Water Quality Impacts of Wildland Fires*

Aregai Tecle and Daniel Neary

In the arid and semiarid Southwestern United States, the forest understory vegetation (mostly grasses, forbs, and shrubs) is dry and susceptible to wildland fires. Fire in the form of prescribed burning is often used to protect these areas from wildfire. However, wildland fire suppression has resulted in dense forest fuels in many watersheds. Such fuel buildups, along with frequently recurring drought and widespread insect infestations, have made forest systems susceptible to catastrophic fires that scorch many of the Nation's forests, rangelands, parklands, and private properties (Safford and others 2008; Lutz and others 2009; Stein and others 2013).

In 2013, lightning started a total of 9,230 wildfires in the United States, burning 3,057,566 acres. In the same year, 38,349 human-caused wildfires burned 1,261,980 acres. The total area burned by both types of fires in 2013 was 4,319,546 acres (NIFC 2014). From 2000 to 2011, such fires accounted for a total of $13.7 billion in total economic losses in the United States, including $7.9 billion in insured losses (Haldane 2013; IAWF 2013).

Aregai Tecle is a professor of hydrology in the School of Forestry at Northern Arizona University, Flagstaff, AZ; and Daniel Neary is a supervisory research soil scientist for the Forest Service, Rocky Mountain Research Station, Flagstaff, AZ.

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In addition to causing economic losses, these burns have tremendous effects on the characteristics of water-producing watersheds and the quality of the water coming out of them, especially the quality of surface water. Surface water is the main source of water for most domestic, industrial, and commercial water supplies in the United States. Most surface water results from runoff from precipitation that falls as snow or rain on forested and rangeland watersheds.

This article discusses the effects of wildland fires on water quality and suggests ways of managing fire-prone forested water source areas to prevent their degradation from wildfires. The article uses information from three major fires in Arizona to demonstrate the effects of wildfires on water quality.

General Wildfire Effects

In recent years, the Western United States has seen dramatic increases in the number and intensity of wildfires, causing enormous damage to forests, rangelands, and other rural parts of Arizona and the Southwest. In 2013 alone, for example, five Federal agencies (the Bureau of Land Management, Bureau of Indian Affairs, U.S. Fish and Wildlife Service, National Park Service, and Forest Service) together spent $1,740,934,000 to suppress wildfires nationwide (NIFC 2014). Such costs, though very large, do not include the monetary and material expenditures by other Federal, State, and local agencies and by private entities. State land departments as well as rural and urban community firefighters and land managers also spend substantial amounts to suppress wildfires at the State and local level.

In the last 15 years, three very large fires in Arizona cost the State greatly in terms of financial, environmental, and other valuable resources. From smallest to largest, they are the Cave Creek Complex Fire, the Rodeo–Chediski Fire, and the Wallow Fire. The Cave Creek Complex in 2005 burned 248,310 acres of public and private property in central Arizona, costing $16,471,000 to suppress. The 2002 Rodeo–Chediski burned 468,638 acres and destroyed 491 structures

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in the White Mountains, part of 7.2 million acres that burned nationwide that year. The Wallow Fire in 2011, the largest fire in Arizona history, burned 535,039 acres, destroyed 72 buildings, and injured 16 people, mainly on the Apache–Sitgreaves National Forest.

Such big fires have many damaging effects, some immediate and others delayed. The effects can be short and/or long term. The fires damage or destroy valuable resources such as timber, wildlife and wildlife habitat, understory vegetation, soil and soil chemicals, historical artifacts, and residential homes and other structures. The delayed effects include postfire environmental degradation such as loss of vegetation cover, which leaves the land exposed to impacts from rainfall, runoff, wind, and solar radiation. The result is soil hydrophobicity (DeBano and others 1998); flooding and soil erosion; and offsite downstream degradation of streams, lakes, and reservoirs (Morgan and Rickson 1995; Veenhuis 2002). A good understanding of these possibilities is important for developing appropriate forest and other landscape management to minimize the effects of wildland fires on water quality.

Fire Effects on Water Quality and Flooding

With respect to wildfires, the main concerns for hydrologists and water resource managers are fire effects on water quality and peak flow. The hydrologic influence of vegetation cover ranges from intercepting precipitation and reducing the amount of it reaching the ground to enhancing the rate of infiltration and thereby decreasing the amount and rate of surface flow.

Peak flows in burned areas in the Southwest commonly increase in magnitude from 500 to 9,600 percent during the summer months.

Factors Affecting Soils

Wildfire not only burns the vegetation cover but also destroys material on the forest floor, leaving the ground bare and sometimes with hydrophobic soils that slow infiltration and allow for more and faster surface water movement (DeBano 1981; Morgan and Erickson 1995; Zwolinski 2000; Neary and others 2008; Verma and Jayakumar 2012). Soil hydrophobicity disappears when soil temperatures in areas burned reach 572 °F (300 °C), but temperatures usually remain below this level, leading to hydrophobicity and subsequent increases in flowing water (Dlapa and others 2006). Apart from decreased infiltration and faster surface flow, the other major effect of wildland fires is on water quality.

Factors Affecting Waterflows

The factors that affect postfire water quality are complex and vary significantly from place to place, depending on effective precipitation; soil and vegetation cover characteristics; and the geologic, topographic, and fire severity conditions in the area (Robichaud and others 2000). The water quality concerns may be grouped into physical- and chemical-related problems. The physical water quality and associated problems that follow wildland fires include erosion and sediment yield, turbidity, flooding, and increased water temperature. The chemical water quality problems may include decreased oxygen levels as well as increased production of macronutrients, micronutrients, and basic and acidic ions. Some of the additional chemicals come from the disturbed and bare ground; others are produced from burned plant material. Increases in streamflow also change with time following fire disturbance. In general, Hibbert (1971) and Hibbert and others (1982) found that first-year water yield from various burned watersheds in Arizona increased from as little as 12 percent to more than 1,400 percent of normal flow.

The effects of fires on storm peak flows are highly variable; the magnitude and variability of peak flows depend on factors such as topography, soil and vegetation cover characteristics, fire severity, and precipitation intensity. Peak flows in burned areas in the Southwest commonly increase in magnitude from 500 to 9,600 percent during the summer months (table 1), when intense monsoonal thunderstorms are the norm in the area. For example, the Salt River peak flow rose by 4,000 percent in the year following the Rodeo–Chediski and Wallow Fires. The increases can even be higher, as table 1 shows for a burned chaparral watershed, with peak flow increasing by as much as 45,000 percent. Such results indicate the need for careful management of southwestern watersheds to minimize the occurrence of severe wildfires that disrupt the normal quality and quantity of water flowing from forested areas.

Fire Impacts on Water Quality

The influence of wildfires on water quality can be substantial,

Table 1—*Percent increase in peak flow following wildland fires, by location and vegetation type.*

Location	Vegetation type	Percent increase	References
Eastern Oregon	Ponderosa pine	45	Anderson and others (1976)
Central Arizona	Mixed conifer	500–1,500	Rich (1962)
Central Arizona	Ponderosa pine	9,600	Anderson and others (1976)
Northern Arizona	Ponderosa pine	200–5,000	Leao (2005)
Cape Region, South Africa	Monterey pine	290	Scott (1993)
Southwestern United States	Chaparral	200–45,000	Sinclair and Hamilton (1955); Glendening and others (1961)

depending on the severity of the wildfire, the nature of vegetation cover, and the physical and chemical characteristics of the burned area (DeBano and others 1998). Large and fast streamflows from burned areas can transport large amounts of debris, sediment, and chemicals that significantly affect the quality and use of water downstream. Also, wildfires interrupt or terminate nutrient uptake while increasing mineralization and mineral weathering.

Large and fast streamflows from burned areas can significantly affect the quality and use of water downstream.

The Cave Creek Complex Fire of 2005 generated huge amounts of sediment load in streams. The most obvious environmental effects of the Wallow Fire of 2011 were in the form of bedload and suspended sediments in lakes, reservoirs, and streamflows, affecting fish and other wildlife. Area reservoirs such as Nelson, River, and Luna received large ash flows from severely burned areas, resulting in significant fish kill. Lakes such as Helsey Lake and Ackre Lake were filled with sediment and suffered the most, with their entire fish populations killed. Also, a number of Apache trout and Gila trout streams suffered significant fish kill, including the South Fork of the Little Colorado River, Bear Wallow Creek, Hannagan Creek, KP Creek, Raspberry Creek, and upper Coleman Creek. However, the effects of ash flows and flooding were highly variable, with greater impacts on fish populations in some areas than in others (Meyer 2011).

The most destructive of the three big fires was the Rodeo–Chediski Fire of 2002, with major environmental effects in the form of physical and chemical problems that affected downstream waterquality. Various water quality parameters measured at the Salt River entrance to Roosevelt Lake showed significant increases in the concentration of the major macronutrients calcium, magnesium, and potassium (fig. 1), as well as sulfate, phosphorus, and total nitrogen (fig. 2).

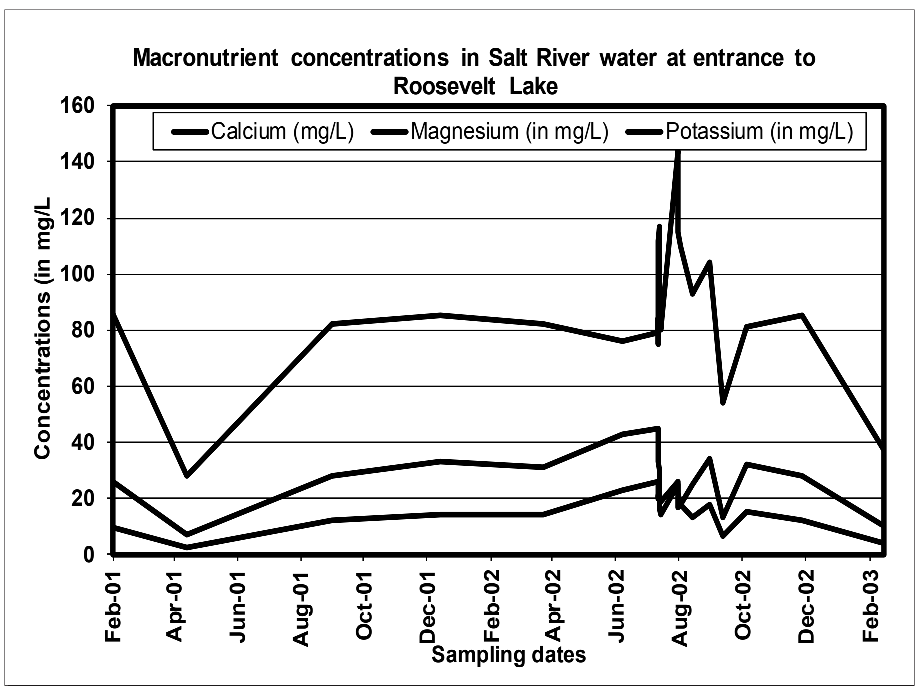

Figure 1—*Macronutrient concentrations of calcium, magnesium, and potassium following the 2002 Rodeo–Chediski Fire in the Salt River at the entrance to Roosevelt Lake.*

Despite increases in calcium and sulfur concentrations following the fire, the values remained less than half of the standard concentrations set by the U.S. Environmental Protection Agency (EPA). For magnesium, potassium, phosphorus, and total nitrogen, however, the respective concentrations rose to twice, 5 times, 390 times, and 22 times their standard levels.

Figure 3 shows the concentrations of the hazardous chemicals arsenic, copper, iron, and lead following Rodeo–Chediski in the Salt River where it enters Lake Roosevelt. The values were high and dangerous, rising to about 6,850 percent, 300 percent, 3,000 percent, and 460 percent of the respective EPA standards.

Figure 4 shows the physical factors

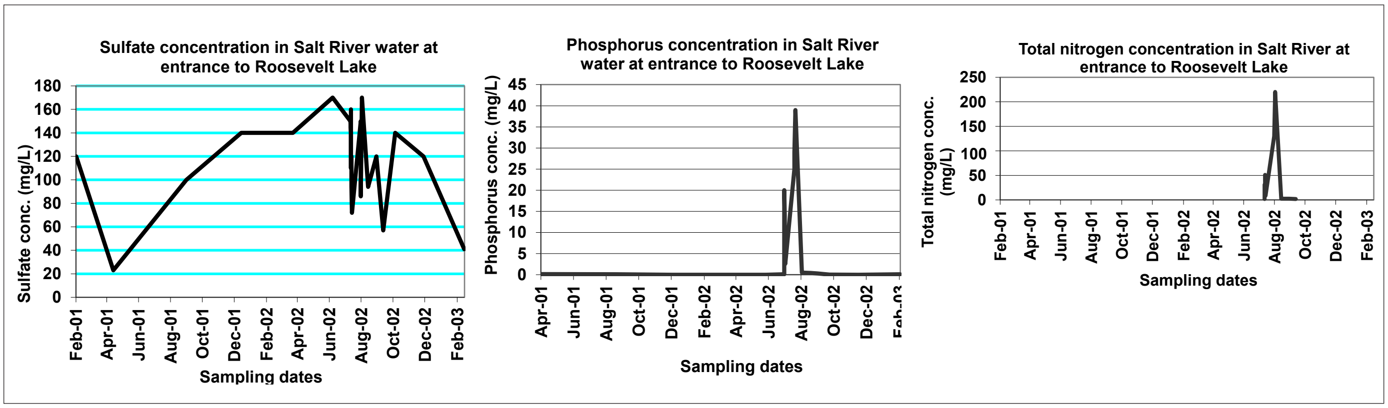

Figure 2—*Macronutrient concentrations of sulfur, phosphorus, and nitrogen following the 2002 Rodeo–Chediski Fire in the Salt River at the entrance to Roosevelt Lake.*

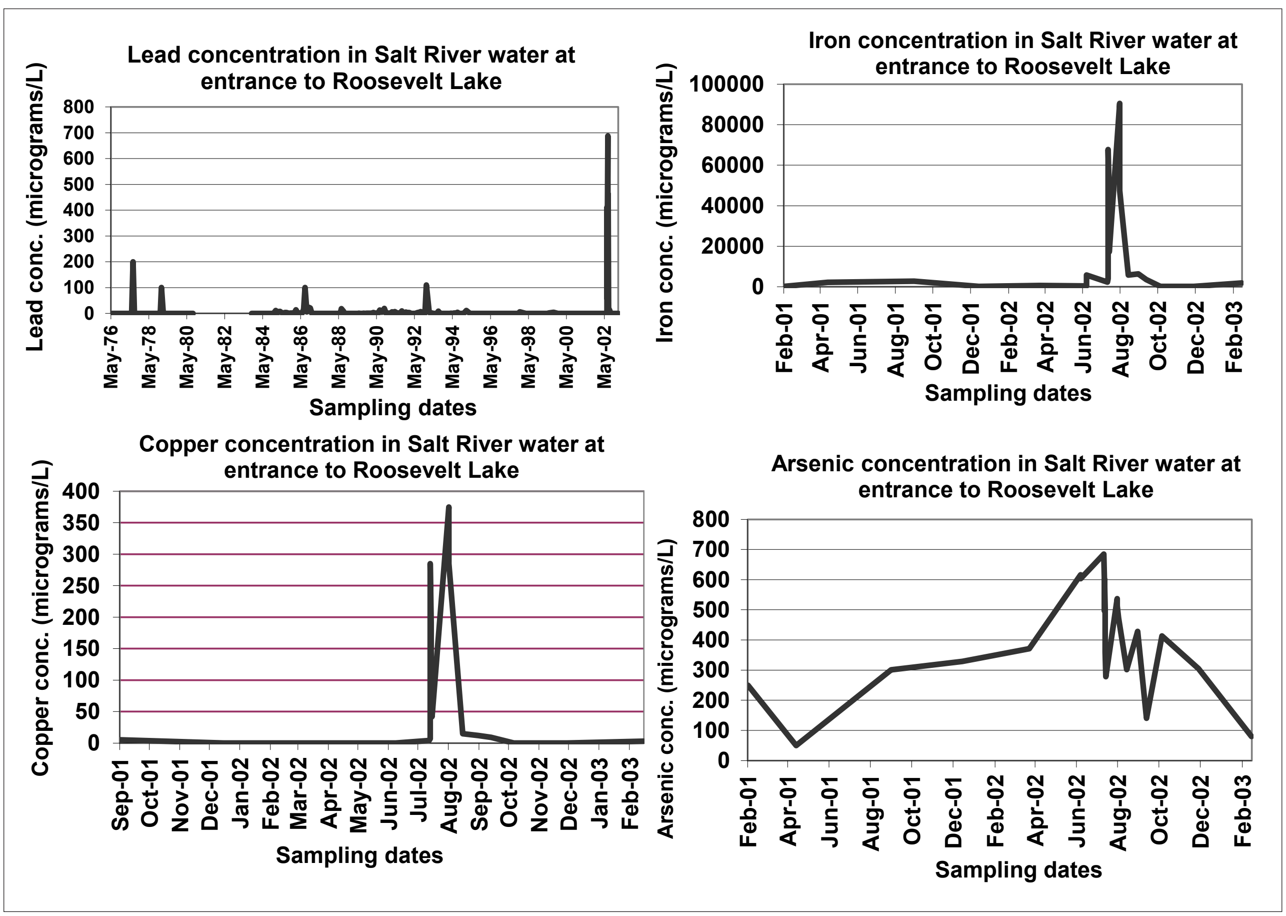

Figure 3—*Hazardous mineral concentrations following the 2002 Rodeo–Chediski Fire in the Salt River at the entrance to Roosevelt Lake.*

of flooding, turbidity, temperature, and specific conductivity in the Salt River following Rodeo–Chediski. The flood magnitude increased by 6,000 percent. Turbidity and specific conductivity measurements showed, respectively, about 1,500,000 percent and 422 percent of EPA standards, and the temperature rose to an uncomfortably high level of 84 °F (29 °C). Table 2 shows values associated with water quality parameters following the Rodeo–Chediski Fire, and it compares the values with standard values for drinking water established by the World Health Organization and the EPA.

Wildfire can have devastating effects on water quality and on water-dependent living things and the physical environment.

To summarize, wildfire can have devastating effects on water quality and on water-dependent living things and the physical environment, as shown by the chemical concentrations and physical water quality levels in table 2. Most of these values are very high and dangerous to aquatic life and other living things. For example, the turbidity value of 51,000 nephelometric turbidity units, if it persisted, would make the reservoir water nontransparent and practically too dark for any limnetic and deeper dwelling aquatic organisms to function properly.

Likewise, the high temperature value as well as the highly elevated presence of salts and other chemicals would make the water unsuitable for many organisms, as shown following the Wallow Fire, when all the fish died in Lake Helsey and Lake Ackre. The very

Table 2—*Rodeo–Chediski fire effects on water quality in the Salt River at the entrance to Roosevelt Lake, by parameters.*

		Guidelines for drinking water quality	
Parameter	**Postfire water quality level**	**World Health Organization**	**Environmental Protection Agency**
Arsenic	0.685 mg/L	0.01 mg/L	0.01 mg/L
Bicarbonate	312 mg/L	n.i.	380 mg/L
Calcium	144 mg/L	n.i.	380 mg/L
Chloride	2,110 mg/L	(>250 mg/L)	250 mg/L[a]
Copper	0.375 mg/L	2 mg/L	1.3 mg/L
Iron	90 mg/L	2 mg/L	0.3 mg/L[a]
Lead	0.690 mg/L	0.010 mg/L	0.015 mg/L
Magnesium	45 mg/L	n.i.	20 mg/L[a]
Mercury	0.7 mg/L	0.006 mg/L	0.002 mg/L
Phosphorus	39 mg/	n.i.	0.1 mg/L[a]
Potassium	26 mg/L	n.i.	5 mg/L
Sulfate	170 mg/L	(>250 mg/L)	250 mg/L
Total nitrogen	220 mg/L	n.i.	10 mg/L[a]
Dissolved oxygen	7.4 mg/L	n.i.	>5 mg/L[a]
Suspended sediment	25,800 mg/L	>600 mg/L (TDS)	500 mg/L (TDS)[a]
Specific conductivity	6,970 µS/cm	n.i.	1650 µS/cm
Temperature	29 °C	n.i.	18–20 °C (for adult trout and salmon)[b]
Turbidity	51,000 NTU	n.i.	1 NTU[a]

[a] Secondary drinking water standard.
[b] U.S. Environmental Protection Agency (2003).
Note: n.i. = no information; µS/cm = microsiemens per centimeter; TDS = total dissolved solids; NTU = nephelometric turbidity units.

high macro- and micronutrient values would also lead to increased algal growth and eutrophication of the water, making it unfit for drinking and for aquatic habitat.

Luckily, the serious effect of the Wallow Fire on the various water quality parameters did not persist for long (Paterson and others 2002; Wondzell and others 2003). As figures 1–4 show, the highly elevated levels of the various Salt River water quality parameters decreased rapidly within a short time after the burn period.

Postfire Watershed Degradation

The impacts of wildfires on peak flow and water quality can greatly vary. Because insufficient vegetation cover is left in watersheds after wildfires and because soils become hydrophobic, most precipitation is readily converted to surface flow, which moves downstream with little or no difficulty. Such flows may be large, with velocities forceful enough to severely disturb and damage watersheds and stream channels. This may produce large quantities of sediment and other chemical contaminants that can be detrimental to downstream ecosystems. Wildfires can also interrupt or terminate nutrient uptake, increase soil mineralization, and lead to mineral weathering. Increased water temperatures decrease dissolved oxygen; along with the introduction of nutrients and toxic materials into water bodies, lack of dissolved oxygen can cause eutrophication, destroying aquatic life. As a result, downstream ecosystems and socioeconomic conditions deteriorate.

To remedy the problem, it is important that land managers and other interested parties make every effort to minimize the occurrence of damaging fires. This can be done through forest thinning at the right level made with the appropriate harvesting methods or through a carefully designed prescribed fire. To use such methods successfully, forest managers should pay careful attention to the causes of wildfires and other harmful forest disturbances. Land managers need help from well-educated and insightful decision makers;

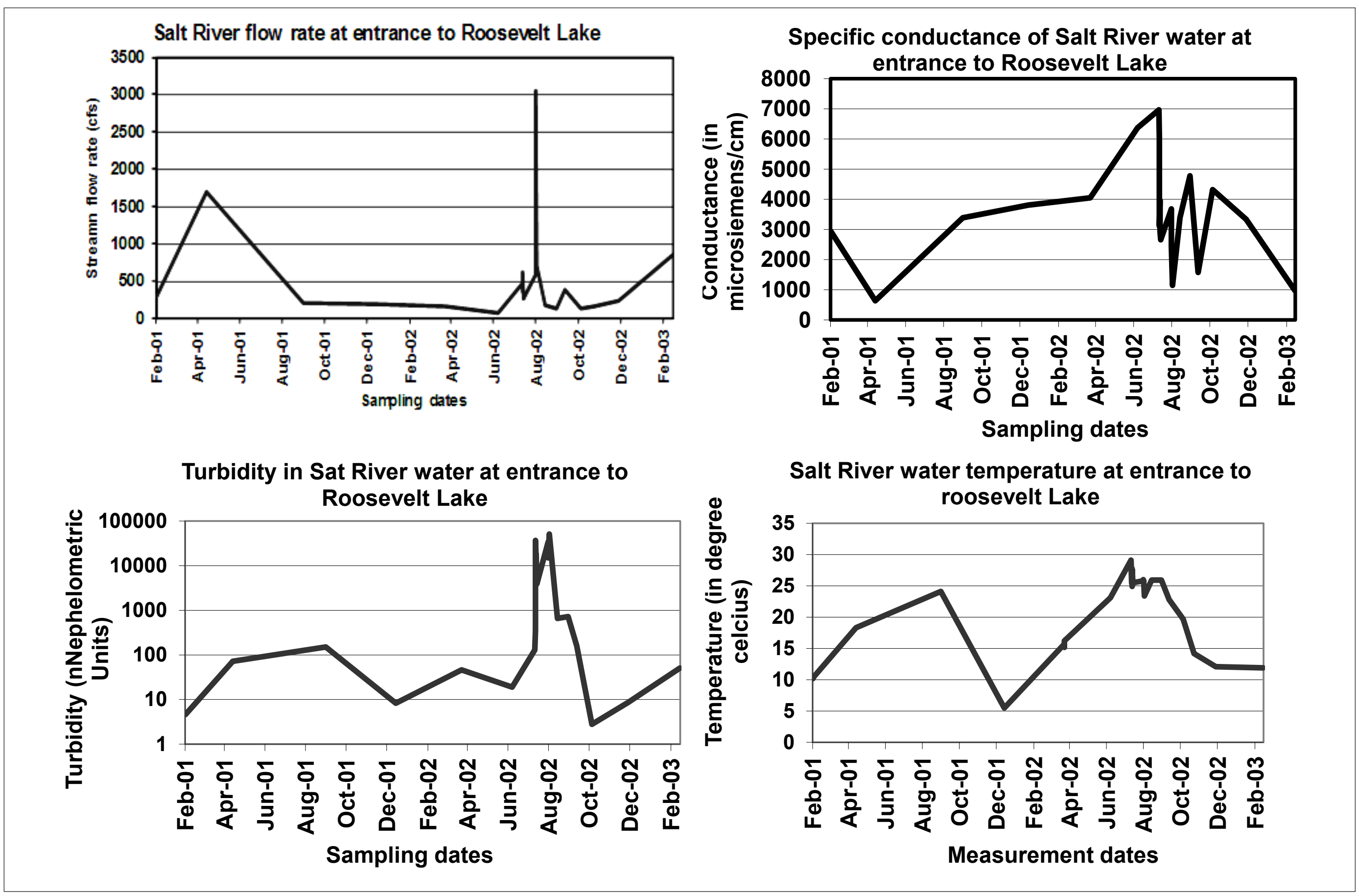

Figure 4—*Flooding and physical water quality effects of the 2002 Rodeo–Chediski Fire in the Salt River at the entrance to Roosevelt Lake.*

appropriate rules and regulations to serve as guidelines; and adequate budgets, along with skilled workers to prevent and control wildfires. Preventing wildfires is preferable to postfire remediation because restoring burned and/or degraded forested watersheds to predisturbance conditions is extremely expensive and takes a very long time. ■

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