Wildland Fire Use Risk Assessment
In Lassen Volcanic National Park

Bluff WFU, 2004

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Preface

I am currently the Fire Management Officer (FMO) at Lassen Volcanic National Park in Northern California. I have been in this position for two years and was the Assistant FMO at Lassen for two years prior to becoming the FMO. My entire career has been with the National Park Service, having worked at Zion, Grand Canyon, and Sequoia and Kings Canyon National Parks before coming to Lassen. I attended Western Oregon State College in Oregon where I earned a Bachelor of Science degree in Secondary Education.

I would like to thank the following people for the tremendous help I received in completing this project. I can honestly say I couldn't have completed it without their help:

- **Mike Powell**-For taking the extra time to sit with me and teach me RERAP in three days.
- **Calvin Farris**-For GIS, Statistics, modeling help, as well as being a sounding board for crazy potential TFM projects.
- **Craig Carter**-For the never ending offers to help with Fire Family Plus, and figuring out my impossible FF+ problem.
- **Bob Loveless**-For guiding me in the right direction while trying to figure out what project to do and preventing me from starting something I couldn't finish.
- **Kelley Lewelling-**For all of the GIS expertise. Chasing our two year old and taking care of the newborn at the same time also allowed me time to finish this project.

Mike Lewelling
March 2006

Executive Summary

Successful wildland fire use (WFU) in combination with prescribed fire is essential to meeting the fire restoration objectives set forth in the Lassen Volcanic National Park Fire Management Plan (March 2005). Since the park is relatively small (106,170 acres), and past fires have shown large fire runs, it is felt by fire managers that intensive management containment actions need to occur to be successful managing WFU fires within the park boundary. This kind of intensive management (line construction, prep and burn out of existing trails), was used successfully in 2004 and 2005 while managing the Bluff (3414 acres) and Horseshoe (1,525 acres) WFU's. While these management actions have been successful, they are also more expensive and have a greater impact to wilderness values.

In fall of 2005, a new Superintendent entered on duty at the park. In looking at the WFU program into the future, she wanted to know what the risk is of WFU fires leaving the park boundary if they are not so intensively managed. Knowing this would provide valuable information needed for planning for risk in the future, as well as anticipating the potentially higher costs and impacts to wilderness.

The park's Fire Management Plan (2005) provides managers guidance on the goals and objectives of the fire program. It strives to balance the protection of lives and property while maintaining healthy ecosystems for future generations. One of the main goals of the program is: "Restore and maintain desired fire regimes to the maximum extent practicable so park ecosystems exhibit a high degree of health and function." In order to achieve this goal, WFU must play a major role in the program; however the Superintendent is uncertain what the risks are of managing these types of fires. Knowing this, this analysis provides valuable information to the decision-maker to help achieve this goal.

The objective of this analysis was to test the hypothesis that under current fuels conditions (2005 data) and historical weather observations within Lassen Volcanic National Park, less than or equal to 25% of the modeled ignition scenarios are high risk by time period (month) to the park boundary with a .05 level of significance. High risk scenarios are defined as those individual ignition points with ≥51% chance of reaching the park boundary before a fire-ending event.

This project used the Rare Event Risk Assessment Process (RERAP) as the main analysis tool to provide probabilities of individual modeled fire ignitions reaching the park boundary prior to a fire ending event. RERAP uses historical weather analysis, as well as GIS fuel model information as major components of this analysis.

During the process of analyzing fuel model data, an additional opportunity presented itself to compare the year 2000 fuel model information with the year 2005. During 2004 and 2005, approximately 10,000 acres were treated in the park with WFU and prescribed burning which is more than 10% of the burnable vegetation in the park. Comparing the

two fuel conditions (before and after the fires) provided an opportunity to test whether there is a reduction in risk by having fires on the landscape.

The results of this analysis showed that during the months of June and July, the null hypothesis was rejected, meaning that fires occurring during those two months will have a greater than 25% chance of crossing the park boundary if management actions are not taken to stop them. The month of August was very close to having the hypothesis rejected; however, for it and the months of September and October, the hypothesis was accepted.

The additional analysis of comparing the fuel model layers of 2000 and 2005 showed that there *is* a significant reduction of risk by having fires on the landscape. In other words, the calculated risk of a fire leaving the park boundary was reduced when that fire ran into a previously treated area (WFU or prescribed fire).

The implication of this analysis is that the management team must acknowledge that as all fires are different, all fires carry a different level of risk. Choosing to manage fires with greater identified risk means that the risk will need to be mitigated for the fire to be successful. The mitigation of risks has the potential for incurring greater financial costs as well as more impacts to wilderness values. These costs, however, can be looked at as an investment into the future of successful fire management in the park. This analysis pointed out that continued management of fires will continue to reduce future risk. The lower the risk, the fewer risk mitigations, resulting in lower cost and fewer wilderness impacts.

The main recommendation from this paper is to continue with the wildland fire use program as outlined in the Fire Management Plan (FMP). This will ensure each fire receives an appropriate risk assessment, and therefore will be managed appropriately with all risk mitigations in place. It will only be through a balanced use of WFU as well as prescribed fire and manual/mechanical treatments that the goals outlined in the FMP will be achieved.

Introduction

Successful wildland fire use (WFU) in combination with prescribed fire is essential to meeting the fire restoration objectives set forth in the Lassen Volcanic National Park Fire Management Plan (March 2005). Managers feel that intensive management containment actions need to occur to be successful in managing WFU fires within the park boundary. However, more intensive management actions result in higher costs as well as greater impacts to the wilderness.

During September of 2005 a new Superintendent entered on duty at the park. While she is supportive of the WFU program in general, she would like to know what percentage of future WFU will need to be aggressively managed. She would like a risk assessment completed that will show what percentage of future WFU incidents would escape the park boundary if management actions are not taken to stop them. This information would provide her with an idea of the future potential risk as well as identify other management considerations for the WFU program as a whole.

The objective of this analysis is to test the hypothesis that under current fuels conditions (2005 data) and historical weather observations within Lassen Volcanic National Park, less than or equal to 25% of the modeled ignition scenarios are high risk by time period (month) to the park boundary with a .05 level of significance. High risk scenarios are defined as those individual ignition points with greater than or equal to 51% chance of reaching the park boundary before a fire-ending event.

Background

Lassen Volcanic National Park was established by an Act of Congress on August 9, 1916 (39 Stat. 442) "for recreation purposes by the public and for the preservation from injury or spoliation of all timber, mineral deposits and natural curiosities or wonders within said park and their retention in their natural condition and…provide against the wanton destruction of the fish and game found within said park and against their capture or destruction…" Incorporated into the park were Cinder Cone and Lassen Peak National Monuments, which were established by Presidential Proclamation (No. 753 and 754) on May 6, 1907, as part of the Lassen Peak Forest Reserve. See Figure 1 for Lassen Volcanic National Park vicinity map.

FIGURE 1. Vicinity Map, Lassen Volcanic National Park

The park encompasses 106,170 acres of mountainous terrain at the southern end of the volcanic Cascade Mountain Range in northeastern California. Preserved within the park is the site of the most recent volcanic eruption within the continental United States, prior to the Mount Saint Helens eruption in May 1980. Approximately 400,000 people visit the park each year. The park provides opportunities for visitors to learn about volcanism and other park phenomena and enjoy various recreational pursuits such as sightseeing, camping, picnicking, and hiking. Seventy-nine percent of the park is congressionally designated wilderness.

Wildland fire has long been recognized as one of the most significant natural processes operating within and shaping the northern Sierra Nevada and southern Cascade ecosystems. Virtually all vegetation communities show evidence of fire dependence or tolerance. Many forest types in the park have short to moderate natural fire return intervals (4-19 years in Jeffery Pine (*Pinus jefferyi* Grev. & Balf.)) as evidenced by research conducted in the park (Taylor, A.H. 2000). Wildland fire has the potential to threaten human lives and property. Consequently there is a need to manage wildland fire so that threats to humans and property are reduced, while at the same time restoring and/or maintaining its function as a natural process.

As with much of the west, fire has been excluded from the landscape of the park for much of the past century. Elimination of frequent surface fire has caused a forest density increase and a forest compositional shift from fire-resistant pines to fire intolerant white fir (*Abies concolor* {Gord. And Glend.} Lindl. Ex Hilebr.) and incense cedar (*Libocedrus decurrens* Torr.). In each case, the onset of forest changes coincides with the date of fire suppression. *P. jefferyi* and *P.jefferyi*/*A. concolor* forests are more dense; the density increase began after fire was eliminated in about 1905. (Taylor, A.H. 2000)

The park views the management and use of fire as essential to achieving the mission of the National Park Service as well as goals and objectives set forth in the Fire Management Plan (FMP). The *desired condition* centers around Goal #2 from the FMP: *"Restore and maintain desired fire regimes to the maximum extent practicable so park ecosystems exhibit a high degree of health and function."* In other words, it would be desirable to allow all natural fire starts (if they are predicted to achieve desired results) to play their natural role in the ecosystem.

This use of fire as a management tool is supported in the National Fire Plan, 2001 Federal Wildland Fire Management Policy, National Park Service Directors Orders 18, NPS Reference Manual 18, Lassen Volcanic National Park General Management Plan (2001) and Resource Management Plan (1999). The Fire Management Plan provides the guidance of how wildland fire will be managed in the park and provides goals and objectives for a balanced protection/restoration fire program.

The management of natural fires has been a part of the FMP since the early 1980's and remains an approved management tool in the current version. During the 1980's and 1990's, the park had managed only three large fires (those over 100 acres) and all three were converted to wildfire status and had to be suppressed. These fires were beneficial to the park ecologically, but the conversion to suppression was perceived negatively in a local political sense. Managers re-evaluated the program and decided that to be successful at managing WFU fires, fuels needed to be treated along the park boundary to provide a buffer, and each fire would need to be managed much more aggressively in order to keep fires from leaving the park boundary.

In 2004, these strategies were put to the test during the 3,414 acre Bluff WFU fire. Initial fire effects appear to be desirable; however, in order to keep the fire within the target area of its plan, aggressive management tactics (line construction, prep and burn out of existing trails) were employed on approximately 80% of its perimeter. These intensive holding actions increased the overall cost as well as increased the impact to the wilderness.

In 2005, the park had another large WFU, the 1,525 acre Horseshoe fire. This fire also needed intensive management, although the critical northern flank was bounded by the Bluff fire from the year before. The benefit was that since the Bluff fire effectively reduced fuel loadings, it reduced the risk of the Horseshoe fire making a run to the north and therefore reduced the need for management actions on that part of the fire. There was still concern on the east flank that the fire could make a run to the east, and burning ahead of the fire and holding on existing trails was needed.

Although the park Superintendent (Decision-Maker) is pleased with the management and ecological benefit of these fires, she would like to understand the parks potential fire environment better in order to make more educated decisions about WFU. It is known that some fires will start close to the park boundary, while others will be further away, and some will start early in the year, while others will be late. Each of these factors influences the risk of managing natural fires, and the Superintendent would like to know what these risks are by time periods throughout the summer season so she may be able to understand the *overall* risk better.

The results of this assessment are intended to be used by the Superintendent to better understand the potential WFU program as a whole in the park. Many agencies as well as individual units manage WFU differently for a wide variety of reasons such as different missions, philosophy, goals and objectives. In addition, units with large landscapes (Gila National Forest, Selway/Bitteroot National Forest) may not need to manage WFU as intensively as smaller land areas like the park and smaller wilderness areas. Each unit needs to have its own management philosophy that takes into account missions, goals and objectives in order to address how fire will be managed. This assessment is intended to paint a picture of the risks and management issues related to managing WFU within the park.

Scope

The decision for the continued use wildland fire use as a management tool was made in the park's 2005 Environmental Assessment for the Fire Management Plan. Therefore the results of this project are not intended to make a decision if the park will or will not have

WFU as a management tool, but rather will be used as a support tool for making programmatic decisions regarding WFU.

The intent of this project is to provide the Superintendent with information related to the risks and management issues related to WFU. It is not intended to make *individual* fire decisions. Individual fire decisions will be made through the Wildland Fire Implementation Plan (WFIP) process. (Although much of this work could be valuable during the WFIP process).

The spatial scope of this project is limited within the boundary of Lassen Volcanic National Park, specifically the eastern two thirds.

This paper assumes a level of familiarity with a number of fire modeling programs.

This project will use the Rare Event Risk Assessment Process (RERAP) Version 7 beta 2 as the main analysis tool to evaluate the risk of modeled fires leaving the park boundary. As with all models, RERAP is only as good as the data input into the program, the user's skill level manipulating the data within the program, and the manager's ability to interpret the results.

The results of this analysis will only be valid until there is significant change of fuels on the landscape. This will most likely occur as a result of prescribed burning or future WFU.

Problem Statement

Although the Superintendent recognizes wildland fire use as a valuable tool in managing and maintaining a healthy ecosystem in the park, she is concerned with collateral cost and wilderness minimum tool issues that arise from aggressive management actions taken on some fires. Because of this, she is uncertain what the overall risk is of natural fires moving beyond the park boundary if the forward spread is not checked by management actions.

Management Goal

The management goal for this project is Goal #2 from the park Fire Management Plan: "Restore and maintain desired fire regimes to the maximum extent practicable so park ecosystems exhibit a high degree of health and function."

Project Objective

The objective of this analysis is to test the hypothesis that under current fuels conditions (2005 data) and historical weather observations within Lassen Volcanic National Park, less than or equal to 25% of the modeled ignition scenarios by time period (months) are high risk to the park boundary with a .05 level of significance. High risk scenarios are defined as those individual ignition points with greater than or equal to 51% chance of reaching the park boundary before a fire-ending event.

Methods

As mentioned earlier, the Rare Event Risk Assessment Process (RERAP) version 7 beta 2 was used as the risk analysis tool for this project. The purpose of RERAP is to estimate the risk that a fire will reach a particular point of concern before a fire-ending event occurs. Inputs to RERAP require climatological analysis obtained using Fire Family Plus software, as well as fuel model data from the park geographic information system (GIS) layers. These methods are presented here in procedural order.

Historical Weather

Three Forest Service owned Remote Automated Weather Stations (RAWS) surround the park (although there is no permanent station within the park). Of the three, (Bogard, Chester, Manzanita Lake), the Manzanita Lake station best represents most of the park. This is also the station the park uses for National Fire Danger Rating System (NFDRS) inputs. Historic weather information for this station was retrieved from the Kansas City Fire Access Software (KCFAST) linked off of the National Fire and Aviation Management Web Applications (FAMWEB) web site.

Weather Data Processing

Weather data from the Manzanita Lake RAWS was processed using Fire Family Plus software. Fire Family Plus is a software package that allows the user to analyze climatological data. The Manzanita Lake RAWS has weather records available from 1962, however this study will use records from 1985-2005. Although some Fire Behavior Analysts (FBAN) prefer using the last 10 years of data, this study will use 20 years to reflect a more comprehensive weather bin. Craig Carter, a local Fire Family Plus instructor who is also a Fire Behavior Analyst, provided input and guidance in making these decisions.

Time Periods- Fire Family Plus requires climatological time periods to generate a percentile weather report needed later in the process. These are time periods which reflect similar seasonality.

To determine the time periods, an Energy Release Component (ERC) graph was created using the Climatology function of Fire Family Plus. The Energy Release Component is a number related to the available energy (BTU) per unit area (square foot) within the flaming front at the head of a fire. The park uses ERC to track seasonal severity. By analyzing the "average" line on the ERC graph, time periods were chosen based on similar climatological characteristics throughout the season.

Winds-A wind analysis must be completed to determine if there is a predominate wind direction. This information is then used in RERAP to identify potential areas of concern (downwind) of a potential ignition. The WIND function in Fire Family Plus was used to obtain these results.

Percentile Weather Report-The Percentile Weather Report, a required input into RERAP, was produced in Fire Family Plus. This report used the historic weather to produce fire environment conditions grouped by severity level for the time period selected. Severity levels are produced in Fire Family Plus by assigning a percentage of the weather bin values in pre-defined categories of "low" (0-15), "moderate" (16-89), "high" (90-97), and "extreme" (98-100). This means that the highest 3% of all the values in the weather bin are representative of "extreme" weather severity. For each of the severity levels 1, 10, 100, 1000 hour time lag fuel moistures, herbaceous and woody fuel moistures, and wind speed were produced; these were then used in RERAP.

To run the percentile weather report, a user-defined variable was required. For this project, Spread Component was the selected analysis variable because RERAP analyzes spread and this index is best for modeling spread. South, Southwest, and West winds (from the "results" of the WIND analysis), were used to identify areas of concern downwind. The median values for each severity level were used to determine the fire environment conditions. If there were less than 10 observations at the median value, a range of values was selected around the median value using as close as possible an equal number of values below and above the median. Only the extreme severity level needed such adjustments. The Percentile Weather Reports were then imported directly into RERAP.

Risk Assessment

To analyze risk, RERAP version 7 beta 2 was selected as the risk analysis tool. The purpose of RERAP is to estimate the risk that a fire will reach a particular point of concern before a fire-ending event occurs. This project uses three program modules within the RERAP software; TERM, SPREAD DATA, and RISK. First, the probability distribution of when a fire-ending event might occur was estimated in the TERM module. This module supports the remaining steps of the process. Fire spread rates were then estimated in the SPREAD DATA section. The final step was to combine the TERM and SPREAD DATA to determine the probability that the fire will reach the point of concern (the park boundary) before a fire-ending event occurs in the RISK module.

Details of methods for each of these modules are discussed below

TERM
A fire-ending event is defined as a weather event where the fire environment can no longer support fire spread. For this project, this event is defined as 1" of rain over a two-day period until November, or ½" inch of rain over two days after November. Although the Manzanita Lake RAWS was used for all other weather analysis, it was felt that the Chester RAWS better represented a worse case scenario for rain as it is on the East side of the park where drier conditions exist. Given this information, the Chester RAWS was used for the fire-ending event analysis.

SPREAD DATA
This module includes three heading tabs: Time periods and Severity Levels, Segments, and Hours and Rates of Spread. Each is discussed in more detail below.

Time Periods and Severity Levels
The TERM file was imported into the SPREAD DATA module. Time periods from the ERC graph and the Percentile Weather generated in Fire Family Plus were then entered into the "Time Periods and Severity Levels".

Segments:

For RERAP to calculate spread, transect lines were created from the point of a fire start to the point of concern. Each transect line was then divided into segments that separate potential changes in fire behavior and spread along that line, such as changes in slope, aspect or fuel model.

Fuels Data/GIS Layers
Before placing the fires and transect lines on a map, the park's Fuel Model GIS layer was evaluated. In 2000, Calvin Farris, currently the park's Fire Ecologist, developed a FARSITE landscape at 30 meter resolution. This was a three year project that included a comprehensive fuels inventory combined with satellite image analysis. For this project, the 30 meter resolution was too fine of a scale, so a new layer was created rescaling to a 20 acre resolution using the majority re-sampling function in ESRI's ARC 9.1 software. Majority re-sampling is a technique for re-sampling raster data in which the value of each cell in an output is calculated using the most common value within a 4x4 neighborhood of the input raster.

As this fuel model layer was created using the year 2000 landscape, this provided an additional opportunity to compare the risk of five years ago to the present. Since 2000, there have been several landscape size fire treatments of prescribed burning as well as WFU which has treated a total of almost 10,000 acres within the park. RERAP was run using the 2000 data and then again after draping the new fires on the landscape and using the same transect lines to see if there was a reduction of risk after the treatments of the past few years. This is called the 2005 run in this project and was the analysis used to answer the hypothesis.

Transects-Transect lines are needed for RERAP to calculate the risk of fires burning from a start location to an area of concern. For both fuel model layers, (Year 2000 and 2005) transects were placed within the eastern two thirds of the park. While WFU is allowed throughout the entire park, this eastern portion best represents the location where most WFU fires will occur within the park and this will be the analysis area. The western third contains Lassen Peak, Chaos Crags and other large expanses of rock. A 3X4 grid was then placed over the analysis area, and one point location was selected in each grid. This point was the beginning of each of the 12 transect lines and was selected in an area that there would likely sustain fire spread. For example, the points were not placed in rock. Continuous vegetation was required to exist along the length of the transect. This technique for locating ignition point was used so that there would be represented fires spread throughout the analysis area.

The main point of concern for this project area is the park boundary downwind of the predominate wind direction (Southwest/West). Transect lines were then drawn in a Southwest to Northeast direction from each of the 12 point locations toward the park boundary, avoiding the Fantastic Lava Beds which is a large area of rock. These transects were labeled A through L.

For each transect, fire start locations were identified. One start was located at the origin of each transect line. For transect lines greater than 400 chains in length, two additional fire start locations were placed at the closest segment breaks, dividing the transect into thirds. For those transects less than 400 chains, the segment break closest to dividing the transect in half was used. Ignition point locations were then labeled "A, A_1, B, B_1, and B_2" and so on through "L_1". This created 29 ignition point locations. See Figures 7 and 8 for the Transect Maps.

Segments-Each transect line must be divided into segments. These segments reflect areas of similar slope, aspect and fuel model. A new segment is needed if the transect crosses a significant change in slope, aspect or fuel model. Inputs needed for each segment include: vegetation type, fuel model, segment length (in chains), slope %, aspect, shelter, shade, wind vector and spread direction. This information was then collected for the segments using the fuel models in the 2000 GIS fuel model layer.

In addition to running the model for the 2000 data, it was also run using the 2005 data. As there has not been a GIS analysis completed for fuel model changes due to the recent fires within the park, professional judgment and intimate knowledge of the burned areas was relied upon to assign fuel models where the transects hit recent burns. For transects B, C, D, H, and J, where the transect hit either the Prospect Peak, or the Fantastic prescribed burns, the fuel model was changed to a 9. This reflects the amount of needle-drop following these burns, as well as the raising of the canopy base height. Transects G and I each ran into areas of the Bluff WFU of 2004 where there was significant fire intensity and fuel consumption. This area had contained sparse fuel model 8 with shallow litter and a prevalence of volcanic soil prior to the fire. The Bluff fire burned very hot through this area mostly through spotting, consuming most ground fuels Therefore, this area will not support fire spread for the next several years unless there were to be extreme burning conditions. Fuel model was left as an 8; however, rate of spread was changed to zero for low and moderate severity levels, and left as normal rate of spread for high and extreme with no crown fire. This change reflects extreme burning conditions which were observed when the Bluff fire burned into the 1987 Snag fire. In this case, there was little ground fuels, but the fire did spread from log to log by spotting during extreme burning conditions.

Hours and Rate of Spread-Using the weather data and segment line data, the program computes an hourly rate of spread for each segment, for each time period. For each time period, hours of spread per day were then manually entered for low, moderate, high and extreme weather conditions using local knowledge. A set of rules was established based on past fire occurrence observations to adjust fire spread conditions and to initiate crown fire spread.

Fuel models found along the transect lines included 2, 5, 8, 9 and 10 with 8 being predominate along all transects. The following is a brief descriptor of each.

Fuel Model 2-Fire spread is primarily through the fine herbaceous material, in addition to litter and dead-down stem-wood from timber overstory. (Anderson 1982) For the park this is mostly *P. jefferyi* areas.

Fuel Model 5-Fire is generally carried in the surface fuels that are made up of litter cast by the shrubs and the grasses or forbs in the understory. (Anderson 1982) Most of the fuel model 5 in the park is represented by low Pinemat Manzanita (*Arctostaphylos nevadensis*, Gray) mixed with open California Red Fir (*Abies magnifica*, A. Murr).

Fuel Model 8-Slow-burning ground fires with low flame lengths are generally the case, although fire may encounter an occasional “jackpot” or heavy fuel concentration that can flare up. Only under severe weather conditions involving high temperatures, low humidities, and high winds do the fuels pose fire hazards. (Anderson 1982) Most of the study area is fuel model 8 and past experience within the park corresponds to the description of severe weather conditions with this fuel model. Only during very high and extreme weather conditions do fires in this fuel model within the park experience large fire growth, mostly from spotting. *A. concolor* and Lodgepole Pine (*Pinus contorta* Dougl. ex. Loud), represent much of the fuel model 8 in the park.

Fuel Model 9-Fires run through the surface litter faster than model 8 and have longer flame height. (Anderson 1982) *P. jefferyi* stands most represent this fuel model within the park.

Fuel Model 10-Fires burn in the surface and ground fuels with greater intensity than the other timber models. Crowning, spotting, and torching of individual trees are more frequent in this fuel situation leading to potential fire control difficulties. (Anderson 1982) Older stands of *A. concolor, P. contorta, P. jefferyi and A. magnifica* represent fuel model 10 within the park.

For fuel models 2 and 5, the computed rates of spread for each appeared to be adequate for all weather severity levels. For fuel models 8 and 10 in the 2000 fuel model layer with no recent fires, it was felt that the rates of spread for high and extreme conditions did not reflect significant fire growth seen in recent fires in the park. For these fuel models, crown fire was turned on during high and extreme weather conditions during July, August, September, and October unless there was a downhill slope greater than 20%. This decision was made to reflect actual burning conditions seen in the park during high and extreme conditions. The hourly rate of spread was lowered for these crown fire events due to the fact that crown fire spread is substantially greater than surface spread, but only usually occurs during a short period of time during the heat of the day. Tables 1 and 2 summarize the hourly rates of spread with and without crown fire.

TABLE 1: Hours of Spread per Day Used in RERAP with No Crown Fire

	LOW	**MODERATE**	**HIGH**	**EXTREME**
June	0	0	1	2
July	1	1	2	3
August/Sept	2	3	4	5
October	1	1	2	3
November	0	0	1	2

TABLE 2: Hours of Spread Per Day with Crown Fire

	LOW	**MODERATE**	**HIGH**	**EXTREME**
June	0	0	1	2
July	1	1	1	2
August/Sept	2	3	2	3
October	1	1	1	2
November	0	0	1	2

For the transects that hit recent fires, the segments that were changed to a fuel model 9 used that models rate of spread, kept the hourly rate of spread but did not have any crown fire. Crown fire was turned off to reflect the raising of the canopy-base height. For transects G and I, crown fire was also turned off; however, the fuel model was kept at an 8.

RISK MODULE:

The Risk Module runs five thousand randomly generated scenarios for each ignition point using the probabilities and spread rates established in the TERM and SPREAD DATA sections. These scenarios use a randomly generated weather bin which includes all severity levels. The program then determines the percent of scenarios in which the fire reaches the point of concern using the "Risk over Time" function. RERAP does not provide a measure of confidence in the resulting probabilities. RERAP runs a "Monte Carlo" simulation where the programmers feel the error is insignificant enough as to not be included in the results. (Dick Bahr, {NPS National Fuels Specialist and RERAP "help" contact} personal communication, February 2006.)

For each of the 29 ignition point locations, a Risk over Time run was completed for the dates of June 15, July 15, August 15, September 15 and October 15 for a total of 145 fire scenarios. These same 145 fire scenarios were run again using the 2005 fuels layer. As stated above, the 2005 RERAP run was used to answer the hypothesis, but the 2000 results are discussed.

Assumptions

Spotting was not modeled. Recent fires have shown large fire growth due to spotting during high and extreme weather conditions. Turning on the "crown" function during high and extreme weather conditions for fuel model 8 was intended to simulate the spotting.

As there is no confidence value associated with the RERAP results, the statistical error is unknown and therefore is not a part of the outcome.

RERAP is only a model and is only as good as the data input into the program, the user's skill level manipulating the data within the program, and the manager's ability to interpret the results.

The results of this analysis will only be valid until there is significant change of fuels on the landscape. This will most likely occur as a result of prescribed burning or future WFU.

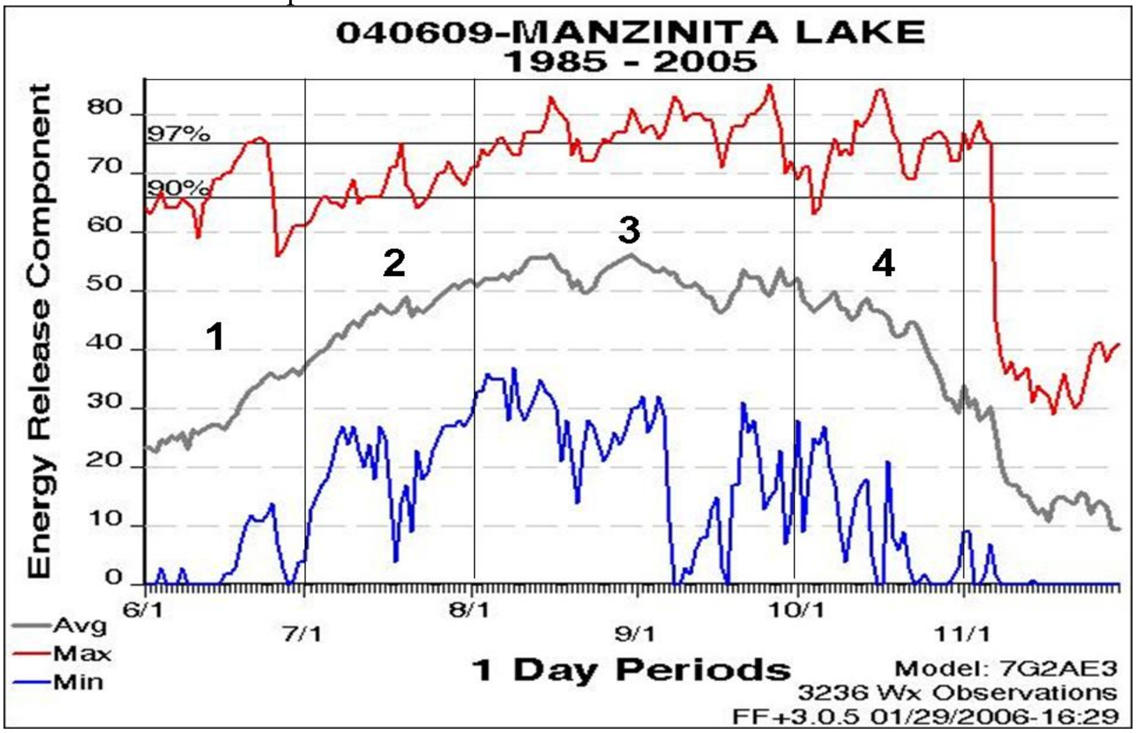
Results

The results are shown here in procedural order.

Weather Data Results-

Time periods-Time periods were chosen by analyzing the "average" line on the ERC graph. The park's fire season is relatively predictable as represented by the classic bell shaped curve of the "average" line on of the ERC graph. This means that on average, June is relatively cool with low to moderate fire behavior expected, however conditions are expected to become warmer and drier. July continues to get warmer and drier with ERC's trending upward. During August and September ERC's level out, and October starts the downward trend toward a season ending event usually in November. This information is summarized in Figure 2.

FIGURE 2: ERC Graph and RERAP Time Periods



Time periods for this analysis were derived from these changes in the average ERC line. Using this information, the time periods for the analysis are; June, July, August and September, and October. While fuel moistures are normally high in June, lightning does occur and wildland fires have happened during this month. The Fires Summary in Fire Family Plus shows 36 lightning fires occurring in June or earlier using 36 years of data.

Winds-Winds were analyzed in the WIND report function of Fire Family Plus for June 1 to November 30, 1985-2005. The result is the percentage of days the wind blew in each direction during the analysis period, summarized in Figure 3. Winds were predominately out of the southwest and west approximately 78% of the time. This figure corresponds to local knowledge of critical fire growth from historic fires being from the southwest to the northeast, as demonstrated in the fire history map, Figure 4.

FIGURE 3: Wind Direction, Manzanita Lake RAWS. June 1-August 30, 1985-2005

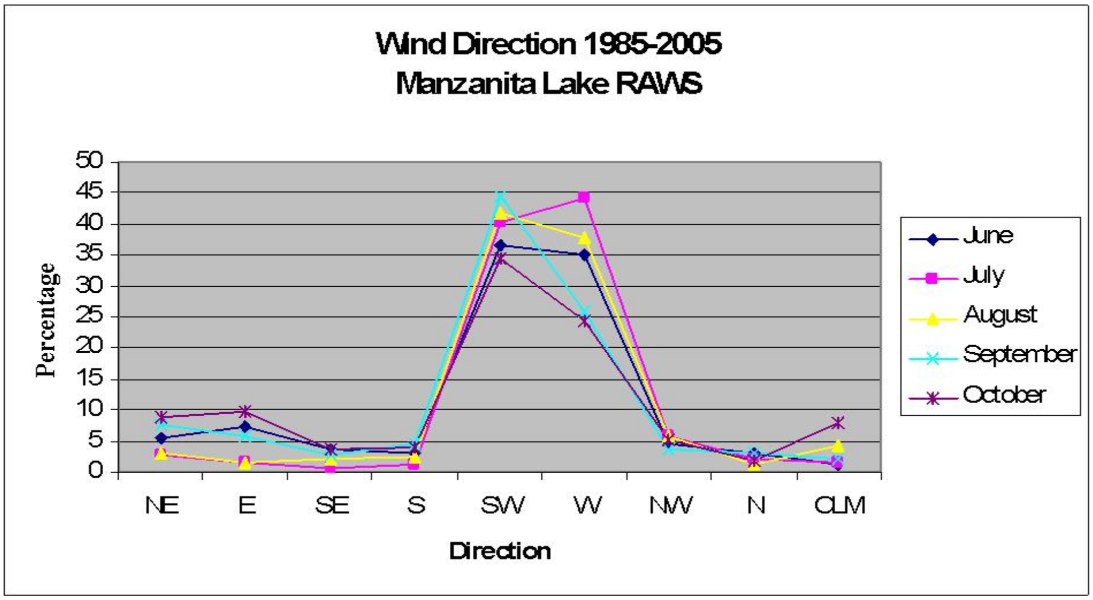
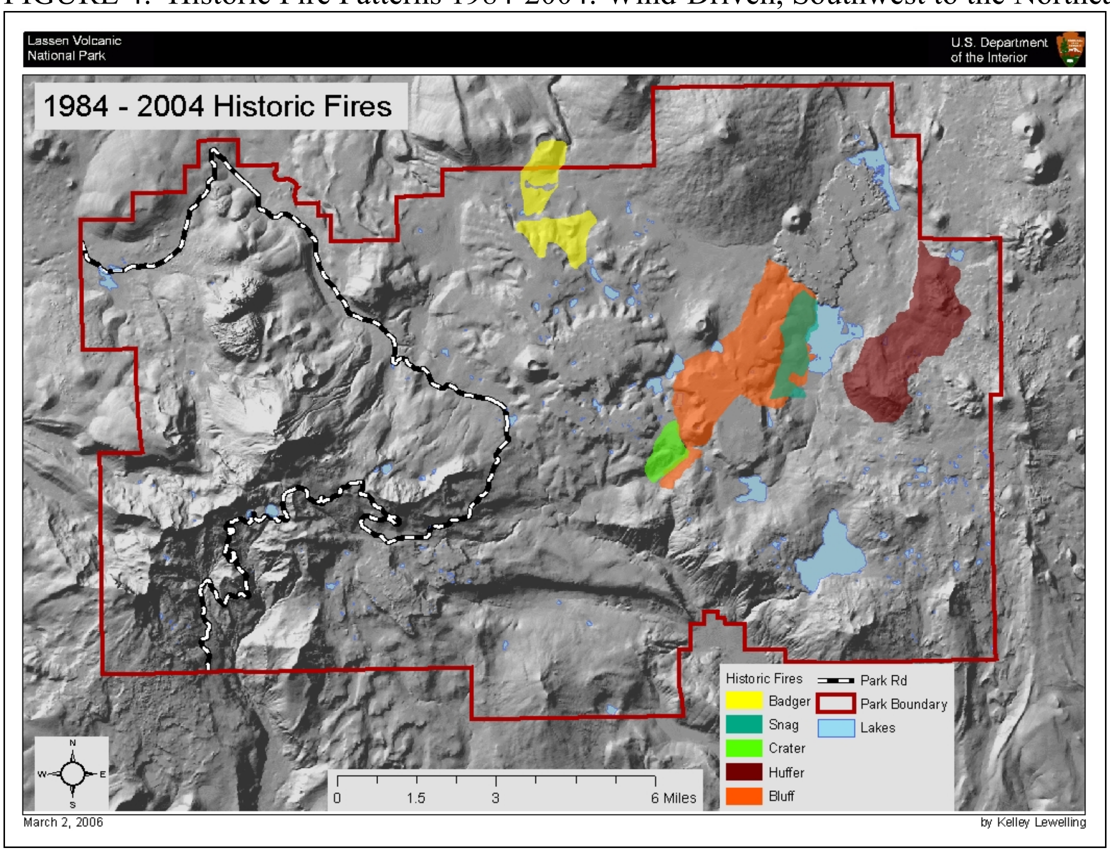


FIGURE 4: Historic Fire Patterns 1984-2004: Wind-Driven, Southwest to the Northeast



Percentile Weather Report-the Percentile Weather Report results from Fire Family Plus are produced into a "text" document that is then be imported directly into the RERAP program. See Figure 5 for a sample percentile weather report. All percentile weather reports are available upon request.

FIGURE 5: Sample Percentile Weather Report

FireFamily Plus Percentile Weather Report for RERAP

Station: 040609: MANZINITA LAKE Variable: SC
Model: 7G2AE3
Data Years: 1985 - 2005
Date Range: August 1 - September 30
Wind Directions: S, SW, W

Percentiles, Probabilities, and Mid-Points

Variable/Component Range	Low	Mod	High	Ext
Percentile Range	0 - 15	16 - 89	90 - 97	98 - 100
Climatol. Probability	15	75	7	3
Mid-Point SC	4 - 4	8 - 8	13 - 13	16 - 22
Num Observations	41	156	15	18
Calculated Spread Comp.	4	7	13	16
Calculated ERC	40	55	51	56

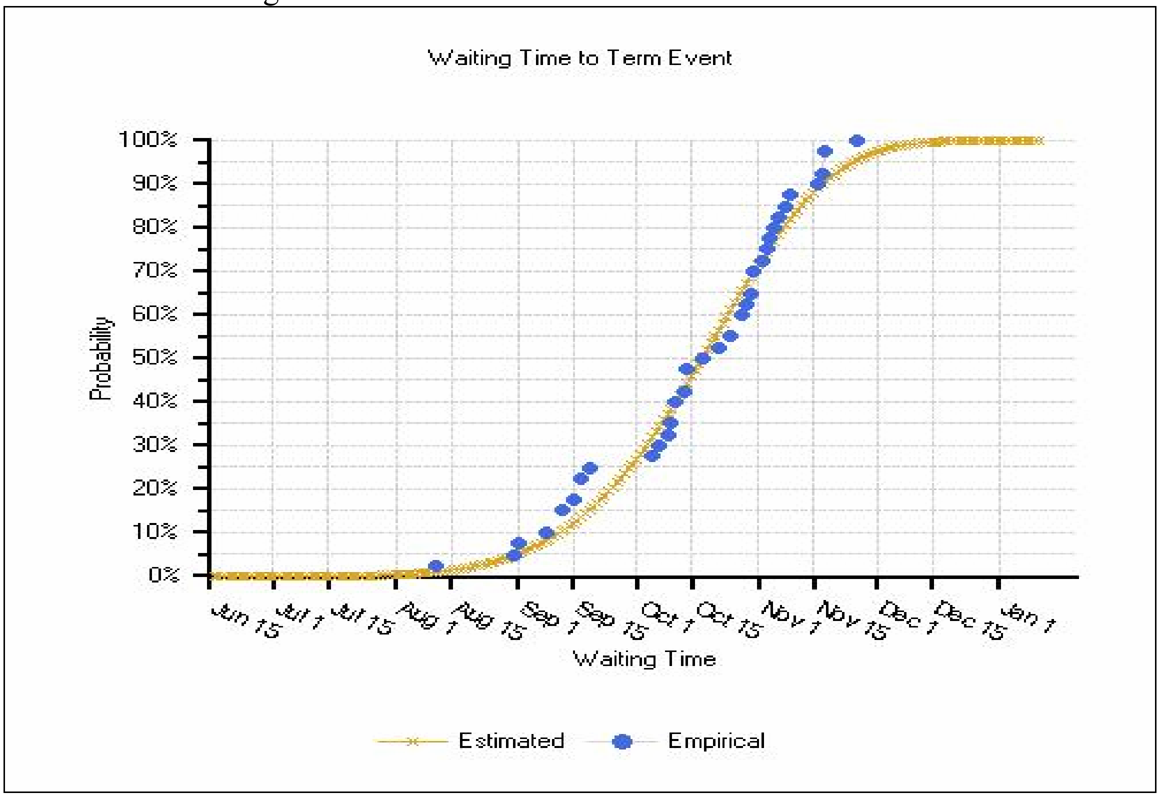
Fuel Moistures

1 Hour Fuel Moisture	9.30	4.70	5.20	3.90
10 Hour Fuel Moisture	11.40	6.40	7.30	6.00
100 Hour Fuel Moisture	14.80	11.00	11.20	10.80
Herbaceous Fuel Moisture	21.10	18.30	18.30	15.20
Woody Fuel Moisture	99.50	87.90	92.00	86.00
20' Wind Speed	3.00	5.80	10.10	11.90
1000 Hour Fuel Moisture	13.60	12.00	12.80	12.00

1191 Weather Records Used, 936 Days With Wind (78.59%)

Fire Ending Event-The fire ending event results from the TERM Module are represented in the Waiting Time to TERM Event graph, Figure 6.

FIGURE 6: Waiting Time to TERM Event



Outputs from the graph show the following:

50% probability of a fire-ending event by 10/18
75% probability of a fire-ending event by 11/3
90% probability of a fire-ending event by 11/18
99% probability of a fire-ending event by 12/1

Transects-Figure 7 shows transect lines, ignition point locations and fuel model from 2000 data, and Figure 8 shows ignition points and transects with the 2004-2005 fires

FIGURE 7: Modeled Ignition Points, Fuel Models and Transects, 2000 Fuels Data

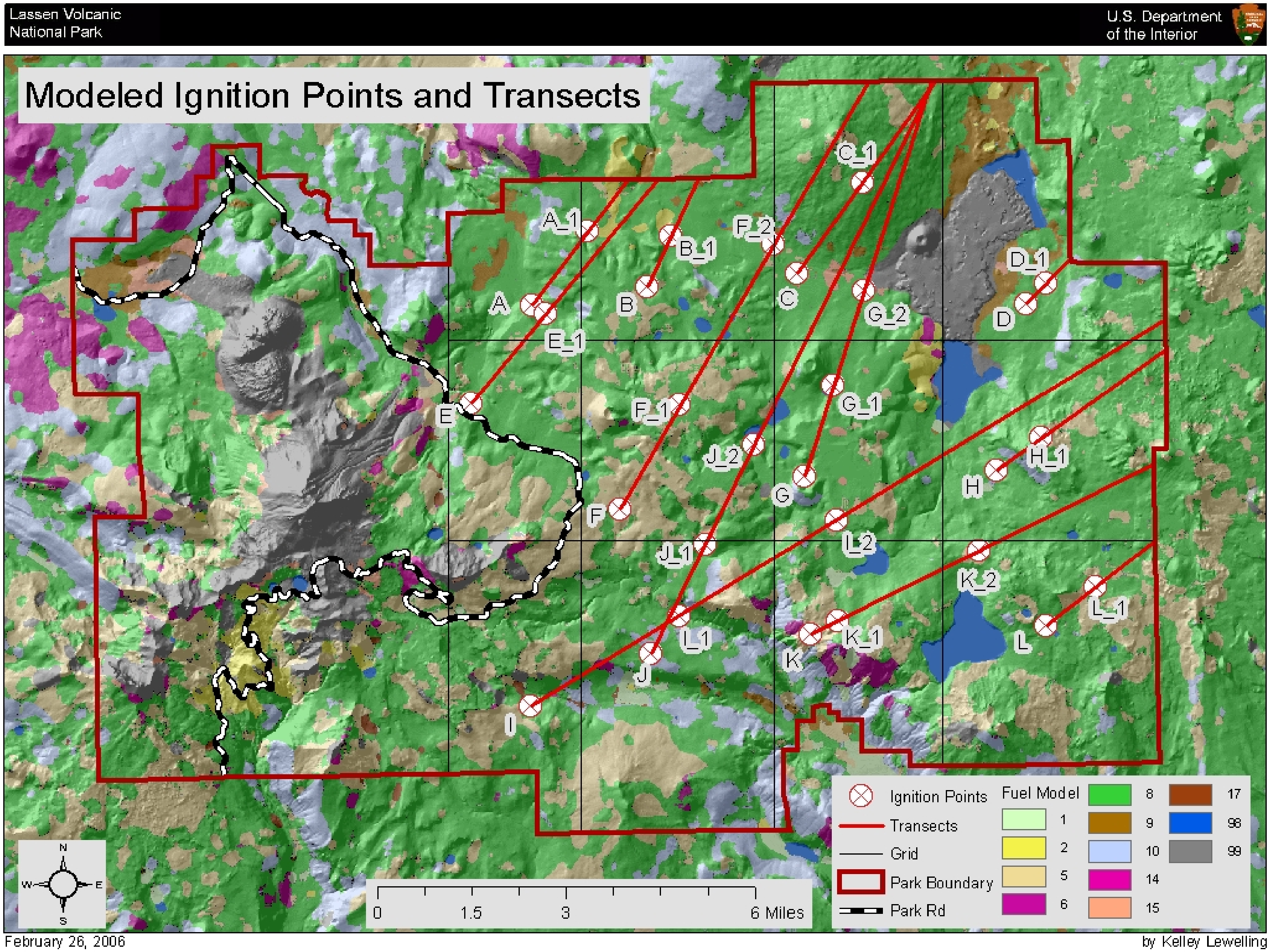
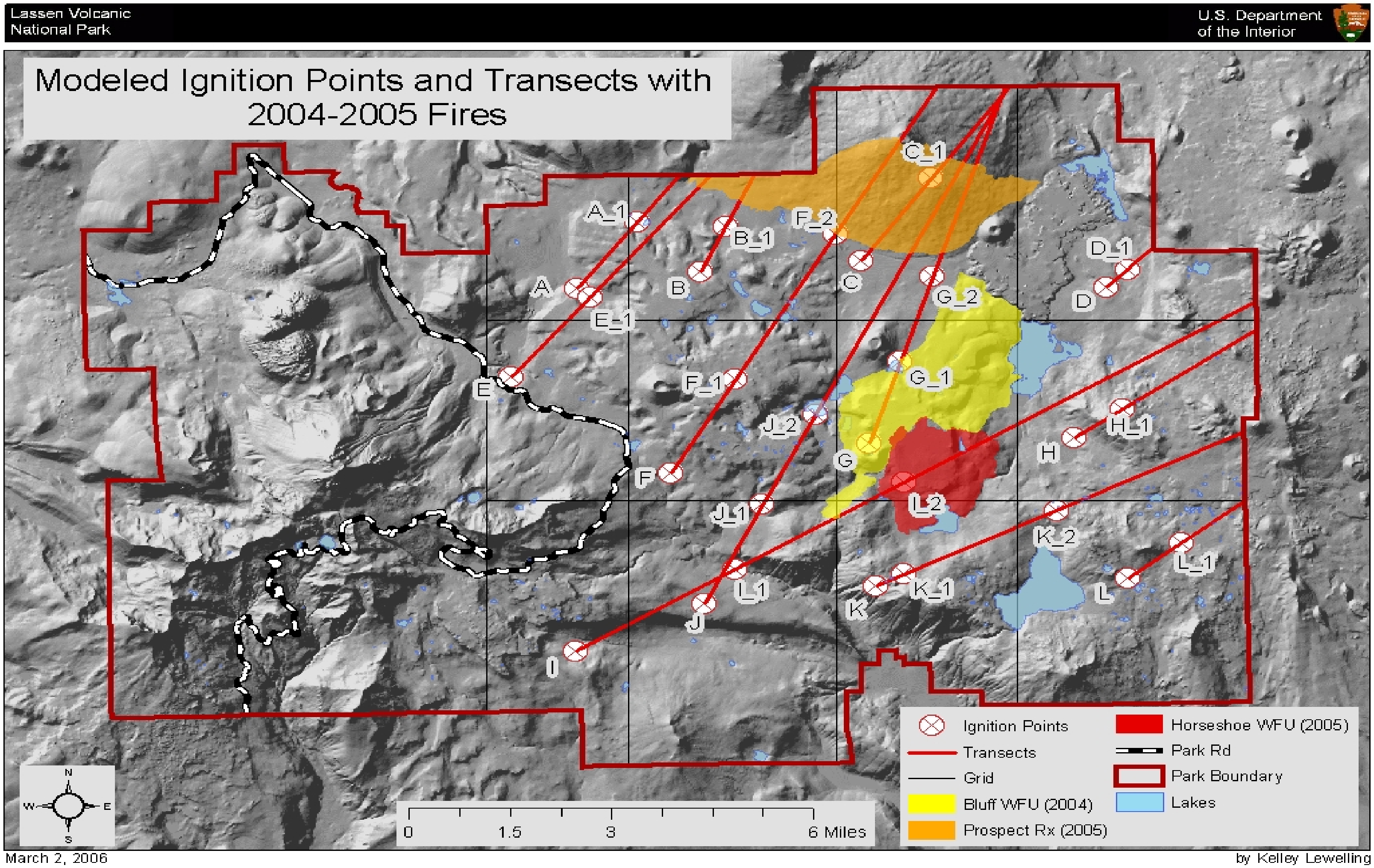


FIGURE 8: Modeled Ignition Point and Transects With 2004-2005 Fires



RERAP Results-

For an example of a RERAP report, please refer to the appendix.

The "Risk over Time" module in RERAP was run for each of the 290 scenarios covering the 2000 and 2005 fuels layers. Each run calculates the risk of a fire reaching the point of concern before a fire-ending event. Each of the 29 ignition points was run for each of the five time periods. For each run, a probability value is given as "Total Risk." These values were entered into separate spreadsheets labeled 2000 and 2005 by transect line as the rows and month as the columns.

In order to test the hypothesis, "high risk scenarios" must be defined and identified. "High risk" is defined using a *simple majority* rule. For this analysis, the rule is that any single scenario having a risk value of 51% or greater will be assumed to have a high enough risk to threaten the park boundary as determined by the park Superintendent. Using this rule, a threshold value of $\geq$ 51% in the spreadsheet will receive a value of "1", while those scenarios with < 51% receive a value of "0". Tables 3 and 5 provide a list of the transects and the raw data for the 2000 and 2005 fuels layers respectively. Tables 4 and 6 provide the respective threshold values and are the values from which the hypothesis will be tested.

TABLES 3 and 4: 2000 Fuels Layer Raw Data

2000 Fuels Layer

Transect #	June	July	August	September	October
A	97	96	83	33	1
A_1	100	100	99	97	62
B	96	94	77	25	0
B_1	99	98	92	60	5
C	76	68	38	2	0
C_1	96	93	76	24	0
D	99	98	91	57	4
D_1	100	99	97	79	22
E	81	73	40	3	0
E_1	97	96	83	32	0
F	14	8	1	0	0
F_1	38	26	6	0	0
F_2	90	85	58	9	0
G	24	17	3	0	0
G_1	52	41	12	0	0
G_2	89	83	56	6	0
H	93	89	65	5	0
H_1	97	95	85	39	0
I	0	0	0	0	0
I_1	5	3	0	0	0
I_2	31	24	5	0	0
J	2	1	0	0	0
J_1	9	5	1	0	0
J_2	28	20	4	0	0
K	42	31	8	0	0
K_1	44	32	10	0	0
K_2	87	81	53	7	0
L	98	97	90	51	0
L_1	99	98	92	58	4

Threshold Values ≥51%

June	July	August	September	October
1	1	1	0	0
1	1	1	1	1
1	1	1	0	0
1	1	1	1	0
1	1	0	0	0
1	1	1	0	0
1	1	1	1	0
1	1	1	1	0
1	1	0	0	0
1	1	1	0	0
0	0	0	0	0
0	0	0	0	0
1	1	1	0	0
0	0	0	0	0
1	0	0	0	0
1	1	1	0	0
1	1	1	0	0
1	1	1	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
1	1	1	0	0
1	1	1	0	0
1	1	1	1	0

TABLES 5 and 6: 2005 Fuels Layer Raw Data

2005 Fuels Layer

	June	July	August	September	October
A	97	96	83	33	1
A_1	100	100	99	97	62
B	88	82	4	0	0
B_1	99	96	88	1	0
C	0	0	0	0	0
C_1	79	57	0	0	0
D	0	0	0	0	0
D-!	100	100	98	88	0
E	81	73	40	3	0
E_1	97	96	83	32	0
F	0	0	0	0	0
F_1	0	0	0	0	0
F_2	75	48	0	0	0
G	0	0	0	0	0
G_1	0	0	0	0	0
G_2	87	80	3	0	0
H	0	0	0	0	0
H_1	87	83	8	0	0
I	0	0	0	0	0
I-1	5	3	0	0	0
I-_2	31	24	5	0	0
J	0	0	0	0	0
J_1	0	0	0	0	0
J_2	1	0	0	0	0
K	42	31	8	0	0
K_1	43	35	10	0	0
K_2	88	80	52	7	0
L	98	97	90	51	0
L_1	99	98	92	58	4

Threshold Values ≥51%

June	July	August	September	October
1	1	1	0	0
1	1	1	1	1
1	1	0	0	0
1	1	1	0	0
0	0	0	0	0
1	1	0	0	0
0	0	0	0	0
1	1	1	1	0
1	1	0	0	0
1	1	1	0	0
0	0	0	0	0
0	0	0	0	0
1	0	0	0	0
0	0	0	0	0
0	0	0	0	0
1	1	0	0	0
0	0	0	0	0
1	1	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
1	1	1	0	0
1	1	1	0	0
1	1	1	1	0

Results by Time Period/Hypothesis Test

The following results by time period will include a general discussion about the results, and then test the hypothesis.

Using the definition of a high risk scenario, modeled ignitions are assumed to hit the park boundary, or they did not (represented by a "1" or a "0"). This is a statistical analysis using the binomial distribution to accept or reject the null hypothesis. In hypothesis testing the null and an alternative hypothesis are put forward. If the data are sufficiently strong to reject the null hypothesis, the null hypothesis is rejected in favor of an alternative hypothesis. (Freund, J.E. 2001)

Hypothesis- The objective of this analysis is to test the hypothesis that under current fuels conditions (2005 data) and historical weather observations within Lassen Volcanic National Park, less than or equal to 25% of the modeled ignition scenarios by time period (months) are high risk to the park boundary with a .05 level of significance. High risk scenarios are defined as those individual ignition points with greater than or equal to 51% chance of reaching the park boundary before a fire-ending event.

Although the hypothesis test for the project is for the 2005 fuels data, the 2000 data will also be tested for comparison.

In order to test the hypothesis, a Binomial Distribution Probability table was created in Microsoft Excel with 29 independent trials with a 25% probability of success on each trial. The probabilities were then graphed as a bar chart, (see Figure 9). This graph can be used to test the probability that less than or equal to .25 of modeled ignitions will hit the park boundary with a .05 level of significance. The number of "successes" (high risk fires) out of the 29 "trials" for each time period can be identified on the X axis. If the sum of the probabilities (heights of the bars) from that value to the right is less than 0.05, the hypothesis must be rejected. In this graph, 12 or more high risk fires was the cut off for the 0.05 level of significance. While the statistical analysis was completed by using the Binomial Distribution Probability, the raw proportion values are included for additional comparison.

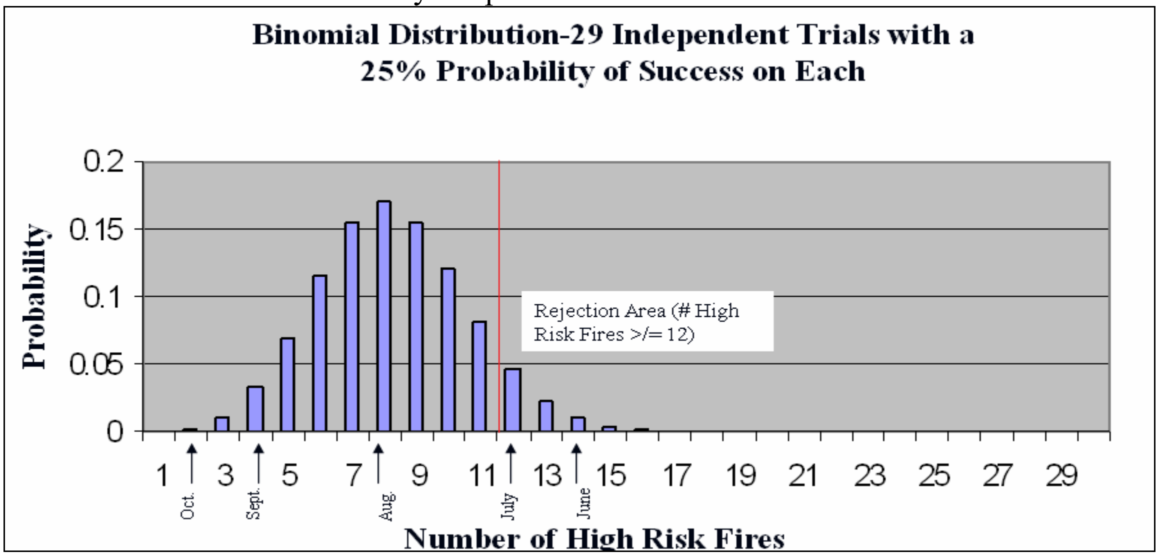
To formally test the hypothesis, the following five step process is followed (Freund, J.E. 2001):

For this analysis,

1. **Null Hypothesis:** H_0 p ≤ 25%.
   Alternative Hypothesis: H_A p >25%.
2. Level of Significance= 0.05
3. The test statistic is the number of fire scenarios that meet the "high risk scenario" threshold for each time period.

4. The test is "*x*" (number of high risk fires) and the corresponding binomial probability where n =29 and p=0.25, is the sum of all probabilities to the right of x.
5. If the corresponding probability for the test statistic and the sum of all values to the right are less than 0.05, the Null Hypothesis must be rejected.

FIGURE 9: Binomial Probability Graph



2000 Data

June 15- During this time period, individual probabilities of the ignition points reaching the park boundary before a fire-ending event ranged from 0-100%. 11 ignition points had a 95% or greater probability (A, A_1, B, B_1, C1, D, D_1, E_1, H, L, and L_1), while four had less than 10%. 18 of the 29 ignition points met the threshold criteria of ≥51% for a proportion of .62.

1. **Null Hypothesis:** H_0 p ≤ 25%.
   Alternative Hypothesis: H_A p >25%.
2. Level of Significance= 0.05
3. The test statistic is the number of fire scenarios that meet the "high risk scenario" threshold for each time period=**18**
4. Probability= 0.000026
5. Since .000026 is less than 0.05, the Null Hypothesis must be rejected. In other words, the data does not support the claim that ≤0.25 of high risk fires will hit the boundary starting June 15 using the year 2000 fuels data.

July 15- During this time period, individual probabilities of the ignition points reaching the park boundary before a fire-ending event ranged from 0-100%. 9 ignition points had a 95% or greater probability. 17 of the 29 ignition points met the threshold criteria of ≥51% for a proportion of .59

1. **Null Hypothesis:** H_0 p ≤ 25%.

Alternative Hypothesis: H_A p >25%.
2. Level of Significance= 0.05
3. The test statistic is the number of fire scenarios that meet the “high risk scenario” threshold for each time period=**17**
4. Probability= 0.000121
5. Since 0.000121 is less than 0.05, the Null Hypothesis must be rejected. In other words, the data does not support the claim that ≤0.25 of high risk fires will hit the boundary starting July 15 using the year 2000 fuels data.

August 15- During this time period, individual probabilities of the ignition points reaching the park boundary before a fire-ending event ranged from 0-99%. 2 ignition points had a 95% or greater probability while 11 had 10% or less. 15 of the 29 ignition points met the threshold criteria of ≥51% for a proportion of .52.

1. **Null Hypothesis:** H_0 p ≤ 25%.
   Alternative Hypothesis: H_A p >25%.
2. Level of Significance= 0.05
3. The test statistic is the number of fire scenarios that meet the “high risk scenario” threshold for each time period=**15**
4. Probability = 0.001784
5. Since 0.001784 is less than 0.05, the Null Hypothesis must be rejected. In other words, the data does not support the claim that ≤0.25 of high risk fires will hit the boundary starting August 15 using the year 2000 fuels data.

September 15- During this time period, individual probabilities of the ignition points reaching the park boundary before a fire-ending event ranged from 0-97% while 18 had 10% or less. 5 of the 29 ignition points met the threshold criteria of ≥51% for a proportion of .172.

1. **Null Hypothesis:** H_0 p ≤ 25%.
   Alternative Hypothesis: H_A p >25%.
2. Level of Significance= 0.05
3. The test statistic is the number of fire scenarios that meet the “high risk scenario” threshold for each time period=**5**
4. Probability = 0.884675
5. Since 0.884675 is more than 0.05, the Null Hypothesis must be accepted. In other words, the data supports the claim that ≤0.25 of high risk fires will hit the boundary starting September 15 using the year 2000 fuels data.

October 15- During this time period, individual probabilities of the ignition points reaching the park boundary before a fire-ending event ranged from 0-62% while 27 had 10% or less. 1 of the 29 ignition points met the threshold criteria of ≥51% for a proportion of .034.

1. **Null Hypothesis:** H_0 $p \leq 25\%$.
   Alternative Hypothesis: H_A $p > 25\%$.
2. Level of Significance= 0.05
3. The test statistic is the number of fire scenarios that meet the "high risk scenario" threshold for each time period=**1**
4. Probability = 0.999761
5. Since 0.999761 is more than 0.05, the Null Hypothesis must be accepted. In other words, the data supports the claim that ≤0.25 of high risk fires will hit the boundary starting October 15 using the year 2000 fuels data.

An overall risk value was then calculated for comparison with the 2005 fuels data. The overall risk value is the average of all proportions; i.e. high risk fires divided by total number of fires or $\frac{x}{n}$.

Overall Risk Value: $\frac{x}{n}$ or $\frac{56}{145}=$ **.386**

2005 Data

June 15- During this time period, individual probabilities of the ignition points reaching the park boundary before a fire-ending event ranged from 0-100%. 7 transects had a 95% or greater probability (A, A_1, B_1, D_1, E_1, L, and L_1) while 10 had 0%. The 10 transects with a probability of 0% maintain that probability throughout all time periods, meaning that these transects have no chance of hitting the park boundary regardless of time of year. 14 of the 29 transects met the threshold criteria of ≥51% for a proportion of .48.

1. **Null Hypothesis:** H_0 $p \leq 25\%$.
   Alternative Hypothesis: H_A $p > 25\%$.
2. Level of Significance= 0.05
3. The test statistic is the number of fire scenarios that meet the "high risk scenario" threshold for each time period=**14**
4. Probability = 0.005645
5. Since .005645 is less than 0.05, the Null Hypothesis must be rejected. In other words, the data does not support the claim that ≤0.25 of high risk fires will hit the boundary starting June 15 using the year 2005 fuels data.

July 15- During this time period, individual probabilities of ignition points reaching the park boundary before a fire-ending event ranged from 0-100%. The same 7 transects mentioned above maintained a 95% or greater probability. 12 of 29 transects met the threshold criteria of ≥51% for a proportion of .45.

1. **Null Hypothesis:** H_0 $p \leq 25\%$.
   Alternative Hypothesis: H_A $p > 25\%$.
2. Level of Significance= 0.05

3. The test statistic is the number of fire scenarios that meet the “high risk scenario” threshold for each time period=**12**
4. Probability = 0.039032
5. Since 0.039032 is less than 0.05, the Null Hypothesis must be rejected. In other words, the data does not support the claim that ≤0.25 of high risk fires will hit the boundary starting July 15 using the year 2005 fuels data.

August 15- During this time period, individual probabilities of ignition points reaching the park boundary before a fire-ending event ranged from 0-99%. 2 transects maintained a 95% or greater probability. 8 of 29 transects met the threshold criteria of ≥51% for a proportion of .28.

1. **Null Hypothesis:** H_0 p ≤ 25%.
   Alternative Hypothesis: H_A p >25%.
2. Level of Significance= 0.05
3. The test statistic is the number of fire scenarios that meet the “high risk scenario” threshold for each time period=**8**
4. Probability = 0.443227
5. Since 0.443227 is more than 0.05, the Null Hypothesis must be accepted. In other words, the data supports the claim that ≤0.25 of high risk fires will hit the boundary starting August 15 using the year 2005 fuels data.

September 15- During this time period, individual probabilities of ignition points reaching the park boundary before a fire-ending event ranged from 0-97%. One transect remained at 95% or greater while 4 of 29 met the threshold criteria of ≥51% for a proportion of .103.

1. **Null Hypothesis:** H_0 p ≤ 25%.
   Alternative Hypothesis: H_A p >25%.
2. Level of Significance= 0.05
3. The test statistic is the number of fire scenarios that meet the “high risk scenario” threshold for each time period=**4**
4. Probability = 0.954494
5. Since 0.954494 is more than 0.05, the Null Hypothesis must be accepted. In other words, the data supports the claim that ≤0.25 of high risk fires will hit the boundary starting September 15 using the year 2005 fuels data.

October 15- During this time period, individual probabilities of ignition points reaching the park boundary before a fire-ending event ranged from 0-62% with 62 being the highest value. One transect met the criteria of ≥51% for a proportion of .034.

1. **Null Hypothesis:** H_0 p ≤ 25%.
   Alternative Hypothesis: H_A p >25%.
2. Level of Significance= 0.05
3. The test statistic is the number of fire scenarios that meet the “high risk scenario” threshold for each time period=**1**

4. Probability = 0.999761
5. Since 0.999761 is more than 0.05, the Null Hypothesis must be accepted. In other words, the data supports the claim that ≤0.25 of high risk fires will hit the boundary starting October 15 using the year 2005 fuels data.

Overall Risk Value: $\frac{x}{n} or \frac{39}{145} =$ **.268**

TABLE 7: Summary of Hypothesis Results; Accepted or Rejected

	June 15	July 15	August 15	September 15	October 15
2000 Fuels Layer	Reject	Reject	Reject	Accept	Accept
2005 Fuels Layer	Reject	Reject	Accept	Accept	Accept

TABLE 8: Raw Risk Value $\frac{x}{n}$; Proportion of High Risk Fires

	June 15	July 15	August 15	September 15	October 15
2000 Fuels Layer	**.62**	**.59**	**.52**	**.172**	**.034**
2005 Fuels Layer	**.48**	**.45**	**.28**	**.103**	**.034**

Difference Between 2000 and 2005 Results
As an additional point of interest for this project, a statistical test was performed concerning the difference between the probabilities from the 2000 and 2005 fuels layers. Using the "overall risk rating" from above, the raw data shows that there was a reduction in risk from .386 to .268 after the fires of 2004 and 2005. This test was performed to see if the difference between the two proportions is significant, or whether the difference can be attributed to chance.

The hypothesis for this test is as follows, and will use the statistic for test concerning difference between two proportions

Null Hypothesis: $H_O\ p_1 = p_2$
Alternate Hypothesis: $H_A\ p_1 > p_2$
Reject Null: $z \geq z_\alpha$ **where**

$$z = \frac{\frac{x_1}{n_1} - \frac{x_2}{n_2}}{\sqrt{\hat{p}(1-\hat{p})\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}} \text{ with } \hat{p} = \frac{x_1 + x_2}{n_1 + n_2}$$

$z_{\alpha} = 1.645$ (95%)
$\hat{p} = .327$
$z = 2.127$

Reject Null: $z=2.127 > z_{\propto}=1.645$ Since 2.127 is greater than 1.645, the null hypothesis must be rejected; in other words there is a significant difference (reduction of risk) of high risk scenarios using the 2005 fuels layer compared to the 2000 fuels layer.

For comparison, the same statistical analysis was completed by time period. Using the formula from above, the results are as follows:

Constants:
$n_1 = 29$
$n_2 = 29$
$z_{\alpha} = 1.645$ for $\alpha = 0.05$

TABLE 9: Results for test concerning difference between two proportions

	June 15	**July 15**	**August 15**	**September 15**	**October 15**
x_1	18	17	15	5	1
x_2	14	13	8	3	1
z	**1.056<1.645**	**1.051<1.645**	**1.878>1.645**	**0.761<1.645**	**0=**
$H_O\ p_1=p_2$	**Accept**	**Accept**	**Reject**	**Accept**	**Accept**

Discussions/Recommendations

The objective of this analysis was to test the hypothesis that under current fuels conditions (2005 data) and historical weather observations within Lassen Volcanic National Park, less than or equal to 25% of the modeled ignition scenarios by time period (months) are high risk to the park boundary with a .05 level of significance. High risk scenarios are defined as those individual ignition points with ≥51% chance of reaching the park boundary before a fire-ending event.

Interpretation of Results: The results of the hypothesis are straight forward, meaning that for each time period there is a "yes" or "no" answer. For the 2005 data, fires starting in June and July do have a greater than 25% probability of reaching the park boundary, August, September and October have a less than 25% probability. When this is compared to the 2000 fuels data, the results of the hypothesis are the same with the exception of August, where the hypothesis was rejected as it has a greater than 25% probability. The face value implication for these results is that the longer a fire is allowed to burn, the greater the probability there is that the fire will reach the park boundary.

By evaluating the raw probabilities in Table 8, it appears that there is a significant reduction in risk comparing the 2000 results to the 2005. In each case except October, there is a reduction in the probability that the fires would hit the boundary. In fact, when the average of all probabilities from each fuel model layers were statistically analyzed for a significant reduction in risk, the hypothesis confirmed that there was a significant difference. However, when the probability differences were tested by time period, August was the only time period where the hypothesis confirmed that there was a *significant* reduction of risk. (Table 9)

By looking at the RERAP summary reports, it appeared that the model made significant runs during the month of August, more than other months. This would correspond to the ERC graph having the highest values during this time and thus having a greater number of days with "high" and "extreme" burning conditions. Although fires that started in June and July had a higher probability, the significant fire growth did not happen until August on those fires.

By comparing historic fire experience, the model can be interpreted to a greater extent. Most major fire runs have happened in August and early September, and most fire growth can be attributed to running and spotting that correspond to high and extreme burning conditions which the model also indicated. Fires that start in June and July *can* have a higher risk of reaching the boundary simply because the fire has longer to burn before a fire-ending event. There have also been several instances where the risk of one fire is reduced because it burns into or adjacent to an earlier fire. (Bluff, Horseshoe, Hoffman).

While the results of the analysis provide important modeled facts about the risks associated with WFU in the park, the real value is taking ownership of the results and provide talking points with the Superintendent as well as the park's management team. The intent of this project from the beginning was to be able to provide the new park Superintendent information about risk and management issues relating to managing WFU in the park for the future.

The decision to use WFU as a tool cannot be made without an extensive amount of information. This analysis provides an excellent starting point to discuss what the identified risks mean for the management of the fire program as a whole, as well as addressing the second part of this analysis which shows that having fires on the landscape reduces these identified risks.

Discussion

It is critical that the management team, which includes the Superintendent as the decision-maker, in the park share and/or at least understand the same fire management philosophy. It is a very large commitment for a park, or any management unit to manage WFU, and there must be some level of understanding of what that commitment is and what it means before the first Go/No-Go decision is to be made. That is why this analysis was intended to gather information at a programmatic level, not on an individual fire level. In general, it is much easier to put fires out than to manage them, so a commitment to this philosophy is essential. The management philosophy in the park has been, and is recommended to remain, dedicated to a holistic approach to managing the ecosystem, in which fire is a key element. This means appropriately using all the "tools in the toolbox," in which WFU plays a major role.

This analysis points out that there is a potential for significant risk associated with managing WFU within the park. It also points out that the more fuel treatments (WFU and/or prescribed fire) there are, the more the risk is reduced. As we know from several studies within the park, fire is a critical element of change needed for a healthy ecosystem and preserving wilderness values. The National Park Service mission also directs us to manage NPS lands *unimpaired* for future generations, and the park views continued fire suppression an impairment. This points out a dilemma; we must continue to manage fire on the landscape to have a healthy ecosystem as well as comply with the NPS mission, but we must also comply with the objectives of protecting people and property from the risks of fire. The critical key to this dilemma is a sound risk management philosophy accepted by the management team.

The first step in risk management is identifying the risk. This analysis did an excellent job of not only providing a numerical value of risk; it also identified risk spatially and temporally. By evaluating each fire start, it became obvious that the ignition points near the park boundary had a higher risk, while the points farther away had a lower risk. It also pointed out that the fires that started in June had a higher risk than those that started in October. While this may seem be an elementary point, thoroughly understanding this provides the management team further knowledge from which to start discussions on new fire starts.

As every fire is different, every fire needs to be evaluated individually to see if it can be managed successfully. The results of this analysis point out that fires starting in June and July have a higher risk. While that may (or may not) be the case, fires that start at that time may not start moving until later in the year. June and July are still early season in the park, and many fuels are still green and/or have high fuel moistures. Fires starting during that time period have historically not shown much growth until August. The Bluff WFU, which started June 28, of 2004 was an example of this scenario. It took the Bluff a month to grow to 10 acres, another month to hit 100 acres, then at the end of September there were several days of significant growth. The point is that the Bluff fire met other criteria for the continued management of the fire from June on and was very successful.

The next step in risk management is risk mitigation. When there is a fire start, the value of that start must be weighed against the risk. If a fire has a high enough value, the identified risks must be mitigated in order to manage that fire. As this analysis pointed out, fires starting further away from the boundary, or those that start later in the year may not need to be managed very aggressively, with the ideal being hands off monitoring. On the other hand, we know that some fires will have much more risk, such as those close to the boundary. If the value of these fires is high enough and the decision is made for them to be managed, the risks will need to be mitigated. These mitigations may mean more intensive management.

If we assume that managing these higher risk fires has a high enough value for the overall long term management of the park, then we have to assume the more intensive risk mitigations and higher costs are justified (assuming all costs are responsible and legitimate). These higher costs can also be considered an "investment" to reducing costs in the future. While a full cost analysis is not in the scope of this project, some sample figures are included here to show this point. The Bluff WFU was very intensively managed on approximately 80% of its perimeter, and had a per acre cost of $214. The Horseshoe WFU started south of the Bluff and had the Bluff fire to run into on its northern flank. The Horseshoe WFU still needed intensive management, but critical holding concerns were held to approximately 25% of the perimeter since the fire could run into the Bluff with no threat to the boundary. The Horseshoe WFU cost $43/acre. In contrast, three years ago on an adjacent wilderness to the park, a 50 acre suppression fire had a cost of approximately $300/acre. There are many places in the park where intensive management will need to occur if the park chooses to manage fires as WFU; however, this analysis shows that the more fires there are on the landscape, the future risk will go down, and commensurate with lower risk will be lower cost.

Potential impacts to wilderness can be looked at the same way. We know that resuming normal fire regimes is critical to the health of the ecosystem and therefore, the health of the wilderness. As stated in the above paragraph, mitigation measures on some fires may need to be fairly intense if they are to be successful. Lessons learned from the Bluff and Horseshoe WFU's have shown park management areas where impacts to the wilderness can be minimized; however there are some residual impacts that cannot be avoided if safety is to remain the number one priority. These impacts can also be considered an "investment" into the future of maintaining wilderness values. With successive fires, risks will be reduced, which will then reduce the need for intensive mitigation measures on future fires.

Continued management of natural fires (as well as prescribed fires) within the park will reduce the overall risk of fires leaving the park boundary, as well as have lower financial costs and fewer impacts to the wilderness. Sound risk management will be the key for all Go/No-Go WFU decisions and their continued successful management from the start to the seasons end. This analysis provides a valuable piece of the risk management process and will be an important tool in managing WFU in the future. It will only be with the combination of manual/mechanical fuel treatments, prescribed burning, and wildland fire use that the park will achieve the goal of restoring and maintaining desired fire regimes to the maximum extent practicable so park ecosystems exhibit a high degree of health and function.

Recommendations

Based on the findings of this analysis, WFU should remain a critical fire management tool into the future of the program in the park. It points out that the critical link to successful management of these fires should be in the individual fire risk assessment. This assessment will need to take into consideration the time of year and distance from the boundary, as well as the fuels it is not only burning in, but also the fuels it will burn into. The side benefit to continued WFU is less risk in the future; however the main focus should remain mitigating the risks of current fires. The following are additional recommendations:

- Continue with the wildland fire use program as outlined in the Fire Management Plan
- As all fires are different, utilize the Wildland Fire Implementation Plan (WFIP) process to evaluate what management actions (risk mitigations) are needed on any given fire.
- Refer to this analysis during Go/No-Go WFU decisions as well as for input into long term risk assessments.
- Utilize tactics that reduce overall costs while maintaining high level of safety
- Utilize tactics that are commensurate with wilderness values.
- Complete a thorough landscape level risk, hazard and value assessment of the park

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Appendix
Sample RERAP Report
All others available by request

Risk Report

Assessment Name:	Lassen SW
Assessment Date:	6/16/2006
Total Distance (ch):	485

Description

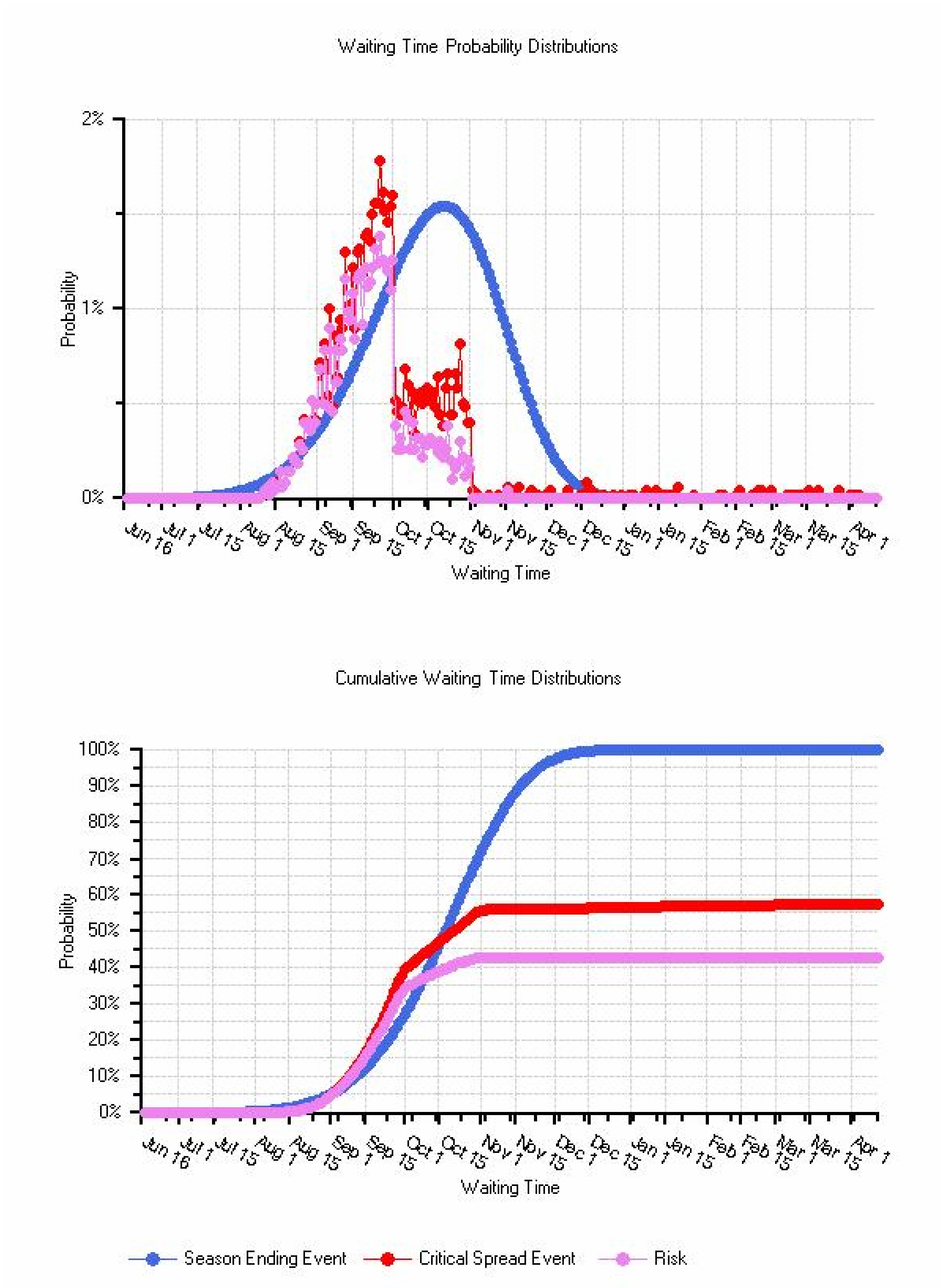
SW Wind Risk Assessment for Wildland Fire Use

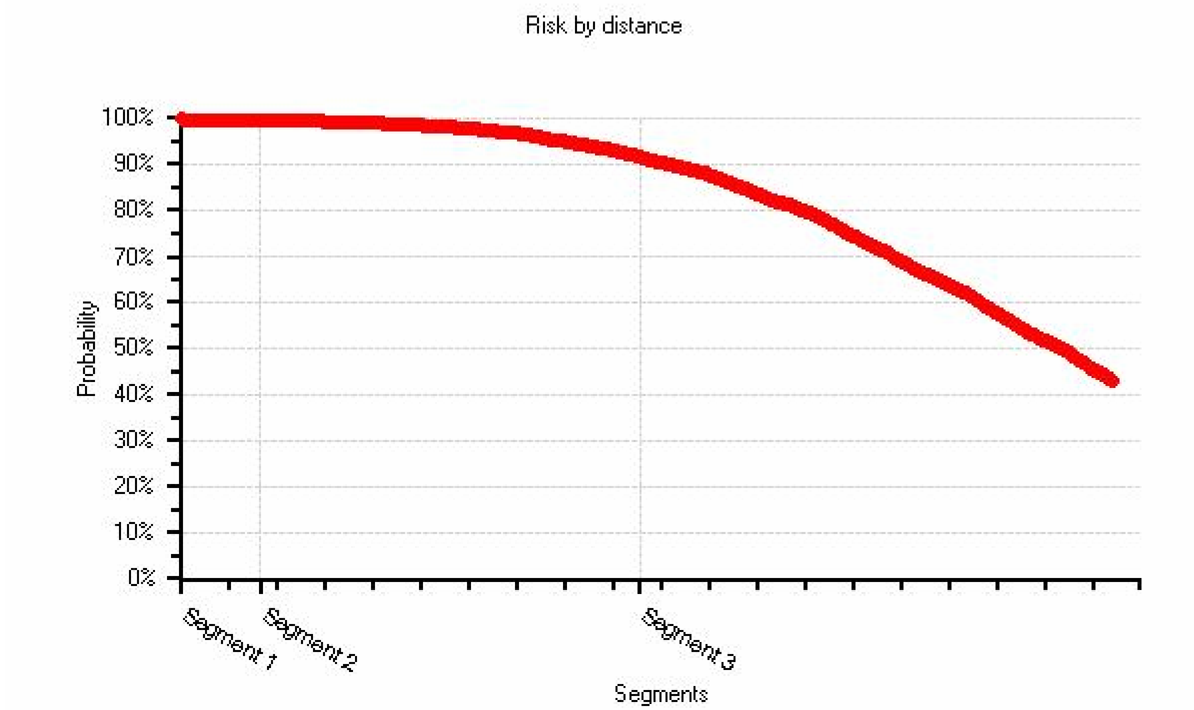
Risk Summary
Total Risk: 43%

Term File Information	
Season Start Date:	6/15/2006
Alpha Value:	5.5
Beta Value:	0.0075
File name:	Lassen.trm

Period #	Start Date	Name	Risk
0	6/15/2006	June	0%
1	7/1/2006	July	0%
2	8/1/2006	Aug Sept	34%
3	10/1/2006	Oct	8%
4	11/1/2006	Nov	0%

Seg #	Map ID	Veg Type	Fuel Model	Length (ch)	Slope %	Aspect	Elev	Shelter	Shade	Wind Vector	Spread Dir
3	Fuel Model	Brush	5	41	8	N	A	U	U	200	200
4	Fuel Model	Conifer	8	198	18	E	A	S	S	275	275
5	Fuel Model	Conifer	8	246	8	W	A	S	S	340	340


Waiting Time Probability Distributions
Probability
2%
1%
0%
Jun 16
Jul 1
Jul 15
Aug 1
Aug 15
Sep 1
Sep 15
Oct 1
Oct 15
Nov 1
Nov 15
Dec 1
Dec 15
Jan 1
Jan 15
Feb 1
Feb 15
Mar 1
Mar 15
Apr 1
Waiting Time
Cumulative Waiting Time Distributions
Probability
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Waiting Time
Season Ending Event
Critical Spread Event
Risk



Time Period Details

Time Period:	1
Start Date:	6/15/2006
Period Name	June

Weather Observations (days):	533
Aligned Observations (days):	388
Aligned Percent:	73%

Conditions by Severity Level

	Low	Mod	High	Ext
Probability	15	75	7	3
Uncorrected 1 hour FM %	11	6	5	7
10 hour Fuel Moisture %	14	8	7	9
100 hour FM %	18	13	11	14
Herbaceous FM %	183	101	59	66
Woody FM %	175	129	107	103
20' wind speed	3	6	9	16
1000 hour FM %	26	19	18	19

Data by Time Period, Severity Level, and Segment

Seg #	Map ID	Moisture Correction				Wind Adjustment				Flame Length			
		Low	Mod	High	Ext	Low	Mod	High	Ext	Low	Mod	High	Ext

1	Fuel Model	1	1	1	1	0.4	0.4	0.4	0.4	0.8	1.4	4.1	3.5
2	Fuel Model	4	4	4	4	0.2	0.2	0.2	0.2	0.3	0.4	0.5	0.7
3	Fuel Model	4	4	4	4	0.2	0.2	0.2	0.2	0.4	0.5	0.6	0.7

Seg #	Map ID	Hourly Rate of Spread (ch)				Burn Period (hrs/day)				Daily Spread (ch)			
		Low	Mod	High	Ext	Low	Mod	High	Ext	Low	Mod	High	Ext
1	Fuel Model	0.9	2.8	12	15	0	0	1	2	0	0	12	30
2	Fuel Model	0.2	0.3	0.5	0.8	0	0	1	2	0	0	0.5	1.6
3	Fuel Model	0.2	0.4	0.5	0.9	0	0	1	2	0	0	0.5	1.8

Seg #	Map ID	Common or Rare				Probability				Expected Daily Spread (ch)			
		Low	Mod	High	Ext	Low	Mod	High	Ext	Low	Mod	High	Ext
1	Fuel Model	C	C	C	C	1.3%	6.3%	0.0%	0.0%	0.000	0.000	0.003	0.005
2	Fuel Model	C	C	C	C	6.1%	30.6%	3.2%	1.4%	0.000	0.000	0.016	0.023
3	Fuel Model	C	C	C	C	7.6%	38.0%	3.7%	1.6%	0.000	0.000	0.019	0.028

Expected daily spread with aligned wind conditions: 0.1 chains per day
Average daily spread under all wind conditions: 0.1 chains per day

Time Period Details

Time Period: 2
Start Date: 7/1/2006
Period Name July

Weather Observations (days): 601
Aligned Observations (days): 499
Aligned Percent: 83%

Conditions by Severity Level

	Low	Mod	High	Ext
Probability	15	75	7	3
Uncorrected 1 hour FM %	7	5	5	5
10 hour Fuel Moisture %	8	6	6	6
100 hour FM %	14	11	10	12
Herbaceous FM %	105	39	41	74
Woody FM %	136	97	95	111
20' wind speed	5	6	8	12
1000 hour FM %	18	13	13	15

Data by Time Period, Severity Level, and Segment

Seg #	Map ID	Moisture Correction				Wind Adjustment				Flame Length			
		Low	Mod	High	Ext	Low	Mod	High	Ext	Low	Mod	High	Ext
1	Fuel Model	1	1	1	1	0.4	0.4	0.4	0.4	1.2	3.8	4.6	4.6
2	Fuel Model	4	4	1	1	0.2	0.2	0.4	0.4	0.4	0.5		
3	Fuel Model	4	4	1	1	0.2	0.2	0.4	0.4	0.4	0.5		

Seg #	Map ID	Hourly Rate of Spread (ch)				Burn Period (hrs/day)				Daily Spread (ch)			
		Low	Mod	High	Ext	Low	Mod	High	Ext	Low	Mod	High	Ext
1	Fuel Model	2.1	9	14	17	1	1	2	3	2.1	9	28	51
2	Fuel Model	0.3	0.3	18 C	26 C	1	1	1	2	0.3	0.3	18	52
3	Fuel Model	0.3	0.4	17 C	25 C	1	1	1	2	0.3	0.4	17	50

Seg #	Map ID	Common or Rare				Probability				Expected Daily Spread (ch)			
		Low	Mod	High	Ext	Low	Mod	High	Ext	Low	Mod	High	Ext
1	Fuel Model	C	C	C	C	0.2%	0.3%	0.4%	0.3%	0.004	0.024	0.107	0.129
2	Fuel Model	C	C	C	C	7.7%	35.0%	2.8%	1.2%	0.020	0.116	0.515	0.623
3	Fuel Model	C	C	C	C	8.0%	37.5%	3.7%	1.5%	0.025	0.144	0.639	0.774

Expected daily spread with aligned wind conditions: 3.1 chains per day
Average daily spread under all wind conditions: 2.6 chains per day

Time Period Details

Time Period: 3
Start Date: 8/1/2006
Period Name Aug Sept

Weather Observations (days): 1191
Aligned Observations (days): 936
Aligned Percent: 79%

Conditions by Severity Level

	Low	Mod	High	Ext
Probability	15	75	7	3
Uncorrected 1 hour FM %	9	5	5	4
10 hour Fuel Moisture %	11	6	7	6
100 hour FM %	15	11	11	11
Herbaceous FM %	30	30	30	30
Woody FM %	100	88	92	86

	Low	Mod	High	Ext
20' wind speed	3	6	10	12
1000 hour FM %	14	12	13	12

Data by Time Period, Severity Level, and Segment

Seg #	Map ID	Moisture Correction				Wind Adjustment				Flame Length			
		Low	Mod	High	Ext	Low	Mod	High	Ext	Low	Mod	High	Ext
1	Fuel Model	2	2	2	2	0.4	0.4	0.4	0.4	1.0	3.9	5.0	6.4
2	Fuel Model	5	5	2	2	0.2	0.2	0.4	0.4	0.3	0.4		
3	Fuel Model	5	5	1	1	0.2	0.2	0.4	0.4	0.4	0.5		

Seg #	Map ID	Hourly Rate of Spread (ch)				Burn Period (hrs/day)				Daily Spread (ch)			
		Low	Mod	High	Ext	Low	Mod	High	Ext	Low	Mod	High	Ext
1	Fuel Model	1.4	10	17	26	2	3	4	5	2.8	30	68	130
2	Fuel Model	0.2	0.3	23 C	31 C	2	3	2	3	0.4	0.9	46	93
3	Fuel Model	0.2	0.4	23 C	31 C	2	3	2	3	0.4	1.2	46	93

Seg #	Map ID	Common or Rare				Probability				Expected Daily Spread (ch)			
		Low	Mod	High	Ext	Low	Mod	High	Ext	Low	Mod	High	Ext
1	Fuel Model	C	C	C	C	0.2%	0.2%	0.4%	0.2%	0.005	0.072	0.280	0.242
2	Fuel Model	C	C	C	C	8.2%	37.0%	2.9%	1.2%	0.026	0.348	1.352	1.167
3	Fuel Model	C	C	C	C	7.5%	39.6%	3.7%	1.5%	0.033	0.433	1.679	1.450

Expected daily spread with aligned wind conditions: 7.1 chains per day
Average daily spread under all wind conditions: 5.7 chains per day

Time Period Details

Time Period: 4
Start Date: 10/1/2006
Period Name Oct

Weather Observations (days): 493
Aligned Observations (days): 313
Aligned Percent: 63%

Conditions by Severity Level

	Low	Mod	High	Ext
Probability	15	75	7	3
Uncorrected 1 hour FM %	24	5	5	5
10 hour Fuel Moisture %	29	8	7	8

100 hour FM %	21	12	12	12
Herbaceous FM %	30	30	30	30
Woody FM %	94	84	82	93
20' wind speed	6	5	7	12
1000 hour FM %	16	13	12	14

Data by Time Period, Severity Level, and Segment

Seg #	Map ID	Moisture Correction				Wind Adjustment				Flame Length			
		Low	Mod	High	Ext	Low	Mod	High	Ext	Low	Mod	High	Ext
1	Fuel Model	2	2	2	2	0.4	0.4	0.4	0.4	0.0	3.7	4.6	5.5
2	Fuel Model	5	5	2	2	0.2	0.2	0.4	0.4	0.1	0.4		
3	Fuel Model	5	5	1	1	0.2	0.2	0.4	0.4	0.1	0.4		

Seg #	Map ID	Hourly Rate of Spread (ch)				Burn Period (hrs/day)				Daily Spread (ch)			
		Low	Mod	High	Ext	Low	Mod	High	Ext	Low	Mod	High	Ext
1	Fuel Model	0.0	8	13	21	1	1	2	3	0	8	26	63
2	Fuel Model	0.0	0.3	17 C	29 C	1	1	1	2	0	0.3	17	58
3	Fuel Model	0.0	0.3	16 C	28 C	1	1	1	2	0	0.3	16	56

Seg #	Map ID	Common or Rare				Probability				Expected Daily Spread (ch)			
		Low	Mod	High	Ext	Low	Mod	High	Ext	Low	Mod	High	Ext
1	Fuel Model	C	C	C	C	1.3%	0.3%	0.4%	0.2%	0.000	0.021	0.100	0.145
2	Fuel Model	C	C	C	C	Infinity	37.2%	2.9%	1.2%	Infinity	0.100	0.485	0.702
3	Fuel Model	C	C	C	C	Infinity	38.4%	3.7%	1.5%	Infinity	0.124	0.602	0.873

Expected daily spread with aligned wind conditions: NaN chains per day
Average daily spread under all wind conditions: NaN chains per day

Time Period Details

Time Period: 5
Start Date: 11/1/2006
Period Name Nov

Weather Observations (days): 382
Aligned Observations (days): 234
Aligned Percent: 61%

Conditions by Severity Level

	Low	Mod	High	Ext

Probability	15	75	7	3
Uncorrected 1 hour FM %	22	9	8	8
10 hour Fuel Moisture %	27	11	9	12
100 hour FM %	25	19	17	18
Herbaceous FM %	30	30	30	30
Woody FM %	70	70	70	70
20' wind speed	5	3	9	11
1000 hour FM %	24	22	20	19

Data by Time Period, Severity Level, and Segment

Seg #	Map ID	Moisture Correction				Wind Adjustment				Flame Length			
		Low	Mod	High	Ext	Low	Mod	High	Ext	Low	Mod	High	Ext
1	Fuel Model	4	4	4	4	0.4	0.4	0.4	0.4	0.0	1.1	2.0	2.3
2	Fuel Model	6	6	6	6	0.2	0.2	0.2	0.2	0.1	0.3	0.5	0.5
3	Fuel Model	6	6	6	6	0.2	0.2	0.2	0.2	0.1	0.4	0.5	0.5

Seg #	Map ID	Hourly Rate of Spread (ch)				Burn Period (hrs/day)				Daily Spread (ch)			
		Low	Mod	High	Ext	Low	Mod	High	Ext	Low	Mod	High	Ext
1	Fuel Model	0.0	1.6	6	8	0	0	1	2	0	0	6	16
2	Fuel Model	0.1	0.2	0.4	0.5	0	0	1	2	0	0	0.4	1
3	Fuel Model	0.1	0.2	0.4	0.5	0	0	1	2	0	0	0.4	1

Seg #	Map ID	Common or Rare				Probability				Expected Daily Spread (ch)			
		Low	Mod	High	Ext	Low	Mod	High	Ext	Low	Mod	High	Ext
1	Fuel Model	C	C	C	C	1.3%	6.3%	0.0%	0.0%	0.000	0.000	0.003	0.003
2	Fuel Model	C	C	C	C	6.1%	30.6%	3.2%	1.4%	0.000	0.000	0.012	0.013
3	Fuel Model	C	C	C	C	7.6%	38.0%	3.6%	1.6%	0.000	0.000	0.015	0.017

Expected daily spread with aligned wind conditions:	0.1 chains per day
Average daily spread under all wind conditions:	0.0 chains per day