HYDROLOGIC EFFECTS OF WILDFIRE

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The effect of forest fires on water, especially surface water quantity and quality, is an important topic because surface water constitutes the main source of water for most domestic, industrial, and commercial uses in the United States. The bulk of the surface water is the product of runoff from precipitation that falls as snow or rain on our forested and rangeland watersheds. In many areas, such as the arid and semi-arid Southwest, the vegetation in these watersheds is dry and susceptible to wildfires. Oftentimes fire in the form of prescribed burning is used to protect these areas from wildfire. However, such fire suppressions have resulted in overcrowded vegetation and the production of abundant fuels in watersheds.

Dense vegetation and frequently recurring drought conditions across the country in general, and in the Southwest in particular, have led to numerous catastrophic fires that have scorched many of the nation's forests, rangelands, parks, and other large-scale real estate properties. For example, 77,534 fire incidents burned 6,790,692 acres in the United States in 2004. These burns have tremendous effects on the characteristics of water-producing watersheds and the quantity and quality of the water coming out of them.

GENERAL WILDFIRE EFFECTS

In the past few years, the western part of the United States has seen dramatic increases in the number and intensity of wildfires, which cause enormous damages to forests, rangelands, and other rural areas. In the year 2004 alone, for example, five federal agencies—the Bureau of Land Management, the Bureau of Indian Affairs, the Fish and Wildlife Service, the National Park Service, and the Forest Service—together spent $890,233,000 suppressing wildfires nationwide. The same activity cost the agencies $1,326,138,000 and $1,661,314,000 in 2003 and 2002, respectively. These costs, though very large, do not include any monetary and material expenditures by other federal, state, or local governmental agencies and private sources. State land departments, fire fighters in rural and urban communities, and land managers also spend substantial amounts of money and materials to suppress local wildfires.

There have been very large fires close to home in Arizona recently, which cost the state very much in terms of financial, environmental, and other valuable resources. In June 2005, one fire—the Cave Creek Complex fire—burned 248,310 acres of forest, pasture land, and private property all over central Arizona. That fire, which was the second largest fire in Arizona's history, cost $16,471,000 to suppress. The largest fire in state history was the Rodeo-Chediski fire, which burned 468,638 acres and destroyed 491 structures in the White Mountain area of Arizona in 2002. That fire was a part of 6.7 million acres of forest and wildlife habitat area burned in the United States in that year. Such large fires have many damaging effects, some immediate and others delayed, on the environment. At the time of burning, numerous valuable land resources such as timber, wildlife and wildlife habitat, understory vegetation, soil and soil chemicals, historical artifacts, and residential homes are immediately either damaged or destroyed. The delayed effects include numerous forms of post-fire environmental degradation, such as loss of vegetation cover which leaves land exposed to impacts from rainfall, runoff, wind, and solar radiation, resulting in soil hydrophobicity (DeBano et al. 1998), flooding, soil erosion, and off-site downstream degradation of streams, lakes, and reservoirs (Morgan and Erickson 1995; Veenhuis 2002). Knowledge and good understanding of these possibilities is important for developing appropriate forest and other landscape management techniques to minimize wildfire's effects on water.

EFFECTS ON WATER YIELD AND PEAKFLOW

The main concern for hydrologists and water resource managers is the impact wildfires have on

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water quantity and quality. The amount of vegetation cover influences not only the amount of precipitation reaching the ground but also the amount of water infiltrating into the ground and moving along the surface. The presence of vegetation decreases water yield by intercepting precipitation, enhancing infiltration rate, and slowing surface movement. Wildfire, on the other hand, not only burns vegetation cover but also destroys forest floor material, leaving the ground bare and sometimes with hydrophobic soils that slow the infiltration rate and allow for more and faster surface water movement (DeBano 1981; Morgan and Erickson 1995; Zwolinski 2000). However, soil hydrophobicity disappears when the temperature of the burned area reaches 300° C. For most fire burns, soil temperatures remain below this level, leading to hydrophobicity and a subsequent increase in water yield (Dlapa et al. 2006). But the factors affecting water yield are more complex and vary significantly from place to place, depending on rates of precipitation and evapotranspiration, type of soil, and vegetation cover, as well as geology, topography, vegetation type, and fire severity (Robichaud et al. 2000). The increase in water yield also changes with time following fire disturbance. In general, Hibbert (1971) and Hibbert et al. (1982) found that first-year water yield from various burned watersheds in Arizona increases from as little as 12 percent to more than 1400 percent of normal flow.

The effects of fires on storm peak flows are complex and highly variable, as shown in Table 1. The magnitude and the variability of peak flows are dependent on many factors, such as topography, soil and vegetation characteristics, fire severity, and precipitation intensity. Peak flows over burned areas in the Southwest commonly increase in magnitude from 500 to 9600 percent (see Table 1) of that occurring on unburned areas during the summer months when highly intensive monsoonal thunderstorms are the norm in the area. Peak flow on the Salt River increased by a very significant 4000 percent after the year 2002 Rodeo-Chediski fire (Figure 1). However, other researchers (Sinclair and Hamilton 1955; Glendening et al. 1961) have found that the increase could be even higher from a burned chaparral watershed (see Table 1); the increase in peak flow from burned chaparral watersheds can reach as much as 45,000 percent. These results reaffirm the need for careful management of Southwestern watersheds to minimize the occurrence of severe wildfires that upset the normal quality and quantity of water supply in the area.

EFFECT ON WATER QUALITY

Similar to effects on water quantity, the influence of wildfires on water quality can be substantial depending on the severity of the wildfire and the physical and chemical characteristics of the burned area (DeBano et al. 1998). Large and fast streamflows from burned areas can pick up and transport large amounts of debris and chemicals that significantly affect the quality and use of water downstream. The most obvious effects come in the form of bedload and suspended sediments in the streamflow, but substantial changes in the amounts of anions and cations can also occur. Table 2 shows the effects of the Rodeo-Chediski fire on water quality compared to safe drinking water parameters. The values in Table 2 are from samples taken from Roosevelt Lake in the Salt River system immediately following the Rodeo-Chediski fire. These very high values are dangerous to aquatic life and other living things. For example, the turbidity value of 51,000 NTU, if it persisted, would make the reservoir water nontransparent and practically too dark for any aquatic organism to function properly. Likewise,

Table 1. Percent increase in peak flow following forest burn at different locations.

Location	Vegetation Type	Percent Increase	References
Eastern Oregon	Ponderosa pine	45	Anderson et al. 1976
Central Arizona	Mixed conifer	500–1500	Rich 1962
Central Arizona	Ponderosa pine	9600	Anderson et al. 1976
Cape region of South Africa	Monterey pine	290	Scott 1993
Southwestern United States	Chaparral	200–45,000	Sinclair and Hamilton 1955; Glendening et al. 1961
Northern Arizona	Ponderosa pine	200–5000	Leao 2005

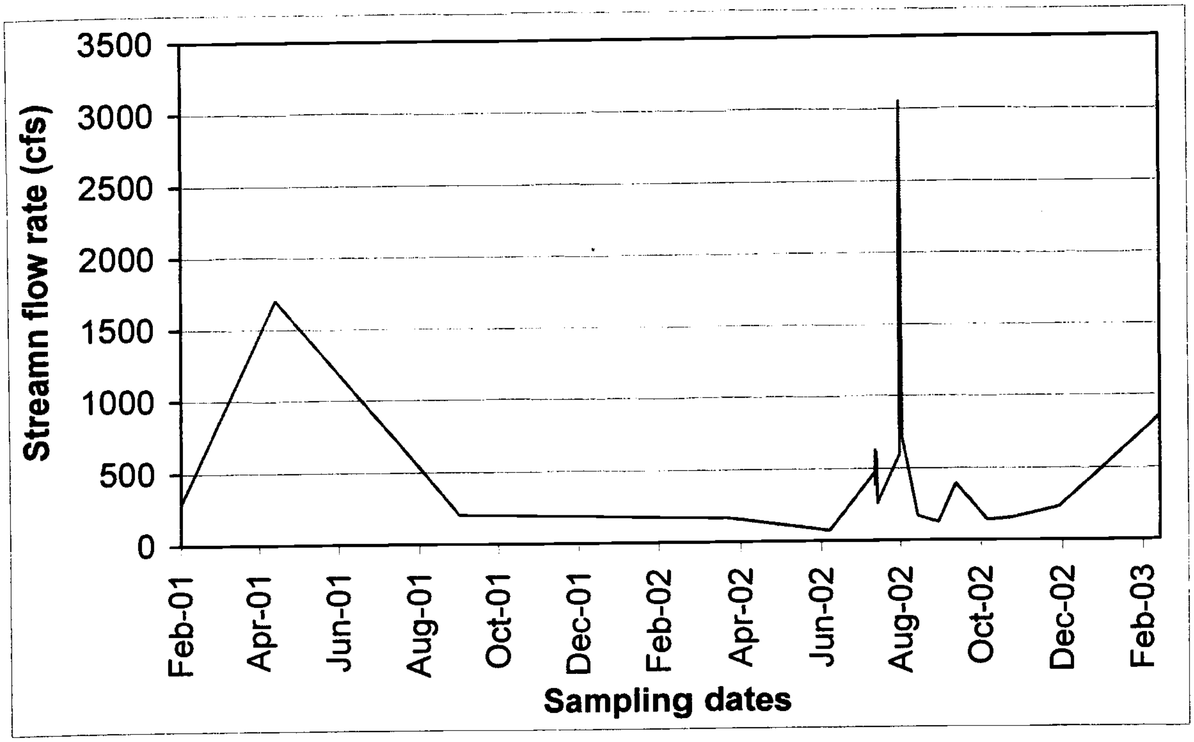

Figure 1. Salt River flow rate at entrance to Roosevelt Lake following the Rodeo-Chediski fire in 2002.

Table 2. Effect of Rodeo-Chediski fire on Roosevelt Lake water quality.

Water Quality Parameter	Post-Fire Values	Secondary Drinking Water Standard
Arsenic	685 mg/L	0.05 mg/L
Bicarbonate	312 mg/L	380 mg/L
Calcium	144 mg/L	50 mg/L
Chloride	2110 mg/L	250 mg/L
Copper	375 mg/L	1 mg/L
Iron	90,600 mg/L	0.3 mg/L
Lead	690 mg/L	0.05 mg/L
Magnesium	45 mg/L	20 mg/L
Phosphorus*	39 mg/L	0.1 mg/L
Potassium	26 mg/L	5 mg/L
Sulfate	170 mg/L	100 mg/L
Total nitrogen	220 mg/L	10 mg/L
Dissolved oxygen	7.4 mg/L	> 5 mg/L
Suspended sediment	25,800 mg/L	500 mg/L
Specific conductivity	6970 µs/cm	1650 µs/cm
Temperature	29° C	
pH	0.1	6.5–8.5
Turbidity	51,000 NTU	(monthly average) 1 NTU (average for 2 days) 5 NTU

*Phosphorus in elemental form for marine animals.
**µs = microsiemens.

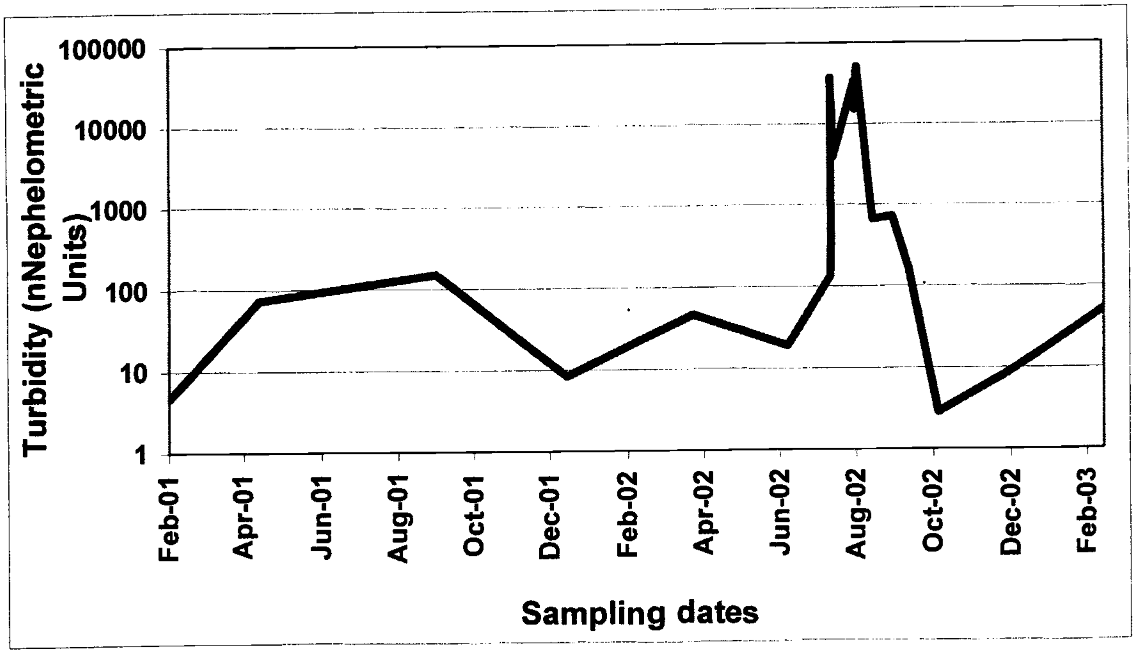

Figure 2. Turbidity of Salt River water at entrance to Roosevelt Lake immediately after the Rodeo-Chediski fire.

the high temperature and low pH values as well as the highly elevated presence of salts and other chemicals would make the water unsuitable for many organisms if the situation had persisted for a long time. The very high macro- and micronutrient values would also lead to increased algal growth and eutrophication of the water, making it unsuitable for drinking. Luckily, the serious effect of the fire on the various water quality parameters did not persist long (Paterson et al. 2002; Wondzell and King 2003). This is demonstrated in Figure 2, which shows a rapid decrease in the turbidity of Salt River water at the entrance to Roosevelt Lake shortly after the burn period.

CONCLUSION

The impacts of wildfires on water and water quality are varied and significant. Because there are insufficient amounts of vegetation cover on watersheds after wildfire burns, most precipitation that falls on such areas is readily converted to surface flow, which moves downstream with little or no difficulty. However, high precipitation over severely burned and unmanaged watersheds may produce large and rapid flows that can carry large quantities of sediment and other chemical contaminants downstream. Hence, it is important that foresters, land resource managers, and any other interested parties make all efforts to minimize the occurrence of damaging fires. This can be done through forest thinning and appropriate harvesting methods, prescribed fire, and paying careful attention to possible occurrences of fires and other hazardous disturbances and dealing with them diligently before they become out of hand. This requires insightful legislation and availability of the budgetary and other resources that are essential for prevention of catastrophic fire. Such proper management of watersheds may produce the right amount of good quality water yield for use by humans, plants, and wildlife.

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