MANAGING FOR FUTURE RISKS OF FIRE, EXTREME PRECIPITATION, AND POST-FIRE FLOODING

WORKSHOP REPORT

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MANAGING FOR FUTURE RISKS OF FIRE, EXTREME PRECIPITATION, AND POST-FIRE FLOODING

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LUCAS MOUTTET, FORT COLLINS UTILITIES

EXECUTIVE SUMMARY

On September 22–23, 2014, 23 scientists, resource managers, and urban planners convened in Las Vegas, Nevada, to discuss research and management needs related to severe fires and post-fire flooding in the Intermountain West. The workshop was motivated by the concerns of water management agencies about the potential for a changing climate to exacerbate fire impacts through: 1) projected increases in acres burned; 2) potential changes in the intensity of future extreme precipitation; and 3) the frequency of extreme events, which the National Climate Assessment projects to at least double across the region. The workshop was convened by the University of Arizona with funding provided by the U.S. Bureau of Reclamation.

The main purpose of this workshop was to further the understanding of the scientific and management decision-making research needs and gaps at the confluence of wildfire, post-fire floods, and extreme precipitation. Participants accomplished this by sharing lessons learned and best practices from case studies, through group discussions identifying research and management needs, and through the suggestions of participants to inform the development of a toolkit of processes and products to inform water and floodplain managers. Research, data, and management needs identified by workshop participants focused on the topics of extreme precipitation, fire ecology, flooding and sediment transport, water supply and reservoir infrastructure, and water quality. Key needs in each area are described briefly below and in further depth later in the body of this report.

RESEARCH NEEDS

- Optimization and prioritization of where to site new gauges
- Diagnostic analysis of storm formation, distribution across the watershed, and subsequent intensity
- Prediction of where large-scale debris flows will originate after severe, stand-replacing fire
- improved models for erosion and sediment transport in steep channels
- Identification of effective mitigation measures to reduce impacts on drinking water
- Fire effects on the biological productivity of streams

DATA NEEDS

- Site-specific precipitation data at 15-minute time resolution, to determine flood-triggering events
- Pre- and post-flood LIDAR measurements to measure flood elevations
- Reliable stream gauges that can withstand extreme flooding
- Frequent (every three years pre-fire; annual post-fire) reservoir bathymetric data to identify the location and amount of sediment deposited
- Baseline pre- and post-fire water chemistry data to understand potential infrastructure corrosion

MANAGEMENT NEEDS

- Integrated measures of watershed condition and extreme precipitation potential
- Best processes to develop integrated upstream-downstream planning and collaboration for promoting resilient forests and clean drinking water
- Improved fire-flood hazard mitigation plans
- Improved peer-to-peer and researcher-to-manager understanding of the relationship of fire/flood watershed water quality cycles
- Protection plans for refugia areas
- Operation or maintenance plans for regular bathymetric data collection—needed as an iterative process because plans are revised based on data
- Landscape characteristics to optimize water retention on the landscape

TOOLKIT

Workshop participants described the characteristics of a toolkit for assessing and managing flood impacts associated with wildfire. Collectively, the participants envisioned a web-based resource, supplemented by trainings, research, and other interactive elements. Participants identified several potential partners with possible interest in co-developing and maintaining such a resource, including NOAA RISAs, USDA-NRCS, the Water Utility Climate Alliance, Fire Science Consortia, and EPA. Participants identified the following web resource components:

- links to data
- links to guidance documents such as decision-support tools, vulnerability assessments, and scenario-planning exercises
- information such as case studies, synthesis and assessment documents, and hazard mitigation plans
- training on scenario planning and anticipatory planning (e.g., triple bottom-line vulnerability assessments and cost-benefit analyses)
- resources for locating grants and funding for research and action.

NATIONAL INTERAGENCY FIRE CENTER

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INTRODUCTION

During the last several decades, acres burned by wildfires in the southwestern United States have increased three-fold (Fleishman et al., 2013). The acreage of the largest wildland fires in the Intermountain West has increased by an order of magnitude, from tens of thousands to hundreds of thousands of acres, and each of the intermountain states in the Colorado River Basin has experienced its fire of record during the last 15 years. These changes in the sizes of wildfires are often attributed to a combination of early snowmelt, increased temperatures (e.g., Westerling et al., 2006; Williams et al., 2013), land management practices, and other factors (e.g., O'Connor et al., 2011). Moreover, the severity of some of these large wildland fires has increased, generating long flaming fronts, replacing acre upon acre of entire forest stands, incinerating soils, and establishing conditions ripe for erosion and debris flows (Stephens et al., 2013).

In many parts of the Intermountain West, fires break out in the arid foresummer or during long stretches of consecutive days without rain (Holden et al., 2007) due to human ignitions; they can spread rapidly because they occur during the windiest time of the year, and they often occur in steep and complex terrain. Following severe wildland fires, the inevitable high-intensity summer thunderstorm can trigger extensive erosion, debris flows, and other geomorphic changes. "In addition, debris flows following wildfire can occur in places where flooding or sedimentation has not been observed in the past, and can be generated in response to low-magnitude rainfall" (Tillery et al., 2011). Intense precipitation, years after a severe fire, can also generate debris flows and other geomorphic changes; this occurred in the Sabino Canyon Recreation Area in Tucson, Arizona, during a high-intensity precipitation episode in 2006, three years after the 84,750-acre Aspen fire (Magirl et al., 2007; Griffiths et al., 2009). Cascading from these secondary impacts of severe, stand-replacing wildfires are reduced downstream water quality and impacts to reservoirs, drinking water treatment infrastructure, and other infrastructure essential to urban areas such as roads, culverts, and pipelines. Furthermore, impacts can include the loss of water supply and storage, carbon sequestration, and other ecosystem services.

WORKSHOP OBJECTIVES

The main purpose of this workshop was to further the understanding of the scientific and management decision-making research needs and gaps at the confluence of wildfire, post-fire floods, and extreme precipitation. The workshop participants (Appendix A) aimed to better understand the connections between wildfire, post-fire flooding, and extreme precipitation, and evaluate the current state of knowledge of the overall topic. They accomplished this by sharing lessons learned and best practices from case studies (Appendix B), through group discussions identifying research and management needs, and through the suggestions of participants to inform the development of a toolkit of processes and products to inform water and floodplain managers (see Appendix C for the workshop agenda). This white paper provides a brief background of the topics covered during the workshop and describes workshop outcomes, mostly related to research, data, and management needs identified during workshop discussion.


DANITA DELIMONT

CLIMATE & EXTREME PRECIPITATION

CLIMATOLOGY OF THE INTERMOUNTAIN SOUTHWEST

Although the region is characterized mostly as arid to semiarid, the climate of the interior Southwest is varied and is strongly influenced by topographic contrasts, variations in the tracks of mid-latitude storms, the North American monsoon, and proximity to major bodies of water—the Pacific Ocean, the Gulf of California, and the Gulf of Mexico (Steenburgh et al., 2013). Of primary concern to this workshop, temperatures in the mountain and plateau forest regions are generally cooler than the rest of the region, and they influence the occurrence of snow, which makes up more than 60% of annual precipitation in the mountains of Utah and Colorado (Steenburgh et al., 2013). The majority of annual precipitation in much of the northern Great Basin, the intermountain areas, and the Colorado Rockies falls during the winter (December–February) and spring (March–May). In contrast, the majority of precipitation in the eastern half of Colorado and New Mexico falls between May and September, and much of Arizona and western New Mexico have a bi-modal annual precipitation pattern, receiving around half of their precipitation during the winter months and half during the summer months (June–August), with a strong dry period during the spring.

The region is prone to drought episodes, spanning from months to years and even multiple decades. The northern part of the interior Southwest, especially the intermountain region, which receives precipitation from multiple sources throughout the year, is less prone to long droughts (Steenburgh et al., 2013). Winter precipitation in the southern part of the region, including Arizona and New Mexico, is more strongly influenced by long-term interactions between the atmosphere and the ocean (e.g., El Niño, La Niña, Pacific Decadal Variability), and is thus more prone to longer droughts. Paleoclimate studies demonstrate the occurrence of multi-decade droughts once or twice per century across large parts of the interior Southwest (Cook et al., 2004). Modern and paleofire studies show strong connections between well-known climate patterns (e.g., El Niño, La Niña, Pacific Decadal Variability), drought, fuel regimes, and the occurrence and extent of fire (Swetnam and Betancourt, 1998; Westerling et al., 2003; Steenburgh et al., 2013; Fleishman et al., 2013). In some forest types such as ponderosa pine-dominated forests, wet conditions that generate increased fuel and more continuous fuel loads contribute to the rapid spread of fire when the forest dries out during drought episodes.

Extreme precipitation and floods are associated with winter half-year storm tracks, the propensity for warm ocean conditions to pump moisture into the atmosphere, and the summer half-year land-sea contrasts characteristic of the North American monsoon. Winter and spring storms can produce heavy precipitation and snowfall, especially during multi-day storm events. Atmospheric rivers, narrow bands of low-level tropical moisture, often entrained near the head of a cold front, can penetrate far inland and have produced notable historic floods (Steenburgh et al., 2013). Some warm winter or spring storm episodes can drop rain on top of the snowpack as well. Summer thunderstorms typically deliver large amounts of precipitation, with very high intensity during short periods of time.

Climate contributes to floods by exacerbating seasonal conditions or timing of precipitation and through the persistence of wet and/or warm episodes. For example, warm, slow-moving multi-day winter or spring storms such as atmospheric rivers can dump copious amounts of precipitation, contributing to flooding. Spring runoff floods can occur during years when snowpack persists late into the spring, or through heat waves or rain-on-snow warm storm episodes. Flash flooding is typically associated with summer thunderstorms, but occasionally tropical storms or the remnants of tropical cyclones can cause warm season or early fall flooding by dropping large amounts of precipitation, mostly in the southern part of the region. Figure 1 (below) shows the regional patterns of primary weather phenomena that lead to extreme precipitation and flooding across the western U.S.

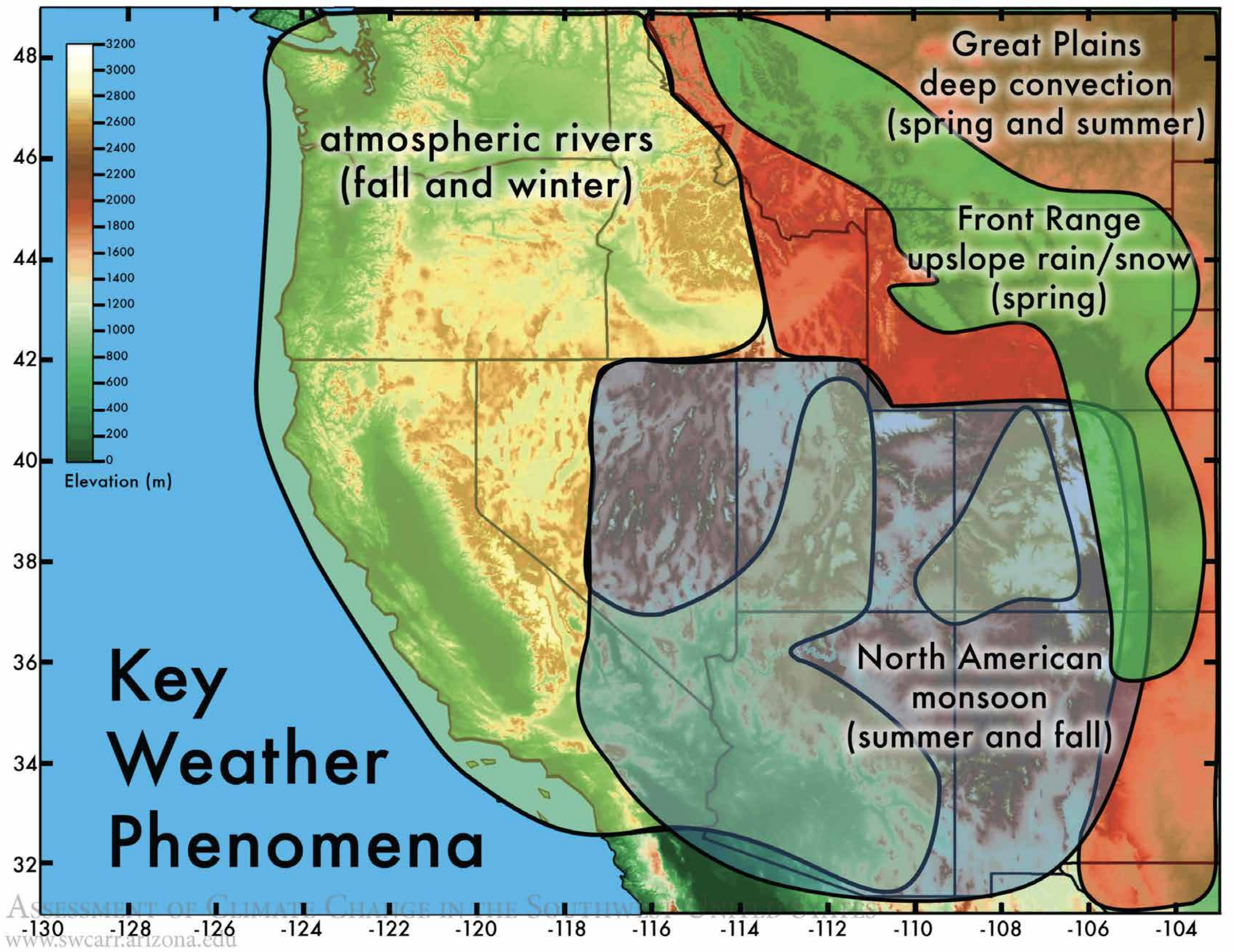


Figure 1: Key weather phenomena that cause extreme precipitation in the Southwest. Schematic illustration of regional patterns of the primary weather phenomena that lead to extreme precipitation and flooding while also contributing to water supplies (Guan et al., 2010; Dettinger et al., 2011), across the western United States. Modified from Ralph et al. (2011); see http://www.westgov.org/wswc/167%20council%20meeting%20-%20id/167%20council%20mtg%20-%20oct2011.html. Figure and caption taken from Gershunov et al., 2013.

OBSERVED CLIMATE TRENDS

Annual average temperatures, as averaged across the region, have increased 1.5 degrees Fahrenheit during the last 110 years, with a notable increase since the middle of the 20th century; in contrast, annual precipitation has not shown a strong trend (Hoerling et al., 2013). The observed increases in temperature have contributed to the earlier arrival of snowmelt and "peak streamflow" (the point at which half of the year's flow passes the stream gauge) in many snowmelt-dominated streams in the Southwest (Stewart et al., 2005; Barnett et al., 2008). Moreover, increases in temperature have been attributed to an increasing fraction of late winter and early spring precipitation falling as rain rather than snow at middle and lower elevations (i.e., less than around 7,500 feet) (Knowles et al., 2006; Regonda et al., 2005). The aforementioned trends contribute to conditions that would promote early snowmelt runoff floods. The frequency of extreme precipitation in the Southwest shows no statistically significant trend during the last 110 years (Hoerling et al., 2013), despite increases in extreme precipitation in many parts of the U.S. (Georgakakos et al., 2014). It is interesting to note that river flooding has decreased in the Southwest (Georgakakos et al., 2014).

PROJECTIONS OF THE FUTURE

TEMPERATURE

Given the assumptions of continued high rates of greenhouse gas emissions, downscaled climate model projections for the Southwest region confidently project temperature increases, including increases in the frequency, severity, and length of heat waves (Gershunov et al., 2013). Compared with the end of the 20th century, projections for the region include increases in annual average temperature of 3 to 5 degrees Celsius (5-9 degrees F) in the Intermountain Southwest by the middle to the end of the 21st century (Cayan et al., 2013) and an increased number of hot nights (i.e., nights in the hottest 2% of the 1971-2000 period) (Hatfield et al., 2014).

PRECIPITATION

Greater uncertainty is associated with projections of future Southwest precipitation. However, there is medium to high confidence in the following overall patterns: precipitation is projected to decrease in the southern part of the Southwest, with the winter and spring precipitation garnering the greatest agreement among model projections. Mountain snowpack also is projected to decrease during the late winter and spring months (February through May) due to the effects of increasing temperatures on snow hydrology (Reclamation, 2011; Cayan et al., 2013; Garfin et al., 2014). The winter and spring precipitation projections are related to observed and projected poleward shifts in the mid-latitude northeastern Pacific storm track and the projected enhancement and poleward extension of the descending (drying) limb of the north-south tropical atmospheric circulation known as the Hadley Cell, which causes a greater frequency of high pressure and clear, dry days (Cayan et al., 2013). Climate models show less agreement about projected changes to North American monsoon summer precipitation; thus, especially in those areas where monsoon precipitation accounts for much of the annual precipitation, the sign and magnitude of change is not yet clear. On the other hand, other hydrologic measures such as soil moisture are confidently projected to become more depleted due to projected temperature increases and changes in snowpack and recharge (Cayan et al., 2013; Gershunov et al., 2013; Georgakakos et al., 2014).

CLIMATE AND WEATHER EXTREMES

Enhanced precipitation extremes are projected for the Southwest, due to both the greater moisture availability in a warming atmosphere and the evaporative effect of increased temperatures (Gershunov et al., 2013). In terms of future high (wet) precipitation extremes, the most important projected change is in the amount of water vapor that the atmosphere can hold; recent studies show that the amount of global atmospheric water vapor has increased (Walsh et al., 2014), consistent with projected changes. Warmer air can hold up to around 30% more moisture, with a 9 degree-F increase in temperature—approximately the amount projected for annual average temperature increases in the interior Southwest (Cayan et al., 2013). Climate change projections show increases in heavy precipitation, even in regions where total annual precipitation is projected to decrease, such as the Southwest (Walsh et al., 2014). Such changes would lead to an increase in the potential for flash flooding (Georgakakos et al., 2014). The recent National Climate Assessment notes that "[w]arming is likely to directly affect flooding in many mountain settings, as catchment areas receive increasingly more precipitation as rain rather than snow, or more rain falling on existing snowpack. In some such settings, river flooding may increase as a result—even where precipitation and overall river flows decline" (Georgakakos et al., 2014).

Projected climate changes will interact with non-climate related land-use changes and through indirect effects of climate on vegetation and land cover. For example, climate change has increased the vulnerability of southwestern forests to tree mortality, insect infestations, disease outbreaks, and wildfire (Fleishman et al., 2013; Joyce et al., 2014). Projected climate changes suggest that Southwest forests will be affected by the combination of increased drought severity and frequency and by other extremes, and by the cascade of impacts from these extremes to biogeochemical cycles (Fleishman et al., 2013; Joyce et al., 2014). The risk of further episodes of widespread tree mortality in the Southwest is projected to increase through the effects of increased temperatures, episodic drought, and interactions with pests and pathogens. Projected forest fire impacts will be compounded by the legacy of fire suppression and associated historical increases in forest density (Joyce et al., 2014). If fuels and ignitions are available, the future area of forest burned is projected to increase substantially by mid-century, including estimates as low as 43% to 175% in Arizona and Rocky Mountain forests, respectively (Fleishman et al., 2013).

RESEARCH, DATA, AND MANAGEMENT NEEDS

Workshop participants noted the need for improved understanding of storm profiles and patterns. They highlighted the specific need for improved understanding of watershed-scale patterns and the influence of topography on the formation and intensity of storms

(Appendix D). Of equal importance is the need for more weather observation sites situated throughout watersheds; currently, observation sites are mostly in urban areas. The Slide Fire was the first fire with enough precipitation and gauge data to allow a comprehensive retrospective examination of the watershed-scale sequence of precipitation impacts on the post-fire landscape. Gauge locations and density sufficient for planning—before post-fire precipitation episodes—are key, and participants mentioned needs for funding and human resources to improve monitoring and preparedness.

Defining recurrence intervals for extreme precipitation events, such as a 1,000-year event, was also deemed an important research need, especially given that the Southwest has had two “1,000-year” storms in the past year (N.B.: referring to storms in 2013 and 2014). Participants remarked: “Maybe these weren’t 1,000-year storms? Or maybe recurrence intervals aren’t a good way to frame extreme events?” These are questions that drive the need for improved operational definitions of storm recurrence. Other research needs articulated by participants include: combining satellite and ground data, the long-term effect of climate on watershed parameters (including changes in vegetation and moisture), and the effects and timing of snowmelt on water supply (Appendix D).

The most important data need identified by participants is site-specific data with a resolution (10-15 minutes) sufficient to identify post-fire debris flow and flood event triggers and provide alerts. Participants noted that interpolated data, such as the PRISM data set (http://www.prism.oregonstate.edu/; Daly et al., 1994; DiLuzio et al., 2008), which interpolates from ground observations, is insufficient for identifying event triggers due to its coarse resolution. Also important is the pre-planning and analysis needed to site and install gauges, including alert system tipping buckets and Doppler radar installations.

From a management standpoint, creating a type of advanced warning system that combines fire, flood, and precipitation danger in a rating system, including the condition of the watershed, would be most beneficial for participants. Elements of an early warning system include an information hub that communities and groups can tie into and that can also send out reverse 911 messages. Participants recommended that the system be distributed partly as a mobile app to make it easily and quickly accessible by users. Participants also noted that a public awareness campaign would be needed to inform at-risk residents and facilities managers about the usefulness of the system and how to access and interpret data and warnings.


BRIAN VARRELLA, FORT COLLINS UTILITIES


DAVID HOSANSKY

FIRE ECOLOGY

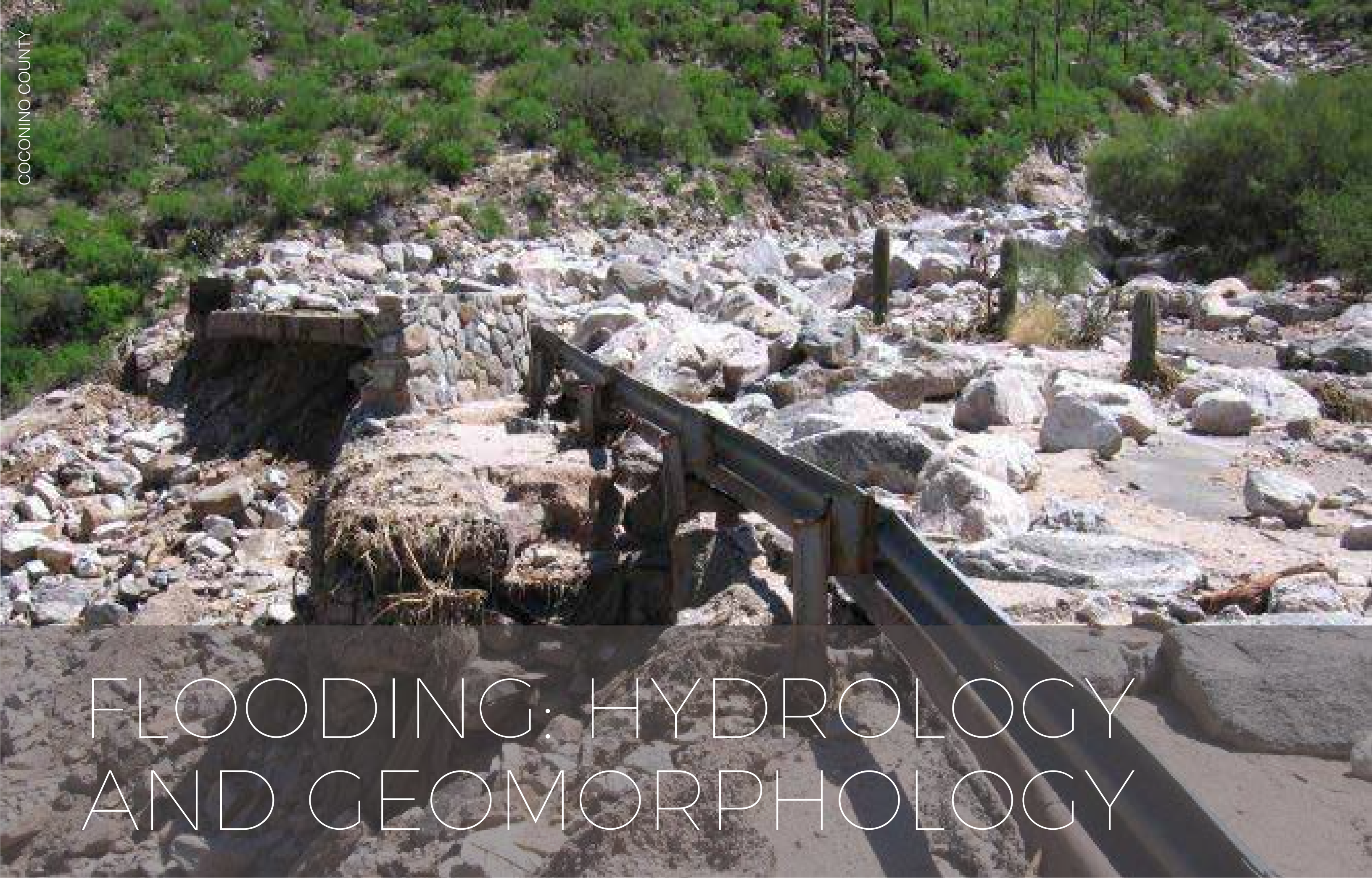
FOREST HEALTH

The health of a forest plays a large role in the severity and size of wildfire. As described earlier, several factors—including early snowmelt, increased temperatures, and land management practices—have increased the acreage of the largest wildland fires in the Intermountain West from tens of thousands to hundreds of thousands of acres (Williams et al., 2013). The severity of these large fires has also increased in some instances, with long flaming fronts that replace entire forest stands and incinerate soils (Joyce et al., 2014). Dry, windy conditions propel and sustain these types of fires, and in many parts of the region fires break out in the arid foresummer or during long stretches of consecutive days without rain. They often occur during the windiest time of year and can spread rapidly along steep and complex terrain.

Disturbances such as massive drought and bark beetle tree mortality episodes (e.g., Breshears et al., 2005) can contribute to conditions for stand-replacing fires during discrete times, such as when dying and dead trees retain their needles, typically during the first year of mortality (Allen, 2007). In addition, landscape-scale tree mortality can increase erosion potential due to lost forest capacity to hold soil moisture and retain particles (Breshears et al., 2011).

RESEARCH, DATA, AND MANAGEMENT NEEDS

Severe, stand-replacing wildland fires and tree mortality disturbances set the stage for large-scale debris flows (Youberg et al., 2010), and thus discussion mostly revolved around identifying needs to ameliorate the impacts of debris flows and sediment transport, both of which affect downstream water quality. The most important concern is identifying where large-scale debris flows will occur and how they will be conveyed downstream (Appendix E). Participants asked big questions: Is prediction possible? What would we need in order to make these predictions? In addition, as one participant noted, ash is an important regulator of post-fire runoff, which prompted an important research question: Can we use remote sensing to determine the depth of the ash layer after a fire? Another key need that focuses on both management and data is improving post-fire response. Research to determine improved methods for strategically sizing and placing forest treatments would improve post-fire response, because the connectivity of burn patches influences post-fire response and burned area recovery strategies. With respect to management, there is a need for social science studies to determine the best collaborative and/or public participation planning processes to gain buy-in for forest and watershed health treatments. Participants remarked that creating a healthy and resilient forest would improve the ability to maintain downstream drinking water quality, and it would be extremely useful for mitigating large, severe fires in the first place.



COCONINO COUNTY

FLOODING: HYDROLOGY AND GEOMORPHOLOGY

POST-FIRE CHANGES TO SOIL AND VEGETATION

Fire behavior and intensity during a wildfire determines burn severity and hydrologic responses after a fire (Keeley, 2009). In areas of moderate to high burn severity, consumption of vegetation, soil organics, and fine roots lead to increased runoff volumes and velocities due to a decrease of the surface roughness and an increased soil-water repellency, or a decrease in water infiltration (Youberg, 2013). This increase in the volume and velocity of runoff, in addition to decreased soil erosivity thresholds, results in an increased likelihood of flooding, erosion, and debris flows (Moody, Martin, and Cannon, 2008; Parsons et al., 2010; Moody and Ebel, 2013; Nyman et al., 2011).

FLOODING AND DEBRIS FLOWS

The combination of extreme precipitation and erosion can cause damaging floods and debris flows (Sham, Tuccillo, and Rooke, 2013) that are influenced by burn severity, slope steepness, and, particularly, rainfall intensity (Moody and Martin, 2009; Cannon et al., 2011; Kean et al., 2011; Staley et al., 2012). Just as important as rainfall intensity in determining the impact of post-fire flooding and geomorphic response is the footprint of the storm over the burned area and the susceptibility of the landscape. Debris flows, different than floods, are a combination of a matrix composed of water and fine sediment that supports and transports clasts ranging from gravel to boulders (Moody et al., 2013). In undisturbed areas, debris flows are often initiated by prolonged or intense precipitation falling onto saturated hillslopes (Cannon and Ellen, 1985; Webb et al., 2008b; Montgomery et al., 2009). In recently burned areas, however, debris flows are typically generated by relatively common, 2- to 10-year frequency, short-duration, low-magnitude storms (Cannon et al., 2008). Due to the high runoff volumes in recently burned areas where vegetation has been removed, even low-magnitude rainfall may generate a debris flow (Youberg et al., 2013).

IMPLICATIONS OF EXTREME PRECIPITATION

As floods and debris flows may be generated by storms with recurrence intervals of less than 10 years (Youberg, 2013), the implications of extreme precipitation events in post-wildfire areas are potentially very severe. The impacts of post-fire floods and debris flows generated by extreme precipitation events are much larger and more widespread than events triggered by common storms, and the impacts may be seen much farther downstream in the watershed (Youberg, 2013). A larger area of impact means that more communities would be put at risk.

RESEARCH, DATA, AND MANAGEMENT NEEDS

Workshop discussions on addressing the gaps and needs in research, data, and management of flooding and hydrologic or geomorphic change focused mostly on the needs for better tools and models to inform better response and mitigation (Appendix F). The most important research need identified by participants of the workshop is better models for erosion and sediment transport in steep channels. Two data needs stood out: LIDAR measurements of flood elevations taken pre- and post-flood, and reliable stream gauges that can withstand extreme flooding. Models that account for the non-stationary properties of flood-generating storms that originate from multiple sources (e.g., monsoon thunderstorms, tropical cyclones) and the ability of models to discriminate between multiple storm sources would also improve knowledge of the behavior and impact of post-fire flooding on soils, as well as knowledge of infiltration rates post-fire.

From a management perspective, the top priority by far is conveying to property owners that the dynamics of their landscape are constantly changing. If they understand this, they can better help prepare their property for flooding and hopefully prevent any or further damage. Other management needs identified by participants are hazard mitigation plans that address this unique scenario and a wildfire insurance program, such as the National Flood Insurance Program (NFIP), especially for people in the wildland-urban interface (WUI) who are currently not receiving insurance but are at greater risk of damage from fire and post-fire flooding.


RONNIE SCHELBY/U.S. ARMY CORPS OF ENGINEERS, ALBUQUERQUE DISTRICT


NATIONAL INTERAGENCY FIRE CENTER

FIRE & WATERSHEDS

WATER QUALITY

Wildfires alter watershed characteristics and often lead to changes in water quantity and quality in and downstream of burned areas (Neary et al., 2005). These changes can result in impacts to streams, reservoirs, aquatic habitat, and irrigation and hydroelectric infrastructure and may pose threats to communities who rely on clean water for municipal water supplies (Emelko et al., 2011; Smith et al., 2011; Sham et al., 2013; Bladon et al., 2014). In the first few years and up to a decade after a wildfire, runoff from burned areas produces changes in several water quality parameters, including nutrients such as nitrates and sulfates, pH, total dissolved solids (TDS), turbidity, and organic carbon, all of which may affect the color, taste, odor, and treatability of the water for drinking water purposes (Writer and Murphy, 2012). At the workshop, Dr. Chi Ho Sham (The Cadmus Group, Inc.) explained in his talk, Impacts of Wildfires on Water Quantity and Quality, that sediment transport increases up to 20 times post-fire, and total suspended solids (TSS) and turbidity may increase by orders of magnitude as well.

The magnitude of post-wildfire hydrological and erosional responses is a function of the size of the wildfire; the magnitude of the combustion of organic matter such as the surface litter, twigs, small branches, and trees; the size and arrangement of the burned patches on the landscape; and, most significantly, the intensity, amount, duration, and frequency of rain falling on the burned area. In addition to these factors, Dr. Sham explained that the magnitude of the effects on soil also depends on soil moisture and soil texture and properties. Though snowmelt can produce post-wildfire water quality impacts through landslides and slope failures, the main driver of the post-wildfire response in the western United States is rainfall; the timing, magnitude, and duration of precipitation are key factors in determining sediment transport (Ryan et al., 2011).

WATER SUPPLY

Wildland fire can affect water supply in many different ways. In addition to directly impacting reservoirs and other infrastructure, fires can have a substantial impact on the streamflow regime of streams and rivers, and they can affect the annual and seasonal water yield as well as the timing and amount of streamflows (Neary et al., 2011). Increased sediment from hillslope and channel erosion can lead to long-term effects on stream channels and reservoirs (Moody and Martin, 2001). Debris flows may enter reservoirs or lakes relied upon for drinking water and degrade the water quality. Excessive sediment in reservoirs not only affects water quality, but it may also threaten structures such as dams. Following the 2002 Hayman fire near Denver, Colorado, the Strontia Springs and Cheesman reservoirs, important for Denver’s drinking water supplies, were inundated with sediment. It is possible to dredge bodies of water affected by flooding and debris flows; however, this method is costly and resource intensive (Sham et al., 2013). Given this cost and the relatively slow pace of sediment removal, Denver Water felt the effects of the Hayman fire for several years, including reduced reservoir storage capacity.

RESEARCH, DATA, AND MANAGEMENT NEEDS

An entire session at the workshop was devoted to identifying the research, data, and management needs related to water quality and supply (Appendices G-I). The session was divided into three groups to discuss needs related to:

- Water quality for drinking water
    - The most important research need is an improved understanding of effective mitigation measures to reduce the impact on drinking water quality. Another key research need focused on a longer timescale: improved understanding of the relationships between fire intensity and severity on groundwater. Similarly, data sets are needed to monitor and document the length of time a fire will continue to have impacts on water quality; this would help with long-term planning of potential impacts. A better understanding of the types of organic and inorganic chemical constituents being carried down from the burn area is also needed. Improved communication between researchers and water managers and among water management peers would enhance managers' understanding of the relationship between fire-and-flood cycles and their impacts on water quality cycles. Finally, informing elected decision makers about the complexity of the relationships between watershed attributes and subsequent post-fire water quality issues would help managers and others gain support to fund strategic pre-fire planning and mitigation measures.
- Water quality for ecosystems
    - Participants identified two important research needs to mitigate impacts of fires and floods on ecosystems: establishing baseline conditions in order to measure changes and determining how fires change the biological productivity of streams. Key research questions related to streams are: What are the tipping points? How does algae react to excess nitrogen and phosphorous? High-priority data needs include long-term data sets of evolving nutrient levels (pre- and post-fire), data to help define the availability of sediment (using remote sensing), and data on post-fire properties of streams, such as stream temperature, dissolved oxygen, and other chemical properties. The highest priority management needs identified in the workshop are protection plans for refugia areas and sediment control infrastructure and plans for managing sediment, both of which could help ameliorate impacts on riparian habitats.
- Water supply, reservoir infrastructure, sediment issues, and loss of capacity and supply redundancy
    - Several research needs related to water supply and sediment issues in reservoirs were deemed important by participants, including researching the timing of sediment transfer from storage reservoirs, determining the effect of burned areas on snowmelt magnitude and timing, and performing cost avoidance analyses associated with differences in sedimentation rates. Reservoir bathymetric data, including the location and amount of sediment deposited, taken frequently—every three years pre-fire and annually post-fire—would help anticipate management of sediment accumulation in reservoirs. Since the data would be collected recurrently, an operation or maintenance plan would need to be in place to implement changes based on the data. Another high-priority need is for baseline data of pre- and post-water chemistry, as well as an improved understanding of the sediment chemistry and how the constituents are mobilized into the water column over time, to mitigate against potential infrastructure corrosion. The highest priority management science need is improved understanding of landscape characteristics to optimize water retention on the landscape, in contrast to increasing water retention by raising the heights of dams.

COCONINO COUNTY

MANAGEMENT PERSPECTIVES AND DECISION SCIENCE

INTRODUCTION

The process of planning, decision making, and managing short- and long-term wildfire risks is highly complex and burdened with high levels of uncertainty. Such processes involve a wide range of community institutions and agencies, ranging from the private sector to the federal government, which must coordinate short- and long-term planning and response activities to be effective. Wildfire can, to a greater or lesser extent, impact all of a community's residents; businesses and response activities will often require their active engagement. The natural dynamics of wildfire and post-wildfire events and impacts are complex, and understanding these dynamics requires a wide range of science and expertise. Many of the factors that influence the risks of wildfire and subsequent community and environmental impacts are not well understood and their future trends are uncertain. To be effective in this environment, several basic approaches for planning are suggested:

1. The process be participatory and include a wide range of stakeholders, including multiple agencies, as well as the public at large;
2. A panel of experts on the dynamics of wildfire and post-wildfire events be convened; and
3. An exploratory scenario planning approach be used to develop strategic plans that anticipate an uncertain future.

VULNERABILITY

Dr. Ray Quay (Arizona State University) outlined the risks and costs of wildfire to urban areas in his talk, Fire, Post-fire Flooding and Extreme Precipitation: Management Perspective, Risks to Urban Areas, Values at Risk, Costs. The risk of wildfire is largest in the WUI and in remote areas. The primary risks of wildfire include risk to life, property, and health from reduced air quality; secondary risks pertain to the economy, tourism, and traffic. Risks to urban areas also include risk to streets, bridges, sewers, and other public infrastructure. A community's vulnerability to the threat of wildfire can be assessed using the following three factors:

1. Occupancy, or the area that is inhabited and developed
2. Interface, or the WUI
3. Dispersal, or the distance between concentrated populations in the forest system

Storm events within a watershed that has been impacted by wildfire can result in increased amounts of runoff, erosion, and sediment and debris transport. This can create catastrophic flood events and may harm the quality and quantity of runoff within a watershed. There are four critical components that must be considered when assessing a watershed's increased vulnerability to storm events after wildfire:

1. Risk of the occurrence and type of wildfire
2. Probability that a storm event will occur, the intensity of the event, and the time span between the fire and event
3. Watershed characteristics (size, soil permeability and erodibility, and slope)
4. Assessment of the potential flood event and its potential impacts

MITIGATION AND RISK REDUCTION

There are many strategies for reducing the risk of a wildfire, including control burns, or prioritized fuel reduction, treatment of structures and urban/rural landscapes for ignitability, and funding other professional mitigation efforts (Muller and Schulte, 2006). Managing activities in the WUI can reduce the risk of a wildfire being started and reduce vulnerability of urban areas during a wildfire. During high fire risk conditions, limiting access to the forest from the WUI and patrolling areas of high activity (picnic areas, campsites, etc.) can reduce the risk of accidental ignition. Such monitoring is effective if volunteer groups are trained and used to monitor activities. Once a large fire has burned, having an emergency preparedness and response plan may help to mitigate some of the damage to water quality (Sham et al., 2013).

ECOSYSTEM SERVICES

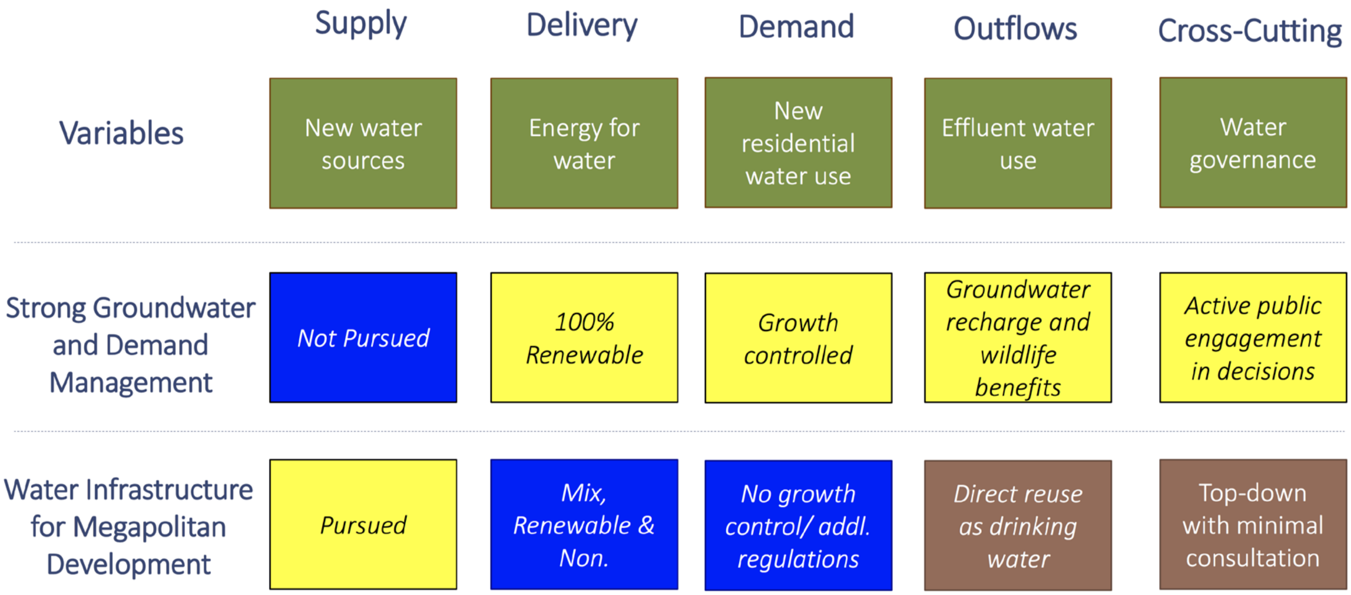
Ecosystem services are the benefits that people obtain from ecosystems (Millenium Ecosystem Assessment, 2005). Ecosystem services can be separated into four main categories: provisioning and production services (e.g., timber, fiber, food, water supply), regulating services (e.g., carbon storage, water quality, pollination), habitat and supporting services (e.g., biodiversity), and recreational and cultural services (e.g., aesthetics, spiritual value, fitness). Production services are typically the main focus of economists, although researchers have mentioned that the services provided by healthy watersheds are often undervalued and under-protected (Postel and Thompson, 2005). The watersheds of the intermountain region of the Colorado River Basin provide a wide array of these beneficial goods and services.

In recent years, researchers and others have framed watershed restoration and protection efforts in terms of the value of their ecosystem services. There have been initiatives in many countries, including the United States, to link the protection of forested watershed headwaters with payments from downstream communities for the services of upstream forests (Postel and Thompson, 2005; Stenger et al., 2009; Goldman-Benner et al., 2012). Payments for watershed ecosystem services, so-called water funds, have been planned or implemented in the Intermountain Southwest, including in Santa Fe, New Mexico, Denver, Colorado (Bottorff, 2014), and Flagstaff, Arizona (Stempniewicz et al., 2012). Similar mechanisms could serve as a potent tool for adapting to uncertain or changing conditions while addressing the intersection of complex driving forces of watershed change, such as fires, extreme precipitation, and post-fire floods.

ANTICIPATORY PLANNING AND SCENARIO PLANNING

In addition to outlining the risks and costs of wildfire to urban areas, Dr. Quay also described reasons why planning can be difficult. For example, there is large uncertainty related to (a) climate extremes and when and where they will occur, and (b) the wide range of community institutions required to coordinate planning and response. He emphasized that uncertainty about the future need not be a barrier to planning and decision making. To address difficulties, Dr. Quay described the idea of anticipatory planning, which involves anticipating a wide range of possible futures and developing multiple strategies. He provided several case studies from Phoenix, Arizona, including water resources plans and future water scenarios. In particular, he described in depth two sustainable water future scenarios: (1) strong groundwater and demand management, and (2) water infrastructure for megapolitan development. The differences between the two scenarios are outlined in Figure 2. After running a water simulation analysis of both scenarios aimed at identifying maximum sustainability of water supplies, results show that at a certain point, climate change pushes the system away from a preference for the strong groundwater and demand management scenario to a preference for investment in water infrastructure to support megapolitan development. Dry conditions yield less than sufficient water supply, and the annual demand met by groundwater will become too high for a sustained yield.

Exploratory scenario planning is a type of anticipatory planning that identifies a range of possible future scenarios, rather than a single future that is most likely, in order to prepare for situations in which one or more factors is highly uncertain and/or out of the control of resource managers and planners (Börjeson et al., 2006; Chakraborty et al., 2011; Holway, 2011; Holway et al., 2012; Quay, 2010, 2011; Weeks et al., 2011). Exploration of the implications of these futures can help communities or organizations achieve long-term goals or reduce the impact of adverse conditions. Scenario planning methods are particularly useful for planning problems that are burdened with highly uncertain futures, such as natural disasters and climate change. Using an assessment of a wide range of futures (foresight), decision makers and managers can anticipate strategic actions that can be taken now and over time to adapt to possible future impacts. The process of exploratory scenario planning in practice can take many forms (Gidley et al., 2009; Hopkins and Zapata, 2007; Sheppard et al., 2011; van Drunen et al., 2011; Varum and Melo, 2010; Walker et al., 2013). Often there are five phases: 1) Scenario Definition; 2) Scenario Construction; 3) Scenario Analysis; 4) Scenario Assessment; and 5) Risk Management (Mahmoud et al., 2009). When addressing issues of public policy and management, participatory scenario-planning processes are used to engage the widest number of relevant institutions and stakeholders. Typically, ranges of futures/scenarios relevant to the planning issue are created through



	Supply	Delivery	Demand	Outflows	Cross-Cutting
Variables	New water sources	Energy for water	New residential water use	Effluent water use	Water governance
Strong Groundwater and Demand Management	*Not Pursued*	*100% Renewable*	*Growth controlled*	*Groundwater recharge and wildlife benefits*	*Active public engagement in decisions*
Water Infrastructure for Megapolitan Development	*Pursued*	*Mix, Renewable & Non.*	*No growth control/ addl. regulations*	*Direct reuse as drinking water*	Top-down with minimal consultation

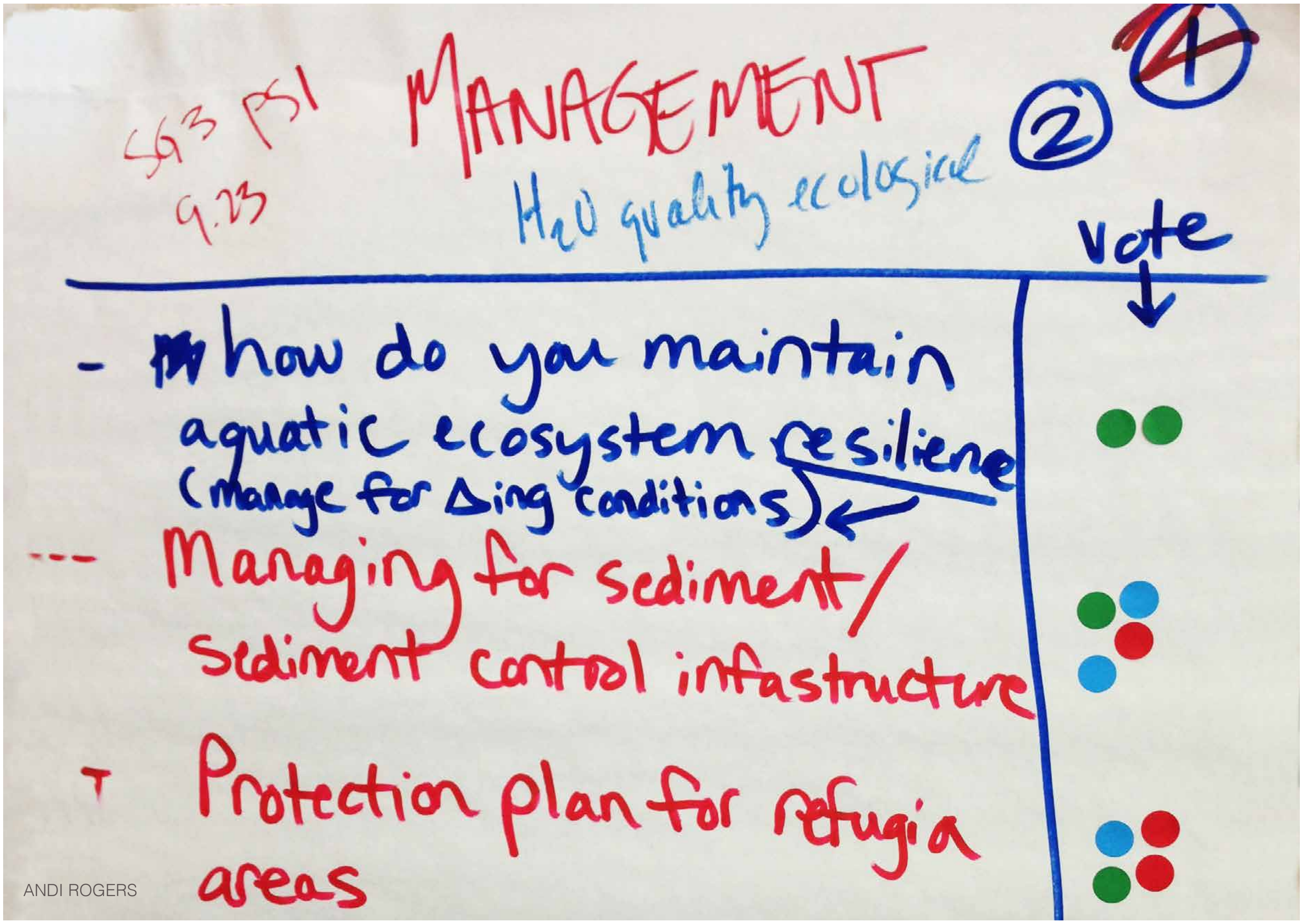
Figure 2: The differences in supply, delivery, demand, outflows, and cross-cutting between two sustainable future water scenarios—strong groundwater and demand management, and water infrastructure for megapolitan development. Modified from Keeler et al. (2015).

a participatory process. Experts working with stakeholders analyze the ways in which these scenarios impact (negatively or positively) the ability for the community to achieve objectives or maintain resource management values. The group then uses this analysis to anticipate how the community may adapt to possible future changes. Scenario planning, then, can be a potent tool for addressing the complex interactions of severe fires, post-fire floods, and their downstream impacts.

ENHANCING COORDINATION AND COLLABORATION

Workshop discussion about anticipatory and scenario planning illuminated some key research information and tools that could enhance coordination and collaboration. These included county, state, and FEMA multi-mitigation plans; source water protection cost/benefit analyses (such as triple bottom-line analyses); tools that measure the impact of each scenario; an inventory of anticipatory planning tools such as sensitivity and dynamic simulation models and examples (by state, region, and topic); and tools for providers with little capacity.

In addition, this workshop and others like it enhance coordination and collaboration by bringing together managers, scientists, and policymakers. Anne Bradley (The Nature Conservancy in New Mexico) outlined outcomes from a related workshop, Fostering Resilience in Southwestern Ecosystems, convened in February 2014. The workshop provided managers, scientists, and policymakers the opportunity to interact and discuss concepts of resilience in a time of changing climate and fire regimes. Objectives of the February 2014 workshop were to identify and evaluate current and potential resilience-building practices; identify management goals and objectives for improving practice; identify and prioritize future research needs; collaboratively develop a set of key recommendations and next steps; and improve natural resource managers' ability to help communities become fire adapted. Some key needs identified by participants in the February 2014 workshop, as outlined in Ms. Bradley's presentation at the September workshop, included the need for post-fire evaluation of previous management actions and evaluation of the long-term effectiveness of post-fire treatments. Also, participants acknowledged that there is a limited set of tools, such as thinning, prescribed fire, and planting; how we use them and how well they are accepted was a key discussion of the challenges of moving from restoration to resilience.



SG3 PSI
9.23

MANAGEMENT ② ④
H_2O quality ecological

vote

- how do you maintain aquatic ecosystem resiliene (manage for Δing conditions) ●●
- Managing for sediment/ sediment control infastructure ●●●●
- Protection plan for refugia areas ●●●●

ANDI ROGERS


ANDI ROGERS

A FIRE-FLOOD TOOLKIT

Workshop participants described the characteristics of a toolkit for assessing and managing flood impacts associated with wildfire. Some elements that participants valued, based on discussion of existing resources, included data tools (precipitation, LIDAR, aerial photography), online analysis tools (e.g., fire risk maps, post-fire flood risk prediction), assessment processes and reports, research and public record bibliographies, multi-entity knowledge-exchange consortia and peer-to-peer learning networks (e.g., the Joint Fire Science Program fire consortia), and cross-disciplinary trainings. However, they noted that these elements lack connections between the watershed, fire, floodplain, and water resources communities, and lack coordination between municipal, county, state, watershed, and federal efforts.

Collectively, the participants envisioned a web-based resource, supplemented by trainings, research, and other interactive elements. One precedent for such a system is the National Integrated Drought Information System, which combines a number of elements: a multi-source (e.g., multiple agencies), multi-jurisdictional (e.g., state, national), and multi-scale (state, regional, national) web portal; a research branch; capacity building for regions and communities; and a suite of pilot projects to gain knowledge through doing and to support exchange of knowledge across parts of the United States. Other precedents included alliances, such as the Arkansas River Basin Roundtables, which combines perspectives on multiple aspects of basin watershed health with an online document archive, and a joint planning and project implementation consortium.

Workshop participants cited the following attributes of an online system, conceived of as a proof-of-concept project, which would require ongoing maintenance:

- Geographic scope: the western United States
- Temporal scope: ranging from pre-fire to post-flood
- Scalability
- Comprehensiveness
- Geospatial location referencing
- Queryable
- Connections to social media

They defined the following elements, perhaps as pages, of a fire-flood web portal:

- Data
    - Data inventory, including fire, hydrology, precipitation (including forecasts), water quality
    - Links to existing datasets
        - Parsed by political (e.g., state) and watershed boundaries
- Guidance
    - Decision-support tools
    - Vulnerability assessments

    - Scenario planning practice guides, assessments, and case studies
- Information resources
    - Scientific literature, bibliographies
    - Synthesis and assessment documents
    - Hazard mitigation plans
    - Case studies
        - Individual projects such as research projects, mitigation and restoration projects, etc.
    - Library of PowerPoint presentations and graphics
- Training resources
    - Scenario planning and other anticipatory planning methods, including triple bottom-line vulnerability assessments and cost-benefit analyses
    - Transdisciplinary (climate and weather, ecology, fire, floodplain management geomorphology, hydrology, water quality, water resources) training information and dates of trainings
- Funding resources
    - Information for resource managers to locate grant opportunities and calls for proposals for research and actions such as project implementation
- Social media resources
    - Blog and Q&A threads
- Ability to provide feedback on the website and to contribute to website development (Wiki-like)

Finally, participants noted the considerable challenges in developing this much-needed resource. These include identifying an appropriate and willing sponsor, garnering funds for development and maintenance, garnering review of the website content and usability, and researching integration with other online resources and initiatives. They suggested a phased approach to funding, which could draw upon resources from individual agencies for implementation of particular aspects of the overall package. Another approach to garnering funding, suggested by participants, is to charge fees for some tools and services. Funding estimates included approximately $50,000 for initial development and $50,000 for revision, based on the U.S. Army Corps of Engineers' After Wildfire Website (http://afterwildfirenm.org/). Another estimate for maintenance, based on the Sonoran Institute's SCOTie website (Successful Communities Online Toolkit - http://www.scotie.org/), was for a half-time employee devoted to website content maintenance, with costs on the order of $25,000-$40,000 per year. Participants also identified potential partners that may have the motivation, interest, and expertise to develop and implement a pilot toolkit, including NOAA Regional Integrated Sciences and Assessments (RISA) programs, USDA-Natural Resources Conservation Service (NRCS), the Water Utility Climate Alliance, and the EPA.

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Appendix A: Workshop Participants

First Name	Last Name	Organization
Anne	Bradley	The Nature Conservancy in New Mexico
Keely	Brooks	Southern Nevada Water Authority
Evan	Canfield	Pima County Regional Flood Control District
Gregg	Garfin	University of Arizona
Mia	Hammersley	University of Arizona
Lauren	Jaramillo	University of New Mexico
Ted	Johnson	CDM Smith
Don	Kennedy	Denver Water
Eric	Kennedy	Arizona State University
Elizabeth	Kurtz	Arizona State University
Deborah	Martin	USGS - Boulder
Jill	Oropeza	City of Fort Collins
Ray	Quay	Arizona State University
Andi	Rogers	Southwest Decision Resources
Jeanne	Ruefer	Tetra Tech, Inc.; Assoc. of State Flood Plain Managers
Stephen	Scissons	U.S. Army Corps of Engineers
Windy	Selig	Selig Facilitation in Natural Resources
Chi Ho	Sham	The Cadmus Group, Inc.
Tim	Skarupa	Salt River Project
Paul	Summerfelt	City of Flagstaff Fire Department
Tim	Sutko	Clark County Flood Control District
Anne	Tillery	USGS - New Mexico
Ann	Youberg	Arizona Geological Survey

Appendix B: Case Studies

ARIZONA — PAUL SUMMERFELT, CITY OF FLAGSTAFF WILDLAND FIRE MANAGEMENT OFFICER

Several large fires in Flagstaff, Arizona, especially in 2006 and 2010, destroyed forests, threatened water supplies, and resulted in severe post-fire flooding. The city, county, and state have spent millions on fire suppression. But, said Summerfelt, society will end up spending more money on post-fire impacts because suppression does not address one of the root causes—the accumulation of fuels in the forest. “The only way to get ahead of this is pre-fire,” he said.

Flagstaff voters, tired of dealing with “too much water in their houses, and not enough out of the faucet,” Summerfelt said, acknowledged the need for pre-fire treatment to reduce the risk of severe wildfires and post-fire flooding in two local watersheds. In 2012, 74% of Flagstaff voters approved a $10 million bond measure. The effort focuses on treating forests—both those already approved for treatment and new areas analyzed for treatment. The city and county are now igniting more prescribed fires, and in 2014, two million trees were cut in the city to reduce fire risk. In order to gain voter approval for the bond, Mr. Summerfelt emphasized the role of community preparation—it takes time and effort before even discussing the bond with the community. He cautioned that the worst time to engage with the public is during a fire event. In preparing the community, he emphasized that establishing credibility and gaining the support of partners are both essential steps. To effectively communicate the benefits and opportunities of investing in watershed treatment to reduce the risks to water quality and supply, he suggested that it is important to convey that (a) forests are critical infrastructure, (b) the brunt of a lack of watershed treatment will be borne by the city and its residents, and (c) waiting for help from others, such as the federal government, will not address the imminent risks to individuals. He mentioned that people are willing to spend money if they perceive the problem as personal, as a threat to their health, safety, and property.

NEW MEXICO — STEPHEN SCISSONS, U.S. ARMY CORPS OF ENGINEERS

Two large fires in New Mexico in 2011 and 2012 decimated hundreds of thousands of acres of forest and led to multiple post-fire flooding events. The Las Conchas fire in 2011 started when wind knocked a tree into a power line in the Jemez Mountains in the center of the state. The fire burned almost 160,000 acres at the incredibly rapid rate of one acre per second. At the time, Las Conchas was the largest instrumentally recorded fire in the history of New Mexico. On August 21 of the same year—about 20 days after full containment of the fire—a rainfall event led to runoff that was more than four times greater than pre-fire runoff. In Santa Clara Canyon, the rainfall event was a 1-inch/8-hour event, and in Cochiti Canyon the event was a 1.6-inch/8-hour event; in other words, only a five-year extreme precipitation recurrence event. Scissons pointed out that these impacts were not restricted to riparian areas, but extended to Cochiti Reservoir, a key drinking water supply for Albuquerque. Ash, debris, and sediment transport halted water delivery from Cochiti to Albuquerque for a month.

The Whitewater-Baldy Complex fire in 2012 began as two separate lightning-caused fires in the Gila National Forest of Southwest New Mexico and burned about 300,000 acres. It succeeded Las Conchas as the fire of record. During the September 2013 precipitation event that drenched areas from the Front Range of Colorado all the way to southern New Mexico, five to six inches of rain fell in Whitewater Creek in 10 hours. The event aggraded and filled in between six and eight feet of an incision that developed in 2011—a startling amount of debris and sediment transport.

Before the two aforementioned fires, the 2000 Cerro Grande fire—infamous for being an escaped prescribed fire that produced extensive damage to the city of Los Alamos, New Mexico—was the largest severe fire event in the historic record. This prompted discussion regarding expectations about changes in the severity and extent of fires, their impacts on water quality and infrastructure, and the need for revised water infrastructure design standards. Moreover, Scissons emphasized great uncertainty about current structural flood risk reduction measures and whether they will last sufficiently to address the risks of what may be larger or more severe future fires.

COLORADO — JILL OROPEZA, CITY OF FORT COLLINS WATERSHED PROGRAM MANAGER

In May 2012, forests near Fort Collins, Colorado, were stressed by drought and experiencing high mortality from insect infestation. In June, the High Park fire burned 87,000 acres. The fire led to power loss and shut down of the Poudre River supply pipeline—one of two water supplies for the City of Fort Collins—for 100 days following the fire, forcing the city to switch to the Horsetooth Reservoir as an alternative. Post-fire flooding impacted water quality, damaged personal property and infrastructure, and threatened public safety.

Oropeza outlined “better practices”—labeled as such because they are continually improving—for post-fire management. These include (1) a distributed water quality monitoring network with a strong baseline source, supported by collaborative partnerships to maintain instruments and share observations, (2) real-time instrumentation with memoranda of agreement for private landowner monitoring partners to install alternate power supplies to fend off loss during fire or flood episodes, accompanied by high-resolution depiction of variability that can track events and integrate with warning systems, (3) early warning capabilities, (4) integrated flood, weather, and water quality alert systems, (5) storm event sampling that can also track watershed recovery and compare it with the worst-case scenario, and (6) increased reservoir capacity to accommodate sedimentation, and with an ability to manage, reduce, or avoid turbidity.

Oropeza mentioned water quality research needs, including impacts on taste and odor (important for local businesses, such as breweries), information on how fires impact total organic carbon and disinfection by-products, and fire impacts on riverbank sediments. Research needs related to post-fire treatments include evaluation of the effectiveness of mulching to control sediment transport at the basin scale and post-implementation monitoring of treatments to evaluate their effectiveness in reducing water quality impacts and improving sediment retention.

High Park Fire lessons learned by the city of Fort Collins are as follows:

- Before the fire: 1) the planning process must consider fires as precursors for subsequent disasters such as floods, thus, floodplain planning needs to incorporate adequate buffers downstream of burned watersheds; 2) better tools are needed for scenario planning to inform emergency response and financial planning, starting with fire hazard maps and incorporating burn severity information and hydrologic response models; and 3) better coordination of fuels reduction and forest management funding and work is needed to address wildfire risk at the landscape scale.
- During the fire: building an understanding of new watershed conditions is needed to address treatment and operational challenges; integrated early warning systems are effective in saving lives and assets.
- After the fire: agencies need to have access to subject matter experts, scientific literature, and other tools to make informed decisions about post-fire recovery, and coalitions need to allow restoration work to continue after emergency funding sources are exhausted.

Appendix C: Workshop Agenda

MANAGING FOR FUTURE RISKS OF FIRE, POST-FIRE FLOODING AND EXTREME PRECIPITATION
SEPTEMBER 22-23, 2014 — SOUTHERN NEVADA WATER AUTHORITY — LAS VEGAS, NV

WORKSHOP OBJECTIVES

- Identify and document biophysical and management science needs and gaps with regard to the overall topic of fire, post-fire flooding, and extreme precipitation
- Evaluate the state of knowledge and develop common understanding of current research and management
- Share lessons learned and best practices from case studies and participant expertise to inform the development of a toolkit for water and floodplain managers

Day 1 (September 22, 8:15am – 5:30pm)	
8:15 – 8:45	Registration
8:45 – 9:15	Welcome and Introductions – *Gregg Garfin, University of Arizona*
9:15 – 9:45	Fire and Watersheds – *Chi Ho Sham, The Cadmus Group, Inc.*
9:45 – 10:15	Flooding and Hydrology/Geomorphology (research and tools) – *Deborah Martin, USGS*
10:15 – 10:45	Management Perspective, Risks to Urban Areas, Values at Risk, and Costs – *Ray Quay, Arizona State University*
10:45 – 11:05	BREAK
11:05 – 11:35	Climate/Extreme Precipitation/Fire Changes – *Gregg Garfin, University of Arizona*
11:35 – 11:55	Outcomes of Fostering Resilience in Southwestern Ecosystem Workshop – *Anne Bradley, The Nature Conservancy*
11:55 – 12:15	Introduction of Toolkit – *Gregg Garfin, University of Arizona*
12:15 – 1:30	LUNCH
1:30 – 1:40	Group Session Overview – *Andi Rogers, Southwest Decision Resources*
1:40 – 2:55	Small Group Discussion 1: Pre, During, and Post-Fire Discussion
2:55 – 3:15	BREAK
3:15 – 3:45	Case Study: Arizona – *Paul Summerfelt, City of Flagstaff*
3:45 – 4:15	Case Study: New Mexico – *Stephen Scissons, U.S. Army Corps of Engineers*
4:15 – 4:45	Case Study: Colorado – *Jill Oropeza, City of Ft. Collins*
4:45 – 4:50	Group Discussion 2 Overview – *Andi Rogers, Southwest Decision Resources*
4:50 – 5:30	Group Discussion: Case Study Reflection/Discussion
5:30	ADJOURN

Day 2 (September 23, 8:30am – 4:00pm)	
8:30 – 8:45	Recap of Day 1 – *Gregg Garfin, University of Arizona*
8:45 – 8:55	Group Discussion and World Café Overview – *Andi Rogers, Southwest Decision Resources*
8:55 – 10:15	Small Group Discussion 2 – World Cafe: Assessing Needs and Gaps: Forests, Floods, Extreme Precipitation
10:15 – 10:35	BREAK
10:35 – 11:40	Small Group Discussion 3 – World Cafe: Assessing Needs and Gaps: Water Quality, Supply, Infrastructure
11:40 – 12:40	LUNCH
12:40 – 12:50	Group Discussion Overview – *Andi Rogers, Southwest Decision Resources*
12:50 – 1:50	Perspectives on Management of Pre- and Post-wildfire – *Ray Quay, AZ State University.* Group discussion
1:50 – 2:10	BREAK
2:10 – 2:15	Group Discussion Overview – *Andi Rogers, Southwest Decision Resources*
2:15 – 3:55	Small Group Discussion 4: Moving Forward/Addressing Needs – The Toolkit
3:55 – 4:15	Wrap Up and Next Steps – *Gregg Garfin*
4:15	ADJOURN

Appendix D: Needs Related to Extreme Precipitation

(Needs in red were voted to be highest priority by participants).

Research	Data	Management
Optimization of where to site new gauges; prioritization (5)	Site-specific data: temporal scales = 15 minute resolution for triggering events; interpolated data are not sufficient (5)	Flood alert systems (1)
Need to recalculate recurrence intervals for, e.g., 1,000-yr precipitation event (4)	Lack of observations; lack of mountain observations, orographic effects (0)	Communication to the public about extreme precipitation; develop in conjunction with watershed post-fire severity classes (0)
Better way to model what topography does to rainfall ›› influence on storm formation and intensity (2)	Pre-planning needed to install gauges; Alert system tipping buckets, radars, analysis (4)	then combine with precipitation potential; system approach ›› precipitation. ranking + watershed condition = integrated measure; NWS Arizona does this – PSAs; Clark County/USFS (9)
Understanding effect of storm track on subsequent precipitation (0)	High water mark data collection (both sides of channel) (1)	
Diagnostic analysis of storm formation, distribution across watershed, subsequent intensity (5)		
Combining satellite and ground data (3)		
Long-term effect of climate on state of watersheds (2) • Changes in vegetation and moisture		
Effects and timing snowmelt on water supply (1)		
Impacts of losing snowpack on water supply		
Defining extreme precipitation (3)		

Appendix E: Needs Related to Fire Ecology

(Needs in red were voted to be highest priority by participants).

Research	Data	Management
Predictions of large fire locations (0)	Up-to-date pre-fire vegetation layers, including invasive species for fire behavior modeling (1) • Include status (moisture content)	What pre-fire treatments are most effective by forest type (2)
As it relates to non-characteristic fire (severe, stand-replacing), can we predict where large-scale debris flows will originate (5) • Sediment routing: if big event, when and how is it conveyed downstream	Status of soil moisture as an indication of potential fire behavior (fuel profile, moisture condition; duff layer moisture) (0) • What is the duff layer depth	What is best process (collaboration, planning, etc.) that results in a resilient forest with healthy/clean drinking water (5)
Impacts of forest treatments (thinning, burning) in riparian areas, in order to maintain appropriate stream temperatures (0)	Status of soil moisture as a post-fire predictor of runoff (2) • Remote sensing needed – at what scale available and useful for hydrologic models?	How do we communicate new, recent, relevant info on beetle-kill impacts? Improve this (1) • Misinformation about how beetle kill affects fire danger over time • Need better communication with public
Can we use remote sensing to determine the depth of the ash layer after fire? (3) • Ash is important regulator of post-fire runoff		
Can you use fire severity to predict the physical (thickness of ash layer) and chemical properties of ash to understand the effects on soil hydraulic properties (e.g., hydrophobic, etc.) (1)		
Strategic size and placement of treatments (3) • In terms of post-fire response • Connectivity of burn patches influences the post-fire response		

Appendix F: Needs Related to Flooding, Geomorphic Change, and Sediment Transport

(Needs in red were voted to be highest priority by participants).

Research	Data	Management
Identify floods and rainfall events as forcing mechanisms (4) • Discriminate between monsoon and tropical storms ›› each yields a different 100-yr storm	LIDAR pre-and post-flood (9) – to measure flood elevations	Convey to property owners that the dynamics of the landscape on which they live is in constant flux (10) • This trumps property rights concerns
Better models for erosion and sediment transport in steep channels (7)	Models that account for non-stationary storms (5)	Wildfire insurance program like the NFIP (people in the WUI are not receiving insurance) (5)
Dynamics of debris flows (1)	Reliable stream gauges that can withstand extreme flooding (6)	Identify zones at risk, at local level (4)
Erosion and sediment entrainment once it gets in the channel—sediment routing (4)	Infiltration rates post-fire (4)	Hazard mitigation plans (5)
Sediment deposition (long-term issue)—what is persistence of sediment deposition? Qualified by type of event (1)	Hydrology and hydraulics of the arid West (0)	Use of major events to indicate future events—to identify vulnerable properties (0)
Fragmentation/connectivity: how can we assess and represent this in models? (4)	Wildfire housing zoning hazards on a parcel basis (0)	Changing property rights (0)
Slope erosion (0)	Fuel mitigation on parcels and how it affects neighboring parcels (“multiplier effect”) (0)	Moving risk and moving targets as pertains to how to address people’s rights (0)
	Plot data at basin scales (0)	
	New methods to determine discharge (1)	

Appendix G: Needs Related to Water Quality for Drinking Water

(Needs in red were voted to be highest priority by participants).

Research	Data	Management
Treatability (organics, heavy metals, N) (0)	Real-time monitoring of a broader spectrum of measurements (continuous) (2)	Inform elected decision makers about complexity of watershed ›› water quality to be able to strategically fund (4)
Better understanding of what kinds of constituents are coming down from burn area (3)	Longer-term data sets on how long the fire will continue to have impacts (4)	More peer-to-peer, research-to-manager understanding of the relationship of fire/flood watershed water quality cycles (5)
What are effective mitigation measures to reduce impact on drinking water? (5)	Monitoring of water temperature and other conditions that favor algae (0)	Management response plans that include more (in terms of mitigation) downstream users (3)
What impacts do fire treatments have on water quality? (0)		More regional communication and collaboration on water quality in regards to fire/flood fire/flood (2)
Source to tap: research on cost benefit of integrative pre-fire investment (1)		Cost/benefit of removal/avoidance of sediment from reservoirs (0)
Fire increases nutrients in sources ›› more understanding of connections between source water treatment and distribution (0)		Effectiveness of oxidants in dealing with mobilized metals (0)
Long-term effects of fire on groundwater (intensity, severity) (3)		
Can ashes/ash water be used in agriculture? (2)		
Can we use fire-affected water for construction? (1)		
Water quality analysis from burns in WUI residential areas – rare earth metals from households (0)		
Ash fallout: how does it affect water, weather downstream of distant fires? (0)		
How do reservoir dynamics influence mobilization of constituents? (2)		
Research into coagulents specific to ash removal (1)		

Appendix H: Needs Related to Water Quality for Ecosystems

Research	Data	Management
Differences between ecosystems (connectivity) (2)	More geochemical data collection (e.g., Mn) / sediment resuspension (0)	How do you maintain aquatic ecosystem resilience (manage for changing conditions)? (2)
Establishing baselines (monitoring) (baseline is changing conditions) (3)	Using remote sensing to define availability of sediment (3)	Managing for sediment/sediment control infrastructure (4)
What are the mechanisms of sediment transport at different stream orders? (2)	Identify refugia areas (2)	Protection plan for refugia areas (4)
How do fires change the biological productivity of streams (tipping points) (N, P, how algae reacts) (4)	Bathymetry data (pre/post)(LIDAR) (2)	Temporarily removing species (0)
Cost/benefit pre/post-fire (2)	DO – temperature – chemical properties post-fire (3)	Incorporate ways to make environment a stakeholder (manage trade-offs) (1)
Calculating environmental flow demand (0)	Evolving nutrient levels (pre/post)—long-term continuous data sets (3)	
When to intervene for restoration and when to allow natural landscape recovery (1)		

Appendix I: Needs Related to Water Supply, Reservoir Infrastructure, Sediment Issues, Loss of Capacity, and Supply Redundancy

(Needs in red were voted to be highest priority by participants).

Research	Data	Management
Timing of sediment transfer from one storage reservoir (3)	Frequent reservoir bathymetric data (annual post-fire; pre-fire every 3 years); need the location and amount of sediment deposited (6)	Operation or maintenance plan for recurrence of bathymetric data collection ›› this is an iterative process, because plan is revised based on data ›› this affects reservoir lifetime and post-deposit operation of the reservoir (9)
Effect of burned areas on snowmelt magnitude and timing; depends on vegetation type and elevational gradient (3)	Assessing sediment available for transport that is released by fire (2)	Are there landscape changes that could be used to optimize retention of water (mediate early snowmelt) in the landscape rather than reservoirs? (1)
How can we capture water lost from unused irrigation canals? (1) • Transport between reservoirs, unlined and unused irrigation canals • In some flood events ditches convey flood waters—and they were not designed for this	Understanding chemistry of sediment and how the constituents are mobilized into water column over time (4)	Adjust water right laws to change delivery timing (1)
Cost avoidance analysis: difference in sedimentation rate (4)	Baseline data pre/post-water chemistry to understand potential infrastructure (corrosion) (5)	Landscape characteristics to optimize water retention on the landscape instead of in a reservoir (without raising the level of a dam) (10)
Develop model to understand reservoir response (2)	Research mitigation measures for protecting infrastructure (3)	How to address redundancy in water storage (2)
Understand processes that lead to post-fire eutrophication (2)	Identify potential temporary sediment storage basin reservoirs (0)	