Monsoon rainstorm over Miller Canyon in the Huachuca Mountains, southern Arizona

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Southwest Wildfire Hydrology & Hazard Workshop Overview

This open-file report (OFR) presents materials from the 2012 *Southwest Wildfire Hydrology & Hazards Workshop*, including the workshop schedule, presentation abstracts, and a list of attendees. The oral presentations and posters are part of this OFR and are available for viewing from the Arizona Geological Survey Document Repository ([http://repository.azgs.az.gov/](http://repository.azgs.az.gov/)). A second OFR scheduled for fall 2012 will host white papers produced by the working groups.

Approximately 70 participants, representing various federal, state, and local agencies, researchers and practitioners, gathered at the University of Arizona’s Biosphere 2, north of Tucson, between April 3rd-5th for the 2012 *Southwest Wildfire Hydrology and Hazards Workshop*. The purpose of the workshop was two-fold: 1) share the most recent research regarding post-fire hydrology and hazard assessments and mitigation and warning systems; and 2) discuss ideas for bridging funding gaps for research and warning system implementation.

Representatives from the U.S. Forest Service kicked off the 3-day workshop with a discussion of the philosophy and policies of the Burned Area Emergency Response (BAER) program, which is responsible for rapid post-fire assessments of forest service lands burned by wildfires. Included in this presentation was a discussion of the operations, restrictions and limitations of BAER, along with examples from the BAER assessments for the 2011 Wallow, Monument and Horseshoe 2 Fires. Subsequent presentations addressed modeling of post-fire hydrologic processes, warning systems, and current research. Dr. Peter Robichaud’s lunchtime keynote address focused on recent research regarding the effectiveness of hillslope mitigation treatments used by BAER teams. The day was rounded out with an evening keynote talk by Dr. Thomas Swetnam on historical and current fire regimes in the Southwest, and the implications of climate change.

The second day of the workshop consisted of a field trip to the 2011 Monument Fire near Sierra Vista, Arizona, to see post-fire flood warning systems installed by the USGS, hillslope treatments implemented by the BAER team, channel mitigation measures implemented by county and federal agencies to protect downstream private residents, and to observe evidence of, and damages from, post-fire floods and debris flows. The workshop closed with final presentations on post-fire research and a roundtable discussion on key issues, such as pre-season readiness, during-incident support, post-fire responses for hazard warnings and research, and identification of steps needed to address those issues. Working groups formed to synthesize the workshop findings, and to recommend actions to effectively address the issues.

The organizing committee thanks all of the participants for attending and contributing to the success of the workshop. We also thank the University of Arizona’s Water Science Center’s Water Sustainability Program, and the Biosphere 2 Landscape Evolution Observatory for supporting the project.

Ann Youberg (ed.) Tucson, Arizona
14 May 2012
This workshop was organized by:

Mike Schaffner, NOAA
Steve DeLong, University of Arizona, Biosphere 2
Ann Youberg, Arizona Geological Survey
Sue Cannon, US Geological Survey
Chad Kahler, NOAA
David Goodrich, USDA-ARS
Erin Boyle, NOAA
Marc Stamer, US Forest Service
Todd Ellsworth, US Forest Service
Christopher Smith, US Geological Survey
John Brost, NOAA
Brian Cosson, AZ Department of Water Resources
Dale Cox, US Geological Survey
Dan Neary, US Forest Service
Karen Koestner, US Forest Service
James Leenhouts, US Geological Survey
Speaker Schedule for Southwest Wildfire Hydrology and Hazards Workshop

Tuesday, April 3, 2012

Burned Area Emergency Response Programs – Chair: Dan Neary

8:00 to 9:30 am: Todd Ellsworth, Marc Stamer and Penny Luehring: *Overview of Burned Area Emergency Response Program, its limitations, and the need for interagency and public collaboration*, Presentation and Panel Discussion

9:30 to 9:40 am: Break

Modeling of Post-fire Hydrologic Processes – Chair: Todd Ellsworth

9:40 to 10:00 am: William Reed, Mike Schaffner*, Chad Kahler and Erin Boyle: *2011 wildfire in the mountainous terrain of southeast Arizona: Verification of empirical formulas used to estimate from 1-year through 10-year peak discharge from post-burn watersheds and associated increased flash flood potential of post-burn hyperconcentrated flows*

10:00 to 10:20 am: David Goodrich, E. Canfield, D.P. Guertin, I.S. Burns, L.R. Levick and T.J. Clifford: *Rapid post-fire hydrologic watershed assessment using the AGWA GIS-based hydrologic modeling tool*

10:20 to 10:40 am: John Moody: *An analytical method for predicting post-wildfire peak discharges*

10:40 to 11:00 am: Evan Friedman and Paul Santi: *Debris-flow hazard assessment and monitoring within the 2010 Medano Fire burn area, Great Sand Dunes National Park and Preserve, Colorado*

11:00 to 11:20 am: Sue Cannon, Joe Gartner, Jason Kean and Dennis Staley: *Lessons learned from public release of post-fire debris-flow hazard assessments in southern California*

Lunch and Keynote

11:20 to 1:00 pm: Dr. Peter Robichaud: *Reducing the risk - Improving our understanding of post-wildfire erosion control treatment effectiveness*

1:00 to 1:20 pm: Break
Post-fire Warning Systems – Chair: Sue Cannon

1:20 to 1:40 pm:  Jayme Laber: The NOAA/USGS Debris Flow Early Warning System for southern California

1:40 to 2:00 pm:  John Brost, Ken Drozd, Glen Sampson, Erin Boyle, and Ryan Fliehman: From fires to floods: How the NWS in Tucson Arizona helped raise flash flood awareness after a historic wildfire season

2:00 to 2:40 pm:  Chris Smith, Brian Cosson, and Mike Shaffner: Post-Fire USGS and ALERT Systems, Presentation and Panel Discussion

2:40 to 3:00 pm:  Break

Post-fire Research – Chair: Ann Youberg

3:00 to 3:20 pm:  Alicia Kinoshita, Terri Hogue and Jongyoun Kim: Utilizing remote sensing indices to evaluate hydrologic recovery in the Arroyo Seco watershed

3:20 to 3:40 pm:  Jess Clark, Carolyn Napper, Kevin Cooper and Marc Stamer: Utilization of satellite imagery to evaluate and predict out-year post-fire watershed response and potential application in the southwest

3:40 to 4:00 pm:  Joel Sankey and Cynthia Wallace: The relative contribution of natural vegetation dynamics and common seeding treatments to post-fire soil stability in rangelands of the Great Basin, USA

4:00 to 4:20 pm:  Joel Sankey, Sujith Ravi, Cynthia S.A. Wallace*, Robert H. Webb, and Travis E. Huxman: Fire and soil microtopography in a Chihuahuan Desert shrub-grass ecotone

Poster Session – Chair: Mike Schaffner

4:20 to 6:00 pm:  Burned Area Emergency Response

Rory Steinke and Polly Haessig: BAER from a practitioner’s viewpoint, treatment effectiveness and lessons learned

Pete Wohlgemuth: The role of research in the Burned Area Emergency Response (BAER) process

Modeling Post-fire Hydrologic Processes

Lee Benda and Dan Miller: Enhancing pre- and post-fire planning using automated tools in a web browser

Terri Hogue, Alicia Kinoshita*, Brandon Hale and Carolyn Napper: Post-fire hydrologic model assessment for design storm runoff and mitigation
Barbara Ruddy: A new technique for implementing USGS models for assessing post-wildfire debris-flow hazards

Brent Travis and Brian Wahlin: Accounting for wildfire effects in slope failure risk analysis

Ann Youberg, Susan Cannon, Karen Koestner, Erik Schiefer and Dan Neary: Model assessments for predicting post-fire debris-flow potential in Arizona

**Post-fire Research**

Brandon Hale, Alicia Kinoshita, Terri Hogue and Carolyn Napper: Evaluating wildfire recovery with paired field hydrology and remote sensing in Southern Sequoia National Forest

Stephen Monroe: Rito de los Frijoles – Post Las Conchas Fire Floods – 2011

Carlton J. Rochester, Robert N. Fisher, Cheryl S. Brehme, Denise R. Clark, and Stacie Hathaway: Reptile and Amphibian Responses to Large-scale Wildfires in Southern California

Anne Tillery and Kerry Jones: Analysis of floods and debris flow hazards following short duration, high intensity rainfall events on Las Conchas and Track Fire burn scar areas during summer 2011, northern New Mexico

Stephanie Yard and Allen Haden: Montezuma Creek channel repair - Coronado National Memorial


**Dinner and Keynote**

6:00 to 8:00 pm: Dr. Thomas Swetnam; Wildfires, *Climate Change, and Black Swans in the Southwest - Coping with Surprise*
Wednesday, April 4, 2012: Field trip to area burned by the 2011 Monument fire –
Leaders: Ann Youberg and Chris Smith

Breakfast buffet: 6:15 am
Load vans: 7:00 am
Depart: 7:15 am
Those coming from Tucson under their own power should meet at 10:30 am at
the Coronado National Memorial Visitor’s Center.
Return: 6:30 pm
Dinner: 7:00 pm
Optional tour of B2 Biodomes: 8:30 pm

Thursday, April 5, 2012

Post-fire Research, continued – Chair: Steve DeLong

8:00 to 8:20 am: Joe Wagenbrenner, Pete Robichaud, Robert Brown, Dan Neary: Changes in
peak flow rates and sediment yields from the Wallow Fire, Arizona

8:20 to 8:40 am: Erica Bigio, Thomas Swetnam, Christopher Baisan: A fire history reconstruction
of the western San Juan Mountains: Results from tree-ring and alluvial sediment
methods

8:40 to 9:00 am: Allen Haden and Christopher Tressler: 2010 Schultz fire- sediment analysis and
reduction options

9:00 to 9:20 am: Jamie Macy: Depth of unconsolidated cinder deposits and potential water-
storage capacity at Cinder Lake for runoff events exacerbated by the Schultz Fire,
2010, Coconino County, AZ

9:20 to 9:40 am: Steve DeLong, Whitney Henderson and Ann Youberg: Post wildfire landscape
change in a small headwater catchment from terrestrial LiDAR

9:40 to 10:00 am: Break

Wrap up and Group Discussion – Facilitator: David Goodrich

10:00 to 12:00 am
Topic: Burned Area Emergency Response
Oral Presentation and Panel Discussion

Todd J. Ellsworth¹, Marc Stamer², and Penny Luehring³

Overview of Burn Area Emergency Response Program, Limitations, and Need for Interagency/Public Collaboration

The unprecedented 2011 wildfires that swept through both northeastern and southeastern Arizona burned over 825,000 acres destroying homes, and otherwise greatly disrupting the lives of residences that live in and around the fire areas. These large wildfires presented challenges in terms of staffing Burned Area Emergency Response (BAER) teams, facilitating coordination between the BAER Teams, researchers and other federal, state and local agencies to identify and address threats to critical values at risk. With the need to identify and address critical values at risk in limited time frames, active involvement and interaction between the BAER teams, key cooperators and private landowners becomes crucial to display and disclose risk from the post-fire environment, and assist communities with recovery efforts.

Focusing on examples from the Wallow, Horseshoe 2, and Monument Fires, this panel will discuss the Burn Area Emergency Response process, limitations, and role in interagency/public collaboration including the role of researchers.

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Cost and effectiveness evaluations of BAER treatments such as mulching with and without seeding and wood shred mulching has provided valuable practical lessons for future post wildfire land treatments. In terms of cost, aerial seeding costs $35-$50/acre, aerial straw mulch $500/acre and aerial wood shred application, $1,500-$2,000/acre. Hydromulching with seed is the most expensive at $2,500/acre. Though seeding alone is cheaper and faster to implement than mulching, seeding alone has not been generally effective in pinyon-juniper woodlands and is only slightly effective in ponderosa pine forests in the first two years post fire. Straw mulch without seeding on slopes greater than 35% shows limited success on northern slopes and low success on southern aspects. Straw mulching provides immediate soil protection on slopes up to 40%, and when combined with seeding, germinated plants hold straw in place from runoff and wind. Wood shred mulch is expensive and slowest to implement but is most effective on slopes from 35-70%, allowing native plants to regenerate. Overall, wood shred mulch without seeding on moderate to steep slopes and seeding with mulch over the top on low slopes are the most effective treatments in terms of cost and effectiveness. Observations indicate that seeding does not interfere with native grass regeneration two to four years post treatment. The overall effectiveness of land treatments implemented by BAER sometimes results in unrealistic expectations by the public and local agencies. Long-term rehabilitation and restoration requires patience, commitment and collaboration between agencies, technical experts and the public.

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Peter M. Wohlgemuth

The Role of Research in the Burned Area Emergency Response (BAER) Process

Academic and agency research – whether in the earth sciences, life sciences, or social sciences – can assist or improve the BAER process of assessing post-fire landscape damage, identifying potential hazards and associated values at risk, and implementing mitigation treatments. Once a wildfire starts and a BAER team is assembled, research can do little to affect the outcome, and researchers can only be a distraction to the already overwhelming task of assessment reconnaissance. However, following the fire, research can be critical in discovering, quantifying, and ultimately modeling post-fire watershed and ecological responses, both for general principles and for building a local knowledge base. Burn severity determinations could be refined, rainfall/runoff relationships could be improved, post-fire vegetation development could be documented, mitigation treatment effectiveness could be evaluated, and existing watershed models could be validated. Although there are institutional barriers that must be overcome, this knowledge could then be communicated back to BAER practitioners to improve the process for future wildfires under similar circumstances.

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Topic: Modeling Post-fire Hydrologic Processes

Oral Presentations and Panel Discussion

William Reed¹, Michael Schaffner²*, Chad Kaher³, and Erin Boyle⁴

2011 Wildfire in the Mountainous Terrain of Southeast Arizona: Verification of Empirical Formulas used to Estimate from 1-Year through 10-Year Peak Discharge from Post-Burn Watersheds and Associated Increased Flash Flood Potential of Post-Burn Hyper-Concentrated Flows

In the desert southwest of the United States, wildfire alters the hydrologic response of watersheds greatly increasing the magnitudes and frequency of flash floods. The NOAA National Weather Service is tasked with the issuance of flash flood warnings to save life and property. Tools that allow the weather forecast offices to quickly access the peak flow magnitude and flood potential from burned areas is highly desirable. The application of readily available topographic and burn severity data make this possible through a series of empirical equations.

In studies of post-burn peak flows throughout southeast Arizona, Reed and Schaffner have demonstrated that future peak flows can be estimated for burned basins using a multivariate runoff index defined by several watershed characteristics. Therefore, a series of empirical equations were developed to estimate peaks flows with 1-year through 10-year recurrence intervals from both small and larger sized burned basins. The basin properties used are 1) the hyper-effective drainage area, the area of the basin with moderate and high severity burn, in square miles, 2) the modified channel relief ratio, and 3) the mean basin elevation, in thousands of feet above mean sea level. The modified channel relief ratio in feet/feet is the average slope of the basin along the first order channel measured from 1,250 feet below the ridge to the basin outlet.

Five basins in Cochise County, Arizona burned by either the 2011 Horseshoe II Fire or the 2011 Monument Fire are used to evaluate the usefulness of the Reed-Schaffner Equation 12 to forecast post-burn peak flows and associated increased flash flood potential. An estimate of post-burn peak flows for these basins with an emphasis on the first significant flash flood that occurred were evaluated. It is the experience of the authors that these “first flush” peak flows are often hyper-concentrated flows. Thus often peaks from post-burn basins are essentially sediment carrying water flows with entrained post-burn debris. Indirect measurement of observed peak flows are compared to the values obtained from Equation 12 for five basins using the return interval of the causative rainfall events. Additionally, the values obtained from Equation 13 are evaluated for special circumstances. This report provides the first verification for this southeast Arizona Sky Island Complex post-burn flood forecasting technique.
Three basins burned by the 2011 Wallow Fire are also used to evaluate the usefulness of the Reed-Schaffner Equation 12 to forecast post-burn peak flows and associated increased flash flood potential. Additionally, the values obtained from Equation 13 are evaluated for special circumstances. For this burned area the channel relief ratio was used unmodified. This modification of Equation 12 and 13 was done because the Wallow Fire occurred within the Central Arizona Highlands outside of the area for which the original equations were developed (the Sky Island Complex of southeast Arizona). This report provides the first verification for this Central Arizona Highlands post-burn flood forecasting technique.

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David Goodrich\textsuperscript{1}, E. Canfield\textsuperscript{2}, D.P. Guerrtin\textsuperscript{3}, I.S. Burns\textsuperscript{4}, L.R. Levick\textsuperscript{5}, and T.J. Clifford\textsuperscript{6}

\textit{Rapid Post-Fire Hydrologic Watershed Assessment using the AGWA GIS-based Hydrologic Modeling Tool}

Rapid post-fire watershed assessment to identify potential trouble spots for erosion and flooding can potentially aid land managers and Burned Area Emergency Response (BAER) teams in deploying mitigation and rehabilitation resources. These decisions are inherently complex and spatial in nature and require a distributed hydrological modeling approach. The extensive data requirements and the task of building input parameter files have presented obstacles to the timely and effective use of complex distributed rainfall-runoff and erosion models by BAER teams and resource managers. Geospatial tools and readily-available digital sources of pre-fire land cover, topography, and soils combined with rainfall-runoff and erosion models can expedite assessments if properly combined, provided a post-fire burn-severity map is available. The AGWA (Automated Geospatial Watershed Assessment) hydrologic modeling tool was developed to utilize nationally available spatial data sets and both empirical (SWAT) and more process-based (KINEROS2) distributed hydrologic models (see: www.tucson.ars.ag.gov/agwa). Post fire hydraulic, infiltration, and erosion parameters as a function of burn severity have been estimated from a thorough examination of post-fire watershed response from historical fires. Through an intuitive interface the user selects an outlet from which AGWA delineates and discretizes the watershed using a Digital Elevation Model (DEM). The watershed model elements are then intersected with soils and land cover data layers and burn severity maps to derive the requisite model input parameters. The chosen model is then run, and the results are imported back into AGWA for graphical display. AGWA can difference results from pre- and post-fire model simulations and spatially display the changes in watershed response due to burn severity. This allows managers to identify potential problem areas where mitigation activities can be focused. An overview of AGWA, derivation of post-fire model parameters, application of it by BAER teams to the 2010 Wallow and Las Conchas fires in Arizona and New Mexico, and pros and cons of using AGWA from the BAER team perspective will be discussed.

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An analytical method for predicting post-wildfire peak discharges was developed from analysis of paired rainfall and runoff measurements collected from selected burned basins. Data were collected from 19 mountainous basins burned by 8 different wildfires in different hydroclimatic regimes in the western United States (California, Colorado, Nevada, New Mexico, and South Dakota). Most of the data were collected for the year of the wildfire and for 3-4 years after the wildfire. This provides some estimates of the changes with time of post-wildfire peak discharges, which are known to be transient and have received little documentation. The only required inputs are the burned area and a quantitative measure of soil burn severity, $\Delta NBR$ (change in the normalized burn ratio), which is derived from Landsat reflectance data and available from either the U.S. Forest Service or the U.S. Geological Survey. The method predicts the post-wildfire unit peak discharge (peak discharge per unit burned area) for: (1) the year of a wildfire and the first year after a wildfire, and (2) the second year after a wildfire. It can be used at three different levels depending on availability of data for the user; each level requires either more data or more processing of the data. Level 1 requires only the burned area. Level 2 requires the burned area and the basin average value of $\Delta NBR$. Level 3 requires the burned area and the calculation of the hydraulic functional connectivity, which is a variable that incorporates the sequence of soil burn severity along hillslope flow paths within the burned basin.

Measurements indicate that the unit peak discharge response increases abruptly when the 30-minute maximum rainfall intensity is greater than about 5 mm h$^{-1}$ (0.2 inch h$^{-1}$). This threshold may relate to a change in runoff generation process from saturated-excess to infiltration-excess overland flow. The threshold value was about 7.6 mm h$^{-1}$ for the year of the wildfire and the first year after the wildfire, and it was about 11.1 mm h$^{-1}$ for the second year after the wildfire. (Moody, 2011, USGS Scientific Investigation Report 2011-5236)

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Evan Q. Friedman\textsuperscript{1} and Paul M. Santi\textsuperscript{2}

\textit{Debris-flow Hazard Assessment and Monitoring within the 2010 Medano Fire Burn Area, Great Sand Dunes National Park and Preserve, Colorado}

A debris-flow hazard assessment was conducted for the Medano Creek Watershed, at Great Sand Dunes National Park and Preserve, in response to the 2010 Medano Fire that burned approximately 6,000 acres in and around the preserve. Debris-flow probability and volume predictions were made based on implementation of empirical regression models using GIS. The models integrate data for burn severity, rainfall intensity, topographic characteristics, and soil properties into a hazard assessment for the burned basins of Medano Creek Watershed in response to short duration, high-intensity storm events. Model output provided park resource managers with information on potential basin-specific hazards to roads, campsites, and park visitors. Monitoring equipment installed in several basins provided information on the first significant rainfall events following the fire, and the resulting debris-flow and sediment-laden flood responses, throughout the spring, summer, and fall of 2011. Measurements of rainfall, observations of debris flow response, and field surveys of deposits provided the basis for model validation. Of the three probability models utilized, two predicted high probability of debris flow occurrence for all basins that produced debris flows with numerous false positives, while the other failed to predict high probability in any of the basins. The volume model predicted volumes an order of magnitude higher than those measured. Comparison of rainfall data with pressure head recorded in channels provided insight into the relative timing of debris flows to peak rainfall. Debris flows were recorded 5 to 9 minutes after the beginning of periods of maximum 5-minute rainfall intensity (37.9 to 68.9 mm/hr), and as soon as six minutes after the first rainfall of a storm event was recorded, suggesting that short periods of intense rainfall were responsible for initiation.

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Lessons Learned from Public Release of Post-fire Debris-flow Hazard Assessments for Basins Burned by Wildfires in Southern California

During the 2009 fire season in southern California, over 296,000 acres of land burned in 18 different fires. Of particular note, the Station fire, the largest fire in the history of Los Angeles County, burned 160,577 acres of steep, rugged terrain of the San Gabriel Mountains. This mountain range has a history of producing large-magnitude debris flows from recently burned hillslopes. In response to the emergency, the U.S. Geological Survey released assessments of debris-flow hazards as maps showing estimates of the probability and volume of debris flows from each of the 10 largest fires adjacent to infrastructure. The hazard assessments were based on statistical models developed from post-fire hydrologic-response monitoring data collected throughout southern California steeplands. Debris-flow probabilities and volumes are estimated as combined functions of different measures of basin burned extent, gradient, and material properties in response to both a 3-hour-duration, 1-year-recurrence thunderstorm and to a widespread, 12-hour-duration, 2-year-recurrence storm. The intent of the assessments was to provide information about potential debris-flow impacts to the public, and quantitative data critical for mitigation, resource-deployment and evacuation decisions by land-management, city and county public-works and flood-control, and emergency-response agencies. Here, we describe some of the hits and misses of the assessments and of the public release of this information.

The hazard-mapping approach illustrated the relative potential hazards on both regional and local scales. On a regional scale, for example, relatively low debris-flow probabilities and small volumes were calculated for basins burned in the Sheep fire in San Diego County, while conditions in basins burned by the Station fire in San Bernardino County and the La Brea fire in Ventura County resulted in relatively high probabilities and large volumes. This distinction allows for regional-scale prioritization of debris-flow hazard mitigation efforts and emergency-response planning when resources are limited. On local scales, the mapping approach also provided representation of the relative debris-flow potential for individual basins, with the caveat that it is unlikely that a single thunderstorm will impact an entire burned area. Comparison of predicted debris-flow volumes with actual measures indicates that the model predicts well within an order of magnitude for volumes greater than 1,000 m$^3$ and less than about 500,000 m$^3$. Temporally detailed data on the timing of debris flows within storms indicated that the assessment of the widespread, 12-hour-duration storm was not necessary because debris flows were almost exclusively triggered during intense bursts of rainfall of less than 15-minute-duration embedded in both frontal and convective storms.

Although the release of the hazard assessment for the Station fire was accompanied by an extensive multi-agency public information campaign, the public response to both mandatory and voluntary evacuation orders was low, and decreased with each sequential winter storm. Interviews with local residents indicated that the low compliance could be attributed to: 1) a lack of a personal understanding of just how dangerous and destructive debris flows can be, 2) inconsistent messaging from different agencies regarding potential magnitudes of a debris-flow...
response, 3) a poor understanding of the uncertainties inherent to both weather and debris-flow predictions, and 4) a desire to protect personal property. Communication on a one-to-one basis throughout the storm season was necessary to avoid this last, all-too-human tendency. These observations also indicate that effective evacuations in response to debris-flow hazards require an increased awareness of the potential magnitudes and impacts by all parties involved, and this awareness must be established well in advance of any emergency.

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Important objectives of pre-fire analyses are to determine where strategic fuels reductions (by vegetation removal or controlled fire) will yield the greatest benefits to aquatic ecosystems, inclusive of threatened and endangered fish species, and will reduce risks to infrastructure and to municipal water supplies. Important objectives of post-fire analyses are to identify the locations of heightened flooding and erosion response to fire and to propose mitigation to alleviate impacts to a similar set of resources. Post-fire analyses on federal lands are undertaken by Burned Area Emergency Response (BAER) teams who face severe time constraints that limit their access to and use of data-analysis tools to predict impacts in post-fire environments. Consequently, they often rely solely on burn-severity maps. A more efficient technology is needed to provide critical data and environmental analysis for post-fire environments. Geographic Information Systems (primarily ESRI’s ArcGIS) provide the standard software for geospatial data access and analysis. Use of GIS provides substantial advantages, but requires specialized software, hardware, and expertise, which can lead to bottlenecks in information transfer and promotes an expert system of analysis that can limit access to information in time-critical situations. The recent advent of internet-based technology for exploration of GIS data and for analysis can streamline access to and use of geospatial data and tools, particularly for post-fire environments and also for pre-fire planning.

NetMap (www.netmaptools.org) is a community-based platform for using available tools and models that focus on interactions among vegetation, fires, erosion, roads, and aquatic ecosystems. It provides risk-assessment capabilities and new analysis options in forestry, riparian management, pre- and post- fire planning, restoration, and conservation. NetMap digital landscapes and tools presently cover most of Washington, Oregon, southeast Alaska, and portions of northern California, Idaho and Montana. Although NetMap’s standard databases work within ArcGIS, new browser based tools are aimed at streamlining access to information. For example, NetMap’s Post-Fire browser allows users (including the Remote Sensing Application Center) to upload Burned Area Reflectance Classification (BARC) maps (or field validated burn severity maps) to a server where a set of hands-free automated analyses is conducted. Analyses include mapping burn severity to channels, predicting surface erosion, shallow failure, gully and debris flow potential, peak flows, aquatic habitats (by species), channel sensitivity, and potential road impacts related to drainage diversion, surface erosion, shallow failure and debris flow. Using Google Maps or Google Earth, users can visually search for spatial overlaps among predicted erosion locations, road impacts and aquatic habitat sensitivity. Users can specify search thresholds for identifying where the highest erosion potential spatially overlaps with the most sensitive habitats. Individual hillslopes, road segments and stream reaches where impacts are concentrated can be identified thereby
allowing strategic prioritization for field verification and mitigation. A similar tool structure supports pre fire (vegetation) planning with burn severity being replaced with fire risk.

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\textit{Post-fire Hydrologic Model Assessment for Design Storm Runoff and Mitigation}

Wildfires alter land surfaces and enhance hydrologic response, including flooding and debris flows. Burned Area Emergency Response (BAER) teams are charged with rapidly assessing the impacts of wildfire, including determining areas that pose threats to human life, values at risk, and natural resources. Accurate predictions of post-fire storm response are critical for efficient treatment and mitigation. A range of hydrological models are currently applied to predict post-fire runoff; however few of these models have been rigorously tested for accurate performance across a range of diverse biomes and climatology. The goal of the current study is to provide guidance to BAER teams, specialists, and policy makers for post-fire hydrologic monitoring and management. This includes an assessment of a suite of models, their capabilities, and performance across regional areas. A review of hydrologic models used by the USFS reveals inconsistency in parameter estimation, model usage, and awareness of alternative modeling practices. Peak flow is highly sensitive to model parameters and currently, a systematic protocol for gathering parameters and running models does not exist. Initial model evaluation includes the Rowe Countryman and Storey, USGS Regression, TR-55, Wildcat5, and HEC-HMS systems. Parameters (inputs and outputs) for each model and study site (southern and northern California, Colorado, and Montana) are acquired and models are executed under pre- and post-fire conditions to simulate design storm runoff. Study models are typically developed for pre-fire conditions and fine-tuned for specific regions; however models are not readily transferable to different hydro-climatic regimes. In addition, simulated peak flows are inconsistent between models at each site, with less confidence in the larger design storms (25- and 50-year peak flow events). Ultimately, results from this study will provide modelers with more efficient post-fire flow estimates including awareness to model advantages and disadvantages for specific regions, parameter estimation methods, time requirements, and data availability.

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**A New Technique for Implementing Models for Assessing Post-wildfire Debris-flow Hazards**

A debris flow can be one of the most devastating post-wildfire hazards. Debris flows are fast-moving, high-density slurries of water, sediment, and debris that can be enormously destructive. Debris flows are frequently triggered by intense rainfall or rapid snowmelt on steep hillsides covered with erodible material. Although debris flows are a common geomorphic process in some unburned areas, a wildfire can transform conditions in a watershed with no recent history of debris flows into conditions that pose a substantial hazard to residents, communities, infrastructure, aquatic habitats, and water supply systems.

A new technique was used to estimate the probability and volumes of debris flows for three wildfires in Arizona in 2011. Model inputs include rainfall intensity and basin characteristics of slope, percent of basin burned, and soils. While the old technique uses a conventional watershed-characterization method at pre-selected points, this new technique uses continuous-parameterization, using the 1/3-arc-second National Elevation Dataset (10-meter nominal resolution) and its derived flow-direction grid as a base, to compute the debris-flow model predictions for every pixel within the 10-meter digital-elevation watersheds.

This new technique provides a synoptic view of entire study areas with estimates of debris-flow volume and probability in a continuous manner for the entire stream channel length within a watershed. The advantage is that this technique evaluates the potential for debris flows along all points of a stream channel as opposed to a pre-selected point defining a watershed. The result is that all areas within the watershed are individually evaluated and the areas with a high probability for a debris flow or potentially large volume of a debris flow are identified.

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\textit{Accounting for Wildfire Effects in Slope Failure Risk Analysis}

While it has been well established that wildfires significantly change the potential for landslides and slope failures in general within the watershed, the exact mechanisms by which this occurs is still largely unknown. In particular, fire changes the effective infiltration rate at the surface – a critical parameter in slope failure prediction. This change varies spatially and temporally, the latter being over both long timeframes (years) as well as the short timeframes inherent to single rainfall event (minutes). Further, the change to the infiltration rate can be positive or negative: On the one hand, fire tends to make the surficial soils water repellent, effectively decreasing the rainfall infiltration rate; on the other, fire deposits ash and removes organic matter, which can increase the infiltration rate.

This study addresses these effects by exploring the mechanisms involved with surficial failures under burned watershed conditions, utilizing recently developed stochastic models that relate variable infiltration rates with changes to slope failure risk. It is shown that slope failure risk can be increased not only from the direct effect that wildfires have on the overlaying surface properties, but also indirectly by introducing greater and unavoidable calculation uncertainties.

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Model Assessments for Predicting Post-Fire Debris-Flow Potential in Arizona

Several large, devastating wildfires occurred in Arizona during the past 2 years, after a 4-year period without any large wildfires. In June, 2010, the human-caused Schultz Fire near Flagstaff burned 15,075 acres of mostly steep terrain. Subsequent rains from the 4th wettest monsoon on record produced numerous debris flows, significant erosion, and substantial flooding of the downslope residential areas. In May and June of 2011, 3 very large human-caused wildfires (Wallow, Horseshoe 2, and Monument Fires) burned over 791,000 acres, posing serious threats to communities below burned slopes. The USGS assisted the Burned Area Emergency Response (BAER) teams, tasked with rapid assessment of damages from wildfires, in predicting the probability of post-fire debris flows from burned basins using models developed for this purpose [Cannon and others, 2010, GSA Bull, 122(1-2), 127-144]. These models, while providing quick results, have not been evaluated for use in Arizona’s varied physiographic provinces. Here we use data these four wildfires to compare basin responses with the modeled probabilities from the 3 USGS post-fire debris-flow models (Models A, B and C). We documented debris-flow occurrence and runout distances using field monitoring and geomorphic mapping in conjunction with 1:12,000 stereo aerial photographs where available (Schultz and Horseshoe 2 Fires). Tipping bucket rain gauges and radar data were used to assess rainfall intensity and storm totals. Hydrologic responses from basins within the burned areas were assessed for debris or flood flow occurrences following significant rainfall. Morphometric, soils, and burn severity data were entered into the 3 USGS models along with average rainfall intensity and storm totals from several storms, some of which produced debris flows. Model results were then statistically assessed for the accuracy of predicted debris-flow occurrence. Results for this study will provide BAER teams with needed information for selecting appropriate models to assess post-fire debris-flow potential in Arizona.

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Keynote

Peter R. Robichaud

Reducing the Risk: Improving Our Understanding of Post-Wildfire Erosion Control Treatment Effectiveness

Wildfires around the world have continued to increase in size, severity, and cost. Development into wildland areas has also increased putting public safety, homes, roads, public infrastructure, water quality, and valued natural resources at risk, not only from the fire itself, but also from the post-wildfire hydrologic response (secondary fire effects). Major concerns after wildfires are the potential increases in flooding, debris flows, sedimentation, and erosion. To reduce the potential damage to life, property, and resources from these post-fire responses, various treatments are commonly implemented. Given the expense of these post-fire treatments, it is important to apply treatments where they are most needed and to have some assurance that the treatments will effectively mitigate the threats to the value(s) at-risk.

We have developed and implemented rapid response approaches to measure treatment effectiveness by monitoring post-fire sediment yield and runoff response from hillslopes and small catchments, flow rates and sediment transport/deposition in channels, through culverts, and in road drainage systems, and, more recently, post-fire wind erosion rates. Rapid response protocols allow measurements to be made during the first post-fire year when runoff and erosion are likely to be greatest with continued monitoring through the initial recovery period. Although most of our treatment effectiveness studies measure responses from natural rainfall, we also use high-intensity rainfall simulation and concentrated flow (rill) experiments to compare treated and untreated areas within a burned area. Treatment effectiveness is highly dependent on rainfall characteristics. Our study sites in the Western U.S. encompass a range of rainfall regimes including monsoonal rains in the southwest (Arizona, Colorado, New Mexico and Utah), thunderstorms in the Northern Rockies and eastern Sierras, and Pacific frontal systems in Southern California.

Matched catchment studies found that contour-felled log erosion barriers reduced runoff, peak flows, and sediment yields for lower intensity storms (<2-yr return interval, 10-min maximum rainfall intensity [I_{10}]) but not for higher intensity storms (≥2-yr I_{10}). Hillslope mulch treatments (agricultural straw, wood strands, wood shreds and, in some cases, hydromulch) appear to outperform the barrier-type treatments in reducing runoff and erosion. Several studies to quantify the effectiveness of road and channel treatments are in progress. Post-fire management has responded to these research findings and modified its treatment strategies. Contour-felled log erosion barriers, commonly used in the 1990’s, are seldom used for treating long hillslopes today. Since 2002, mulches, especially agricultural straw, are increasingly used for post-fire hillslope stabilization, while seeding grasses for this purpose has decreased.

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Topic: Post-fire Warning Systems

Oral Presentations

Jayme Laber

The NOAA/USGS Debris Flow Early Warning System for Southern California

Flash floods and debris flows are common following wildfires in southern California. On December 25, 2003, sixteen people were swept to their deaths by debris flows generated from basins burned the previous fall. In an effort to reduce loss of life by floods and debris flows, the National Oceanic and Atmospheric Administration’s (NOAA) National Weather Service (NWS) and the United States Geological Survey (USGS) established a prototype flash flood and debris flow early warning system for recently burned areas in an eight-county area of southern California. This prototype system combines the existing NWS Flash Flood Monitoring and Prediction (FFMP) system and USGS rainfall intensity-duration thresholds for debris flow and flash flood occurrence. Thresholds are defined for the occurrence of debris flows and flash floods in response to storms during the first winter after a fire, and following at least one year of vegetative recovery. Advisory outlooks, watches, and warnings are disseminated to emergency management personnel through NOAA’s Advanced Weather Information Processing System (AWIPS). In addition to the early warning system, an area within the southern California study area is dedicated to intense instrumentation and research to develop new geologic, hydrologic, and hydrometeorologic methods for precipitation and debris-flow forecasting, measurement, and analysis techniques. This presentation will also include a brief case study of significant debris flows that occurred on February 6, 2010 in La Canada Flintridge, CA from the 2009 Station burn area.

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\textit{From Fires to Floods: How the NWS in Tucson Arizona helped Raise Flash Flood Awareness after a Historic Wildfire Season}

Historic wildfires burned across southeast Arizona drawing national media attention in June 2011. The Horseshoe 2 and Monument fires destroyed or damaged over 80 residences, businesses and other structures. Additionally these fires modified soil conditions such that flash flood occurrence and severity could be magnified by over an order of magnitude. Thus the post-wildfire flash flooding and debris flows may cause damage more devastating than the fires.

Southeast Arizona rapidly transitioned from the spring drought conditions to the wet summer Monsoon season by the first week of July. The Monsoon season is characterized by frequent thunderstorm activity (almost daily over the mountains), severe convection, heavy rainfall and flash flooding. The National Weather Service recognized the immediate need to raise awareness of the increased potential for flash flooding and debris flows in the burned areas. Within a few days of the Monument fire becoming contained, heavy rainfall caused a flash flood which damaged multiple homes, closed major roads, caused a debris flow and re-sculptured the water channels.

This presentation will discuss how the flash flood level of awareness was raised in a couple of weeks within the affected communities and the educational materials used. Emerging technologies, social media applications and multiple interactions with various public agencies were employed to help disseminate this information.

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Post-Fire USGS and ALERT Systems

The United States Geological Survey (USGS) and the Arizona Department of Water Resources (ADWR) often provide assistance to entities impacted by wildfire to install flood warning systems or provide additional equipment for existing systems. The purpose of this presentation will highlight various elements related to responding to BAER team and local agency requests. These include the corporative design, installation, operation, and maintenance of flood warning systems; data collection for science and flood warning purposes; data access and notification; leveraging the infrastructure of existing systems; field equipment limitations during post-fire flood events; challenges related to coordination with multiple levels of government; and funding issues.

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Wildfire intensity and size are increasing across the western United States, causing short- and long-term post-fire consequences. Current management efforts are generally concentrated around immediate effects, typically only during the first post-fire rainy season. However, burned systems are altered for prolonged periods of time, creating long-term concerns for downstream communities, water resource management, and ecosystem recovery. Vegetation biomass is a controlling element of hydrology recovery and the application of remotely sensed data streams to wildfire studies can enhance the understanding and monitoring of post-fire response in large and ungauged burned areas. The goal of the current study is to integrate remote sensing data from multiple satellite platforms, including Moderate Resolution Imaging Spectroradiometer (MODIS) and Landsat (both available since 2000), to improve predictions of the spatial and temporal variability of key parameters controlling post-fire response for the Arroyo Seco, an urban-fringe watershed in southern California burned by the 2009 Station Fire. Study variables include enhanced vegetation indices (EVI), surface temperature, albedo, evapotranspiration (ET), and soil moisture. The UCLA remotely-sensed ET product is used to provide detailed insight on vegetation growth and plant water availability pre- and post-fire. The developed timeseries can be used to evaluate hydrologic water budgets over large burn areas. A UCLA downscaled MODIS-AMSR-E soil moisture product is used to evaluate the spatial variability of post-fire surface soil moisture and the influence on storm runoff response. Ultimately, study parameters will be incorporated into a multi-variable model to predict monthly and seasonal hydrologic recovery, improving long-term post-fire water resource monitoring and management.

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Utilization of Satellite Imagery to Evaluate and Predict Out-Year Post-Fire Watershed Response and Potential Application in the Southwest

Burned Area Emergency Response (BAER) teams, along with other agencies that have jurisdictional responsibility (Natural Resource Conservation Service, state, counties, cities, etc.), prescribe and implement treatments based on expected post-fire response and associated threats to life, property, and resources. Vegetative cover is often used to evaluate watershed recovery and the start of a return to pre-fire response behavior. The objective of this project is to use remote sensing technologies to assess the rate of natural vegetative regeneration post-fire and evaluate the level of risk for continued increased post-fire watershed response. If remote sensing indices are effective in determining the rate of natural vegetative recovery in burned areas, then can we determine how peak flows, debris flows, and sedimentation and erosion factors have changed and will this information enable us to determine the level of risk for an area? This discussion summarizes steps taken, initial findings from the Horseshoe 2, Monument, and other fires, and identifies future needs to implement a decision support tool with national application that will give land managers and emergency response personnel an indication of the level of risk relative to pre-fire or immediate post-fire levels.

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\textbf{The Relative Contribution of Natural Vegetation Dynamics and Common Seeding Treatments to Post-fire Soil Stability in Rangelands of the Great Basin, USA}

Increases in size and frequency of wildland fires as well as the length of the fire season have been observed in recent decades throughout the western USA. In rangelands, the impact of a longer fire season is especially important to understand given that larger and more frequent fires coupled with persistence of dry conditions and frequent droughts are expected to exacerbate the degradation of soil resources and adversely impact ecosystem functioning. Moreover, there are important questions regarding the effectiveness of common post-fire seeding treatments used to promote soil stability in the short-term after fire and the establishment of a desirable vegetation community in the long-term. To inform these issues, we examined how the increased length of the annual fire season and the timing of fire impact the length of time soils are prone to erosion for different post-fire treatments as evidenced in remotely sensed vegetation dynamics. The treatments considered were drill and aerial seeding in the first year after fire relative to untreated plots. We analyzed the landscape greenness dynamics (phenometrics) derived from time-series of MODIS-NDVI satellite imagery for a dataset of 32 large fires that burned in 2000-2003 with replicate burned-untreated, burned-drill seeded, and burned-aerial seeded plots. We also examined treatment effects on longer-term soil stability in the context of a chronosequence of vegetation recovery from 88 fires that burned 1990-2003. Fire and rehabilitation treatment data for both analyses were derived from a database of ESR (Emergency Stabilization and Rehabilitation) projects amassed for the sagebrush steppe biome of the Great Basin by the U.S. Geological Survey and U.S. Forest Service. Results indicate that the length of time that soils were prone to degradation after fire varied with the time of year that fires burn, and suggest the potential for greater soil degradation with increased occurrence of early relative to late-season fires. Significant effects of seeding treatments on the short- and longer-term post-fire vegetation dynamics that might enhance soil stability were not evident. Findings have implications for the refinement of rehabilitation efforts that are commonly employed in burned rangelands.

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Fire suppression, overgrazing, and accelerated soil erosion processes (hydrologic and aeolian) can render desert grasslands susceptible to encroachment by woody plants, with ecohydrologic, biogeochemical, and socio-economic consequences. At its extreme, shrub encroachment leads to the formation of a patchy landscape with raised, fertile shrub patches interspaced with sunken, nutrient-depleted bare soil patches; this patterning is considered to be an irreversible process of land degradation. Recent studies have indicated that in the early stages of shrub encroachment, when there is sufficient herbaceous connectivity, fires (prescribed or natural) might help to reverse the degradation associated with shrub encroachment by increasing shrub mortality and homogenizing soil resources. We used LiDAR (light detection and ranging) to examine changes in microtopography and spatial patterning of soil resources in replicated burned, clipped, and control areas in a shrub-grass transition zone in the northern Chihuahuan Desert four years after a prescribed fire. Geostatistics reveal the pattern of the microtopography is more homogeneous in plots that had been treated with burning, followed by those that were clipped, when compared to control areas. The homogeneity of the topography is quantified most dramatically by lower variogram sill values. These results provide further evidence that prescribed fires in the early stages of shrub encroachment may help to reverse associated land degradation processes.

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Changes in Peak Flow Rates and Sediment Yields from the Wallow Fire, Arizona

The Wallow Fire burned over 217,000 ha in eastern Arizona in 2011, including 3 catchments that had been used for water yield experiments between 1966 and 1986. Few studies have compared post-fire effects directly to pre-fire conditions. We compared post-fire runoff and sediment yields at the small catchment (120-230 ha) scale to pre-fire measurements. The maximum peak flow rates during the pre-fire monitoring occurred as a result of snow melt and ranged from 194 to 222 L s⁻¹ km⁻² in the 3 catchments. Erosion rates from undisturbed hillslope plots in one of the catchments averaged 8.4 kg ha⁻¹ yr⁻¹ over 4 years. The weirs in the three catchments were re-instrumented in July 2011 to measure rainfall and runoff rates. Additional measurements were made in one catchment—about half of which burned at high severity, 25% was unburned, and 25% was moderate or low burn severity—to measure hillslope erosion rates and catchment-scale sediment yields. One intense rain event (30-min maximum intensity of 54 mm hr⁻¹) occurred before re-instrumentation occurred, but high water marks at the weirs indicated the peak flows were at least 2800 L s⁻¹ km⁻² and 3900 L s⁻¹ km⁻² in the two affected catchments, or 14 and 18 times the pre-fire peak flows. The peak flow rate in the third catchment occurred later in the summer and was 1200 L s⁻¹ km⁻² (5 times the pre-fire peak). Twenty-one other runoff events were measured in this catchment in 2011, and these were caused by lower intensity rain storms (30-min maximum intensity values between 4 and 15 mm hr⁻¹). The event runoff ranged from 0.01 to 2.1 mm and resulted in a total storm flow of 9.1 mm. The pre-fire peak flows were exceeded by at least 10 post-fire runoff events in each of the three catchments. The post-fire sediment yields at the hillslope scale averaged 14 Mg ha⁻¹, or more than 1600 times the pre-fire value at the hillslope scale. Catchment-scale sediment yields were lower, and totaled only 0.8 Mg ha⁻¹ (or 1.6 Mg ha⁻¹ if we assume only the high burn severity contributed sediment). Data collection will continue through 2012.

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A Fire History Reconstruction of the Western San Juan Mountains: Results from tree-ring and alluvial sediment methods

In 2002, a severe wildfire burned several tributary watersheds along three main valleys of the San Juan Mountains near Durango, Colorado. Post-fire debris flows and flooding incised tributary channels and alluvial fan deposits, creating exposures of older alluvial sediment deposits. Alluvial sediments were sampled from several exposures located within the upland tributary channels and on alluvial fans at the watershed outlet. Sediment deposits exhibited charcoal within fine-grained layers and concentrated along unit boundaries. The charcoal represented an association with fire events in the contributing watershed, and the deposit characteristics were associated with fire severity. Low-severity fire events were represented by fine-grained deposits, while high-severity fires were represented by charcoal-rich debris flow deposits. The ages of fire-related sedimentation events within the upland tributary channels ranged between 200 – 4,100 \(^{14}\)C years before present with increased sedimentation occurring between 800 – 1,100 \(^{14}\)C years bp. On the alluvial fans at the watershed outlet, individual deposits ranged between 300 – 2,500 \(^{14}\)C years bp, though ages were typically less than 700 \(^{14}\)C years bp. The range of sediment characteristics represented both low and high severity fires over the study period and the dominance of one fire regime is not evident. Tree-ring material was collected from three tributary watersheds and is composed of both fire-scarred trees and age-structure data. Fire-scar dates indicate that low-severity fires occurred every 20 – 30 years on south-facing slopes. The combination of age-structure data and fire-scarred trees suggests that portions of the north-facing slopes experienced high-severity fire within the past 300 years.

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\textit{2010 Schultz Fire – Sediment Analysis and Reduction Options}

The Schultz Fire was started by an abandoned campfire on June 20, 2010 and burned approximately 15,000 acres of ponderosa pine forest within the Coconino National Forest. The burned area is located on the eastern flanks of the San Francisco Peaks approximately four miles northeast of Flagstaff, Arizona. The vast majority of the area was severely burned with total loss of trees and ground cover. No private lands were burned, however, nearly 1,000 residential properties within Coconino County are located immediately down-slope of the burned area. High sediment concentrations in flood flows that originate on the Coconino National Forest in the Schultz Fire burn hinder the function of structural mitigation measures installed to reduce property damage in the downstream neighborhoods on private lands. The potential for flooding and excess sediment remains high nearly two years after the burn and initial burn area treatments.

The objective of the study was to define the origins of and to estimate the amount of sediment delivered to the private lands downstream of the Shultz Fire burn area. Additionally, the study provides estimates of how much sediment can be stored or reduced on U.S. Forest Service lands through installation of channel and watershed restoration practices, before it reaches the private lands.

Sediment sources were estimated from stream bank erosion, hill slope erosion and roadway erosion process models. Sediment contributions from streambank erosion greatly outweigh contributions from other sources combined for all watersheds. Estimation of sediment transport through these ephemeral reaches provides an understanding of where channels are aggrading or incising and the magnitude of these sediment processes. Sediment transport estimates were made using the RiverMorph v5 beta FlowSed/PowerSed module. This utilizes annual flow duration curves and regional suspended and bedload sediment rating curves for sediment calculations. Comparisons of the sediment transport results with sediment source results indicate that sediment supply is generally much greater than sediment transport. However, the balance of the sediment is in unstable channels ready to be transported in future storm runoff events. Sediment transport results also indicate that several areas in each watershed could be utilized to store sediment on historic debris fans for longer periods of time.

The results of the sediment analysis indicate that if natural channel sediment reduction practices are constructed on the USFS lands, the sediment transport and supply can be reduced to the point where single-thread natural channels can be successfully constructed through the neighborhoods if rights-of-way and other issues can be overcome. The practices considered for the USFS lands consist of channel reconstruction of single-thread channels to reduce sediment
transport rates and the enhancement of existing debris fans to maximize sediment aggradation. Work is suggested for areas with milder slopes (<10%) from just upstream of the FR 420 road to the boundary with private lands. Major portions of the channels within a watershed would need to be restored in order to meet the sediment reduction targets for construction of channels within the private lands. All watersheds considered have the potential to meet these sediment reduction targets.

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_Depth of Unconsolidated Cinder Deposits and Potential Water-Storage Capacity at Cinder Lake for Runoff Events Exacerbated by the Schultz Fire, 2010, Coconino County, AZ_

The 2010 Schultz fire northeast of Flagstaff, Arizona, burned more than 15,000 acres on the east side of the San Francisco Mountain from June 20 to July 3. As a result, several drainages in the burn area are now more susceptible to increased frequency and volume of runoff, and downstream areas are more susceptible to flooding. Resultant flooding in areas downgradient of the burn has resulted in extensive damage to private lands and residences, municipal water lines, and roads. Coconino County, which encompasses Flagstaff, has responded by deepening and expanding a system of roadside ditches to move flood water away from communities and into an area of open U.S. Forest Service lands, known as Cinder Lake, where rapid infiltration can occur. Water that has been recently channeled into the Cinder Lake area has infiltrated into the volcanic cinders and could eventually migrate to the deep regional groundwater-flow system that underlies the area. How much water can potentially be diverted into Cinder Lake is unknown and Coconino County is interested in determining how much storage is available. The U.S. Geological Survey conducted geophysical surveys and drilled four boreholes to determine the depth of the cinder beds and their potential for water storage capacity. Results from the geophysical surveys and boreholes indicate that the cinders are underlain by basalt at about 30 feet below land surface. An average total porosity for the upper 30 feet of cinders was calculated at 43 percent for an area of 300 acres surrounding the boreholes, which yields a total potential subsurface storage for Cinder Lake of about 4,000 acre-feet. Ongoing monitoring of storage change in the Cinder Lake area was initiated using a network of gravity stations.

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*Post Wildfire Landscape Change in a Small Headwater Catchment from Terrestrial LiDAR*

The 2011 Horseshoe Two fire in the Chiricahua Mountains of southeastern Arizona led to erosion during subsequent convective summer monsoon storms. Here we present ultra-high resolution maps of a landscape change derived from rapidly deployed, repeat 3D laser scans on a single headwater catchment. The study site sits at 2500 masl and, prior to the wildfire, was characterized by pine forest on steep, convergent, but unchannelized slopes. The site was moderately to severely burned; most trees and low vegetation were killed, but fine roots were preserved within the upper part of the soil. Terrestrial LiDAR data were first collected within two weeks of the fire using a Leica C10 instrument, after initial eolian erosion, but prior to rainfall-induced erosion. The drainage was then scanned three more times after one moderate (5.3 cm) and several minor (<3 cm) rainfall events. The larger rainfall event led to incision into colluvial valley heads, and mobilization of sediment up to boulder size. The erosion appeared consistent with excess shear stress erosion caused by convergent overland flow on steep hillsides. Boulder deposition adjacent to gullies were indicative of debris flow activity. Upslope of incised gullies, widespread sheet flow led to extensive erosion of finer grained soil and colluvium, and development of shallow gully networks. Smaller rainfalls led to net aggradation of fine material on the newly incised gully channel beds. These techniques allowed us to calculate average surface lowering rates, estimate volumetric sediment flux and to map these changes at centimeter scale, offering a previously unattainable level of quantification of post wildfire landscape response.

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Wildfires alter land surfaces and land-atmosphere interactions, causing enhanced runoff and debris flows. Many agencies attempt to predict post-fire runoff peaks and volumes to identify values-at-risk and determine if protective measures must be implemented. The current study evaluates hydrologic behavior and recovery for five watersheds in the Southern Sequoia National Forest: three watersheds burned in the Bull Fire (2010), one watershed burned in the Canyon Fire (2010), and one control watershed (unburned) chosen outside the perimeter of the Bull Fire. The effects of wildfires have been extensively analyzed, but these studies typically focus on debris flows immediately following the fire and vegetation recovery on a plot-scale. This study attempts to couple the hydrologic effects of the wildfire with vegetation recovery at the watershed scale, evaluated through in-situ instruments and remote sensing. The five study sites are instrumented with tipping buckets and pressure transducers to measure precipitation and discharge throughout the two year study period (October 2010 – September 2012). Stream discharge is measured at five-minute intervals, the tipping buckets are event-based to track storm duration and intensity, and channel cross-sections are measured every two months to detail sediment deposition or scour that accompany rainfall-runoff events. Remote evaluation of regrowth is estimated using the Landsat Normalized Differenced Vegetation Index (NDVI), which estimates vegetation “greenness” and can serve as a proxy for watershed recovery. Pre-storm NDVI values provide insight on antecedent watershed conditions and potential rainfall-runoff partitioning. As recovery takes place, NDVI values will increase and rainfall-runoff response will correspondingly respond. Preliminary results include precipitation-discharge relationships from data collected in-situ and Landsat NDVI values for the period of October 2010 through February 2012.

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*Rito de los Frijoles – Post Las Conchas Fire Floods – 2011*

The Las Conchas fire began on June 26, 2011 when an aspen tree fell and brought down a power line near the Las Conchas Fishing Access Area on the Santa Fe National Forest. The fire ranks as the largest wildfire in New Mexico history. There are no structures and developed areas in most of Bandelier National Monument’s major watersheds, with the exception being Rito de los Frijoles where numerous important cultural sites as well as the park’s visitor center and administrative offices are located. Burn severity was moderate to high across approximately one third the Rito de Los Frijoles watershed. The La Mesa Fire in 1977 and the Cerro Grande Fire in 2000 also burned portions of the watershed. Increases in flood frequency and magnitude were observed after both of these events and National Park Service has constructed flood and fire histories for Frijoles Canyon dating to the 1700s. A rainfall event in the upper Rito de los Frijoles watershed during the afternoon of August 21, 2011 produced a large flood in the mid and lower portions of Frijoles Canyon. During the week following the flood National Park Service and United States Geological Survey hydrologists completed a total station survey of the Rito de los Frijoles channel near the Bandelier National Monument Visitor Center. These survey data were combined with sub-meter accuracy LiDAR data collected in 2010 and were used to construct a HEC-RAS model for the reach and in slope area calculations estimating discharge for the flood. A maximum discharge of 7,000 cubic feet per second was established for the August 21 flood event. Gridded radar precipitation data and rainfall data from weather stations from the Frijoles watershed were combined with streamflow gaging station data to quantify pre and post Las Conchas Fire rainfall runoff relationships. This combination of data are being used to create an updated floodplain delineation for the Rito de los Frijoles, with particular emphasis on guiding measures to protect visitors to the monument and the important sites located in the canyon bottom.

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\textbf{Reptile and Amphibian Responses to Large-scale Wildfires in Southern California}

In 2003, southern California experienced several large fires which burned thousands of hectares of wildlife habitats and conserved lands. In order to investigate the effects of the fires on reptile and amphibian communities, we compared the results from herpetofauna sampling from several years prior to the fires to results from sampling in the second and third years after the fires among 38 burned and 17 unburned plots. The sampling plots were spread over four vegetation types and four open space areas within San Diego County. Our capture results indicated that burned plots of chaparral and coastal sage scrub lost herpetofaunal species diversity after the fires and displayed significant shifts in overall community structure. Additionally, post-burn herpetofauna community structure was more similar to that found in unburned grassland. We did not find differences in herpetofaunal species diversity or community composition in grasslands or woodland/riparian vegetation after the fires. We foresee that a continued unnatural fire regime for southern California may result in a simplification of the southern California reptile and amphibian communities.

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**Analysis of Floods and Debris Flow Hazards Following Short Duration, High Intensity Rainfall Events on Las Conchas and Track Fire Burn Scar Areas during Summer 2011, Northern New Mexico**

During the summer of 2011, wildfires burned nearly 500,000 acres of forested lands in the State of New Mexico. Two of the fires in northern New Mexico included the Las Conchas wildfire, the largest in the state’s history and the Track Fire which burned much of the Chicorica Creek watershed, a major source of water for the City of Raton, New Mexico. The Las Conchas wildfire burned a total of 156,593 acres including portions of the Santa Clara, Cochiti, San Ildefonso, and Santa Domingo Pueblos and also portions of Bandelier National Monument and the Valles Caldera National Preserve. Some of the Las Conchas wildfire burn area was previously burned by the Cerro Grande Fire in 2000. Freshly burned landscapes are at risk of damage from post-wildfire erosion hazards such as those caused by flash flooding and debris flows. The risk of hydrologic hazards may persist for years after a fire and can negatively impact water resources, ecology, businesses, homes, reservoirs, roads, and utility infrastructure in wildland/urban interface areas. Following the Las Conchas and Track Fires, several high volume (low frequency) floods occurred in and downstream of burn scar areas as the result of otherwise typical summer monsoonal rainstorm events. Personnel from the U. S. Geological Survey and National Oceanic and Atmospheric Administration visited significantly impacted areas in both burn areas, conducted debris-flow assessments of burned areas and collected data to support numerical modeling (slope-area computations) and documentation of high volume floods downstream of burn scar areas. In response to a design storm of 28.0 millimeters of rain in 30 minutes (10-year recurrence interval), the probabilities of debris flows estimated for basins burned by the Las Conchas Fire were greater than 80 percent for two-thirds (67 percent) of the modeled basins. In response to a design storm of 38 millimeters of rain in 30 minutes (10-year recurrence-interval), the probabilities of debris flows estimated for basins burned by the Track fire were greater than 80 percent for the majority of the tributary basins to Raton Creek in Railroad Canyon and for six basins that flow into Lake Maloya, the main water supply for the City of Raton. Debris-flow hazard assessments and flood-frequency predictions conducted in wildfire threatened areas before fires occur could help land and resource managers plan for and mitigate the effects of post-wildfire hazards in advance of a fire occurrence.

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Montezuma Creek Channel Repair – Coronado National Memorial

Debris flow events such as those in 2006 play an important role in shaping the morphology of Montezuma Creek through Coronado National Memorial. Stable stream morphology is based upon equilibrium between sediment supply and carrying capacity of the stream. Debris flows quickly deliver large amounts of sediment to the stream and importantly; much of this material may be larger than the receiving stream has the capacity to carry during moderate, frequent flow events. The stream may only have enough power to convey these large particles at very high discharges that occur infrequently. The result is local aggradation, over widening of affected stream channels, and loss of flood capacity.

Montezuma Canyon Road is the major thoroughfare through Coronado National Memorial. Both park visitors and Department of Homeland Security border patrol agents utilize the road. On July 27th 2008 the park experienced a major rainfall event and consequent flooding (3.74 inches over a four-hour period). The extreme flooding event caused serious damage to the road and drainage facilities. Some of this damage may have been compounded by previous flooding events and wildfire, which have substantially altered the watershed and stream channel. Numerous debris flows initiated after fires in the 1980s and 2006 have mobilized large-diameter sediment, overwhelming the competence of the stream, causing aggradation and channel instability. Relatively small and frequent flooding events impacted the roadway and road drainage. Given the amount of sediment still available to be moved through Montezuma Canyon and the proximity of the road and stream system, maintenance will be high for the foreseeable future and a more stable channel alignment and road drainage provisions which accommodate high sediment yields will help ensure that future road damage and maintenance issues are minimized.

A geomorphic approach was the basis for this design project. Additionally, the hydrology and sediment transport capabilities of the streams were analyzed to ensure that the geomorphic dimensions were reasonable and justified for the current conditions. The geomorphic approach to design utilizes relationships derived from field measurements of local reference streams. The geomorphic approach provides an excellent means of creating a channel and floodplain shape that not only provide water and sediment conveyance, but also provide important ecological functions that encourage establishment and support of riparian plants and habitat along the stream.

The stream channel upstream of the double nine-foot culverts at the visitor’s was designed in 2009 to allow moderate frequent flows to be contained within a channel and ease flooding issues along the roadway. Design enhancements included creating a new, appropriately shaped,
and sloped channel and flood plain. This channel realignment involved approximately 1200 feet of channel excavation to tie into a bedrock sill upstream of the wellhead. Additionally, low water crossings and channel maintenance templates were provided to help improve sediment transport from tributary channels across the roadway.

The first major test of the constructed design occurred during Monsoon generated storms in 2011 following the Monument Fire in Montezuma Canyon. Despite the increase in flow and sediment transport created by the recent fire, the flooding and high sediment loads were successfully transported through the reconstructed channel without major channel alteration or damage to infrastructure. Monitoring of the constructed channel after the fire provides evidence that natural channel design methods can be utilized successfully when dealing with major changes in discharge and sediment regimes such as those experienced after wildfires.

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Hydrologic and Erosion Impacts of the 2010 Schultz Wildfire, Coconino National Forest, Arizona

The Schultz Fire burned 6,100 ha on the eastern slopes of the San Francisco Peaks. The fire burned between June 20th and 30th, 2010, across moderate to very steep ponderosa pine and mixed conifer watersheds. About 40% of the fire area was classified as high-severity, mostly on mountain slopes greater than 30% and in places exceeding 100%. Eleven burned watersheds were evaluated for potential threats from storm runoff and debris flows, with 50% of five basins and 70% of two basins burned to high severity. Upper mountain slopes rise to over 3,300 m and are the source for high-energy water, coarse sediments, and woody material. Steep mountain basins have ephemeral swales with slopes that can exceed 30%, while well-defined ephemeral piedmont and lower-fan channels slope up to 5%. Over the course of an active 2010 Monsoon, ranking the fourth highest in rainfall on record, the burned area received numerous precipitation events. The largest event occurred on 20 July and was characterized by a peak rainfall of 24 mm in ten minutes, resulting in numerous debris flows, historic floods and substantial hillslope soil and channel alluvium erosion. Flood flows were an order of magnitude larger than those produced by similar pre-fire rainfall events. Debris flows were common in most of the mountain drainages, with some flows reaching the toe of the piedmont. Substantial amounts of soil were eroded from a newly developed rill and gully system, removing the A horizon and much of the B horizon. All upper channels were incised deeply, some up to 5 m, with most scoured to bedrock. Sediment sorted out rapidly below the piedmont with only sands and finer sediments reaching the toe of the lower fans.

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