Evaluating the Socioeconomic Impacts of Rapid Assembly and Geospatial Data in Wildfire Emergency Response Planning: A Case Study using the NASA RECOVER Decision Support System (DSS)

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Introduction

The true costs of wildfire for the economies of the western United States are often far greater than what is reported by the media. The millions of dollars used to suppress wildfires are typically reported as the actual cost of the fire, but this estimate does not account for the rehabilitation, direct, or indirect costs that could persist well after the fire has been extinguished. These costs, which may not be fully realized until several years after the fire, easily surpass the suppression expenses. Further, as wildfires continue to increase in size and frequency, without a similar uptick in the amount of land managers assigned to deal with wildfires, it is likely that the reliance on rapid assembly of geospatial data and satellite imagery will also increase. This project uses the NASA RECOVER wildfire decision support system as a case study to assess the socioeconomic impact of geospatial data for emergency response planning and to aid in the development of objective and defensible science.

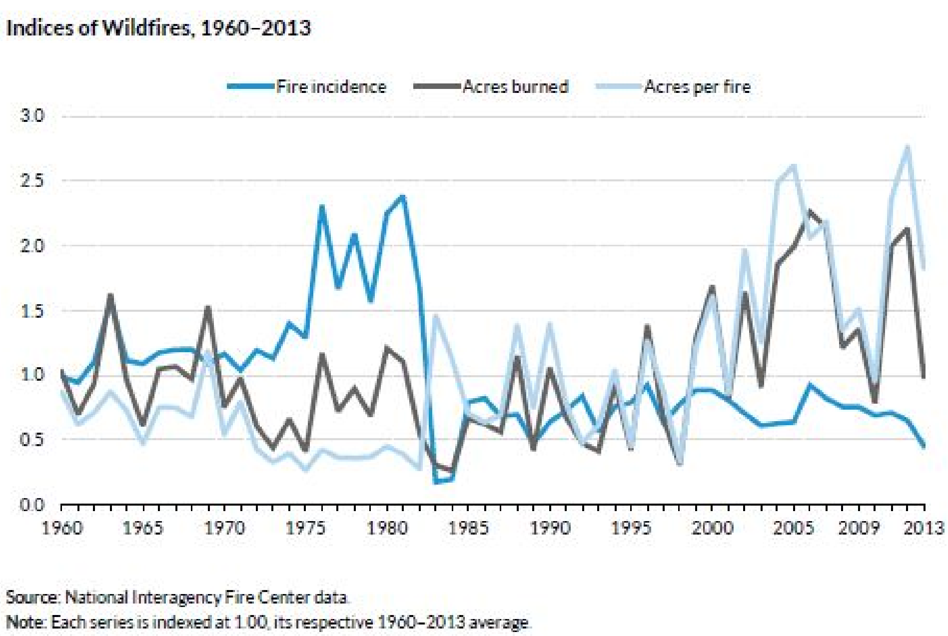
Literature Review

The federal and state wildfire management agencies have reported significant increases in costs over the years. Some of the cost increases are attributable to inflation [e.g. real suppression cost per acre increased by 17% from 1985-89 to 2009-13 while nominal costs increased by over 400% (Brusentsev and Vroman, 2016)], but a large percentage of the increase is the result of an increase in acres burned, a change in land use, a better understanding of the role of fire in ecological processes, and policy requiring an assessment of all of the damages associated with wildfires.

Changes in Acres Burned and Land Usage

Brusentsev and Vroman (2016), primarily relying on data from the National Interagency Fire Center (NIFC), provide a good summary of wildfire statistics for the United States. The two primary fire management agencies, the USDA's Forest Service (USFS) and the Department of Interior (DOI), have experienced over a 400% increase in annual fire suppression costs between 1985-89 and 2009-13. They also report that over a longer 54 year time period, in spite of the annual number of fires not trending upward, the total acres burned and the number of acres burned per fire has increased to the point that in several recent years the burned acreage has exceeded twice the average for the time period. Their figure, reproduced below as Figure 1, provides a visualization of this increase in burns along with the large amount of variability across years. The variable on the vertical axis is the ratio of the annual data to the average for the period of time. So it can be seen that fire incidence was high in the late 1970s whereas both acres burned and acres per fire were significantly above average in the most recent decade.

Figure 1: National Wildfire Incidence 1960 - 2013 (from Brusentsev and Vroman, 2016)



Given the dry conditions found across the western portion of the United States, many of the larger fires occur in this region. Figures 2 and 3 below illustrate the upward trend of both acres burned and fire frequency across the western United States.

Figure 2: Acres Burned per Year Across Western United States 1960 - 2016

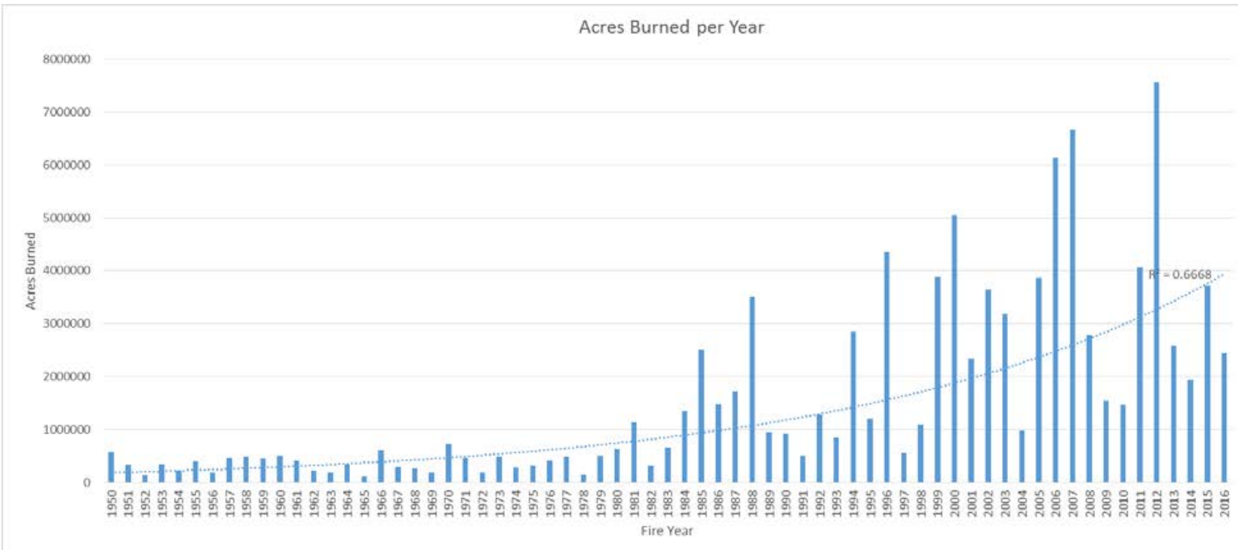
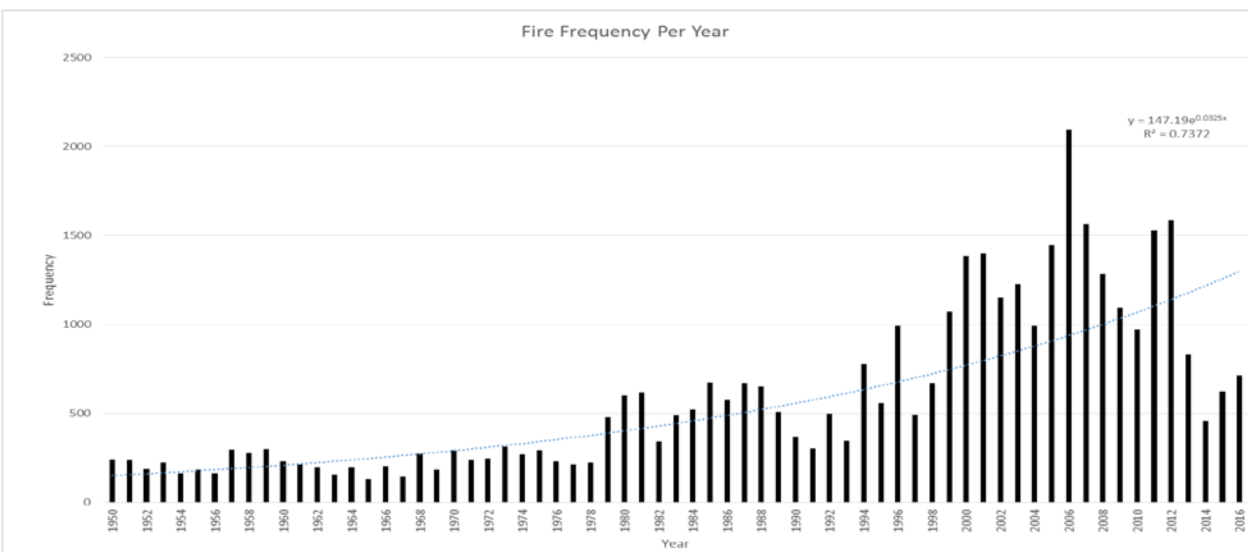


Figure 3: Fire Frequency per Year Across Western United States 1960 - 2016



In both of the above figures, the pace of the upward trend and the variability in acres burned increased since the mid-1990s.

USDA (2015) reports that in 2015 the Forest Service battled over 36,000 fires, but the estimated 1 – 2% of fires that are not suppressed quickly account for 30% of annual costs. However, the additional funds needed to combat these fires are transferred from other programs provided by the USFS. Specifically, the percentage of the appropriated budget allocated to wildfires has risen to 52% for FY 2015 from only 16% in FY 1995, and the non-fire personnel has decreased by 39% between 1998 and 2015 in order to pay for the more than doubled USFS fire personnel. As will be discussed below, this shift of resources toward the immediate need of fire suppression has negatively impacted the implementation of long term fire prevention plans.

One of the most costly changes in land use has been the increase in homes close to wildlands. The wildland urban interface (WUI), where natural areas and development meet, has made fire management increasingly more costly as more people build in rural areas that lie adjacent to public lands. When the total costs associated with wildfires are determined, the impact of increased development along the WUI is significant.

Changes in the Practice and Policy of Wildfire Management

As fire managers and other scientists improved their understanding of the role of fire in ecological processes, fire management practice has shifted away from an almost exclusive emphasis on fire suppression toward an integrated approach of considering fuel reduction, restoration, rehabilitation and suppression.

The earliest theories of fire management, including Sparhawk (1925), of almost 100 years ago, understood that there was an optimal level of fire control. However, in spite of the early literature's emphasis on efficiency, the USFS adopted a "10:00 a.m. policy" in 1935. (Donovan et al, 1999). This policy called for "fast, energetic and thorough suppression of all fires in all locations" and if fires were not suppressed during the first day, "the attack each succeeding day will be planned and executed with the aim, without reservation, of obtaining control before 10 o'clock in the next morning." (p. 99) This inefficient policy continued until the late 1970s when Congress mandated a cost-benefit analysis. The USFS and Bureau of Land Management (BLM) complied in 1979 with the National Fire Management Analysis (NFMAS) and the DOI's National Park Service (NPS) began using FIREPRO in the mid-1980s. These computerized programs used the cost plus loss framework to find the most efficient level of wildfire management. This framework (also termed cost plus net value change) minimizes the sum of the suppression costs and the damages associated with the wildfire. While both of these programs addressed the efficiency requirements associated with a cost-benefit analysis, the outcomes were very different since the NPS considers public enjoyment of resources rather than just resource utilization. In addition, practice and theory did not always coincide and the optimal allocation between suppression and other fire management tools was not always found.

A 2001 USDA and USDOI policy update encouraged a systemic approach across all fire management components rather than implementing a budget and planning process separately for suppression, fuel reduction, prevention and rehabilitation. The traditional least cost plus loss planning and budgeting methods were not designed for this unified approach, so effort was made to either update the methodology or develop a new approach to estimate wildfire costs. Rideout et al (2008) discusses how unifying this process increases both the consistent treatment across components and efficiency by taking advantage of the synergies and complementary impacts associated with managing the different components. According to Miller (2005), when using GIS for prescribed burns, land managers interested in efficiently reaching goals across several land characteristics benefit from a systemic approach. Lankoande and Yoder (2006) used national level data to estimate suppression productivity and find that "the marginal dollar of suppression expenditures provides on average only 12 cents worth of damage reduction …. (whereas) the marginal dollar of pre-suppression expenditures provides $3.76 worth of suppression expenditure reduction." (p. 4) Given the interrelatedness of the fire management tools and the financial straits of fire management agencies, efficiently allocating resources across all options is intuitively pleasing.

True Costs of Wildfires

In addition to the agencies' balancing act in determining how to allocate their resources, incorporating the true costs of wildfires can be a daunting task. Historically the US Forest Service has only included suppression costs when reporting the costs associated with wildfires. The media, while frequently including the costs of destroyed homes and other structures, also tends to underestimate the true costs associated with wildfires. Estimating the complete costs of wildfires can be a difficult undertaking given the far-reaching impacts of fire on damaging protected resource; private property losses; temporary (or permanent) loss of commercial activity, recreational opportunities and tourism; decreased air and water quality; habitat losses; cultural losses; increased fragility of ecosystems; and increased mortality and morbidity. However, inclusion of these costs, while significantly increasing the estimates, provides a more accurate assessment of the opportunity costs associated with wildfires.

Numerous studies have estimated wildfires' true costs. The Western Forestry Leadership Coalition (2009) categorizes wildfire costs into direct, rehabilitation, indirect and additional. The direct costs are primarily suppression costs but sometimes immediate short term rehabilitation efforts funded through the Burned Area Emergency Rehabilitation Program (BAER) are also included. Other longer-term rehabilitation costs include damages to the landscape resulting from flooding, landslides, invasive species, and erosion. Indirect costs, which can be difficult to quantify, include the reduction in economic activity for the surrounding area. The final category, additional costs, is used as a catch-all of the most difficult damages to quantify such as decreases in mortality and morbidity, and existence values for various aspects of the ecosystem.

These studies, without exception, find that the suppression costs are a small percentage of the true costs associated with wildfires. In the studies summarized in Western Forestry Leadership Coalition (2009), the suppression costs ranged from 3% to 53% of the total costs with the variation largely attributable to the characteristics of the terrain, the severity of the fire, and the proximity to a population base. Dunn et al (2005) estimated the costs associated with the Old, Grand Prix, and Padua wildfires of southern California in 2003 as almost $1.3 billion without including a value for lost income due to road and rail closures, lost recreation, and loss of ecosystem services. Even without those additional losses, the costs associated with fire suppression only accounted for approximately 5% of the total wildfire costs. Rahn (2009) estimated the total economic impact of wildfires in San Diego County in 2003 at approximately $2.45 billion with the suppression costs only 1.8% of the total. Although the suppression costs are a miniscule percent of the total costs, he concludes that a more effective use of suppression resources would have a significant impact on total costs. That is, "(r)educing the total acreage lost in a wildfire is strongly correlated with reducing the overall economic loss." Given the significant WUI, much of the suppression efforts have shifted to the protection of the citizens in this interface. Rahn also reports that increasing the staffing levels on a truck from three to four "also accounted for an increase in the total number of fires that were held to less than ten acres." This change in outcome resulting from a small change in inputs suggests that the total costs from a wildfire can be influenced by relatively small changes in practice.

Dynamic Component to Fire Management

Many of the non-direct costs have a dynamic element. The values of these costs (or damages) are influenced by the passage of time and the choices made as time progresses. Efficiently using resources maximizes the net benefits associated with protecting assets threatened by wildfires. Choices based on accurate and more complete data regarding the characteristics of the land burned and the value society places on rehabilitation increase the likelihood of making optimal decision.

Studies analyzing the value of assets impacted by wildfires show the sensitivity of that value to the policies implemented and the time since the wildfire. Englin et al (2001) found a statistically significant non-linear effect of time since wildfire on non-motorized recreation users with "an initial positive visitation response to recent fires, with decreasing visitation for the next 17 years, followed by an 8-year rebound in use." (p. 1843) They further find that the value of a day hiking trip at the Wyoming, Idaho and Colorado sites studied are approximately $90 - $250, with the variation based on the site's characteristics. After estimating the costs of forest fires in Colorado, Lynch (2004) concludes that "damages to forest watershed values in the arid West may ultimately result in the most serious, long-term costs of large fires" and "(t)hat 'greening up' may well be a cover of noxious plants and another set of costs." Kobayashi et al (2014) find that the productivity of western rangelands is being reduced by invasive grasses. The increase of these grasses has escalated the wildfire cycle (increasing the cost of wildfire suppression) and, where these grasses have irreversibly transitioned to a dominant status, decreased the capacity of the rangeland to provide foraging and other ecosystem services. Since they also find that ranchers do not tend to rehabilitate the lands on their own, once the quality of these rangelands is diminished, it is difficult to improve them. Mueller et al

(2009), using a hedonic approach, find that repeated forest fires in southern California cause housing prices to decrease for houses located near the fires. In particular, they find that a second fire will reduce the value of a nearby house by a significantly larger amount (approximately 23%) than the first fire (about 10%). This result lends support for a quick remediation of the burned lands so as to prevent additional fires in the same region.

Practices that address the dynamic nature of fire management and help prevent future wildfires provide long-term benefits and ultimately reduce fire suppression needs. However, the budget constraints of the primary federal agencies frequently result in an emphasis on reactive rather than proactive practices. Scientists agree that the Hazardous Fuels Reduction program provides economic benefit and improves the quality of the land, but only 14% of the USFS appropriated funds went to this component of fire management. Western Forest Leadership Coalition (2009) Active fire management "can reduce the severity of inevitable fire, improve recovery time, and contribute to ecosystem functioning before, during and after a blaze….. Healthy ecosystems that experience a disturbance such as fire are more likely to recover without long-term or devastating negative effects." (p. 13) The push toward long-term practices that support the development and maintenance of resilient fire-adapted lands "has potential to break out of the cycle of fire suppression, fuel accumulation, and continued exposure of human and natural systems to extreme fire conditions." (O'Connor et al, 2016).

The Role of GIS-based Assessment and Planning

Using a fire management decision support system (FMDSS) to reduce uncertainty and more efficiently make better informed decisions helps alleviate some of the agencies' financial pressure and reduce the damage imposed on society. After providing an overview of the geospatial tools used in wildfire management decisions across the globe, O'Connor et al (2016) concludes that GIS can effectively be

> "used to inform short and long-term fire management strategies by identifying and quantifying specific risks to human assets, opportunities for fire-induced enhancement of natural resources, strategies to mitigate negative fire

> transmission from one land ownership to another, and pre-identification of landscape conditions hazardous to hire responders on the ground."

However, they also conclude that "constraints on time, resources, and expertise necessary to use spatial fire management tools effectively continue to limit the widespread adoption of spatial fire planning, even in the most advanced wildfire management organizations."

BAER teams in fifteen western states and nine southern states are using Landsat data for post fire assessments. These teams identify and alleviate problems associated with land stability, water, invasive species, and habitat. The use of Landsat data shortens their response time for both pressing situations and long-term planning. Imagery allowing an examination of pre and post fire vegetation across the acreage to plan remediation and the ability to assess the progress of these remediation efforts over time has provided savings to the fire management agencies. The annual cost savings from "operational efficiency improvements, avoided alternative replacement costs (assuming Landsat data were not available), and opportunity costs related to economic and environmental decision-support" are estimated at $28 - $30 million. (NGAC – LAC, 2014).

RECOVER Decision Support System

Designed to assist the efforts to manage wildland fires in the Savanna ecosystem – primarily the semiarid grass and shrub dominated regions – of the western United States, the Rehabilitation Capability Convergence for Ecosystem Recovery (RECOVER) system aids the assigned emergency rehabilitation teams by providing the critical and timely information needed for management decisions regarding stabilization and recovery strategies (Schnase et al., 2014). RECOVER is an automated, site-specific decision support system that rapidly brings together in a single analysis environment all of the information necessary for post-fire rehabilitation decision-making and long-term ecosystem recovery monitoring. Moreover, RECOVER makes use of the rapid resource allocation capabilities of cloud computing to automatically collect earth observational data, derived decision products, and historic biophysical data which is then assessed by land managers to determine an adequate rehabilitation plan. Nevertheless, as the western United States experiences annual, or at least frequent, significant fire events, the total cost of a single large wildfire can range from several million dollars to over a billion dollars, with the local economies and communities being impacted the most. Although only a small portion of the United States' multi-billion dollar annual budget to support fire suppression activities actually goes towards post-fire rehabilitation activities, the potential social and economic impact of a successful, or unsuccessful, rehabilitation strategy can be financially quite significant.

Purpose

According to our agency partners, data assembly, pre-RECOVER, was the most significant bottleneck in wildfire-related decision-making (Schnase et al., 2014). After a major wildfire event, federal land management agencies are required by law to develop and certify a comprehensive plan for public safety, burned area stabilization, resource protection, and site recovery due within 21 days of fire containment. Initial rehabilitation plans, however, must be submitted by the first week from when the fire was contained which places a substantial burden on the agencies' resources, mainly staff time and availability, to assemble and collect the necessary data for the decision-making process. In order to meet the statutory requirements of producing a rehabilitation and stabilization plan within the one- and three-week timeframe, RECOVER was developed to provide site-specific, automatically deployable, and context-aware datasets on any given fire, in a single application, that assists the land managers with the post-fire rehabilitation and ecosystem recovery planning process. Further, to address the absence in the existing services for post-fire stabilization and restoration planning as well as the monitoring of vegetation recovery for semiarid lands, RECOVER provides specific data that helps BAER teams assess the effects of wildfire, identify areas in need of reseeding or other post-fire treatment, and monitor the subsequent ecosystem recovery in response to prescribed treatments (Schnase et al., 2014). Given the importance of reseeding after a significant fire event to the savanna ecosystem – i.e. to stabilize hydrophobic soils in order to minimize the probability of a debris-flow or to restore wildlife habitat and livestock rangeland to productive levels– RECOVER's features have the potential to significantly reduce the costs associated with the BAER assessment and planning phases as well as to better improve the land through rapid and accurate assessments of the effects of a fire event.

Background

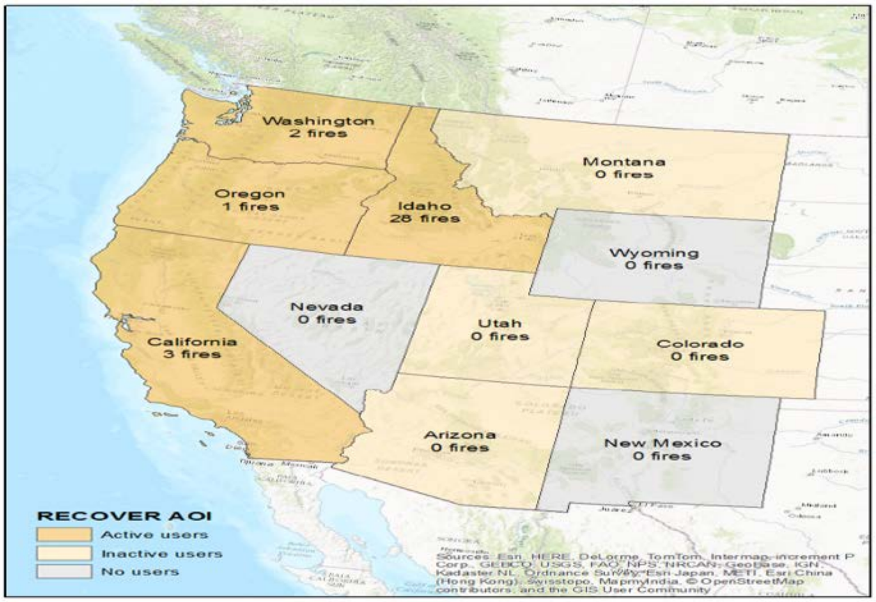
The RECOVER project is funded by the NASA Applied Sciences Program, which supports the development of objective and defensible science, with Idaho State University's (ISU) GIS Training and Research Center (TReC) serving as the lead organization. ISU's GIS TReC is also supported by the NASA Goddard Space Flight Center's Office of Computational and Information Sciences and the Technology Office and Biospheric Sciences Laboratory. In addition, federal and state agencies like the US Department of Interior's Bureau of Land Management and the Idaho Department of Lands have been essential partners since the early phases of RECOVER and have provided invaluable feedback throughout its maturation. In all over a dozen individuals from partnering agencies have contributed to the advancement and improvement of RECOVER making it a truly collaborative product.

During the early phases of RECOVER's development, great efforts were taken to develop system requirements that accounted for the actual decision-making process of the land manager in response to a large fire event. According to our agency partners, and alluded to above, the time and resource commitment needed to gather and assess all of the information required to submit a comprehensive rehabilitation plan could be unfeasible or impracticable. Thus, one of the objectives of RECOVER was to drastically reduce the amount of staff and time needed to gather the information for the BAER assessment reports and to allow them to shift their attention to more important and potentially impactful tasks of analysis, planning, and monitoring (Schnase et al., 2014). Proving successful from an early stage, the initial demonstrations by RECOVER yielded results that far surpassed the contemporary data gathering methods that relied heavily on field observations, web maps were produced in under one hour for a fire consuming over 250,000 acres, indicating the strong financial benefits RECOVER may have with land management agencies.

Current status

Since first being put into use during the 2013 fire season, RECOVER has been called upon to provide web maps for 36 wildland fires and has supported and improved the work and decision-making of nine different state and federal agencies throughout the western half of the United States. Figure 4 provides a visual of the fires using RECOVER by state. As shown, while RECOVER has been used throughout the West, most of the users are in Idaho.

Figure 4: Map of Fires Using RECOVER 2013-2016



In addition to a summary of RECOVERY use by state, the figures below organize the data by user. Less aggregated data is also provided in Table 1 below where the variability in acres burned is more transparent.

Figure 5: Percentage of Fires and Acres Burned Managed with RECOVER by User

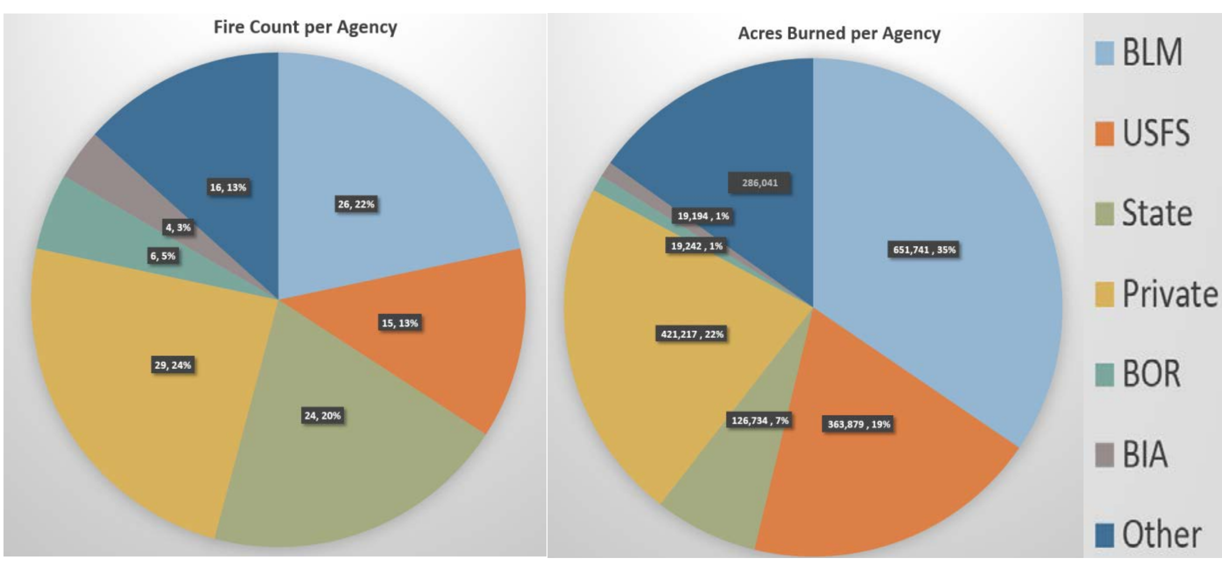


Table 1: List of RECOVER Users by Fire, Year, State and Acres Burned

Specific Fire	Year	State	Acres Burned	Active User
Timbered Dome	2016	Idaho	2,096	ID-BLM
Baker-ORPAC	2016	Oregon	336,504	OR-BLM
Henry's Creek	2016	Idaho	52,935	ID-BLM
Yale Road	2016	Washington	5,873	WHATCOM Conservation District
Spokane Complex	2016	Washington	6,358	NOAA & WHATCOM Conservation District
Pioneer	2016	Idaho	64,369	IDL and USFS
MM14	2016	Idaho	4,311	ID-BLM
Blue Cut	2016	California	36,323	NOAA-NWS
Lawyer 2	2015	Idaho	2,213	IDL
Cape Horn	2015	Idaho	1,326	IDL
Soda	2015	Idaho-Oregon	279,144	ID-BLM
Dodge	2015	California	10,570	Caltrans
Clearwater	2015	Idaho	68,127	IDL
Valley	2015	California	76,067	Caltrans
Powerhouse	2015	California	30,274	Caltrans
Johnston (Prescribed)	2015	Idaho	0	USDA-ARS
Motorway	2015	Idaho	33,983	IDL
Woodrat	2015	Idaho	7,797	IDL
Clearwater Complex	2015	Idaho	47,282	IDL
Lolo 2	2015	Idaho	1,405	IDL
Parker Ridge	2015	Idaho	995	IDL
Tepee Springs	2015	Idaho	3,337	IDL
Big Cougar	2014	Idaho	65,279	IDL
Timber Butte	2014	Idaho	7,013	IDL
Whiskey	2014	Idaho	9,452	IDL
2 ½ Mile	2013	Idaho	924	ID-BLM
Pony	2013	Idaho	148,170	ID-BLM
Incendiary Creek	2013	Idaho	1,100	IDL
State-line	2013	Idaho-Utah	30,206	ID-BLM
Mabey	2013	Idaho	1,142	ID-BLM
Chips	2012	California	76,343	USFS
Charlotte	2012	Idaho	1,029	ID-BLM
Ridgetop	2012	Idaho	16,616	ID-BLM
Drive-In	2011	Idaho	1,223	ID-BLM
Jefferson	2010	Idaho	188,151	ID-BLM
Crystal	2006	Idaho	220,000	ID-BLM

RECOVER has also seen improvements from its early years as well and what used to take an estimated fifty minutes to produce all of the web maps now takes under five minutes. Land managers and active users now have almost instantaneous access to information and data that used to take weeks, if not more, to gather and assemble into a single format. Ultimately, RECOVER aids in not only saving agencies on staff time and the associated costs, but also in assisting these land managers in accurately identifying potential areas that need, or not, rehabilitation and recovery efforts which benefit all users of the land, from hunters and ranchers to wildlife and recreationalists.

Interview Process

To date, seven structured interviews have been conducted with personnel from land management agencies who have used the RECOVER DSS, or other geospatial data and satellite imagery, as part of their official post-fire rehabilitative duties. The interviewees were identified through previous RECOVER DSS interactions and were contacted in early January 2017 to gauge their interest in participating in the study. The participants were provided with a copy of both the interview questions and project proposal ahead of the interview as well as given a choice between conducting the meeting in person or via teleconference. (A copy of the interview questions is included in the appendix of this paper.) Further, potential participants were also identified and categorized into two subcategories – *tier one* and *tier two* users – based off their agencies role in the rehabilitation and recovery of lands directly affected by wildland fire. Those entities that utilize geospatial data and satellite imagery, potentially RECOVER, and assume primary responsibility for the rehabilitation and recovery efforts of public land after a fire event are considered *tier one* users while those that are concerned with other issues like roads and transportation, water quality, and wildlife habitat, to name only a few, fall into the *tier two* category. However, this section will focus exclusively on the structured interviews with the personnel from land management agencies – *tier one* users – and an analysis of their interviews only will be provided.

The land management agencies that have successfully been targeted for participation in the study thus far are the Idaho Department of Lands, Idaho Fish and Game, and the Bureau of Land Management Boise, Idaho Falls, and Pocatello district offices in Idaho. The Idaho

Department of Lands was represented by a GIS program manager and the Idaho Fish and Game by a biologist. Representatives from the Bureau of Land Management have included a fire ecologist, supervisory natural resource specialist, range technician, fuels program manager, and an emergency stabilization and rehabilitation (ES&R) lead. Moreover, despite the wide ranging positions and roles of the participants to date, all interviewees, to some extent, have used geospatial data and satellite imagery to support their efforts of post-fire rehabilitation and recovery of public lands. Still, the participants from these organizations not only vary in their positions, responsibilities, and levels of expertise utilizing geospatial data but also with their familiarity using RECOVER to support post-fire decision making focused on ecosystem rehabilitation. Therefore, the results of these interviews are mixed as each respondent focused only on their own experience with RECOVER and geospatial data as well as the needs or responsibilities of their agency, which provided a very narrow perspective of RECOVER's efficacy and overall impact.

Analysis of Results and Trends

Throughout the interviews several main themes and trends consistently were brought up that strongly indicate the use of RECOVER, and other geospatial tools, greatly benefited the land management personnel and agencies in their efforts to rehabilitate the land post-fire. Responses from the interviewees on the use and benefit of RECOVER consistently referenced the improvement in communication on multiple levels – i.e. between team members, partner agencies, or the public – as well as the significant amount of dollars saved by agencies on staff time and related costs in compiling the information needed for the Bureau of Land Management's Emergency Stabilization and Rehabilitation (ES&R) or the Forest Service's Burned Area Emergency Response (BAER) plans. Participants also frequently mentioned that RECOVER's rapidly assembled and site-specific data provided key decision-makers with the necessary information needed that assisted them in quickly, among other things, identifying and assessing the recreational and agricultural sites post-fire that had the greatest potential for negatively impacting the region, both socially and economically, in order to determine the appropriate treatment. In addition, RECOVER provided these decision-makers with reliable, and often times difficult to obtain, data that allowed them to make better-informed decisions related to restoration and recovery, leading in some instances to a drastic reduction in the overall rehabilitation costs. Thus, there is little doubt that RECOVER, as well as other geospatial tools, have had a profound and positive impact on the land management agencies that utilize its features as well as the general public that benefits from the better-informed rehabilitative decisions related to the public lands they depend on or enjoy.

Staff time and related-costs

After a wildland fire has been contained the lead land management agency must submit a preliminary rehabilitation and recovery plan, either an ES&R or BAER proposal, within seven days and a final comprehensive report two weeks later. Due to the tight time constraint and competition for funding these agencies face, only conducting field observations of a large acre fire is not feasible nor is it adequate to submit a comprehensive rehabilitation and recovery plan. However, RECOVER can produce a fire-specific web map, regardless of the fire's size, encompassing all the information necessary to support the development of rehabilitation and recovery plans within five minutes, a useful and cost-effective tool as suggested by the interviewees. Participants also indicated that dedicating a large team to collecting and analyzing all the necessary data for developing and submitting an ES&R or BAER plan can become quite costly and burdensome on an understaffed or smaller agency. Further, depending on the size and location of the fire, participants stated that RECOVER saved them between two and five days, using anywhere from two to a dozen or more staff, worth of time collecting and assessing data needed to produce rehabilitation plans or present updates to community stakeholders. This benefit could equate up to hundreds of hours of time saved performing one task and would allow management to shift their staff's attention towards other aspects of their post-fire duties. This could have a much larger benefit to the public as well in that the land managers will theoretically have more time to focus their attention and efforts on multiple aspects of the rehabilitation and recovery process, as opposed to primarily focusing on collecting data for their official rehabilitation plans, which would ultimately benefit the land and land users.

Improved communication

Essentially, RECOVER's asset as a tool to improve communication across multiple spectrums was expressed by the interviewees universally. Communicating effectively with the community and local stakeholders, as well as with area decision-makers like county commissioners, was the most common situation in which RECOVER was employed to improve communications. Participants stated that preparation time for these meetings were reduced significantly, both in the number of staff members working and total hours spent completing the project. Further, the benefit to the affected community of land managers using RECOVER in their public briefings of post-fire rehabilitation efforts is that area stakeholders and residents are able to access the same information the agency is using for their rehabilitation plans and are therefore better-informed as a result. This information could also be of significant use to the members of the public that depend on the recreational or agricultural aspects of the land as they can use the information presented, that is derived from RECOVER, to make professional or personal decisions that will likely have an impact on the region's economy. RECOVER was also recorded as being used to improve communication between agencies partnering together on some rehabilitation or recovery project. Partnering agencies were able to reduce time and the communication barrier that is present whenever two separate entities collaborate on a project by being the sole web map used and referenced in order to effectively coordinate rehabilitation efforts.

Better-informed decisions

Arguably, RECOVER's greatest potential benefit arises from the better-informed decisions key personnel are able to make because RECOVER produces a comprehensive and reliable web map, comprised of multiple features, that provides the decision-maker with the most accurate and complete picture of the land post-fire. RECOVER allows the land manager to identify certain areas of high-risk to events like debris-flow or the severity of the burn on the land in order to determine an adequate and defensible treatment or management strategy that will restore or improve the land post-fire. As these agencies are required to submit a rehabilitation plan in such a short time frame, without the availability or use of geospatial technologies like RECOVER land managers must sometimes make suggestions for treatment without a complete analysis of the affected land. One of the participants stated that after a particular fire event on an area that included relatively steep slopes, they had begun to initiate the process to include a half a million dollar aerially mulch treatment into their rehabilitation plan. However, before finalizing and submitting the request the participant looked at the debris-flow probability feature in RECOVER and determined that the suggested treatment was unneeded and the potential cost could no longer be justified. Without the data and information provided by RECOVER, a half a million dollar mulch application likely would have been approved and deployed unnecessarily to an area that could recover without intervention.

Conclusions

Our preliminary results show value in using RECOVER to assist in rehabilitation planning. Much of the added value is found in the improved communication and decision making. As additional interviews are completed, we are hoping to provide quantifiable anecdotal evidence of RECOVER's socioeconomic benefits as well as a richer analysis from a wider range of users with respect to both fire size and agency.

References

Brusentsev, Vera and Wayne Vroman. 2016. "Wildfires in the United States: A primer." *Urban Institute*. https://cdpsdocs.state.co.us/coe/Website/Data_Repository/Wildfires%20in%20the%20United%20States_Brusentsev%20and%20Vroman.pdf

Carroll, Mark, John Schnase, Keith Weber, Molly Brown, Roger Gill, George Haskett, and Tess Gardner. 2013. "A new application to facilitate post-fire recovery and rehabilitation in Savanna ecosystems." https://earthzine.org/2013/06/22/a-new-application-to-facilitate-post-fire-recovery-and-rehabilitation-in-savanna-ecosystems/

Donovan, Geoffrey H., Douglas B. Rideout and Philip N. Omi. 1999. "The Economic Efficiency of the National Fire Management Analysis System and FIREPRO" ISDA Forest Service Gen. Tech. Rep. PSW-GTR-173.

Dunn, Alex E., Armando Gonzalez-Caban, Karen Solari. 2005. The Old, Grand Prix, and Padua Wildfires: How Much Did These Fires Really Cost? USDA Forest Service-Pacific Southwest Research Station, Riverside, California: 17 pp

Englin, Jeffrey, John Loomis, and Armando Gonzalez-Caban. 2001. "The dynamic path of recreational values following a forest fire: a comparative analysis of states in the Intermountain West" *Canadian Journal of Forest Research* 31: 1837-1844.

Environmental Protection Agency. 2010. *Guidelines for Preparing Economic Analyses.* December 17, 2010 (Updated May 2014). https://yosemite.epa.gov/ee/epa/eerm.nsf/vwAN/EE-0568-50.pdf/$file/EE-0568-50.pdf

Kobayashi, Mimako, Kimberly Rollins, and Michael H. Taylor. 2014. "Optimal Livestock Management on Sagebrush Rangeland and Ecological Thresholds, Wildfire, and Invasive Plants." *Land Economics* 90(4): 623-648.

Lankoande, Mariam and Jonathan Yoder. 2006. "An Econometric Model of Wildfire Suppression Productivity" Washington State University School of Economic Science Working Paper Series, WP 2006-10.

Lynch, Dennis L. 2004. "What Do Forest Fires Really Cost?" *Journal of Forestry 102(6): 42-49.*

Miller, Carol. 2005. "When to Prescribe" *Wildfire* 14(4): 16-21

Miller, Holly M., Leslie Richardson, Stephen R. Koontz, John Loomis, and Lynne Koontz. 2013. *Users, Uses, and Value of Landsat Satellite Imagery—Results from the 2012 Survey of Users.* USGS https://pubs.usgs.gov/of/2013/1269/pdf/of2013-1269.pdf

Mueller, Julie, John Loomis and Armando Gonzalez-Caban. 2009. "Do Repeated Wildfires Change Homebuyers' Demand for Homes in High-Risk Areas? A Hedonic Analysis of the Short and Long-Term Effects of Repeated Wildfires on House Prices in Southern California." *Journal of Real Estate Finance and Economics* 38: 155-172.

National Aeronautics and Space Administration. *Measuring Socioeconomic Impacts of Earth Observations. https://www.nasa.gov/sites/default/files/files/SocioeconomicImpactsPrimer.pdf*

National Geospatial Advisory Committee – Landsat Advisory Group. 2014. "The Value Proposition for Landsat Applications – 2014 Update." October 6, 2014. https://www.fgdc.gov/ngac/meetings/december-2014/ngac-landsat-economic-value-paper-2014-update.pdf

O'Connor, Christopher D., Matthew P. Thompson and Francisco Rodriguez y Silva. 2016. "Getting Ahead of the Wildfire Problem: Quantifying and Mapping Management Challenges and Opportunities" *Geosciences 6*(3), 35; doi:10.3390/geosciences6030035

Rahn, Matt. 2009. *Wildfire Impact Analysis. http://tcf.sdsu.edu/sdsu_newscenter/images/rahn2009fireanalysis.pdf*

Rideout, Douglas B., Yu Wei, Andrew G. Kirsch, and Stephen J. Botti. 2008. "Toward a Unified Economic Theory of Fire Program Analysis with Strategies for Empirical Modeling" Chapter 18 in *The Economics of Forest Disturbances: Wildfires, Storms, and Invasive Species*: 361-380.

Schnase, J.L., Carroll, M.L., Weber, K.T., Brown, M.E., Gill, R.L., Wooten, M., May, J., Serr, K., Smith, E., Goldsby, R., Newtoff, K., Bradford, K., Doyle, C., Volker, E., and Weber, S. 2014. "RECOVER: An automated cloud-based decision support system for post-fire rehabilitation planning." *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* XL-1: 363-370.

Sparhawk, W.N. 1925. "The use of liability ratings in planning forest fire protection." Journal of Agricultural Research 30(8): 693-792.

Theobald, David M. and William H. Romme. 2007. "Expansion of the US Wildland-Urban Interface." *Ecological Applications* 15(3): 799-805.

USDA. 2015. *The Cost of Fighting Wildfires is Sapping Forest Service Budget*. https://www.usda.gov/media/blog/2015/08/5/cost-fighting-wildfires-sapping-forest-service-budget

US Forest Service, USDA. 2014. The Rising Cost of Fire Operations: Effects on the Forest Service's Non-Fire Work. https://www.fs.fed.us/sites/default/files/2015-Fire-Budget-Report.pdf

U.S. Wildfire Cost-Plus-Loss Economics Project. http://www.wildfire-economics.org/index.html

Western Forestry Leadership Coalition. 2009. *The True Cost of Wildfire in the Western U.S.* (Updated April 2010). https://www.blm.gov/or/districts/roseburg/plans/collab_forestry/files/TrueCostOfWilfire.pdf

Zybach, Bob, Michael Dubrasich, Gregory Brenner and John Marker. 2009. U.S. Wildfire Cost-Plus-Loss Economics Project: The "One-Pager" Checklist. http://www.wildfire-economics.org/Library/Zybach_et_al_2009a.pdf

Appendix

Interview Questions

1. How was RECOVER used in your efforts with fire X?
2. What specific data did you find most useful from the RECOVER DSS?
3. Pre-RECOVER, how much time on average did you, or your office, spend collecting and analyzing the relevant data needed to submit an ES&R or BAER plan?
4. Using RECOVER, how much time was spent collecting that same data?
5. How did RECOVER improve BAER or ES&R decision-making?
6. Were communications improved by using RECOVER?
    a. Between team members?
    b. Cooperating agencies?
    c. The public?
7. Roughly how much time was saved using RECOVER for improved communication?
8. Did RECOVER reduce the cost or improve the effectiveness of data assembly? Decision-making for ES&R plan? And post-fire recovery and rehabilitation monitoring?
    a. Approximate dollar amount saved.
    b. Approximate time saved – personal and staff.
9. How did RECOVER assist your team in assessing burn severity?
10. How did RECOVER assist/improve the planning or implementation of emergency watershed rehabilitation measures to help stabilize soils, control water movement and protect property?
11. How did data acquired using RECOVER help circumvent issues related to post-fire hazards such as debris-flows?
12. Was the data acquired using RECOVER helpful in planning reseeding efforts?
    a. Or targeting wildlife habitat areas for rehabilitation efforts?
13. Did RECOVER assist in reseeding efforts that helped place rangeland back into use for grazing in a reasonable timeframe?
14. How do you plan to continue using RECOVER in upcoming fire seasons?
15. Is there anything else you would like to tell us about the value of RECOVER, satellite imagery, and geospatial data for wildfire management?