Socioeconomic Impacts of the NASA RECOVER Decision Support System for Wildfire Emergency Response Planning

William Toombs and **Keith Weber**, Idaho State University, GIS Training and Research Center, Pocatello, Idaho;

Tesa Stegner, Idaho State University, Department of Economics, Pocatello, Idaho;

John L. Schnase, National Aeronautics and Space Administration Goddard Space Flight Center, Office of Computational and Information Sciences and Technology, Greenbelt, Maryland;

and **Eric Lindquist** and **Frances Lippitt**, Boise State University, School of Public Service, Boise, Idaho

Abstract—Today's extended fire seasons and large fire footprints have prompted State and Federal land management agencies to devote increasingly larger portions of their budgets to wildfire management. As fire costs continue to rise, timely and comprehensive fire information becomes increasingly critical to response and rehabilitation efforts. The National Aeronautics and Space Administration's Rehabilitation Capability Convergence for Ecosystem Recovery (RECOVER) postfire decision support system is a server-based application designed to rapidly provide land managers with the information needed to develop a comprehensive rehabilitation plan. This study evaluated the efficacy of RECOVER through structured interviews with land managers (n = 20) who used RECOVER and were responsible for postfire rehabilitation efforts on over 715,000 ha of fire-affected lands. Although the benefit of better-informed decisions is difficult to quantify, the results of this study illustrate that RECOVER's decision support capabilities provided information to land managers that either validated or altered their decisions on postfire treatments. Savings from streamlining data collection were estimated at over US $1.2 million and nearly 800 hours of staff time, and communication within an agency and with local stakeholders and partnering agencies was improved.

Keywords: GIS, land management, postfire recovery, uncertainty, value of information, wildfire policy

INTRODUCTION

The total cost of wildfire for the economies of the western United States is often far greater than what is reported by the media and strains the already limited resources of land management agencies. The millions of dollars used to suppress wildfires are typically reported as the actual cost of the fire, but this estimate usually does not account for the rehabilitation, direct costs, and indirect costs that persist well after a fire has been extinguished. For instance, costs related to watershed damage, debris flow, flooding, soil erosion, and an increase in invasive species, which may not be fully realized until years after a fire, can easily surpass the suppression expenses of a significant fire event (Western Forestry Leadership Coalition 2009). Additionally, some of the societal impacts of wildfires—such as effects on health, recreation, air and water quality, employment, infrastructure closures, wildlife habitat loss, and damage to cultural heritage sites— have also been underreported. Yet they too should be considered in the total cost of any fire event in order to gain a more accurate portrayal of the social

In: Hood, Sharon; Drury, Stacy; Steelman, Toddi; Steffens, Ron, tech. eds. The fire continuum—preparing for the future of wildland fire: Proceedings of the Fire Continuum Conference. 21-24 May 2018, Missoula, MT. Proc. RMRS-P-78. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 358 p.

and economic impacts of wildfire. As Richardson et al. (2012) pointed out, concerns are growing among the public, wildfire researchers, and policymakers that the reported cost represents only a partial measure of the actual socioeconomic impact of damage from wildfire, limiting the effectiveness of the decisionmaking and policymaking process. In an effort to address these concerns, some land management agencies have adopted geospatial tools to assist in the collection and deployment of crucial information to support their prevention, suppression, and rehabilitation objectives. As wildfires in the western United States continue to increase in size and frequency, without a concomitant increase in the number of people managing wildfires, fire managers are likely to grow progressively more reliant on geospatial data and satellite imagery to develop rehabilitation plans.

After a fire is contained, and if deemed necessary, a burned area emergency response (BAER) team is assigned to rapidly assess the postfire conditions and develop a preliminary stabilization and rehabilitation plan. These BAER teams face strict time constraints, so data assembly, analysis, and decisionmaking must happen quickly in order to meet the statutory requirements (Robichaud et al. 2009). Currently, the postfire planning process requires substantial human resources and the information gathered depends on the availability of staff, time, funds, and data for a particular region (Dombeck et al. 2003; Schnase et al. 2014). Consequently, there are significant knowledge gaps in the postfire environment related to the lack of data and information that could significantly impact the planning effort (Venn and Calkin 2008). Given the importance of postfire stabilization and restoration for ecosystem recovery, especially in cases of severe fire events where the affected soil becomes hydrophobic or cannot return to prefire conditions, rapidly acquiring necessary data such as fire severity or debris-flow probability products becomes essential for the decisionmaking process (Robichaud 2009; Schnase et al. 2014; Venn and Calkin 2008). However, despite a wide variety of information services available to the wildfire community, none address the specific needs of postfire stabilization and restoration planning (Calkin et al. 2011; Schnase et al. 2014). Reducing uncertainty in the postfire planning environment will not only allow for better-informed decisions, but may also potentially reduce the direct and indirect costs associated with making decisions based on poor quality or untimely information (Kangas et al. 2010).

Thompson and Calkin (2011) stated that the uncertainty in wildland fire management, beyond the unpredictability of wildfire behavior, largely stems from inaccurate or missing data and that improved decision support technology could significantly reduce uncertainty in the postfire planning environment. The best geospatial tools used for postfire planning and decisionmaking, therefore, attempt to address knowledge gaps by presenting land managers with complete and reliable actionable information that allows decisionmakers to make better-informed decisions (Lentile et al. 2006). The value of information stems from the ability to make better decisions if new information is available (Kangas et al. 2010). The value of information can be negated, however, if the decisionmaker cannot take action—i.e., lack of timely access—regardless of the quality and accuracy of the data (MacCauly 2006; McCaffrey and Kumagai 2007). Thus, the timeliness of data accessed by the decisionmaker is a critical component to making the information valuable and actionable. Through the rapid collection and deployment of data crucial to submitting a comprehensive rehabilitation plan, lead land management agencies have the potential to meaningfully reduce costs and time associated with the postfire land management process. Further, these better-informed decisions are beneficial not only to the individual or agency tasked with postfire rehabilitation but also to the local community and the ecosystem as a whole.

To help illustrate the significant societal value of geospatial tools and Earth-observing satellite imagery, this research used the National Aeronautics and Space Administration’s (NASA’s) Rehabilitation Capability Convergence for Ecosystem Recovery (RECOVER) postfire 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. RECOVER is a highly automated, site-specific, decision support system that assembles nearly 30 fire-specific geospatial data layers and reports in an easy-to-use web map in as little as 5 minutes (Schnase et al. 2014). These data are available to the land manager in a near real-time environment to support their rehabilitation planning efforts.

Through structured stakeholder interviews with users of RECOVER and other geospatial tools, this project sought to identify the actual impact of rapid assembly and deployment of geospatial data in wildfire emergency response planning in order to assess the value of information derived from RECOVER's web maps and how these data influence and improve postfire decisionmaking. An analysis of the value of information derived from RECOVER provided a rich contextual comparison to those decisions made in the absence of geospatial tools, as well as assisted in determining a monetary value for the immediate outcomes of land managers' better-informed decisions enabled by RECOVER-based data. In addition, these interviews highlighted the significant time savings and cost savings for decisionmakers and support staff who used RECOVER, which are expressed later as approximate dollars saved. Finally, although more difficult to quantify, the ultimate social benefits of better-informed decisions—i.e., impacts on the ecosystem, recreation, and land use—are also considered in the final estimation of RECOVER's overall socioeconomic impact in the postfire emergency response planning process.

BACKGROUND

Changes in Land Use and Area Burned

Since 1985, both Federal and State land management agencies have reported significant increases in overall fire-related costs, with the Federal government shouldering the bulk of the expenses (Brunsentsev and Vroman 2016; Center for Western Priorities 2014; NIFC 2017). Some of the increased costs are attributable to inflation (e.g., real suppression cost per hectare increased by 17 percent from 1985–1989 to 2009–2013 while nominal costs increased by over 400 percent [Brusentsev and Vroman 2016]), but a significant increase in costs is the result of larger wildfires, an expansion of the wildland-urban interface (WUI), a better understanding of the role of fire in ecological processes, and policy changes requiring an assessment of all of the damages associated with wildfires (Brunsentsev and Vroman 2016; Vilsack 2015; Wigtil et al. 2016). The two primary fire management agencies, the Forest Service, U.S. Department of Agriculture, and the Department of the Interior, report that over a 54-year time period, despite no upward trend in the number of annual fires, the total area burned and length of the fire season more than doubled (Brusentsev and Vroman 2016). Given the generally xeric conditions found across the western United States, many of the large fires occur in this region (figs. 1 and 2).

Arguably, one of the most costly changes in land use has been the increased number of homes close to wildlands, which now account for one-third of all homes in the United States (Martinuzzi et al. 2015; Theobald and Romme 2007). The WUI, where undeveloped wildland and human development meet, has made fire management increasingly more costly. Fires in the WUI represent one of the most difficult

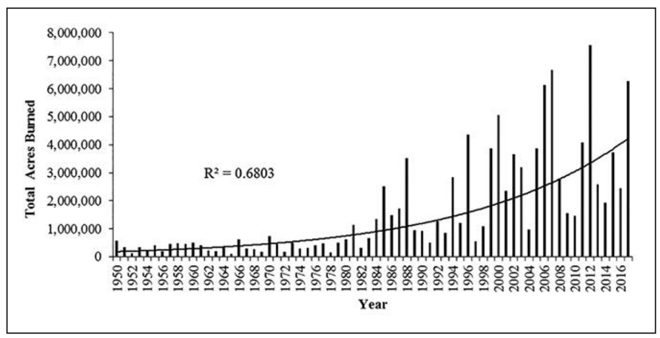

Figure 1—Acres burned per year across the western United States, 1950 through 2017. The line of best fit follows an exponential growth curve (Source: Idaho State University n.d.).

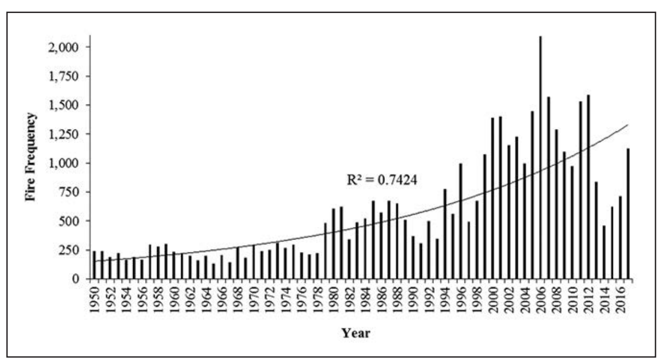

Figure 2—Fire frequency per year across the western United States, 1950 through 2017. The line of best fit follows an exponential growth curve (Source: Idaho State University n.d).

problems that agencies must manage because of the potential for loss of life, livelihoods, health, and property (Curth et al. 2012). Moreover, as social factors largely influence where and how people are affected by wildfires, better understanding wildfire potential, vulnerability, and management will help address persistent economic, structural, and human life losses from WUI fires as well as rising suppression costs (Wigtil et al. 2016). When the total costs associated with wildfires are determined, the impact of increased development along the WUI is significant.

True Costs of Wildfires

In addition to the agencies' balancing act in determining how to allocate their resources, incorporating the true costs of wildfire is a daunting task. Historically, the Forest Service has included only suppression-related expenses when reporting costs associated with wildfires. The media, while frequently including the costs of destroyed homes and other structures, also tend to underestimate the true costs associated with wildfires (USDA FS 2014). Estimating a comprehensive cost of wildfires can be a difficult undertaking given the far-reaching impacts of wildfire across multiple spectrums of the affected ecosystem and regional economy. Attempting to quantify some of these categories—e.g., a decline in air and water quality, loss of recreational or cultural heritage sites, and increased probability of debris flow—is challenging as they represent indirect costs that might not be realized for several years. However, inclusion of these costs, while significantly increasing the estimates, provides a more accurate assessment of the opportunity costs associated with wildfires.

Contemporary research that attempts to assess the comprehensive costs and impacts of wildland fire has categorized wildfire-related costs into direct, rehabilitation, indirect, and additional classes (Western Forestry Leadership Coalition 2009). These studies, without exception, find that the direct costs of suppression are only a small percentage of the expenditures associated with wildfires. In the research summarized by the Western Forestry Leadership Coalition (2009), suppression costs ranged from 3 to 53 percent of total cost, 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 2003 Old, Grand Prix, and Padua wildfires of southern California at almost $1.3 billion (all amounts reported in U.S. dollars) without including the value of lost income due to road and rail closures, lost recreational opportunities, or negative impacts on ecosystem and human health. Even without accounting for those additional losses, the costs associated with fire suppression accounted for only approximately 5 percent of the total estimated wildfire costs. Similarly, Rahn (2009) estimated the total economic impact of wildfires in San Diego County in 2003 at approximately $2.45 billion, with suppression costs representing less than 2 percent of the total. Although suppression expenses are a miniscule percentage of the total costs, these estimates are typically presented as the full and actual cost of wildfire.

Dynamic Component to Fire Management

Many of the indirect costs involved in fire management have a dynamic element. The value of these costs (or damages) is 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 wildfire. Choices based on accurate and more complete data regarding the characteristics of the land burned and the value that society places on rehabilitation increase the likelihood of making optimal decisions.

Studies analyzing the value of assets impacted by wildfires show the sensitivity of that assessment to the policies implemented and the time elapsed since the wildfire. Englin et al. (2001) found a statistically significant nonlinear effect of time since wildfire on nonmotorized 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." After estimating the costs of forest fires in Colorado, Lynch (2004) concluded 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 invasive annual 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 forage and other ecosystem services. Mueller et al. (2009), using a hedonic approach, found that repeated forest fires in southern California caused housing prices to decrease in areas located near previous fires. In particular, they found that a second fire will reduce the value of a nearby house by a significantly larger amount (approximately 23 percent) than the first fire (about 10 percent). This result lends support for quick remediation of burned lands 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, 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 percent of the Forest Service-appropriated funds went to this component of preventive fire management (Western Forestry Leadership Coalition 2009). From O'Connor et al. 2016, 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." Further, 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 Geographic Information System-Based Assessment and Planning

Using a fire management decision support system (FMDSS) to reduce uncertainty in order to make better-informed decisions helps alleviate some of the agencies' financial pressure and reduce the damage imposed on society by wildfire. With these concerns in mind, BAER teams, which identify and alleviate problems associated with land stability, water, invasive species, and habitat, frequently use Landsat data for postfire assessments. The use of Landsat data shortens their response time for both pressing situations and long-term planning. This imagery allows for examination of both prefire and postfire vegetation across a fire area and allows for improved remediation planning and the ability to assess the progress of remediation efforts over time. 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 million to $30 million (NGAC–LAC 2014).

RECOVER Decision Support System

The RECOVER decision support system is made up of a RECOVER server and a RECOVER client. The RECOVER server is a specialized Integrated Rule-Oriented Data System (iRODS) data grid server deployed in the Amazon Elastic Compute Cloud (EC2). The RECOVER client is a full-featured Adobe Flex Web Map geographic information systems (GIS) analysis environment. When provided a wildfire name and geospatial extent, the RECOVER server aggregates site-specific data from predesignated, geographically distributed data archives. It then does the necessary transformations and reprojections required for the data to be used by the RECOVER client. It exposes the tailored collection of site-specific data to the RECOVER client through web services residing on the server. RECOVER is transforming the information-intensive planning process by reducing from days to a matter of minutes the time required to assemble and deliver crucial wildfire-related data (Schnase et al. 2014).

Designed to provide postfire data to land managers across the western United States, RECOVER aids 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 the information necessary for postfire rehabilitation decisionmaking and long-term ecosystem recovery monitoring. RECOVER uses rapid resource allocation capabilities to automatically collect Earth observational data, derived decision products, and historical biophysical data, which are then accessed by land managers to determine a sound rehabilitation plan. Utilizing this type of decision support tool has the potential to be useful to land managers, especially as the western United States typically experiences significant fire events annually, and the total cost of a single large wildfire can range from several million to over a billion dollars. Although only a small portion of the United States' multibillion dollar annual budget to support fire suppression activities actually goes toward postfire rehabilitation activities, the potential social and economic impact of a successful, or unsuccessful, rehabilitation strategy can be significant.

RECOVER's Purpose

According to agency partners—primarily the Idaho Department of Lands, Forest Service, and Bureau of Land Management (BLM), data assembly, pre-RECOVER, was the most significant bottleneck in wildfire-related decisionmaking (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 within 21 days of fire containment. In some cases containment is delayed due to specific fire circumstances, giving land managers more time to assemble data and prepare plans. In these instances, RECOVER benefits the land manager by providing the manager with actionable information very quickly and providing him or her with additional postfire data describing the event (e.g., fire-affected vegetation [differenced Normalized Burn Ratio]). Initial rehabilitation plans, however, must be submitted within 1 week of when the fire was contained, which places a substantial burden on the agencies' resources, mainly staff time and availability, to collect and synthesize the necessary data for the decisionmaking process.

RECOVER was developed to provide site-specific, automatically deployable, and context-aware datasets on any given fire as quickly as possible to help land managers meet these statutory deadlines. RECOVER provides data that helps BAER teams assess the effects of wildfire, identify areas in need of reseeding or other postfire treatment, and monitor subsequent ecosystem recovery in response to prescribed treatments (Schnase et al. 2014). Given the potential of reseeding after a significant fire event—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 can significantly reduce the costs associated with assessment and planning phases as well as to better improve the land through rapid and accurate assessments of the effects of a fire event.

During the early phases of RECOVER's development, efforts were taken to develop system requirements that accounted for the actual decisionmaking process of the land manager in response to a fire event. According to agency partners, the time and resource commitment needed to gather and assess all of the information required to submit a comprehensive rehabilitation plan—especially after a few hundred thousand hectares burned—could be impractical. Thus, one of the objectives of RECOVER was to allow fire managers to shift their attention to more important and potentially impactful tasks of analysis, planning, and monitoring by significantly reducing the number of staff and amount of time needed to gather the information for the assessment reports (Schnase et al. 2014). Initial demonstrations by RECOVER yielded results that surpassed the contemporary data gathering methods, which relied heavily on field observations. Currently, RECOVER produces fire-specific web maps in less than 5 minutes, providing land managers with immediate actionable information.

Current Status of RECOVER

Since the 2013 fire season, RECOVER has been called upon to provide web maps for 60 wildland fires (fig. 3) and has supported and improved the work and decisionmaking of 9 different State and Federal agencies throughout the western United States.

While RECOVER has been used throughout the West, most users are located in Idaho. In addition to a summary of RECOVER users by State, figure 4 organizes the data by agency user. Land managers

Figure 3—Number of wildfire events that used the RECOVER decision support system across the western United States, 2013 through 2017.

now have almost instantaneous access to information and data that in the past took days or weeks to gather and assemble into a usable format. RECOVER saves agency costs for staff time and helps land managers accurately identify potential areas for rehabilitation and recovery efforts. This, in turn, benefits the ecosystem as well as primary users of the land such as hunters, ranchers, and recreationists.

METHODS

Interview Process

Twenty semistructured interviews were conducted with personnel from Federal and State agencies, representing a wide range of job functions and responsibilities, who had used RECOVER, or other geospatial data and satellite imagery, as part of their duties. These participants represent 78 percent (n = 47) of the fires in which RECOVER has provided web maps, an area covering over 715,000 ha. Fifteen interviews, representing about 555,000 ha, were with individuals who had personally used RECOVER to perform their job functions. Five interviews, representing an additional 160,000 ha, were with personnel who had requested fire data from RECOVER but did not use the tool to support

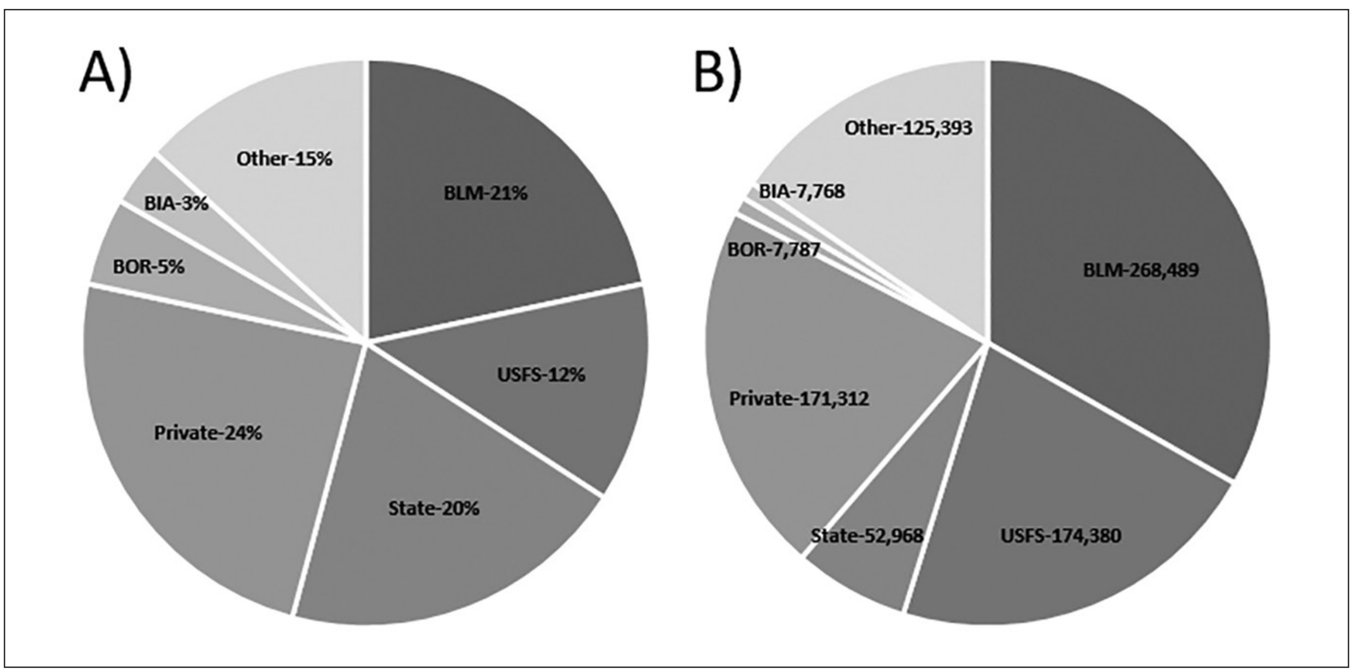

Figure 4—Percentage of fires (A) and hectares burned (B) by user agency. BIA: Bureau of Indian Affairs; BLM: Bureau of Land Management; BOR: Bureau of Reclamation; USFS: USDA Forest Service.

their postfire efforts. The responses and results of the actual users of RECOVER will be the focus of this paper. The participants were categorized into two subcategories, tier one and tier two users, based on their agency's role in the rehabilitation and recovery of lands directly affected by wildland fire. Personnel of entities that utilize geospatial data and satellite imagery (i.e., RECOVER) and assume primary responsibility for the rehabilitation and recovery efforts are considered tier one users (n = 15); participants whose agencies are concerned with other issues such as roads and transportation, water quality, and wildlife habitat fall into the tier two category (n = 5).

Through the semistructured interviews we sought to acquire insight into how RECOVER was being used, which features were thought to be most beneficial, and whether the individual or agency intended to adopt the tool. For the tier one participants, we wanted to understand how they perceived the relevance and usability of RECOVER's web map features for postfire decisionmaking. Specifically, we wanted to learn whether RECOVER's web maps reduced uncertainty in the decisionmaking environment by providing crucial and timely data to the user that aided in developing a rehabilitation plan, assessing burn severity, planning reseeding efforts, or helping circumvent postfire hazards such as debris flows. We also asked whether RECOVER had significantly reduced the amount of staff time that went into data collection for their Federally mandated rehabilitation report and whether RECOVER had improved communication within their agency, with partnering agencies, or with community stakeholders. Further, we requested the participants attempt to quantify the total staff time or dollars saved as well as to highlight specific instances where RECOVER data enabled the user to make a better-informed decision that either prevented or validated a potentially expensive rehabilitative treatment. Although attempting to quantify the indirect benefits of RECOVER proved a difficult task, several respondents provided data that could be aggregated and analyzed for trends, which helped assess the economic value of RECOVER's use.

Calculations

The participants' responses to questions about the value of information provided and whether staff time and related expenses were saved by using RECOVER were not easily quantifiable, because, to our knowledge, there are no universally acceptable approaches. We therefore developed our own approach to filling in these gaps. Where respondents gave ambiguous answers or rough estimates (i.e., "several days," "10 to 12 staff," and "a few hours"), we took the liberty of assigning values to these responses. "Several days" translated to a standard workweek of 5 days, "a few hours" became 3 hours, and "10 to 12 staff" became 11 staffmembers. Where public records were available, we used the actual hourly wage reported for the previous fiscal year (FY 2016–2017) of the participants who provided measurable data about the time or resources saved using RECOVER. We calculated the hourly rate of those respondents for whom public records were unavailable by using the 2016 U.S. general schedule (GS) pay rates for Federal employees with a standing equivalent to level 10, step 5 ($34.58 per hour) of the program. Additionally, the percentage used to account for fringe benefits was 21 percent, while 35 percent of that sum was chosen to assess the overhead rate and eventually arrive at the fully loaded hourly rate of $56.48 (table 1).

FINDINGS

Several recurring themes consistently emerged throughout the interviews that strongly indicated

Table 1—Calculation of fully encumbered hourly rate.

Expense	Amount (U.S. dollars)	Proportion of hourly wage
Hourly rate	$34.58	
Fringe benefits	$7.26	21%
Subtotal	$41.84	
Overhead rate	$14.64	35%
Fully loaded rate	**$56.48**	

the use of RECOVER played a critical role for land management personnel and agencies in their postfire rehabilitation efforts. All 20 respondents, regardless of actual level of use, initially sought to employ RECOVER for a variety of duties and objectives. For instance, attaining data and information on burn severity, debris-flow probability, and prefire vegetative cover were the most common responses (n = 14) with a majority coming from the tier one category (n = 11). The prevalence of tier one users finding these specific web maps to be of value is not surprising as land rehabilitation and recovery are their primary concern, and these web maps directly address the health and status of the affected ecosystem. Ninety percent (n = 18) of the total participants and about 93 percent (n = 14) of tier one users reported they plan to use RECOVER in future fire seasons, highlighting RECOVER's usability and effectiveness in reducing uncertainty in postfire decisionmaking.

Assistance in Reducing Uncertainty

As RECOVER was designed to support the development of BLM's Emergency Stabilization and Rehabilitation (ES&R) plans and Forest Service BAER plans, ascertaining whether its use actually reduced uncertainty in core areas such as assessing burn severity, planning reseeding efforts, mitigating postfire hazards, and developing a comprehensive rehabilitation plan was crucial. Of the 15 tier one RECOVER users, 40 percent (n = 6) reported they were able to circumvent some sort of postfire hazard, like a debris flow, by utilizing in a timely manner RECOVER's web maps. Quantifying the ultimate benefit of avoiding a postfire hazard like a debris flow is difficult because of the unique circumstances of each wildfire, but the occurrence of such an event can easily have catastrophic social and economic repercussions totaling in the millions of dollars (De Graff 2014). Still, over 45 percent (n = 7) of tier one users agreed that RECOVER assisted with the overall planning of reseeding efforts and 80 percent (n = 12) relied on RECOVER to help determine burn severity. Reducing uncertainty in these areas has the potential to save the agency costs and increase the effectiveness of its ecosystem recovery and sustainability efforts. Further, 40 percent (n = 6) of tier one users reported that RECOVER significantly improved their ability to develop a comprehensive rehabilitation plan. Without RECOVER, these land managers would very likely have needed to rely on field observations and invested significant agency resources over several days to acquire the data necessary to submit their plan.

Staff Time and Related Costs Saved

One of RECOVER's primary benefits is the rapid allocation and deployment of crucial geospatial data to support wildfire emergency response planning. Therefore, we wanted to gauge how much actual staff time was saved using RECOVER for various data collection duties. Twelve participants stated that RECOVER had saved their agencies a cumulative 800 hours of staff time, or roughly $43,000, of data collection expenses related to the rehabilitation plans. This also may benefit the public by allowing land managers more time to focus their attention on more important aspects of the rehabilitation and recovery process. Similarly, 60 percent (n = 12) of both tier one and tier two users reported that RECOVER improved overall communications by providing comprehensive and reliable maps automatically; 25 percent (n = 5) recorded improvements within the agency, and 50 percent (n = 10) with partnering agencies as well as with the public. Improved communication between partnering agencies is particularly important because wildfires typically expand into multiple jurisdictions (Federal, State, and private), where several different landowners may be affected (table 2). Cooperation and information sharing among the affected landowners will benefit the lead agency responsible for the rehabilitation planning as well as the users of the land. In total, participants determined approximately $2,000 and almost 60 hours of staff time were saved using RECOVER, instead of previous methods, for communications.

Better-Informed Decisions

Seventy-five percent (n = 15) of all RECOVER users and over 85 percent (n = 13) of tier one participants reported that the information RECOVER provided helped personnel make better-informed decisions that both directly and indirectly affected the roughly 715,000 ha of land they managed or monitored. Three tier one users attempted to place a monetary value on the benefits of RECOVER's use and value of

Table 2—Wildfires and management jurisdictions. BLM: Bureau of Land Management; BOR: Bureau of Reclamation; COE: U.S. Army Corps of Engineers; FS: USDA Forest Service.

Fire	Area burned (ha)	State	Land ownership (ha)
Powerhouse	13,619	California	BLM – 152; FS – 7,862; State – 100; Undetermined – 5,505
Charlotte	440	Idaho	BLM – 92; Private – 348
Gap	197	Idaho	BLM – 134; Private – 63
Henry's Creek	21,422	Idaho	BLM – 2,075; BOR – 2,993; COE – 979; Private – 12,104; State – 3,271
Pioneer	76,278	Idaho	BOR – 1,890; FS – 73,985; Private – 329; State – 17; Undetermined – 57
Soda	93,253	Idaho	BLM – 72,834; BOR – 79; Private – 15,425; State – 4,915
Baker-ORPAC	136,179	Oregon	BLM – 45,600; BOR – 7; FS – 1,160; Private – 89,412
Juntura Complex	64,919	Oregon	BLM – 9,822; State – 30,986; Private – 24,111
Yale Road	2,573	Washington	State – 2,280; Private – 97

information by citing approximate staff time savings and immediate outcomes enabled by RECOVER. One participant reported that the agency had requested RECOVER's debris-flow probability feature before making any decision about a $500,000 wood mulch aerial application. After analyzing RECOVER's data and the results from the field observation assessment, the agency determined that the probability of a debris-flow event occurring was minimal and no longer justified the expense, thus saving $500,000. A second interviewee explained that the value of information provided by RECOVER would have taken several support staff working an entire week, or 280 hours, to gather all of the data RECOVER can deliver in a matter of minutes; we estimate the avoided expense at $15,814. A third participant discussed how RECOVER was used to validate a $700,000 wood mulch application treatment and confirm the accuracy of field observation assessments. In all, the actionable data and information that RECOVER provided had a minimum economic value of over $1.2 million to its users.

DISCUSSION

The sample of interviewees, although relatively small in number, represents a significant number of the larger fires that occurred in the targeted States. These participants were responsible for over 715,000 ha of fire-affected land, including the subsequent postfire planning and rehabilitation to ensure ecosystem recovery. Moreover, the interviewees represent 78 percent (n = 47) of fires for which RECOVER has produced decision support system web maps and aided postfire decisionmaking. The high percentage of RECOVER users interviewed, as well as the large area of land affected, illustrates the importance of their responses and the potential to extrapolate these results to similar postfire environments.

Participants frequently reported that RECOVER's rapidly assembled and site-specific data provided key decisionmakers with the information needed to identify sites that had the greatest potential for negatively impacting the region, both socially and economically, and helped them determine appropriate treatment plans. RECOVER provided decisionmakers and their support staff with reliable data that often are otherwise difficult to obtain in a format that dramatically reduced the staff time needed to assemble such information. Due to the tight time constraint on reporting and the competition for funding that these agencies face, RECOVER's ability to reduce data collection time by hundreds of hours per fire makes it a valuable and cost-effective tool for adoption by land management agencies.

The greatest potential benefit of RECOVER arises from the better-informed decisions that it enables. RECOVER allows land managers to effectively identify high-risk areas and determine more efficient treatments or management strategies that will restore or improve the land. By providing critical data quickly, land managers can complete thorough analyses before critical deadlines. Without this ability, land management agencies run the risk of recommending unnecessary and expensive treatment strategies, or forgoing a much needed rehabilitation technique.

These results illustrate the significant social and economic value for land management agencies, as well as for the land and land users, in using RECOVER and other geospatial data to assist in postfire rehabilitation planning. Although much of the added value is found in improved communication and decisionmaking by RECOVER users, a significant portion arises from staff time and cost savings from the reduction of data collection duties. In total, RECOVER saved 788.75 hours of staff time and had a positive economic impact of at least $1.2 million on land management agencies.

CONCLUSIONS

Projected increases in annual fire events and areas burned indicate the demand on agencies' resources related to fire planning, suppression, and postfire rehabilitation and recovery will only increase in the coming years. Wildland fires, especially those in the western United States, will continue to consume an increasingly large part of land management agencies' attention and budgets. The demands and constraints of the postfire environment—primarily the lack of time and access to reliable information and data—will continue to be a source of pressure for agencies and their personnel attempting to plan rehabilitation measures without universal adoption of geospatial tools. To reduce the negative impact that wildfires have on local economies, land management agencies must attempt to use all practicable resources and tools at their disposal to restore or improve public lands following a wildfire. As land management agencies continue to face budget cuts amid congressional and public pressure to streamline their operations and reduce runaway spending, utilizing proven geospatial tools and data to perform previously labor-intensive duties will go a long way toward making wildfire management more efficient.

ACKNOWLEDGMENTS

This study was made possible by a grant from the National Aeronautics and Space Administration Applied Sciences, A.35 Wildfires Program (NNX12AQ78G). This project was led by Keith T. Weber (PI), John L. Schnase (Co-PI), and Mark Carroll (Co-PI).

Conflicts of Interest

The authors declare no conflicts of interest.

REFERENCES

Brusentsev, Vera; Vroman, Wayne. 2016. Wildfires in the United States: A primer. Washington, DC: Urban Institute. 22 p.

Calkin, David E.; Thompson, Matthew P.; Finney, Mark A.; Hyde, Kevin D. 2011. A real-time risk assessment tool supporting wildland fire decsionmaking. Journal of Forestry. 5: 274–280.

Carroll, Mark L.; Schnase, John L.; Weber, Keith T.; [et al.]. 2013. A new application to facilitate post-fire recovery and rehabilitation in savanna ecosystems. Institute of Electrical and Electronics Engineers, Oceanic Engineering Society: Earthzine. https://geospatial.inl.gov/bias/TessGardner/publications/A-New-Application-to-Facilitate-Post-Fire-Recovery-and-Rehabilitation-in-Savanna-Ecosystems/. [Accessed 2019 June 10].

Center for Western Priorities. 2014. The wildfire burden: Why public land seizure proposals would cost western states billions of dollars. Denver, CO. 9 p. http://westernpriorities.org/wp-content/uploads/2014/08/The-Wildfire-Burden1.pdf. [Accessed 2017 August 7].

Curth, Monica de Torres; Biscayart, Carolina; Ghermandi, Luciana; Pfister, Gabriela. 2012. Wildland-urban interface fires and socioeconomic conditions: A case study of a northwestern Patagonia city. Environmental Management. 49: 876–891.

De Graff, Jerome V. 2014. Improvement in quantifying debris flow risk for post-wildfire emergency response. Geoenvironmental Disasters. 1: 5–15.

Dombeck, Michael P.; Williams, Jack E.; Wood, Christopher A. 2003. Wildfire policy and public lands: Integrating scientific understanding with social concerns across landscapes. Conservation Biology. 18: 883–889.

Dunn, Alex E.; Gonzalez-Caban, Armando; Solari, Karen. 2005. The Old, Grand Prix, and Padua wildfires: How much did these fires really cost? A preliminary report on expenditures and discussion of economic costs resulting from the 2003 Old, Grand Prix and Padua Wildfire Complex. [U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station]. 17 p. https://www.fs.fed.us/psw/publications/adunn/2003_wildfires_report.pdf.

Englin, Jeffrey; Loomis, John; Gonzalez-Caban, Armando. 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.

Idaho State University. n.d. ISU GIS TReC Historic Fires Database. http://giscenter.isu.edu/Research/Techpg/HFD/

Kangas, Annika S.; Horne, Paula; Leskinen, Peeka. 2010. Measuring the value of information in multicriteria decisionmaking. Forest Science. 56: 558–566.

Kobayashi, Mimako; Rollins, Kimberly; Taylor, Michael H. 2014. Optimal livestock management on sagebrush rangeland with ecological thresholds, wildfire, and invasive plants. Land Economics. 90: 623–648.

Lentile, Leigh B.; Holden, Zachary A.; Smith, Alistair M.S.; [et al.]. 2006. Remote sensing techniques to assess active fire characteristics and post-fire effects. International Journal of Wildland Fire. 15: 319–345.

Lynch, Dennis L. 2004. What do forest fires really cost? Journal of Forestry. 102: 42–49.

Macauley, Molly K. 2006. The value of information: Measuring the contribution of space-derived earth science data to resource management. Space Policy. 22: 274–282.

Martinuzzi, Sebastiín; Stewart, Susan I.; Helmers, David P.; [et al.]. 2015. The 2010 wildland-urban interface of the conterminous United States. Res. Map. NRS-8. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 124 p. [includes pull-out map].

McCaffrey, Sarah; Kumagai, Yoshitaka. 2007. No need to reinvent the wheel: Applying existing social science theories to wildfire. In: Daniel, Terry C.; Carroll, Matthew S.; Moseley, Cassandra; Raish, Carol, eds. People, fire and forests: A synthesis of wildfire social science. Corvallis, OR: Oregon State University Press: 12–36.

Miller, H.M.; Richardson, L.; Koontz, S.R.; Loomis, J.; Koontz, L. 2013. Users, uses, and value of Landsat Satellite Imagery—Results from the 2012 Survey of Users. US Geological Survey, Open-file Report 2013-1269. (Washington, DC).

Mueller, Julie; Loomis, John; Gonzalez-Caban, Armando. 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 Geospatial Advisory Committee–Landsat Advisory Group [NGAC–LAC]. 2014. The value proposition for Landsat applications—2014 update. Washington, DC. https://www.fgdc.gov/ngac/meetings/december-2014/ngac-landsat-economic-value-paper-2014-update.pdf. [Accessed 2017 August 7].

National Interagency Fire Center [NIFC]. 2017. Federal firefighting costs (suppression only). Boise, ID. Available at https://www.nifc.gov/fireInfo/fireInfo_statistics.html.

O'Connor, Christopher D.; Thompson, Matthew P.; Rodriguez y Silva, Francisco. 2016. Getting ahead of the wildfire problem: Quantifying and mapping management challenges and opportunities. Geosciences. 6: 35–53.

Rahn, Matt. 2009. Wildfire impact analysis. Fire Impact Analysis. 1: 1–15. http://www.wildfire-economics.org/Library/Rahn_2009.pdf. [Accessed 2017 August 7].

Richardson, Leslie A.; Champ, Patricia A.; Loomis, John B. 2012. The hidden cost of wildfires: Economic valuation of health effects of wildfire smoke exposure in Southern California. Journal of Forest Economics. 18: 14–35.

Robichaud, Peter R. 2009. Post-fire stabilization and rehabilitation. In: Cerdà, Artemi; Robichaud, Peter R., eds. Fire effects on soils and restoration strategies. Boca Raton, FL: CRC Press: 299–320.

Robichaud, Peter R.; Lewis, Sarah A.; Brown, Robert E.; Ashmun, Louise E. 2009. Emergency post-fire rehabilitation treatment effects on burned area ecology and long-term restoration. Fire Ecology. 5: 115–128.

Schnase J.L.; Carroll, M.L.; Weber, K.T.; [et al.]. 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.

Theobald, David M.; Romme, William H. 2007. Expansion of the US wildland-urban interface. Ecological Applications. 15: 799–805.

Thompson, Matthew P.; Calkin, Dave E. 2011. Uncertainty and risk in wildland fire management: A review. Journal of Environmental Management. 92: 1895–1909.

USDA Forest Service [USDA FS]. 2014. The rising cost of fire operations: Effects on the Forest Service's non-fire work. Washington, DC: U.S. Department of Agriculture, Forest Service. https://www.fs.fed.us/sites/default/files/2015-Fire-Budget-Report.pdf. 16 p. [Accessed 2017 August 7].

Venn, Tyrone J.; Calkin, David E. 2008. Challenges of socio-economically evaluating wildfire management on non-industrial private and public forestland in the western United States. Small-scale Forestry. 8: 43–61.

Vilsack, Tom. 2015. The cost of fighting wildfires is sapping Forest Service budget. The Seattle Times, Opinion. August 4. http://www.seattletimes.com/opinion/the-cost-of-fighting-wildfires-is-sapping-forest-service-budget/. [Accessed 2017 August 7].

Western Forestry Leadership Coalition. 2009. Conclusions and recommendations updated 2010. The true cost of wildfire in the western U.S. Lakewood, CO. 15 p. https://www.blm.gov/or/districts/roseburg/plans/collab_forestry/files/TrueCostOfWilfire.pdf. [Accessed 2017 August 7].

Wigtil, Gabriel; Hammer, Roger B.; Kline, Jeffrey D.; [et al.]. 2016. Places where wildfire potential and social vulnerability coincide in the coterminous United States. International Journal of Wildland Fire. 25: 896–908.