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Entiat Experimental Forest: Catchment-scale runoff data before and after a 1970 wildfire

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[1] Effects of wildfire on water quantity and quality are issues of major concern. Much has been learned from previous research, although site-specific data from both before and after wildfire are rare. The Entiat Experimental Forest (EEF) in central Washington State provides such a hydrologic record. In August 1970 a severe wildfire occurred following 10 years of stream gauging as part of a controlled land use experiment. A modified data collection program continued through 1977. Existing data from the EEF are available on the internet. Data housed at the site include downloadable daily discharge, air temperature, humidity, precipitation, water temperature, 10-m DEMs, watershed boundaries, and gauge locations. These data are an archive for assessment of hydrologic response and model formulation, calibration, and testing. The EEF is being reinstrumented to investigate recovery from effects of the 1970 fire on water quantity, quality, and flow regime. *INDEX TERMS:* 1860 Hydrology: Runoff and streamflow; 1871 Hydrology: Surface water quality; 1803 Hydrology: Anthropogenic effects; 1829 Hydrology: Groundwater hydrology; *KEYWORDS:* aquatic habitat, runoff and streamflow, semiarid hydrology, surface water quality, wildfire effects

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1. Introduction

[2] Fire has been an important disturbance process in the interior Columbia River basin, United States, for millennia [*Hessburg and Agee*, 2003; *Wright and Agee*, 2004]. Effects of wildfire and associated land management activity, such as fire suppression and watershed rehabilitation, on water quantity and quality are issues of major concern. This is particularly true in the western U.S. and some European countries where large, severe wildfires are perceived to be occurring with greater frequency [*Conedera et al.*, 2003; *Pierson et al.*, 2001; *Rieman et al.*, 2003; *Robichaud and Elsenbeer*, 2001]. Effects of fire on soil and vegetation can lead to increased runoff, flooding, erosion, degradation of water quality, mass soil movements, and debris flows that may threaten human life and property [*Conedera et al.*, 2003; *DeBano et al.*, 1998; *Meyer et al.*, 2001; *Tiedemann et al.*, 1979; *Wells et al.*, 1979; *Wondzell and King*, 2003]. Effects of postfire rehabilitation on runoff, peak flows, erosion, sedimentation, and other fire-affected processes are subjects of active investigation sponsored by land management agencies [*Robichaud et al.*, 2000]. Recovery of prefire watershed conditions depends largely on recovery of terrestrial plant communities, with associated increases in infiltration and evapotranspiration [*Pierson et al.*, 2001; *Swanson*, 1981; *Wright and Bailey*, 1982].

[3] Effects of fire on runoff, flow regime, and water quantity and quality have been studied for decades. Increases in peak flows, water yield, sediment load, and turbidity are commonly cited as important potential effects [*Beschta*, 1990; *DeBano et al.*, 1998; *Moody and Martin*, 2001; *Robichaud et al.*, 2000; *Swanson*, 1981; *Tiedemann et al.*, 1979; *Wells et al.*, 1979; *Wondzell and King*, 2003]. Damage to forest vegetation and the litter layer by fire can expose soil to rain splash and hasten delivery of precipitation to the soil surface, thereby increasing runoff and surface erosion [*Johansen et al.*, 2001; *Robichaud and Brown*, 1999]. Soil infiltration capacity can be reduced when surface pores are sealed by ash or fine sediment made available by destruction of soil structure and mobilized by rain splash, and by fire-induced formation of hydrophobic compounds on the soil surface [*Cannon et al.*, 2001; *DeBano et al.*, 1977; *DeBano et al.*, 1998; *Giovannini et al.*, 1988; *Martin and Moody*, 2001; *Robichaud and Hungerford*, 2000; *Swanson*, 1981; *Wells*, 1981; *Wright and Bailey*, 1982]. Reduced infiltration through these mechanisms and reduced evapotranspiration caused by damage to vegetation can result in increased runoff, sediment mobilization and delivery to channels, flooding, and debris flows [*Beschta*, 1990; *Cannon et al.*, 2001; *Conedera et al.*, 2003;

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Elliott and Parker, 2001; *Krammes and Rice*, 1963; *Meyer and Wells*, 1997; *Tiedemann et al.*, 1979; *Wells*, 1987]. Increased peak flows can increase channel bed and bank erosion, further increasing sediment concentration in streamflow [*Beschta*, 1990; *Swanson*, 1981; *Tiedemann et al.*, 1979; *Wondzell and King*, 2003].

[4] Fire can affect water quality by increasing nutrient losses to erosion, reducing nutrient uptake, and increasing leaching [*Beschta*, 1990; *Grier*, 1975; *Richter et al.*, 1982; *Tiedemann et al.*, 1979]. Fire can volatilize nitrogen in vegetation and litter, increase nitrification, and mineralize cations, which may be redistributed and converted to more soluble salts. Increased runoff can result in increased total cation and bicarbonate losses [*Grier*, 1975; *Tiedemann et al.*, 1979; *Wells et al.*, 1979]. Large volumes of soil and nutrients can be transported to channels by fire-related debris flows [*Helvey et al.*, 1985; *Meyer et al.*, 2001]. Fire can also increase stream water temperature primarily by increasing exposure to solar radiation [*Anderson et al.*, 1976; *Beschta*, 1990; *Tiedemann et al.*, 1979].

[5] Despite the importance of wildfire as an ecological and social issue, relatively few hydrologic data exist beyond the plot and hillslope scales. Fire data at the catchment scale are mostly associated with paired watershed studies of prescribed fire effects on water quantity and quality. Catchment-scale hydrologic effects of wildfire are less well known, because prefire data are rarely available [*Moody and Martin*, 2001]. We know of only three published cases having site-specific, prewildfire data: one of these comes from the San Dimas Experimental Forest in southern California [*Hoyt and Troxell*, 1934] and one from a eucalyptus forest in Australia [*Langford*, 1976]. The third of these "natural fire experiments" comes from the Entiat Experimental Forest (EEF), located in central Washington State, U.S.A. [*Helvey*, 1980]. This data note reports on an archive of downloadable data for the EEF (daily discharge, air temperature, humidity, precipitation, water temperature, 10-m DEMs, catchment boundaries, and gauge locations) as a resource for model formulation, calibration, and testing of wildfire effects on catchment-scale runoff. EEF data also provide the opportunity to contrast long-term hydrologic recovery between catchments that were or were not subject to postfire rehabilitation treatments.

2. Entiat Experimental Forest

[6] The EEF was originally established to study effects of timber harvest and road building on quantity, quality, and timing of streamflow (Figure 1). Site selection criteria included: (1) three or more 2.5–15.5 km^2 catchments; (2) similarity among catchments in climate, physical characteristics, and vegetation, all of which should represent much of the forested land east of the Cascade Mountain crest in Washington State; (3) absence of disturbance by recent fire, heavy grazing, logging, or road building; and (4) reasonable year-round access [*Helvey et al.*, 1976a].

[7] McCree Creek, Burns Creek, and Fox Creek catchments were selected to be the new experimental forest. These are adjacent catchments, each approximately 500 ha in size. They lie in the headwaters of the Entiat River watershed in central Washington State on the east slope of the Cascade Range about 55 km north of Wenatchee at 47°57′N, 120°28′W. Catchment elevations range from 549 to 2134 m, mean aspects from 205 to 237 degrees, mean channel gradients from 27 to 29%, and mean hillslope gradient is about 50%. Mean annual temperature at 920 m elevation is 6.7°C. Mean annual precipitation is 58 cm; most falls from November to May, and only 10% falls from June to September. Seventy percent of precipitation is snow, and hydrographs are dominated by snowmelt. Annual peak flows occur in May or June. During the period 1962–1970, 50% of the time discharge was greater than 12.7, 20.7, and 19.2 L s^{-1} and mean maximum daily flow was 164.4, 243.7, and 167.2 L s^{-1} in McCree, Burns, and Fox Creeks respectively [*Helvey*, 1974; *Helvey et al.*, 1976a; *Tiedemann et al.*, 1978].

[8] Bedrock is primarily granodiorite and quartz diorite. Glaciofluvial sediment is abundant on the lower slopes. Glacier Peak is 56 km to the northwest, and pumice deposits from multiple eruptions vary from a few centimeters to more than six meters in thickness. Soils are well-drained Entisols. Prior to a severe fire in 1970 the forest overstory consisted predominantly of ponderosa pine (*Pinus ponderosa* Laws.) and Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) at higher elevations. Stand-replacing wildfire had apparently not occurred in the 200 years prior to 1960, although fire scars on large trees indicated a history of periodic fire [*Helvey et al.*, 1976a].

3. Historical Data

[9] Data collection in the EEF began in 1960 and continued through 1977. During the period 1960–1970 discharge data were collected using sharp-crested, 120°, V notch weirs near the mouth of each of the three experimental catchments. Weir ponds had capacities of 20–50 m^3. Stage height was measured using a stilling well float and punch tape recorder.

[10] Following 10 years of calibration, the EEF catchments burned unexpectedly on 24 August 1970 as part of a 486 km^2, lightning-caused wildfire complex [*Helvey*, 1980; *Martin et al.*, 1976]. *Tiedemann et al.* [1978] describe fire effects in the EEF as severe and uniform. However a few small patches, generally less than 10 ha, of mature ponderosa pine survived. By the end of the 1971 growing season, land surface cover by native and seeded plants averaged only 8.6% [*Tiedemann and Klock*, 1973]. During the fire discharge in McCree Creek declined from 6.25 to 1.71 L s^{-1}, and immediately after the fire, strong diurnal discharge patterns were nearly eliminated owing to reduced transpiration [*Berndt*, 1971].

[11] After the fire two contour roads were constructed in McCree and Burns catchments, dead trees were logged, and grass and clover seed and nitrogen fertilizer were applied by helicopter [*Helvey*, 1980]. Fox Creek was designated an experimental control and not seeded, fertilized, roaded, or logged [*Tiedemann and Klock*, 1976]. Effects of wildfire on streamflow quantity, quality, and timing became primary research objectives, and were examined until the cessation of data recording in 1977 [*Helvey*, 1980].

[12] In mid-March 1972 record high air temperatures and an exceptionally deep snowpack produced flows greater than three times the maximum measured during calibration in McCree Creek. On 18 March a debris flow, apparently initiated by failure of weathered granitic material on steep slopes, destroyed the McCree Creek weir.

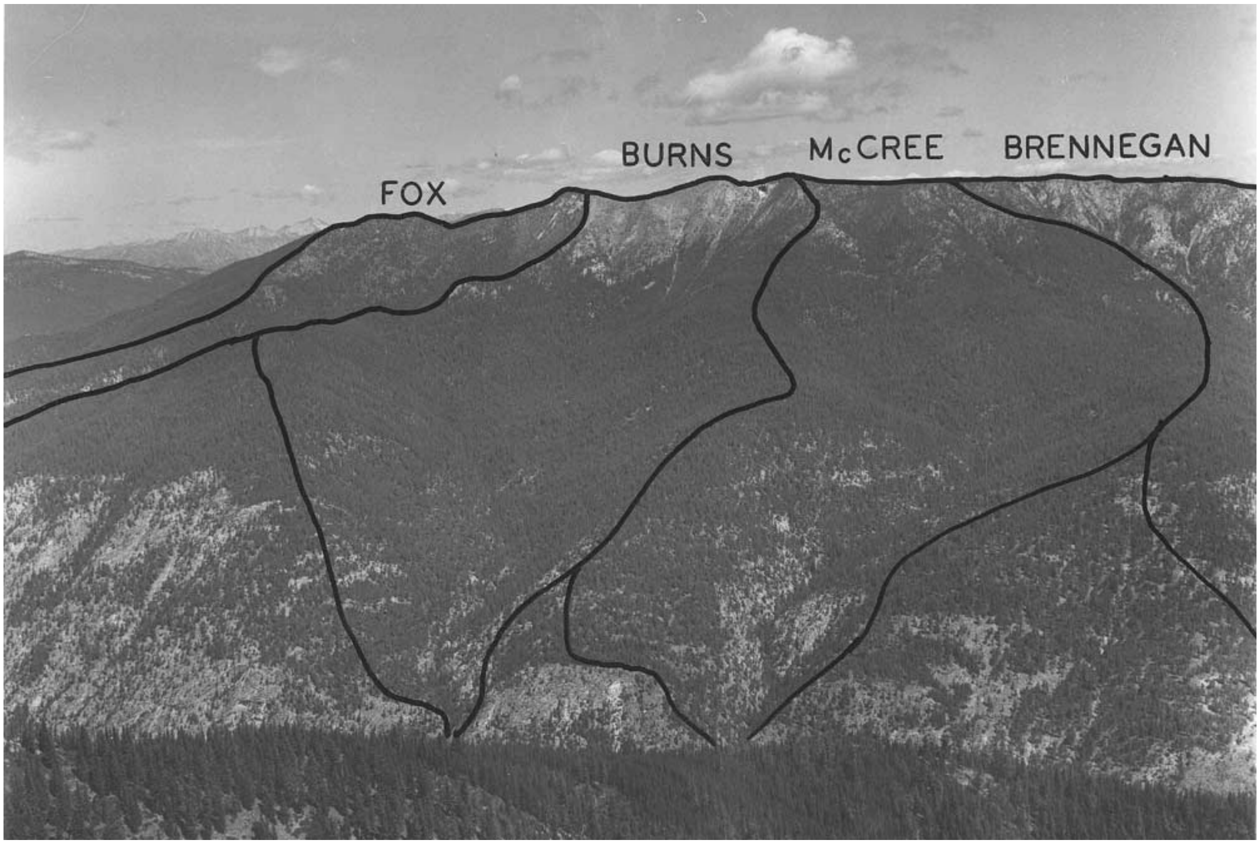

Figure 1. The Entiat Experimental Forest, looking toward the northeast.

Intense rainstorms on 9 and 10 June initiated a similar failure and debris flow in Fox Creek, destroying that weir [*Helvey*, 1974]. These weirs were replaced during the summer and autumn of 1972 with Parshall flumes at the gauging sites. Postfire gauging records for McCree and Fox Creeks were incomplete owing to persistent sedimentation in the flumes. During 1973–1975 those missing data were estimated from discharge at the Burns weir [*Helvey*, 1980; *Helvey and Fowler*, 1999]. Record quality, based on USGS standards [*Corbett et al.*, 1943], was excellent for all stations until 1972. Records for Burns were good for 1972–1977 and fair to poor for Fox and McCree [*Helvey and Fowler*, 1999]. During the first postfire year total water yield from the EEF was 50% greater than predicted using the Entiat River and nearby Chelan River as controls [*Helvey*, 1974]. The most complete postfire discharge data were from Burns Creek. During water years 1972–1977 measured runoff in Burns Creek exceeded predictions by 10.7 to 47.2 cm, using the Chelan River as a control [*Helvey*, 1980].

[13] Precipitation was measured in shielded weighing bucket gauges with a 203-mm orifice. Only one gauge in the study area, approximately 200 m from the Burns Creek weir, covered the entire period of record. After 1972 storage gages were installed at nine locations distributed throughout the McCree and Burns catchments. High-elevation gauges were serviced only once each year due to difficult access, but a more frequent schedule was utilized where feasible. These other gauges provided data for periods of approximately one year each. An additional six gauges within 48 km of the EEF have records covering the study period [*Bowles et al.*, 1975].

[14] Water temperature sensors and punch tape recorders were installed in 1968 at the three gauging stations and temperature was recorded hourly. Three additional recorders were installed in Fox Creek in the fall of 1972 [*Helvey and Fowler*, 1999]. Mean daily maximum water temperatures during December 1969 to February 1970 were about 3.3°C. Maximum water temperatures in July and August were 10°–11°C before the 1970 fire [*Helvey et al.*, 1976a]. During the first two postfire years mean daily maximum water temperatures increased in Burns Creek by 5°–6°C based on control data from the Entiat River [*Helvey*, 1974; *Helvey et al.*, 1976b]. In general stream temperatures peaked in the summer 1973 and declined until the end of data collection in 1977 [*Helvey and Fowler*, 1999].

[15] Beginning in 1966 air temperature and humidity measurements were made using a hygrothermograph and chart recorder at the Burns weir weather station. Daily maximum and minimum values were recorded [*Helvey and Fowler*, 1999]. Mean daily maximum air temperatures during December 1969 to February 1970 were about −1.1°C, and maximum air temperatures in July and August were about 32.2°C before the 1970 fire [*Helvey et al.*, 1976a]. Tests for postfire changes in mean monthly air temperature were inconclusive [*Helvey et al.*, 1976b]. Aerial measurements of midslope soil and plant surface temperatures were made on 29 August 1969, near the time of maximum daily air temperature. Mean values ranged from 19.8 to 22.9°C [*Tiedemann et al.*, 1978].

[16] Historical Entiat data are located at http://oregonstate.edu/~vachek/EEF_Fire_Data.htm. Data housed at the site include daily mean discharge for Burns (1 January 1961 to 31 December 1977), Fox (1 January 1962 to 31 December 1975) and McCree Creeks (1 January 1962 to 31 December 1975). Most meteorological data were collected at the Burns weir weather station. Meteorological data cover most of the period of record and include daily minimum and maximum air temperature (15 May 1966 to 12 December 1975) and humidity (15 May 1966 to 31 December 1969), daily precipitation (1 October 1962 to 31 December 1975) and data from the precipitation storage gauges. Minimum and maximum daily water temperature data are available for Burns Creek (1 July 1969 to 11 December 1974), Fox Creek (1 January 1969 to 31 December 1971), and McCree Creek (4 April 1969 to 16 October 1977). GIS data layers also available online include 10-m DEMs, catchment boundaries, and gauge locations. Other relevant data, not currently available online, may be obtained from the U.S. Forest Service, Okanogan-Wenatchee National Forest, Wenatchee, Washington. These data include soil layers in GIS format and vegetation maps in paper format. Postfire vegetation development for the years 1971–1974 is summarized by *Tiedemann and Klock* [1976].

4. Current and Future Investigations

[17] In 2003 we began reanalyzing the EEF historical records and reinstrumenting the three gauging stations with redundant stage height recorders (pressure transducers and capacitance rods) and water temperature sensors. We also instrumented the Burns weather station (920 m), and a new Fox Creek weather station (650 m) with a rain gauge and air temperature, humidity, and wind speed sensors, all recording to data loggers. During the spring 2004 two similar weather stations were added, one on the eastern McCree catchment divide (1300 m) and one on the Burns-Fox divide (2000 m). In addition, Parshall flumes with recording pressure transducers were installed on Burns Creek and on one of its tributaries at about 1200 m elevation, and 30 self-contained, logging water temperature sensors were installed along the entire length of Burns Creek.

[18] Current objectives include analysis of the new hydrologic record for signatures of the 1970 fire, assessing hydrologic recovery, and analysis of water source and flow path in the EEF, with emphasis on the Burns Creek catchment where the most complete historical record exists. The EEF record also provides the opportunity to contrast hydrologic recovery between catchments where postfire rehabilitation measures were applied (McCree and Burns) with the Fox Creek catchment which had no rehabilitation treatment. In addition we will use 11 other gauged catchments in the Entiat River drainage basin to form the basis for nested hydrologic monitoring in this portion of the interior Columbia River basin. Data from these other catchments are available through the Washington State Department of Ecology at http://www.ecy.wa.gov/apps/watersheds/flows/regions/state.asp.

5. Summary

[19] In recent years interest in the hydrologic recovery of burned systems has increased. Nevertheless, few data exist at the catchment scale that document the effects of wildfire on runoff characteristics. The EEF is the site of one of only three known published studies that chronicle a "natural fire experiment" before and after wildfire. This data note reports the archive of downloadable data for the EEF, including daily discharge, air temperature, humidity, precipitation, water temperature, 10-m DEMs, watershed boundaries, and gauge locations. This data note is intended to inform interested researchers of the records available for the EEF, which may be useful for evaluating the long-term hydrologic effects of wildfire. Our objective is to present an opportunity to further analyze and build on an existing data set to increase understanding of the effects of severe wildfire on water quantity, quality, and timing, as well as increase understanding of long-term hydrologic recovery following severe disturbance such as fire. Increased predictive capability regarding effects of severe wildfire and mechanisms and rates of hydrologic recovery will inform land management responses to these events. For example, improved knowledge of long-term hydrologic recovery following wildfire could help guide decisions regarding the relative value and advisability of various postfire rehabilitation approaches.

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