Application of hazard and risk analysis at the project level to assess ecologic impact[1]

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Abstract

The application of hazard and risk analysis to specific project areas prone to uncharacteristic wildland fires is a useful way to estimate the effects of management alternatives (including no action). These project-level analyses need to be done in the context of surrounding landscape conditions. A landscape-level analysis is often at the catchment scale or larger, while project work is generally at a smaller scale, limited by practical considerations such as budget, land ownership patterns and public perception. This difference in scale requires an interpretative procedure to select an ecologically effective project alternative, and we propose a decision process involving several steps of hazard and risk analysis. The first step is to evaluate wildfire hazard and risk elements at the landscape level over longer time frames to provide insight into the factors dominating fire behavior and the most imperiled physical or ecologic domain such as vegetative succession, watershed values or human health and safety. Second, we suggest an additional spatial consideration to estimate the representative elemental scale (RES) of the fire process in the landscape. Consideration of the RES allows estimation of project-scale impacts to landscape-scale problems, while considering the hazard and risk assessment helps estimate longer-term project impacts, and possible cumulative impacts from multiple project activities. Third we propose considerations and objective functions to be used in locating and sizing project areas, and applying treatment prescriptions to specific situations within the project area.

The latter steps require fire history data and output from a fire behavior or vegetative succession computer model. We use data from the Southwest Oregon Demonstration Project (Roloff et al. submitted) to illustrate the methods proposed. Roloff et al. (submitted) demonstrate a formal model incorporating these concepts.

Keywords: hazard, risk, wildfire, fuel treatment, project planning

Introduction

Designing a project to reduce the long-term ecological, economic, and social risks associated with uncharacteristic wildland fire is a complex exercise involving several layers of consideration. In any project proposal, the short-term impacts are the most apparent. Project activities can be described and costs can be estimated.. Proposed activities usually alter forest structure and/or composition through removal of vegetation, disturb soils and/or understory vegetation through machinery operation, or alter hydrologic conditions with road construction or maintenance. Wildlife habitat, sensitive species, or water quality can be immediately and adversely impacted from project

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activities. Reviewers of project plans may find these short-term impacts to be sufficient reason to oppose the project action.

The more difficult, and arguably more important analysis, however, must evaluate the long-term effects of the project. Will some or all of the short-term impacts be temporary? How will subsequent vegetative succession and change affect the hazards and risks involved, and change future conditions for the values at risk? Will the project activity or multiple projects installed over time reduce important long-term risks? How can short-term impacts be most credibly compared against the long-term effects? How does the proposed project fit into and impact landscape-scale processes that may overwhelm or defeat project-scale goals? Answering such questions, particularly in an atmosphere of controversy and lack of trust, is an important part of project planning.

The most important and often controversial issue is the probability that a future wildfire would cause major damage to important values in the area. In the Western U.S. forests, particularly in the long-needled pine and associated ecosystems, a Century of fire suppression has left forests with fuel quantities and arrangements that virtually guarantee an uncharacteristic wildfire in the future (Covington et al. 1994, Sampson et al. 2000). More importantly, however, is the fact that in much of the region, no other known natural disturbance will replace fire's effects and alleviate the fuel buildup problem (Harvey 1994; USDI/USDA 1996). In the absence of fire, and without intentional mechanical intervention, the fuels will continue to build until an uncharacteristic fire is inevitable. That, as a risk element, may be unacceptable in many situations where high-value resources are involved. Where that is the case, the short-term impacts of a treatment may be the least damaging option available if they offer a reasonable chance of diverting, mitigating, or dampening the impacts of a future wildland fire.
Work to develop useful hazard and risk concepts and processes over the past decade may offer some useful insight for analyzing project impacts on the risks posed by uncharacteristic wildfires. In this context, we define "uncharacteristic wildfires" as those of such high intensity and severity that important ecosystem components or processes can be altered or destroyed over significant portions of the burned area. Using this definition, the primary objective of project action is to alter fuel conditions such as amount and arrangement so that a wildfire burns with impacts more typical of the natural process in the ecosystem. Thus, one possible project action could be the use of "characteristic" fires as a tool to reduce fuels and lower the risk of "uncharacteristic" events. The difficult step is using the knowledge gained from a hazard and risk assessment to determine if a proposed project is the correct action, in the correct location, to minimize risk.

Several efforts have described hazard and risk from wildfire at a catchment scale of 100 to 10,000 km^2 (for a summary see Sampson et al., 2000). Due to the complexity of these modeling efforts, the available data, and long recurrence interval of uncharacteristic fires, large grid sizes of 1 km^2 or larger and long time series of greater than 10 years are used in the analysis. Our proposed strategy first uses the longer time frame hazard and risk model to identify critical landscapes as potential locations for project areas, examine long term implications without project treatment, identify high value physical and ecological processes like long term vegetative succession and watershed function.

Second, output from a fire behavior or vegetative succession computer model is used to assess different project actions, locations and sizes. The project size and location at which an acceptable or possibly detectable change in the relative risk to the high value processes is the representative elemental scale (RES).

The third step is to examine project alternatives and their impact on critical processes identified in the hazard and risk assessment as well as describe short-term project impacts and define the realm and extent of manipulable physical variables (e.g., fine fuels, coarse fuels, fuel breaks, etc.).

Definitions and Concepts

For this paper, we will use the definitions of hazard and risk that were proposed by the National Resource Council (1989).

Hazard is "an act or phenomenon posing potential harm to some person(s) or thing(s)."

Risk is something that "adds to the hazard and its magnitude the probability that the potential harm or undesirable consequences will be realized."

In this context, it is uncharacteristic fuel conditions such as amount, type and/or arrangement that are the hazard element in the hazard-risk consideration. Those conditions provide the basis upon which an uncharacteristic wildfire can form. They are the "phenomena" that can make the difference between a fire that is generally characteristic for the ecosystem involved and an uncharacteristic event.

The primary risk element is ignition, particularly an ignition occurring as part of a cluster of ignitions that overwhelm suppression capabilities, or at a time when severe fire weather conditions exist. Those are events for which long-term probabilistic estimates can be created. Brought together, the probability of ignition in a landscape containing fuels of various hazard ratings provides a hazard-risk rating for different landscapes or units within the landscape. These relative ratings can illustrate differences between areas, even when they cannot be used to predict when or where an uncharacteristic wildfire may occur (Sampson and Neuenschwander 2000).

Woods et al. (1988) introduced the concept of a *representative elemental area* (REA) in a hydrologic context. The REA is the minimum area in which variability for a specific process is at a tolerable level for the analysis at hand. We propose a representative elemental scale (RES) for consideration in wildfire hazard and risk planning. This scale is the area and location at which a particular forest treatment would need to be applied so as to affect fire behavior and its impact on selected values at risk.

All wildland areas share wildfire risks with their surroundings. These *shared risks* are multi-directional: the project area can be the transmitter, where ignition and escape occurs within the project area and travels outward to impose risk on surrounding areas and larger landscapes, or it can be the receiver, where ignition and escape occur elsewhere and travel into the project area. A complete hazard and risk consideration will evaluate the implications of project action options on all the forms of risk present.

Spatial Considerations in Wildfire Hazard and Risk Analysis

Landscape Consideration

Evaluating relative wildfire hazard and risk at the large multi-watershed scale has involved several steps, including an assessment of ignition risk from historical records and an evaluation of vegetation cover and condition from aerial imagery. In a Colorado study, Neuenschwander et al. (2000) utilized a 10-year fire history database to evaluate the frequency of reported ignitions within the study area. The ignitions were evaluated in terms of their occurrence in relationship to both landscape and ecological units. For that study, the geographic units chosen were the 8-digit hydrologic unit codes (HUCs) assigned to watersheds by the U.S. Geological Survey (Seaber et al. 1987). The ecological unit was the vegetation type as identified by the 3rd revision of AVHRR satellite cover type classification (Loveland et al. 1991). This coverage has a pixel size of 1 km^2, the same as that of the coarsest dataset, which established the level of resolution for the GIS analysis (Sampson and Neuenschwander 2000). GIS analysis produced an ignition density table (number of ignitions per 10,000 acres per 10 years), both in terms of density within watersheds and density within fuel types. Data from the large, uncharacteristic wildfires listed in the database illustrated the connections between ignition frequency, general vegetation type, and eventual fire size.

This type of study provides a sense of relative (high, medium, low) hazard and risk conditions between watersheds within a regional analysis. While it has no predictive value as to where the next ignition may occur, or where a combination of multiple ignitions and weather may overwhelm suppression capacity and result in a large, uncharacteristic wildfire, the comparative hazard and risk analysis provides a basis for recognizing that projects within high-risk watersheds face different conditions than those in low-risk areas. In addition, this relative hazard of ignition can be combined with spatial consideration of other values such as a low gradient stream where siltation could be an impact or critical nesting habitat for bird species. These larger areas that contain these high value domains can become a subset for further investigation.

The Idaho Panhandle National Forest (IPNF) study was done to evaluate the hazard-risk methodology at a much finer resolution. This study covered sections of federal, state, and private land in the North Zone of the IPNF to identify geographic locations with the highest wildfire hazards and risks (Harkins et al. 1999). The wildfire hazard-risk assessment consists of five models: wildfire hazard-risk, which combined fuel hazard, ignition risk, and precipitation in a manner similar to that done in Colorado, caribou habitat, timber resources, recreation areas, and human structures.

The models are in 30-m raster format, dividing the project into a grid of 30 m x 30-m square cells. For each of the models, a relative hazard or risk score of very low, low, moderate, high, or very high was assigned to each grid cell. The scores are based on important features of each model, such as suitable and optimal habitat, species density, important habitat areas, topography, land use, etc. The final hazard or risk score was assigned to each fire zone based on a mean, maximum, or majority statistic of the grid cells within each fire zone.

Fuel hazards were determined with the NEXUS crown fire model (Scott 1999). NEXUS computes the minimum critical wind speed needed to initiate and sustain a crown fire. NEXUS requires 5 data types: fuel model, slope, crown bulk density, height to lower limbs, and weather data. The NEXUS results were spatially linked to the other attributes in the wildfire hazard-risk models. Ignition risk was developed from the historical ignition record, using the same methods as were used in the Colorado study.

With the use of this much finer scale data, the relative hazard rating actually begins to point towards critical areas for possible project implementation (those with a higher risk score and higher hazards). The fire model may indicate a RES by indicating a size beyond which fires get very destructive, and this can be compared with the patch size of groups of high hazard data to refine the RES.

In the Southwest Oregon Risk Demonstration Project (SORDP), a high-resolution landscape analysis is based on aerial imagery at a resolution of 30m x 30m pixels (Roloff et al. submitted). These data were interpreted into Ecological Land Units (ELU's) to portray existing conditions in terms of forest type, structure, size and density. Data from almost 2,000 geo-referenced plots were assembled to provide vegetation attributes to each ELU. These data provided the inputs required by fire behavior (FARSITE) and fire effects (FOFEM) models. Fire ignition data for 16 years were compiled to provide an ignition density map (number of ignitions per 100 ha). Combining the ignition risk with the fuel hazard conditions provides a hazard-risk attribute for each pixel in the landscape.

The finer resolution and availability of field data for establishing vegetation comp[illegible]ion and structure attributes at the ELU scale provided by the SORDP allows this study to be used for project inferences and strategic planning that the Colorado and IPNF studies did not support. The following process utilizes data outputs from that study to illustrate the steps in incorporating hazard-risk analysis into project plans.

Values at Risk

In this step, the important values that might be damaged or destroyed by an uncharacteristic wildfire are identified and located geographically on the landscape map. Such values might be threatened or endangered species such as the northern spotted owl (*Strix occidentalis*), an important or threatened habitat, important economic values, or nearby homes. In addition to those that are imposed by law or regulation, such as the owl, and those that are readily apparent, such as a rural home, it may be important to involve local stakeholders in the identification of values that may be less obvious. In building these maps, it may also be important to identify surrounding areas that need to be protected to provide buffer zones, foraging areas, etc.

For analytic purposes, it is preferable to develop individual maps for the important values at risk so that they can be independently assessed. Each of the different values will carry different levels of importance to people, and it is important to recognize those differences. Once the values at risk have been identified and mapped, combined maps can provide areas of overlapping zones of importance, which can also be a useful consideration. This allows either an individual analysis where one value "trumps" all others, or a combined analysis where the values are rated at roughly equal importance.

Project Size Considerations

Estimation of the representative elemental size (RES) can be based on the fire history in the landscape under study. Table 1 shows the fire size data developed in the SORDP study area.

Table 1. Fires according to final area burned, SORDP study area, 1986-2000.

			Cumulative	
Final Fire Size (ha)	Number	Percent	Number	Percent
0.01 – 1	10,323	87.27%	11,289	100.00%
1 – 10	1,143	9.66%	1,506	12.73%
10 – 100	245	2.07%	363	3.07%
100 – 1,000	93	0.79%	118	1.00%
1,000 – 10,000	18	0.15%	25	0.10%
10,000 – 100,000	7	0.06%	7	0.06%
Total	11,289	100.00%		

These data suggest that the fires that become large and likely to create uncharacteristic impacts in this landscape are those that grow to around 100 ha. Since around 1/3 of the fires that reach the 10-100 ha size get significantly larger, a project that converts a fire of that size from uncharacteristic to characteristic behavior would provide an elevated level of confidence that landscape level impacts may be successfully affected. The goal for project analysis, then, might be to establish project conditions such that they are capable of changing the behavior of an oncoming fire of about 100 ha in size.

It has been theorized that a treatment area, to be effective in altering the behavior of an oncoming wildfire, needs to be somewhere in the range of 2-4 times the size of the oncoming fire (Neuenschwander, pers comm. 2003). If that is the case, projects in this landscape need to be in the 200 – 400 ha size range in order to be deemed significant in affecting future wildfire impacts. Thus, for this location, we suggest that 200 ha represents an appropriate project size consideration wherever possible.

Project Location Considerations

Using the hazard-risk and values at risk maps developed above, it is possible to establish tentative project locations in the landscape. Where the landscape contains multiple ownerships, it may be necessary to constrain the analysis to the landowner conducting the analysis. More effective, however, would be a cooperative project where all landowners participate in considering project potentials and their ultimate impact on the important values in the landscape.

In identifying areas for project considerations, rules such as the following may be helpful in the prioritization process:

1. Areas where high-risk probabilities and most hazardous fuel conditions coincide.
2. Areas where important values will be protected from long-term or ecologically damaging harm.
3. Areas (ELU's) where the available management options are well known and proven to be effective in affecting wildfire events.
4. Areas large enough to have a high opportunity to affect anticipated wildfires.
5. Areas where altering a moderately size area of high hazard or risk decouples two or more larger areas.

Neighborhood Considerations

Once the potential project areas are identified using the criteria above, the immediate surroundings of the project area are considered. Locating important attributes there, including fuel hazards, ignition risks, topography, and values at risk, provides important spatial information for the GIS model. With that information, the project planner can consider some of the important questions about shared risk facing the project area. Some of those questions might be:

1. Where does the project lie in relation to high ignition areas and prevailing winds? If it is upslope or downwind from areas with high ignition risks and high fuel hazards, the risk assessment obviously is higher, even if the project conditions themselves do not rate such a high-risk rating.
2. Where are the neighborhood's most important values at risk located in relation to the project area? Again, if they are upslope or downwind, they are more likely to be affected by a fire burning from within, or through, the project area. The type of value may impact the treatment decision on land in proximity to important values. Critical watershed values may entail special siting of roads or other activities, while wildlife values may indicate the protection of large patches of hiding cover.
3. At this juncture, altering the vegetation in the fuel model and attempting to detect change to the hazard or risk may be useful

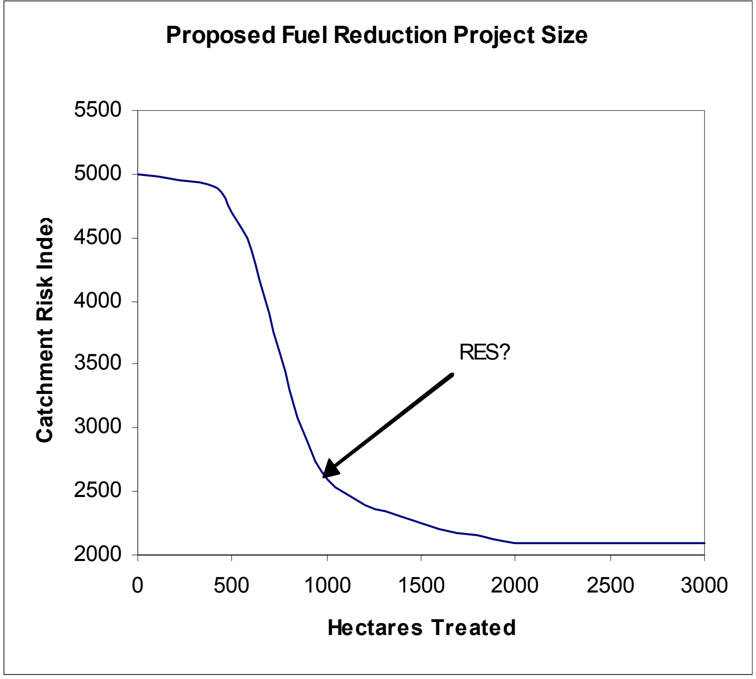

Figure 1. Hypothetical fire effects model response to different size projects.

(for an example, see Roloff et al. 2005). This sensitivity analysis may allow an examination of the RES and allow for some adjustment. A hypothetical output from several iterations of the fire effects model may look like Figure 1.

Once these shared risk questions are answered, the case for hazard and risk at the project level is largely at hand. It needs to be presented in a logical fashion to convince others of its merit, but the facts should largely be available.

Treatment Considerations

While project locations may have been chosen with consideration for the efficacy of known treatments, it is important to demonstrate that the proposed treatments will, indeed, change the risks affecting either the project or the surrounding landscape. This can be aided by using the new modeling tools available through forest research. The recent addition of a fire effects extension to the Forest Visualization System (FVS) designed by the Forest Service offers one such tool (Roloff et al. 2005).

In the FVS model, useful primarily where one has stand data and tree lists from plot surveys, it is possible to model the effects of fires under different stand treatments and weather conditions. The simulations thus provided can help communicate the likely effect of a post-treatment wildfire on the treated area and its surroundings.

Treatment prescriptions need to be based upon, and fully described, in relation to the specific conditions found within the project area. In a project of 200 ha, as proposed for southwestern Oregon, it is highly unlikely that a single ELU exists. Breaking the project area down into ELU's, and adapting treatment to each ELU individually, provides evidence that the treatment program is ecologically-based rather than an attempt to force a single management approach across different ecosystems, conditions, or micro-sites.

Extra attention needs to be paid to project boundaries where they are important. If the project area is located downwind or upslope from areas where uncharacteristic wildland fire is likely, are there opportunities to widen or intensify treatment areas that could be more effective in diminishing a fire's intensity? If a specific critical value is located within the project, or at a boundary where a fire is likely to exit the project, can it be buffered as part of treatment? While these questions are very specific to project details, their consideration will fortify the project's value in explicitly addressing existing situations. Similarly, landscape position may bring other concerns to the forefront. A project located high in a catchment where stream density is low and overland flow is rare may have very different hydrologic impacts to a similar sized project farther down in the stream network (MacDonald et al. 2000).

Estimating impact on wildfire behavior

Recognizing that the goal of project action is to alter fire behavior, both within the project area and, hopefully, at the landscape scale, it becomes important to estimate what effect the project is likely to have. As noted before, the project may affect landscape impacts in two ways: 1) the fire starts inside the treated project area and, because of the treatment, behaves in a more characteristic manner, allowing managers to determine whether and how to let it burn its course; or 2) the fire starts outside the treated project area and is burning in an uncharacteristic manner when it hits the project edge, where it drops out of the crowns and proceeds in more characteristic, manageable behavior. There is, unfortunately, a third option, which is that the fire hits the project area with such force that it overwhelms the treatment and destroys the values within the project.

We used weather data from a station near the SORDP area as one way to quantify how well a project in that area may perform under future conditions. Using the "Grandad" station records, which contained 112,631 daily and hourly readings from 1985 to early 2003, we developed a frequency distribution for wind speeds during summer days. We selected the highest wind reading for an individual day and then reduced the number of readings to 2924 by removing the months of November through April. Summary statistics for the weather site over the period 1985-1998 and 2000-2001 are shown in Table 2.

Table 2. Summary statistics for 16 years at the Grandad weather site.

	Wind (kph)	Temperature (C)	Relative Humidity (%)
Average	12.2	20.1	51.5
Standard Deviation	4.8	8.2	26.1
Coeffic. Variability	40%	22%	51%
Max	59.7	39.8	100
Min	0	-17.4	3.9

The resulting plot of wind speed over the time period is shown as an exceedence curve in Figure 2. An example of how to use this curve would be as follows:

1) For the current untreated condition, use FOFEM and the Stand Visualization Model to illustrate the wind speed at which the current forest will crown out and begin to exhibit uncharacteristic behavior. This threshold, under existing conditions, can then be characterized with the corresponding exceedence probability; and,

2) For the proposed treated condition, run the models to establish that same wind speed threshold, and exceedence probability. For the proposed treatment, "grow" the stand for some appropriate time in the model, and then determine the same threshold wind speed where uncharacteristic fire behavior begins.

This analysis then allows several larger scale risk and hazard parameters to be attached to that particular alternative. Using Figure 2, and the determination that 16 kph winds cause damaging behavior under existing conditions, it can be stated that a fire event during 20% of the recorded days of weather conditions would probably exhibit uncharacteristic behavior. After a treatment that creates a 24 kph threshold, a fire event that was active during 2% of the recorded weather conditions would probably exhibit uncharacteristic behavior. The difference between those two estimates (20% compared to 2%) reflects the reduction in risk probability as a result of the treatment. The long-term growth and change result would give us a sense of how long the project benefits could be anticipated to have a positive effect.

Wind is a simple variable and is used here to provide illustration. In practice this variable could be whatever is critical to the fire behavior processes. Exceedence curves can be constructed for any time series data such as temperature, relative humidity, fuel moisture, or other metrics (see Dunne and Leopold, 1978 for details).

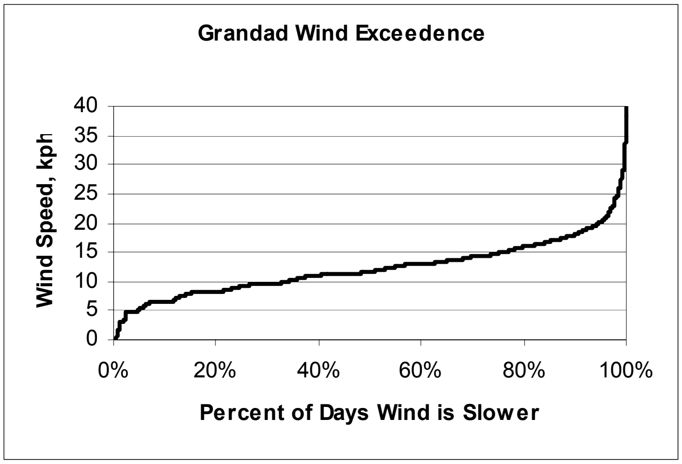

Figure 2. A wind exceedence curve for the summer months.

After all of the proposed scenarios have been examined in such a manner, it is presumed that fine-tuning of the alternatives can optimize the reduction in risk probability as well and the long-term project benefits. Hopefully, selecting a proper RES, and examining project location critically, can minimize these iterations and model scenarios.

Conclusion

We have shown an approach to applying hazard and risk modeling to the challenge of comparing the short- and long-term risks of applying fuel management techniques to forest areas subject to catastrophic wildfires. The major question is whether the short-term impacts of project action (which may, in some instances, be detrimental to important species or values), are balanced by a reduction in long-term or more harmful risk in the event of a wildfire on untreated conditions. Those are judgments that are often difficult to make, particularly when people bring significantly different experiences, value judgments, or professional biases to the debate.

In this exercise hazard and risk assessment, a process with very little temporal clarity and often large-scale resolution, is used to identify critical physical and ecological processes and locations where these functions of value are at risk. Next, individual ignition, fire behavior, and vegetation data are viewed in these critical areas to assess the correct size and location of project to implement (the representative elemental scale). This scale is tested for sensitivity using fire effects modeling. Finally, actual weather data are used to assess temporal impacts of different alternatives.

The question of balancing risk has, as we have shown, both temporal and spatial elements. If a project can result in affecting landscape-level wildfire behavior, its benefits are greatly enhanced. In order to have a chance to do that, it has to be located in a place, and large enough, to affect wildfire behavior. If the project treatment or series of management actions can maintain a healthy, fire-tolerant condition over a long period of time, the benefits, in terms of affecting long-term risk, are magnified. Project plans, to win the public and financial support needed, need to address both of these dimensions successfully.

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