

Hydrologic Impacts of High Severity Wildfire: Learning from the Past and Preparing for the Future

Daniel G. Neary^a, Karen A. Koestner^a, Ann Youberg^b

^aUSDA Forest Service, Rocky Mountain Research Station, 2500 Pine Knoll Drive, Flagstaff, Arizona 86001

^bArizona Geological Survey, 416 Congress Street, Suite 100, Tucson, Arizona 85701

Abstract: Wildfire is a natural disturbance with epic potential to drastically alter watershed hydrologic condition. Basins with high-burn severity, especially those with steep previously forested terrain, have flashier hydrographs and can produce peak-flows orders of magnitude greater than pre-fire conditions. This is due to fundamental changes in the hydrology of burnt watersheds, especially in the short term (1-3 years). Consumption of the canopy and forest-floor organic horizon that formerly intercepted precipitation, moderated infiltration, and protected mineral soil, results in decreased evapotranspiration and infiltration, and increased runoff. Further, newly exposed soil surfaces are subject to rain-drop erosion, which may be exacerbated by fire induced soil-water repellency. Though the hydrologic impacts of high-severity wildfire have been well documented in the scientific literature, the socio-political ramifications of a latent, continuous, and highly unpredictable disturbance regime (i.e. post-fire flooding and sedimentation) has not been addressed. Fires are increasing in size, frequency, and severity. Simultaneously, development continues in the wildland-urban interface and the number of people living in or visiting forest areas is growing. Understanding the post-fire hydrologic response of watersheds is paramount for effective risk management and mitigation of post-fire hydrologic and geomorphic hazards. Equally important is educating communities that are at high-risk for post-fire flooding and sedimentation hazards. This presentation encompasses research on hydrologic and geomorphic impacts of past fires, a real-time perspective on recent post-fire hazards and mitigation (including the 2010 Schultz Fire and others). It identifies some high-risk areas where opportunity exists to educate and prepare the public for post-fire hazards after wildfires.

INTRODUCTION

Knowledge of fire effects has risen in importance to land managers because fire, as a disturbance process, is an integral part of the concept of ecosystem management and restoration ecology. Fire initiates changes in ecosystems that affect the composition, structure, and patterns of vegetation on the landscape. It has shaped plant communities and landscape hydrology for as long as plants and lightning have existed on earth (Pyne 1982). It affects soil and water resources of ecosystems that are critical to overall functions and processes (DeBano et al. 1998, Neary et al. 2005). Hydrologic functions can be seriously impacted, and watershed condition altered for decades. Fire is a dynamic process, predictable but uncertain, that varies over time and landscape space. As a landscape-level disturbance, wildfires can produce changes in not only vegetation but also hydrologic responses. This was certainly the case for the Schultz Fire when steep terrain, high severity fire, and an unusually wet Monsoon interacted to produce flood flows not seen in a thousand years.

FIRE EFFECTS

Fire Severity

At fine spatial and temporal scales the effects of a specific fire can be described at the stand and community level (DeBano et al. 1998, Neary et al. 2005). The commonly accepted term for describing the ecological effects of a specific fire is *fire severity*. This term describes the magnitude of the disturbance and, therefore, reflects the degree of change in ecosystem components. Fire affects both the aboveground and belowground components of the ecosystem. Thus severity integrates both the heat pulse above ground and the heat pulse transferred downward into the soil. It reflects the amount of energy (heat) that is released by a fire that ultimately affects resources and their functions. It can be used to describe the effects of fire on the soil and water system, ecosystem flora and fauna, the atmosphere, and society (Simard 1991). It reflects the amount of energy (heat) that is released by a fire that ultimately affects resource responses. Fire severity is largely dependent upon the nature of the fuels available for burning, and the combustion characteristics such as type (flaming versus smoldering), duration, location (ground, crown, or both) etc. that characterize a fire.

Wells et al. (1979) and DeBano et al. (1998) developed criteria to rate fire severity:

- a. Low severity burn—less than 2 percent of the area is severely burned, less than 15 percent moderately burned, and the remainder of the area burned at a low severity or unburned. A visual indicator is black ash.
- b. Moderate severity burn—less than 10 percent of the area is severely burned, but more than 15 percent is burned moderately, and the remainder is burned at low severity or unburned. A visual indicator is gray ash.
- c. High severity burn—more than 10 percent of the area has spots that are burned at high severity, more than 80 percent moderately or severely burned, and the remainder is burned at a low severity. A visual indicator is white or orange ash.

The Wells et al. (1979), DeBano et al. (1998), and Neary et al. (2005) discussed criteria for defining burn severity class boundaries. Although they are somewhat arbitrary, they were selected on the basis of experience, recognizing that even the most severe of fires has spatial variation due to random variation in the fire environment (fuels, weather, and terrain), and particularly localized fuel conditions. Recently, Key and Benson (2004) developed a series of procedures for documenting fire severity in the context of field validation of satellite images of fire severity.

Most wildfires burn in patterns that produce a matrix of severities. The Schultz Fire no exception (Figure 1). The majority of the area burned at moderate (27%) or high (40%) severity across slopes of 30% to over 100%, through forests of ponderosa pine and mixed conifer (Youberg 2011). Nine of eleven watersheds were almost completely burned, with areas of high severity fire covering more than 50% in three watersheds and more than 70% in two others. The burn severity characteristic of the Schultz Fire that contributed to the hydrologic response was the significant amount of uniform high severity fire in the upper portions of five watersheds (Figure 1).

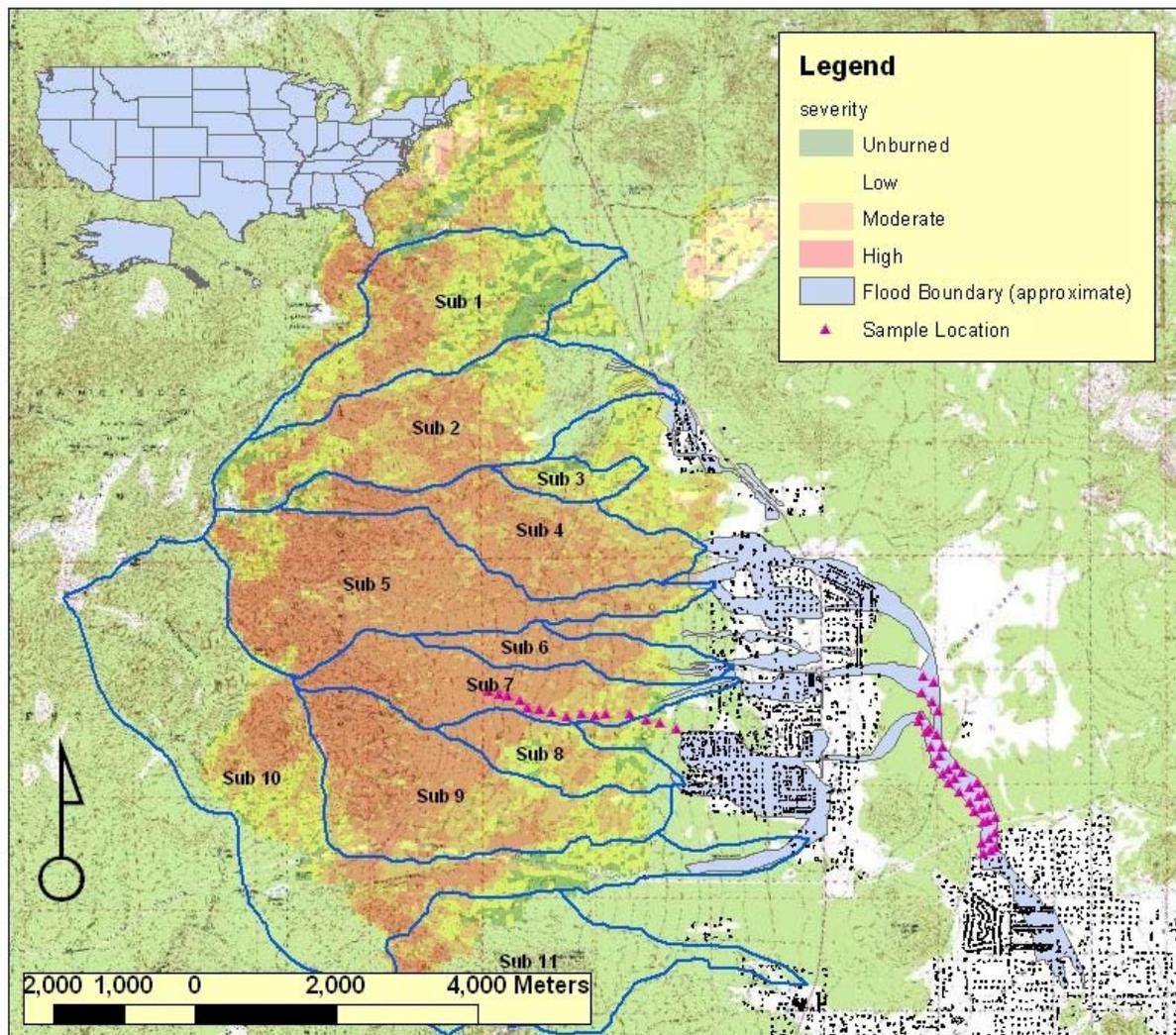


Figure 1. Schultz Fire boundaries with severity classification, watershed delineation, post-fire flood flow boundaries, and sediment sample locations (Koestner et al. 2011).

Hydrologic Alterations

Forested watersheds are some of the most important sources of water supply in the world. Maintenance of good hydrologic condition is crucial to protecting the quantity and quality of streamflow on these important lands (Neary et al. 2005). The effects of all types of forest disturbance on storm peak flood flows are highly variable and complex, producing some of the most profound hydrologic impacts that forest managers have to consider (Anderson et al. 1976). Wildfire is the forest disturbance that has the greatest potential to change watershed condition (DeBano and others 1998). Wildfires exert a tremendous influence on the hydrologic conditions of watersheds in many forest ecosystems in the world depending on a fire's severity, duration, and frequency. Fire in these forested areas is an important natural disturbance mechanism that

plays a role of variable significance depending on climate, fire frequency, and geomorphic conditions. This is particularly true in regions where high severity fire, steep terrain, high fuel loads, and post-fire seasonal precipitation interact to produce dramatic impacts (DeBano et al. 1998, Neary et al. 1999, 2005).

Watershed condition, or the ability of a catchment system to receive and process precipitation without ecosystem degradation, is a good predictor of the potential impacts of fire on water and other resources (such as roads, recreation facilities, riparian vegetation, and so forth). The surface cover of a watershed consists of the organic forest floor, vegetation, bare soil, and rock. Disruption of the organic surface cover and alteration of the mineral soil by wildfire can produce changes in the hydrology of a watershed well beyond the range of historic variability (DeBano et al. 1998). Low severity fires rarely produce adverse effects on watershed condition, but high severity fires usually do. Most wildfires are a chaotic mix of severities, but in parts of the world, high severity is becoming a dominant feature of fires since about 1990 (Neary et al. 1999, Robichaud et al. 2000). Successful management of watershed resources and human populations in a post-wildfire environment requires an understanding of the changes in watershed condition and hydrologic responses induced by fire. Flood flows are the largest hydrologic response and most damaging to many natural and cultural resources (Figure 2).



Figure 2. Flood flow at Campbell Avenue and Highway 89, July 20, 2010, after the Schultz Fire.

Post-fire Hydrologic Response – Lessons Learned

So, what do we know about post-wildfire hydrologic responses? Fires can produce some substantial effects on the streamflow regime of both small streams and rivers. They can affect annual and seasonal water yield, peakflows and floods, baseflows, and timing of flows. Adequate baseflows are necessary to support the continued existence of many wildlife populations. Water yields are important because many forest, scrubland, and grassland watersheds function as municipal water supplies. Peakflows and floods are of great concern because of their potential impacts on human safety and property. Next to the physical destruction of a fire itself, post-fire floods are the most damaging aspect of fire in the wildland environment. It is important that resource specialists and managers become aware of the potential of fires to increase peakflows. Following wildfires, flood peak flows can increase dramatically, severely affecting stream physical conditions, water quality, aquatic habitat, aquatic biota, cultural resources, and human health and safety. Often, increased flood peak flows of up to 100 times those previously recorded, well beyond observed ranges of variability in managed watersheds, have been measured after wildfires (DeBano et al. 1998, Neary et al. 2005). Potentials exist for peak flood flows to jump to 2,300 times pre-wildfire levels. But these responses are a function of burn severity, terrain, and climate. Managers must be aware of these potential watershed responses in order to adequately and safely manage their lands and other resources in the post-wildfire environment.

BAER – “AFTER THE FIRE AND BEFORE THE FLOOD”

BAER Objectives

Federal land management agencies have policies required an immediate assessment of site conditions following wildfire and, where necessary, implementation of emergency response measures. This is the Burned Area Emergency Response (BAER) program (Robichaud et al. 2000). This used to be called a rehabilitation program until agencies accepted the fact that, at best in the short term focus of BAER (18 months), complete rehabilitation is unlikely to occur. These directives delineated the objectives of the BAER program as:

- a. Minimizing the threat to life and property onsite and offsite.
- b. Reducing the loss of soil and onsite productivity.
- c. Reducing the loss of control of water.
- d. Reducing deterioration of water quality.

BAER Treatments

BAER treatments are grouped into three distinct categories: hillslope, channel, and road and trail (Figure 3). Commonly used hillslope treatments are broadcast seeding, mulching, contour log erosion barrier construction, straw wattles placement, contour trenching, terrace construction, scarification, silt fence establishment, geotextile placement, sand bag placement, and slash spreading. Uses and effectiveness of these practices are discussed in Robichaud et al. (2000). Channel treatments sometimes used are straw bale check dams, log check dams, rock dams,

rock-wire gabions, straw wattles dams, log grade stabilizers, rock grade stabilizers, channel debris clearing, streambank armoring, and debris basin construction. Commonly use road and trail treatments are rolling dips, waterbars, culvert removal, culvert upgrades, trash racks, ditch cleaning and armoring, outsloping, and armoring stream crossings.



Figure 3. Examples of BAER treatments (Clockwise from the upper right): Straw awattle placement, terrace construction, contour trenching, aerial seeding, log erosion barrier placement, straw wattle dam installation, and streambank armoring.

BAER Effectiveness and Limitations

The effectiveness and limitations of BAER treatment effectiveness are discussed in Robichaud et al. (2005). Two of the major limitations of BAER treatments are cost and slope. Some treatments are so expensive that only small areas can be treated within the limits of funds available for BAER. Slopes are a major limitation as well. Once slopes exceed 60%, most BAER treatments are not effective. Several BAER treatments used on the Schultz Fire as discussed in other papers in the Symposium Session on the Schultz Fire.

SOCIO-ECONOMIC CONSIDERATIONS

Socio-economic considerations of increased hydrologic responses after wildfires are a major concern. It is the first concern of BAER responses. In a completely wildland environment, these impacts usually extend to only roads and there are few cultural impacts. However, increased urbanization of forest areas in the West has increased the complications of altered hydrologic responses. In many cases, people may experience streamflow responses totally outside of their frame of reference. The Schultz Fire of 2010 is a classic case. Houses, roads, utility lines, and human life were affected by flood flows across an alluvial fan that had not been really active within living memory and the recorded history of the area. Other areas in the Southwest could face similar conditions in the future.

HAZARDS, RISKS, AND EDUCATION

One of the approaches to dealing with altered post-wildfire hydrologic responses is risk assessment and hazard mapping. Although traditional flood hazard mapping is well developed for identifiable streams, similar mapping of alluvial fans is relatively new (Pelletier et al. 2005). In addition, flood flows after wildfires are many times in excess of responses measured for known rainfall events. So, the actual risks are higher than what would be expected from past history of an area. Floods after stand-replacing crown fires are in a category of their own. They are like hurricanes in that they can be predicted to some degree but can't be stopped. Safety lies in getting out of the way. Education is the key to avoiding flood-related tragedies. Property can't always be spared or protected, but people can if they are educated on the potential hazards of their environment.

SUMMARY AND CONCLUSIONS

Fires are increasing in size, frequency, and severity. Simultaneously, development continues in the wildland-urban interface and the number of people living in or visiting forest areas is growing. Understanding the post-fire hydrologic response of watersheds is paramount for effective risk management and mitigation of post-fire hydrologic and geomorphic hazards. Equally important is educating communities that are at high-risk for post-fire flooding and sedimentation hazards. This presentation encompasses research on hydrologic and geomorphic impacts of past fires, and presents a real-time perspective on recent post-fire hazards and mitigation, including the 2010 Schultz Fire and others from earlier fire seasons and 2011.

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