Appendix A: Comparative Risk Assessment

The National Cohesive Wildland Fire Management Strategy (National Cohesive Strategy) is a national strategy inclusive of all lands – applicable and relevant to local, state, tribal, and Federal entities. A key to the National Cohesive Strategy is its inclusiveness. The success of Phase II of the National Cohesive Strategy hinges on regional and national trade-off analyses with meaningful participation by diverse partners.

The following appendix, Comparative Risk Assessment Framework for Wildland Fire Management, describes possible approaches and methodologies for the analytical processes of Phase II. The primary purpose of the example is to demonstrate and test the framework and explore risk-based approaches. The regional and national analyses of Phase II are expected to utilize more comprehensive data than was possible in the current example. The expectation is that Phase II will rely on the best available information from local, regional, and national sources that can be consistently assembled. While this will surface data shortcomings, there is a commitment to continuously update the National Cohesive Strategy and improve the datasets used in the Comparative Risk Assessment.

A Comparative Risk Assessment Framework for Wildland Fire Management

I. Background

Major investments are being made throughout the United States in ongoing efforts to reduce human and ecological losses from catastrophic wildfire. It is becoming increasingly clear that landscape scale changes in vegetation structure and fuel loadings are needed to significantly alter wildfire behavior, reduce wildfire losses, and achieve longer term fire resiliency. The most efficient way to achieve these long-term landscape goals remains unclear, and there are different perceptions on the relative role and effectiveness of management activities versus natural and managed wildfire to reduce fuels.

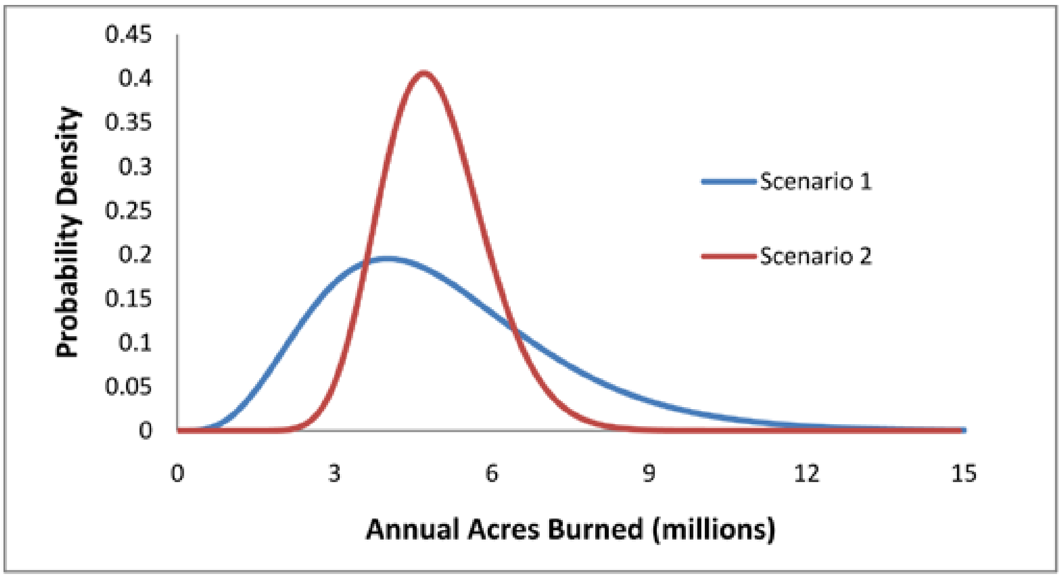
Risk is an inescapable component of living with wildfire. Whether one uses risk in the conventional sense of “something bad may happen” or a more precise definition such as the expected loss from an uncertain future event(s), the basic elements of uncertainty and loss are there. Following this basic reasoning, one can view the National Cohesive Strategy as a classic problem of *risk management.* That is, effective management requires understanding the nature of wildfire and its contributing factors, recognizing the consequences—good and bad—of fire, addressing uncertainty, and crafting plans that reduce the chances of catastrophic losses. Real-world constraints on funding, available resources, and administrative flexibility further require consideration of economic efficiency and practicality.

In order to help meet the challenges of the National Cohesive Strategy, the Science Panel proposes using comparative risk assessment as a rigorous basis for analyzing strategic alternatives (see complete report at http://www.forestsandrangelands.gov). Risk assessment is a long standing and mature scientific approach to quantifying risk; comparative risk assessment simply extends the analysis to include the decision space available to managers and stakeholders to allow them to explore the trade-offs between alternative courses of action. Taking this additional step requires understanding preferences and risk tolerance. Ultimately, choosing among available options demands clarity in management objectives, and where multiple objectives are present, understanding management priorities. A cornerstone of the National Cohesive Strategy will be regional strategies that address regional risks. A shared risk framework ensures consistency and comparability across goals, performance measures, methodologies, and data collection.

Recent developments in technology and decision support systems have improved the ability to assess, monitor, and respond to wildfire risk. For example, wildfire simulation models support tactical and strategic decisions related to reducing wildfire risk, and have been coupled with geospatial data on values to build risk-based decision support systems. The result has been a rapid advance in the application of risk analysis across a full range of wildfire management activities. Risk analyses are now being applied across the U.S. for a wide range of wildfire problems, including risk monitoring, strategic budget planning, wildland fire decision support systems, and fuel treatment planning.

Any rigorous approach to risk begins with a clear definition of the terminology. Herein, risk is defined as a composite measure of the probability of a set of possible outcomes and the consequences associated with each outcome. That is, risk is a two-dimensional measure that includes both the probability and magnitude of potential outcomes. For example, consider the two probability distributions shown in Figure 1, which represent the uncertainty in the number of acres burned annually under two scenarios. Both distributions have an average value of 5 million acres, but the wider spread in the curve tagged Scenario 1 suggests greater uncertainty in what the actual value in a given year will be. If the social or ecological consequences associated with each acre that burns increases with the total acres burning, then Scenario 2 would be preferable to Scenario 1, despite having the same expected value. Discerning such differences requires understanding the consequences of fire beyond simple summary statistics.

Figure 1. Quantifying risk as a probability distribution



Although the full probability distribution is preferred for many comparative risk assessments, reducing risk to a single index can aid risk comparisons across complex landscapes where the sheer numbers to consider can be overwhelming. One such index is the probabilistic expectation of net resource value change in response to fire. Mathematically, this is defined as:

$$E(NVC_j) = \sum_i p(f_i) RF_j(f_i)$$

where:

$E(NVC_j)$	expected net value change to resource *j*
$p(f_i)$	probability of a fire at intensity level *i*
$RF_j(f_i)$	response function for resource *j* as a function of fire intensity level *i*

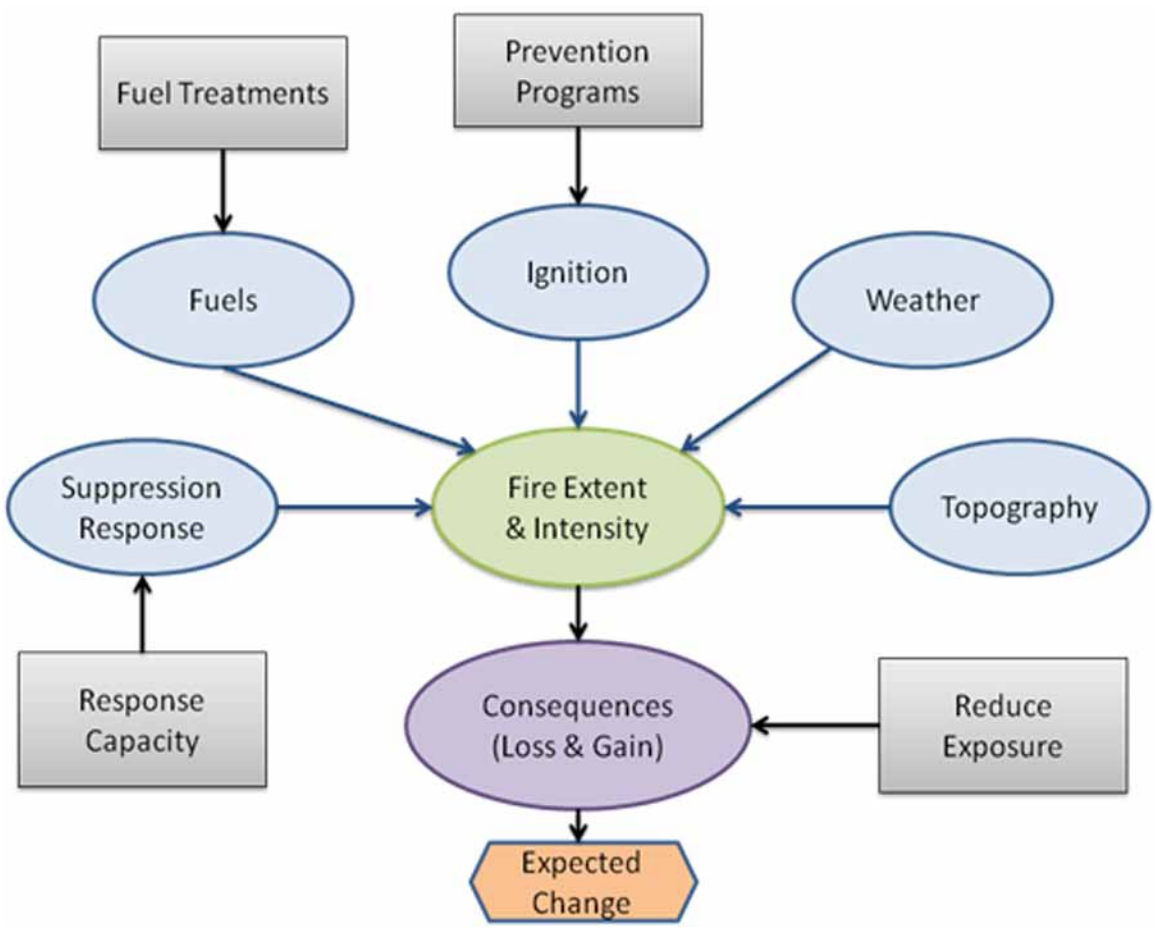
Thus, the expected NVC is the product of burn probability at a given fire intensity and the resulting change in resource value, summed over all possible fire intensities. The components required to generate spatially explicit wildfire risk indices are: 1) burn probability maps generated from wildfire simulation models, 2) spatially identified resources, and 3) response functions describing the impact of fire on the resource(s) in question.

Essential Elements for Analyzing Risk

One of the first steps in comparative risk assessment is developing a conceptual model that simplifies the problem into a set of basic components and provides a framework for discussing strategic options. For example, consider the hypothetical case of a single wildfire. Whether a wildfire ignites and how extensively and intensively it burns depends on the interactions of five factors: a source of ignition, available fuels, topography, weather, and suppression response. By itself, the fire is simply an event. It can be described by its location, intensity, duration, extent, or other characteristics, but it has no normative value—it is neither good nor bad. The consequences matter, however, whenever homes and other structures are involved, or when critical habitat for an endangered species will be rendered unsuitable for decades following the fire. Naturally, the extent of the loss of value depends on the extent and intensity of the fire and how many homes or acres of habitat are affected.

This simple model of risk can be completed by adding consequences (value changes) and management options available that might directly affect factors contributing to risk (**Figure 2).** For example, a fire prevention program could lessen the probability of human caused ignitions. Similarly, a fuels treatment program might change fire behavior and make it less damaging or easier to suppress. A third option might be to consider adding firefighting capacity to the local community or management unit so that wildfires are more often contained before they grow large and damaging. Finally, some consideration might be given to reducing the likelihood of a wildfire damaging homes or other structures by focusing on the immediate area around the home or near critical habitats. The intent in this option is not to change fire directly, but rather to lessen the consequences if it occurs.

Figure 2. A simple conceptual model of wildfire, its contributing factors, consequences, and management options.



The next step in comparative risk assessment is translating the conceptual model into a probabilistic model that can be used to generate quantitative estimates of risk, given alternative management choices as inputs. Such models must be parameterized and validated using rigorous statistical methods and checked against empirical data if they are to rise to the standard of high-quality risk assessment tools. Finding the appropriate balance among model complexity, data demands, and utility is a major challenge. The example analyses described in following sections suggest that current models and data are available to help meet this challenge, but more work is needed.

Balancing Regional and National Priorities

Developing an overarching national strategy invariably will involve tradeoffs between regional and national priorities. As the National Cohesive Strategy evolves, various regional strategies will be proposed that include different investment levels and mixes of options for reducing wildfire risk. These differences would reflect varying levels of emphasis on the major goals of the National Cohesive Strategy, in addition to recognizing fiscal and practical constraints. For example, each regional strategy could consist of a given funding level for each of the three key components of the National Cohesive Strategy– Landscapes, Fire Adapted Communities, and Wildfire Response. The National Cohesive Strategy will comprise selected strategies from each region.

Assembling the various options into regional alternatives and then choosing among those alternatives to build a national strategy is fundamentally an exercise in social choice and collaborative decision making. Formal analytical methods exist that can help structure the decision process and make trade-offs transparent. Consistency among the methods used in each region will help facilitate national comparisons. There is a tension between adopting a top-down approach and retaining analytical and decision flexibility at regional and local scales. The more disparate regional analyses are, the greater the difficulty of integrating analyses, maintaining and updating analyses over time, and comparing outputs over time to previous versions.

One of the primary challenges for both regional and national efforts is developing performance measures (i.e., assessment endpoints) that accurately represent accomplishments in risk reduction and integrate the diversity of regionally specific issues and management priorities. Regional analyses can provide more refined risk analysis than available at the national scale and clarify the relative priority of protecting potentially competing resource demands. However each region may identify alternative methods for considering risk to individual resources and consider different sets of values. Accommodating these differences—while maintaining the capacity for national comparison—requires careful attention to methods and data.

II. Probabilistic Assessment of Wildfire Risk: A National Example

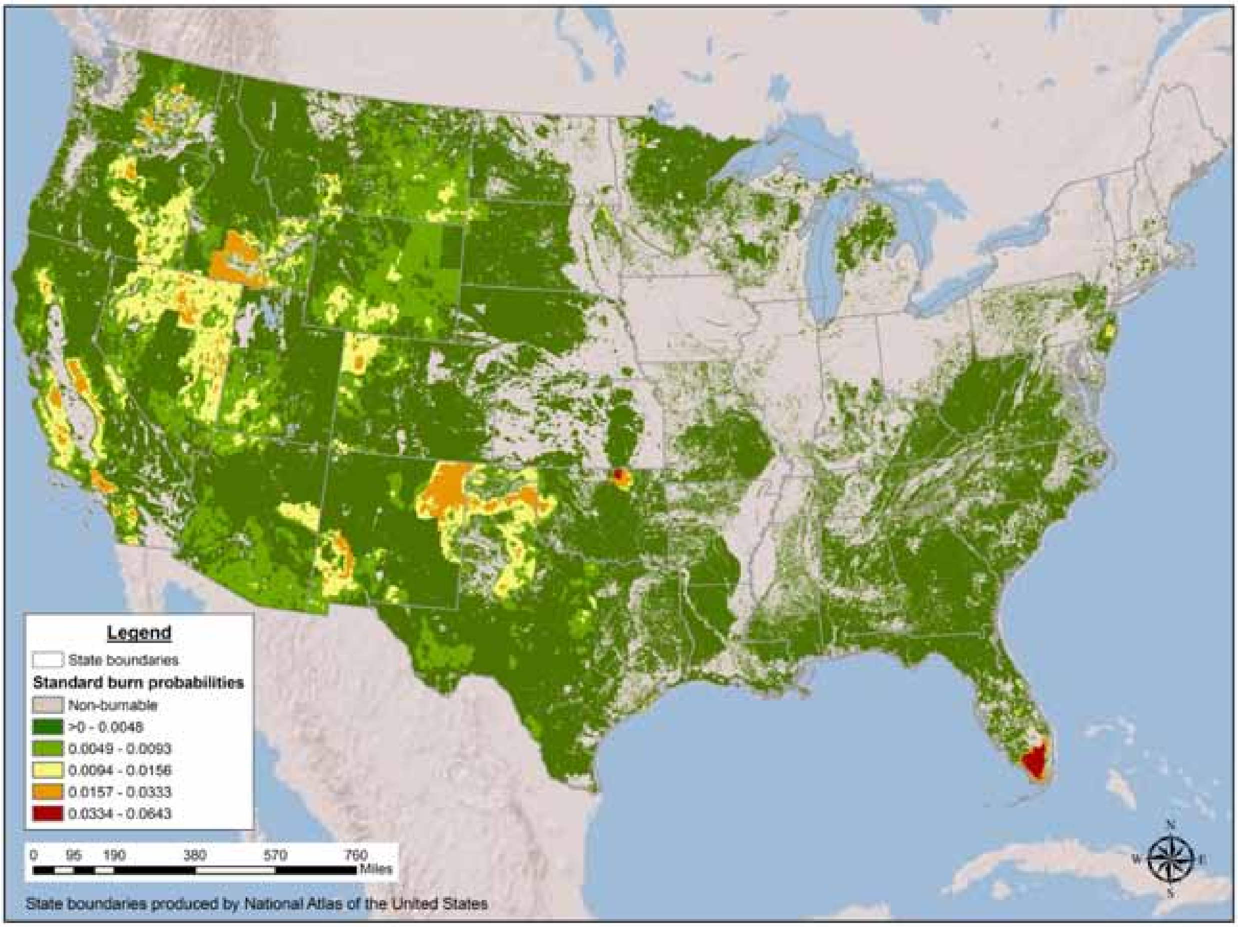
A recent publication*, Wildland Fire Risk and Hazard: Procedures for the First Approximation, describes a baseline assessment framework from which to build national, regional, and sub-regional analyses. This national assessment provides an example of how wildfire risk can be assessed at the national level. It was completed to facilitate monitoring trends in wildfire risk over time, and to develop information useful in prioritizing fuels treatments and mitigation measures. The project employed a risk framework that included:*

- Estimating spatially explicit fire probability and intensity through the use of a wildfire simulation model
- Characterizing important resource values and assets (for example, municipal watersheds, endangered species habitat, and where people live)
- Developing response functions to quantify how important resource values and assets change under varying levels of fire intensity
- Calculating expected NVC and summarizing by geographical areas

Seven broad categories of developed and natural resources were included in the assessment: populated areas, fire-adapted ecosystems, fire-susceptible species, energy infrastructure, recreation infrastructure, municipal watersheds, and air quality. These values were consolidated into a single measure using relative scoring criteria commonly used in problems involving multiple variables that are not directly comparable. It is recognized that the resources considered in this first approximation do not include all the resources deemed important to each region of the Country.

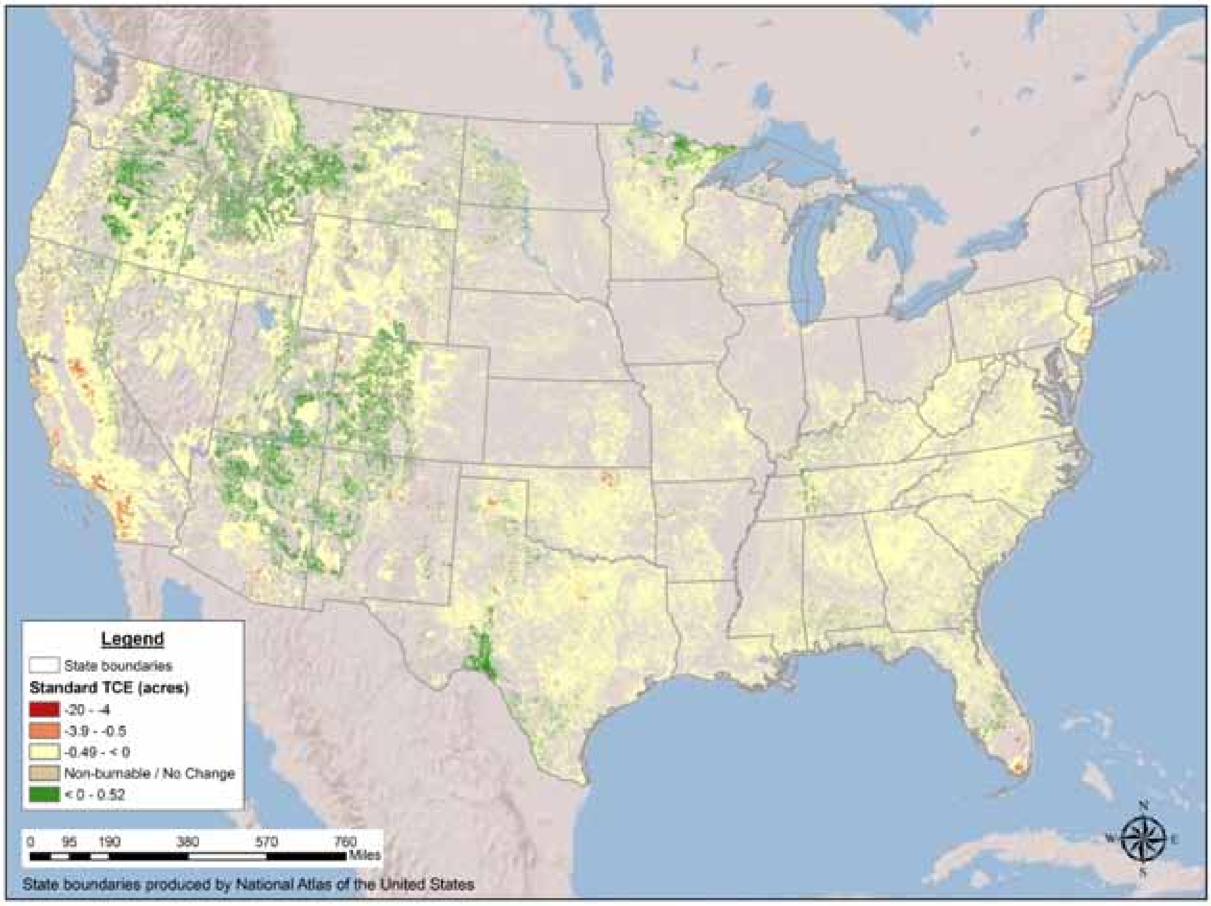
The national maps of burn probability and conditional fire intensities reveal important regional differences. First, burn probabilities are generally higher in the western half of the Country, with the notable exception of southern Florida (Figure 3). Fires often grow larger in the west because of the continuity of wildland vegetation. Second, flame lengths tend to also be greater in the west and along the edge of the east coast because of the potential for crown fire caused by conifer forest and fuel structure. Higher probabilities of low flame lengths predominate in the eastern half of the Country.

Figure 3. National map of burn probability generated using simulation modeling.



Similar regional patterns are apparent in the national risk map (Figure 4). Higher expected losses appear concentrated in southern Florida, southern California, and the along Sierra Nevada mountain range. Examining the factors that comprise risk helps identify why some regions have higher values than others. For example, southern Florida exhibits high burn probabilities and high conditional flame lengths, as well as fire-susceptible endangered species like the Cape Sable Seaside Sparrow. Southern California has moderately high burn probabilities and conditional flame lengths paired with high population density and other resource values exposed to fire. The risk map suggests the beneficial influence of wildfire to fire-adapted ecosystems throughout the interior Great Basin and Northern Rockies regions.

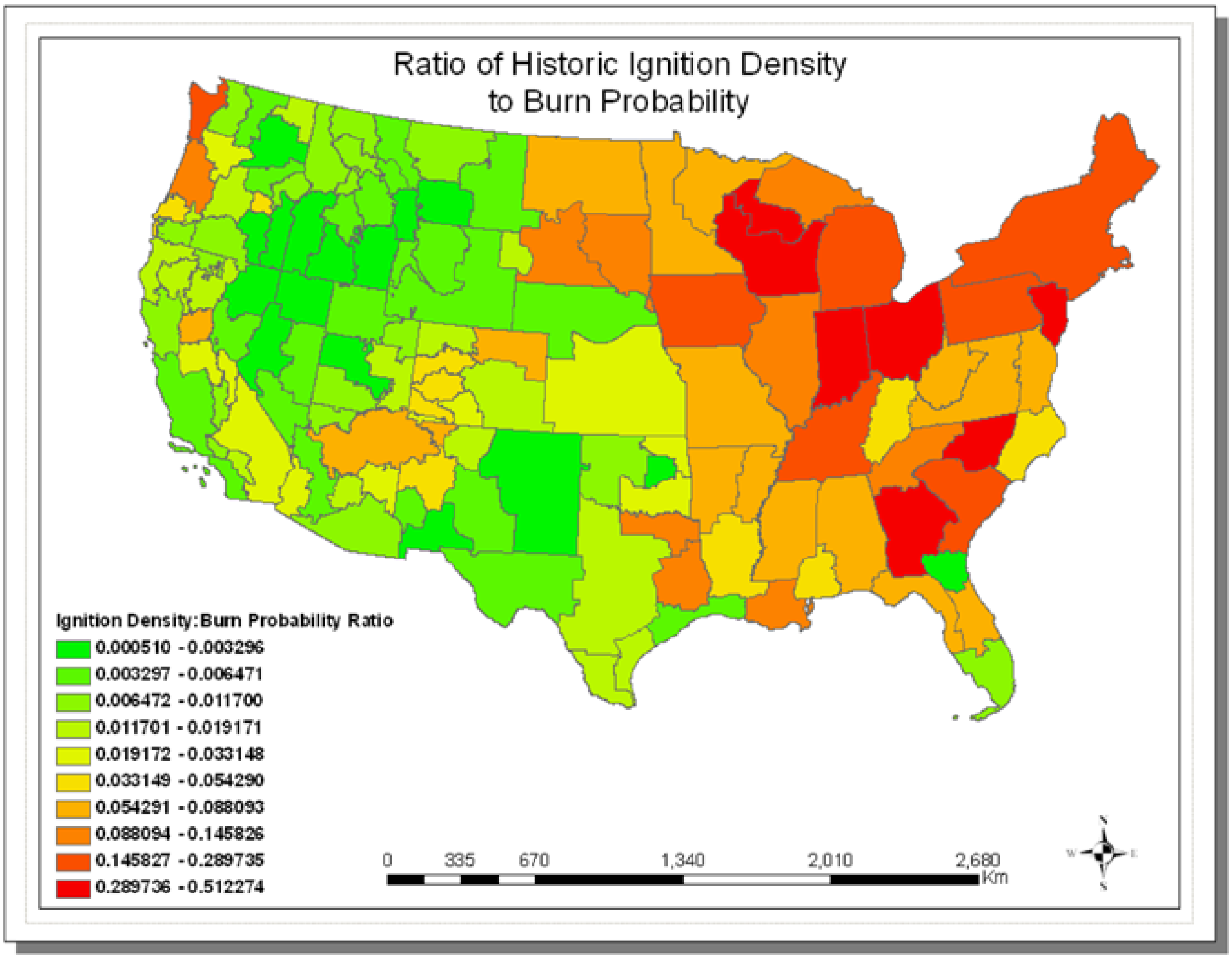
Figure 4. National map of wildfire risk as quantified by the total change equivalent (TCE), an area-based measure (acres per 18-acre pixel per year) of relative acres gained/lost due to wildfire.



Estimates of overall risk can be summarized by resource category and geographic area. In this analysis, populated areas contribute most to national wildfire risk (58 percent) followed by municipal watersheds (20 percent), fire susceptible species (13 percent), infrastructure (7 percent), air quality (2 percent) and recreation (.02 percent). Fire adapted ecosystems actually reduce overall risk by 1 percent, which demonstrates a net beneficial response to wildfire. Although benefits are observed across broad areas, their overall magnitude is quite modest relative to anticipated losses associated with populated areas and watersheds. Among geographical areas, California representing 30 percent of national wildfire risk, followed by the Southern Area (22 percent), Southwest (17 percent), Great Basin (10 percent), Rocky Mountain (10 percent), Northwest (5 percent), Northern Rockies (4 percent) and Eastern (3 percent).

The national risk maps also highlight an important distinction between wildfire risk and wildfire occurrence. While relevant to emergency fire response and firefighting infrastructure, ignition locations or densities depict only localized impacts from nearby ignitions and not from fire spread or area burned. This is because burn probability can be relatively high in areas with large fires, even though ignition probability is low. As fires grow large, they spread long distances and burn locations distal to the ignition. Figure 5 depicts the ratio of ignition density (#/ac/year) and burn probability from historical fire records. High values in Eastern areas and the Northwest coast imply high numbers of ignitions relative to the total area burned.

Figure 5. Ratio of ignition density (#/ac/yr) to burn probability from historical data (1980-2008). High values shown in red and orange indicate many ignitions relative to area burned.



III. Exploring Options for Reducing Risk

The discussions above focus on current levels of risk or simple conceptualizations of how natural factors and management actions affect risk. Broader management options that might be taken to affect those risks are implied, but have not been specifically analyzed. More complete analyses of regional and national investment strategies are expected as the National Cohesive Strategy progresses. In the interim, it is instructive to consider the types of options available, how they might be analyzed, and what available information might be relevant. The simple conceptual model in Figure 2 identified four basic options for affecting risk:

- Invest to prevent human caused ignitions
- Invest in fuel treatments
- Invest to build capacity in wildfire response
- Invest to protect values exposed to risk

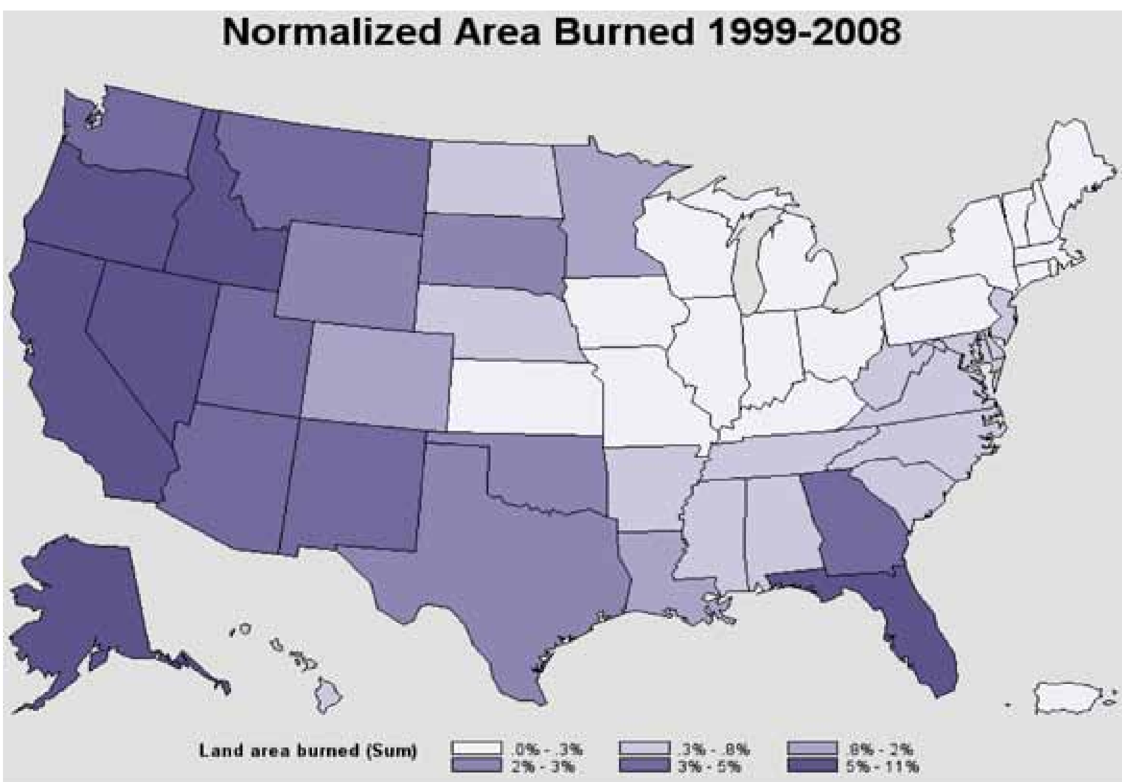
We speak to each of these individually, but as will become readily apparent, the real work is in trying to understand how they might best be applied together.

To understand how each option might play out, it's necessary to 1) establish a historical point of reference, 2) develop an analytical capacity to examine the relative effectiveness of each option, and 3) project conditions into the future. Fortunately, there are numerous completed and ongoing assessment and planning efforts that provide a good start on having the tools and information needed. For example, Fire Program Analysis (FPA) is an interagency effort that focuses on investment effectiveness. The analytical system designed and built to support FPA models the effectiveness of fire prevention programs, investments in preparedness resources, and landscape fuel treatments. Effectiveness is evaluated by examining various performance measures tied to the probability and intensity of areas burning within the analysis area and the suppression costs associated with responding to wildfires. FPA is not the only modeling framework available to tackle these issues, but it is remarkable in its level of detail and extensive accounting and analysis features.

One of the more critical data sets used by FPA is the historical fire occurrence data compiled by Federal and state agencies. FPA uses these data to determine the location and cause of wildfire ignitions, as well as providing a basis for model calibration. The FPA data set has some known issues associated with data accuracy and completeness, especially regarding fires on non-Federal lands. Updated versions of the data set will correct some problems related to duplicate records and missing or inaccurate location information, but the updated data will likely still exclude some fires that occurred historically. The FPA records for fires occurring from 1999 to 2008 are used here for illustrative purposes, recognizing that improved and more comprehensive data may become available that could change the results.

As a point of reference, approximately 447,000 recorded wildfires occurred across the US between 1999 and 2008, burning nearly 70 million acres during this time period. Although the Southern geographic region led all regions with number of recorded wildfires (41 percent of total), most of the acreage burned in western states—over 18 million in Alaska alone—which tend to experience fewer, but larger fires on average. The 10-year historical average for the conterminous 48 states is close to the roughly 5 million acres per year of simulated wildfires used to generate the burn probability map shown above in Figure 3. Dividing the area burned in a 10-year period by the land area of each state produces an area-adjusted map of historical burning that corresponds well to the simulated burn probability map (Figure 6).

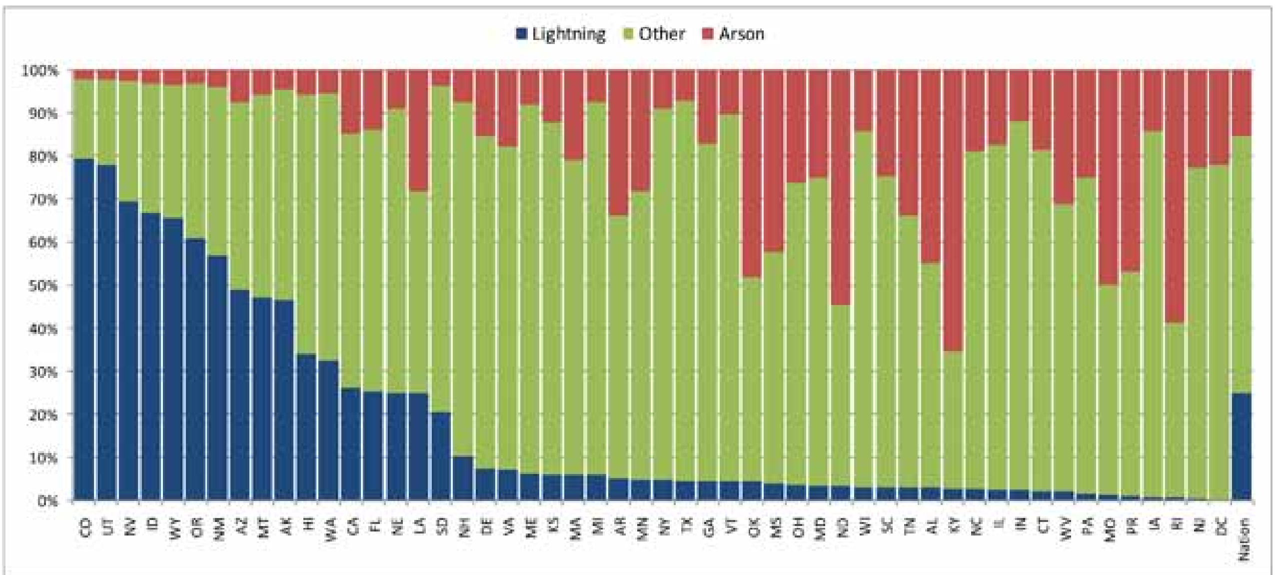
Figure 6. Cumulative area burned in each state from1999-2008. Areas are normalized by dividing the area burned by the total land area in each state.



Option 1. Invest to Prevent Human Caused Ignitions

There is an old adage that the best way to stop a wildfire is to make sure it never starts. Wildfire prevention programs form an important component of any comprehensive wildfire management strategy. Ranging from the familiar Smokey the Bear© public education campaign to focused law enforcement, prevention efforts target those sources of human ignitions that can be avoided, including arson, debris burning, campfires, smoking, off-road vehicle use, and others. The degree to which human-caused ignitions contribute to wildfire is substantial. Nationwide, human ignitions (everything except lightning) accounted for nearly 75 percent of all wildfires starts, yet only 30 percent of the acreage burned. This disparity is due to geographical differences in wildfires; the western states experience larger fires dominated by lightning ignitions, while smaller wildfires in most eastern states are human caused (Figure 7).

Figure 7. Historical distribution of reported cause of wildfire ignitions by state (1999-2008)



Despite a long and storied history of fire prevention programs in the United States, scholarly analysis of the effectiveness of these programs is scarce. A recent article by Prestemon and others (2010) is a notable exception, who remark "although a common belief is that wildfire prevention education is worthwhile, there is a striking absence of studies documenting its effectiveness." One of the more commonly used tools for estimating the effects of prevention programs is the Risk Assessment and Mitigation Strategies (RAMS) model, which was developed in the mid 1990's using expert opinion. The RAMS model uses a combination of effectiveness factors and preventability factors to calculate the expected reduction in human ignitions given a prescribed mix of program elements such as patrols, signs, law enforcement, and public contact. The degree to which fire can be prevented varies by specific cause. The FPA incorporates RAMS in its suite of models and caps the preventability levels by cause. For example, no more than 7 percent of arson fires can be prevented within FPA, while 16 percent of fires started by debris burning and children can be prevented.

For illustrative purposes, the maximum preventability factors and historical fire information from FPA were used to calculate the upper limit for expected change in ignitions and area burned. Nationwide, an estimated 9.4 percent of the reported ignitions from 1999 to 2008 could have been prevented, which would have reduced the expected acres burned by 3.4 percent. The differences among states are dramatic, again, depending on whether fires are predominately human-caused. Normalized by land area within each state, the greatest gains in terms of ignitions per square mile are found in high-fire-frequency states such Georgia, New Jersey, South Carolina, and Florida. In terms of relative change in the number of ignitions, many eastern states exceed the national average, while western states dominated by lightning-caused ignitions show relatively small benefits. Further analyses at the county level would show similar variation among counties within many states such as California with a mix of urban and wildland areas.

A comparison of these national results with the empirical results of Prestemon and others (2010) from Florida suggests that the limits on preventability imposed by RAMS may seriously underestimate the benefit of prevention programs in some areas. Using a sophisticated empirical model, Prestemon and others show that increased investment in wildlife prevention education (WPE) could result in reductions in preventable ignitions upwards of 80 percent, with associated reductions in acres burned a more modest 10 percent or less. Prestemon and others go further in their analysis, incorporating estimates of change in net value similar to the process described above to estimate that the marginal benefits of averted wildfire damages are 35 times the investment in WPE in Florida; reduced suppression costs alone account for 15 percent of the estimated benefit.

Option 2. Invest in Fuel Treatments

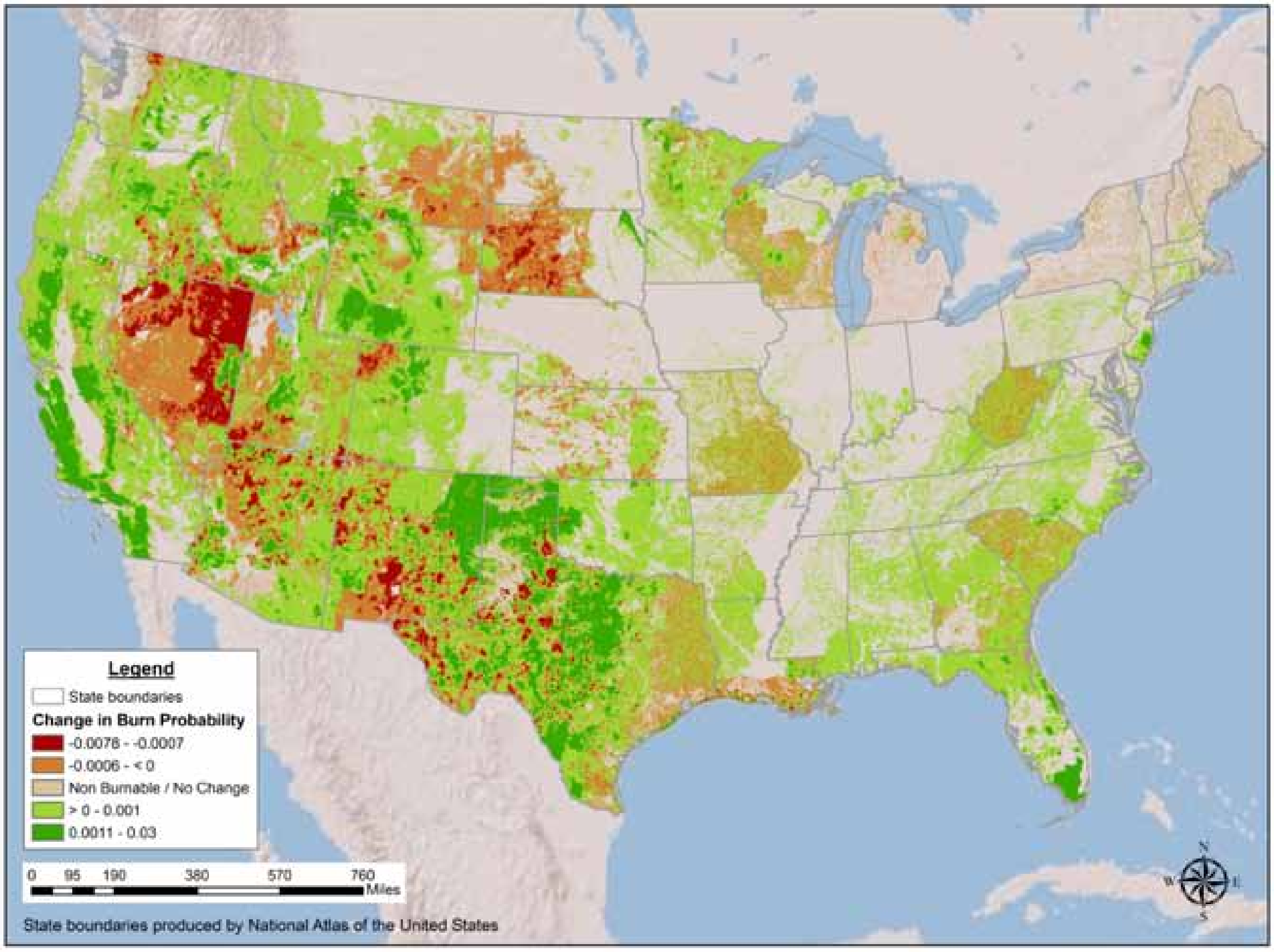
Considerable research has been conducted on landscape fuel treatment design, especially the spatial arrangement of treatments to achieve optimum reduction in fire spread and intensity. Viewing the landscape treatment problem through the lens of risk assessment offers a more comprehensive framework to inform fuel treatment strategies in terms of location, amount, type, and spatial patterns of treatments. While risk provides a comprehensive index of likelihood, intensity, and potential effects, the measure needs to be decomposed to develop and analyze options for operational fuel treatment strategies. Specifically, wildfire risk factors combined with: 1) spatial pattern of values, 2) fire management objectives, and 3) fire regime, determine fuel treatment and overall fire management strategies. The risk factors determine the relative mix of intensity and likelihood of wildfire, while the spatial pattern of values determines the interaction of wildfire risk factors with values perceived to be at risk. Fire management objectives determine whether mitigation emphasizes restoring natural fire regimes, or suppression to protect highly valued resources (HVR), or a strategy in between. All of these components inform operational fuel treatment strategies.

The complexity and importance of a comprehensive fuels management program cannot be overstated. Local effectiveness depends heavily on the type of vegetation involved, the nature of the treatment, the spatial extent and location of treatments, and interactions of all of the above with topography, weather, infrastructure, and the suppression resources engaged if and when a wildfire occurs.

These complexities notwithstanding, it is informative to examine how broad-scale applications of fuel treatments might affect risk using basic models with simplifying assumptions. Fuel treatment scenarios were modeled spatially but very generally for each Fire Planning Unit (FPU) as part of the FPA process. The methods consisted of first soliciting treatment prescriptions by fuel and vegetation type from local fire planners. These prescriptions contained details on changes to surface fuel models and canopy characteristics that constitute treatments applicable to current fuel type descriptions. Then, an automated procedure applied these prescriptions to specific stands throughout the planning unit until roughly 15 percent of treatable landscape was treated. The quasi-random placement of treatment units meant that smaller areas within the planning unit varied considerably from this average figure. The treatment effect was estimated by running the fire behavior models for a treated landscape using identical simulation settings as for the reference baseline landscape. The contrast between risk metrics for each landscape illustrates the magnitude of possible changes resulting from this treatment level and considering only fuel types in placing treatments.

The FPA fuel treatment scenario resulted in modified burn probability (Figure 8) and conditional flame length across the Country. Intersecting these modified burn probability and flame lengths with the resource layers resulted in total national risk being reduced by 24 percent. Risk reduction to individual units was highly variable, ranging from an 11 percent increase in risk to 69 percent reduction in risk. This range of results is due largely to the following factors: 1) the arrangement of fuels relative to values, 2) the effectiveness of treatment in reducing fire spread and intensity in certain fuel types, and 3) how the individual planning units defined the treatment prescriptions that were evaluated.

Figure 8. Changes in simulated burn probability resulting from fuel treatments on 15% of each FPU (standard run minus treatment run). Thus, red and orange colors indicate increases in burn probability with treatment whereas green colors indicate reductions of burn probability (positive difference).



The effect of treatment on national risk to individual resource categories varied across categories. Beneficial effects of wildfire on fire adapted ecosystems were reduced while all other resources experienced a reduction in loss. Fire susceptible species experienced the lowest reduction of risk at 16 percent with recreational areas seeing a risk reduction of 63 percent. Populated areas that represented 58 percent of national risk in the standard run experienced a 23 percent reduction in risk. The ranking of geographical areas based on contribution to national risk did not change between the treated and standard runs. However, the relative contribution to national risk was reduced in the 2 highest ranked areas, California and Southern Area, while the Southwest, Great Basin, and Rocky Mountain all increased as a proportion of national risk.

Estimating changes in risk by looking at both burn probability and fire intensity is highly informative, but computationally demanding. By simplifying further and assuming that risk is proportional to area burned, the potential magnitude of changes in risk from fuel treatments can be examined using statistical approximation. A statistical model was fit to the simulation results during the FPA analysis completed in 2010. This model used a series of matched simulations to derive statistical relationships that use the fire spread inherent in a particular location, the weather conditions during a wildfire, and the extent of fuel treatment in the area surrounding the fire ignition point to estimate the expected size of each simulated wildfire. The statistical model fits the simulated data reasonably well in most planning units, with exceptions in some eastern states with highly fragmented fuel patterns. The statistical approximation approach promises to be useful for analyzing a broad range of options.

Option 3. Invest to Build Capacity in Fire Response

Analyzing investments in wildfire response can be very complicated. In addition to the complexities of fire behavior, one has to address interactions among the distribution of available resources, their performance on the fire, the dispatch logic used to send resources to a fire, and multiple operational constraints. The FPA includes a highly detailed Initial Response Simulator which addresses many of these issues, but is designed to only simulate responses in the first 18 hours following discovery of a wildfire. This simulator will be essential to understanding the feedback between initial attack effectiveness and behavior of fires that escape. Although poorly quantified at present, highly successful initial attack means that fires escape only under the rarest and most extreme weather conditions, becoming more severe. Thus, potential benefits to fuels or habitat from wildfires burning under moderate conditions are never realized, and, in turn, increases demand for initial attack effort and resources. Through more detailed analysis and the modeling in FPA, this feedback process may become understood and incorporated into the risk framework.

Once a wildfire has escaped initial containment efforts, further complications arise as resources are drawn from remote locations, fire behavior becomes difficult to predict, and even the objectives of the suppression response may change from day to day depending on circumstances that are not easily understood, much less modeled. Ongoing research directed at better understanding the management context and decision processes used in large fire suppression may lead to more reliable models that can capture the principal factors influencing performance—however it might be measured.

Option 4. Invest to Protect Values Exposed to Risk

The motivation behind options designed to lessen values at risk is relatively simple. If you cannot change the likelihood of a wildfire occurring, you might instead focus on lessening the chances that fire would have negative consequences. Such thinking motivates many of the activities focused at homeowners in the wildland-urban interface, who are taught to actively manage areas adjacent to their homes to reduce the chances of wildfires reaching their homes, or are encouraged to think ahead and have emergency supplies readily at hand and evacuation plans that can be implemented at a moment's notice. Similarly, important cultural or archeological sites may be managed in ways that offer passive resistance to wildfires. Species conservation plans also can be designed to manage risks by ensuring that no single event has the capacity to eliminate large blocks of the population or critical habitat.

Analyzing such options seems easy at first glance, but becomes increasingly difficult the better it is understood. In the analytical framework proposed above, reducing the exposure to risk is as simple as changing the response functions or benefit/loss values. This presumes, of course, that the appropriate values are addressed in the analysis to begin with and that the initial response functions accurately capture changes in value. Neither presumption is likely to go unchallenged. Although society generally agrees that human lives and property are important and should be protected, it seems that consensus often stops there. The range of other values that should be included in the analysis and how these values might change with fire can often be contentious. A second problem concerns the sensitivity of the response function to management actions. In the prototype risk analyses described above, stylized response functions were used that only crudely capture the effects of fire at varying intensities on values of concern. If the function is derived with little or no empirical basis, any change in that function could seem arbitrary without quantitative analyses to support it. Furthermore, the signal to noise ratio in the response function may be very weak and much of the change in the function due to proposed management actions may not rise to the level necessary to overcome the noise.

The net results of these considerations is that any action short of major shifts in policies or broad-scale changes in management are likely best left to local analyses that can be appropriately scaled to capture the appropriate changes.

An important concept related to reducing exposure is socioeconomic vulnerability. The intersection of human population, valued resources, and wildfire creates opportunities to strategically allocate wildfire response or prevention actions to minimize risk to human life and property. In the field of hazards, risk, and resiliency, a clear distinction is made between risk assessments which describe the expected loss of assets, and vulnerability assessments which characterize the exposure, sensitivity, and resilience of communities to a hazard. Both types of analyses apply to the goals and objectives of the National Cohesive Strategy.

In the risk assessment realm, additional research would address the expected impact of wildfires on economic activity and housing/infrastructure value. By looking at regional economic output in addition to the potential damage to structures a more complete view of the economic costs of wildfires can be compared across regions and among communities. Such analyses could, for example, highlight areas where natural resource or recreational dependent communities might be affected more severely by wildfire compared to communities with a diversified economic base.

Social vulnerability to natural hazards is a growing area of interdisciplinary research included in risk reduction strategies. Studies have analyzed how vulnerability varies among different segments of the population and how they will respond to a hazard, how hazards affect business and regional economic output, and how social vulnerability to hazards has changed over time across the US. This research attempts to characterize hazards and vulnerability from a more holistic perspective, particularly in the wake of natural disasters such as Hurricane Katrina or the Gulf Oil Spill, where economic damages do not fully represent the long term changes made to the physical, ecological, social and economic structure of the communities in the Gulf of Mexico.

IV. Risk Analyses at Smaller Spatial Scales

As stated above, the comparative risk framework can be applied to management problems at a range of scales. Three examples from ongoing and recently published work demonstrate this scalability. These include analyses at the scale of a Forest Service region, forest, and project. Regional analyses will play prominently in the early phase of the development of regional strategies, and in later implementation and monitoring. The forest and project examples will be particularly useful in later implementation phases of the National Cohesive Strategy and illustrate a consistent application of risk assessment and management across scales.

The Regional prototype is being developed in the Forest Service's Pacific Northwest Region (Region 6) and considers multiple threats (climate change, insect and disease, invasive plants) and values (carbon, critical habitat, etc.) to meet the needs of ongoing, regionally specific assessments. Thus the regional assessments can serve both local and national needs, the former having a scope beyond fire and fuels. The process leverages regional data sets to the extent they are available. Specific questions that are being addressed in the Region 6 example include:

- Are there associations among threats like wildfire, insects, and climate change that form spatial patterns in the region?
- Which human and ecological values are most associated with particular threats?
- How and where is management opportunities aligned with the occurrence of particular threat – value combinations?
- Where are restoration activities needed most and how are they associated with management opportunity?
- How can watersheds be ranked relative to the complete constellation of threats and values that face land managers?

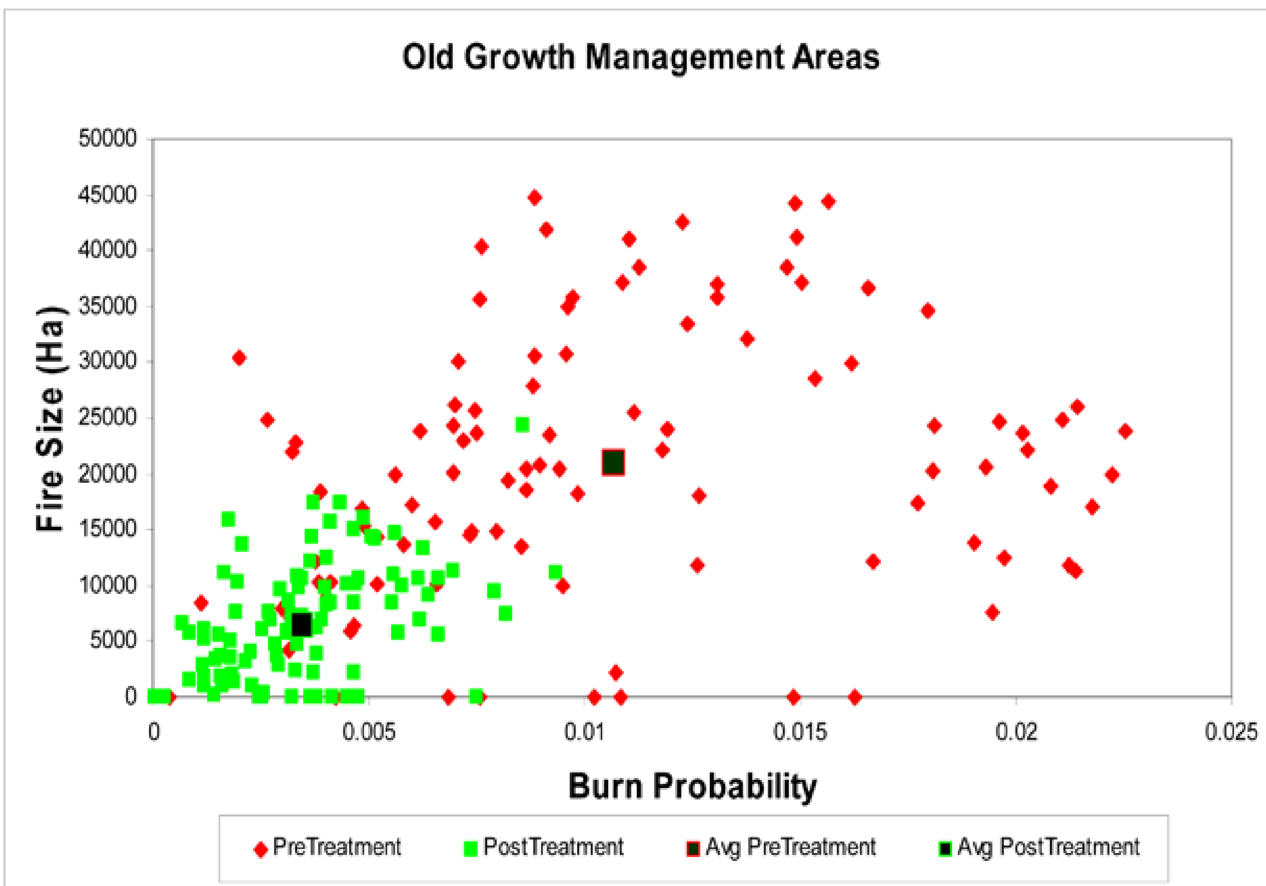
Risk analyses also can be applied at the level of a national forest or similar management unit to address a range of fuel treatment planning issues, including assessing the relative risk to resources of local values, and the assessment of treatment effectiveness for forest-wide plans. The example presented here was excerpted from a larger risk assessment study on the Deschutes National Forest in central Oregon. This work demonstrated the application of risk assessment to analyze the relative risk to human and ecological values. The assessment focused on three key questions of keen interest to Federal managers and policymakers:

- Are the wildfire risks to conservation and other forest plan reserves more or less than land designations receiving fuel treatments?
- What is the relative wildfire risk to urban interface areas compared to different land-use designations?
- Are specific conservation reserves responsible for the transmission of wildfire to other reserves?

The analyses revealed spatial variation in wildfire risk that is useful in prioritizing fuels treatments and guiding other wildfire mitigation activities. The work also illuminated the conflict between biodiversity conservation efforts on Federally managed lands and the high wildfire risk on fire-prone landscapes. In this study, estimates of burn probabilities and conditional flame lengths were used to examine the relative risk among land management allocations, conservation reserves, urban interface areas, and other designations on the Forest and surrounding lands. Thus, the highly valued resources were tiered directly to forest plan standards and management plan land designations. Selected outputs from these analyses revealed wide variation among and within polygons belonging to specific land designations, providing a clear identification of priority targets for mitigation activities. Specific designations and conservation reserves showed markedly higher conditional flame lengths, such as spotted owl active and potential home ranges. In contrast, the general forest matrix showed relatively high burn probabilities and lower conditional flame length. Most of the urban interface showed lower burn probability and expected flame length.

A fuel treatment priority map for the Forest was used to simulate fuel treatments and examine change in wildfire risk. The treatment scenario called for 64,000 ha of treatments in the general forest management areas. The ratio of the burn probability after and before the treatments was used to examine change in wildfire likelihood. The analysis suggested large reductions in burn probability in conservation areas and other reserves. For instance, the likelihood of a fire in the old growth reserves was 30 percent of the pre-treatment conditions. The effect of treatments on both burn probability and fire size for specific reserves like old growth show large reductions post treatment (Figure 9).

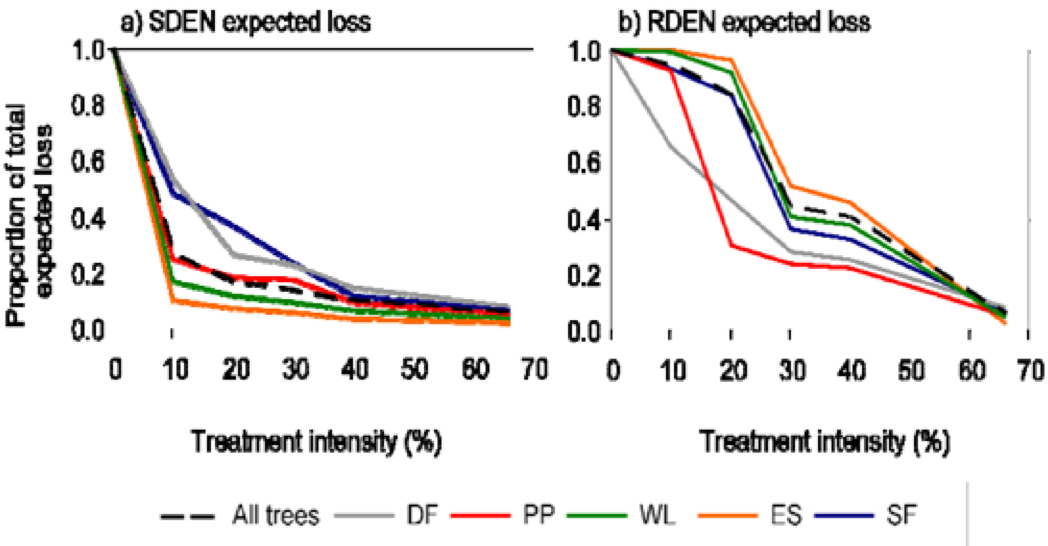
Figure 9. Change in burn probability and fire size to old growth units on the Deschutes National Forest after simulating treatments on about 20% of the forested areas. Treatments were not placed inside old growth units.



Example Project Scale Prototype

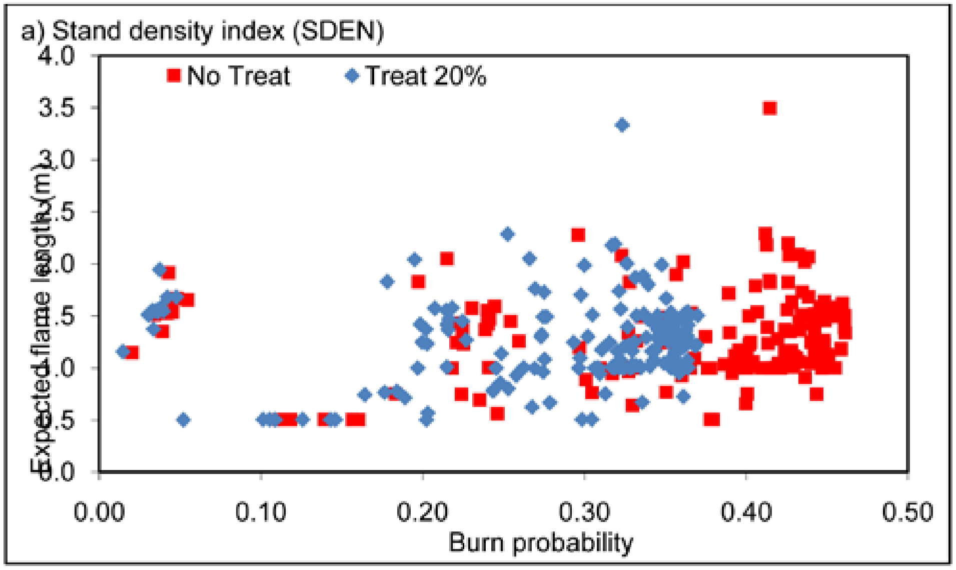
Individual project planning can readily benefit from targeted risk assessments. Ager and others (2010) used risk analysis to examine the tradeoff between landscape restorations versus protection of structures within a typical wildland-urban interface in eastern Oregon. The treatment strategies were evaluated by simulating 10,000 wildfires with random ignition locations and calculating burn probabilities by 0.5 m flame length categories for each 30 x 30 m pixel in the study area. The burn conditions for the wildfires were chosen to replicate severe fire events based on 97th percentile historic weather conditions. The burn probabilities were used to calculate wildfire risk profiles for each of the 170 residential structures within the urban interface, and to estimate the expected (probabilistic) wildfire mortality of large trees (>21 inches) that are a key indicator of stand restoration objectives. Expected wildfire mortality for large trees was calculated by building flame-length mortality functions using the Forest Vegetation Simulator, and subsequently applying these functions to the burn probability outputs. Results suggest that treatments on a relatively minor percentage of the landscape (10 percent) result in a roughly 70 percent reduction in the expected wildfire loss of large trees for the restoration scenario (Figure 10).

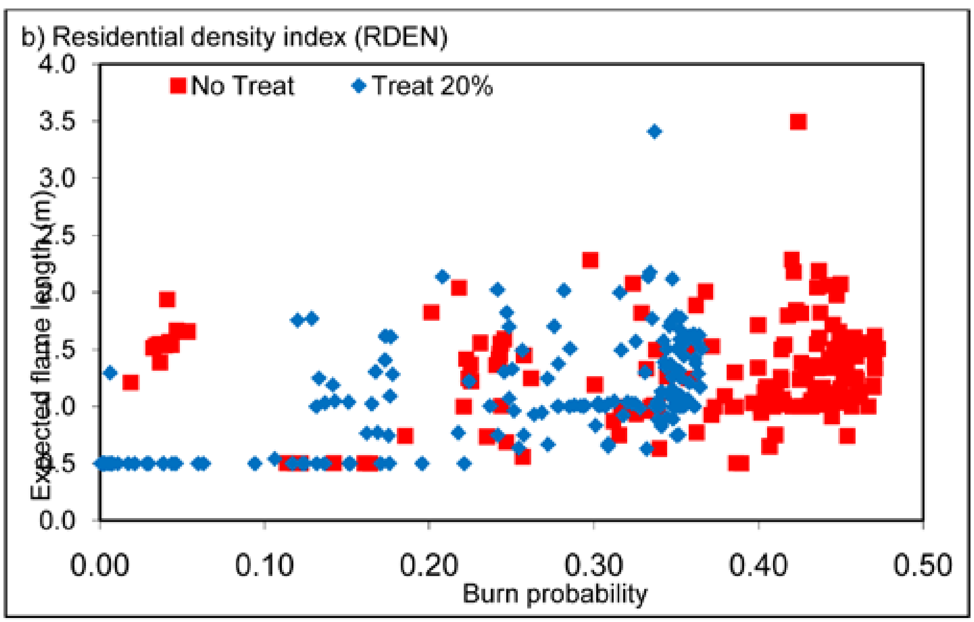
Figure 10. Graph from Ager et al (2010), which shows the expected loss of old growth trees (>53.3 cm diameter at 137.2 cm above ground) as a function of 6 treatment intensities and 2 spatial treatment scenarios. The graphs indicate that treatments in the urban interface area (RDEN scenario) are relatively ineffective at reducing expected loss of large trees compared to treatments in the wildlands (SDEN scenario) where stands were thinned to promote fire resiliency. Species codes are: DF: Douglas-fir, PP: ponderosa pine, WL: western larch, ES: Engelmann spruce, SF: subalpine fir.



Treating stands near residential structures resulted in a higher expected loss of large trees, but relatively lower burn probability and flame length within structure buffers. Substantial reduction in burn probability and flame length around structures was also observed in the restoration scenario where fuel treatments were located 5–10 km distant (Figure 11). This study demonstrated tradeoffs between ecological management objectives on wildlands (large fire resilient trees) versus protection of structures.

Figure 11. Example of flame length and annual burn probability scatter plots from Ager et al. (2010) showing values for individual structures for the Mt Emily wildland urban interface in northeastern Oregon. The stand density (SDEN) and residential density (RDEN) scenarios used different spatial treatment priorities that emphasized fire resiliency in the wildlands versus protection of structures in the urban interface. Points are average values for all pixels within a 45.7 m radius around each structure. The figure shows that burn probability, and to a lesser extent flame length, can be reduced around structures when fuel treatments are located outside the interface to address forest restoration and create fire resilient forests.





The Mount Emily study and others like it quantify off-site fuel treatment effects that often are not analyzed in fuel management studies. Moreover, they revealed spatial variation in burn probability and intensity that is useful for prioritizing fuels treatments to protect specific human and ecological values. This work advances the application of quantitative risk analysis to the problem of wildfire threat assessment for fuel treatment projects. Risk scatter plots and burn probability were developed as a decision tool to evaluate risk, prioritize treatments, and measure the potential treatment effects. The methods employed here demonstrated a quantitative approach to risk assessment using existing models that are widely used within the USDA Forest Service and other public land management agencies in the US.

V. Historic Range of Variability for Wildfire Risk

One of the more engaging discussions that occur frequently is whether historical levels of wildland fire can be restored and sustained. Quantitative risk analysis was performed for an assumed historical condition that would serve as a baseline for comparing modern risk in areas where ecological processes and ecosystem sustainability are likely and possible objectives. This historical risk is not applicable where lands are no longer managed for ecological sustainability. Sustainability is defined by both disturbance processes and vegetation/ecosystem structure (including vegetation and wildlife species and populations). Maps delineating these land management objectives were not available, and for demonstration purposes, public land was used to indicate potential areas.

The procedures for producing the historical risk analysis are based on LANDFIRE data products. Two main risk components, namely average historical burn probability and distributions of fire severity, were derived from LANDFIRE layers of mean fire return interval (MFRI) and biophysical setting (BPS), respectively. A national map of each of these data themes was created for the conterminous United States at a resolution of 270 meters. Historical Burn Probability was derived from the MFRI data which represent 22 classes of average historical fire intervals. The reciprocal of the midpoint of the interval is the estimated historical burn probability. The Historical Fire Severity Distribution was derived from the BPS data theme which represents the vegetation that may have been dominant on the landscape prior to Euro-American settlement. Each BPS map unit was matched to a vegetation succession model which includes information on disturbance regimes, including fire. For each succession model the probability of three fire severity types: surface, mixed and stand replacement were available. The fire severity types were linked back to the individual BPS vegetation map units so that they could be spatially analyzed in concert with the derived historical burn probability. The absolute probability of a specific fire severity was then the product of the historic burn probability and the conditional fire severity probability. The historical probability and severity information was then used to analyze the historical risk to contemporary high valued resources and compared with modern risk.

Comparison of the historical and modern risk components reveals the well known shift toward much lower rates of burning than historically existed. Burn probabilities for almost all areas are lower now than under historical conditions (Figure 12). The ratio of modern to historical probabilities identifies many places where the departure is the greatest – particularly in forests (Figure 13). Much higher burn probabilities occurred historically in agricultural areas no longer managed for wildland values. However, the ratio map also indicates substantial regions of the West and Southwest where burn probabilities are actually higher today. These correspond to places where invasive annual grasses have contributed to higher burning rates and larger fires than historical conditions could sustain (for example cheat grass replacing sage brush in the Great Basin). The same trend appears where excessive numbers of human ignitions occur adjacent to urban areas.

Figure 12. Historical burn probabilities derived from LANDFIRE data layers. These probabilities are substantially higher than modern probabilities (see Figure 3).

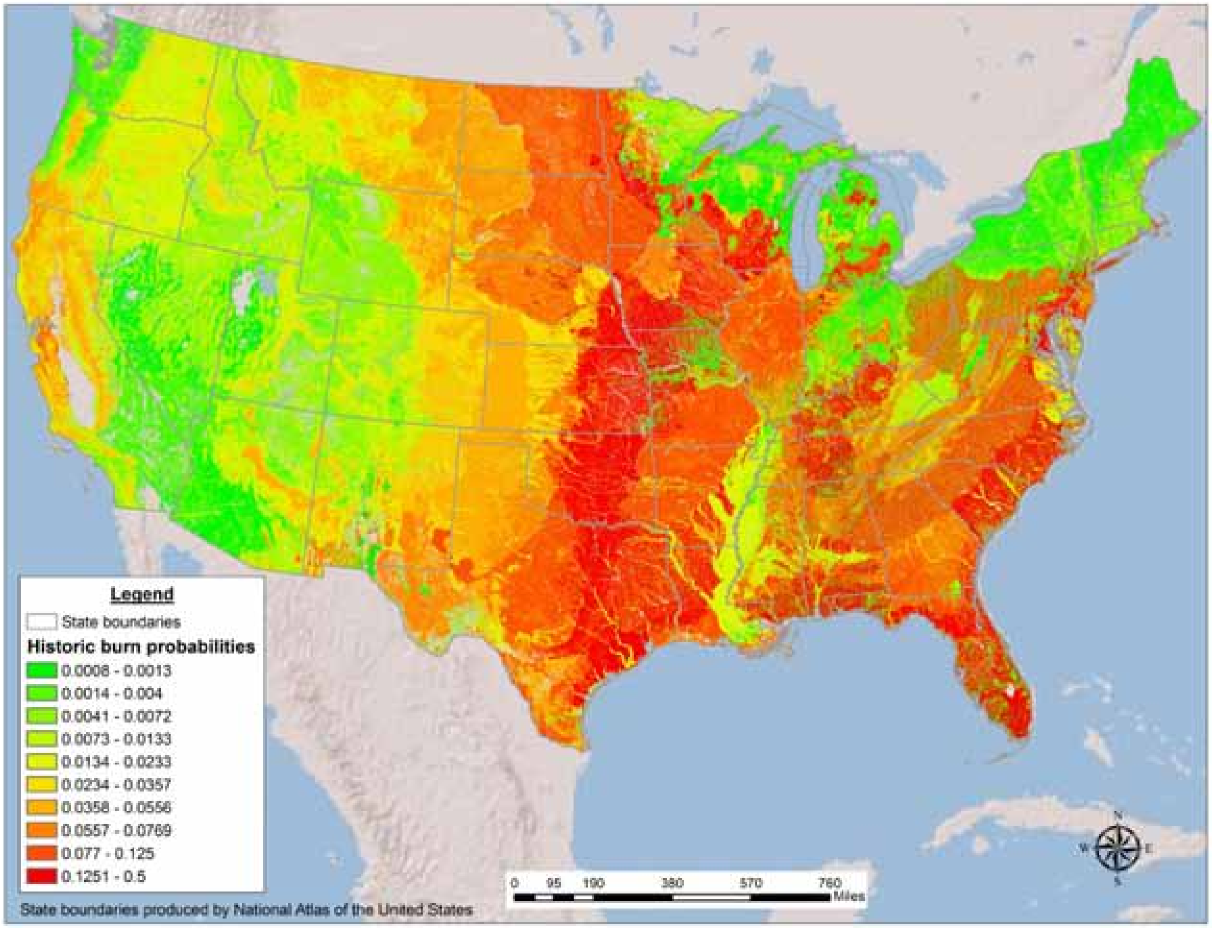
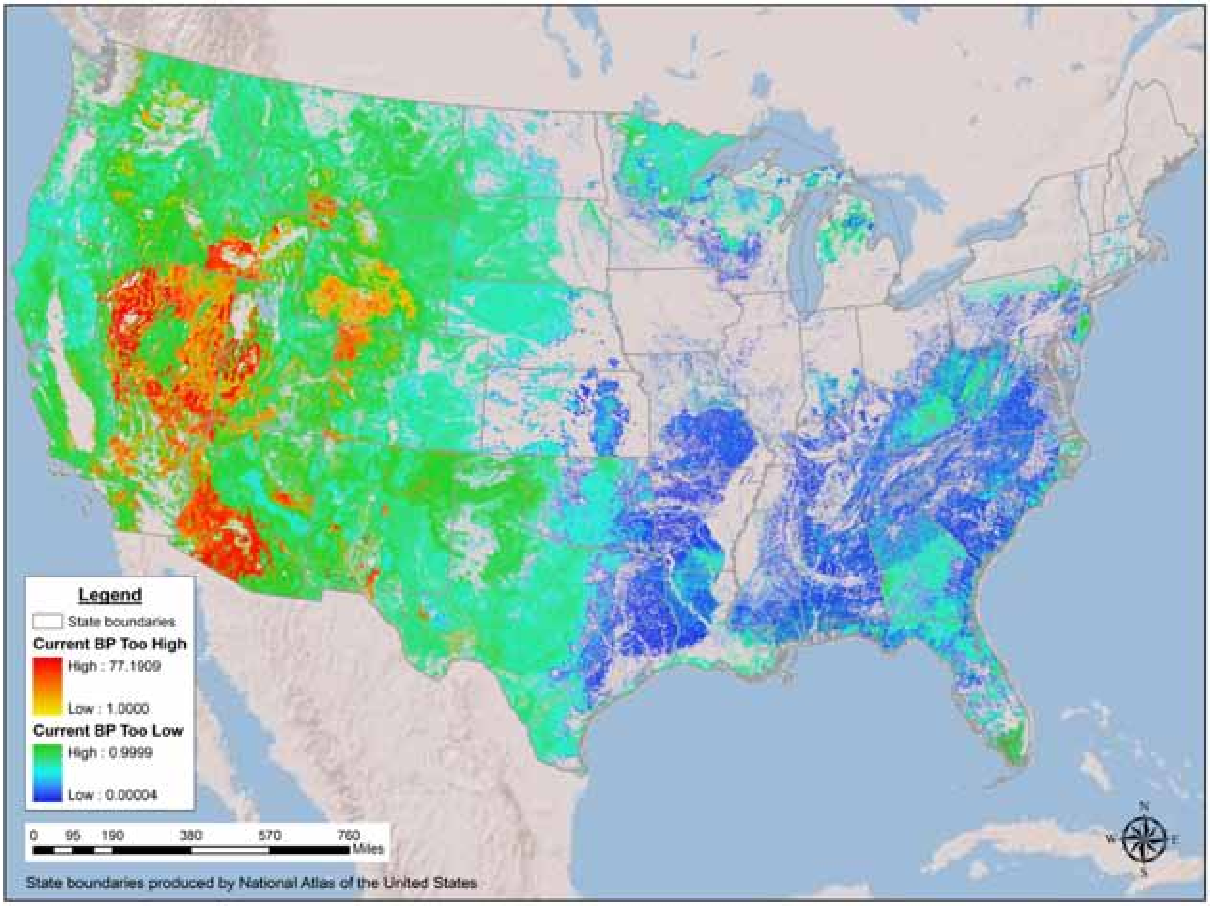


Figure 13. Ratio of modern to historical burn probabilities. Ratios are higher now than historical values in the Southwest and Great Basin, likely because of invasive grasses and increased human ignition. Ratios are substantially lower today in most of the forest types of the Country than historically existed.



Sustainability

The combined use of the historical risk components and treatment effectiveness suggests areas and frequencies of fire that would be important to sustaining ecological process and structure. For many lands, historical fire regimes are not consistent with modern land use objectives. Some lands, particularly some public lands in the west, however, do have management objectives consistent with ecosystem sustainability for which the historical conditions are a relevant comparison. As an example calculation, the large public ownership in the west is where historical fire regimes confer a net reduction in risk. This includes increased rates of burning in many low elevation forest types as well as fuel treatments to decrease rates of burning in some desert shrublands. Using the estimates of historical and modern burning rates by ecoregion on Federal lands in the west, it is possible to estimate the amount of area requiring annual burning. Summary tables were generated of the annual acres burned historically by ecoprovince and under the current fire regime. The difference is the total additional area requiring burning by ecoprovince achieving estimated historical burning rates. This same process could be used ultimately to estimate the area requiring burning by severity class or intensity class that conforms to historical regimes.

If it were a goal to return fire to the wild landscapes of the west, the amount of annual burning that would occur is substantially more than is currently occurring. Using a few ecoprovinces as examples indicates how much of an increase in burning would occur (Table 1). For instance, the Middle Rocky Mountain Steppe-Coniferous Forest-Alpine Meadow Province historically burned over 490,000 acres per year whereas now the area burns approximately 72,000 acres per year. Achieving the historic burn rate would be an increase in burning of approximately 500 percent above current. The Nevada-Utah Mountains-Semi-Desert-Coniferous Forest-Alpine Meadow Province historically burned over 222,000 acres compared to approximately 155,000 acres now. Achieving the historic burn rate would be an increase in burning of approximately 43 percent above current. The Sierran Steppe-Mixed Forest-Coniferous Forest-Alpine Meadow Province historically burned over 803,000 acres compared to approximately 70,000 acres now. Achieving the historic burn rate would be an increase in burning of approximately 1,047 percent or ten times the amount of burning. On Federal lands in the eastern U.S, even more dramatic contrasts are seen between estimated historical burning rates that the modern rates. Burning rates would have to increase by thousands of percent for most ecoprovinces. The historical contribution of Native American burning practices to the historical fire regime in many of these areas would probably have to be considered dominant over natural ignitions.

The issue of smoke management and tolerance will play a considerable role in decisions regarding the degree to which fire will be tolerated on the landscape. If the goal is to return fire to the landscape on these ecoprovinces to the extent it likely existed in the pre-European settlement era, smoke tolerance constraints are likely to limit implementation. It warrants discussion concerning the potential goal to increase fire on the landscape, but to what degree. It is shown here that achieving the same level of burning as pre-European settlement would involve dramatic shifts from current burning levels in most regions even if wildfire, prescribed fire, and fuels treatment were jointly counted toward the acres burned level.

Conclusions

Living with and managing wildland fire inherently involves facing uncertainty and the potential for catastrophic losses. Ultimately, the success of the Cohesive Wildland Fire Strategy may hinge on how well risk is properly understood, quantified, and managed. Formal comparative risk assessment as described above could provide a sound foundation for analyzing and evaluating alternative management strategies. The examples shown above demonstrate the types of risk analyses made possible with modern information and tools at multiple planning scales. Additional information and details are available in the complete report of the science panel, which also addresses additional issues relevant to wildland fire and risk assessment. Information provided above and in the complete report establishes a solid foundation for moving forward.

Table 1. Examples of estimated historical burning rates as compared to current rates for selected ecoprovinces in the western United States

Ecoprovince	Historical Burn Rate (ac/yr)	Current Burn Rate (ac /yr)	Net Diff. (ac/yr)	Historical % of Current
Middle Rocky Mountain Steppe-Coniferous Forest-Alpine Meadow	493,123	72,071	421,052	584%
Nevada-Utah Mountains-Semi-Desert-Conif Forest-Alpine Meadow	222,107	155,215	66,891	43%
N. Rocky Mountain Forest-Steppe-Conif Forest-Alpine Meadow	159,945	17,107	142,837	835%
Sierran Steppe-Mixed Forest-Coniferous Forest-Alpine Meadow	803,369	70,324	733,045	1,042%
S. Rocky Mtn Steppe-Open Woodl.-Conif Forest-Alpine Meadow	507,141	114,478	392,662	343%
Southwest Plateau and Plains Dry Steppe and Shrub	59,769	2,968	56,800	1,914%

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Literature Cited

Ager, A. A., Vaillant, N. M., Finney, M. A. (2010). A comparison of landscape fuel treatment strategies to mitigate wildland fire risk in the urban interface and preserve old forest structure. Forest Ecology and Management 259: 1556-1570.

Prestemon, J. P., Butry, D. T., Abt, K., Sutphen, R. (2010). Net benefits of wildfire prevention education efforts. Forest Science 56(2): 181–192.

USDA Forest Service (in review). A Comparative Risk Assessment Framework for Wildland Fire Management: Science Report to the Cohesive Strategy Oversight Committee.