OCCURRENCE AND PERSISTENCE OF WATER-REPELLENT SOILS ON THE STERMER RIDGE WATERSHEDS FOLLOWING THE RODEO-CHEDISKI WILDFIRE

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Wildfires have been shown to cause water repellency in the underlying soils by restricting infiltration of water into the soil profile and thereby producing overland flow (DeBano and Krammes 1966). Overland flow caused by the water-repellent layer can cause excessive soil erosion, resulting in sediment-laden streams. The water-repellent layer is produced when organic hydrophobic substances are volatilized during the combustion of surface litter layers. These volatilized compounds are then distilled downward into the soil where they condense on cooler soil particles and form a hard-to-wet layer (DeBano et al. 1970; Savage 1974; DeBano 1981, 1999, 2003; Doerr et al. 2000). This mechanism contributed to the extensive water repellency found in the soils on the Stermer Ridge watersheds following the Rodeo-Chediski wildfire of 2002.

The Rodeo-Chediski wildfire of 2002, the largest and most costly in Arizona's history, damaged, destroyed, or disrupted the hydrologic functioning on many of the 475,000 acres of burned ponderosa pine forest. The degree to which the hydrologic functioning will return to pre-fire functioning, if ever, is open for conjuncture. It is vital, therefore, that the impacts of this historical event be documented in terms of time-trend response of the persistence of water-repellent soils in a ponderosa pine forest.

METHODOLOGY

Study Area

Two nearly homogenous watersheds, 60 acres each, were established in 1972 by the University of Arizona and the USDA Forest Service along Stermer Ridge, located about 9 miles southwest of Overgaard, Arizona. These watersheds are located in uneven-aged ponderosa pine forests at the headwaters of the Little Colorado River. Much of the information on the hydrologic and ecologic functioning of ponderosa pine forest in the region was obtained on volcanic soils before these watersheds were established. The main objective of the Stermer Ridge watersheds, therefore, was to obtain baseline data on the hydrologic functioning and ecologic changes of ponderosa pine forests growing on sedimentary soils (Ffolliott and Baker 1977).

These watersheds both have the relatively flat topography that is common on the Colorado Plateau at elevations between 6800 and 7000 feet. Cretaceous undivided material similar to the Coconino Sandstone formation lies beneath the watersheds. McVickers soils in the Soldier-Hogg-McVickers association are the major soils found on both watersheds. Hendricks (1985) described these soils as being moderately well drained with a fine, sandy loam texture. Sixty-five percent of the annual precipitation of 20–25 inches falls from late October to April, coming as snow, rain, or a combination thereof, and the remainder falls during the summer monsoonal rainstorms occurring from July to early September. More than 90 per-cent of the pre-fire intermittent streamflow was a result of snowmelt runoff or winter rains. Summer monsoon storms, while often intense, rarely produced significant stormflows before the wildfire.

The watersheds were "decommissioned" in 1977 after the completion of the baseline studies (Ffolliott and Baker 1977). However, the control structures (3 ft H-flumes) were left in place in anticipation of future streamflow monitoring efforts. After the Rodeo-Chediski wildfire, these control structures were refurbished and reinstrumented with water level recorders and a weather station was reestablished on the site. The original 30 sample plots installed on each watershed to sample on-site hydrologic and ecological parameters were reestablished to study the impacts of the Rodeo-Chediski wildfire on hydrologic processes and ecological changes (Ffolliott and Neary 2003a, 2003b; Neary et al. 2003). A classification system relating fire severity at a sam-

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ple plot to fire-induced soil changes (Hungerford 1996) was extrapolated to a watershed basis to determine the relative proportions of the watersheds that burned at low, moderate, and high fire severity (Wells et al. 1979). This assessment indicated that one of the Stermer Ridge watersheds experienced a high-severity, stand-replacing fire, while the other had been exposed to a low- to moderate-severity, stand-modifying fire.

FIELD SAMPLING

Water repellency of the soils on the watersheds after the Rodeo-Chediski wildfire was determined following the summer monsoonal seasons of 2002, 2003, 2004, and 2005 and the snowmelt runoff seasons of 2003, 2004, and 2005 to relate water repellency to fire severity and to estimate change in water repellency over time following fire. Soil water repellency was measured by the Water Drop Penetration Time (WPT) method outlined by Letey et al. (2000). The sampling procedure began by removing the litter and duff layers on each sample plot to expose the bare mineral soil. Then a drop of distilled water was placed on the mineral soil surface with an eye dropper and the time it took for the drop to penetrate into the surface was recorded. This procedure was then repeated and the longest of the two times was used to assign four levels of water repellency according to the following criteria, developed by the National Wildfire Coordinating Group (2003): Strong = more than 40 sec, moderate = 10–40 sec, slight = less than 10 sec, and none = 0 sec.

The occurrence and degree of water repellency in relation to fire severity at a sample plot was extrapolated to a watershed basis using knowledge of the incidence of water repellency on the watersheds. The relationships between water repellency and the physiographic features of the watersheds were assessed by grouping the plots according to hillslope position (lower, middle, upper), slope percent (> 6 percent, 6–10 percent), and aspect (quadrant). The levels of water repellency were grouped by their frequencies of occurrence, and chi-square tests were used to determine significant differences in the level of water repellency among the various physiographic parameters (Zar 1999). All tests were conducted at an alpha level of 0.10.

RESULTS AND DISCUSSION

Watershed Differences

Nearly two-thirds of the soils on the Stermer Ridge watershed burned by a high-severity fire had a strong level of water repellency when first measured following the summer monsoonal season of 2002. The remaining third of the soils had a moderate level of water repellency. Strong water-repellency levels were measured in only one-third of the soils on the watershed that burned at low to moderate fire severity and 15 percent had moderate water repellency. Almost half of the soils on the less severely burned watershed had slight or no water repellency (Figure 1). These results were similar to the findings of Campbell et al. (1977), who found a high occurrence of strong water repellency on sites where soils were exposed to high fire severity, following a wildfire in a ponderosa pine forest on limestone soils near Flagstaff, Arizona. The Stermer Ridge results were also consistent with the conceptual model of the effects of fire severities on soil resources proposed by DeBano et al. (1995), which indicates that a fire of high severity causes more hydrophobic substances to condense in the soil profile compared to a less severe fire.

Due largely to the extensive water-repellent soils on both watersheds following the Rodeo-Chediski wildfire, historically high peak streamflows occurred during the summer monsoonal seasons of 2002 (Ffolliott and Neary 2003a, 2003b; Neary et al. 2003). The highest post-fire peak streamflow event occurred on the severely burned watershed, with an estimated peak streamflow of 232 ft^3/sec, or 2350 times greater than that measured during the 1972–1976 pre-fire period. This flow also represents the highest known post-fire peak flow recorded in the montane forests of the southwestern United States. The highest peak streamflow on the low to moderately burned watershed was about half the magnitude of the severely burned watershed, but it was also far in excess of pre-fire measurements.

The proportion of the severely burned watershed having a strong level of water repellency gradually declined during the first three sampling periods compared to the water repellency on the low to moderately burned watershed (Figure 1). Parenthetically, the appearance of a small increase in the proportion of the former watershed having soils with a condition of strong water repellency was likely caused by the inability to measure water repellency at the same location on a sample plot on a continuing basis because of the destructive nature of the sampling procedure.

Nearly all water repellency had broken down on both watersheds 3 years after the fire, when about 75 percent of the severely burned watershed and more than 95 percent of the low to moderately

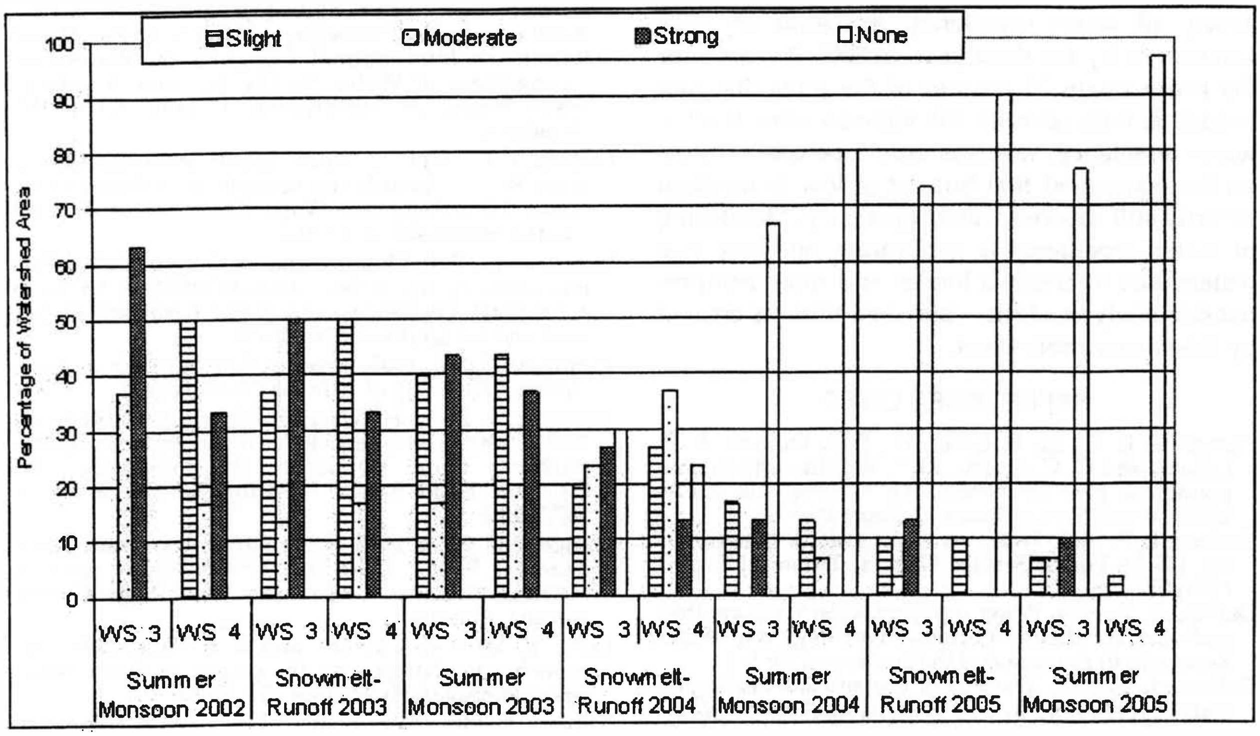

Figure 1. Changes in the occurrence of water-repellent soils on the Stermer Ridge watersheds following the Rodeo-Chediski wildfire of 2002.

burned watershed displayed no water repellency (Figure 1). This finding could be attributed to the continued erosion of the water-repellent soils, to the point were the water-repellent layer was eroded away (Garcia et al. 2004). Also, continued exposure to wetting and drying generally decreases the severity of water repellency in soils over time (Neary et al. 2005).

Not many long-term monitoring studies have been conducted on the longevity of soil water repellency following fire. However, when it has been measured, the results vary widely and appear to be dependent on site-specific characteristics (Doerr et al. 2000). The study reported in this paper shows that a small proportion of water repellency can remain 3 years after fire, which is similar to other findings. Campbell et al. (1977), for example, reported water-repellent soils persisting for 4 years, and Huffman et al. (2001) found water-repellent soils persisting 22 months after wildfire in a ponderosa pine forest on the Colorado Front Range. Water repellency in soils in lodgepole pine stands in the Upper Cascades of Oregon still persisted 6 years after wildfire (Dyrness 1976).

Physiographic Parameters

After the first summer monsoonal rains, the middle to lower slopes of the Stermer Ridge watersheds exhibited a higher proportion of strong water repellency than was found on the upper slopes. This difference was attributed largely to the generally deeper soils and greater deposition of organic matter on the middle to lower slopes. Little relationship was evident between water repellency of the soils and slope percent or aspect, probably because both watersheds are relatively flat and mostly north facing.

SUMMARY

Many studies have documented the hydrologic importance of post-fire water repellency in soils on infiltration, overland flow, and soil erosion (Savage et al. 1972; DeBano and Rice 1973; Campbell et al. 1977; DeBano 1981, 1999, 2003; Huffman et al. 2001, and others). This study evaluated the spatial and temporal persistence of water repellency in soils on the Stermer Ridge watersheds following the Rodeo-Chediski wildfire. Water repellency in soils began disappearing 2 years after the fire and nearly all water repellency was gone on both watersheds by the third year. In 2005, 3 years after the fires, nearly 25 percent of the plots that had burned at high severity still showed some level of water repellency, whereas only 3 percent of plots on the watershed that burned at low to medium severity still showed water repellency. Monitoring of water repellency is continuing on these two watersheds to create a longer and more comprehensive analysis of the watershed impacts created by this catastrophic event.

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