POST-WILDFIRE PEAKFLOWS IN ARIZONA MONTANE FORESTS: SOME CASE STUDIES

Daniel G. Neary,[1] Peter F. Ffolliott,[2] and Gerald J. Gottfried[3]

SOUTH FORK OF WORKMAN CREEK

A fire that was started by lightning on July 6, 1957, burned 60 acres of the ponderosa pine forest on the upper part of South Fork, one of the three Workman Creek watersheds north of Roosevelt Lake, about 50 miles north of Globe. South Fork lies on the western slope of the Sierra Ancha Mountains. The steepest slopes on the 316 ac watershed are situated on northerly aspects above the control section. The underlying rock formation is quartzite overlaid by sandstone. Soil depths vary from a few inches to more than 15 ft. Pre-fire forest vegetation was largely intermixtures of (mostly) ponderosa pine, Douglas-fir, and white fir with some Gambel oak and New Mexican locust.

The intensity of this fire was not documented. However, all but a few of the larger trees along the edge of the burn area were killed and most of the lesser vegetation and litter was consumed as a consequence of the extremely dry conditions at the time of the burn (Rich 1962). The burned area, which extended over 20 percent of the South Fork watershed, was seeded to a mixture of herbaceous plants immediately after the fire in an attempt to mitigate post-fire erosion rates. A "good stand" of grass was established by the end of the summer.

Streamflow Measurements

Streamflow measurements were initiated on the Workman Creek watersheds in 1939 and continued through 1983, at which time the measurements were discontinued and the watersheds, were mothballed until the Coon Creek Fire of 2000 (see below). A 90° V-notch weir located at the outlet of the South Fork and a water-level recorder were used to obtain the streamflow measurements.

Post-Fire Peakflows

The first rain after the fire, which fell on July 16, 1957, was one of the heaviest and most intense summer storms measured on the Workman Creek watersheds up to that time of record. The rainfall recorded in two gages located inside the burned area was 3.50 and 4.05 inches, respectively, with a peak intensity exceeding 2 inches per hour midway through the storm. The resulting peakflow from South Fork was 78 cubic feet per second (cfs), which was 2.1 times that of the highest previously measured peakflow on the watershed (Rich 1962). The duration of this initial post-fire peakflow was relatively short, however, with the recession streamflow dropping rapidly to 0.08 cfs within 12 hours of the peak and 0.05 cfs in 48 hours. All of the subsequent peakflows in the first two summers after the fire were also higher than expected. In contrast to summer flows, winter peakflows for this period did not exceed the expected values.

RATTLE BURN

A wildfire designated as the Rattle Burn swept through 717 acres of even-aged stands of ponderosa pine forest on the Coconino National Forest from May 7 to 9, 1972. This human-caused fire, about 20 miles southwest of Flagstaff, destroyed up to 90 percent of the smaller trees and 50 percent of the larger sawtimber and burned much of the litter and duff to mineral soil in some of the timber stands. Other stands were left virtually unaffected by the fire. Three small watersheds representing burns of high and moderate severities and an unburned control were established after the fire to assess its effects on hydrology, soils, timber and forage production, and wildlife resources (Campbell et al. 1977). The three watersheds were situated on flat topography with only a few slopes ranging up to 20 percent. Soils were derived from limestone. Pre-fire forest vegetation on the watersheds was mostly ponderosa pine with some Gambel oak and a few widely scattered alligator juniper.

The intensity of the fire on the severely burned watershed was estimated to be 10,000 British ther-

[1]Rocky Mountain Research Station, Flagstaff
[2]School of Renewable Natural Resources, University of Arizona
[3]Rocky Mountain Research Station, Phoenix

mal units per second per foot, and the intensity of the moderate fire was 2500 British thermal units per second per foot (Campbell et al. 1977) . Most of the trees were killed by the fire and much of the ground vegetation, litter, and duff was consumed on the severely burned watershed, which was 20 acres in size. The fire was confined largely to the litter and duff on the 10 ac moderately burned watershed with little damage to the forest overstory. The unburned watershed of about 44 ac was located adjacent to the severely burned watershed. The two burned watersheds were allowed to recover naturally from the fire.

Streamflow Measurements

Post-fire streamflow from the three watersheds was measured from 1972 to 1975 using 2 ft H-flumes instrumented with automatic water-stage recorders. Annual water yields from the severely burned, moderately burned, and control watersheds for this 3 yr period averaged 1.1, 0.8, and 0.2 inches, respectively (Campbell et al. 1977). Runoff efficiencies, defined as the ratio of streamflow to precipitation, on severely burned, moderately burned, and control watersheds averaged 3.6, 2.8, and 0.8 percent, respectively.

Post-Fire Peakflows

The initial post-fire streamflows on Rattle Burn were generated by a rainfall event on September 2, 1972. Peakflows of 10.98 and 0.25 cfs were recorded on the severely burned and moderately burned watersheds, respectively (Campbell et al. 1977). Peakflow from the severely burned watershed exceeded the flume's capacity. No runoff occurred on the unburned watershed from this rainfall, precluding a comparative analysis of the fire's impacts on peakflows from all three watersheds. However, as a result of a rainfall event on October 17, 1972, streamflows were recorded on all three of the Rattle Burn watersheds, with peakflows of 10.98, 0.43, and 0.43 cfs on the severely burned, moderately burned, and unburned watersheds, respectively. These peakflows were translated into flows of 366.0, 21.5, and 6.1 cfs per sq mi, respectively, to provide a basis for comparison. In these latter terms, peakflows from the severely burned and moderately burned watersheds were, respectively, 60 and 3.5 times that observed on the unburned watershed. Peakflows from the two burned watersheds did not approach these magnitudes in the subsequent years of streamflow measurement.

COON CREEK FIRE

The Coon Creek Fire originated on April 26, 2000 at an unattended campfire site in the lower reaches of Coon Creek on the eastern side of the Sierra Ancha Mountains. The wildfire eventually burned approximately 9600 acres including parts of the Workman Creek watersheds and the Sierra Ancha wilderness area. The burned area originally supported a vegetative cover of mixed ponderosa pine and oak, ponderosa pine, and mixed conifer forests and chaparral shrubs. Although most of the fire intensities were low, approximately 20 percent of the area was burned at high intensity. The fire crossed the three experimental watersheds (South Fork, Middle Fork, and North Fork) at the headwaters of Workman Creek (Gottfried and Neary 2001). These watersheds, which cover a total of 1087 ac, were established in 1939 to be the site of several watershed experiments investigating the hydrology of mixed conifer forests and the impacts of forest management treatments on watershed resources.

The three watersheds were mothballed in 1983 following more than 40 yr of continuous hydrologic monitoring and evaluation. The Middle Fork of Workman Creek, which had been the hydrologic control for the earlier watershed experiments and is the focus of this paper, supported an undisturbed old-growth mixed conifer forest prior to the fire. Forest vegetation on South Fork and North Fork had been modified by the earlier experimental treatments and contained mosaics of forest, shrub, and grass covers at the time of the fire. The Middle Fork burned at a high intensity. Vegetation and the soil surface on two-thirds of the watershed were subject to high soil heating where litter, duff, and logs were completely consumed. Intensities on the other two watersheds were low to moderate.

Streamflow Measurements

The weirs and a flume at Workman Creek were reopened in June of 2000 to assess the impacts of the Coon Creek Fire on streamflow volumes, peakflows, and soil erosion and sedimentation rates. Main Dam, a combination 90° V-notch weir and Cipolletti weir, measures streamflows from the entire three-watershed area. The South Fork and North Fork watersheds are gauged by 90° V-notch weirs and streamflows from the main part of Middle Fork are measured at a trapezoidal flume.

Post-Fire Peakflows

Several record peakflows have been estimated at Main Dam since the wildfire. A 15 min rainfall at an intensity of 2.6 in/hr on Middle Fork in June of 2000 produced a peakflow that was more than seven times that of the previous highest peakflow of 289 cfs measured on October 10, 1972 (Neary and Gottfried 2002). The streamflow overtopped the weir, so peakflow was estimated from high-water marks.

Two other peakflow events were observed in August of 2001. The higher of these peakflows, between 409 and 420 cfs, was recorded on August 11, 2001, when a thunderstorm produced a rainfall event of approximately 1.3 in/hr in intensity. The partially cleaned settling basin and associated hydrologic structures at Main Dam were filled with sediment after this event. Observations at South Fork and North Fork showed less sediments trapped behind the weir walls, suggesting that most of the streamflows originated from the severely burned Middle Fork. Main Dam was overtopped by both events and the instrument shelters were partially submerged in the second event. These two peakflows contained large amounts of sediment and several logs, making streamflow calculations difficult.

RODEO-CHEDISKI FIRE

The Rodeo-Chediski wildfire was actually two fires that ignited on the Fort Apache Reservation and then merged into one devastating burn. The cause of the Rodeo Fire, which began a few miles from Cibecue on the Reservation on June 18, 2002, was arson, whereas the Chediski Fire was set as a signal fire by a seemingly lost person a few days later. This second fire spread out of control and eventually merged 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 35,000 people were forced to flee the inferno. The fire had burned 276,507 ac of Apache land and 462,606 ac in total by the time that most of the firefighters had left the area on or about July 13. Nearly 500 buildings had been destroyed, with more than half of the burned structures being peoples' homes.

Streamflow Measurements

Two nearly homogeneous watersheds, 60 ac each, had been 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 School of Renewable Natural Resources, University of Arizona to obtain baseline hydrologic and ecological information on watersheds located in ponderosa pine forests on sedimentary soils (Ffolliott and Baker 1977). Cretaceous undivided material with mineralogy similar to that of the Coconino Sandstone formation lies beneath the watersheds. The two watersheds are situated on relatively flat topography, with few slopes exceeding 10 percent. Their elevations range from 6800 to 7000 feet. The most recent timber harvest before the fire removed approximately 45 percent of the merchantable sawtimber by group selection in the early 1960s. Sixty-five percent of up to 25 inches of annual precipitation falls from October to April, much of it as snow, and the remainder in rainstorms from July to early September. Summer storms, although often intense, rarely produced significant stormflows before the watersheds were burned.

The two watersheds had been mothballed in 1977–78 after completion of the baseline watershed measurements. However, the control sections (3 ft H-flumes) were left in place. Following cessation of the Rodeo-Chediski Fire, these control sections were refurbished and re-instrumented with water-level recorders, and a weather station on the site was reestablished to study the impacts of varying fire severities on hydrologic processes. A fire severity classification system that relates fire severity to the soil-resource response to burning (Hungerford 1996) was used to determine the relative portions of the watersheds that were burned at low, moderate, and high severities (Wells et al. 1979). This extrapolation indicated that one of the Stermer Ridge watersheds experienced a high-severity, stand-replacing fire, and the other watershed had been exposed a low to medium severity, stand-modifying burn.

Post-Fire Peakflows

Summer stormflows on the Stermer Ridge watersheds had been uncommon. The highest peakflow measured in a summer stormflow event in the 1972–76 pre-fire period was about 0.10 cfs. However, high-water marks observed on the control sections in the first visit of researchers to the watersheds following the fire indicated peakflows in orders of magnitude larger than earlier recorded (Ffolliott and Neary 2003). The estimated peakflow on the watershed that experienced the high-severity, stand-replacing fire was almost 8.9 cfs or nearly 90 times that measured in 1972–1976 period. Peakflow on the watershed subjected to the low to medium intensity, stand-modifying burn was about one-half less in magnitude but still far in excess of the previous observations. A subsequent rainfall event generated even higher peakflows on the watersheds. On the severely burned watershed, the peakflow following this second event was estimated to be 232 cfs or about 2350 times that measured earlier. This flow represents the highest known post-fire peakflow measured in the montane forest ecosystems of Arizona or, more generally, elsewhere in the southwestern United States.

SUMMARY

The post-fire peakflows reported in this paper have been documented more or less on a controlled watershed basis; either pre- and post-fire measurements were made on a watershed or an unburned control watershed was available for comparison purposes. Although specific case studies have been presented, the increases in peakflows that have been observed are likely to bracket the post-fire peakflows that might be expected in Arizona montane forests. It is further assumed that the post-fire peakflows observed immediately following the Rodeo-Chediski fire are likely to represent the upper end of the range of these values.

Other wildfires impacting peakflows have occurred in the montane forests but are more difficult to analyze on a watershed basis because of instrumentation or design limitations. One example is the Dude Fire of 1990, one of the more devastating wildfires in Arizona's history, which burned 27,120 ac of mostly ponderosa pine forests surrounding Dude, Bonita, and Ellison Creeks in central Arizona, destroying more than 60 homes and structures, and, sadly, resulting in the loss of six lives. Because streamflow measurements are not available for the individual watersheds impacted, it is not possible to directly assess the fire's impacts on the peakflows from these burned watersheds. However, streamflow records from the U.S. Geological Survey gaging station situated on Tonto Creek above Roosevelt Lake can be used to qualitatively assess the Dude Fire in the general context of its effects on peakflows within a broader and larger river-basin scale.

The 675 sq mi area monitored by the U.S. Geological Survey gaging station includes the area burned by the Dude Fire. In comparing mean daily streamflow records at this gaging station for 2 years preceding (1988–89) and 2 years following (1991–92) the fire to the streamflow measurements obtained in the year of the fire (1990), significantly higher peakflows than observed in the 2 years either before or after the fire occurred in the initial post-fire period following summer monsoonal rainfall events of similar magnitudes. The initial stormflow following the fire had a peak that was 80 times the baseflow at the time. Although the proportion of this increase that is attributable to the Dude Fire is unknown, there can be little doubt that the fire played a significant hydrologic role in generating this increase.

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