Managing for Future Risks of Fire, Extreme Precipitation, and Post-Fire Flooding

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 Tucson, Arizona's Sabino Canyon Recreation Area, 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, impacts to reservoirs and drinking water treatment infrastructure, and to other infrastructure essential to urban areas, such as roads, culverts, and pipelines. Furthermore, impacts can include the loss of ecosystem services, such as water supply and storage, and carbon sequestration.

Workshop Objectives

The main purpose of this workshop is 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 will strive to better understand the connections between wildfire, post-fire flooding, and extreme precipitation, and evaluate the current state of knowledge of the overall topic. We will accomplish this by sharing lessons learned and best practices from case studies, and through the suggestions of participants to inform the development of a toolbox of processes and products to inform water and flood plain managers. This white paper provides a brief background of the topics covered during the workshop.

Climate & Extreme Precipitation

Climatology of the Intermountain Southwest

Although the region is characterized mostly as arid-to-semi-arid, 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). Temperatures in the the mountain and plateau forest regions, of primary concern to this workshop, are generally cooler than the rest of the region, and they influence the occurrence of snow, which provides more than 60% of annual precipitation in the mountains of Utah and Colorado (Steenburgh et al. 2013). Much of the northern Great Basin, the Intermountain areas, and Colorado Rockies receives the majority of its annual precipitation during the winter (December-February) and spring months (March-May). In contrast, the eastern half of Colorado and New Mexico receives the majority of its precipitation between May and September, and much of Arizona and western New Mexico has a bi-modal annual precipitation pattern, receiving around half of its 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), thus more prone to longer droughts. Paleoclimate studies demonstrate the occurrence of multidecade 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 Nino, La Nina, 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, too. Summer thunderstorms typically deliver large amounts of precipitation, with very high intensity, during short periods of time.

Climate contributes to floods through exacerbation of 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.

Observed Climate Trends

Annual average temperatures, as averaged across the region, have increased 1.5°F 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 streamgage), 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 ft.) (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 3-5°C (5-9°F) in the Intermountain Southwest by the middle to the end of the 21st century (Cayan et al. 2013), 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 region 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; also, mountain snowpack 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 more moisture, up to around 30% more, with a 9°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 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).

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 treatabilility of the water for drinking water purposes (Writer and Murphy, 2012). Increased sediment from hillslope and channel erosion can lead to long term effects on stream channels and reservoirs (Moody and Martin, 2001). 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. Though snow melt 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.

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 and others, 2008; Parsons and others, 2010; Moody and Ebel, 2013; Nyman and others, 2013).

Flooding and Debris Flows

The combination of extreme precipitation and erosion can cause damaging floods and debris flows (Sham, Tuccillo, & Rooke, 2013). Factors influencing post-fire flooding, erosion and debris flows include burn severity, slope steepness, and particularly, rainfall intensity (Moody and Martin, 2009; Cannon and others, 2011; Kean and others, 2011; Staley and others, 2012). 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 and others, 2008b; Montgomery and others, 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, 2013). 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. 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).

Implications of Extreme Precipitation

As floods and debris flows may be generated by storms with recurrence intervals of less than ten 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.

Management Perspectives & Decision Science

Introduction

The process of planning, decision-making and managing short term 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, who must coordinate short term 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 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. In order to be effective in this environment, several basic approaches for planning are suggested, as follows:

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

Vulnerability

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 "wildland-urban interface" (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 run-off 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 after the fire the event occurs.
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 & Schulte, 2006). Managing activities in the WUI can help 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 ad 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, Tuccillo, & Rooke, 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 underprotected (Postel and Thompson, 2005). The watersheds of the intermountain region of the Colorado River Basin provide for 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). Examples of where payments for watershed ecosystem services, so-called “water funds,” have been planned or implemented in the Intermountain Southwest include Santa Fe, New Mexico, and Denver, Colorado (Botorff, 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.

Scenario Planning

Uncertainty about the future need not be a barrier to planning and decision- making. Exploratory Scenario Planning is a method of identifying 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, Höjer, Dreborg, Ekvall, & Finnveden, 2006; Chakraborty, Kaza, Knaap, & Deal, 2011; Holway, 2011; Holway et al., 2012; Quay, 2010, 2011; Weeks, Malone, & Welling, 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, Fien, Smith, Thomsen, & Smith, 2009; Hopkins & Zapata, 2007; Sheppard et al., 2011; van Drunen, van't Klooster, & Berkhout, 2011; Varum & Melo, 2010; Walker, Haasnoot, & Kwakkel, 2013). Often there are five phases: 1) Scenario Definition; 2) Scenario Construction; 3) Scenario Analysis; 4) Scenario Assessment; 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 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.

A Fire-Flood Toolbox for Water and Floodplain Managers

Watershed roundtable discussions in Colorado's Arkansas River Basin have generated some exciting ideas about coordination from headwaters forests to downstream drinking and agricultural water supply reservoirs. Among the topics addressed by the Arkansas Roundtable are the nexus of wildfire, post-fire flooding and related impacts. The Arkansas Roundtable's Watershed Health Working Group has generated a preliminary toolkit, linked to an emergency event life cycle. The draft Watershed Health Life Cycle Tools and Processes addresses nine categories of action, including:

- collaborative dialogue with community and key stakeholders
- condition assessment and data gathering
- coordinated planning for an event or threat
- resilience initiatives and pre-event mitigation
- active event response
- immediate post-event assessment and mitigation
- mid-term event mitigation
- watershed restoration and sustainability initiatives, and
- periodic review of lessons learned.

Workshop participants will examine some of the aforementioned actions, and will craft other actions, tools, and processes to address issues related the combination of fire, extreme precipitation and post-fire flooding.

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