CATASTROPHIC WILDFIRE HAZARD ASSESSMENT IN PINYON-JUNIPER WOODLANDS UTILIZING A MANAGERIAL PARADIGM

by

Benjamin D. Baldwin

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Approved:

Neil E. West
Major Professor

Michael J. Jenkins
Committee Member

James E. Bowns
Committee Member

Thomas L. Kent
Dean of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

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To see a world in a grain of sand
And a heaven in a wild flower,
Hold infinity in the palm of your hand
And eternity in an hour.

—William Blake
ABSTRACT

Catastrophic wildfire hazard assessment in pinyon-juniper woodlands utilizing a managerial paradigm

by

Benjamin D. Baldwin, Master of Science
Utah State University, 2003

Major Professor: Dr. Neil E. West
Department: Forest, Range and Wildlife Sciences

The impetus for this research was the increasing threat of catastrophic wildfires resulting from the accumulation of fuels across the West. Guided by the priorities, goals, and guiding principles outlined by the national fire plan (NFP), the objective was to identify those areas within a pinyon-juniper woodland-dominated landscape with the highest hazard of catastrophic wildfire. The intent was to help managers prioritize proactive fuels management efforts outside of the wildland urban interface (WUI). Based on a management paradigm, constraints were placed on the data collection, analysis, and model development. A geographic information system (GIS) was used to create a hazard assessment at a landscape scale in Tintic Valley, Utah. Hazard categories were a classification of fuels based on crown cover of pinyon-juniper trees, utilizing remotely sensed data. The data set consisted of digital orthophoto quadrangle (DOQ) images from 1993. The methods were developed in three phases. Phase One resulted in a hazard
assessment protocol. In Phase Two, data layers were created to further divide the hazard categories into more tractable management units. Phase Three, through the retrospective examination of recent wildfires, indicated the limitations and utility of the assessment technique. The protocol presented provides a relatively fast, inexpensive, and timely hazard classification technique for pinyon-juniper woodlands at a watershed level. It is intended to be used for coarse-scale assessments of fuel hazards for strategic planning purposes. While not appropriate for fire behavior predictions, this assessment can focus managerial efforts for additional tactical planning.
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PROBLEM CONTEXT

The occurrence of large, high intensity wildland fires has been increasing since the mid-1980's (Arno 1996). In some cases extreme weather or prolonged climatic conditions (i.e., drought) have been attributed as the cause of large wildfires. In recent years, however, federal agencies have recognized the influence of management on the increase in wildfire. The U.S. Forest Service (USFS) goes so far as to state that "uncontrollable wildfire should be seen as a failure of land management and public policy, not as an unpredictable act of nature" (USGAO 2000, p. 2). With the acknowledgement of management influence, it must also be noted that, "the challenge of managing wildland fire in the United States is increasing in complexity and magnitude" (USDA and USDI 1995, p. 4).

With over 75 years of aggressive fire suppression programs (i.e., 10 am policy of the USFS), the wildlands of the West are covered by extensive buildups of fuels, including large expanses of continuous, mature pinyon-juniper woodlands. These woodlands represent landscapes at risk of catastrophic wildfire because they have or could easily cross the combustion threshold. The 1988 wildland fires, which included Yellowstone National Park, prompted the establishment of the National Commission on Wildfire Disasters (P.L. 101-286 1989). This commission stated in 1994:

The vegetative conditions that have resulted from past management policies have created a fire environment so disaster-prone in many areas that it will periodically and tragically overwhelm our best efforts at fire prevention and suppression. The resulting loss of life and property, damage to natural resources, and enormous costs to the public treasury, are preventable. If the warning in this report is not heeded, and preventative actions are not aggressively pursued, the costs will, in our opinion, continue to escalate.
The Commission also stated in its report: "The question is no longer if policy-makers will face disastrous wildfire and their enormous costs, but when" (USDA and USDI 1994, p. 5). The "when" occurred that same year—1994.

The severity of the 1994 fires and resulting firefighter deaths stimulated a review of federal agency fire policy (Federal Wildland Fire Management Policy and Program Review 1995). This review resulted in the first single, comprehensive federal fire policy for both the Departments of the Interior (DOI) and Agriculture (DOA). The 1995 Federal Fire Policy recognized the effects of past land-use practices, the need for landscape-level resource management, and both the urgent and enormous nature of the potential wildfire problems. Additionally, since 1997 the U.S. General Accounting Office (GAO) has released a series of reports and testimony on the extent and seriousness of the wildland fire problem. The 1999 GAO report stated the fuels buildup has been "the most extensive and serious problem related to the health of national forests." This report estimated over 39 million acres of USFS land at risk of catastrophic fires due to accumulated fuels. This number increased to over 125 million acres as the DOI agencies and states identified their high risk land (USGAO 2002a). Federal Interagency websites now reports that there are 190 million acres at risk (NFP 2002).

In response to the increased media focus and growing public concern over the fires in 2000, President Clinton asked the secretaries of DOI and DOA to prepare a report. In September of 2000 they submitted Managing the Impact of Wildfires on Communities and the Environment, A report to the President in response to the Wildfires of 2000 (USDA and USDI 1000). This report resulted in several proposed actions, Congressional
appropriations, action plans, and agency strategies, which collectively are known as the National Fire Plan (NFP).

One proposed action was the reinstatement of the Interagency Federal Wildland Fire Policy Review Working Group to review the 1995 Federal Fire Policy (USDA and USDI 2001a). Upon review, this policy was found to be still generally sound and appropriate. However, the Working Group made several additional conclusions, three of which are relevant to this research. The first conclusion was that the conditions of fire-adapted ecosystems continue to deteriorate and the fire hazard situation in these areas was worse than previously recognized. Secondly, the fire hazard situation was more complex and extensive than understood in 1995. Third, the implementation of the 1995 Federal Fire policy has been incomplete. The Working group stated: "Conditions on millions of acres of wildland increase the probability of large, intense fires beyond any scale yet witnessed." The resulting report, the 2001 Federal Wildland Fire Management Policy, provided the philosophical and policy foundation for current wildland fire management activities (USGAO 2001).

In addition to the review process, Congress expressed its support with substantial appropriations for the fiscal years 2000 and 2001, $2.88 and $2.26 billion, respectively (NFP 2002). In addition to the increased financial resources, came directions for aggressive planning and implementation to reduce the wildfire risks. Congress provided directions in the committee report for the FY 2001 Interior and Related Agencies Appropriations Act (P.L. 106-291 2001) to the DOI and DOA to work with the governors to develop a long-term strategy to deal with the hazardous fuels situation. The result of
this collaborative effort was the report: A Collaborative Approach for Reducing Wildland Fire Risks to Communities and the Environment: *A 10-Year Comprehensive Strategy* (USDA and USDI 2001b). This report outlined the long-term priorities, goals and guiding principles of this strategy. The relevant highlights included priority setting that places emphasis on protection of high-priority watersheds at risk. There should be a long-term emphasis to maintain and restore fire prone ecosystems at a landscape scale.

There were 4 goals of the 10-Year Comprehensive Strategy, 2 of which pertained to this research. They were reduction of hazardous fuels and restoration of fire adapted ecosystems. Two of the guiding principles that are pertinent here are (1) priority setting that emphasizes the protection of communities and other high-priority watersheds at-risk and (2) accountability through performance measures and monitoring for results.

These recent reports acknowledged the necessity of a management paradigm shift from reactive to a proactive approach. Fire management is composed of 3 components. The first 2 are reactive: (1) suppression of wildland fires, and (2) rehabilitation and restoration after the burn. The third component is proactive- reduction of the risk of future fires by removing accumulated hazardous fuels (USGAO 2000). A proactive approach by definition requires predictability. For fuel treatments, the priority needs to be based on stable variables that can be influenced by management actions. The timeframe of this stability is determined by the responsiveness of the management agency including additional constraints (e.g., budget, timetables, planning and the National Environmental Policy Act (NEPA) clearance process).

Federal agencies and the general public recognize the severity of the hazardous
fuels threat. Recent congressional appropriations have removed many of the funding constraints. However, problems remain that prohibit implementation of the NFP. In March 2002, the GAO reported that neither the DOA nor the DOI had established effective leadership to implement the NFP. Currently, agencies do not have a consistent method to determine how many high risk areas there are, where they are located, or how to prioritize attention to them (USGAO 2002b).

This problem is augmented by the shear magnitude of western wildland acres involved. With over 190 million areas identified as at risk, there is a definite requirement for a systematic approach. The rationale for the priority system has been outlined, "The priority for treatments to reduce hazardous fuels should be given to areas where the risk of catastrophic wildfires is the greatest to communities, watersheds, ecosystems or species" (USGAO 2000). However, determining the level of risk is problematic. Initially, agencies reported the numbers of acres treated to measure their progress in reduction of the threat. This focused on total number of acres treated rather than the acres in the highest-priority areas. Ultimately, the incentive is to focus on the easiest and least costly areas (USGAO 2000).

Recent focus has been on the Wildland - Urban Interface (WUI), which is defined as the line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels (Glossary of Wildland Fire Terminology 1996). This area receives high priority because of the high societal value and resulting media attention. Yet this criterion fails when applied to millions of acres of rangelands with little or no urban interface. Rangelands outside of the WUI require
additional measures to determine levels of risk and a prioritization method appropriate to the scale of the landscape.

**Fire Research**

Examination of fire management issues is dependent upon the scales, both in time and space, under consideration. Any investigation of fire begins with recognition of the fundamentals—the combustion process. Combustion has been conceptualized as the fire fundamentals triangle (figure 1). These are the three basic components that are essential for combustion to occur: oxygen, heat, fuel. Upon combustion, the investigation shifts scale to fire behavior (what the fire does). This involves examining the other forces that influence fire. Countryman (1972) introduced the fire environment concept—the interacting influences that determine fire behavior. The fire environment triangle is composed of weather, topography, and fuel as the three sides, or legs, with fire in the center (figure 2). These components can change in space and time, including their interactions with each other. These changes result in alterations of the fire behavior.

The weather component consists of the state of the atmosphere at a given time and place, usually involving temperature, relative humidity, and wind speed and direction. Weather proves to be the most dominant influence on fire behavior (Pyne et al. 1996). Bessie and Johnson's (1995) investigations showed that weather is the most controlling factor of wildfires. Weather affects the condition of the fuel, the behavior of the fire, and in some cases, its ignition (Fraser 1977). Weather is the hardest component to predict, however, due to its high variability and rapid change in both space and time.
Figure 1. The fire fundamentals triangle. Based on Pyne et al. (1996).
Figure 2. The fire environment triangle. Based on Countryman (1972).
The term 'weather' is used ambiguously within the fire research literature. This confusion is usually based on the scale of consideration of the research. Both the spatial and temporal scales are important and often the distinction between weather and climate blurs. Whereas weather pertains to given areas in specified times (e.g., small scale, short time frame), climate refers to the meteorological conditions that characteristically prevail in a particular region (e.g., large spatial scale, long time frame). Climate is referred to obliquely as weather patterns, averages, or the characteristic weather of an area.

Topography refers to the general characteristics of the landscape (landform, aspect, slope, elevation). Temporally, topography changes very little, but varies greatly with space. Topography has short-term affects on fire behavior as it moves across the terrain. In the long-term, topography affects broader climatological trends, soils, vegetation patterns and potentials, and fire regimes.

The fuel component is a critical leg in both of the fire triangles (Pyne et al. 1996). While weather and topography affect fire behavior, without fuels, fire cannot exist. Fuels are described by either type or state. The type of fuel is a basic description, whereas the state of the fuel is dependent on the changing environment, usually related to the moisture content. The type of the fuel includes description of its properties and components. The physical properties of the fuel affect how it burns and include both intrinsic and extrinsic aspects. Intrinsic properties include factors that influence the actual combustion (chemical content, density, etc). The extrinsic properties address broader fuel descriptions (arrangement, continuity, quantity, size, etc). Descriptions also include the fuel components, which are related to how the vegetation grows. These are categorized
by vertical layer—ground, surface, or crown fuel. Each component represents significant differences in fire behavior.

While all three components of the fire environment triangle change over time, fuels change both in type and state in very predictable ways. Andrews and Williams (1998), in their evaluation of fire potential, utilize a fire pyramid to illustrate change in fuels over time (figure 3). Changes in time are grouped into five categories: successional, annual, seasonal, diurnal, and abrupt (see Pyne et al. 1996 for complete descriptions).

The pyramid was constructed with the longest-term changes at the base, with a decreasing time frame moving up the pyramid, resulting in the fastest changes or shortest time frame at the pinnacle. Each layer creates the context for the layer above it. Risks change rapidly at the top of the pyramid due to the quickly changing conditions, while conditions at the base of the pyramid change slowly and the relative risks remain constant. "Mitigating hazards at the bottom of the pyramid, though, are more certain of reducing risks in time and space" (Andrews and Williams 1998, p. 66). While weather and topography may play a more important role than fuel in governing fire behavior (Bessie and Johnson 1995, Pyne et al. 1996), they are beyond management control (i.e., they cannot be realistically manipulated). Fuels are the one leg of the fire environment triangle that resource managers can manipulate (Pollet and Omi 2000).

Fire Terminology

Review of the fire-related literature provided a multitude of different definitions and notions to risk related terms and frequently these terms were used inconsistently.
Figure 3. The fire pyramid. Based on Andrews and Williams (1998).
Bahmann and Allgöwer (2000) called for a more consistent wildfire risk terminology, noting that there is considerable confusion on the use of these terms. They attributed this confusion to the wide range of possible notions that can be assigned, depending on the user. Often these terms were used as "abbreviations for complex and difficult to explain matters." In order to provide the most consistent and applicable model, all fire related definitions used here were take from the Glossary of Wildland Fire Terminology (1996). Research relevant to this thesis was interpreted to conform to the following definitions:

FIRE DANGER: Sum of constant danger and variable danger factors affecting the inception, spread, and resistance to control, and subsequent fire damage; often expressed as an index.

FIRE DANGER RATING AREA: Geographical area within which climate, fuel, and topography are relatively homogeneous, hence fire danger can be assumed to be uniform.

HAZARD: A fuel complex defined by kind, arrangement, volume, condition, and location that forms a special threat of ignition and resistance to control.

HAZARDOUS AREAS: Those wildland areas where the combination of vegetation, topography, weather, and the threat of fire to life and property create difficult and dangerous problems.

RISK: (1) The chance of fire starting as determined by the presence and activity of causative agents. (2) A causative agent. (3) (NFDRS) A number related to the potential of firebrands to which a given area will be exposed during the rating day.

Essentially, danger refers to the potential ignition, behavior, and damage caused by fire. Hazard describes the landscape at one point in time, while risk integrates time
into the description. For example, a hazard map would display the spatial distribution of wildfires, while a risk map would display the possibility of occurrence of wildfires.

**Fire Models and Systems**

Over the past 80 years, the fire research community has developed numerous fire models to support wildland fire management. The models can be placed in two broad categories: fire prediction models and fire danger rating systems. Fire prediction models simulate fire behavior, usually with site-specific data. Fire danger rating systems produce coarse scale indices of scenarios for large areas under which fire might burn. In essence, these are a prediction of potential fire behavior (Deeming et al. 1972). Both categories of models are related and often are built upon one another. In some cases the distinction becomes quite blurred. The following are selected examples with relevance to this thesis. This review should in no way be regarded as a complete list of models and systems used in the U.S.

**Fire Prediction Models**

These are more recent models that capitalize on the computational speed and efficiency of modern computers. All three models predict surface fire behavior using Rothermel's (1972) mathematical model.

The BEHAVE fire behavior prediction system (Andrews 1986, Andrews and Bevins 1999) produces output tables of calculated fire behavior based on user supplied environmental conditions. The FARSITE fire growth simulation model (Finney 1996, 1998) predicts fire growth and behavior across the landscape. The NEXUS Crown fire
hazard assessment model (Scott 1999), incorporates Rothermel's (1991) crown fire models to simulate full range of fire behavior.

All three of these models or systems simulate how a particular fire will behave on a specific landscape. Emphasis is on the upper levels of the fire pyramid, that is to say rapidly changing short term factors. They require detailed information (weather, topography, fuels) to be provided by the user. These programs produce outputs that are applicable to smaller areas with specific time frames.

**Fire Danger Rating Models**

As early as 1914 the need for a fire danger rating system was noted (Albright and Meisner 1999). During the 1940's and 1950's several different groups researched and developed rating systems. By 1954 there were at least eight fire danger rating systems in use in the United States (Deeming et al. 1972). The first truly National Fire Danger Rating System (NFDRS) was introduced in 1972 (Deeming et al. 1972) and has undergone two major revisions, once in 1977 (Deeming et al. 1977) and again in 1988 (Burgan 1988). These models are described in terms of: (1) fire behavior and (2) vegetation type (Pyne et al. 1996).

**National Fire Danger Rating System (NFDRS)** (Deeming et al. 1977): This is a rating system that provides broad area assessment of fire potential with a focus on the factors that control the moisture content of fuels. Calculations are based on daily weather, while the fuel and topographic components are held constant. The system fails to account for variation resulting from topographic gradients or changes in fuel type. The scale of
spatial consideration is large regions with a one kilometer square resolution. Temporally, the focus is a 24-hour period for estimates of fire danger based upon "worst" conditions. Since 1999, the Wildland Fire Assessment System (WFAS) (Burgan et al. 1997) has added a graphic interface to the NFDRS. WFAS is an internet-based system (www.fs.fed.us/land/wfas) that provides nation wide maps of the fire danger, weather maps, and "greenness" maps.

In addition to the NRDRS, there are a number of geographic information system (GIS) assessment approaches that shift from a danger rating to risk and/or hazard assessments. Continual advancements in computer technology allow for spatially explicit risk and hazard analysis utilizing GIS. These systems provide means to analyze large amounts of spatially explicit data and examine multiple spatial relationships across extensive areas. With existing programs, it is relatively easy to create maps of hazard or risk and overlay the maps to generate integrated and comprehensive evaluations of landscapes.

GIS is a widely used analysis tool which lends itself to information sharing among different users allowing for assessments to extend beyond administrative boundaries, agency designations, or single scale approaches. Most of these assessments (Chuvieco and Congalton 1989, Chou 1991, Woods 1991, Chuvieco and Salas 1994, Stratton 1998, Burton et al. 1999) used combinations of the fire environment components to assess both potential of wildfires and wildfire behaviors.

Schmidt et al. (2002), developed coarse-scale spatial data at a national-level for fuel and vegetation. This project involved mapping and characterization of historic
natural fire regimes and current vegetation conditions, and development of an index of departure for use in national-level fire management planning. These data are intended for strategic planning by federal land managers, states, and other non-governmental organizations in fire and fuel management planning, assessments of ecosystem health, and risk assessments.

The Utah Fire Assessment Project (Wimmer et al. 2000), identified general hazard areas at a state-wide level for fire management. The assessment defined, and then ranked risks, values, and hazards. The final analysis rating was a combination of these factors. Risk was defined as the potential for fire occurrence and was based upon historical fire occurrence, fire size, and ignition source. Values, also called "social concerns" were based on features to be protected, in which human population and dwelling density census data was used as an indicator. Hazard was defined as areas with the potential for extreme fire behavior based upon present vegetation. The vegetation map was produced from modified Utah GAP Analysis data (see Edwards et al. 1995 for complete description). The original 36 GAP vegetation types were combined into 16 associations based on similar fire behavior and resistance to control. These 16 associations were further grouped into four hazard level ratings. These hazard categories were grouped together based on similar fire behavior characteristics. The assessment was based upon overstory vegetation present and provides no information about dead and down fuels or understory vegetation. Final analysis of these categories provided a coarse scale, statewide assessment of areas of concern.
Pinyon-Juniper Woodlands

The Western United States is covered with large amounts of Pinyon-Juniper savannas, woodlands, and forests, totaling over 55 million acres, with approximately 17.5 million acres located in Utah and Nevada (Mitchell and Roberts 1999). In many places the vast expanses of seemingly endless trees dominate the landscape and its ecosystems. Nevertheless, the current vegetation is an inaccurate representation of either past or future landscapes.

The plant communities of the Great Basin have been experiencing rapid change since the arrival of European settlers some 150 years ago (Miller and Tausch 2001). Much of this landscape was once an open grassy savanna. There was a mosaic of vegetation consisting of an herbaceous matrix of grasses and forbs with a scattering of shrubs and trees, more dominant on the foothills. This mosaic was in a constant state of flux, shifting between dominance of herbaceous or woody species, primarily because fire allowed only transitive dominance by one growth form (West 1999).

Arthur Bailey (1996) called fire "an enigma," which is certainly true for pinyon-juniper fires. Frequency, severity and timing play crucial roles in how fire will affect landscapes. Frequent fire may have favored savanna over woodland on gentle slopes and deep rock-free soils (West 1999), but more importantly, fire enabled herbaceous species to retain a co-dominant position with shrubs/trees over most of the landscape (Burkhardt and Tisdale 1976, Gruell 1985). These pre-settlement fires were frequent, low-intensity, surface fires, which moved rapidly through the continuous, fine fuels. During the past century, plant composition shifted from open grassy savannas to
more woody dominance, primarily, pinyon-juniper woodlands. These woodlands have increased in distribution and density across the West.

The literature cites three main reasons for the recent expansion of pinyon and juniper trees. First, climate change since the last Ice Age favors woody species (Miller and Wigand 1994). Second, competitive advantage was shifted to trees through the introduction of domestic livestock which consumed the herbaceous and browse understory. Lastly, changes in the fire regime allowed enhanced tree establishment (Blackburn and Tueller 1970, Burkhardt and Tisdale 1976, Young and Evans 1981). Fire regime refers to the season and frequency of burning and therefore type and intensity of the fire (Bailey 1988). The altered fire regime is the result of several different factors—all somewhat related—that combine in causing drastic and continuing change.

There are two main processes involved in altering the fire regime. First, through the reduction of the amount of fire and second, by removing fuels. European settlers did both. They reduced the amount of fire in two significant ways. The first way was by removing the native peoples from the landscape. There is increasing evidence that native peoples modified their surroundings. For example, Amerindians frequently burned portions of the landscape (Pyne et al. 1996). The second way fire was removed was by an active fire suppression program on the part of the European settlers who tried to extinguish any fires that did occur.

The second process through which the fire regime was altered occurred through the reduction of sufficient fuels for fire to burn. The settlers introduced domestic livestock, which foraged mostly on the herbaceous species, thus removing continuous
fine fuels from the landscape. Any of these factors that reduce the herbaceous component favor the woody species. With a reduction in fine fuels to carry surface fires, there was a further reduction in the amount of fires. This reduction in disturbance resulted in a positive feedback mechanism by which woody species continued to assert dominance. Whereas the potential for fire was initially reduced as the trees increased in cover and dominance, there was a drastic reduction in the understory cover and production (West et al. 1975, Tausch 1980, West 1984). This further reduced the chance of fire and subsequently shifts the competitive advantage to pinyon-juniper trees. As the fire frequency lengthened, the chance of fire within these systems was reduced for about a century.

Once the understory was sufficiently reduced by woody dominance, surface fire was virtually eliminated. Jameson (1987, p. 10) stated, "Stands of moderate tree density, where competition from trees reduces the herbaceous fuel, and the trees themselves are too widely spaced to carry a fire, are exceedingly difficult to burn." The literature is replete with similar references to the pinyon-juniper woodlands. Hester (1952) called these woodlands an "asbestos" variety. Everett (1987) labeled it "fire safe." And Young (1983) deemed it "hard to burn."

Regarding the issue of fire safe sites, some clarification must be made. Papers from about 1950 to 1986 referred to all of the woodlands as "fire safe" or "fire proof." A distinction must be made concerning locations versus successional phases of the woodlands. In the first case, there were sections of the landscape (e.g., very rocky, steep dissected topography) that historically were fire safe or fire proof. Quite simply, it was
not possible for large amounts of fuels to grow and accumulate on such sites. In the second case, the woodlands lack fine fuels to burn due to the successional state of the woodland. In other words they were fuel insufficient sites. The fire safe sites were very limited in area and remain relatively successionally static over time (Creque et al. 1999a).

In the second case, fuel insufficient sites were a function of time over most of the landscape. They should not be viewed as persistent and stable, but rather as a phase undergoing a very slow but inevitable transition. Yet as early as 1934, where livestock grazing was abolished in some national parks (Erdman 1970), there were large amounts of pinyon-juniper woodlands burning, often in a catastrophic way. These earlier burns however, were primarily on the more mesic sites at higher elevations. This return of fire has become more apparent in recent years with increasingly larger amounts of pinyon-juniper rangelands burning at intermediate to lower elevations. However, these pinyon-juniper fires are distinctly different from pre-settlement fires.

Usually occurring during the summer, these current fires are high intensity, high severity, catastrophic crown fires. In most cases, these fires occur in severe weather conditions and prove difficult to suppress. The return of fire is not surprising. Arthur Bailey (1996, p. 161) stated, "If the fire return interval is abnormally long due to fire suppression, a major conflagration can be expected because of the fuel load." Fuel loads within pinyon-juniper woodlands exists as a majority of standing live trees because there is little accumulation of standing dead, litter or duff layers as in other forests. Within pinyon-juniper woodlands it is evident that the trees increase in size and proximity over time and that these changes affect fire behavior.
Although, appearing homogeneous and seemingly unchanged over long periods of
time, pinyon-juniper woodlands are subtly dynamic systems. Many of the models in the
older literature were linear successional models (see Barney and Frischknecht 1974 and
Everett and Ward 1984). These models, based on Clementsian ideas of plant ecology
(Clements 1916, Sampson 1917, 1919), assumed this system moves toward the
equilibrium of a persistent climax; the climax being pinyon-juniper woodlands. While in
some settings, such successional models may accurately describe the change in vegetation
over time, these models failed to fully explain changes occurring in most Great Basin
pinyon-juniper woodlands (West and Van Pelt 1987).

Failing to consider the influence of disturbances limits the usefulness of these
earlier theories and models. Several of these disturbances can modify ecological site
potentials (due to soil erosion or climatic change), livestock, altered fire regime,
dominance by woody species and, perhaps, most importantly the introduction of exotic
plants (Miller and Tausch 2001). More recent attempts to better understand
pinyon-juniper woodlands shifted focus to other models, specifically 'state and transition'
models (Westoby et al. 1989, Friedel 1991) and catastrophe models (Jameson 1987,
Lockwood and Lockwood 1993, Stringham et al. 2001). State and transition models
identify multiple stable states and focus on the transitions and thresholds between them.
Catastrophe theory and the resulting models combine classical successional and state and
transition models using each where it is applicable. Catastrophe is defined as a sudden
discontinuous change (Jameson 1988). In other words, a threshold has been crossed.

Realizing there is considerable variation between authors use of common terms, I
offer the following three definitions for the sake of clarification. First, state is defined as a relatively stable, recognizable assemblage of species occupying a site (Westoby et al. 1989). It consists of a biotic framework build upon an abiotic foundation (Stringham et al. 2001). Second, transitions are defined as a trajectory or pathways of change from one state to another (can be among or between states). It should be noted that transitions have the following characteristics: (1) triggered by either natural events, management or both; (2) may occur quickly or over a long period of time; (3) once initiated the system does not come to rest until the transition is finished (Westoby et al. 1989). And third, threshold is defined as "a boundary in space and time between two states. The initial shift across the boundary is not reversible on a practical time scale without substantial intervention by the range manager" (Friedel 1991). Therefore, a system must cross a threshold to reach another state.

To better understand pinyon-juniper woodlands, the following conceptual threshold diagram is presented (figure 4). Moving left to right, the first circle represents the pre-settlement fire-maintained savanna, followed by two states of pinyon-juniper woodlands. The first ellipse represents the fire-safe state, while the second ellipse or state occurs after sufficient canopy (cover and proximity) has developed putting it at risk for crown fire. The third ellipse is an unknown future state influenced by the possible presence of exotic plants or altered fire frequency. Within this model there are three thresholds. The first threshold (T1) represents the change from a herbaceous to a woody matrix. The combustion threshold (T2) is the point at which pinyon-juniper woodlands will carry a crown fire. This combustion threshold represents a state change within the
pinyon-juniper woodlands from a non-burnable to burnable state.

The literature suggests that much of the pinyon-juniper woodlands has crossed or is nearing this threshold (Miller and Tausch 2001). This threshold is based on a relationship between site potentials, vegetation characteristics, physical variables, and associated fire weather. With this interaction between variables, it is possible to have a changing or moving threshold. That is, an increase in one variable will allow for a decrease in another variable, while still crossing the combustion threshold. The third threshold (T3) occurs when the catastrophic crown fires burn these woodlands. This conceptual diagram focuses on the transitions that occur in pinyon-juniper woodland development and the thresholds that are crossed.

Figure 4. Conceptual threshold model of Pinyon-Juniper Woodlands.
Pinyon-juniper woodlands have long been understudied and overlooked. Even the language associated with this ecosystem reflects this oversight. For example, it has often been referred to not as forest, but qualified as "elfin" or "pygmy" forests and often demoted to woodlands, or even P-J. While often scientifically and managerially neglected, pinyon-juniper ecosystems are important parts of the Great Basin landscape (West and Young 2000). First and foremost they cover huge amounts of the landscape and often represent the dominant vegetation of given mountains and valleys. These woodlands provide important habitat for a variety of wild animals (West 1999). They occupy a transitional zone between lower shrub and grasslands and higher elevation forests (West and Young 2000), usually reflecting the floristic diversity of adjacent vegetation types (West et al. 1975).

An important overlooked topic pertaining to pinyon-juniper systems are the problems associated with post disturbance restoration. With limited understory species, harsh site conditions and the increasing risk of exotic weed monocultures, pinyon-juniper woodlands represent huge management challenges. For decades these woodlands presented little hazard, requiring little more than custodial management. But with increased risk of stand-replacing fires and post-fire consequences, there is now need for more pro-active management. Perhaps Westoby et al. (1989, p. 271) said it best by stating, "Seize the opportunities and evade the hazards." While the current trends in pinyon-juniper woodlands reflect successional trajectories that were initiated over a century ago, management agencies must now deal with these problems.

After this preliminary review of the social, political, economic and ecological
contexts to the current fire problems across the West, I chose to demonstrate how prioritization of proactive management could be applied in an area currently dominated by pinyon-juniper woodlands.
OBJECTIVES

This study had one primary objective: Identify those areas within a particular pinyon-juniper woodland dominated landscape with the highest hazard of catastrophic wildfire utilizing remote sensing and GIS. This involved examining stand characteristics within pinyon-juniper woodlands with the realization that they potentially represent different states with several transitions and thresholds.

The overall objective of the research was to help managers prioritize and focus proactive efforts. Because of this managerial focus, numerous constraints were placed on the data collection, analysis, model development and possible application.

These imposed constraints are:

* Use of existing, readily accessible data sources
* Use of existing, readily accessible computers and applications
STUDY AREA

The study area for this research was located in eastern Juab County, on the eastern edge of the Great Basin in west-central Utah (figure 5). More specifically the area was defined by the upper Tintic Valley drainage basin (for more intensive review, see Creque 1996). The area defined by Creque was chosen for the following reasons. First, there was an extensive base of recent research to further build upon. This included Creque's (1996) ecological history work, Bureau of Land Management GIS fire assessments, and other university research. Second, the area was representative of the eastern Great Basin in respect to ecological sites, vegetation, climate, topography, and soils. Third, it was an appropriate size for a management application i.e. landscape scale delineated by a watershed boundary. Most importantly, Tintic Valley represented a landscape that was and is at risk of catastrophic wildfire (Boulter fire in 1996 and the Railroad Complex fire in 1999, see Appendix) and exotic weed invasion (primarily cheatgrass - *Bromus tectorum* and squarrose knapweed - *Centaurea triumfettii*). (All scientific names used in this research conform to the Natural Resources Conservation Service (NRCS) PLANTS (Plant List of Accepted Nomenclature, Taxonomy and Symbols) database, available ONLINE http://plants.usda.gov/, [4, Sept. 2002]).
Figure 5. Location of the Tintic Valley study area.
METHODS

Creating a fire hazard assessment requires identification of the objectives, scales of consideration (temporal and spatial) and components used to create it. Explicit identification of assumptions upon which the assessment is based is required to ensure that the application of the assessment does not exceed its intended use.

Hazard Assessment Objective

My major objective was to provide a hazard assessment of pinyon-juniper woodlands for catastrophic wildfire. The assessment was intended to be appropriate to direct the prioritization and strategic planning of proactive fire management on a landscape level, utilizing easily obtainable data.

Scale of Consideration

Assessment objectives required that the temporal scale be long enough to provide a reasonable level of predictability. Constrained by the same objectives, the spatial scale needed to be large enough to provide a realistic prioritization technique for pinyon-juniper woodlands, i.e., watersheds, yet the scale needed to be small enough to allow resolution of component differences.

Assessment Components

Initially, all three components of the fire environment (weather, topography, and fuel) were considered for inclusion in the assessment. The components were examined under the constraints of the management objectives, the scale of consideration,
characteristics of the study area, GIS capabilities, and data limitations. The fuel component was selected to provide the most tractable basis for the hazard assessment.

**Model Assumptions**

* Successionally mature Pinyon-Juniper Woodlands have a high fire danger and in turn are at high risk of catastrophic wildfire.

* Mature woodlands contain low amounts of fine fuel on the ground and these fuels are of little significance in catastrophic wildfires.

* Fuel classifications provide the greatest degree of predictability of wildfire occurrence within Pinyon-Juniper Woodlands.

* Climate and topography are relatively homogeneous across the study area.

* Weather sets the threshold bounds for fires once adequate fuel exists. Under wet conditions, no fire will burn, and conversely, under extreme weather conditions almost all fuels conditions will burn.

* Between these two thresholds, fuels play an important role in fire hazard. Heterogeneity in the fuels allow for a greater degree of predictability.

* By identifying and classifying the fuel hazard, areas with high priority of treatment can be defined and categorized.

* GIS provides a platform which is rapid, flexible for multiple data sources and types, adaptable to multiple management objectives, and adjustable for multiple scales.

* Occam's razor approach can be applied to the GIS model, built on reliable
knowledge with minimal complexity.

* Digital orthophoto quads (DOQs) are an appropriate data source for the indirect classification of fuels within Pinyon-Juniper woodlands.

* Mature tree size is usually larger than resolution limits (one meter) therefore they are “visible” on the DOQ.

* Crown cover is obtainable from DOQs.

• Crown cover represents available fuel for catastrophic wildfire.

GIS Analysis

All GIS analysis was performed on a desktop personal computer (Dell OptiPlex™ GX400 Intel® Pentium® 4 with a 1.80 Gigahertz (GHz) processor utilizing the 845G chipset, 512 MegaByte (MB) of RAM with an 80 GigaByte (GB) hard drive, utilizing a 32MB, ATI, Radeon™ VE Video Board). To create and analyze GIS data the following programs were used: ArcView versions 3.2 and 3.3 (with Spatial Analyst extension), ArcInfo Workstation 8.2, ArcGIS Desktop 8.2 (specifically the ArcCatalog and the ArcToolbox components) developed by the Environmental Systems Research Institute (ESRI) of Redlands, California.

Data Acquisition

All data (unless otherwise noted) were acquired from the Automated Geographic Reference Center (AGRC) in the capitol building in Salt Lake City, Utah utilizing the internet (www.agrc.utah.gov/). The AGRC was established by the State of Utah Division of Information Technology Services to manage the Statewide Geographic Information
Database (SGID). The AGRC acts as a fully automated internet clearinghouse and repository for GIS data layers available to the public as free downloads.

Data Types

Digital Orthophoto Quadrangles

The main data source for this research was digital orthophoto quadrangles (DOQs). DOQs combine the image characteristics of a photograph with the geometric qualities of a map. A DOQ is a computer-generated image of an aerial photograph in which image displacement caused by terrain relief and camera tilt has been corrected. A digital image is produced from high quality scanning (scanning aperture between 7.5 and 32 micrometers) of the original aerial photographs. The aerial photographs originated from the U.S. Department of Agriculture's National Aerial Photograph Program (NAPP). Several photogrammetric equations were applied to each image picture element (pixel) to generate a rectified orthophoto (USGS 2001). The resulting DOQ is a spatially accurate raster image with all features represented in their true geographic positions.

DOQs were chosen for several reasons. First, they are easy to understand and use. They are based on aerial photographs, which have been a standard management tool for many years. Thus, there is usually little additional training necessary before DOQs can be used. Secondly, they are easily available to all users. DOQs are easily available both in geographic extent and the means to obtain them. USGS websites make it relatively easy to order, and many states now have internet sites for DOQ downloads. Thirdly, they can be obtained at low, or in some cases at no direct cost. Fourthly, they have a management
appropriate scale (1:24,000). Finally, they are high applicable for GIS use. Because they are: (1) digital, (2) raster images and (3) corrected, direct measurements of distance, areas, and positions can be made directly from the DOQ. These factors allow for the automated analysis of large areas, yet still capitalize on the fine resolution of the DOQs.

The DOQs utilized for this study were gray-scale images composed of 8-bit binary data. The geographic extent was 7.5 minutes longitude by 7.5 minutes latitude. The naming convention corresponded to the USGS 7.5 minute quadrangle map name of the same area. Each DOQ was composed of four quarter quadrangle (geographic extent 3.75 minutes longitude by 3.75 minutes latitude) that have been mosaiced together often including some color-matching and balancing (Personal Communication, September 10 2002, B. Meisman RS/GIS Lab DOQ Technician). The radiometric image brightness data were stored as 256 gray levels represented as integers in the range of 0-255. The pixel size or resolution was 1-meter. They were referenced to the North American Datum of 1927 (NAD 27) and cast on the Universal Transverse Mercator (UTM) Projection. The file size for each DOQ was between 30 and 45 megabytes (MB).

These DOQs meet National Map Accuracy Standards at 1:24,000 scale. The quality and accuracy depend on the (1) aerial photographs; (2) source digital elevation model (DEM); (3) the scanning process; (4) ground control positions (See USGS fact sheet 057-01 2001 for further details).

**Topography**

Topographic data were created from Digital Elevation Model (DEM) data (USGS
Produced by the United States Geological Survey (USGS), DEMs are digital representations of cartographic information in a digital raster format. Essentially a DEM was made by laying a grid over the corresponding topoquad contours and interpolating elevations at each point. Each DEM I used was based on a 30 by 30 meter data spacing (e.g., grid) between points. Thereby, the spatial resolution was 30 meters. Elevations were rounded to the nearest meter. The geographic extent was 7.5 minutes longitude by 7.5 minutes latitude, corresponding to the standard USGS 7.5-minute map series. They were referenced to the NAD 27 and cast on the UTM Projection.

Soils

Soil data layers were created from existing digital sources and soils surveys. State Soil Geographic (STATSGO) data were used at a broad scale to determine major land resource areas (MLRAs) within the study area. The mapping scale was 1:250,000 and is intended for broad planning. AGRC soils layers were used to determine soil mapping units. These data consisted of soil survey information that was digitized. The data represented the extent of defined soil types based on the most detailed level of soil geographic data developed so far by the National Cooperative Soil Survey. The data were created by compiling information onto a planimetrically correct base which is then digitized and revised with other information including other remotely-sensed data. The resolution was 30 meters. The geographic extent was 7.5 minutes longitude by 7.5 minutes latitude, corresponding to the standard USGS 7.5-minute map series. They were referenced to the NAD 27 and cast on the UTM projection. Ecological sites were
determined by correlating the soil mapping units with the appropriate range site (Soil Conservation Service 1984).

**GIS Assessment Protocol**

Emphasis for this GIS was placed on spatially congruent data themes, both in scale and extent. All data sources were standardized using the "projectdefine" command in ARCINFO utilizing the following parameters: "map projection" - UTM, "zone" - 12, "units" - meters, "datum" - NAD27, "spheroid" - Clarke 1866. All data layers were clipped to the appropriate study area boundary. Creque (1996) developed this watershed boundary, using DEMs of the six 7.5 minute quadrangles that cover the study area. All areas that contributed water run off to a predetermined pour point were considered within watershed (Creque et al. 1999b). The study area was then divided into six sections, the exterior boundaries defined by the watershed; the interior boundaries corresponded to the USGS 1:24,000 quadrangle maps.

The development of this assessment consisted of three phases: (1) development of hazard classification, (2) additional data layers, and (3) opportunistic examination of recent burns.

**Phase One: Hazard Classification**

The hazard classification was used as the base layer for this assessment. This layer was based on the fuels as determined by classification of the DOQs.

The hazard assessment consisted on the following steps:

1- Data preparation
2- Reclassification
3- Resampling
4- Density calculations
5- Classification of hazard areas

Step One - Data Preparation

DOQs were downloaded in compressed .jpg (JPEG) format and saved as images. The DOQs JPEG images were converted to grids. A grid is defined as "an object that stores spatial data in a locational (or raster) data format in which space is partitioned into square cells, and each cell stores a numeric data value (ESRI 1996). All DOQs were standardized to the parameters outlined previously. In addition, the brightness values were adjusted to mimic the real world (i.e., the darkest values represented the darkest items on the landscape). These grids were then clipped to the corresponding study area sections as delineated by the watershed and USGS 1:24,000 quadrangle boundaries. Although referred to by the USGS quadrangle name, these DOQ grids only represent that portion of the quadrangle that is within the study area (watershed boundary).

Step Two - Reclassification

Next, the DOQs were reclassified. The image brightness values of each DOQ were reclassified from the original 256 values into two categories; tree (representing where pinyon-juniper trees dominated the pixel) and non-tree (representing everything else). This reclassification of the pixel brightness values was accomplished through visual inspection of known areas within the DOQ. Inspection areas were selected that
represented strong contrasts between trees and surrounding non-tree areas. These areas were viewed at a scale appropriate to distinguish trees, typically between 1:1500 and 1:3000. Once at this scale, the attribute table was opened and used to manually select the appropriate values that represented trees. Starting with the darkest values, this process was continued in a stepwise fashion until an acceptable total of trees were included in the tree category. When the range of the brightness values that represent trees were determined, the "reclassify" function was used to reclassify the values into the final two categories. The resulting tree theme was a binary classification of the DOQ into tree or non-tree areas. Due to file size constraints, differences between DOQ brightness values, and viewing considerations (i.e., resolution and scale issues), the analysis was performed on individual DOQs, exemplified here by the Sabie Mountain quadrangle (figure 6).

Step Three - Resampling

The tree theme was resampled from one-meter to 30 meter resolution (figure 7). This subset was resampled using a nearest neighbor algorithm, where the pixel that is closest to the output pixel position is used to determine the value of the output pixel (ESRI 1999a). This method does not average values, thereby retaining pixel values from the original image.

Step Four - Density Calculations

The 30-meter tree grid was converted from a grid to a point theme in which the center of each pixel was the sample point for analysis, i.e., either tree or non tree (figure 8). Each 30-meter pixel was represented by a single point centered in the pixel. The
Figure 6. Tree reclassification theme (30-meter resolution) of Sabie Mountain quadrangle.
Figure 7. Resampled tree theme (30-meter resolution) over tree reclassification theme (1-meter resolution) of Sabie Mountain quadrangle.
Figure 8. Point theme over resample grid theme (30-meter resolution) of Sabie Mountain quadrangle.
"create density" function within the Spatial Analyst extension was used to derive the density theme. The "simple" density method was utilized where the density for each cell is calculated by "summing the value found in the population field for each point found in the search radius and dividing by the area of the circle in area units" (ESRI 2001). Density calculation parameters were set using guidelines outlined in The ESRI Guide to GIS Analysis (1999b). The output grid extent was set the same as the input grid. "Value" was utilized as the population field, cell size equals 10 meters, and search radius was 56.4 meters. This resulted in a search neighborhood of one hectare. The areal units were reported as points per square hectare, in which each point represents a 30 meter pixel. The resulting theme displays the density of tree crown cover pixels per hectare (figure 9).

Step Five - Hazard Classifications

From the resulting density theme, three categories of the trees were created. The three categories represent: high hazard, moderate hazard, low hazard. Each category was created by utilizing the "Map Query" dialog. Areas were selected spatially by defining a Boolean query based on the values of the grid themes. The output will be a grid theme with areas that match the query given a value of 1 (TRUE) and areas that do not match the query given a value of 0 (FALSE). These queries were then converted into shapefiles that were combined for a complete hazard theme. The resulting theme shows hazard areas based on crown cover.

Phase Two: Additional Data Layers

Upon completion of Phase one, additional data layers were prepared. Emphasis
Figure 9. Tree density (30-meter resolution) of Sabie Mountain quadrangle.
was placed on partitioning the hazard classification into more tractable management units. Two types of data themes were developed: (1) Ecological sites, and (2) Topography.

Ecological Sites were developed from existing digital soils surveys. AGRC soils layers were used to identify detailed soil map units. Range sites were determined using the hard copy of the Fairfield-Nephi Soil Survey (Soil Conservation Service 1984) and correlating them with the appropriate soil mapping units as outlined in the detailed soil map units. More recent soil surveys provide a table listing soil unit to range sites relationships making this step easier in such instances. A range site was defined as "a distinctive kind of rangeland that produces a characteristic natural plant community that differs from natural plant communities on other range sites in kind, amount, and proportion of range plants" (Soil Conservation Service 1984, p. 32). These differences were based on the relationships between soils and vegetation. Ecological sites were based on the range site designations (Soil Conservation Service 1984). For situations in which there were soil complexes, the dominant soil type was chosen as the representative for the range site designation. Topographic data layers were derived from exiting DEMs of the study area. Three layers were constructed; slope, aspect, and elevation. Slope, in an ArcView context is the maximum rate of change from each cell to its neighbors (ESRI 1999b). Slope was reported in degrees, ranging for 0 to 100.

Aspect (direction slopes face) was calculated and reported as nine classes (eight cardinal points and flat). Aspect was measured beginning at north and moving in a clockwise direction. It was reported in positive degrees from 0 to 360. Areas with no
aspect (flat) are assigned a value of -1. Elevation was divided into 50 meter increments, beginning at 1657 meters and terminating at 2463 meters.

**Phase Three: Opportunistic Examination of Recent Burns**

Phase three consisted of an examination of recent wildfires that occurred within the Tintic Valley study area. The two fires were the 1996 Boulter fire and the 1999 Railroad complex fire (Appendix). Pertinent fire reports were obtained from the BLM. Digital fire boundary data were collected by the BLM post-burn. These fire boundaries were standardized and applied to the existing themes (figure 10).
Figure 10. Boundaries of recent fires within the Tintic Valley study area over elevation theme (30-meter resolution).
RESULTS AND DISCUSSION

Phase One: Hazard Classification

The hazard assessment developed in Phase One resulted in a hazard classification theme. Three categories of hazard were delineated into, high, medium, and low classes, from fuels classifications. These hazards categories were based on the literature review. High hazard was defined by a canopy cover of greater than 35 percent. Medium hazard was defined by 20 to 35 percent canopy cover. The low hazard category was defined by less than 20 percent canopy cover. Figure 11 provides a more detailed view of the hazard categories, exemplified in the Sabie Mountain Quadrangle. The larger scale of this figure provides the detail necessary for visual differentiation of the hazard categories. Additional analysis indicated that the assessment protocol categorized the Sabie Mountain quadrangle into 6.8 percent of its area into high hazard, 14.7 percent into medium hazard, and 78.5 percent as low hazard. These categories correspond to the level of hazard for catastrophic canopy fire based on available overstory fuel. This assessment should be interpreted in that respect rather than an assessment of ignition risk, difficulty of suppression, or fire behavior.

Descriptions of the characteristics and conditions required for crown or canopy fires were numerous (Van Wagner 1977, Wright and Bailey 1982, Pyne 1984, Rothermel 1991, Pyne et al. 1996, Scott 1999, Scott and Reinhardt 2001). However, there was considerably less detailed information pertaining to pinyon-juniper woodlands, especially in regard to fuel characteristics (arrangement, crown cover, density). Often
Figure 11. Hazard classification (30-meter resolution) of Sabie Mountain quadrangle.

The classification for the high hazard category was lower than the descriptions for crown fire requirements. However, it was more reflective of the characteristics of pinyon-juniper woodlands. The high hazard category was determined based on descriptions of mature and old-growth pinyon-juniper woodland and their dynamics (Miller and Wigand 1994, Miller and Rose 1995, Miller et al. 1999, Miller and Tausch 2001, Waichler et al. 2001). Tree crowns within these woodlands infrequently touch, which may have been a result of their extensive root structure (Young and Evans 1981, West and Young 2000). Pinyon and juniper tree densities and cover seldom reaches levels of other coniferous forests that experience crown fire.

Additionally, these categories were related to the model presented by the
conceptual threshold diagram (refer to figure 4). The distinction between the low and medium categories roughly correlated with the first threshold (T1). The boundary between the medium and high categories roughly matched the combustion threshold (T2). The diagram and hazard categories were based on a static assessment of fuels. This was a simplified examination of the fire environment triangle (fuel, topography, and weather) and the interactions between these components. This simplification allows predictability for management, but diminished the ability to predict fire behavior on the landscape.

These hazard categories focused on only one component of a complex fire behavior relationship. As such, they should not nor were they intended to be used to attempt explanation of fire behavior. Prediction of fire behavior requires examination of all three components and their interactions. Attempts to predict fire behavior without doing so would be unrealistic. Weather is the dominant factor explaining fire behavior, especially catastrophic fire (Bessie and Johnson 1995).

Due to the nature of the results (as GIS themes), built in a stepwise fashion, it was important to identify and discuss several issues about the protocol. The objectives of this research dictated that the protocol itself became an important aspect of the results. The protocol development is thus as important as the final assessment outputs. By creating the GIS themes in a progressive fashion, there was a risk of compounding error throughout the GIS (Congalton 1991). In order to reduce this risk, it became important to identify possible sources of error and the measures taken at each step to minimize it.

The biggest potential source of error in this research was the main data source; the DOQs. There are several limitations of DOQs that need to be addressed. First and
foremost, a DOQ is an image, albeit with the geometric properties of a map. While a DOQ will provide a geometrically accurate representation of what is on the landscape, the radiometric brightness values are not inherent characteristics of actual objects occurring on the land. Treated as an image, a DOQ may be adjusted and manipulated multiple times for image specifications (i.e., visually appealing for the viewer) rather than data integrity. Possible sources of DOQ manipulation include:

* Adjustments to original air photos

* Digitization of air photos

* Mosaicing of multiple air photos into quarter-quadrangles

* Mosaicing of four quarter-quadrangles into single quadrangles

* End-user manipulations

The second limitation of using DOQs as a data source was the spectral restrictions. As with a panchromatic photograph, the spectral range was limited to shades of gray, varying from black to white at the extremes. This provides limited information for classification, constraining the divisions to broad categories.

Another limitation of DOQs was how they represent the world. Through the digitization of the aerial photo, there is a conversion of irregular shapes into square pixels based on the average brightness value of the area. In this case, each pixel represented one meter square. The raster (square, equidimensional) nature of the DOQ allows for rapid and often automated location and analysis. However, this convenience utilizes an artificial representation of the world (many one meter square areas each composed of a composite representation of all objects within those areas). Because of the odd
orientation and shape of natural phenomena, they are not always reliably represented, a limitation often overlooked. DOQs look like accurate images at small scale, but the pixelated effect becomes more apparent at the resolution limits (figure 11). The pixel effect introduces potential error to any attempt to define individuals, perimeter or cover measurements. The larger the size of the pixel in respect to the area of the measurement, the larger the potential overestimation.

The final limitation of the DOQs concerns the file storage format. Due to file size constraints and computing efficiency, the AGRC provided DOQs in JPEG format. The JPEG format utilizes a compression technique in which the file is highly compressed by selectively discarding data (through averaging). The technique is often used with video and image files, whose reconstituted images can be difficult to distinguish from the original file. JPEG compression results in a progressive degradation of the original data each time the file is compressed and reconstituted (saved and opened). While the reconstituted image will exhibit some radiometric differences from the uncompressed original, it will still retain the geometry of the uncompressed DOQ.

Overcoming these limitations required, first, explicit recognition of the limitations inherent in the attributes of the data. A DOQ is an image being utilized as data in an innovative way. Some of these attributes (tonal adjustments, spectral resolution) are merely artifacts of the data collection and preparation process. When this was the case, the objectives and methods were developed to use the data appropriately. Wherever possible (end-user manipulations, classifications), steps were taken to minimize the limitations while maximizing the benefits of the DOQ. Details of specific measures
taken are identified and discussed in sections that follow.

Step One: Data Preparation

The initial step was conversion of the DOQ JPEG images to grids to prevent additional degradation of the brightness values due to repeated JPEG file compression. Grid format is more appropriate for GIS analysis, improving analysis speed and efficiency. Once converted, all six DOQs were mosaiced into one study area DOQ. The study area DOQ file size was approximately 1 GB, which created difficulties (i.e., long processing times, frozen applications) when viewed and analyzed en masse. Additionally, storage and retrieval of the study area DOQ became problematic. This issue was resolved by clipping all DOQs to the study area boundary and then working with each DOQ individually. This reduced the total file size to 283 MB with individual DOQs ranging from 3.46 to 130 MB. While working with each DOQ individually makes GIS development and management more time consuming and tedious, the analysis is ultimately more efficient and useful.

Step Two: Reclassification

Limited by spectral resolution of the DOQ, reclassification requires subjective decisions based on the experience of the user. Classification of the DOQ radiometric brightness values requires overall familiarity with the study area, especially the vegetation and topography. Knowledge of the species composition of each plant community (stand), their color (brightness), and locations, both on the landscape and in relation to other stands and vegetation types, is essential. Brightness values can also be affected by
topographic affects, i.e., slope and resulting shadows. Additionally, other objects on the landscape such as water bodies, roads and structures, may share the same brightness values. An experienced user can select these problematic areas for additional examination during the classification process. Classification of the DOQ without a sound understanding of pinyon-juniper woodland vegetation and the specific study area would result in an inaccurate representation of the landscape.

While the quarter-quads of each DOQ have been spectrally matched and balanced, the same process has not been consistently applied between DOQs. The ranges of values representing trees were consistent within each DOQ. However, the same range of values may not be applicable on surrounding DOQs, resulting in potential misclassification. The tonal differences between DOQs require independent reclassification of each DOQ rather than an application of one set of reclassification values to all DOQs within the study area. While reclassification of individual DOQs required additional time, the process ensured that each DOQ was processed and reclassified based on its unique radiometric brightness characteristics. The range of values of the tree category for the six DOQs utilized in this study ranged from 0 (black) to between 96 and 122, out of a possible 255.

Classification techniques are often beleaguered by questions of accuracy concerning the method and resulting reclassification. There was a relatively high degree of confidence in the spatial accuracy of objects (i.e., they are represented in their correct location), due to the geometric qualities of DOQs. Thematic accuracy (i.e., objects are correctly identified in the reclassification) was more problematic. Determination of actual vegetation on the landscape was constrained by time, as well as money, and thus
beyond the objectives of this research. Rather a coarse categorical approach was utilized in which the emphasis was placed on a binary decision process (i.e., is the object tree-dominated or not). Extensive systematic field data collection is required to determine accuracy of the reclassification. While other vegetation classification approaches do exist, evaluations based on these classifications would result in a comparison of different assessment techniques, data and resolutions rather than comparisons of the accurate classification of vegetation on the landscape. Computational intensity, model complexity, field data collection, cost, and time constraints were all carefully weighed against the desired level of "accuracy." Ultimately, the question of accuracy came down to appropriateness of the data to meet the objectives. Reasonableness and legitimacy in this method became surrogates for accuracy. The evaluation, therefore, shifted from accuracy to confidence. The question then is, "Can the manager be relatively confident in using the classification for direction of management?"

There was a lack of systematic ground truthing of this reclassification other than familiarity with the study area. A highly accurate vegetation classification was not the intent of this research. The vegetation reclassification was merely one necessary step for the hazard assessment. That being said, effort was made to ensure confidence in the accuracy of this method for the objectives. There are several characteristics of the study area, pinyon-juniper woodlands, and this research in particular that maximized confidence in this reclassification.

Pinyon-juniper woodlands of the Great Basin have a relatively simplistic floristic make up, especially in regard to the tree species (West et al. 1998). The study area was
dominated by Utah Juniper (*Juniperus osterosperma*), and Singleleaf Pinyon (*Pinus monophylla*), Colorado Pinyon (*P. edulis*) and their intergrades, with small stands of maple (*Acer spp.*), Gambel Oak (*Quercus gambelli*) and Curlleaf Mountain Mahogany (*Cercocarpus ledifolius*) in topographically restricted areas (Creque 1996). Spectrally, there was a strong contrast between the coniferous pinyon-juniper (dark) and surrounding vegetation and/or bare ground (light). Topographically, there are few abrupt changes within the study area and such changes occurred mostly on the boundaries of the watershed, which allows for easy identification. Within Tintic Valley there was a relatively low amount of human cultural development, so few objects share the same brightness values as the trees, minimizing the possibility of misclassification. The objective, prioritization of management actions, provides the final check of accuracy. As a coarse assessment for strategic planning, the reclassification will alert managers to areas that need additional scrutiny. With closer examination, additional evaluations of the accuracy of the reclassification method can be made.

**Step Three: Resampling**

While the fine resolution of the DOQ was appropriate and necessary for classification of trees, it was unnecessary for analysis at the landscape level. While it is appropriate to aggregate data into coarser resolution within GIS, it is usually impossible to refine data to a finer resolution. Data were aggregated to a coarser resolution in order to improve computing efficiency and allow for data congruency. In terms of computing efficiency, pixel number was reduced by a factor of 30, which resulted in more rapid GIS
analysis. The resampled DOQ was spatially congruent with other existing data layers (ecological sites, soils, topography) with coarser resolution (30 meter). Resampling methods within Arcview create new data themes, thus preserving the original data and themes. After prioritization of areas of concern, fine resolution data could be reexamined for additional scrutiny.

**Step Four: Density calculations**

Density calculations were made on point themes to utilize the existing functions within Arcview with minimal manipulation of existing themes. Some clarification must be made concerning the term "density." Traditionally, in ecology "density" is defined as "the number of individuals in a given unit area" (Bonham 1989). The remote sensing literature has a broader interpretation. The USGS-NPS Vegetation Mapping Program (1999) defined density as "the relationship between the area covered by the overstory of a vegetation community and the total area of a polygon in which the community is found." More specifically, in the Arcview vernacular, "density" refers to points per unit area in which the point represents a pixel value (composed of an average of all objects within), rather than an individual. Density in this context means points per unit area, where the points represent crown cover not individual trees, i.e., density equals the crown cover of pinyon-juniper trees. This usage is more congruent with the Committee on Nomenclature of the Ecological Society of America (1952) definition of density as "the relation between the number and/or volume of individuals of a species (or all species) on an area."

In addition to the ambiguity of the definition of "density," care needs to taken in
interpretation of the Arcview density outputs. The density grid provides a view of the
distribution of values and areas of concentration. The values do not report the density of
particular grid cells (the cell is or is not tree dominated; there are no categories of density
within a cell). Rather the values represent the density of the points within the search
radius that surround and include the particular grid cell. Density values may range from 0
to 100 percent, but maximum number of points per unit area is determined by the
resolution of the grid used to create the point theme. For example, the search area
(hectare) divided by pixel size (30 meter) results in a total possible number of points (11),
one point possible per pixel.

Furthermore, there is potential for extrapolation of density points, if care is not
taken in defining the search radius (neighborhood), and in the areal units that the density
is reported in. For example, if the search area is smaller than the reported areal units, the
density value is extrapolated to the larger area. To avoid possible extrapolation, the
search radius was set to result in a neighborhood area of one hectare, the same as the
reported areal units. Thereby all reported densities were based on existing cover points
rather than extrapolated values.

Phase Two: Additional Data Layers

Additional data layers were created to improve the selection of tractable
management units. Management units were selected that reflected some objective
measures of the landscape. Additionally, the units had to meet with the proactive nature
of the objectives based on predictability over time. Without specific management
objectives and potential treatment method, it was difficult to determine the most appropriate measure to apply to the portioning out of the landscape.

Ecological sites were developed, e.g., for the Sabie Mountain DOQ (figure 12). The complexity of the existing soil survey was reduced to four ecological sites which represent 98 percent of the DOQ. The remainder of the landscape was represented by water and rock outcrops. Ecological sites were utilized because they provide a composite of unique vegetation and soils information representative to each area (Creque et al. 1999b). This information is useful in a management context for sequential development and implementation of appropriate treatments.

Topographic data (slope, aspect, and elevation) (figures 13 - 15) provided useful information for a multitude of potential management questions. The resolution of the data (30 meter) limits its usefulness for site specific analysis, but is sufficient for landscape analysis.

**Phase Three: Opportunistic Examination of Recent Burns**

Recent fire activity combined with available DOQs presented an opportunity to test the protocol. The DOQs were taken in 1993, while the fires occurred in 1996 and 1999. Thus, the DOQ provided an opportunity for pre-fire fuel classification which allowed for retrospective examination of the recent fires. The intent was to examine the fire boundary in relation to hazard categories to test whether theoretical prioritization and proactive treatment could have been important.

Analysis efforts were focused on the Sabie Mountain DOQ. Initial analysis of the
Figure 12. Ecological sites of Sabie Mountain quadrangle.
Figure 13. Slope theme for Tintic Valley study area (30-meter resolution).
Figure 14. Aspect classes for Tintic Valley study area (30-meter resolution).
Figure 15. Elevation classes for Tintic Valley study area (30-meter resolution).
burn areas indicated that the 1999 Railroad Complex reburned portions of the 1996 Boulter fire area. Because of this, the Railroad fire data were disregarded.

The Boulter fire was a lightning caused fire which started in the annual-dominated southern half of Tintic Valley (see Appendix for BLM fire report). The fire traveled in a generally northerly direction over 7 days, from August 13 to August 20, 1996, burning a total of 2550 acres. The fire occurred under moderate to severe weather conditions exhibiting erratic fire behavior including torching and spotting. Interagency reports from the fires were utilized, noting suppression efforts or man-made barriers, which later were verified on site. Digital fire boundaries were collected by the BLM via a helicopter borne Global Positioning System (GPS) post burn and used to calculate total acres burned (Personal Communication, June 3, 1999, T. Thompson, graduate student).

My own field verification of fire boundaries with GPS data collected on foot resulted in obvious discrepancies. The BLM data consisted of more regular perimeters, i.e., excluded small fingers of burnt vegetation and included small islands of unburnt vegetation. These differences appeared to be an artifact of the collection technique and the scale of consideration. While not at an appropriate scale for analysis of fire behavior, the BLM data were spatially congruent with the hazard assessment and additional data layers for examination of potential fuels effects.

Figures 16 - 20, show the Boulter fire boundary in relation to hazard classification, ecological sites and topographic themes, respectively. The fire burned through all three hazard categories, moving northerly across the landscape, from low to high elevations. Field observations indicated that the fire exhibited both surface and
Figure 16. Boulter fire boundary over hazard classification of Sabie Mountain quadrangle (30-meter resolution).
Figure 17. Boulter fire boundary over ecological sites of Sabie Mountain quadrangle (30-meter resolution).
Figure 18. Boulter fire boundary over slope classes of Sabie Mountain quadrangle (30-meter resolution).
Figure 19. Boulter fire boundary over aspect classes of Sabic Mountain quadrangle (30-meter resolution).
Figure 20. Boulter fire boundary over elevation of Sabie Mountain quadrangle (30-meter resolution).
crown fire behavior. The fire burnt old-growth areas (determined by woodland
development and tree size), killing trees on historically fire-safe sites (figure 21).
Ecological sites, slope, and aspect appear to have minimal affect on the final fire boundary.

Initially, it appeared that the hazard assessment failed this test. Yet, upon further
investigation, this result appeared to reflect shortcomings of the available data and
inappropriateness of the questions asked rather than the performance of the hazard
assessment. The assessment did classify the landscape into hazard categories (refer to
figure 11). Questions of how and why the fire moved as it did across the landscape
require analysis of the fire behavior, including all components of the fire environment
triangle (refer to figure 2). Predictions of fire behavior are beyond the intent or
capabilities of this hazard assessment protocol.

These results indicated that a more appropriate test requires additional base-line
data on the fire environment components and observational data of the fire behavior.
Once the base line data have been collected, the fire behavior data could be obtained
through the use of prescribed fire modeling programs (NEXUS, FARSITE, BEHAVE) or
opportunistic examination of naturally occurring wildfire. These tests require more time,
resources, and higher levels of expertise from the users. Additionally, they are applicable
on limited spatial scales (stands, sites polygons). This hazard assessment protocol could
be used to focus attention efforts on high hazard areas which could then be utilized as
sites for additional tests.

This protocol did identify high hazard areas that were burnt. Yet, observations
Figure 21. Location of old-growth pinyon-juniper woodlands in 1993 within the Sabie Mountain quadrangle (30-meter resolution).
pertaining to the management actions beyond the prioritization of hazard areas become highly speculative. Additional information about values to be protected, management objectives, specific treatments, and available resources would be required. Furthermore, prediction of the consequences of these theoretical actions becomes impossible with the scarcity of available data.

The examination of the Boulter fire does emphasize the limitations of this protocol and the tendency to examine questions beyond the scope of the assessment. Retrospective examinations of fire behavior prove to be highly speculative and mainly devoid of quantifiable results. Fire boundaries provide evidence of total area burnt, but not the actual behavior of the fire. Interagency fire reports provide information pertinent to suppression both in scale and content, limiting their use for explanation of fire behavior. Extrapolation of fire behavior from this limited information did prove the importance of experience and professional judgment.

While this opportunistic examination of fire within the study area points out several of the limitations of this method, there are also indications of its potential to improve existing management prioritization. The managerial paradigm adopted by this research provides both a focus of the direction and constraints to its use. This paradigm is characterized philosophically by a shift to proactive ecosystem management, emphasizing multiple possible states, defined by thresholds and transitions.

On a more pragmatic level, the paradigm is defined by constraints of time and funding in the face of many seemingly overwhelming natural resource problems requiring timely attention. The immediacy of the issues often precludes managers the opportunity
of extensive examination of the complexity of the issue. In situations that require prompt management decisions, insufficient scientific support is often compensated for through the professional judgment of the manager. This method was an attempt to balance the potential subjectivity of professional judgment with a more objective, defined protocol. Effort was made to apply technological tools and methods to supplement management by leveraging existing data sources and ecological information while decreasing subjectivity in choices of where to take action.

Effort needs to be made to debunk the myth that wildfires are beyond our control. Admittedly, once the fire starts, especially crown fire, it is extremely difficult to suppress. However, potential for control does exist through proactive approaches. By placing emphasis on aspects of fire behavior and ecosystem variables that managers can manipulate, there may be potential to "control" fire (Loftin 2002).

The current accumulation of fuels has been recognized as a partial result of past management actions and inactions. Pinyon-juniper expansion will continue to be a problem. Many of these woodlands are in a transitional state, increasing in density and cover and expanding into suitable yet unoccupied habitat, under current climatic conditions (Betancourt 1987, Miller et al. 2000a). These modern woodlands are creating conditions for catastrophic crown fires to occur. Such fires are capable of causing shifts from pinyon-juniper woodlands to other states dominated by introduced annual and/or biennial species. In addition, the changing fire regime is causing a more homogeneous and connected landscape in which larger, higher intensity fires burn larger portions of the landscape, including historically fire-safe sites. The effects include loss of diversity,
increase in introduced plant monocultures, accelerated soil erosion and, perhaps, most importantly loss of irreplaceable old-growth woodlands. With a recent increase in the recognition of the importance and uniqueness of the old-growth pinyon-juniper (Miller et al. 1999, Waichler et al. 2001) there is a special need to identify these communities before they are lost. For instance, the recent fires in Tintic Valley have burnt several stands of old-growth woodlands located in the Sabie Mountain quadrangle (figure 21).

While there is ample evidence and recognition of the current fire problems, there are few tools to assist managers in the application of proactive fuels treatments. Many models and rating systems exist, yet differences in objectives and scale considerations reduce their application and utility. Fire behavior models (BEHAVE, FARSITE, NEXUS) have little application for identification of management priorities. Based on complex mathematical models of fire behavior, these models provide a greater understanding and predictability of fire behavior on the landscape. However, this provides limited support for management decisions. Fire danger or hazard assessments (NFDRS, UFAP) focus on aspects of fire behavior that managers cannot affect or control (fuel moisture, greenness, cultural values). They also utilize scales (spatial and temporal) that are incongruent with management objectives. Spatially, the resolution is too coarse to prioritize at units appropriate for treatment (stands to hillsides). Application of the Utah Fire Assessment Project (Wimmer et al. 2000) to the study area provides little guidance for additional proactive management. By utilizing coarse resolution classifications (multiple vegetation types and fire models) the UFAP provided an initial hazard classification of all pinyon-juniper woodlands, which directed and later, was
refined by this research.

The NFP (2000) outlines the need to prioritize high risk areas for fuel reductions, whether they are communities, ecosystems or watersheds at risk. Determination of risk prioritization has not been as well defined. Wildland urban interface (WUI) areas currently are given top priority, placing emphasis on preservation of human infrastructure and human safety. While the WUI criterion is important and justifiable, it has little application within the majority of pinyon-juniper woodlands. With millions of acres of pinyon-juniper in the Great Basin that fail the WUI criterion, other prioritization techniques need to be developed and applied. This thesis has provided a step in this direction.
CONCLUSIONS

This research created a hazard assessment protocol at a scale appropriate for management. It was an alternative to the WUI criterion for prioritization of fire management in pinyon-juniper woodlands. This research involved three phases: development of a protocol (phase one), additional data themes (phase two), and an examination of recent burns (phase three). Phase One described the hazard assessment protocol. Phase Two provided suggestions for further landscape partitioning. Phase Three demonstrated utility and limitations of the assessment.

The protocol utilized an approach based on Occam's razor principle. This resulted in a simplification of several complex systems (pinyon-juniper, fire behavior, and GIS) to maximize understanding and predictability. The method was grounded on these simplified dynamics, with explicit identification of assumptions, constraints and objectives. Using this approach allows for additional layers of complexity (i.e. additional data sources and GIS themes, adjustment of scale) to be added, as necessary, to progressively and more confidently explain phenomena upon the landscape.

This assessment delineates high hazard categories which alert managers to areas requiring additional attention. As preliminary analysis to prioritize management, this protocol is not intended to replace or substitute for existing fire behavior models and danger rating systems. Rather it is intended to work in conjunction with them by focusing management attention at the scale appropriate for additional analysis. It is an attempt to provide resolution to an existing hazard assessment framework. This assessment is finer
than NFDRS fuel models or statewide assessments, yet coarser than site specific fuel inventories. Once areas have been identified, landscape metrics programs (Fragstats, Patch Analysis) may prove useful for analysis of site specific characteristics. FARSITE and BEHAVE can provide valuable information of potential fuels treatments on predicted fire behavior.

Rothermel (1983) warned that "fire behavior, fuels, and meteorology are extremely complicated subjects that can bear limited condensation before losing sensitivity." For this research sensitivity was sacrificed for predictability. Assessments were based on fuel properties (arrangement) focusing on longer term changes at the bottom of the fire pyramid (Andrews and Williams 1998). For future applications, the manager must determine the necessary degree of sensitivity required by the objectives and develop the model accordingly. Often it is assumed that more complex models will produce the most usable results. Yet in coarse scale management applications, added complexity may limit utility. Regardless of model complexity, the logic should be clear enough for managers to understand and interpret the outputs (Miller et al. 2000b).

The advancements in computer technology, specifically the internet, digital data sources, and GIS, were critical for this method. Emphasis was placed on the appropriate application of this technology. The intent was to develop "tools" useful to management while avoiding the trap of focusing on the "tool" rather than the "job" (objectives). All analysis was performed on a desktop personal computer with easily available software applications. The GIS protocol was based on concepts and processes that the manager may master with minimal training. If analysis is performed by a GIS technician, it is
crucial there is intensive communication between the modeler and the manager at all steps of the protocol development and analysis.

Utilizing GIS, this protocol is easy to integrate with existing databases and themes. It capitalizes on the ability of GIS technology to organize and perform complex analyses on large amounts of data, at multiple scales, and visually display the results over space. The GIS theme development was based on computing efficiency and scalability. This provides a basis for multiple queries of spatial relationships, allowing for additionally analysis to be performed as needed. Additional data could improve the protocol by increasing the accuracy of the classification and hazard categories. Other vegetation classification (GAP analysis, field data) could be used to avoid misclassification of known vegetation or mask out areas of no concern. Color DOQs would provide additional spectral resolution for classification. Finer grained DEMs could also help.

Application of this protocol in a timely manner requires: (1) available DOQs, (2) available digital data (DEM, soils, ecological sites), (3) appropriate study areas, and (4) first hand knowledge of the study area. DOQ availability is essential because the creation of these data requires intense computing and GIS capabilities. Lack of any other components would require increased time and effort on the part of the manager to gather this information. Additionally, diverse species composition and/or complex stand patterns, dissected topography, and extremely large study areas all limit the assessment usefulness.

Farris et al. (2000, p. 131) stated, "Simply put, it is impossible to know the
'right' answer for potential fire distribution across a landscape at any given time because of the high amount of variability of all of the factors influencing wildland fire. I have refused to interpret the tone of this statement as a deterrent. Rather I saw it as a challenge to strive for the "best" answer in spite of the enormous complexity and immense constraints. This thesis represents my effort at finding that currently "best" answer. Better efforts will require more investment in research on this topic.
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APPENDIX
## Fire Report

### Status:
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### Reporting Agency:
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### State:
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### District or Field Office:
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### Year:
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### Fire Number:
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### Fire Type - Protection Type:
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### Agency Data:

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#### Owner:
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#### Latitude:
| 39.37.42 (39.9617) |

#### Longitude:
| 112.14.14 (112.2372) |

### UTM:
| 122 394,327 E, 4,424,025 N |

### Fire Management Data:

#### Discovery/Start:
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#### Initial Attack:
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#### Station Mean/AC with Own Vehicle:
| Light Engines (200 gal or less) |
| Heavy Engines (over 400 gallons) |

#### Controlled/Complete:
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#### Declared Out:
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### Site Data:

#### Topography:
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#### Aspect:
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#### Slope:
| 0 - 25% |

#### Elevation:
| 4501 - 5500 feet |

#### Weather Station:
| 4206006 |

#### Special Area:
| PRV5 Fuel Model |

### Remarks:

**This fire was reported to Salt Lake District on 8/13/96 at 17:58 hours by BLM Engine 637. It was turned over to Richfield Fire Center. BLM responded one light and one heavy engine, and Station Manager Steve Jackson. Both Richfield District BLM and Salt Lake District BLM worked to suppress this lightning-caused fire. This fire was declared controlled on 8/20/96 at 16:00, and called out on 4/21/96. Total acreage was 700 acres BLM land on the Salt Lake District, 200 acres private land Tooele County, and 800 acres private lands Juab County.**

### Authorized By:
| JUDY DUNNAM |

### Entered By:
| JUDY DUNNAM |

### Title:
| DISPATCHER |

### Date:
INTERAGENCY FIELD FIRE REPORT

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</tr>
</thead>
<tbody>
<tr>
<td>CAUSE (Give the number):</td>
</tr>
<tr>
<td>1) Lightning</td>
</tr>
<tr>
<td>2) Camp Fire</td>
</tr>
<tr>
<td>3) Smokey</td>
</tr>
<tr>
<td>4) Equipment Use</td>
</tr>
<tr>
<td>5) Other</td>
</tr>
<tr>
<td>FUEL MODEL (Give the number):</td>
</tr>
<tr>
<td>1) Annual Grass A</td>
</tr>
<tr>
<td>2) Suburban Grass B</td>
</tr>
<tr>
<td>3) Open Production of Grass C</td>
</tr>
<tr>
<td>4) Segregation of Grass D</td>
</tr>
<tr>
<td>5) Intermediate Brush E</td>
</tr>
<tr>
<td>6) Brush Heath F</td>
</tr>
<tr>
<td>7) Light Brush G</td>
</tr>
<tr>
<td>8) Medium Brush H</td>
</tr>
<tr>
<td>9) Frequent Ponderosa H, H1</td>
</tr>
<tr>
<td>10) Western Long-Leaf Pine I</td>
</tr>
<tr>
<td>11) Other</td>
</tr>
<tr>
<td>GRASS TYPE:</td>
</tr>
<tr>
<td>1) Annual</td>
</tr>
<tr>
<td>2) Potential</td>
</tr>
<tr>
<td>RESOURCES ON THE SCENE (Show how many of each type):</td>
</tr>
<tr>
<td>Engine</td>
</tr>
<tr>
<td>Handcrew</td>
</tr>
<tr>
<td>Leads of Residents</td>
</tr>
<tr>
<td>Other (Specify):</td>
</tr>
<tr>
<td>TOPOGRAPHY (Place of Origin):</td>
</tr>
<tr>
<td>1) Ridge</td>
</tr>
<tr>
<td>2) Slope</td>
</tr>
<tr>
<td>3) Lowland</td>
</tr>
<tr>
<td>4) Flat</td>
</tr>
<tr>
<td>5) Other</td>
</tr>
<tr>
<td>ASPECT (Place of Origin):</td>
</tr>
<tr>
<td>1) East</td>
</tr>
<tr>
<td>2) West</td>
</tr>
<tr>
<td>3) South</td>
</tr>
<tr>
<td>4) North</td>
</tr>
<tr>
<td>5) Other</td>
</tr>
<tr>
<td>SLOPE (Place of Origin):</td>
</tr>
<tr>
<td>1) 0 - 25%</td>
</tr>
<tr>
<td>2) 25 - 45%</td>
</tr>
<tr>
<td>3) 45 - 65%</td>
</tr>
<tr>
<td>4) 65 - 75%</td>
</tr>
<tr>
<td>5) Other</td>
</tr>
<tr>
<td>ELEVATION (Place of Origin):</td>
</tr>
<tr>
<td>1) 0 - 500</td>
</tr>
<tr>
<td>2) 501 - 1000</td>
</tr>
<tr>
<td>3) 1001 - 2000</td>
</tr>
<tr>
<td>4) 2001 - 3000</td>
</tr>
<tr>
<td>5) 3001 - 4000</td>
</tr>
<tr>
<td>6) 4001 - 5000</td>
</tr>
<tr>
<td>FLAME LENGTH (Average Flame Length at Head of Fire):</td>
</tr>
<tr>
<td>1) Less than 1000</td>
</tr>
<tr>
<td>2) 1001 - 1500</td>
</tr>
<tr>
<td>3) 1501 - 2000</td>
</tr>
<tr>
<td>4) 2001 - 3000</td>
</tr>
<tr>
<td>5) 3001 - 4000</td>
</tr>
<tr>
<td>6) 4001 - 5000</td>
</tr>
<tr>
<td>CONTAINMENT:</td>
</tr>
<tr>
<td>Date</td>
</tr>
<tr>
<td>Time</td>
</tr>
<tr>
<td>Acres</td>
</tr>
<tr>
<td>CONTROL:</td>
</tr>
<tr>
<td>Date</td>
</tr>
<tr>
<td>Time</td>
</tr>
<tr>
<td>Acres</td>
</tr>
<tr>
<td>OUT:</td>
</tr>
<tr>
<td>Date</td>
</tr>
<tr>
<td>Time</td>
</tr>
<tr>
<td>Acres</td>
</tr>
<tr>
<td>ACRES BURNED BY OWNERSHIP:</td>
</tr>
<tr>
<td>1) BLM</td>
</tr>
<tr>
<td>2) FS</td>
</tr>
<tr>
<td>3) U.S. Forest Service</td>
</tr>
<tr>
<td>4) Other</td>
</tr>
</tbody>
</table>

SAFETY CHECKLIST

<table>
<thead>
<tr>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>L: Has the best Metropolitan checks and locating system been observed?</td>
</tr>
<tr>
<td>C: Are the operation with adjacent and interacting personnel observed?</td>
</tr>
<tr>
<td>E: Have estate fuels been identified and understood by all personnel?</td>
</tr>
<tr>
<td>B: Have estate fuels been identified and understood by all personnel?</td>
</tr>
</tbody>
</table>

DATA: |
| DAY: | NAME INDEX: |
| DATE: | PREP LEVEL: |
| NEAREST RANV: | 4110 | 90.8 |
DISCUSSION...HIGH PRESSURE WILL CONTINUE OVER UTAH THE NEXT COUPLE OF DAYS. THE FLOW ALOFT WILL BE FROM THE WEST TODAY AND NORTHWEST TONIGHT AND THURSDAY. THERE WILL BE WEAK WEATHER SYSTEMS MOVING THROUGH THIS FLOW. THERE WILL BE SOME MID AND HIGH LEVEL MOISTURE OVER THE STATE THROUGH THURSDAY WHICH WILL CREATE CONDITIONS FAVORABLE FOR HIGH-BASED DRY THUNDERSTORMS ESPECIALLY DURING THE AFTERNOON AND EVENING.

FOR...TODAY
LAL................. 2-3
HAINES INDEX..... 6
CLEARING INDEX... 1000+

SKY/WEATHER....... PARTLY CLOUDY. 10 PERCENT CHANCE OF HIGH-BASED THUNDERSTORMS OVER THE FIRE THIS AFTERNOON.
TEMPERATURE........ MAX 92-94
HUMIDITY............ MIN 13-15%
WIND - EYE LEVEL... NORTHWEST 1-4 MPH BECOMING NORTHWEST 3-8 MPH BY MID MORNING AND NORTHWEST 6-12 DURING THE AFTERNOON EXCEPT GUSTS TO 45 MPH NEAR THUNDERSTORMS.

FOR...TONIGHT
LAL.................. 2-3 EARLY...THEN 2 AFTER SUNSET.
HAINES INDEX....... 6

SKY/WEATHER....... PARTLY CLOUDY. 10 PERCENT CHANCE OF HIGH-BASED THUNDERSTORMS OVER THE FIRE MAINLY DURING THE EVENING.
TEMPERATURE........ MAX 92-94
HUMIDITY............ MIN 59-61
WIND - EYE LEVEL... NORTHWEST 10-12 MPH DECREASING LATER BECOMING NORTHWEST 2-5 MPH AFTER SUNSET EXCEPT GUSTS TO 45 MPH NEAR ANY THUNDERSTORMS.

OUTLOOK FOR THURSDAY...LITTLE CHANGE FROM TODAY.

\END/