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Protecting the Source: Tools to Evaluate Fuel Treatment Cost vs. Water Quality Protection

Erosion from steep, denuded hillsides after wildfires can clog nearby streams with sediment, reducing water quality and creating challenges for down-stream municipal water systems (image from the Pike & San Isabel National Forests following the 2016 Hayden Pass Fire; source: National Wildfire Coordinating Group, InciWeb).

SUMMARY

High-intensity wildfires are one of the leading causes of severe soil erosion in western U.S. watersheds. This erosion can lead to disruptive deposits of sediment in reservoirs and water supply systems. Fuel treatments such as controlled burns and forest thinning can reduce wildfire intensity and help preserve topsoil. But while these treatments are generally much less expensive than firefighting, property loss, and sediment removal, there are limited funds available for controlled burns and forest thinning. For this reason, land managers can benefit from estimating the erosion potential of high-intensity wildfires in order to decide where to focus fuel reduction efforts.

To help forest managers prioritize forest fuel reduction decisions, scientists from the Rocky Mountain Research Station and other agencies and organizations have developed several modeling tools that predict fire risk and erosion potential in and around watersheds. These tools, which include FSim, FlamMap, and WEPP (Water Erosion Prediction Project), are helping land managers preserve long-term forest health and preserve water supply and access in the western United States. By helping to quantify the connection between forest management and water supply protection, these tools are helping land managers cultivate stakeholder support for forest management efforts.

In 2015 alone, California firefighters responded to more than 6,000 wildfires that burned over half a million acres and destroyed more than 1,000 homes. These fires will long be described in terms of lives and homes lost, acres burned, and billions of dollars in damages. However, one aspect of wildfires is often overlooked: their impact on water supply and distribution systems.

Following a significant forest fire, a large amount of sediment is carried by rainwater and melting snow into rivers, lakes, and streams. Fine sediment can clog the gills of fish and increase mortality, but it can also benefit stream habitats by carrying nutrients into streams, increasing the productivity of algae and aquatic plants, and depositing new soil along riparian areas. Sedimentation into streams is particularly concerning to humans because it can degrade water quality and reduce water storage by filling reservoirs and obstructing water access systems.

According to a 2013 article in Transactions of the American Society of Agricultural and Biological Engineers, forest watersheds in the northwestern United States normally have annual sediment delivery rates of less than 0.03 ton per acre. However, after a disturbance event such as a wildfire, this rate can rise to more than 10 tons per acre, depending on factors such as precipitation and topography. Wildfires and post-fire erosion are natural processes, but we're seeing more frequent and higher-severity fires that are atypical for some forested ecosystems.

"By linking water resources with forest management, fires, and forest conditions," Elliot says, "it really increases your stakeholder base, especially in places like Seattle and San Francisco."

LINKING WATER RESOURCES TO FOREST MANAGEMENT

According to Bill Elliot, a research civil engineer for the Rocky Mountain Research Station's Air, Water, and Aquatics Science Program, "There are several pressures on water supply and distribution systems in the West, including the influence of droughts and an increase in population in the western United States. People need water, and water comes from high-elevation forested areas. We need to get better at managing those areas."

One of the USDA Forest Service's mandates is to protect the nation's water supply. For this reason, Elliot says, "These kinds of fires have been anticipated and managers are trying to minimize their impact in advance." Managers are also working to create a wider understanding of the connection between fires and water resources. "By articulating how forest management and conditions may affect risk of wildfire, and how wildfires, in turn, affect water quality, managers can engage a much broader group of stakeholders," notes Elliot. "This is especially true in cities that procure their drinking water directly from national forests and surrounding forested areas and have a highly engaged and outdoors-oriented citizenry."

LEARNING FROM PAST WILDFIRES

Elliot points to Colorado's Hayman Fire of 2002 as a case where high-density forests in many areas contributed to corresponding high burn intensity. The Hayman Fire led to the deposit of more than 1 million cubic yards of sediment in the Strontia Springs Reservoir.

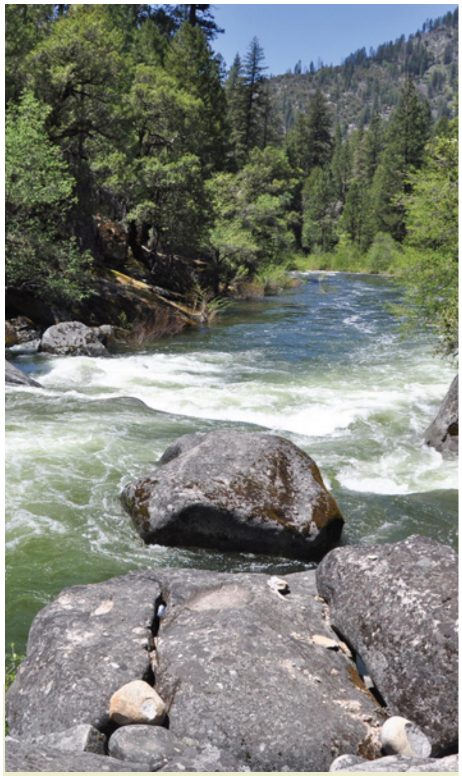
Even 10 years after the Hayman Fire in Colorado, Denver Water continues working to filter sediment from streams that feed into Cheesman Reservoir (source: Cyrus McCrimmon, Denver Post).

Nearby areas, such as the Manitou Experimental Forest, experienced more moderate fire behavior, partly because managers thinned forests to reduce their density prior to the fire. "Manitou had done some fuel treatment (thinning) in the years before the fire, and when the Hayman Fire spread there, the intensity was reduced," Elliot says. "The fire soon burned out, and the impact on the soil and sediment in this area was negligible."

After experiencing ecological, social, and economic impacts of previous wildfires, some fire and fuel managers are taking proactive, broad-scale approaches to thinning. The 2000 Cerro Grande Fire in New Mexico, which destroyed more than 400 homes and resulted in an estimated $1 billion in damage, motivated Santa Fe to implement an intensive, long-term plan of controlled burns and forest-thinning. These efforts are intended to help protect the Santa Fe River Watershed, which provides Santa Fe with a significant percentage of its water.

EROSION COST ANALYSIS IN THE MOKELUMNE WATERSHED

To see whether it makes economic sense to increase investment in fuel treatments to reduce the risk of large, damaging wildfires, the USDA Forest Service, the Sierra Nevada Conservancy, The Nature Conservancy, and a group of stakeholders hired the consulting firm ECONorthwest to create an in-depth study. This 2012 study focused on postfire economic impacts in the Mokelumne Watershed, which provides water for the eastern San Francisco Bay Area. Stakeholders included local land managers, utilities, government agencies, and environmental organizations. According to Nic Enstice, regional science coordinator for the Sierra Nevada Conservancy, "We were hoping to identify potential risks to the water supply in light of increasingly dangerous fire seasons."



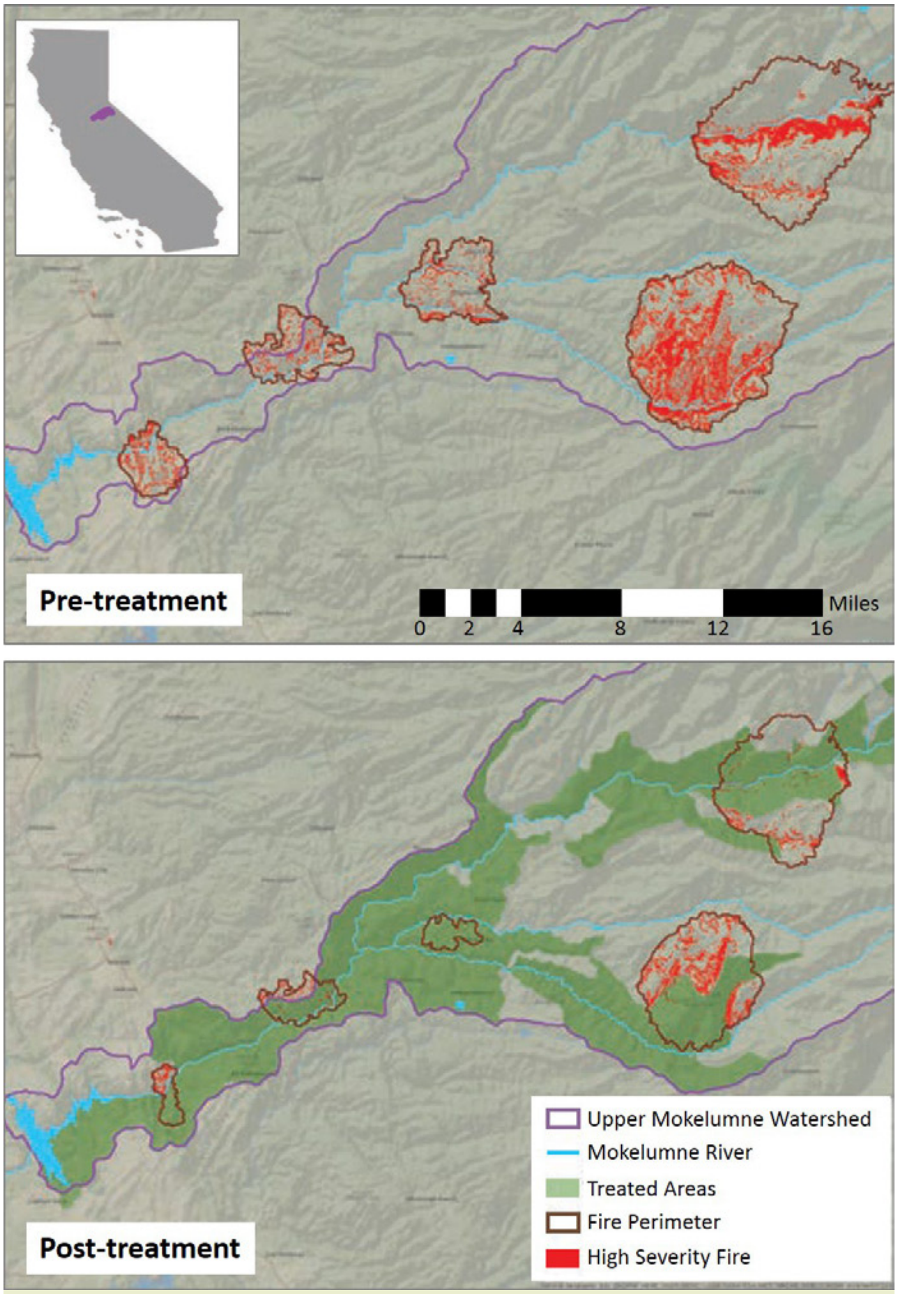
The USDA Forest Service worked with other groups to predict potential fire impacts on the Mokelumne Watershed, which supplies water to the San Francisco East Bay Area in California (source: The Nature Conservancy).

From a technical perspective, the project's results were clear: the estimated economic benefits of modeled fuel treatments were two to three times the estimated losses from wildfires, including the value of structures lost and the costs of fire suppression and postfire restoration. And for five hypothetical fires that the team considered, the modeled fuel treatment scenarios reduced the acreage affected by high-intensity wildfire by approximately 75 percent.

Enstice says the Mokelumne project was also valuable in improving dialogue about land management around stream headwaters. "With the Mokelumne project, our purpose was to help establish a connection between downstream water users and upslope watershed managers," Enstice says. "If this proved successful, we hoped we'd be able to make similar connections across California."

While it's been an ongoing process to connect stakeholder groups, Enstice says, "As a result of the project, there's certainly higher awareness of the connection between forests and water supply than there used to be. We built relationships and even if the results have not yet been acted on by downstream users, they've created bonds between agencies so that dialogue about potential fuel treatment can continue."

Noting that the recent Butte Fire overlaps part of the Mokelumne study area, Enstice adds, "The fires we've had in the Sierra Nevada have also raised awareness of the link between wildfires, burn intensity, and impacts to water quality. Policy shifts are a work in progress, but discussions and understanding about the relevance of upper watersheds to water quality are more common."



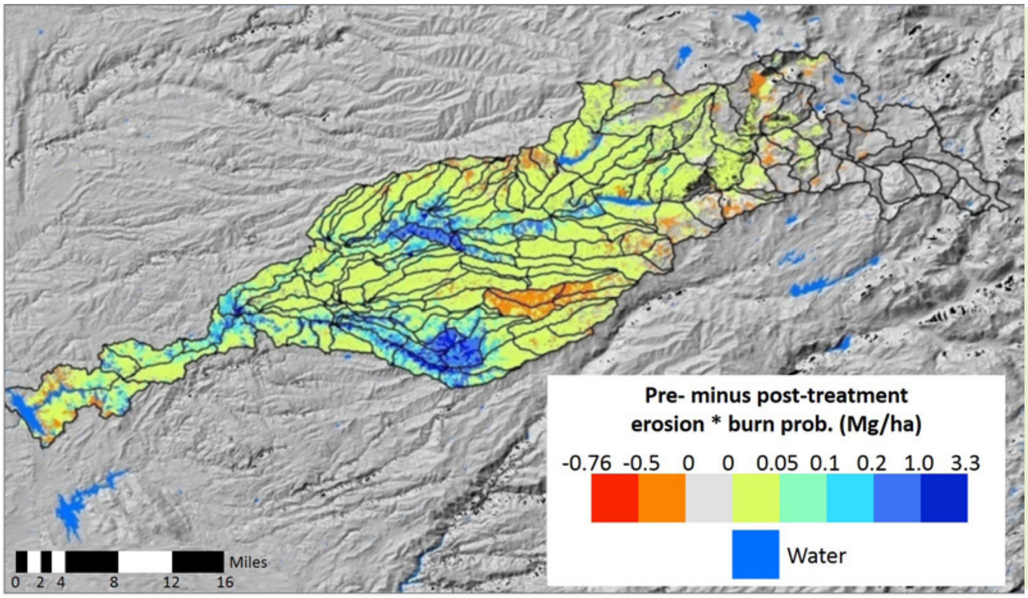
Fuel treatments can significantly reduce the size and severity of wildfires in the Mokelumne Watershed based on predictions from FSim. The sizes of wildfires simulated on the post-treatment landscape (bottom) were reduced by 30-75 percent compared to pre-treatment conditions (top), and the acreage of high-severity wildfires was reduced by 75 percent (source: Buckley and others 2014).

TARGETING FUEL REDUCTION EFFORTS

To help land managers determine where fuel reduction efforts can most likely reduce fire-related sedimentation risk, the USDA Forest Service and many other groups have created several modeling tools, specifically the Water Erosion Prediction Project (WEPP), FSim, and FlamMap. According to Elliot, "These tools help forest managers better link current forest conditions to the risk of fires as well as off-site impacts such as erosion and sediment delivery into water storage and flow areas."

Creation of these tools has been a shared effort between a variety of agencies and organizations, including the Rocky Mountain Research Station, LANDFIRE, the USDA Agricultural Research Service, the University of Idaho, Washington State University, and many other universities and agencies over the years. "Scientists usually focus on a given project within their discipline," says Elliot, whose role has been the development and application of erosion models. "This project has

WEPP, FSim, and FlamMap "help forest managers better link current forest conditions to the risk of fires as well as off-site impacts, such as erosion and sediment flow into water storage and flow areas," Elliot explains.



The difference in predicted sediment delivery from the Mokelumne Watershed before and after fuel treatments based on erosions estimates from WEPP and burn probabilities from FSim. Positive values indicate a predicted decrease in sediment delivery resulting from effects of fuel treatments on wildfire occurrence and severity (source: Buckley and others 2014).

Modeling tools such as FSim, FlamMap, and WEPP can help forest managers estimate the potential effects of fuel treatments on fire behavior and post-fire erosion.

The Fire Simulation (FSim) system models fire ignition and growth based on historical weather data, current fuel load and vegetation data, topography, and wildfire history. FSim simulates thousands of random ignitions to estimate burn probabilities, fire sizes, and fire intensity across large landscapes. Additional information about FSim is outlined in the publication "A simulation of probabilitistic wildfire risk components for the continental United States" (see Further Reading).

FlamMap is a fire behavior mapping program that computes fire potential characteristics for a given landscape. It makes predictions using land cover, topography, and fuel characteristics data from the online Landscape Fire and Resource Management Planning Tools (LANDFIRE) database, along with fuel moisture and weather data. With this information, FlamMap can predict up to 17 fire characteristic "layers," including flame length, rate of spread, fire intensity, and major fire paths. This information can be used to estimate soil and vegetation burn severity and likely erosion following a wildfire. Additional information on FlamMap is available at http://firelab.org/project/flammap.

WEPP is an erosion prediction tool that predicts sediment detachment and movement. The WEPP surface hydrology component uses climate, soils, topography, and vegetation information to predict infiltration, runoff volume, and peak discharge for simulated storms and snowmelt runoff. Originally released in 1995, the WEPP model is continually refined and improved, with new versions released every year or two. One advantage of RMRS WEPP tools is their simple user interfaces. Because some of these WEPP interfaces now rely on Google Maps, large online databases and geographic information system (GIS) data to fill in much of the required information, user input is relatively simple. WEPP can also be used to estimate potential erosion impacts on aquatic ecosystems, as described in the November/December 2014 Science You Can Use Bulletin. Additional information at WEPP can be found at http://forest.moscowfsl.wsu.edu/fswepp/.

been much more of a cross-discipline effort, from all kinds of agencies and consultants, NGOs, and conservancies. It's been a very complex effort and a real team approach."

Lee Benda, a senior scientist with the landscape analysis company TerrainWorks, has used WEPP and FlamMap in multiple locations, including pre-fire analysis of the Shasta-Trinity National Forest and post-fire analysis of the Canyon Creek Complex wildfire in eastern Oregon. "We'd like to see government agencies become more proactive in using these tools—particularly in pre-fire analysis as opposed to post-fire analysis," Benda says. "Two of the problems are that managers just don't have the time immediately after a fire occurs, and that the computing requirements for these tools tend to be pretty high."

WEPP and FlamMap were used for post-fire analysis of the Canyon Creek Complex wildfire in eastern Oregon (source: The National Wildfire Coordinating Group).

"Bill Elliot's in the water business and I'm in the fire business, and that's a good combination … because the real opportunities for these tools are in preemptive action rather than fire suppression," Finney says.

As the lead developer of the FSim and FlamMap tools, Finney hopes that making a connection between forest management and watersheds can help build stakeholder support for fire hazard reduction, shifting land management focus from fire suppression to fire planning. As Finney says, "Bill Elliot's in the water business and I'm in the fire business, and that's a good combination … because the real opportunities for these tools are in preemptive action rather than fire suppression."

A Brief Look: The Human Dimensions Program's Fire Economics Research Team

The RMRS Human Dimensions Program's fire economics research team is using the same wildfire and erosion models and tools as Bill Elliot, but with a different application: the fire economics research team focuses on the economic implications of wildfire management and wildfire risk assessment. The team's research is intended to enhance firefighter and public safety, reduce large fire costs, improve adoption of risk management principles, and improve design and deployment of decision support tools to inform fire and fuels management planning.

Matthew Thompson, research forester at the Fire Lab, says this work connects closely with RMRS model development. "The Bill Elliots and Mark Finneys of the world have done a great job of developing models that can be used in land management decision-making," Thompson says. "Sometimes these are used in a post-fire environment, but what we're increasingly seeing is an interest in thinking preventatively. Through a number of partnerships, including NGOs, nonprofits, and water utilities, we're working to answer certain economic questions."

Thompson goes on to explain, "Essentially, stakeholders are being asked to invest dollars that have uncertain returns because fire is a random process and so are the storms that bring on erosion. We're using modeling tools to estimate the likelihood of a given land management investment paying off and seeing how that investment compares with a responsive project such as post-fire sediment dredging. We also do a lot of risk and decision analysis—there's some behavioral economics and psychology involved."

Additional information on the Human Dimensions Program and its research efforts can be found at http://www.fs.fed.us/rmrs/science-program-areas/human-dimensions.

A POWERFUL DATA COMBINATION

Used together, these three tools—FSim for fire risk simulation, FlamMap for soil and vegetation damage estimates, and WEPP for erosion prediction—are helping land managers decide where to spend limited fuel reduction budgets for the highest watershed benefit. "Before Europeans arrived in western North America, the forests were sustained by disturbance," says Mark Finney, a research forester at the RMRS Fire Sciences Laboratory in Missoula, Montana. "Today, we have a risk of high-intensity fires over much larger areas, and we're not preemptive about fire hazard reduction to the extent that it's needed. But these tools, used properly, can help us do a better job of planning and designing mitigation efforts."

MANAGEMENT APPLICATIONS

- Fuel treatments can significantly reduce the size and severity of wildfires, which can lower postfire erosion and associated impacts on water storage and supply systems.
- The economic benefits of modeled fuel treatments have been estimated at two to three times estimated losses from wildfires, including the value of structures lost and the costs of fire suppression and post-fire restoration.
- Land managers can build stakeholder support for fuel treatment plans by emphasizing the connection between forest management and water supply protection.
- Computer-based modeling tools such as FSim, FlamMap, and WEPP can help land managers target fuel reduction efforts where they are most likely to minimize watershed erosion and water system sedimentation

KEY FINDINGS

- Historical forest management practices combined with changing climate in the western United States have increased the likelihood of high-intensity wildfires.
- Intense wildfires can lead to increased erosion after large storms; sediment from erosion can interfere with water storage and supply systems and necessitate costly remediation projects.
- Wildfire and erosion simulation tools such as FSim, FlamMap, and WEPP provide accurate estimates of the locations and intensities of potential wildfires and associated postfire erosion.
- Combining predictions from tools such as FSim, FlamMap, and WEPP can help land managers decide where to conduct controlled burns and forest thinning to reduce potential fire severity, and thereby reduce the potential for excess sediment delivery from watersheds.

FURTHER READING

Buckley, M.; Beck, N.; Bowden, P.; Miller, M.E.; Hill, B.; Luce, C.; Elliot, W.J.; Enstice, N.; Podolak, K.; Winford, E.; Smith, S.L.; Bokach, M.; Reichert, M.; Edelson, D.; Gaither, J. 2014. **Mokelumne Watershed avoided cost analysis: Why Sierra fuel treatments make economic sense.** Report prepared for the Sierra Nevada Conservancy, The Nature Conservancy, and USDA Forest Service. http://www.sierranevada.ca.gov/our-work/mokelumne-watershed-analysis.

Elliot, W.J. 2013. **Erosion processes and prediction with WEPP technology in forests in the northwestern U.S.** Transactions of the American Society of Agricultural and Biological Engineers 56: 563–579. http://www.treesearch.fs.fed.us/pubs/43831.

Elliot, W.J.; Miller, M.E.; Enstice, N. 2015. **Combining fire and erosion modeling to target forest management activities.** Proceedings of the 3rd Joint Federal Interagency Conference on Sedimentation and Hydrologic Modeling; 2015 April 19–23; Reno, NV. 12 p. http://www.treesearch.fs.fed.us/pubs/49545.

Finney, M.A. 2006. **An overview of FlamMap modeling capabilities.** In: Andrews, P.L.;Butler, B.W., comps. Fuels management—How to measure success: Conference proceedings; 2006 March 28–30; Portland, OR. Proceedings RMRS-P-41. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 213–219. http://www.treesearch.fs.fed.us/pubs/25948.

Finney, M.A.; McHugh, C.W.; Grenfell, I.C.; Riley, K.L.; Short, K.C. 2011. **A simulation of probabilitistic wildfire risk components for the continental United States.** Stochastic Environmental Research and Risk Assessment. 25: 973–1000. http://www.treesearch.fs.fed.us/pubs/39312.

Miller, S.; Elliot, B.; Robichaud, P.; Foltz, R.; Flanagan, D.; Brooks, E. 2014. **From watersheds to the web: Online tools for modeling forest soil erosion.** Science You Can Use Bulletin. Issue 14. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 10 p. http://www.treesearch.fs.fed.us/pubs/47779.

SCIENTIST PROFILES

The following scientists were instrumental in the creation of this Bulletin.

BILL ELLIOT is a research engineer in the Air, Water, and Aquatic Environments Science Program at the USDA Forest Service's Rocky Mountain Research Station lab in Moscow, Idaho. His main research is in the application of the WEPP model to forest conditions. Bill was also heavily involved with data collection and analysis from the WEPP cropland field experiments conducted across the United States in 1987–1988. He is a fellow of the American Society of Agricultural Engineers and a leader with the Soil and Water Conservation Society of America. Bill has a bachelor's degree and Ph.D. in Agricultural Engineering from Iowa State University and a master's degree in Agricultural Engineering from the University of Aberdeen in Scotland.

MARY ELLEN MILLER is a research engineer at Michigan Tech Research Institute in Ann Arbor. In work funded by NASA, Mary Ellen uses earth observations to rapidly generate spatial model inputs in order to predict erosion and runoff in areas burned by wildfire. She works closely with Burned Area Emergency Response teams that assess potential erosion and flood risks. Mary Ellen has modeled hill slope erosion for recent California fires, and she is currently working on validating model results for the 2012 High Park Fire in Colorado. Mary Ellen has a bachelor's degree in Physics, a master's degree in Imaging Science, and a Ph.D. in Environmental Engineering, as well as a certificate in Geographic Information Science.

MARK FINNEY is a research forester with the RMRS Fire, Fuels, and Smoke Program in Missoula, Montana. His research at the Missoula Fire Sciences Laboratory includes studies on fire spread in deep and discontinuous fuel beds and fire simulation for purposes of fire risk assessment. By leading development efforts on major fire management systems such as Wildland Fire Decision Support System and Fire Program Analysis, Mark's research has advanced the understanding of fire behavior and practical management of wildland fires. Mark has a bachelor's degree in Forest Management from Colorado State University, a master's degree in Fire Ecology from the University of Washington, and a Ph.D. in Wildland Fire Science from the University of California, Berkeley.

MATTHEW THOMPSON is a research forester with the RMRS Human Dimensions Program in Missoula, Montana. Matthew works with decision science, risk analysis, and resource economics in the context of wildfire management. His research also supports the Fire Economics Research Program of the National Fire Decision Support Center, which bridges the wildfire science and wildfire management communities. Matthew has a bachelor's degree in Systems Engineering from the University of Virginia, a master's degree in Industrial Engineering and Operations Research from the University of California, Berkeley, and a master's degree in Forest Management and Ph.D. in Forest Engineering from Oregon State University. Matthew's work was profiled in the December 2012 Science You Can Use Bulletin.

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