Jul	3-Sep	34	32	155	4.6	2
2006	28-Jun	11-Sep	58	58	282	4.9	0
2007	30-Jun	16-Sep	41	38	199	4.9	3
2008	21-Jul	12-Aug	12	12	44	3.7	0
2009	4-Jul	12-Sep	17	17	91	5.4	0
2010	26-Jul	15-Sep	14	13	66	4.3	1
2011	4-Aug	2-Oct	32	28	158	4.9	4
2012	9-Jul	16-Sep	40	33	224	5.6	7
Total	28-Jun	2-Oct	276	254	1334	4.8	Load 2=19, 3=3
Average	13-Jul	8-Sep	30.7	28.7	148.2	4.7	2

West Yellowstone. 1,107 smokejumpers were dispatched out of West Yellowstone to 204 incidents. Forty-eight percent of all actions ensued in the month of August. West Yellowstone had the longest winter season of the respective bases with average first jump occurring on July 18, although the proportion of monthly fire load for the end of the year (September and October) was highest at 22%. 2006 was the busiest season in West Yellowstone

Table 10. West Yellowstone smokejumper actions expressed annually.

	1st Jump	Last Jump	# of Missions	# of Fires	# of Jumpers out the door	Avg # of Jumpers per load	# of Reinforcement Loads
WYS							
2004	7-Jul	17-Aug	9	9	32	3.6	0
2005	20-Jul	22-Sep	25	19	129	5.2	6
2006	23-Jun	11-Sep	53	46	302	5.7	7
2007	4-Jul	16-Sep	41	36	209	5.1	5
2008	19-Jun	8-Sep	10	8	70	7	2
2009	1-Sep	18-Sep	4	4	24	6	0
2010	12-Aug	17-Sep	6	6	24	4	0
2011	15-Aug	27-Sep	20	18	104	5.2	2
2012	3-Jul	1-Oct	36	29	213	5.9	7
Total	19-Jun	1-Oct	204	169	1107	5.4	Load 2=30, 3=3, 4=1, 5=1
Average	18-Jul	15-Sep	22.7	19.4	123	5.3	3.2

where more than twice the average (23) number of fires were jumped (53). The West Yellowstone smokejumper base had the least amount of activity among bases in terms of total missions by almost seven missions annually. The Dornier was used almost exclusively (96%) for all missions. Fire Use objectives were managed for on 7% of the dispatches, the highest percentage observed in any jumper organization. Eighty-five percent of all suppression dispatches were for initial attack. West Yellowstone averaged 5.29 smokejumpers per incident. More than 17% of all actions were reinforcement loads, second only to Alaska (Table 10).

North Cascades. More than 1,227 smokejumpers responded to 259 incidents from the North Cascades smokejumper base in Winthrop, WA. July was the busiest month when more than 48% of the yearly activity occurred. Average annual fire jump load was 29, second lowest in use of smokejumper programs. 2004 and 2009 were the busiest years with 67 and 63 dispatches annually. The average first fire jump of the year occurred on June 26 and the last took place on September 7. Eighty-eight percent of all missions were flown on the CASA 212.

More than 91% of all missions were for initial attack of type 4 and 5 fires (91%). The North Cascades smokejumpers have the third lowest average of jumpers per incident at 5.01 (Table 11).

Table 11. North Cascade smokejumper actions expressed annually.

	1st Jump	Last Jump	# of Missions	# of Fires	# of Jumpers out the door	Avg # of Jumpers per load	# of Reinforcement Loads
NCSB							
2004	21-May	25-Sep	67	60	314	4.7	7
2005	30-May	12-Aug	17	16	77	4.6	1
2006	8-Jun	13-Sep	31	25	139	4.5	6
2007	14-Jul	6-Aug	12	11	50	4.2	1
2008	2-Jul	20-Sep	28	24	139	5	4
2009	7-Jun	16-Sep	63	56	271	4.3	7
2010	29-Jul	13-Aug	18	15	117	6.5	3
2011	10-Aug	2-Oct	6	6	41	6.8	0
2012	24-Jun	20-Sep	17	16	79	4.6	1
Total	21-May	2-Oct	259	229	1227	4.7	Load 2=24, 3=3, 4=1, 5=1, 6=1
Average	26-Jun	7-Sep	28.8	25.4	136.3	5	3.3

Redmond. A total of 2,159 smokejumpers responded to 459 incidents out of Redmond, OR smokejumper base. August was the busiest month of the year with 55% of all missions occurring during that month. The average first jump out of Redmond occurred on June 20 and the last on September 23. The average fire load was 51, 5th amongst bases. 2006 (88) fires and 2008 (76) fires were the busiest years for the Redmond smokejumper program. Roughly 92% of all missions were for initial attack purposes. 93% of all fires that were responded to were classified as type 4 and 5. The Shorts Sherpa was used more than 97% of the time for delivering smokejumpers that were dispatched from Redmond. The second lowest average number of jumpers per fire occurred out of Redmond at 4.90. The proportion of reinforcement loads to all jumped fires was found to be lowest at just over 6% (Table 12).

Table 12. Redmond smokejumper actions expressed annually.

	1st Jump	Last Jump	# of Missions	# of Fires	# of Jumpers out the door	Avg # of Jumpers per load	# of Reinforcement Loads
RAC							
2004	25-Jun	31-Aug	57	57	220	3.9	0
2005	21-Jul	28-Sep	29	24	161	5.6	5
2006	16-May	12-Oct	88	84	363	4.1	4
2007	14-May	3-Sep	37	34	176	4.8	3
2008	21-Jun	2-Oct	76	72	324	4.3	4
2009	30-May	27-Sep	57	52	280	4.9	5
2010	9-Jul	14-Sep	36	32	206	5.7	4
2011	2-Aug	2-Oct	51	48	272	5.3	3
2012	22-Jun	6-Oct	28	26	157	5.6	2
Total	14-May	12-Oct	459	428	2159	4.7	Load 2=27, 3=3, 4=1
Average	20-Jun	23-Sep	51	47.7	239.9	4.9	3.3

Redding. The fourth highest base for total activity occurred out of Redding and its satellite bases in Fresno, Porterville, and San Bernardino. More than 2,573 fire jumps were made into 499 incidents. Annual fire activity was spread more evenly than the other respective

Table 13. Redding smokejumper actions expressed annually.

	1st Jump	Last Jump	# of Missions	# of Fires	# of Jumpers out the door	Avg # of Jumpers per load	# of Reinforcement Loads
RDD							
2004	23-May	9-Oct	56	53	311	5.6	3
2005	22-May	6-Oct	15	15	86	5.7	0
2006	24-Jun	24-Sep	97	95	375	3.9	2
2007	9-May	10-Sep	70	64	359	5.1	6
2008	14-May	25-Oct	100	91	612	6.1	9
2009	22-Apr	7-Oct	63	56	342	5.4	7
2010	25-Jul	29-Sep	14	14	81	5.8	0
2011	30-Jul	23-Sep	22	21	89	4	1
2012	8-Jun	11-Oct	62	59	318	5.1	3
Total	22-Apr	25-Oct	499	464	2573	5.2	Load 2=30, 3=5
Average	5-Jun	2-Oct	55.4	52	285.9	5.2	3.4

bases. Fire season typically began in May and ended in October, with most of the fire load occurring in August (35%). The average date for the first fire jump occurred on June 5 and the last jump on October 2, the latest of all bases. Redding averaged 55 missions per year. 2008 and 2006 were the busiest with 100 and 97 fires respectively. Fifty-five percent of all actions were flown in a Shorts Sherpa and another 35% were in a Dornier. More than 94% of all dispatches were for initial attack. Roughly 86% of the incidents in which smokejumpers responded were type 4 and 5 fires. An average of 5.19 jumpers was utilized per incident, fifth amongst bases (Table 13).

McCall. 2,243 smokejumpers were dispatched to 410 incidents out of McCall, ID and satellite bases operated by the McCall smokejumpers. The McCall smokejumpers use more satellite bases/airports than any other Forest Service base. During the study period 9 different airports were utilized with the greatest number of dispatches coming from Ogden, UT. The average 1st and last jump occurred on July 3 and September 4, respectively. Forty-five percent of

Table 14. McCall smokejumper actions expressed annually.

	1st Jump	Last Jump	# of Missions	# of Fires	# of Jumpers out the door	Avg # of Jumpers per load	# of Reinforcement Loads
MYL							
2004	16-Jun	16-Aug	54	52	235	4.4	2
2005	29-Jun	25-Oct	50	48	271	5.4	2
2006	3-Jul	5-Oct	74	70	432	5.8	4
2007	23-Jun	16-Sep	55	51	358	6.5	4
2008	29-Jun	26-Aug	23	22	130	5.7	1
2009	18-Jul	28-Sep	27	27	154	5.7	0
2010	28-Jul	2-Oct	15	13	101	6.7	2
2011	3-Jul	1-Oct	42	36	194	4.6	6
2012	3-Jul	17-Oct	70	64	368	5.3	6
Total	16-Jun	17-Oct	410	378	2243	5.5	Load 2=24, 3=8
Average	3-Jul	24-Sep	45.6	42.6	249.2	5.6	3

the annual fire load occurred in the month of August, although McCall responds to highest proportion of fires of any base in October (4.4%). The McCall smokejumpers averaged 45 missions a year. 2006 (74) and 2012 (70) were the busiest two seasons during the study. Two aircraft split the brunt of the loads with 69% flown on the Twin Otter and 31% using the DC-3T before it was retired. Only 82% of dispatches were for initial attack purposes, the lowest of all bases even though, 81% of all missions were in response to type 4 and type 5 fires. An average of 5.56 jumpers responded to each individual incident (Table 15).

4.3 Steep/Rugged/Inaccessible Terrain

In order to gain a better understanding of firefighter travel time after the departure from motorized transportation, three terrain features were objectified: steep, rugged, and inaccessible. Steep was defined as slope greater than 21.8 degrees (40%). Rugged was calculated using the VRM and defined as values greater than 0.006. Inaccessible was determined by calculating hiking times using a travel time model that considered distance, slope, ground cover, and barriers. Output points greater than two hours from the nearest road were deemed inaccessible. Under the aforementioned parameters, 12% of the area in the western U.S. is steep, 15% is rugged, and 10% is inaccessible. Steep, rugged, and inaccessible parameters coincide on 2.6% of the landscape.

Zonal statistics of steep, rugged, and inaccessible terrain were calculated for every federal jurisdiction in the western U.S. (Table 15). Results were characterized by total area rather than proportion, thus large jurisdictional units had a greater chance of containing terrain within set parameters. Steep terrain is most prevalent in National Forest lands, where 93% of the top 30 jurisdictional units reside. More than half of the 4.3 million acre Salmon-Challis NF qualified as ‘steep’, with roughly 2.4 million acres of terrain greater than 40 percent slope.

Table 15. Top 30 jurisdictions in steep, rugged, inaccessible terrain in western U.S. (by area). Table color-coded by number of times a jurisdiction met the S.R.I terrain criteria: white (one), green (at least 2), and red (all four).

Rank	Steep (S)	Rugged (R.)	Inaccessible (I)	Steep, Rugged, and Inaccessible
1	Salmon-Challis NF (USFS)	California Desert Disrict (BLM)	Nez Perce-Clearwater NF (USFS)	MT Baker-Snoqualmie NF (USFS)
2	Okanogan-Wenatchee NF (USFS)	Los Padres NF (USFS)	Salmon-Challis NF (USFS)	Okanogan-Wenatchee NF (USFS)
3	Humboldt-Toiyabe NF (USFS)	Navajo (BIA)	Okanogan-Wenatchee NF (USFS)	North Cascades NP (NPS)
4	Nez Perce-Clearwater NF (USFS)	Okanogan-Wenatchee NF (USFS)	Humboldt-Toiyabe NF (USFS)	Grand Canyon NP (NPS)
5	MT Baker-Snoqualmie NF (USFS)	Humboldt-Toiyabe NF (USFS)	Bridger-Teton NF (USFS)	Glacier NP (NPS)
6	Lolo NF (USFS)	Salmon-Challis NF (USFS)	Shoshone NF (USFS)	Shoshone NF (USFS)
7	Idaho Panhandle NF (USFS)	Nez Perce-Clearwater NF (USFS)	Yellowstone NP (NPS)	Olympic NP (NPS)
8	Shasta-Trinity NF (USFS)	Ely District (BLM)	Flathead NF (USFS)	Salmon-Challis NF (USFS)
9	California Desert District (BLM)	Tonto NF (USFS)	Death Valley NP (NPS)	Sequoia & Kings NP (NPS)
10	Flathead NF (USFS)	Colorodo River District (BLM)	Payette NF (USFS)	Inyo NF (USFS)
11	Shoshone NF (USFS)	MT Baker-Snoqualmie NF (USFS)	MT Baker-Snoqualmie NF (USFS)	Truxton Canyon FO (BIA)
12	Boise NF (USFS)	Death Valley NP (NPS)	Gallatin NF (USFS)	Bridger-Teton NF (USFS)
13	Payette NF (USFS)	Shasta-Trinity NF (USFS)	Ely District (BLM)	Flathead NF (USFS)
14	Los Padres NF (USFS)	Boise NF (USFS)	Kootenai NF (USFS)	Nez Perce-Clearwater NF (USFS)
15	Wallowa-Whitman NF (USFS)	Battle Mountain District (BLM)	Battle Mountain District (BLM)	Glen Canyon NRA (NPS)
16	Bridger-Teton NF (USFS)	Gila NF (USFS)	California Desert District (BLM)	Navajo (BIA)
17	Sawtooth NF (USFS)	Shoshone NF (USFS)	Lewis and Clark NF (USFS)	Gallatin NF (USFS)
18	Uinta-Wasatch-Cache NF (USFS)	Carson City District (BLM)	Bitteroot NF (USFS)	San Juan NF (USFS)
19	Ely District (BLM)	Central California District (BLM)	Idaho Panhandle NF (USFS)	Bitteroot NF (USFS)
20	Kootenai NF (USFS)	Wallowa-Whitman NF (USFS)	Inyo NF (USFS)	Payette NF (USFS)
21	Bitteroot NF (USFS)	Bridger-Teton NF (USFS)	Caribou-Targhee NF (USFS)	Humboldt-Toiyabe NF (USFS)
22	Klamath NF (USFS)	Uinta-Wasatch-Cache NF (USFS)	Sawtooth NF (USFS).	Death Valley NP (NPS)
23	Beaverhead-Deerlodge NF (USFS)	Coronado NF (USFS)	Grand Mesa, Unc. and Gun. NF (USFS)	White River NF (USFS)
24	Gallatin NF (USFS)	Inyo NF (USFS)	Glacier NP (NPS)	Uinta-Wasatch-Cache NF (USFS)
25	Caribou-Targhee NF (USFS)	Winnemucca District (BLM)	Sequoia & Kings NP (NPS)	Sawtooth NF (USFS).
26	Rogue River-Siskiyou NF (USFS)	Grand Canyon NP (NPS)	Olympic NP (NPS)	Custer NF (USFS)
27	Death Valley NP (NPS)	Idaho Panhandle NF (USFS)	Gila NF (USFS)	Wallowa-Whitman NF (USFS)
28	Grand Mesa, Unc. and Gun. NF (USFS)	Payette NF (USFS)	Boise NF (USFS)	Grand Mesa, Unc. and Gun. NF (USFS)
29	White River NF (USFS)	Wind River/Bighorn Basin District (BLM)	Uinta-Wasatch-Cache NF (USFS)	Olympic NF (USFS)
30	Gila NF (USFS)	Rogue River-Siskiyou NF (USFS)	White River NF (USFS)	Sierra NF (USFS)

Key
Meets All
Meets at least 2
Meets 1

Arid lands in the great basin and southwest accounted for more than half of the top 30 ‘rugged’ federal lands. The BLM’s California Desert District contains 1.54 million acres of ‘rugged’ terrain, the most of any federal jurisdiction. California’s Los Padres NF contains 1.2 million acres of rugged lands, the most of any National Forest. Analysis revealed that inaccessible terrain occurs largely in wilderness areas and national parks. The farthest Euclidean distance from a road in the western U.S. was calculated to be 21.5 miles and lies in the Thorofare Basin, Yellowstone NP. The most remote location in the western U.S. was a roughly 30 hour continuous hike to a point (46.200° x -114.981°) near Halfway Creek between Fish Lake and Moose Creek in the Selway-Bitterroot Wilderness, the third largest wilderness in the contiguous U.S. (Figure 10).

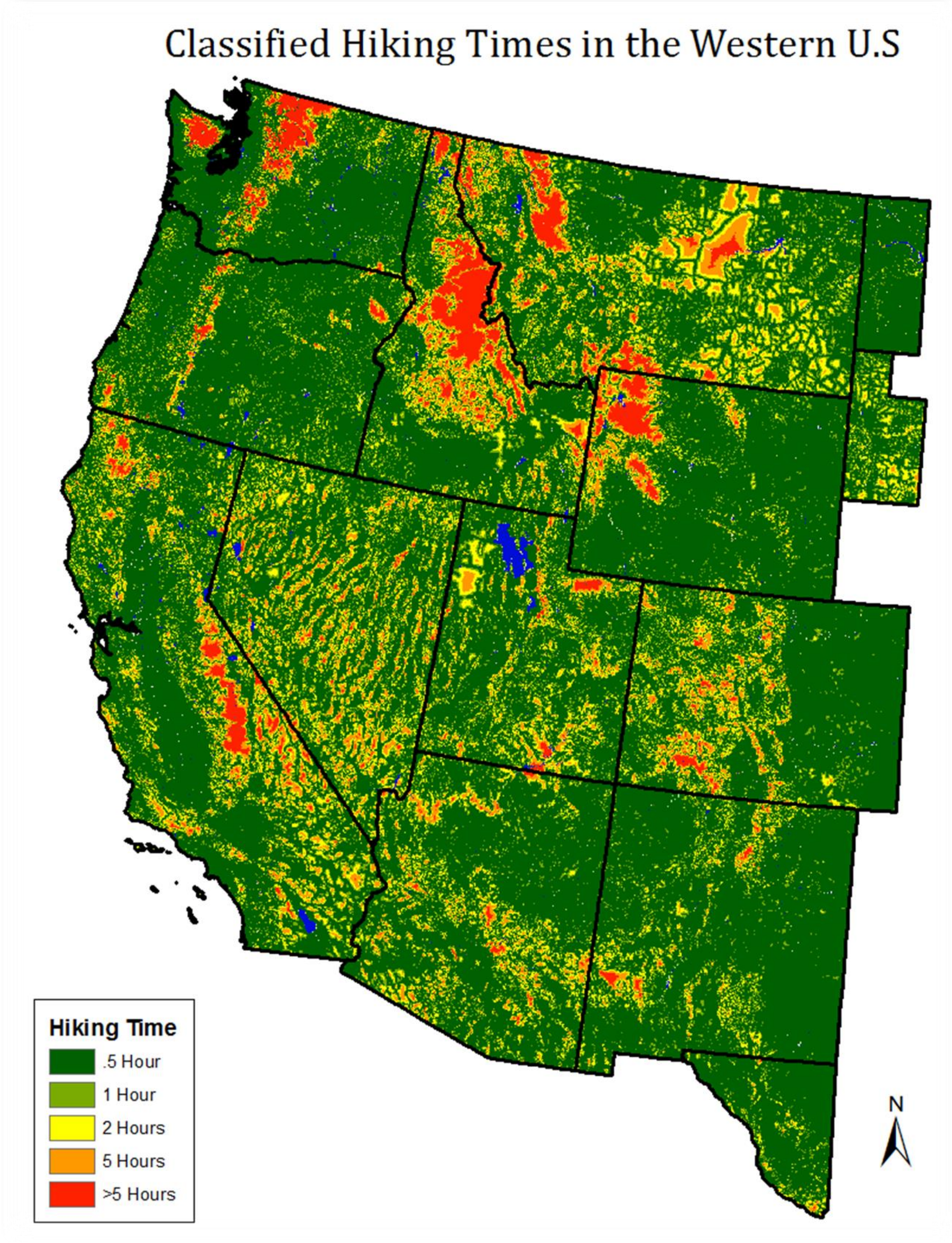


Figure 10. Classified travel times in the western U.S. Results expressed gradually from short (green) to long (red) duration.

The Nez-Perce Clearwater NF encompasses over 3 million acres of land that was determined to be at least 2 hours hiking time from the nearest road. 70% of federal jurisdictions containing the most inaccessible terrain were found in large National Forests with significant conservation of natural resources, one example being the aforementioned Nez-Perce Clearwater NF, where nearly half the total area is designated wilderness. A cumulative distribution of hiking times for the western US reveals that half the landscape (30 m resolution) is a 20 minute or less hike from the nearest road, and 82% is within one hour (Figure 11).

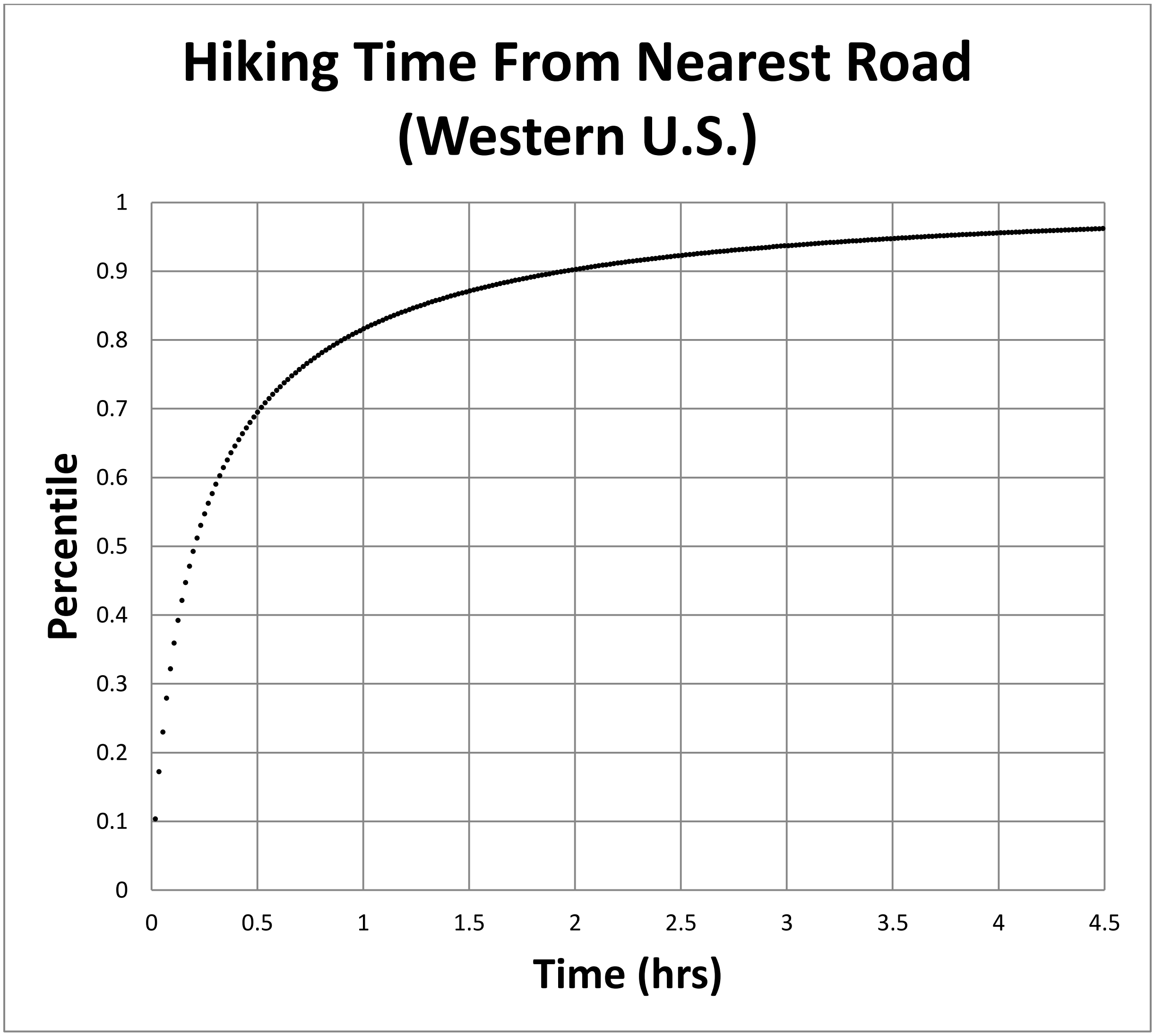


Figure 11. Cumulative hiking time from the nearest road for the western U.S. (30m-resolution).

Yellowstone (1.48 million), Death Valley (1.33 million), Glacier (771,984), Sequoia & Kings (766,741), and Olympic (748,055) National Parks were all ranked in the top 30 for total acreage of inaccessible terrain.

Four of the top six prominent units where steep, rugged, and inaccessible parameters coincide all exist in in the Pacific Northwest Region 6 (Table 15). Landscapes with these characteristics are somewhat rare, as only 2.17 million acres were found on federal lands in the entire western U.S. The Mt Baker-Snoqualmie NF comprises the most coincidental area with 147,364 acres. One third of the top 30 jurisdictions with coincident steep, rugged, and inaccessible terrain are within the National Park Service, with the North Cascades NP leading the way with 111,587 acres.

4.4 Physical Factors of Smokejumper Usage

4.4.1 Distance from Base

Smokejumpers can reach every acre in the western US in less than 1.5 hours from existing bases using the slowest aircraft with the shortest range in the current fleet, and not stopping for fuel along the way. Every fire that smokejumpers responded to was easily within the range of existing bases, although it should be noted that many satellite bases are only staffed on a seasonal or call-when-needed basis (Figure 12). If one considers only bases that are operational for several months every year e.g. Missoula, McCall, etc., coverage to every acre in the western U.S. is still achievable in less than 2.8 hours.

On average, smokejumpers tend to be utilized closer to established bases/airports. The mean distance to nearest base for fires that were jumped was 54 miles (21.6 minutes flight time) versus the mean distance for all fires was 80.2 miles (32.1 minutes).

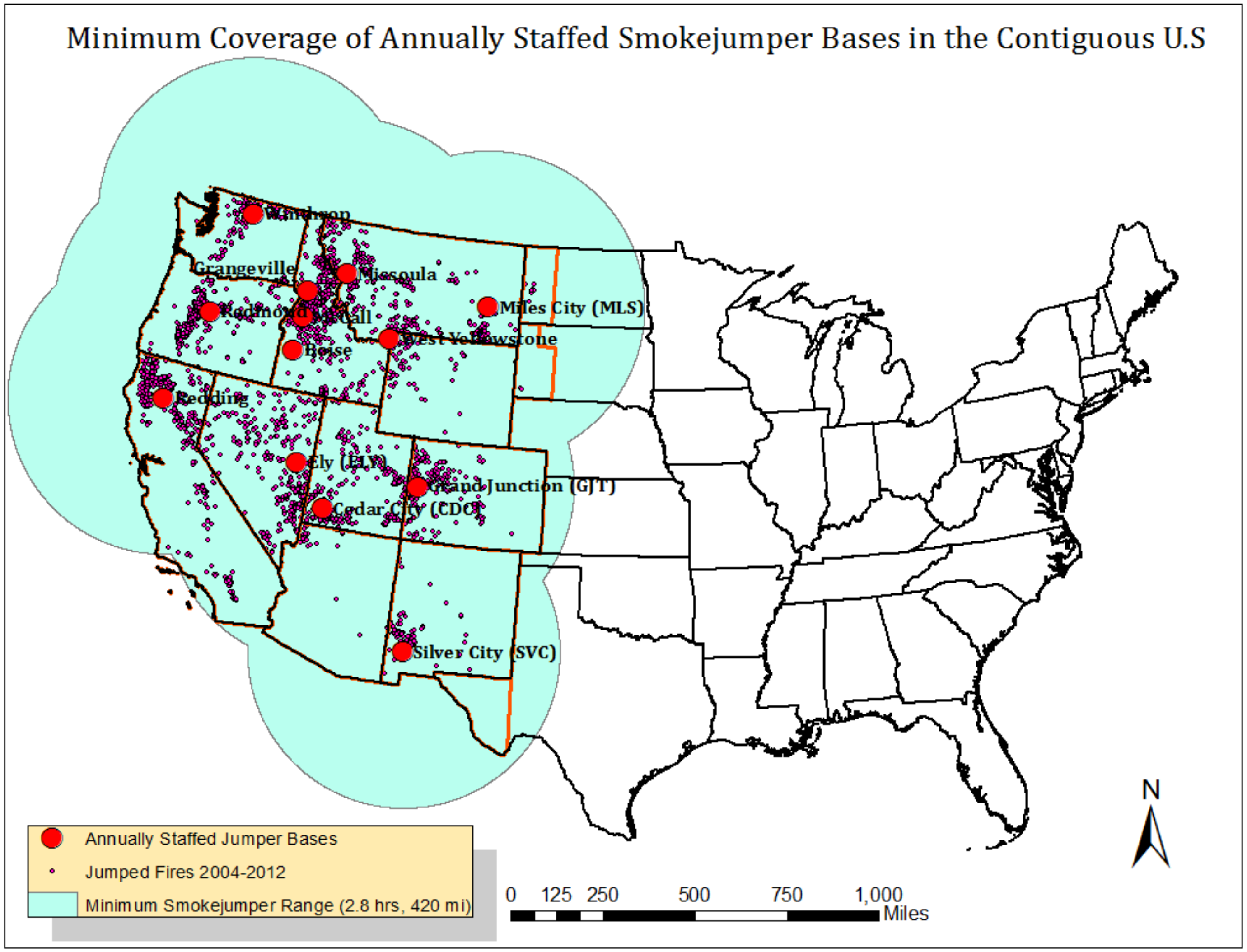


Figure 12. Minimum coverage of annually staffed smokejumper bases in the contiguous U.S. Blue buffer represents the capabilities of the Twin Otter aircraft, the slowest aircraft with the smallest range in the current smokejumper fleet.

For actions where smokejumpers were dispatched, the average distance from the base they were stationed was 95.7 miles (38.3 minute flight time) suggesting most use to be closely correlated with proximity of smokejumper resources. The ratio of smokejumper actions to all actions is highest (2.6%) within 40 miles of bases/airports. Ratios decrease the further an incident lies from a base (Figure 13).

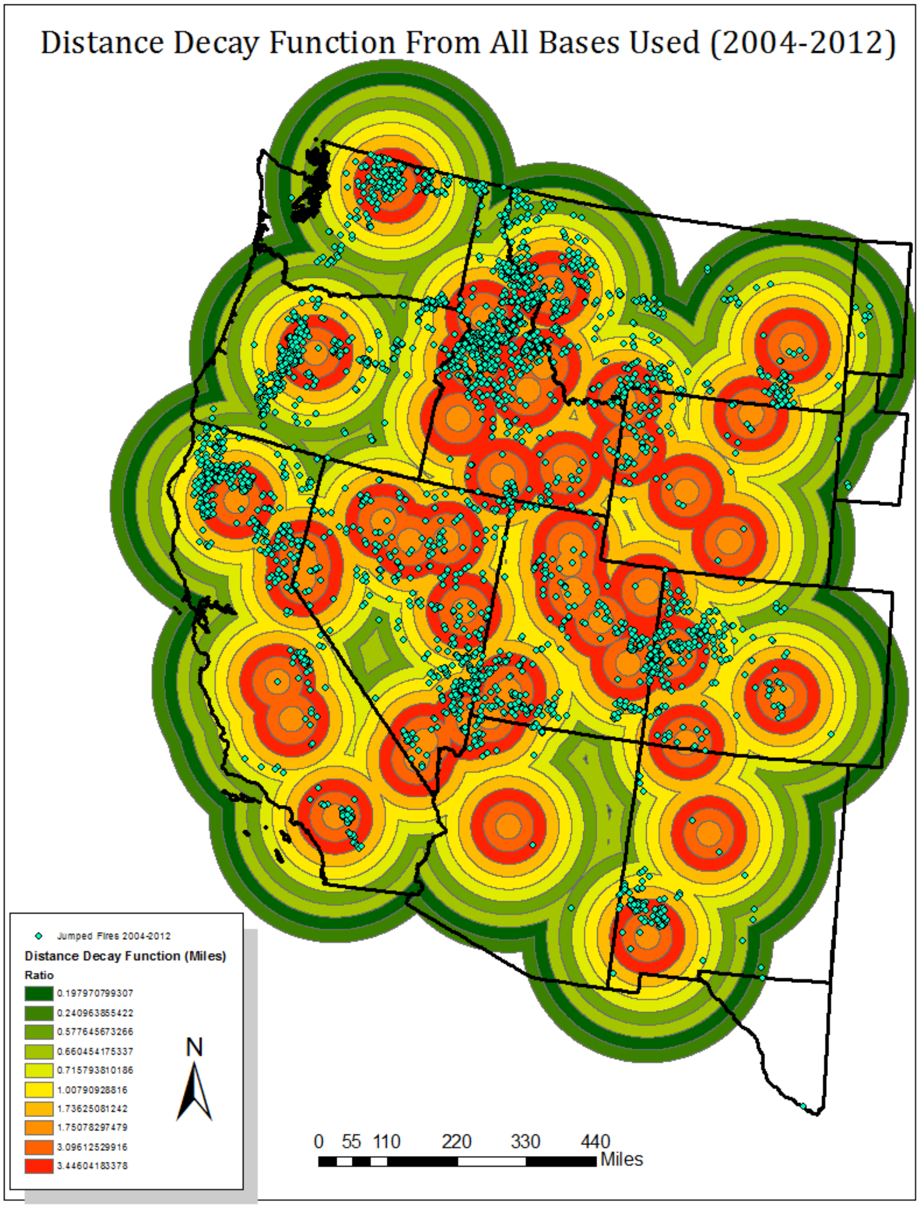


Figure 13. Distance decay function from each base used (2004-2012). Ratio is calculated between jumper missions to all fires. Each ring represents 20 miles and proportions of use are color-coded ascending in color from low (green) to high (red).

4.4.2 Slope/Aspect/Elevation/Roughness

Landscape characteristics including terrain have an effect on smokejumper utilization in the western U.S. On average, incidents in which smokejumpers respond are steeper and higher in elevation. Roughly 40% of all incidents lie on a flat aspect compared to only 7% of smokejumpers incidents. The mean slope for smokejumper incidents was 17 degrees (30.6%), compared with all incidents where a mean slope of just under 8 degrees was observed (13.7 %). More than 86% of all jumper actions were above the median value of slope for all fires. Correlation between smokejumper usage and elevation of an incident is evident in this analysis, as the mean elevation of fires that were jumped was 605 feet greater than the mean of all fires. Spatial analysis revealed 87% of the fires jumped to be higher in elevation than the median of all fires. The vector ruggedness measure attempts to quantify terrain ruggedness, an important variable in accessibility, fire behavior, and ultimately managerial strategy and staffing decisions. Results provide evidence that jumpers are responding to fires in rougher terrain. Mean and median ruggedness of incidents jumpers responded was determined to be 0.004232 and 0.002105 respectively, more than twice as rough as the mean of all fires and six times the median.

4.4.3 Fuels

Analysis of fuel types in the western U.S. suggest smokejumpers are being used on incidents that are primarily occurring in timber. Geospatial analysis showed that nearly 50% of all jumper usage occurred in timber fuel types 8, 9, and 10. Grass fuel types (1, 2, and 3) were the second most frequently jumped, followed by brush (4, 5, and 6) (Figure 14). Comparatively, mapping showed that a majority of all fires across the landscape occur in grass fuel types (~34%), followed by timber, other, and brush (Table 16).

Table 16. Fuel model comparison of all fires to fires in which smokejumpers responded in the western U.S. (2004-2012).

	Grass	Brush	Timber	Slash	Other
ALL Fires	33.5%	14.8%	29.3%	< 1%	22.3%
Smokejumper Missions	27.8%	18.9%	49.5%	< 1%	3.3%

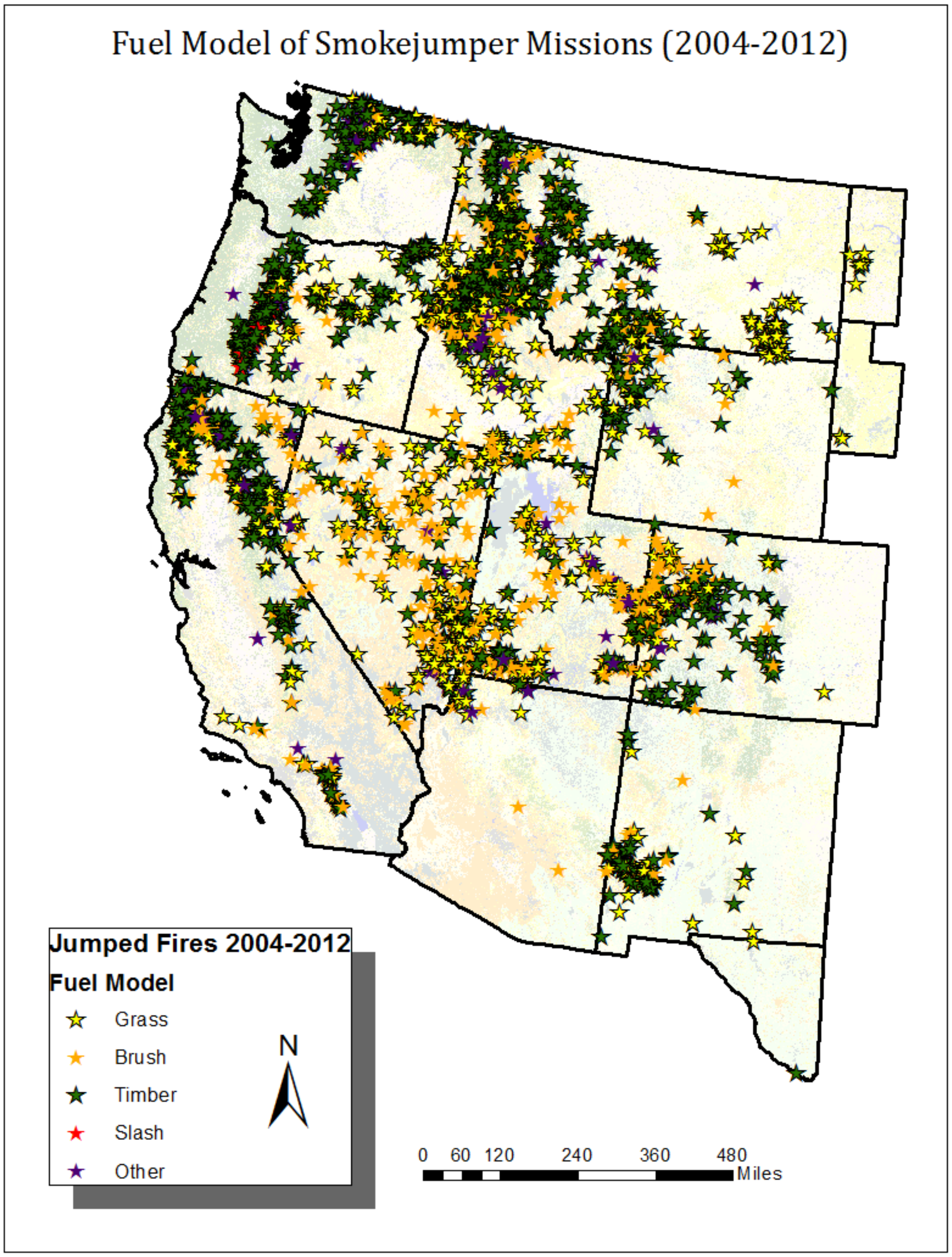


Figure 14. Smokejumper missions (2004-2012) in the contiguous U.S. labeled by fuel model. Timber (green), grass (yellow), brush (orange), slash (red), and other (purple).

4.4.4 Distance from Road

Proximal analysis of fire to the nearest road suggests smokejumpers are being dispatched to incidents further from roads. Results are increasingly evident when mapped against the median distance of all fires to the nearest road (Figure 15). Mean distance from nearest road for all incidents was 0.32 miles compared to 1.29 miles for fires that were jumped. Calculations show that smokejumpers were dispatched to fires that were on average nearly five times further than the mean distance of all fires and 13.6 times further than the median.

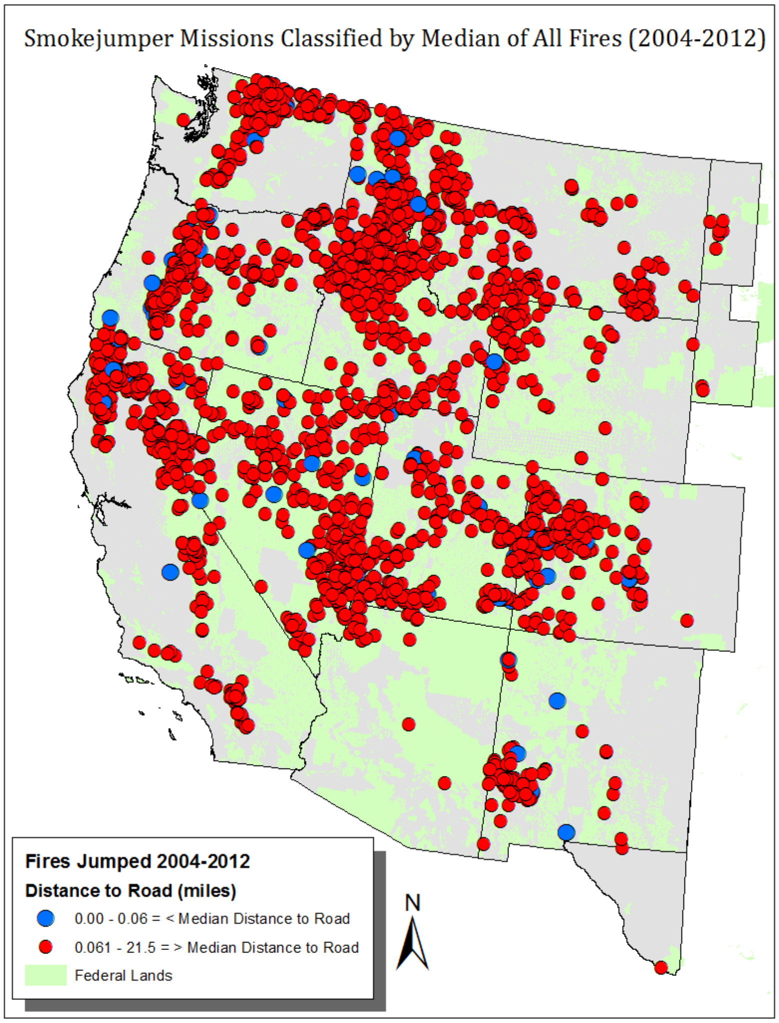


Figure 15. Binary classification of smokjumper missions (2004-2012) mapped by median of total fire load. Blue circles (less than) and red circles (greater than) than the median of all fires that occurred between 2004-2012.

4.4.5 Travel Time

Many factors dictate total time elapsed after leaving the motorized vehicle to arriving on scene of an incident. Thus, distance by itself is not always the optimal way to define this variable. The same travel time model used to define inaccessible terrain was again implemented to analyze factors influencing smokejumper use. In most instances, smokejumpers were dispatched to fires that took longer to reach by means of hiking (Figure 16). The mean hiking time for incidents in which smokejumpers responded was 2.6 hours; 5.7 times longer than the average for all fires (0.46 hours). Comparison of median hiking times between smokejumper fires and all fires reveals an even more compelling trend where smokejumper fires (1.29 hours) are 33.4 times harder to reach than all fires (0.038 hours-2.3 minutes).

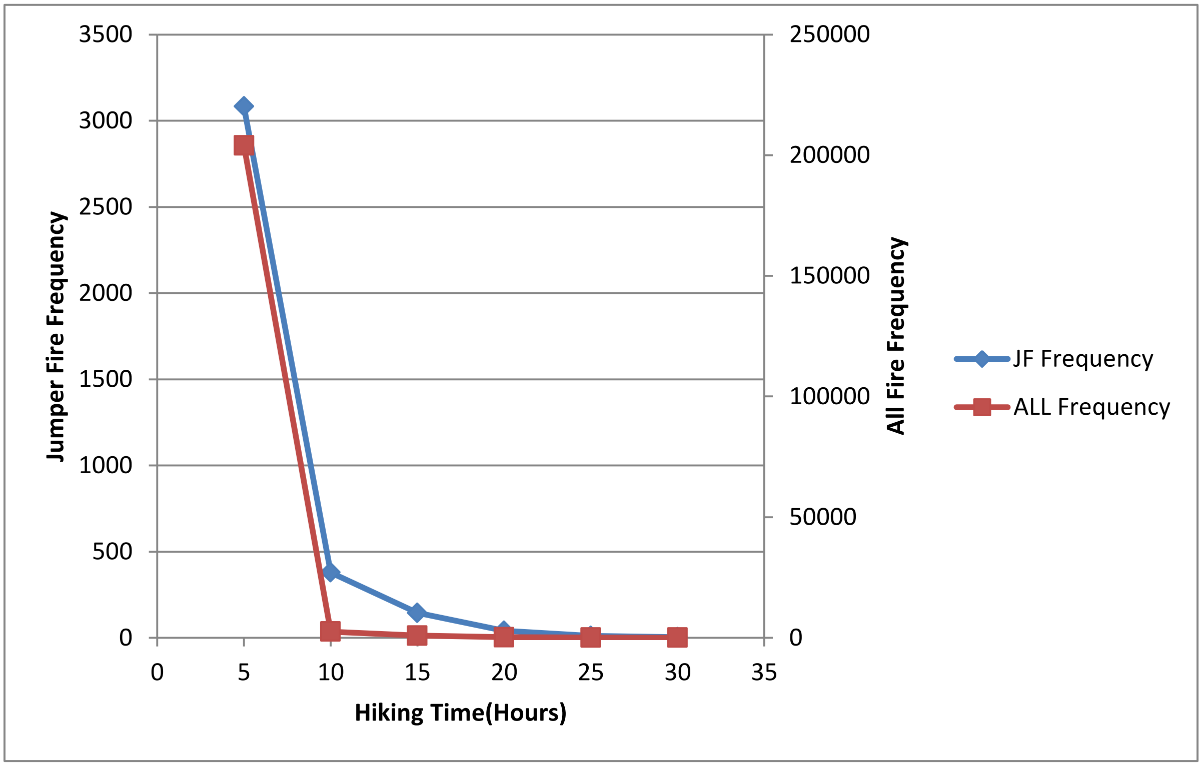


Figure 16. Comparision of travel time between smokejumper missions (blue) (primary axis) and total fire load (red) (secondary axis).

4.5 Comparisons of Smokejumper Actions to All Fires

Considering that smokejumpers can get to every acre in the conterminous U.S. quickly from established bases, it is appropriate to assess utilization relative to the occurrence of all fires. Significant evidence indicates that in the context of total fire load smokejumpers are dispatched to fires in steeper, rougher, and higher terrain (Figure 17). Spatial calculations reveal smokejumpers are most actively used further from roads, on landscapes that are harder access on foot and on incidents that are closer to the bases where jumpers are stationed (Table 17).

Table 17. Comparison of results between total fire load (red), smokejumper missions (blue), and all fires within 10 mile buffer analysis (green).

	All Fires L48		**Jumper Fires L48**		**ALL Fires (10 Mile Buffer)**	
	Mean	*Median*	*Mean*	*Median*	*Mean*	*Median*
Elevation (Ft)	1191.6	1213	1796.9	1801	1496	1548
Slope (Deg)	7.8	4	17.0	16	11.5	9
Hiking Time (Hrs)	0.46	0.04	2.6	1.3	0.96	0.14
Distance to Nearest Rd (Mi)	0.32	0.06	1.5	0.76	0.59	0.13
Distance to Nearest Base (Mi)	80.2	71.6	54.1	47.8	55.4	49.1
Distance to Nearest Base (Hr)	0.53	0.48	0.36	0.32	0.37	0.33
Distance to Base Dispatched (Mi)			95.7	65.8		
Distance to Base Dispatched (Hr)			0.64	0.44		
Roughness (VRM)	0.002119	0.000336	0.004232	0.002105	0.002977	0.000963

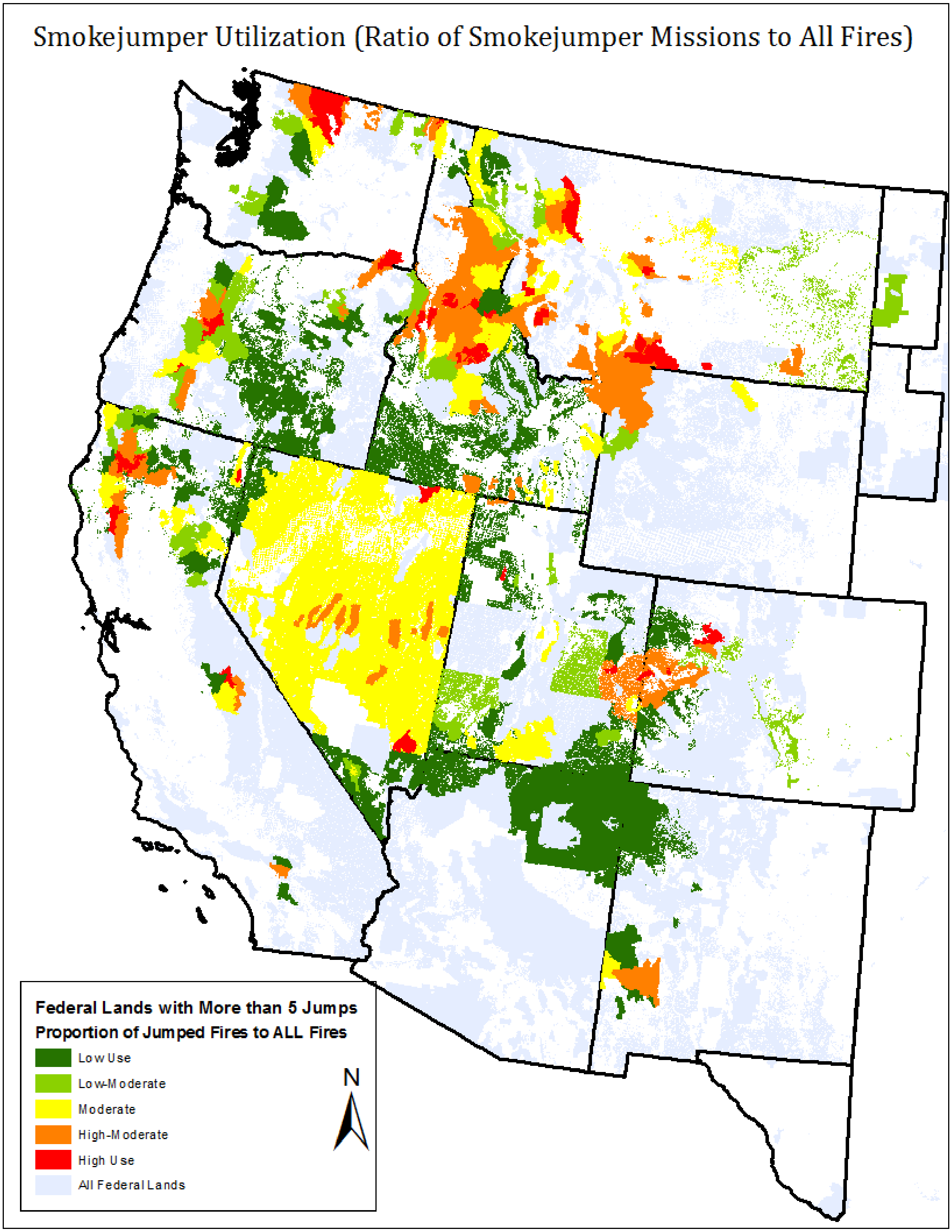


Figure 17. Smokejumper utilization on federally managed lands with more than five smokejumper missions (2004-2012). Proportion of use (smokejumper missions/all fires that occurred) shown gradually from low use (green) to high use (red).

In an effort to identify landscapes that more closely resemble where smokejumpers are currently being used in terms of terrain, a second analysis was performed. This time a 10 mile buffer was placed around every existing action that smokejumpers responded (Figure 18). This successfully reduced the study area and eliminated most private lands, municipal areas, and other landscapes that were not previously jumped in the last nine years.   However, this approach does present shortcomings because it is no longer analyzing fires that occur across much of the landscape that are geographically similar to areas where smokejumpers routinely are used.

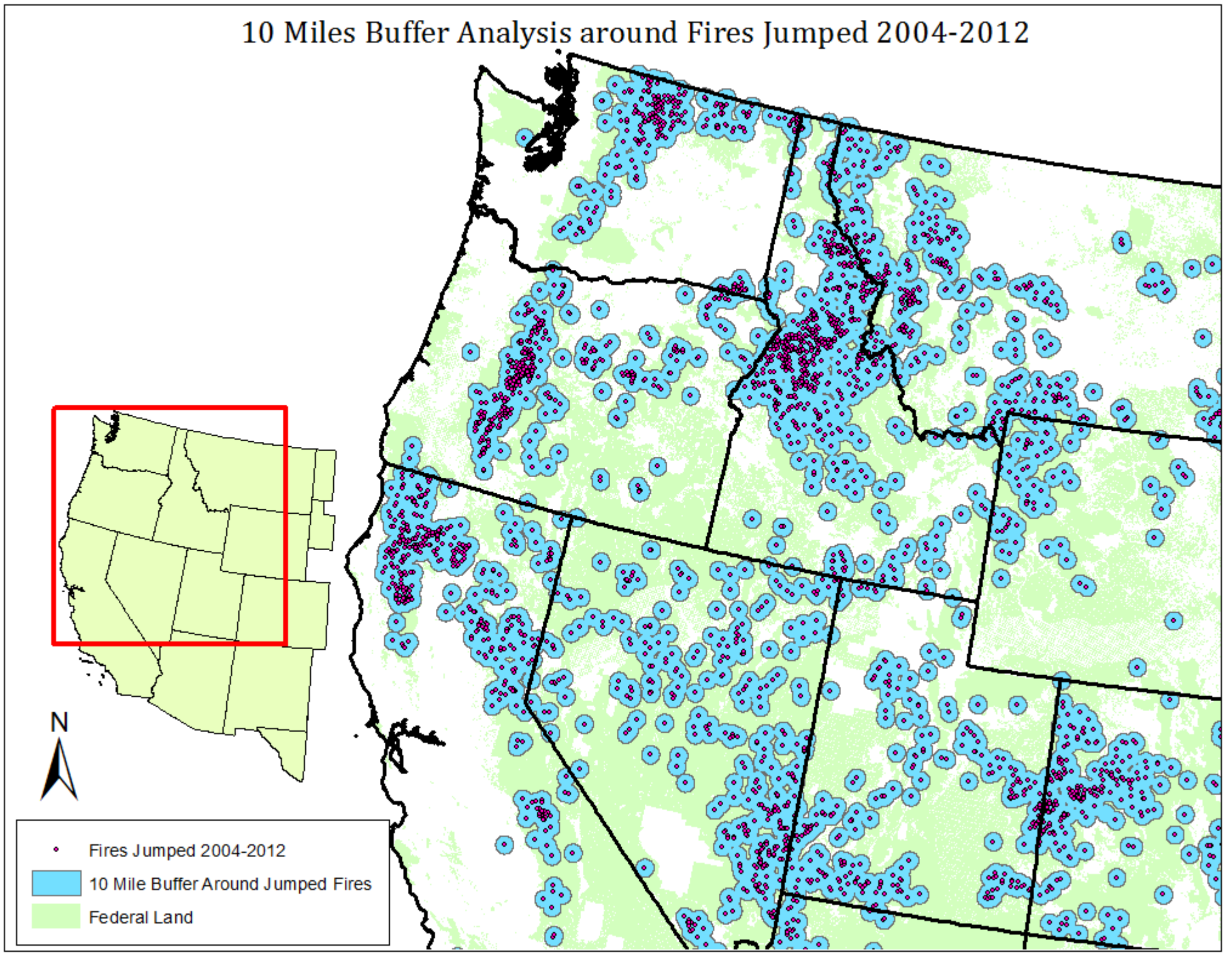


Figure 18. A secondary terrain and accessibility analyis was completed in areas within a 10 mile radial buffer (blue) around smokejumper missions (purple) (2004-2012) that occurred within the contiguous U.S.

Although findings were less significant than comparison between all fires in western U.S., the same general trends appeared. Mean slope (11.46), elevation (1496), and roughness (0.00297) were all lower than the same respective measures of smokejumper fires. A second analysis of all fires within a 10 mile buffer additionally found distance to nearest road (0.59 miles) and hiking time (0.96 hours) averages to be less than jumper incidents. Average proximal distance to nearest base of buffered fires was only marginally greater, which was expected considering only fires within close proximity of jumper fires were considered.

Smokejumper usage has traditionally occurred exclusively on federally and state owned lands. In comparison with total fire load across the landscape, 12 USFS Forests used smokejumpers on at least 10% of all ignitions, led by the Payette (21.6%), Lewis and Clark (16.4%), and Gallatin (16.1%). Eleven USFS Ranger Districts used smokejumpers on more than 20% of all starts, led by the Pomeroy RD (30%), Methow Valley RD (28%), and New Meadows RD (26%) (Figure 17). The Grand Junction Field Office, Moab FO, and Ely District Office all used smokejumpers on roughly 10% of total fire load on their respective lands. Although not widely used in all National Parks, smokejumpers were deployed regularly in several large parks including North Cascades NP (20%), Crater Lake NP (11%), and Yellowstone NP (8.5%).

Smokejumper use tends to be substantial in designated wilderness areas. Twenty-three percent of all fires jumped were in wilderness areas while only 3.1% of total fire load occurred in these areas. Smokejumpers were used on more than 25% of total fire load in 10 different wildernesses (Table 18). Jumpers responded to less than 1% of total fires that ignited on state owned property.

Table 18. Top 20 most used wilderness areas in regards to total proportion of smokejumper missions (2004-2012).

Top 20 Wilderness Areas of Jumper Use	Proportion of all fires that were jumped (%)
Absaroka-Beartooth Wilderness	59.5
Pasayten Wilderness	50.0
Three Sisters Wilderness	45.8
Trinity Alps Wilderness	42.5
Wenaha-Tucannon Wilderness	40.7
Yolla Bolly-Middle Eel Wilderness	39.7
Gospel-Hump Wilderness	39.2
Waldo Lake Wilderness	36.1
Sapphire Wilderness Study Area	27.1
Rogue-Umpqua Divide Wilderness	27.0
San Gorgonio Wilderness	24.6
Frank Church-River of No Return Wilderness	21.9
Ansel Adams Wilderness	20.0
Marble Mountain Wilderness	19.5
Stephen Mather Wilderness	19.2
Bob Marshall Wilderness	19.1
Gila Wilderness	18.2
Sky Lakes Wilderness	16.9
Aldo Leopold Wilderness	14.3
Selway-Bitterroot Wilderness	9.8

4.6 Defining “Smokejumper Fires”

A more refined analysis attempts to map characteristics of fires and terrain that smokejumpers are more likely to respond to regardless of jurisdiction. Three parameters were put into place to identify these characteristics. They are distance (hiking time), steepness (slope), and roughness (VRM). Binary classifications were created for each variable by determining median values of characteristics of fires that were jumped. All fires that fell within areas above the median values for distance, steepness, and roughness were deemed “smokejumper fires.” If one considers only fires meeting these characteristics, 7,462 fires were considered ‘smokejumper’ fires, 3.59% of the total population. Smokejumpers actually responded to 832 of these fires, roughly 20% of the total jumped fire population.

Zonal statistics of terrain and accessibility data show that roughly 2.2 million acres of land distributed on 495 different federally managed lands meet the criteria defined above. Of these areas, 1.28 million acres (58%) are USFS Forests. Lands managed by NPS were second in total area with 592,501 acres followed by BLM with 139,669 acres, USFWS 130,624 acres, and finally BIA with 111,053 acres. Two large forests in Region 6 were found to have the most area that met the aforementioned criteria (Table 19). Five National Parks and two Indian Agencies were in the top 15 in total area. The Methow Valley, Darrington, and Mt Baker Ranger districts were each found to each contain in excess of 40,000 acres.

Table 19. Federal jurisdictions ranked by total area that meets "smokejumper" critria (2004-2012).

Rank by Area	Location	Area (Acres)	# ALL Fires in SRI	# JF In SRI
1	Mt Baker-Snoqualmie National Forest	147,337	128	6
2	Okanogan-Wenatchee National Forest	145,207	286	50
3	North Cascades National Park	111,569	78	11
4	Grand Canyon National Park	105,331	14	0
5	Glacier National Park	78,637	20	1
6	Shoshone National Forest	75,305	20	6
7	Olympic National Park	74,593	42	0
8	Salmon-Challis National Forest	71,385	295	27
9	Sequoia & Kings National Park	66,920	75	0
10	Inyo National Forest	64,952	53	1

While it is important to examine physical attributes of terrain in a spatial context, it is the frequency of fire ignitions that drives the relevancy of these analyses. Investigation of fire occurrence in smokejumper-prone landscapes in relation to total fire load reveals that most fires are occurring on our National Forest lands (Table 20) (Figure 19). The top 17 jurisdictional units with the most fires meeting smokejumper criteria all occur on USFS

Forests. The North Fork, Moose Creek, and Lochsa/Powell Ranger Districts on the Nez-Perce Clearwater NF have had more than 119 total fires each that meet the criteria of a "smokejumper" fire. The North Fork district on the Salmon-Challis NF and the West Fork district on the Bitterroot NF also had more than 115 total ignitions. The Ely District Office led non-USFS lands with 100 fires that met the said conditions.

Table 20. Federal jurisdictions ranked by total "smokejumper" fire occurrence (2004-2012).

Rank by Fire Occurrence	Location	Area (Acres)	# ALL Fires in SRI	# JF In SRI
1	Nez Perce-Clearwater National Forest	37,357	592	99
2	Salmon-Challis National Forest	71,385	295	27
3	Okanogan-Wenatchee National Forest	145,207	286	50
4	Boise National Forest	4,323	218	13
5	Gila National Forest	11,613	194	28
6	Bitterroot National Forest	30,861	175	7
7	Idaho Panhandle National Forests	7,218	174	27
8	Humboldt-Toiyabe National Forest	29,399	171	15
9	Shasta-Trinity National Forest	12,356	159	57
10	Kootenai National Forest	17,013	150	17

Further exploration revealed the Nez-Perce National Forest to have nearly twice the number of jumped fires (99) that met "smokejumper" criteria than any other federal jurisdiction. The Shasta-Trinity NF (17%) and Okanogan-Wenatchee NF (36%) both used jumpers on more than 50 fires that met the conditions. The Methow Valley, Pomeroy, Weaverville, St. Joe, and Big Bar Ranger Districts all had more than 40 total "smokejumper" fires on their respective districts and used jumpers on more than 40% of those fires. Thirteen of the top 45 federal lands with the most smokejumper use are areas with wilderness designation. Wilderness areas where smokejumpers were used most frequently include the Trinity Alps (32), Selway-Bitterroot (30), and Wenaha-Tucannon Wildernesses (22). Federal Forests with the highest proportion of jumped fires that met the criteria to total fires that met “smokejumper” conditions are the Umatilla (51%), Mendocino (46%), and Shasta Trinity NF (36%); all above 35%. Of the 72 jurisdictions that contain five or more fires that were jumped in aforementioned conditions, 69 had a jumper proportion greater than 10%. Nineteen USFS Ranger Districts and three BLM Field Offices had a proportion of “smokejumper” fires jumped to all fires above 20%.

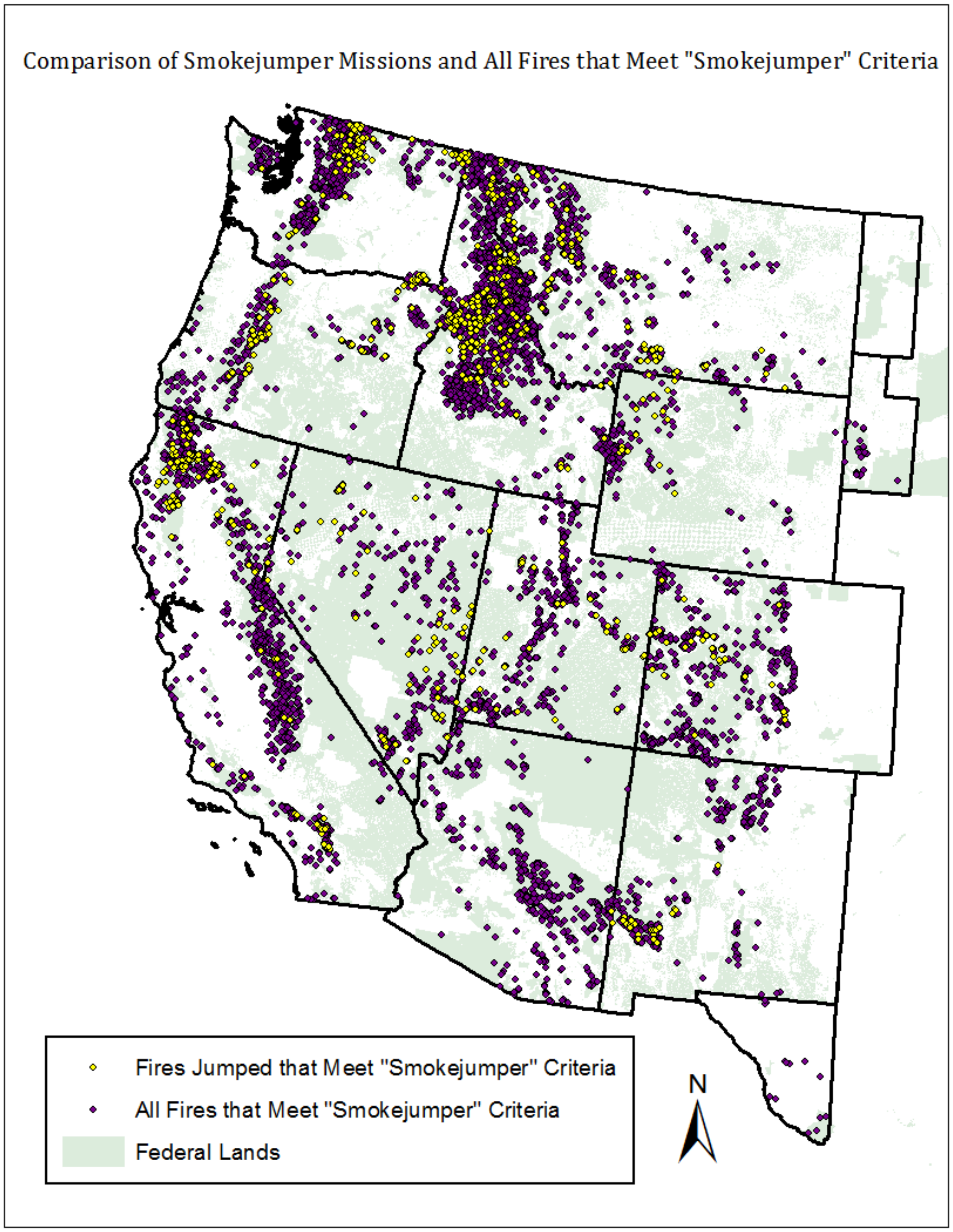


Figure 19. Comparison of smokejumper missions (yellow) to all fires (purple) that meet defined “smokejumper” criteria (2004-2012).

4.7 Identification of areas where smokejumpers may be under-utilized

Geographic characteristics, historical use, and total fire load combine to give us an idea of where smokejumpers might be under-utilized. As discussed previously, spatial examination of geographic characteristics allows one to classify current distribution of smokejumpers fires and to discover terrain with similar physical features. In regards to proportion of jumps per total area of smokejumper terrain (steep, rough inaccessible), jumpers are least used on lands managed by the USFWS followed by the BIA, BLM, NPS, and the USFS (Table 21). It should be noted that total area calculated in which said "smokejumper" terrain parameters were met was highest on USFS land, with 1.28 million acres. The NPS had the second highest total of said land with 592,501 acres although there were only 86 fires jumped, the third lowest of any agency. Fifty-seven separate federally managed areas with at least 15 fires that met "smokejumper" standards had zero smokejumper use including 14 USFS Forests, 30 USFS Ranger Districts, 9 designated wilderness areas, 5 BLM units, 4 National Parks, and 1 USFWS Refuge.

Table 21. Total area comparison between federal agencies (2004-2012).

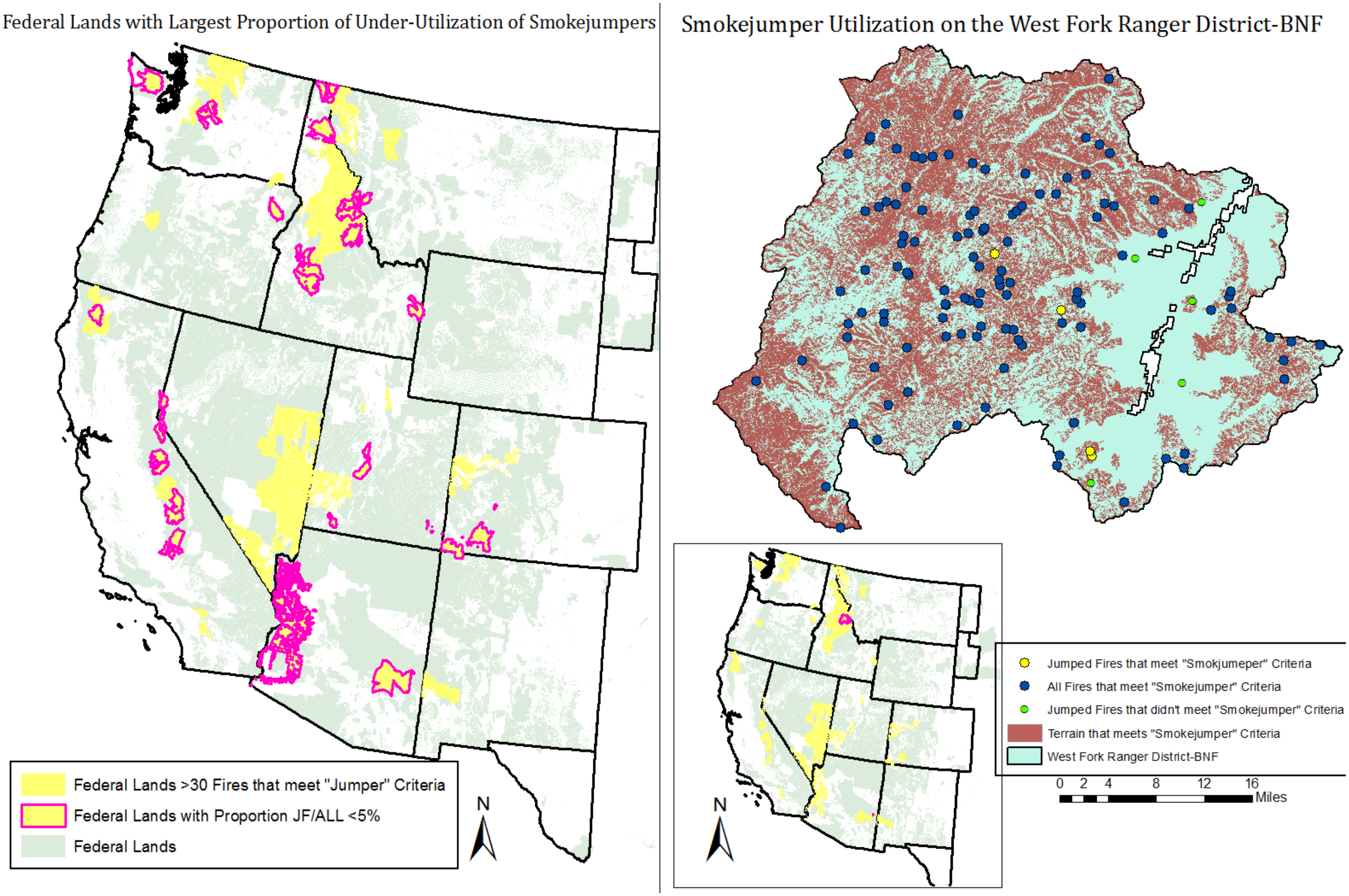
Federal Agency	Total Area (Acres)	Total Area "Smokejumper" Terrain	Percentage of "Smokejumper Area"
USFS	165,055,723	1,280,000	56.8%
NPS	21,635,735	592,501	26.3%
BLM	172,272,542	139,669	6.2%
USFWS	7,544,212	130,624	5.9%
BIA	58,823,695	111,053	4.9%

Table 22. Federal jurisictions with more than 30 fires that fell within "smokejumper" terrain parameters with less than a five percent proportion of smokejumper use (2004-2012).

Jurisdiction	ALL	Jumped	Proportion %
West Fork Ranger District	115	4	3.48
Sequoia & Kings NP	75	0	0.00
Idaho City Ranger District	64	0	0.00
Selway-Bitterroot Wilderness on Bitterroot NF	59	1	1.69
Bonners Ferry Ranger District	49	0	0.00
Yosemite National Park	48	0	0.00
Carson Ranger District	47	2	4.26
Salmon River Ranger District	45	2	4.44
Emmett Ranger District	43	0	0.00
Olympic National Park	42	0	0.00
Salmon-Cobalt Ranger District	42	1	2.38
Cle Elum Ranger District	42	1	2.38
Eagle Cap Ranger District	41	1	2.44
Columbine Ranger District	39	1	2.56
Palisades Ranger District	37	1	2.70
Kern River Ranger District	37	0	0.00
Zion National Park	36	1	2.78
Fillmore Ranger District	36	1	2.78
San Carlos Agency	35	0	0.00
Ute Mountain Agency	35	0	0.00
Mountain Home Ranger District	35	0	0.00
Darby Ranger District	33	0	0.00
Colorado River BLM District	31	0	0.00
Coeur d'Alene River Ranger District	31	0	0.00
Kings Canyon National Park	31	0	0.00

An analysis focusing on jurisdictions with more than 30 fires occurring with "smokejumper" terrain parameters revealed 79 separate federally managed lands (Figure 20). Of those, 28 had a total proportion of jumped fires under 5%, and 17 had zero smokejumper use during the study period (Table 22). The West Fork Ranger District (BNF), Sequoia & Kings Canyon National Park, Idaho City Ranger District (BOF), Selway-Bitterroot Wilderness (BNF), and Bonners Ferry Ranger District (IPF) were the top 5 jurisdictions in total "smokejumper" fires with a proportion of jumper fires less than 5%.

Figure 20. (Left) Federal lands with more than 30 fires that meet “smokejumper” terrain criteria (yellow) with a proportion of smokejumper use less than five percent (pink outline). (Right) Inset of West Fork Ranger District (Bitterroot NF) with “smokejumper” terrain criteria (red), smokejumper missions meeting criteria (yellow circles), all fires that meet criteria (blue circles) and smokejumper fires not meeting criteria (green circles) (2004-2012).



Examination of ratios between fires jumped and total fire load regardless of geographic physical traits is also vital in understanding where smokejumpers are not currently used. Calculation of total proportion of fires that were jumped per administrative unit to total fire load reveals that smokejumpers are used most heavily on USFS lands (4.3%) followed by BLM (3.8%), NPS (2.6%), USFWS (0.85%), and BIA (0.25%) (Table 23). Investigation of federal lands revealed over 1,300 separate jurisdictional areas did not use smokejumpers. These include all but three USFWS lands, 107 NPS lands, 106 USFS Ranger Districts, 51 BIA Agencies, 30 BLM units and 9 USFS Forests. On federals lands with at least 50 ignitions, 140 have no smokejumper use. Thirty-three of the top 100 federal domains of total fire load did not use smokejumpers for any fires that occurred, 12 of which had more than 500 ignitions. Only 16% of the top 100 areas with the most fire load used smokejumpers on more than 5% of the total fires. The Pine Ridge, San Carlos, and Navajo Agencies are among the top 5 federal lands in total fire load, although smokejumpers were used on only six incidents.

Federal Agency	**# of Fires Jumped**	**# of Total Fires**	**Proportion of Fires Jumped**
USFS	2568	59704	4.3%
NPS	86	3271	2.6%
BLM	856	22788	3.8%
USFWS	7	822	0.85%
BIA	59	23884	0.25%

Table 23. Comparison of total fire occurrence between Federal agencies (2004-2012).

4.8 BLM Operational Models in Alaska and Great Basin

BLM smokejumpers use a different operational approach in deploying resources when compared with USFS jumpers. Thirty-one different satellite bases/airports were used in the Great Basin and seven were used in Alaska to deploy jumpers around their respective geographic regions. This model allows jumpers logistical advantages by moving resources to areas with predicted ignitions or depleted resource pool. Further, it allows jumpers to develop relationships with fire managers who might ultimately use them.

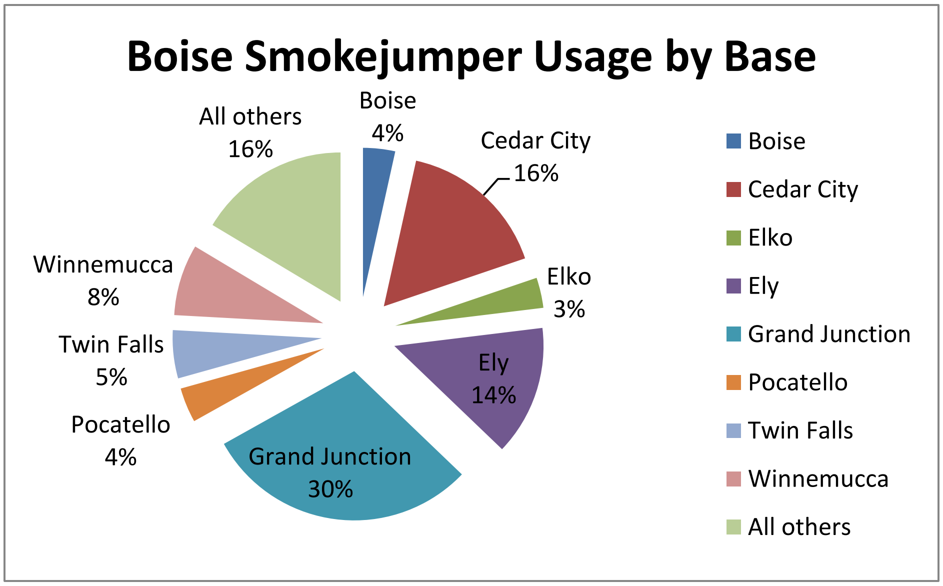


Figure 21. Percentages of Boise smokjumper actions broken down per base.

Boise. Grand Junction, CO, Cedar City, UT and Ely, NV were the three most heavily used bases by the BLM Boise smokejumper program. Roughly 4% of the total Boise smokejumper fire load was dispatched from the main base in Boise, ID (Figure 21). Based on their geographic location (Great Basin), Boise jumpers tend to be dispatched to a different kind of incident than USFS jumpers. Seventy-four percent of all fires were jumped in grass (38%) and brush (34%) fuel models. When compared to all jumps in the western U.S., Boise smokejumpers responded to higher elevations (13%), flatter slopes (-17%), slightly less rough terrain (-1.6%), more than two times closer to roads (-53%), and fires 2.3 times as accessible on foot (-57%). As expected, Boise jumpers were dispatched to fires closer to existing bases/airports.

Alaska. Alaska smokejumper operations run similar to Boise where resources are moved to areas of higher activity or potential, although not to the same magnitude. Seventy-six percent of all missions were dispatched from the main base in Fairbanks, followed by Galena, and McGrath. Speed and range are the primary drivers of usage for smokejumpers in the state of Alaska. The Alaska smokejumpers jump a larger proportion of total fire load than any other active smokejumper program. During the nine year study period, AK jumpers were dispatched to more than 10% of all fires in Alaska. With their current base configuration and aircraft fleet, AK jumpers are capable of reaching 95% of the total fire load in the state of Alaska, the only lapse of coverage befalling the south-east panhandle of the state (Figure 22). Most commonly, fires occur in remote and inaccessible areas that are difficult or impossible to reach by ground. The mean distance from nearest road for all fires is 10.45 miles and the average distance to nearest base is over 100 air miles (0.59 hour flight time). Typically, AK smokejumpers managed fires that were a significant distance from roads (14.92 miles), and a substantial distance from the base they were dispatched (1.09 hour flight time). Due to the nature of Alaskan terrain, there was no attempt to objectifying physical characteristics of the landscape.

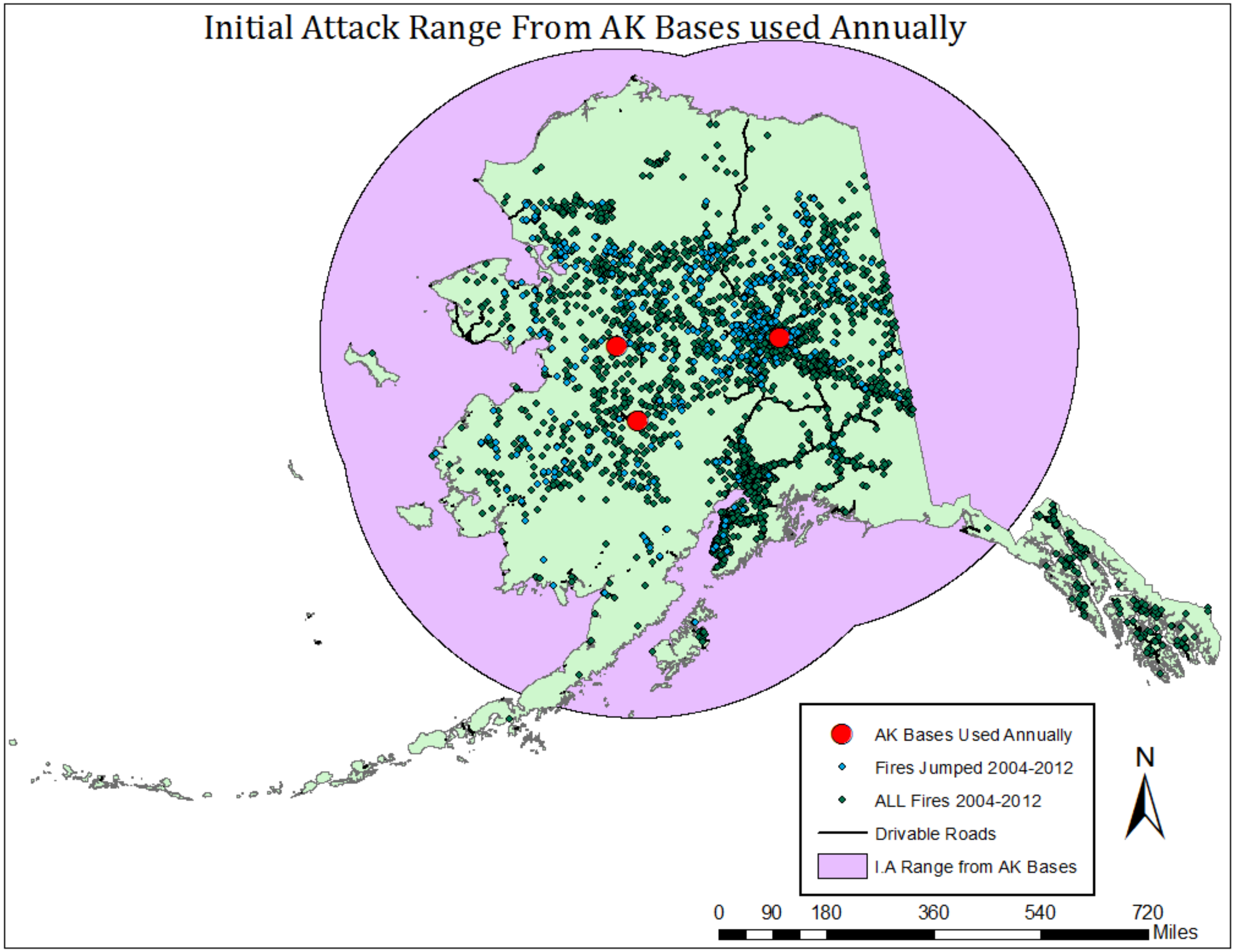


Figure 22. Alaska smokejumper initial attack range (500 miles, 2.77 hours) from bases used annually (Fairbanks, McGrath, Galena) (2004-2012).

5. DISCUSSION

In this study, I intended to both provide systematic results of smokejumper utilization, and to characterize the physical factors of the western U.S. that are related to their usage. I examined the use of U.S. smokejumpers and compared these results with the total fire occurrence. I objectified and spatially identified terrain parameters that were thought to be related to the utilization of smokejumpers, including elevation, slope, inaccessibility (hiking time), terrain roughness, distance to nearest road, and distance to base. This work takes an initial step toward the culminating goal of improving the efficacy of the U.S. smokejumper program and the wildland fire community as a whole.

5.1 Smokejumper Usage

Many current and former firefighters believe that smokejumpers are used in four primary instances: 1) fire proximal location is too inaccessible or “nasty” to reach, 2) fire is too large or complex for local resources to handle, 3) the local resource pool is depleted, 4) fire manager in charge of the staffing decision is “pro” jumper. Staffing decisions can be further broken into two categories, physical and social. Although social factors are vital to firefighter staffing decisions, they are extremely difficult to analyze. This study solely focused on examining the physical factors that may lead to smokejumper usage.

For the study area analyzed (western U.S.), results show a correlation between physical factors and smokejumper use. When compared with total fire load smokejumpers tend to jump more steep, rugged, and inaccessible terrain. Additional analysis suggests that a relationship also exists between smokejumper usage and fire proximity to smokejumper base. What follows is a more thorough assessment of each finding.

Terrain. Slope, elevation, and roughness of terrain affect smokejumper use in the western U.S. Fires occurring on steeper, higher elevation, and rougher terrain were more likely to be jumped compared with those that occurred on flat, low elevation, and smoother landscapes. This suggests that incidents smokejumpers are staffing are in areas fire managers may deem too difficult to reach or unsafe for local resources to engage. Although slope and ruggedness are correlated, the VRM was chosen to quantify surface characteristics because of its ability to clearly distinguish slope from ruggedness. Quantifying ruggedness independently of slope is important because humans may perceive these characteristics differently when assessing travel path, strategy, and staffing levels. With an exception of Redding, CA (495 ft.), the 6 other main bases in the western U.S. averaged an elevation of 4,042 feet above sea level. The geographic location of bases exemplifies the likelihood that jumpers would typically respond to fires that are higher in elevation. However, the mean and median elevations of incidents jumped were still significantly higher than all fires, even when compared to those occurring within a 10 mile buffer. This suggests that jumpers may be used more frequently on ignitions occurring on the upper reaches of the slope or ridge tops.

Accessibility/Distance from Road. Results overwhelmingly suggest that one of the main factors determining smokejumpers usage is ground accessibility and distance to road from an incident. The hiking time model showed that on average fires jumpers respond to are remote and typically challenging to reach on foot. Changing weather patterns, fuels accumulation, and an expanding wildland urban interface have been considered as factors for increased fire damage (Ryan and Opperman, 2013). This in turn puts greater public pressure on land agencies to act on fires that they would typically let burn. Longer, drier, fires seasons with increased fire numbers and severity could weigh on staffing levels, funding, and planning. Remoteness and accessibility of fire proximity compound problems for agency land managers. Smokejumpers offer an easy solution of speed, range, and payload. National Forests such as Nez Perce-Clearwater, Shasta-Trinity, and Okanogan-Wenatchee, all whom have large parcels of remote and inaccessible terrain, continually rely on smokejumpers for initial attack of wildfires, suggesting significant correlation between jumper usage, fire accessibility and distance from road. The fact that each of these jurisdictions is adjacent to a smokejumper base (GAC, RDD, NCSB) highlights the wisdom of decision-making that went in to establishing these bases as well as the comparative advantages of local ownership of IA resources.

Distance from base. A strong correlation was discovered between proximity of fire in relation to placement of smokejumper resources. Fires with locations closer to smokejumper bases were found to have increased probability that smokejumpers would be the resources to respond. I believe there are many factors that influence this finding. Geographic placement of duty station, awareness of capabilities, budget and funding commonalities, and response time/ distance all heavily influence the probability jumpers are used proximal to base. For example, smokejumper bases have been historically placed in geographic locations that are conducive to their use. These areas are typically comprised of an increased amount of steep, rugged, and inaccessible terrain. Subsequently, administrative units that interact with smokejumpers understand their capabilities. Thus, they generally consider smokejumper usage as an option when weighing management decisions, whereas managers and duty officers whom regularly don't use jumpers may not even consider them because they are unfamiliar or unaware of jumper capabilities, response time, or availability. Alternatively, smokejumper bases that are funded by individual administrative units may be more likely to use jumpers. For instance, the Nez Perce-Clearwater, Gallatin, McCall, and North Cascades smokejumper bases all respond to a large portion of fires on their respective ‘home’ units. This phenomenon is also seen largely in spike bases used by both BLM and USFS jumpers all across the west. Finally, I believe speed plays a large role in smokejumper use. Smokejumpers take pride in expedient dispatch times (USFS, 2008) and do not have to deal with unforeseen obstacles associated with driving: such as traffic, bad roads, or vehicle issues.   The median jumper travel time from base to incident for all fires in the western U.S. was 26.3 minutes. Additionally, jumpers have the ability to respond to fires more than 425 miles away in less than 2.8 hours (BLM, 2008). This capability allows jumpers to arrive on scene for initial attack or emerging incidents in a timely manner.

10 mile buffer analysis. When compared to total fire load, correlation between smokejumper use and terrain is clear. However, this analysis considers a copious amount of fires in jurisdictions and geographic locations that jumpers have historically never been used. In an effort to reduce scope, a 10 mile buffer zone was placed around each individual fire on which smokejumpers were used. Finally, only fires with a proximity that fell within those bounds were compared. Nonetheless, smokejumper incidents were still found to be higher in elevation, on steeper slopes, in rougher terrain, closer to roads, and easier to access on foot. This further highlights the strong connection between physical factors and smokejumper use and reduces doubt surrounding the notion that the first analysis of all fires did not correctly capture the observed relationships.

Areas jumpers aren’t being used. It is difficult to speculate why jumpers are used in one area and not another. However using spatial analysis techniques I made an effort to identify areas of infrequent smokejumper use and conjecture a reason.   While visually analyzing point maps displaying historical jumper usage is revealing, classification of terrain was implemented to further analyze where and how land managers can efficiently use smokejumpers. Median values from all jumped fires allowed me to generate physical terrain parameters. These parameters were then mapped and zonal statistics were calculated for every federal jurisdiction in the western U.S. The USFS and NPS were found to have the most acreage that met “smokejumper” parameters; however, only 86 fires were jumped on lands managed by the NPS. This may be traced to management policies where, in most cases, fires are allowed to burn. Conversely, 0.08% of all BLM lands were found to meet aforementioned parameters, although 856 fires were jumped. These results lead one to believe that smokejumpers are being utilized for reasons other than terrain on BLM lands and I will examine this in greater detail later in the discussion. If we are to only examine proportion of fires jumped to all fires regardless of terrain, it is evident jumpers are largely under-utilized on lands managed by the BIA and USFWS. Speculation of this finding can be traced back to terrain, where the USFWS and BIA ranked one and two amongst federal jurisdictions in least amount of “smokejumper” terrain, roughly 10 and 12 times less acreage compared with the USFS, respectively (Table 24).

Table 24. Federal jurisdictions ranked by total number of fires ignitions (2004-2012).

Rank	Land Ownership	Total Area "Smokejumper" (ac)	# of All Fires	# of Jumped Fires
1	Pine Ridge Agency	1.46	3336	0
2	San Carlos Agency	1,783	2317	1
3	Ely District Office	11,748	1550	149
4	Navajo Agency	31,871	1465	5
5	Bend/Fort Rock Ranger District	92.54	1280	70
6	Peaks Ranger District	52.14	1260	0
7	Boise BLM District	124.4	1191	8
8	Fort Apache Agency	508.19	1183	0
9	Pima Agency	477.8	935	0
10	Arizona Strip Field Office	3901	879	26

5.2 Objectifying Steep, Rugged, and Inaccessible Terrain

Collectively, the geospatial layers I produced provide an objective, spatially-explicit characterization of steep, rugged, inaccessible terrain. The wildland fire reporting catchphrase, ‘steep, rugged, inaccessible, terrain’ has become perhaps the most widely used agency slogan. It is a way for fire managers to explain difficulties in control efforts, to justify the deployment or non-deployment of resources and personnel to the public, and to validate decisions not to take direct actions on incidents they might otherwise suppress. Although to some extent, steep, rugged, and inaccessible will always remain in the eye of the beholder; the controversy surrounding the use of terrain (and accessibility) to justify management actions suggests a need for at least some objective data to support decisions and communicate more clearly to the public. These data from this study represent a starting point for the purposes of communication and planning. The thresholds identified could easily be ‘fine-tuned’ and made more sophisticated to better meet the needs of managers and the terrain they oversee.

The biggest weakness of the current approach is in the definition of ruggedness, which is limited by a 3x3 neighborhood and 10-meter resolution data. The vector ruggedness measure at 10m resolution is still too coarse to capture the complexity of the landscape in a way that is truly meaningful to the movement of wildland firefighters. Past use of the VRM has been primarily in the context of animal habitat analysis (Sappington et al., 2007; Olson et al., 2008, Burdett et al., 2010; Marchand et al., 2014, Lone et al., 2014) rather than barriers to human movement and fire behavior. The main problem concerning development and application is that of computational complexity. LiDAR derived DEMs with higher resolution could possibly be useful, however processing of VRM results for a landscape scale would require a tremendous amount of time and memory and may not be realistic or conceivable. This would limit application of the model to relatively small areas of classification.

5.3 Travel Time Model

The travel time model was employed to depict remoteness and spatially reveal geographic areas that may be considered less accessible than others due to the considerable time and distance required to reach these places. I was able to use the model to achieve an estimated hiking time from nearest drivable road for every 30-meter pixel in the western U.S. Although a version of this algorithm has been used in an effort to map wilderness character in many geographic regions of the world at a National Park sized scale (Fritz and Carver, 1999; Tricker et al. 2012 and 2013; Carver et al. 2003, 2012 and 2013) very little work has been completed for regional to national assessments. This model proved to be a vital factor in determining the usage of smokejumpers across the western U.S. and allows an objectified, spatially explicit characterization of inaccessible terrain. Using the travel time layer I created, wildland fire managers with a rudimentary background in GIS can determine hiking time to any geographic location with the click of a button. This application could be especially useful in strategy and staffing and decisions. Furthermore, the model has multifunctional application and can/should be used outside the realm of classifying terrain for wildand fire. For example, natural resource managers could use the model as an information system for recreational activities and trip planning (e.g. walking, hiking). Further application of this model could be in areas of emergency and search and rescue where the algorithm allows one to predict with certain likelihood the proximity of a missing person and which areas can be ruled out within a certain time.

Although the hiking time model used for this analysis is a solid starting point and has been used on multiple peer-reviewed assessments, there are limitations. One can begin by looking at the algorithm used. As mentioned previously in the methods section, the algorithm is based upon Naismith's Hiking Rule with Langmuir's correction. This rule remains constant and assumes the person traveling the landscape is a fit and healthy individual and does not make allowances for load, weather conditions, or navigational skills. Ultimately, the biggest issue is that Naismith's rule does not take fatigue into account. The model assumes that one would never stop or take extended breaks during the journey, a feat that is highly unlikely. Therefore, this model is most accurate for areas that are within 16 hours of the starting point. However, additional factors such as Tranter's correction can be implemented on top of Naismith's rule that allow for modification by a factor, which is dependent on individual fitness level. This in turn calculates a reduced mean work rate. However, Tranter's correction would involve testing every individual firefighter to determine fatigue level and then running the model for each individual, a method that is highly unlikely due to time and computational constraints.

Successful initial attack of wildfire is dependent upon many factors, one being response time. Total response time elapsed from dispatch to arrival on scene of an incident can be broken into 3 measures: 1) total time from dispatch to departure of duty station, 2) motorized travel time from duty station 3) hiking time from vehicle to incident. In some cases, the 1st and 3rd measures may not be applicable. For example, if a resource was already in 'patrol status' and away from duty station, there would generally not be any time accrued from the point in which the dispatch was received. Additionally, I found that 23% of all fires occurred within 30 meters of an established roadbed. Thus, depending on the size of the fire, hiking time from vehicle would be minimal.

As previously mentioned, quick response time may be an influential factor in smokejumper usage. Also, smokejumpers can typically be more easily diverted to fires that are higher priority, emerging, harder to reach by road, or unreported. Depending on incident proximity to duty station, flight time is typically shorter than drive time. However, during smokejumper response time, it is important to consider additional hiking time from jump spot location to fire incident. This added time is variable and dependent upon numerous elements including: geographic location, fire activity, weather conditions, as well as spotter and jumper comfort level. Due to the fact that jump spots are often in locations away from the fire with divergent physical characteristics, analysis of jump spot would typically not be an applicable or relevant measure.

It has to be noticed that only on a good footpath can Naismith's hiking speed be readily maintained. Thus, I selected fuels data for conditions underfoot cost surface inputs because ground fuel conditions heavily impact walking time. This input allows densely vegetated, trackless, and rocky terrain to be considered and weighed heavily in hiking time predictions. Ultimately, regardless of scale at which data inputs are used, landscapes are continually changing. Without annual updates to fuels and vegetation classification, one cannot keep up with current conditions. The fuels data used for the model (LANDFIRE, 2012) was the most accurate and consistent available. While LANDFIRE products have accuracy issues, they provide the most consistent, up-to-date data for landscape scale analyses.

Assessments at landscape scale limit the ability to locate wall-to-wall data containing thorough accuracy and precision, if at all. Past studies by both Carver and Tricker have implemented trail system layers to additionally modify walking speeds. This step increases certainty in the travel time model by eliminating additional cost of remaining on a trail surface. However, for this analysis, trail systems were not considered in the model. I found it to be neither practical nor feasible to locate comprehensive trails layers for the entire study area. In turn, this may create increased hiking times because the model never assumes to be on a trail. However, short grass and barren fuel models were given the same impedance value as if they were to be walking on a footpath.

Road networks serve as the source grid and are a vital component of the travel time model. This road network is used to determine access points from which to calculate inaccessibility. Similar to fuels, roads are in a constant state of fluctuation. New roads are continually being constructed, while existing roads are being decommissioned at a steady rate. I put a tremendous amount of time and effort into gathering what I determined to be the most current, comprehensive road geodatabase. However, it would not be logical to believe that the roads system used in this analysis did not contain errors. This issue can only be resolved by shrinking the overall scope of the study area. Most administrative units update geospatial data annually, generally with improved precision.

5.4 USFS compared to BLM

Perhaps the most striking aspect of the analysis is comparison between USFS and BLM bases. Results suggest that the respective agencies' smokejumper programs are being used on different kinds of fires. The two bases that have thrown the most smokejumpers are typically jumping geographic areas with the least amount of steep and rugged terrain. This may be a function of relative geographic topography of the service area. Others speculate that BLM utilization is even more highly correlated to social interactions. When comparing BLM to USFS smokejumper missions in the contiguous U.S., fire elevation is the only factor measured in this study that was proven to be greater. Perhaps topographic characteristics in relation to base location is a driving force behind the increase in average fire elevation, where Grand Junction (4593ft.), Cedar City (5846 ft.), and Ely (6437ft) comprise more than 60% of all BLM missions in the western U.S.

Fire regimes are characterizations of how fire disturbance events have shaped an ecosystem. Fire regimes are attributable to three main factors: ignitions, climate, and vegetation (Agee, 1993). The Great Basin region of the western U.S. has a considerably different fire regime when compared to most areas in which USFS smokejumpers service. The spatial comparison between all fires jumped suggests Boise smokejumpers are being dispatched to fires with a vegetation component of primarily grass (38%) and brush (36%). Whereas, USFS jumpers are responding to fire predominantly in a timber fuel types (61%). In a broad sense again, these results quantify what we already know; BLM jumpers are generally engaging different kinds of fires in a different geographic environment.

The results of distance to nearest road and accessibility analysis show BLM jumpers responding to fires significantly closer to roads and easier to access than USFS fires. BLM jumpers are being dispatched to fires an average of 0.82 miles closer to roads (53% decrease) and on average 1.51 hours shorter hiking time (57% decrease). Those trends are most likely the result of a more elaborate road system and generally easier terrain to traverse. While it is difficult to speculate on the condition of ground fuels, timber, chaparral, and slash are typically more difficult to navigate swiftly than grass fuel types. Slope and roughness also negatively factor into overall accessibility and hiking time outputs.

In contrast to USFS smokejumper operations, it is possible that BLM jumpers are being dispatched to fires predominantly for speed and complexity. On average, Boise jumpers respond to incidents that are closer to base (7.4 mi) and larger/more complex. Over 66% of all missions were to Type 4 fires and above. Roughly 21% of the total fire load was in response to Type 3 fires, or emerging incidents. One must take into account that fires in grass and brush typically have a much higher rate of spread, however duration of the fire is generally temporally shorter. Additionally, driving time from duty station to incident was not accounted for. Proximity to duty station and degraded road conditions are among factors that greatly increase driving time in rural areas. More often than not, fires occurring in rural landscapes may take more time for ground resources to arrive than in mountainous terrain, regardless of their proximity to road.

5.5 Management Implications/Program Direction

A complete and systematic assessment of smokejumper actions could lead to change in staffing levels, funding, outreach, and planning. The spatial products generated from this project could help improve the management, reporting, and decision making process of wildland fire as a whole. By allowing managers to identify the physical characteristics that explain spatial variation of physical-related parameters, my approach could help smokejumper outreach and overall efficacy of the wildland fire program. Finally, if trends in smokejumper use are indeed the result geographical physical features, movement of bases closer in proximity to steeper, more rugged and inaccessible geographic environment would allow for a more efficient use of jumpers. The future trajectory and direction of the BLM smokejumper program is largely unknown, however, it appears USFS upper fire management in the Washington Office have contradictory views in which way they foresee the movement of the future of the smokejumper program (T. Harbour personal communication, June 2014). Tom Harbour, USFS National Director of Fire and Aviation, recently stated that he views the use of jumpers moving from small, remote fires, to emerging incidents with the potential of threatening life and personal property in the wildland urban interface. Although we do not currently have enough time with consistent record keeping to properly extrapolate historical trends, results from this research indicate smokejumpers are still currently being used on small, remote fires largely in designated wilderness. Until fire managers receive this message and learn to use smokejumpers outside their traditional realm, jumpers will probably continue to be used on incidents where they have historically been used: those occurring in steep, rugged, and inaccessible terrain. If trends to allow more fires to burn in remote areas continue, one might anticipate declining opportunities for smokejumpers through time without changes in practices and utilization patterns.

Data Quality. Consistency of individual data entry into the SMA continues to be an issue that limits key analyses. Fire size (acres, size classification), fuel type, and wind characteristics are currently in a state that cannot be used for analysis. At present, either significant portions of the data are missing, or data entry is not consistent. For example, instead of entering size (acres) of an incident when jump operations occurred, some users are reporting final fire size. The same issue is hindering the fire 'type' and size classification variables, where users are either skipping it all together or entering data upon the final fire complexity. Thus, caution should be used when making conclusions about the complexity of incidents that jumpers respond to. I was unable to update these entries because the FPA FOD records are reported as final fire statistics. Fuel type and yards of drift were not added to the SMA until 2007 and 2012 respectively. Even then, many users are getting around entering valid numbers by using N/A, 0, or -1. It should be noted that data entry and completeness of records are improving every year in the SMA. However, independent, standardized data with continuous coverage have not yet been achieved. Until all users become consistent and vigilant, a complete and accurate assessment will not be feasible without a great deal of data mining and extra work.

The FPA FOD all fire database records date back to 1992, and the Smokejumper Master Action database was just recently brought into existence in 2004. Although the two databases present a greater than adequate number of records to determine present day usage, it is difficult to extrapolate and properly examine long term trends. Smokejumper actions are well documented back to the 1940s, however they are fragmented and often times collected at a base level. Tracking down complete records would not be an easy task. Organization of all jumper records into a single database is feasible, although the amount of time and effort to clean these records into a reliable source for analysis would require immense dedication, skill, and connections to the smokejumper community. Advancements in technology have changed the way we record data, thus creating a discrepancy in accuracy and consistency. For example, the advent of the Global Positioning System (GPS) replaced the Public Land Survey, and enabled an improvement in proximal location. Therefore, while an analysis of historical smokejumper trends would be beneficial and intriguing, we currently do not have the ability to produce such results.

6. CONCLUSIONS and FUTURE WORK

The results of these analyses are summarized below.

1.) The western U.S. can be classified as 12% steep (>40 % slope), 15% rugged (VRM >0.006) and 10% inaccessible (>2 hour hike from nearest road). Steep, rugged, and inaccessible coincide on 2.6% of the landscape
2.) The travel time model potentially sheds new light on the concept of roadlessness in the West, where half the landscape is a 20 minute walk from motorized access, and 82% of the landscape is within one hour.
3.) The most remote and hardest to reach areas in the West occur in Idaho and Wyoming. The farthest Euclidean distance from a road is roughly 21.5 miles and lies in the Thorofare Basin, Yellowstone NP, and the most remote/inaccessible location (~30 hiking time) occurs near Halfway Creek between Fish Lake and Moose Creek in the Selway-Bitterroot Wilderness.
4.) Primary use of smokejumpers during the last nine years in the conterminous U.S. has occurred on USFS (69%) and BLM (20%) jurisdictions.
5.) The USFS (54%), BIA (22%), and BLM (21%) dominated the percentage of total fire load on federal lands in the western U.S.
6.) Roughly 23% of all smokejumper missions were in response to fires occurring within designated wilderness in the western U.S.
7.) When proportionally compared to total fire load, fires in which smokejumpers responded in the contiguous U.S. consistently occurred in higher elevation (51%) steeper (117%), rougher (100%), and more inaccessible (473%)

8.) Smokejumpers consistently jumped fires farther from motorized vehicle access (375%) in relation to all fires.
9.) Smokejumpers are being dispatched to fires within closer proximity to smokejumper bases (-33%).

10.) USFS and BLM smokejumpers are responding to different types of fires. USFS smokejumpers typically are jumping fires in steep, rugged, inaccessible terrain whereas response of BLM jumpers is less determined by factors pertaining to physical terrain.

11.) Alaskan smokejumpers staff more than 10% of all fires that occur in the state of Alaska. On average, fires jumped in Alaska were 14.92 miles from the nearest drivable road.

The spatial products created through this project are as follows.

1.) Transferrable, updated, standardized, and spatially explicit SMA database containing a majority (97%) of all aerial smokejumper missions from 2004-2012.
2.) Standardized vector ruggedness measures for the entire western U.S. at a 10-meter resolution.
3.) Steep, rugged, and inaccessible terrain classification layers for the entire study area (30m).
4.) A current (2013), standardized, comprehensive primary and secondary roads shapefile for the western U.S.
5.) Transferable, easily adjusted, python script and travel time grid for the entire western U.S.
6.) Maps and spatially explicit data broken down by individual administrative unit for both smokejumper missions and total fire load.

Recommendations for future work.

1.) Additions to the SMA database in an effort to standardize and get an improved holistic sense of the use of smokejumpers.
2.) Further analysis and comparison of smokejumper use at a regional level.
3.) Comparison of actions of each individual smokejumpers base.
4.) Investigation or improvement of roughness measure at a finer grain so that we can characterize roughness of terrain in a way that is meaningful to the movement of firefighters.
5.) Further improvements to the hiking time model including addition of driving time, amended cost surface, and addition of supplemental trail networks and bridge infrastructure.
6.) Further upgrades to a standardized, continuous road network of all primary and secondary road systems, beginning at a state level and progressing towards regional.
7.) Buffer analysis of past smokejumper missions that further examines spatial distribution of smokejumper usage.
8.) Comparison of smokejumper utilization during a “big fire season” to a more “normal” year.
9.) Extrapolation of historic fire records from all bases in an effort to understand smokejumper trends.

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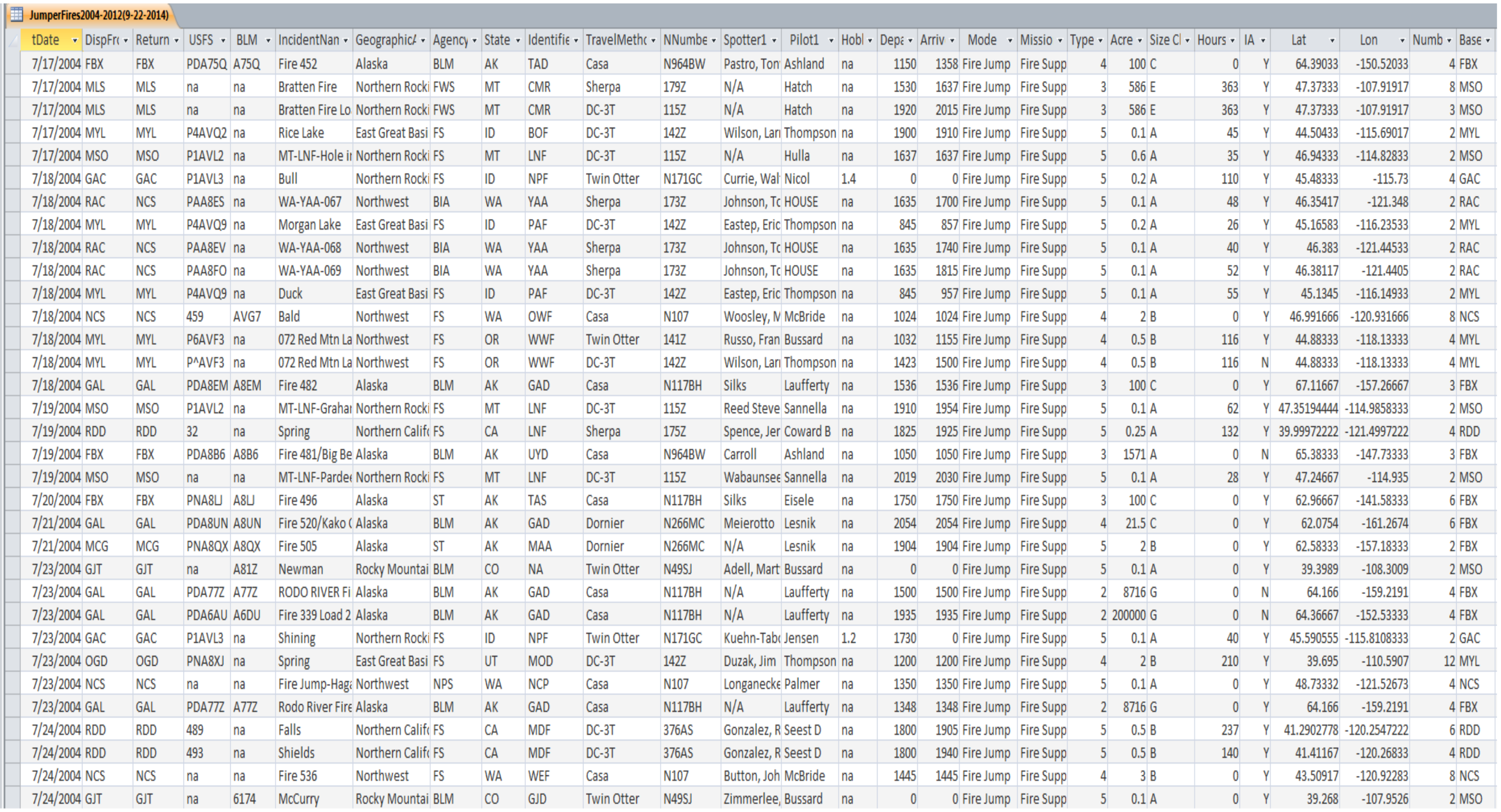
APPENDICES

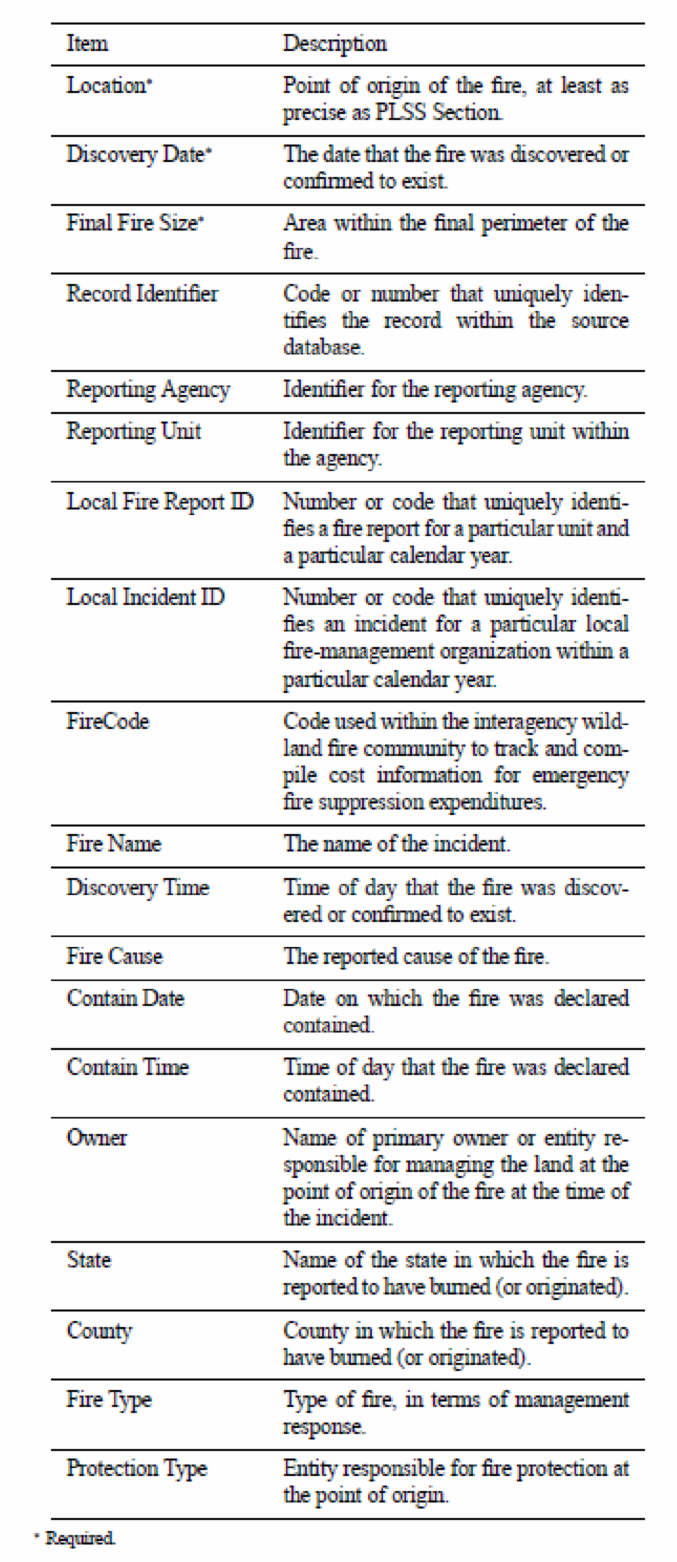
Appendix A. Example of Smokejumper Master Action Database viewed in Microsoft Access 2010. (2012). Missing fields from figure include: Incident ID, User ID, spotter 2, pilot 2, VOR1, VOR2, Fuel Type, Fire Number, Spotter Trainee, Yards of Drift.



JumperFires2004-2012(9-22-2014)

tDate	DispFr	Return	USFS	BLM	IncidentNan	GeographicA	Agency	State	Identifie	TravelMethc	NNumbe	Spotter1	Pilot1	Hobl	Depa	Arriv	Mode	Missio	Type	Acre	Size Cl	Hours	IA	Lat	Lon	Numb	Base
7/17/2004	FBX	FBX	PDA75Q	A75Q	Fire 452	Alaska	BLM	AK	TAD	Casa	N964BW	Pastro, Ton	Ashland	na	1150	1358	Fire Jump	Fire Supp	4	100	C	0	Y	64.39033	-150.52033	4	FBX
7/17/2004	MLS	MLS	na	na	Bratten Fire	Northern Rocki	FWS	MT	CMR	Sherpa	179Z	N/A	Hatch	na	1530	1637	Fire Jump	Fire Supp	3	586	E	363	Y	47.37333	-107.91917	8	MSO
7/17/2004	MLS	MLS	na	na	Bratten Fire Lo	Northern Rocki	FWS	MT	CMR	DC-3T	115Z	N/A	Hatch	na	1920	2015	Fire Jump	Fire Supp	3	586	E	363	Y	47.37333	-107.91917	3	MSO
7/17/2004	MYL	MYL	P4AVQ2	na	Rice Lake	East Great Basi	FS	ID	BOF	DC-3T	142Z	Wilson, Lar	Thompson	na	1900	1910	Fire Jump	Fire Supp	5	0.1	A	45	Y	44.50433	-115.69017	2	MYL
7/17/2004	MSO	MSO	P1AVL2	na	MT-LNF-Hole i	Northern Rocki	FS	MT	LNF	DC-3T	115Z	N/A	Hulla	na	1637	1637	Fire Jump	Fire Supp	5	0.6	A	35	Y	46.94333	-114.82833	2	MSO
7/18/2004	GAC	GAC	P1AVL3	na	Bull	Northern Rocki	FS	ID	NPF	Twin Otter	N171GC	Currie, Wal	Nicol	1.4	0	0	Fire Jump	Fire Supp	5	0.2	A	110	Y	45.48333	-115.73	4	GAC
7/18/2004	RAC	NCS	PAA8ES	na	WA-YAA-067	Northwest	BIA	WA	YAA	Sherpa	173Z	Johnson, Tc	HOUSE	na	1635	1700	Fire Jump	Fire Supp	5	0.1	A	48	Y	46.35417	-121.348	2	RAC
7/18/2004	MYL	MYL	P4AVQ9	na	Morgan Lake	East Great Basi	FS	ID	PAF	DC-3T	142Z	Eastep, Eric	Thompson	na	845	857	Fire Jump	Fire Supp	5	0.2	A	26	Y	45.16583	-116.23533	2	MYL
7/18/2004	RAC	NCS	PAA8EV	na	WA-YAA-068	Northwest	BIA	WA	YAA	Sherpa	173Z	Johnson, Tc	HOUSE	na	1635	1740	Fire Jump	Fire Supp	5	0.1	A	40	Y	46.383	-121.44533	2	RAC
7/18/2004	RAC	NCS	PAA8FO	na	WA-YAA-069	Northwest	BIA	WA	YAA	Sherpa	173Z	Johnson, Tc	HOUSE	na	1635	1815	Fire Jump	Fire Supp	5	0.1	A	52	Y	46.38117	-121.4405	2	RAC
7/18/2004	MYL	MYL	P4AVQ9	na	Duck	East Great Basi	FS	ID	PAF	DC-3T	142Z	Eastep, Eric	Thompson	na	845	957	Fire Jump	Fire Supp	5	0.1	A	55	Y	45.1345	-116.14933	2	MYL
7/18/2004	NCS	NCS	459	AVG7	Bald	Northwest	FS	WA	OWF	Casa	N107	Woosley, M	McBride	na	1024	1024	Fire Jump	Fire Supp	4	2	B	0	Y	46.991666	-120.931666	8	NCS
7/18/2004	MYL	MYL	P6AVF3	na	072 Red Mtn La	Northwest	FS	OR	WWF	Twin Otter	141Z	Russo, Fran	Bussard	na	1032	1155	Fire Jump	Fire Supp	4	0.5	B	116	Y	44.88333	-118.13333	4	MYL
7/18/2004	MYL	MYL	P^AVF3	na	072 Red Mtn La	Northwest	FS	OR	WWF	DC-3T	142Z	Wilson, Lar	Thompson	na	1423	1500	Fire Jump	Fire Supp	4	0.5	B	116	N	44.88333	-118.13333	4	MYL
7/18/2004	GAL	GAL	PDA8EM	A8EM	Fire 482	Alaska	BLM	AK	GAD	Casa	N117BH	Silks	Laufferty	na	1536	1536	Fire Jump	Fire Supp	3	100	C	0	Y	67.11667	-157.26667	3	FBX
7/19/2004	MSO	MSO	P1AVL2	na	MT-LNF-Grahai	Northern Rocki	FS	MT	LNF	DC-3T	115Z	Reed Steve	Sannella	na	1910	1954	Fire Jump	Fire Supp	5	0.1	A	62	Y	47.35194444	-114.9858333	2	MSO
7/19/2004	RDD	RDD	32	na	Spring	Northern Califc	FS	CA	LNF	Sherpa	175Z	Spence, Jer	Coward B	na	1825	1925	Fire Jump	Fire Supp	5	0.25	A	132	Y	39.99972222	-121.4997222	4	RDD
7/19/2004	FBX	FBX	PDA8B6	A8B6	Fire 481/Big Be	Alaska	BLM	AK	UYD	Casa	N964BW	Carroll	Ashland	na	1050	1050	Fire Jump	Fire Supp	3	1571	A	0	N	65.38333	-147.73333	3	FBX
7/19/2004	MSO	MSO	na	na	MT-LNF-Pardee	Northern Rocki	FS	MT	LNF	DC-3T	115Z	Wabaunsee	Sannella	na	2019	2030	Fire Jump	Fire Supp	5	0.1	A	28	Y	47.24667	-114.935	2	MSO
7/20/2004	FBX	FBX	PNA8LJ	A8LJ	Fire 496	Alaska	ST	AK	TAS	Casa	N117BH	Silks	Eisele	na	1750	1750	Fire Jump	Fire Supp	3	100	C	0	Y	62.96667	-141.58333	6	FBX
7/21/2004	GAL	GAL	PDA8UN	A8UN	Fire 520/Kako (	Alaska	BLM	AK	GAD	Dornier	N266MC	Meierotto	Lesnik	na	2054	2054	Fire Jump	Fire Supp	4	21.5	C	0	Y	62.0754	-161.2674	6	FBX
7/21/2004	MCG	MCG	PNA8QX	A8QX	Fire 505	Alaska	ST	AK	MAA	Dornier	N266MC	N/A	Lesnik	na	1904	1904	Fire Jump	Fire Supp	5	2	B	0	Y	62.58333	-157.18333	2	FBX
7/23/2004	GJT	GJT	na	A81Z	Newman	Rocky Mountai	BLM	CO	NA	Twin Otter	N49SJ	Adell, Mart	Bussard	na	0	0	Fire Jump	Fire Supp	5	0.1	A	0	Y	39.3989	-108.3009	2	MSO
7/23/2004	GAL	GAL	PDA77Z	A77Z	RODO RIVER Fi	Alaska	BLM	AK	GAD	Casa	N117BH	N/A	Laufferty	na	1500	1500	Fire Jump	Fire Supp	2	8716	G	0	N	64.166	-159.2191	4	FBX
7/23/2004	GAL	GAL	PDA6AU	A6DU	Fire 339 Load 2	Alaska	BLM	AK	GAD	Casa	N117BH	N/A	Laufferty	na	1935	1935	Fire Jump	Fire Supp	2	200000	G	0	N	64.36667	-152.53333	4	FBX
7/23/2004	GAC	GAC	P1AVL3	na	Shining	Northern Rocki	FS	ID	NPF	Twin Otter	N171GC	Kuehn-Tab	Jensen	1.2	1730	0	Fire Jump	Fire Supp	5	0.1	A	40	Y	45.590555	-115.8108333	2	GAC
7/23/2004	OGD	OGD	PNA8XJ	na	Spring	East Great Basi	FS	UT	MOD	DC-3T	142Z	Duzak, Jim	Thompson	na	1200	1200	Fire Jump	Fire Supp	4	2	B	210	Y	39.695	-110.5907	12	MYL
7/23/2004	NCS	NCS	na	na	Fire Jump-Haga	Northwest	NPS	WA	NCP	Casa	N107	Longanecke	Palmer	na	1350	1350	Fire Jump	Fire Supp	5	0.1	A	0	Y	48.73332	-121.52673	4	NCS
7/23/2004	GAL	GAL	PDA77Z	A77Z	Rodo River Fire	Alaska	BLM	AK	GAD	Casa	N117BH	N/A	Laufferty	na	1348	1348	Fire Jump	Fire Supp	2	8716	G	0	Y	64.166	-159.2191	4	FBX
7/24/2004	RDD	RDD	489	na	Falls	Northern Califc	FS	CA	MDF	DC-3T	376AS	Gonzalez, R	Seest D	na	1800	1905	Fire Jump	Fire Supp	5	0.5	B	237	Y	41.2902778	-120.2547222	6	RDD
7/24/2004	RDD	RDD	493	na	Shields	Northern Califc	FS	CA	MDF	DC-3T	376AS	Gonzalez, R	Seest D	na	1800	1940	Fire Jump	Fire Supp	5	0.5	B	140	Y	41.41167	-120.26833	4	RDD
7/24/2004	NCS	NCS	na	na	Fire 536	Northwest	FS	WA	WEF	Casa	N107	Button, Joh	McBride	na	1445	1445	Fire Jump	Fire Supp	4	3	B	0	Y	43.50917	-120.92283	8	NCS
7/24/2004	GJT	GJT	na	6174	McCurry	Rocky Mountai	BLM	CO	GJD	Twin Otter	N49SJ	Zimmerlee,	Bussard	na	0	0	Fire Jump	Fire Supp	5	0.1	A	0	Y	39.268	-107.9526	2	MSO

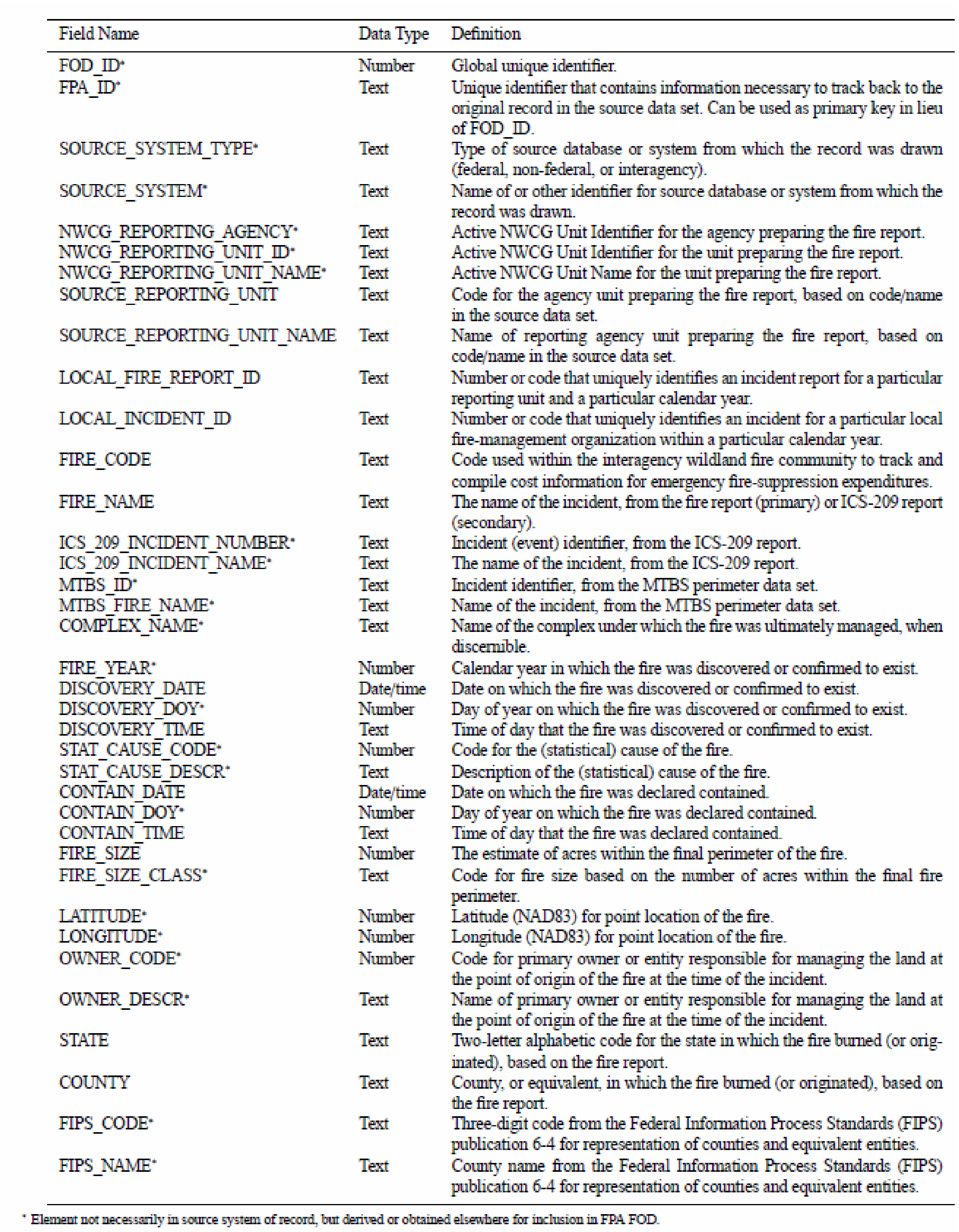
Appendix B. Data elements extracted from wildfire reports that (Short, 2014) used to populate the FPA FOD.



Item	Description
Location*	Point of origin of the fire, at least as precise as PLSS Section.
Discovery Date*	The date that the fire was discovered or confirmed to exist.
Final Fire Size*	Area within the final perimeter of the fire.
Record Identifier	Code or number that uniquely identifies the record within the source database.
Reporting Agency	Identifier for the reporting agency.
Reporting Unit	Identifier for the reporting unit within the agency.
Local Fire Report ID	Number or code that uniquely identifies a fire report for a particular unit and a particular calendar year.
Local Incident ID	Number or code that uniquely identifies an incident for a particular local fire-management organization within a particular calendar year.
FireCode	Code used within the interagency wildland fire community to track and compile cost information for emergency fire suppression expenditures.
Fire Name	The name of the incident.
Discovery Time	Time of day that the fire was discovered or confirmed to exist.
Fire Cause	The reported cause of the fire.
Contain Date	Date on which the fire was declared contained.
Contain Time	Time of day that the fire was declared contained.
Owner	Name of primary owner or entity responsible for managing the land at the point of origin of the fire at the time of the incident.
State	Name of the state in which the fire is reported to have burned (or originated).
County	County in which the fire is reported to have burned (or originated).
Fire Type	Type of fire, in terms of management response.
Protection Type	Entity responsible for fire protection at the point of origin.

* Required.

Appendix C. Data fields used to characterize FPA FOD database (Short, 2014)



Field Name	Data Type	Definition
FOD_ID*	Number	Global unique identifier.
FPA_ID*	Text	Unique identifier that contains information necessary to track back to the original record in the source data set. Can be used as primary key in lieu of FOD_ID.
SOURCE_SYSTEM_TYPE*	Text	Type of source database or system from which the record was drawn (federal, non-federal, or interagency).
SOURCE_SYSTEM*	Text	Name of or other identifier for source database or system from which the record was drawn.
NWCG_REPORTING_AGENCY*	Text	Active NWCG Unit Identifier for the agency preparing the fire report.
NWCG_REPORTING_UNIT_ID*	Text	Active NWCG Unit Identifier for the unit preparing the fire report.
NWCG_REPORTING_UNIT_NAME*	Text	Active NWCG Unit Name for the unit preparing the fire report.
SOURCE_REPORTING_UNIT	Text	Code for the agency unit preparing the fire report, based on code/name in the source data set.
SOURCE_REPORTING_UNIT_NAME	Text	Name of reporting agency unit preparing the fire report, based on code/name in the source data set.
LOCAL_FIRE_REPORT_ID	Text	Number or code that uniquely identifies an incident report for a particular reporting unit and a particular calendar year.
LOCAL_INCIDENT_ID	Text	Number or code that uniquely identifies an incident for a particular local fire-management organization within a particular calendar year.
FIRE_CODE	Text	Code used within the interagency wildland fire community to track and compile cost information for emergency fire-suppression expenditures.
FIRE_NAME	Text	The name of the incident, from the fire report (primary) or ICS-209 report (secondary).
ICS_209_INCIDENT_NUMBER*	Text	Incident (event) identifier, from the ICS-209 report.
ICS_209_INCIDENT_NAME*	Text	The name of the incident, from the ICS-209 report.
MTBS_ID*	Text	Incident identifier, from the MTBS perimeter data set.
MTBS_FIRE_NAME*	Text	Name of the incident, from the MTBS perimeter data set.
COMPLEX_NAME*	Text	Name of the complex under which the fire was ultimately managed, when discernible.
FIRE_YEAR*	Number	Calendar year in which the fire was discovered or confirmed to exist.
DISCOVERY_DATE	Date/time	Date on which the fire was discovered or confirmed to exist.
DISCOVERY_DOY*	Number	Day of year on which the fire was discovered or confirmed to exist.
DISCOVERY_TIME	Text	Time of day that the fire was discovered or confirmed to exist.
STAT_CAUSE_CODE*	Number	Code for the (statistical) cause of the fire.
STAT_CAUSE_DESCR*	Text	Description of the (statistical) cause of the fire.
CONTAIN_DATE	Date/time	Date on which the fire was declared contained.
CONTAIN_DOY*	Number	Day of year on which the fire was declared contained.
CONTAIN_TIME	Text	Time of day that the fire was declared contained.
FIRE_SIZE	Number	The estimate of acres within the final perimeter of the fire.
FIRE_SIZE_CLASS*	Text	Code for fire size based on the number of acres within the final fire perimeter.
LATITUDE*	Number	Latitude (NAD83) for point location of the fire.
LONGITUDE*	Number	Longitude (NAD83) for point location of the fire.
OWNER_CODE*	Number	Code for primary owner or entity responsible for managing the land at the point of origin of the fire at the time of the incident.
OWNER_DESCR*	Text	Name of primary owner or entity responsible for managing the land at the point of origin of the fire at the time of the incident.
STATE	Text	Two-letter alphabetic code for the state in which the fire burned (or originated), based on the fire report.
COUNTY	Text	County, or equivalent, in which the fire burned (or originated), based on the fire report.
FIPS_CODE*	Text	Three-digit code from the Federal Information Process Standards (FIPS) publication 6-4 for representation of counties and equivalent entities.
FIPS_NAME*	Text	County name from the Federal Information Process Standards (FIPS) publication 6-4 for representation of counties and equivalent entities.

* Element not necessarily in source system of record, but derived or obtained elsewhere for inclusion in FPA FOD.

Appendix D. Example of Python script used for computation of hiking time model.

```
# Name: PathDistance_Ex_02.py
# Description: Calculates, for each cell, the least accumulative
#              cost distance to the nearest source, while accounting
#              for surface distance and horizontal and vertical
#              cost factors.
# Requirements: Spatial Analyst Extension

# Import system modules
import time
import arcpy
from arcpy import env
from arcpy.sa import *

# start timing how long script takes to run
startTime = time.time()
print 'Start Time is: 0.0'

#INSERT LOOP HERE TO RUN 'STATES'???

# Set environment settings
# Define your work environment; All input source grids, tables, and python code/AML must be in this directory!!
# env.workspace = "C:/WorkSpace/TDizzle/TEST/SeeleyExperiment"
env.workspace = "M:/Landfire2/MTPathdistance"

# Set local variables
#Source where distances are measured from:
inSource = "RoadN30"
#Source grid for cost:
inCostRast = "fmcostnull"
#Source grid for surface & vertical factor calculations (e.g., Elevation & Slope)
inElev = "elev_1"

# The horizontal factor
#Source grid for horizontal factors (e.g., Aspect)
inHoriz = "aspect_1"
# Create the HfForward Object; these are values used in the Naismith.aml
zeroFactor = 1.0
CutAngleValue = 181.0
SlopeValue = 1.11111111111111E-02 #0.01111
myHorizFactor = HfLinear(zeroFactor, CutAngleValue, SlopeValue)

#The vertical factor
#Source grid for vertical factor calculations (e.g., Slope, which is calculated from DEM)
inVertical = "elev_1"
# Create the VfTable Object
#Source of vertical impedance factors.
myVerticalFactor = VfTable("Naismith5.txt") #VfBinary(zeroFactor, lowCutAngle, highCutAngle)

#The value at which the tool 'stops' running
maxDist = "" #50000

#Backlink grid
#ADD CORRECT NAMES HERE:
# optBacklinkOut = "C:/WorkSpace/TDizzle/TEST/SeeleyExperiment/zjunkback1"
optBacklinkOut = "M:/Landfire2/MTPathdistance/blink1"

# Check out the ArcGIS Spatial Analyst extension license
arcpy.CheckOutExtension("Spatial")

# Execute PathDistance
outPathDist = PathDistance(inSource, inCostRast, inElev, inHoriz,
                           myHorizFactor, inVertical, myVerticalFactor,
                           maxDist, optBacklinkOut)
```