INITIAL ASSESSMENT OF THE RODEO-CHEDISKI FIRE IMPACTS ON HYDROLOGIC PROCESSES

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The Rodeo-Chediski fire was actually two fires that ignited on the Fort Apache Reservation and merged into one. The cause of the Rodeo fire, which began a few miles from Cibecue, a small streamside village on the reservation on June 18, 2002, was arson. The Chediski fire was set on the reservation as a signal fire by a seemingly lost person a few days later. This second fire spread out of control, moving toward and eventually merging with the ongoing and still out of control Rodeo fire. Burning northeastwardly, the renamed Rodeo-Chediski fire then moved onto the Apache-Sitgreaves National Forest, along the Mogollon Rim in central Arizona, and into many of the White Mountain communities scattered along the Mogollon Rim from Heber to Show Low. More than 30,000 local people were eventually forced to flee the inferno.

The Rodeo-Chediski fire had burned 276,507 acres of Apache land, and 462,606 ac in total by the time that most of the multi-agency team of fire-fighters and officials left the area on or about July 13. Nearly 500 buildings had been destroyed, with more than half of the burned structures being the houses of local residents or second homes of summer visitors. Rehabilitation efforts began immediately after the fire was controlled and it was declared safe to enter the burned area to initiate such activities. Culverts were removed from roads to help mitigate the anticipated flash flooding from the high-intensity, short-duration monsoonal rainfall events that commonly occur in Arizona from early July through August and occasionally into September. Temporary detention dams and other diversions were constructed to divert intermittent water flows initiated by these storms away from critical infrastructures. In a major rehabilitation activity, helicopters ferried bales of straw to burned sites susceptible to erosion, where the straw was spread onto the ground to alleviate the erosive impact of the monsoonal rain. Seeding of rapidly established grasses and other herbaceous plants accompanied this rehabilitative activity, which continued into the late summer and early autumn. Crews began to cut fire-damaged, mostly larger trees at risk of falling to the ground along roadways and in areas frequented by people. Removal of these hazardous trees continued into the winter.

Harvesting of fire-damaged trees of commercial value but not expected to survive the burn began on Apache lands in late fall. More than 360 million bd ft of salvageable, mostly ponderosa pine timber is estimated to have been harvested in this emergency operation by early summer of 2003. In a normal year, about 40 million bd ft of timber has been harvested from these forests. As a consequence of the fire, future timber sales on Apache lands will be comparatively small, and according to personnel at the Fort Apache Agency of the Bureau of Indian Affairs, it is expected to take at least 150 years to return to this pre-fire level of harvesting. The Apache Tribe plans to plant 1.2 million seedlings annually in the coming 10 years, hoping to reforest about 75,000 ac of land that had been the most severely burned by the Rodeo-Chediski fire.

THE STERMER RIDGE WATERSHEDS

Two nearly homogeneous watersheds, 60 ac each, were established along Stermer Ridge at the headwaters of the Little Colorado River in 1972–73 as a cooperative project of the Rocky Mountain Research Station, USDA Forest Service, and the University of Arizona to obtain baseline information on watersheds in north-central Arizona located in ponderosa pine forests on sedimentary soils. More specifically, the Stermer Ridge watersheds were established to complement the Beaver Creek watersheds, located on basaltic soils south of Flagstaff, and the other "experimental watersheds" situated on basaltic soils throughout the

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montane forests of Arizona, by representing hydrologic and ecological resource response functions found on sandstone soils (Ffolliott and Baker 1977). Basaltic soils are found on approximately 55 percent of the Salt-Verde River basin, which is a drainage of nearly 13,500 sq mi that supplies water to the people of Phoenix and other cities and farms in central Arizona; the remainder of the basin is largely on sedimentary soils. The information obtained on the Stermer Ridge watersheds therefore allowed comparisons of hydrologic and ecological characteristics to be made between these two soils.

The two Stermer Ridge watersheds exhibit the relatively flat topography that is common on the Colorado Plateau of north-central Arizona, with few slopes exceeding 10 percent. Their elevations range from 6800 to 7000 ft. Beneath the watersheds lies Cretaceous undivided material with mineralogy that is similar to that of the Coconino Sandstone formation. Soils derived from this parent material are classified in the McVickers series, with fine, sandy loam surface textures. The pre-fire forest overstory had been cutover. The most recent timber harvest removed approximately 45 percent of the merchantable sawtimber by group selection in the early 1960s.

The watersheds receive about 20 to 25 inches of annual precipitation, an amount that is commonly associated with the ponderosa pine forests of Arizona. Two major precipitation seasons characterize the area. Sixty-five percent of the annual precipitation falls from October to April, much of it as snow, and the remainder falls in rainstorms from July to early September. More than 90 percent of the intermittent annual streamflow occurs as a result of snowmelt runoff, or occasional winter rains (Ffolliott and Baker 1977). Summer storms, although often intense, rarely produce significant stormflows.

The watersheds had been mothballed in 1977 after completion of the earlier watershed research studies, but the prefabricated control sections (3 ft H-flumes) were left in place. Following the Rodeo-Chediski fire, these sections were refurbished and reinstrumented with water-level recorders; a weather station on the site was reestablished and a set of 30 permanently located plots (points) that had been placed on each watershed to sample on-site hydrologic and ecological parameters were relocated to provide a sampling basis to study the impacts of varying fire severities on the hydrologic processes mentioned. A fire severity classification system that related fire severity to the soil-resource response (Hungerford 1996) on the sample plots was extended to the area of each watershed to determine the relative portions of the watersheds that were burned at low, moderate, and high severity (Wells et al. 1979). This extrapolation of the classification system indicated that one of the Stermer Ridge watersheds had experienced the impacts of a high-severity, stand-replacing fire, whereas the other watershed had been exposed to a low to medium severity, stand-modifying fire.

STUDY PROTOCOL

The data sets and other information collected on the Stermer Ridge watersheds between 1972–73 and 1977 had been archived in electronic formats and paper records, and are therefore available for the planned post-fire hydrologic and ecological assessments. Earlier analyses of these data sets were presented in a series of publications, with the most comprehensive being a publication by Ffolliott and Baker (1977). Other publications based on these data sets are listed in a bibliography on multiple resources evaluations on the Beaver Creek watersheds (Baker and Ffolliott 1998).

Mensurational and other details relative to the procedures and analytical methods that are being implemented in inventorying, evaluating, and monitoring the burned ponderosa pine forest ecosystem and natural resource base largely mimic the procedures and methods implemented to obtain the earlier (pre-burn) data sets (Ffolliott and Baker 1977). Details of these procedures and analytical methods have been summarized in the mentioned publications. The variables of interest in assessing the post-fire hydrology include but are not necessarily limited to those in Table 1.

Impacts of the Rodeo-Chediski fire on the Stermer Ridge watersheds have been separated into on-site and off-site effects (Baker 1990; DeBano et al. 1996) for discussion. Important on-site hydrologic processes include interception, infiltration, transpiration, soil water storage, and overland flow and soil erosion. Off-site processes of primary interest are stormflow and water quality. The following discussion of the initial impacts of the fire on these processes is more qualitative than quantitative in its content. However, this paper also outlines some of the monitoring efforts that have begun to provide a more detailed analysis of the impacts following a longer post-fire evaluation period.

Table 1. Variables in assessing post-fire hydrology.

Variable	Method	Frequency
Precipitation	Weather station	Continuous
Stormflow	3 ft H-flume	Continuous
Transpiration	Heat pulse measurements	Periodic
Sediments		
Suspended	Hand catch samples	During runoff events
Bedload	Survey	Periodic
Nutrients	Hand catch samples	During runoff events
Soil characteristics		
Soil moisture	Gravimetric	Periodic
Soil nutrients	Selected sampling	Periodic
Soil loss	Erosion pins	Continuous

ON-SITE PROCESSES

Interception

One consequence of the Rodeo-Chediski fire and the most obvious impact was the reduction or elimination of the forest overstory and litter and duff layers on the forest floor and, as a result, a reduction in interception losses. The ponderosa pine forest overstory on the watershed that was burned with a high-severity, stand-replacing fire was either totally destroyed by burning, or if living trees were still standing after the fire, they experienced crown damage in excess of two-thirds and are not expected to survive more than 2–3 years (Herman 1950; Schubert 1974; Ffolliott and Guertin 1990). On the watershed exposed to a low to medium severity, stand-modifying fire, nearly 90 percent of the forest overstory survived the burn, with only 5 percent of these trees damaged to the point that they are not expected to survive.

There was nearly total destruction or a large reduction in the litter and duff layers on the watershed that had a high-severity burn. Litter and moisture-retaining duff layers were completely consumed and the top of the mineral soil was exposed on two-thirds of this watershed, and the litter layer was consumed and the duff layer deeply charred on the remainder of the watershed. In comparison, the litter layer was consumed and the duff layer consumed or deeply charred on one-third of the watershed that was exposed to a low to medium severity fire, the litter layer was scorched, charred, or consumed but the duff layer left intact on about half of this watershed, and there was no damage to the litter or duff on 10 percent of the watershed. Although a litter layer was beginning to re-form by early October, 3 months after the fire, on the portions of both watersheds where it has been totally consumed by the fire, it is likely to be 25 years or longer before the litter and duff layers approach pre-fire conditions on these sites (Ffolliott and Guertin 1990).

Infiltration

Infiltration of water into the soil has not been measured on the Stermer Ridge watersheds since the fire. However, extensive water repellency has formed in much of the soil on the watersheds as a result of the fire, causing a reduction in infiltration rates and, as a consequence, increases in the occurrence and magnitude of post-fire overland flows. This situation became especially pronounced on the watershed that was burned with a high-severity fire, where some level of water repellency was found in the soil on three-fourths of the watershed. The duration of this condition is unknown, although fire-induced water repellency is likely to persist to some degree for several years following a fire (DeBano et al. 1998). Water repellency was observed in the soil on 20 percent of the watershed subjected to a low to medium severity fire, where its impact on a watershed basis is expected to be much less.

Transpiration

It has been assumed that the largest component of the pre-fire water budget for the Stermer Ridge watersheds other than the precipitation input was transpiration. Upwards of 75 percent of the annual precipitation can be lost to transpiration in the montane forest ecosystems of Arizona (Ffolliott and Brooks 1996; Brooks et al. 2003). Transpiration is also a component that has been, and will continue to be, significantly altered in its magnitude by the Rodeo-Chediski fire. Less water will be lost to the atmosphere on a watershed basis, and as a consequence, increased overland flows are expected to continue on the watersheds into the foreseeable future.

Studies have begun to estimate the transpiration rates of surviving and severely damaged ponderosa pine trees by the heat plus method (Swanson 1994; Hatton and Iwu 1995). Initial measurements taken by this method in late summer and early autumn indicated that transpiration was occurring in the sample of trees selected for study; however, the trends of these measurements in terms of time and magnitude remain to be determined. When sufficient measurements have been obtained, the estimates of transpiration will be converted to a one-dimensional expression of water depth on a watershed basis and then compared to precipitation inputs to estimate the proportion of the precipitation represented by transpiration.

Soil Water Storage

The initial effect of the Rodeo-Chediski fire on soil water storage of the Stermer Ridge watersheds has likely been manifested through the post-fire changes in infiltration rates and transpiration. The reduction in infiltration has decreased the amount of water that entered the soil as a result of the monsoonal storm events following the fire. However, the loss of vegetation to burning meant that less water was removed from the soil body by the transpiration process. It is assumed that the net effect of these "compensating changes" can be expressed by spatial and temporal measurements of soil moisture storage.

Measurements of soil moisture storage on the Stermer Ridge watersheds began shortly after the fire was controlled. Gravimetric measurements of soil moisture are being obtained at each of the 30 sample plots (points) on each of the watersheds at 1-month intervals when the watersheds are snow-free. These measurements will be used to describe the magnitudes and spatial characteristics of the post-fire soil water regimes relative to the fire severities of the two watersheds.

Overland Flows and Erosion

There were obvious (but unquantified) increases in overland flows on the watersheds as a result of the intense monsoonal rainfalls that began almost immediately after the Rodeo-Chediski fire was contained. Increases in overland flows were especially apparent on the watershed exposed to a high-severity burn. There was evidence of excessive soil movement resulting from overland flows throughout this watershed and debris piles had accumulated on sites where overland flows had been reduced in their velocity by obstructions. Changes in soil water storage and the widespread formation of a water-repellent soil on this watershed were also factors that undoubtedly contributed to the increases in overland flows. Because persistence of increased overland flows following a fire relates to the rate at which the burned watershed eventually recovers and becomes revegetated (DeBano et al. 1998; Brooks et al. 2003), increased overland flows on the Stermer Ridge watersheds are likely to continue well into the future.

Erosive forces on the watersheds were intensified by the Rodeo-Chediski fire because of the large-scale loss of protective covers exposing mineral soil. It is also likely that soil erodibility increased because of the volatilization of soil organic material and a destruction of aggregated soil structure. Furthermore, post-fire rates of surface erosion are likely to be increased more on water-repellent soils than on non-water-repellent soils (DeBano et al. 1998). The reduced infiltration rates on water-repellent soils and consequent increase in overland flows are favorable for the dislodgement and transport of soil particles. Such a phenomenon took place on both of the Stermer Ridge watersheds as witnessed by the large accumulations of sediment in the stream channels.

Sets of erosion pins have been installed at the 30 sample plots (points) on each of the burned watersheds to estimate the changing magnitudes and sites of future surface erosion in terms of the respective fire severities observed.

OFF-SITE PROCESSES

Stormflows

The integrated impacts of the Rodeo-Chediski fire on the on-site hydrologic processes of the watersheds will eventually be evaluated on a watershed basis in terms of the post-fire stormflows. Measurement of these events was initiated when the watersheds were re-instrumented, which (unfortunately) was also after the initial stormflows following the onset of the monsoonal rains had already occurred. That the Rodeo-Cediski fire changed the stormflow-generation mechanisms on the watersheds was apparent, however. Monsoonal storms, while often intense, rarely produced stormflows on the Stermer Ridge watersheds in the earlier period of streamflow measurement from 1972–73 to 1977 (Ffolliott and Baker 1977). But high-water marks in the control sections and stream channels, large debris accumulations in the channels, and undermining of the control sections by flowing water, observed by researchers when visiting the watersheds following the fire, indicated that large stormflow events had taken place.

Peakflows, a subset of stormflow regimes, deserve special attention. The magnitudes of the often observed increased peakflows following a fire are generally more variable than stormflow discharges (DeBano et al. 1998; Neary 2002).

Estimates of the initial post-fire peakflows on the Stermer Ridge watersheds were obtained before the watersheds were re-instrumented from the measurements of high-water marks in the control sections and interpretations of the rating curve for the flumes at the outlets of the watersheds.

Summer stormflows on the Stermer Ridge watersheds are uncommon; when they occurred in the 1972–76 study period, these flows were low in their peak. The highest peakflow measured in a summer stormflow event in the 1972–76 period of record was about 0.10 ft^3/sec. However, high-water marks observed on the first visit to the watersheds following the Rodeo-Chediski fire indicated peakflows in orders of magnitude larger than earlier recorded. The estimated peakflow on the watershed that experienced the high-severity, stand-replacing fire was almost 8.9 ft^3/sec or nearly 90 times that measured in 1972–1976. Peakflow on the watershed subjected to the low to medium severity, stand-modifying fire was estimated to be about one-half less, but still far in excess of the previous observations. A subsequent and higher peakflow on the severely burned watershed was estimated to be 232 ft^3/sec or about 2350 times that measured earlier. This latter peakflow represents the highest known post-fire peakflow measured in the ponderosa pine forest ecosystems of Arizona or, more generally, the southwestern United States.

Post-fire stormflow events with excessively high peakflows are frequently associated with flooding regimes (DeBano et al. 1998; Brooks et al. 2003), which was an immediate concern of the people living downstream of the Rodeo-Chediski fire. For example, a storm near Carrizo Creek, on the Fort Apache Reservation, dropped about 1.5 inches of rain onto a severely burned landscape on August 5, 2002, enough rainfall for meteorologists to call it a "10-year event." The streamflow resulting from this storm registered a peak discharge of 12,000 ft^3/sec at a gauge maintained by the personnel of the U.S. Geological Survey, about the level of a "100-year event" at the site. Fortunately, excessive downstream flooding did not occur as a result of this event or other post-fire streamflows elsewhere on the burn.

Water Quality

Water-quality constituents of primary interest to hydrologists in southwestern ecosystems are sediment concentrations and dissolved nutrients, specifically nitrogen and phosphorus (DeBano et al. 1996). Although there has not been an opportunity to collect samples to determine the quality characteristics of the water flows from the Stermer Ridge watersheds, samples taken of the sediment-laden water running off of burned areas farther downstream after the beginning of the monsoonal thunderstorms had generated increased streamflows contained large amounts of organic debris, dissolved nutrients (including nitrogen, phosphorus, and carbon), and other chemicals that were released by the fire. Some of the elevated concentrations of nitrogen and phosphorus originated from the fire retardants remaining on the site, and some came from the vegetation consumed by the flames.

The sediment- and organic-rich water significantly increased the flow of water into the Salt River, the major tributary to the Theodore Roosevelt Reservoir, a primary source of water for Phoenix and its surrounding metropolitan communities. What made this situation more serious than otherwise was the extent of the Rodeo-Chediski fire and the critically low level of the drought-impacted reservoir, which was less than 15 percent of its capacity at the time of the fire. There was a concern that the flow of ash and debris might threaten the aquatic life inhabiting the reservoir, leaving it lifeless for months to come. However, this dire situation failed to materialize. Although some fish died upstream of the reservoir and a few carcasses showed up at the diversion dam above Roosevelt Dam, the reservoir water body itself suffered little permanent environmental damage. Nutrient levels in the water shot off the chart in the first few days but fell quickly, and therefore the formation of large algae blooms that were predicted to consume much of the water's oxygen did not form. The post-fire debris in the water was never a health risk to people as most of the pollutants were natural elements that were easily removed at water-treatment plants.

OTHER ASSESSMENTS

Other assessments of the impacts of the historical Rodeo-Chediski fire on the Stermer Ridge watersheds focus mainly on ecological characteristics. These assessments include obtaining baseline information for determining the patterns of re-establishment and subsequent survival of trees and herbaceous plants, the recovery of wildlife populations and their habitats, and the accumulation of organic materials that act as a buffer against the erosive forces and that could fuel future fire. Table 2 lists some of the variables in the ecological assessments.

Table 2. Ecological assessment variables.

Variable	Method	Frequency
Trees		
Fire damage/ mortality	Point sampling	Periodic
Growing stock	Point sampling	Periodic
Reproduction	Mil-acre plot sampling	Periodic
Herbaceous plants		
Production	Plot sampling	Seasonally
Utilization	Plot sampling	Seasonally
Wildlife		
Herbivores	Indices	Seasonally
Avifauna	Observations	Seasonally
Organic materials		
Fine fuels	Plot sampling	Periodic
Downed woody fuels	Plot sampling	Periodic

CONCLUSIONS

The information presented in this paper is preliminary and it is important that it be interpreted as such. More accurate and comprehensive assessments of the hydrologic and ecological impacts of the Rodeo-Chediski fire on the Stermer Ridge watersheds will require a longer period of monitoring and evaluation. It is planned, therefore, that post-fire data sets will be collected for a minimum of 3 years, commencing with the re-instrumentation of the watersheds. This time span covers the 3 water years of October 1, 2002 to September 30, 2005. The information to be obtained from these longer assessments will be incorporated into efforts to refine and update the methods and procedures for estimating the magnitudes and trends of post-fire changes in southwestern ecosystem resources within a framework that facilitates both physical and economic analyses of post-fire ecosystem conditions.

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