Report for 2004OR45B: Satellite Remote Sensing of Wildfire Induced Changes in Hydro-Geomorphological Landscape Patterns and Processes

There are no reported publications resulting from this project.

Report Follows

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End Date: 14 February 2005

Title: Satellite Remote Sensing of Wildfire-Induced Changes in Hydro-Geomorphological Landscape Patterns and Processes

Focus Category: Geomorphological Processes, Hydrology, Sediments

Principle Investigator: Dr. Stephen H. Schoenholtz, Associate Professor, Department of Forest Engineering, Oregon State University, 267 Peavy Hall, Corvallis, OR 97331-5706 Telephone: (541) 737-9112; Fax: (541) 737-4316

Congressional District: Oregon 5th

Abstract:

Severe wildfires result not only in dramatic changes in vegetation cover, but also can induce significant changes in hydro-geomorphology. These changes may include decreased infiltration, increased overland flow, increased soil erosion, and debris-flow initiation during post-fire storm events. A number of variables (e.g., fire severity) have been identified that can lead to increased erosion activity and subsequent changes in geomorphic features; however, present methods of characterizing these variables within burned basins may be both time-consuming and labor-intensive. Satellite remote sensing holds great potential for rapid assessment of these variables. This research proposed to use data from the Moderate resolution Imaging SpectroRadiometer (MODIS) and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) to map and characterize burn-induced erosion variables at multiple spatial scales on sites exposed to wildfires in Oregon. A second goal of this project was to quantify wildfire-induced changes in vegetation and soils of humid forested landscapes and correlate these changes with changes in stream-discharge

Problem and Research Objectives:

One goal of the project was to adapt the methods of Key and Benson's (1999) Landsat-based change-detection algorithm, i.e., delta Normalized Burn Ratio (dNBR) to data and imagery derived from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). dNBR is presently used with pre- and post-fire Landsat imagery to quantify wildfire-induced changes in landcover, particularly wildfire-induced changes in vegetation and soil. These burn-severity maps, e.g., Burned Area Reflectance Component (BARC) maps, are presently used to by USFS Burned Area Emergency Rehabilitation (BAER) teams to help identify flood and landslide risks in burned basins. ASTER has improvements in spectral and spatial resolution over Landsat that could offer increased accuracy of the dNBR. ASTER-derived dNBR and BARC burn-severity mapping could assist BAER teams.

A second goal of this project was to quantify wildfire-induced changes in vegetation and soils of humid forested landscapes and correlate these changes with changes in stream-discharge, e.g., quickflow. Wildfires with high burn severity often destroy canopy and surface vegetation and alter soil properties such as organic-matter content, structure, water-repellency, and infiltration capacity. These wildfire-induced changes in vegetation and soil affect the water-balance of the basin (Equation 1):

$$\mathbf{P + G_{in} - (Q + ET + G_{out}) = \Delta S} \qquad \mathbf{[1]}$$

where P is gross precipitation, G_{in} is groundwater inflow, Q is stream discharge, ET is evapotranspiration, G_{out} is groundwater outflow, and S is storage, all in cubic units of measure, e.g., m^3.

In particular, interception storage, evapotranspiration magnitude, and infiltration rates decrease immediately after wildfire. Thus, during times of normal precipitation regime, runoff increases are often observed following wildfire. Changes in soil infiltration capacity may also affect the mode of storm-runoff generation. For example, Horton overland flow, as opposed to saturated overland flow, may occur more frequently on (wildfire-induced) de-vegetated and water-repellent hillslopes.

Changes in the ratio of runoff to precipitation (Rp) are correlated with changes in the contributing (source) area of the basin (Equation 2):

$$\mathbf{Rp = V / P} \qquad \mathbf{[2]}$$

where V = quick-flow in units of depth (e.g., mm) and P = gross precipitation (mm). Thus, changes in the areal extent of vegetation as depicted in BARC imagery are correlated with changes in Rp.

Methods, Procedures, and Facilities:

Study Site

2003 B&B Complex Fire

The 2003 B&B Complex Fire of Central Oregon affected about 37,000 ha (92,000 ac) of various forested catchments within the Metolius River watershed located in North-Central Oregon. Jefferson Creek, the subject of this investigation, is a tributary of the Metolius River (Figure 1). The fire was comprised of the Booth and Bear Creek Fires that initiated independently on 19 August 2003, merged on 04 September 2003, and were deemed contained on 26 September 2003.

The Jefferson Creek basin is a 7,200 ha (17,792 ac) watershed. About 2,400 ha (5,900 ac) of the Jefferson Creek watershed, primarily in the upper basin, was affected by the B&B Complex Fire. The center of the Jefferson Creek watershed is located at latitude 44.657˚

North, and longitude 121.738˚ West; elevation ranges from 2,195 to 1,463 m (7,200 to 4,800 ft). The Jefferson Creek watershed is gauged by USGS streamgaging station 14090350 *Jefferson Creek* located at River Mile 1.3 (i.e., 1.3 mi upstream from the mouth of Jefferson Creek (Figure 1)). A substantial portion of the Jefferson Creek watershed is located on Tribal lands of the Confederated Tribes of the Warm Springs Indian Reservation.

Precipitation and Stream-Discharge Data

Precipitation

Because there are no precipitation gauges located within the Jefferson Creek watershed, precipitation was characterized using data queried from the Oregon Climate Service's Spatial Climate Analysis Service (SCAS) internet-based data explorer. SCAS uses the Parameter-elevation Regression on Independent Slopes Model (PRISM) (Taylor et al., 1993) to derive precipitation data for a specific time and location. PRISM data have a one-month temporal resolution. The watershed is subdivided into three areally equivalent sectors. Monthly PRISM precipitation estimates are acquired for the center of each sector, i.e., centroid, and a mean value is derived. Mean monthly precipitation for the Jefferson Creek watershed is composed of the arithmetic mean of these three centroid points.

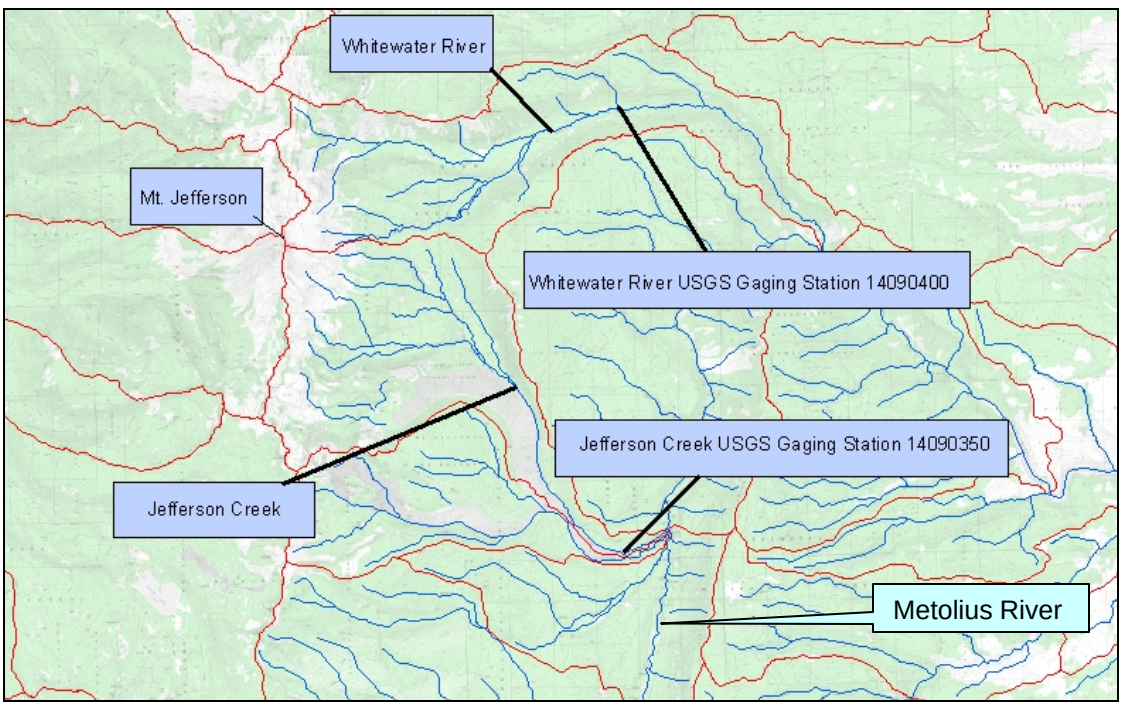

Figure 1. Location of Jefferson Creek and Whitewater River in Central Oregon. Watershed boundaries are delineated by red lines. Stream network is shown by blue lines.

Additional precipitation data were acquired from Remote Automated Weather Station (RAWS) and SNOw TELemetry (SNOTEL) climate data networks. Precipitation data were

obtained from the Western Regional Climate Center's Internet-based data library. Both RAWS and SNOTEL have daily precipitation (and in some instances hourly) data.

PRISM precipitation estimates are based, in part, on data acquired from other climate data networks, e.g., RAWS, SNOTEL. As such, the accuracy of the PRISM precipitation estimates is related to the precision and accuracy of the precipitation gauges comprising the original climate data network, e.g., SNOTEL. Nearby SNOTEL precipitation gauges, e.g., Santiam Junction, OR, cumulatively record precipitation to the nearest 0.01 inch during the water year (01 Oct to 30 September). However, there are instances where the cumulative-precipitation-total *decreases* for short time periods; this is likely related to equipment malfunction. Precipitation measured at SNOTEL stations probably represents approximately 90 percent of the true precipitation values.

Stream Discharge

Mean daily streamflow data for Jefferson Creek (15 September 1983 through 31 January 2005) were acquired from the USGS National Water Information System (NWIS) NWISWeb Internet server. The entire period of record (up to 31 January 2005) was acquired. Mean daily discharge data are rated as "good" for Jefferson Creek; a rating of "good" indicates that the data are within 10 percent of the true-value. There are no known diversions or impoundments upstream from USGS gaging station #14090350 Jefferson Creek, Oregon.

Hydrograph Separation

USGS NWISWeb mean daily discharge data were processed using an Internet-based hydrograph separation program, iSEP. Total streamflow data were divided into both baseflow and "runoff" components; the minimum temporal resolution of the resulting hydrograph separations was one month. iSEP hydrograph separations agree well with manual hydrograph separations using the *local-minimum* method set forth by Sloto and Crouse (1996).

Hydrological Response Ratios

The pre- and post-fire hydrological response ratio (Equation 2), based on the methods of Hewlett and Hibbert (1967), was derived from USGS stream-discharge data and PRISM precipitation estimates. Monthly hydrographs were separated into quickflow and baseflow components using iSEP and the ratio of quickflow to PRISM precipitation estimates comprised the hydrological response ratio, Rp.

Burn-Severity Mapping

Wildfire-induced changes in vegetation and soil were mapped using a change-detection algorithm, i.e., the difference Normalized Burn Ratio (dNBR), devised for delineating and quantifying the effects of wildfire on vegetation and soil (Key and Benson, 1999). High burn-severity pixels on these maps indicate severe damage or destruction of

vegetation and changes in soil (Bobbe et al., 2001). The burn-severity mapping method correctly identifies approximately 66 percent of all high burn-severity pixels.

Principal Findings and Significance:

Goal One:

ASTER is one of five instruments installed on the Terra and Aqua satellites. Unlike Landsat which collects data continuously as it orbits the Earth, ASTER is the only instrument that presently collects data and imagery on an "as-needed" or on-demand basis. Therefore, the ASTER instrument is not always turned on; it has to be "tasked" to collect data. Consequently, using ASTER to retrospectively study other fire sites for comparison with the results from the 2003 B&B Complex Fire and Jefferson Creek is dependent on whether data were collected for a particular site. Thus, ASTER had a limited data-base available to validate the findings from the 2003 B&B Complex Fire.

Most of the high burn-severity pixels of the Jefferson Creek watershed were contained on the Tribal Lands of the Confederated Tribes of the Warm Springs Indian Reservation. Permission was required to enter upon Tribal Lands to ground-truth or verify the accuracy of the classification of burn-severity pixels. Permission was not granted until October 2004, three months after the last available post-fire ASTER image was acquired (11 July 2004). Thus, ground truthing of the 11 July 2004 ASTER image of the 2003 B&B Complex Fire did not occur until after October 2004 when autumn phonological conditions were prevalent and appreciably different from mid-summer (i.e., July) conditions.

Based on these unanticipated limitations, (i.e., validation of ASTER dNBR burn-severity mapping from other fire sites and problems associated with accurately ground-truthing burn-severity pixels) ASTER imagery was not used for the remainder of this project. Instead, Landsat BARC imagery was obtained from the USFS Remote Sensing Application Center (RSAC) for the 2003 B&B Complex, 2002 Biscuit Fire, Oregon, and the 2002 Missionary Ridge Fire, Colorado. Figure 2 is an example of burn-severity mapping of Jefferson Creek Oregon using Landsat-derived dNBR and BARC imagery.

Goal Two:

Table 1 shows annual PRISM precipitation estimates and iSEP-derived annual runoff depths for Jefferson Creek for WY 1985-2004. Figure 3 graphically depicts the annual rainfall-runoff relationship for Jefferson Creek Oregon for WY 1985-2004. Figure 4 is a graph of annual Rp for Jefferson Creek for WY 1985-2004. Although the 2003 B&B Complex Fire occurred in August and September 2003, it is doubtful that the large annual Rp value for WY 2003 (Rp = 0.12) (October 2002 through September 2003) is solely attributable to the effects of wildfire.

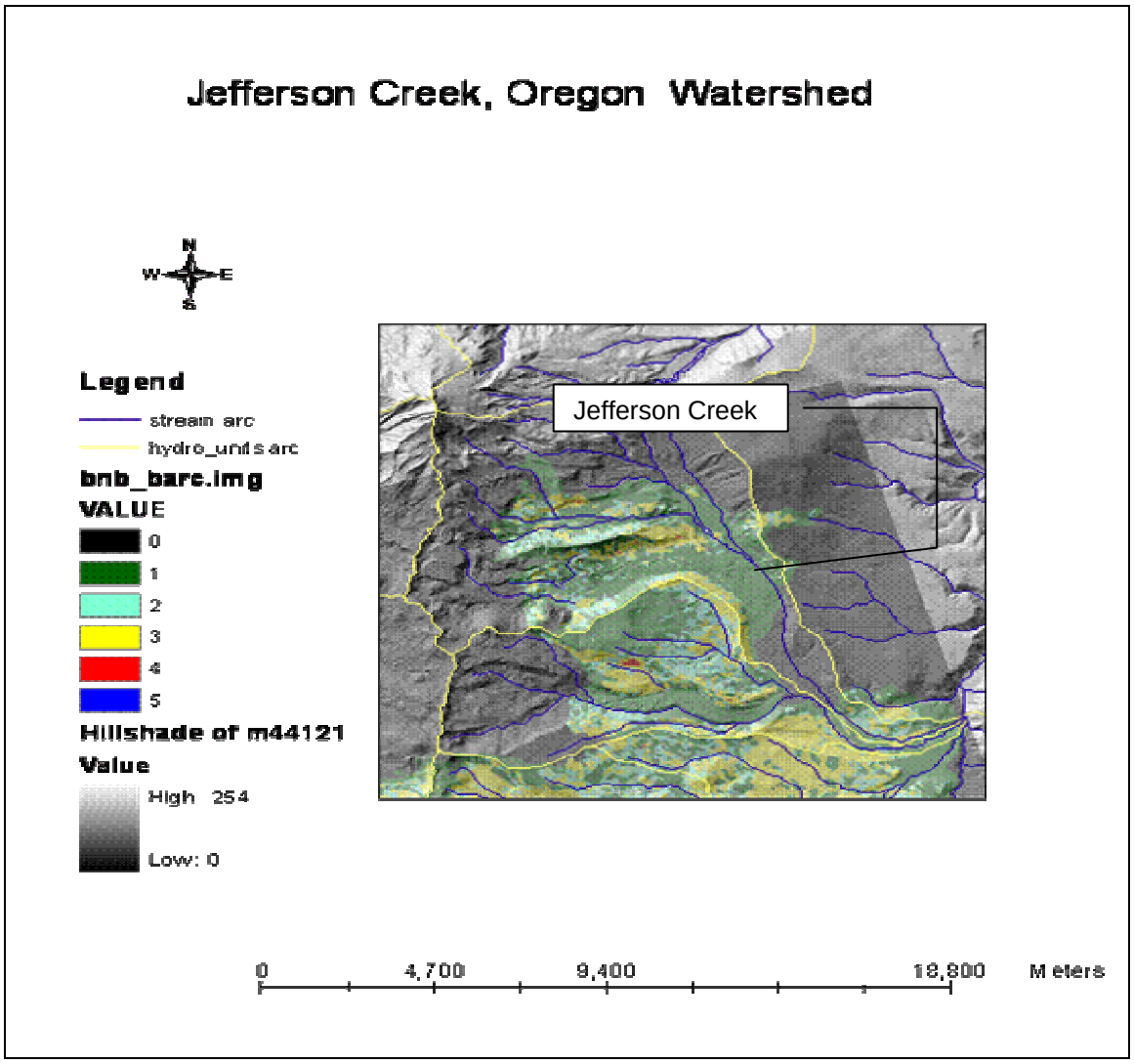

Figure 2. BARC burn severity map of the 2003 B&B Complex Fire, Oregon.

From the rainfall and runoff data of Table 1, a statistically significant ($\alpha = 0.01$) regression relationship exists (Equation 3):

$$\mathbf{RO = -1.65632 + 0.0537652 * P_G} \qquad [3]$$

where RO is runoff depth (in) and P_G is gross precipitation (in). This relationship has a correlation coefficient of 0.87.

Mean monthly basin PRISM precipitation estimates for the Jefferson Creek watershed returned values of 1, 10 and 78 mm (± 10 percent) for July, August, and September 2003, respectively. Mean annual PRISM precipitation estimate for WY 2003 was about 1,896 mm (± 10 percent); this value is below the median annual PRISM precipitation estimate for the basin of 2,064 mm (n = 20, standard deviation = 508 mm) based on data for WY 1985 to 2004.

Table 1. PRISM precipitation estimates and iSEP runoff values for WY 1985-2004 for Jefferson Creek, Oregon.

WY	Precipitation mm (in)	Runoff mm (in)
1985	2122 (83.56)	56 (2.2)
1986	2249 (88.66)	91 (3.57)
1987	1774 (69.84)	45 (1.76)
1988	1903 (74.93)	54 (2.12)
1989	2195 (86.43)	48 (1.9)
1990	1648 (64.87)	55 (2.15)
1991	1717 (67.61)	49 (1.91)
1992	1702 (67.02)	67 (2.65)
1993	2361 (92.97)	60 (2.36)
1994	1378 (54.24)	33 (1.31)
1995	2417 (95.15)	94 (3.71)
1996	2957 (116.41)	156 (6.16)
1997	3455 (136.03)	138 (5.44)
1998	1965 (77.36)	71 (2.79)
1999	2638 (103.84)	81 (3.18)
2000	2072 (81.57)	85 (3.33)
2001	1322 (52.06)	32 (1.25)
2002	2238 (88.12)	78 (3.08)
2003	1896 (74.63)	73 (2.86)
2004	2056 (80.93)	63 (2.47)

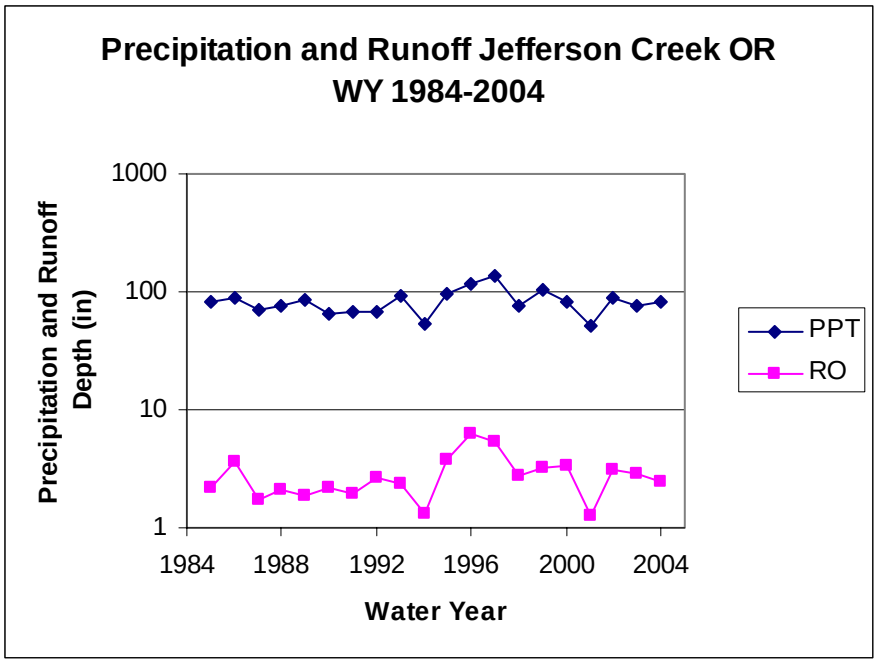

Figure 3. Annual Precipitation and Runoff Values for Jefferson Creek Oregon for WY 1985-2004.

Figure 5 depicts mean monthly Rp for Jefferson Creek. It is apparent that the July 2003 mean monthly Rp of 0.6 may have inordinately affected the mean annual Rp for WY 2003.

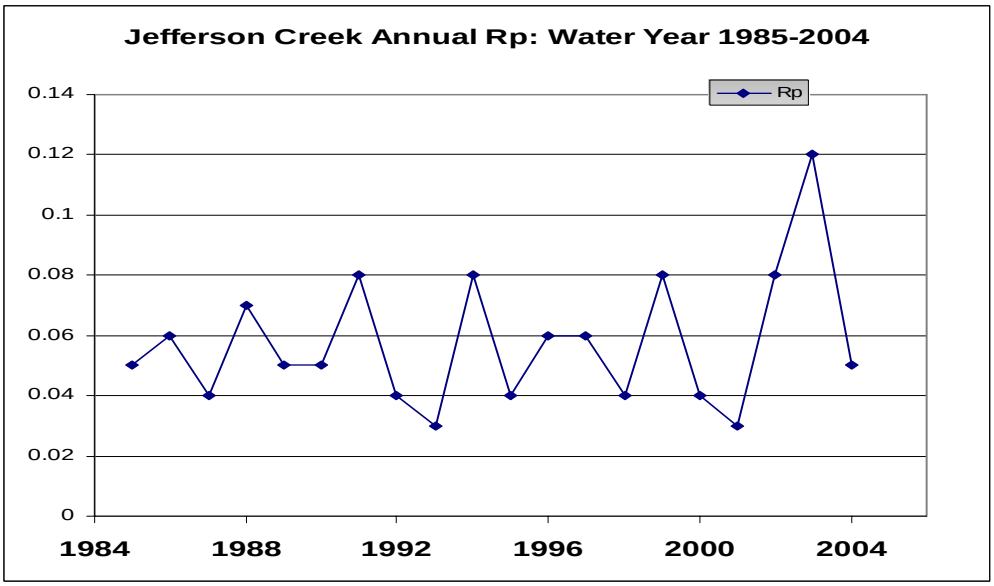

Figure 4. Mean Annual Rp for Jefferson Creek, Oregon WY 1985-2004.

The lumped Jefferson Creek PRISM precipitation estimate of about 1 mm for July 2003 may have caused 0.8 mm of runoff resulting in a Rp of about 0.6. The concept of the variable source area (VSA) hypothesizes that the VSA of a basin is proportional to Rp. The mean monthly July 2003 Rp of 0.6 suggests that 60 percent of the Jefferson Creek watershed was saturated and contributing to storm flow during July 2003. Because soil moisture measurements of Jefferson Creek were not acquired, it is difficult to determine if such a small amount of rainfall (1 mm) could be translated into about 0.8 mm of runoff.

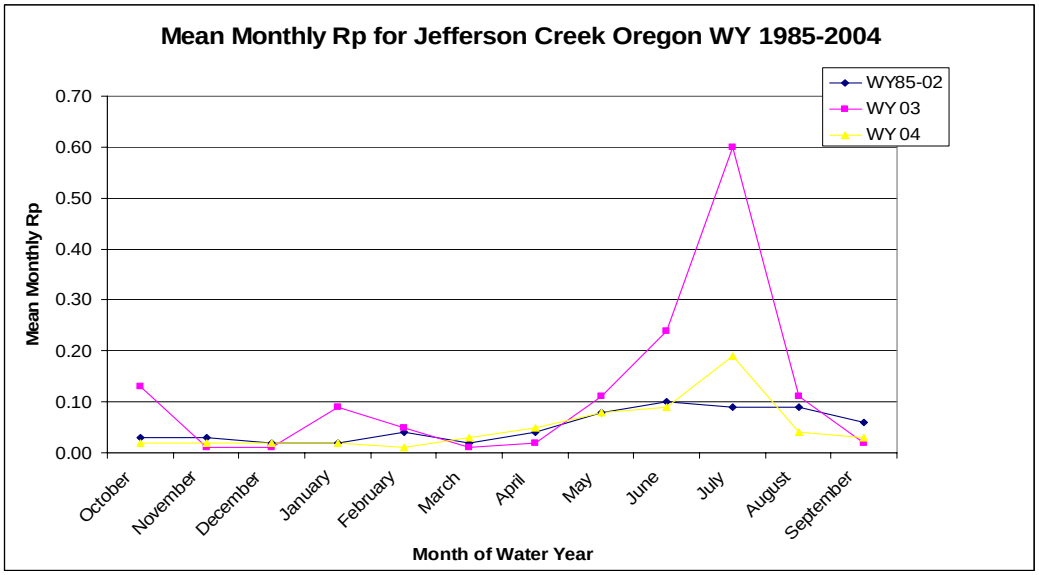

Figure 5. Mean Monthly Rp for Jefferson Creek Oregon: WY 1985-2004.

Figure 6 is a graph of streamflow for April through September 2003. Stream discharge generally decreased through September from a seasonal peak discharge that occurred in May. In particular, the hydrograph for July 2003 appears to show two to three small quickflow events.

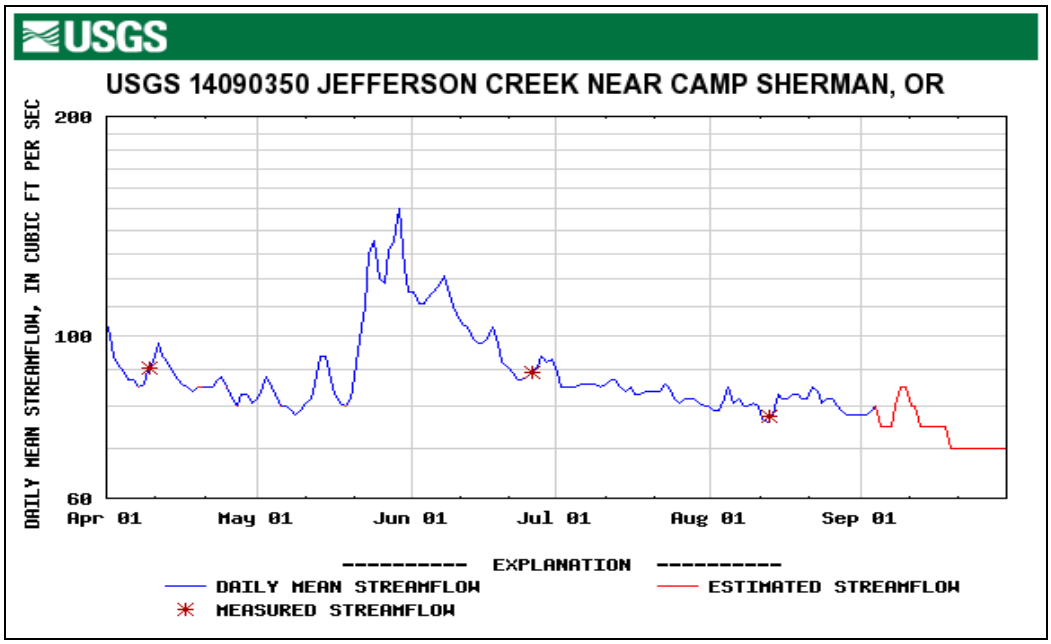

Figure 6. Mean Daily Discharge for Jefferson Creek, Oregon, April through September 2003.

Figure 7 shows a comparison of the mean daily discharge of Jefferson Creek for April 2003 through February 2005 with the median daily discharge of Jefferson Creek based on twenty years of data. Mean daily streamflow for April through October 2003 was below the median daily discharge based on twenty years of record. This suggests that baseflow is likewise depressed indicating that most of the soils of the Jefferson Creek watershed probably have lowered soil moisture content.

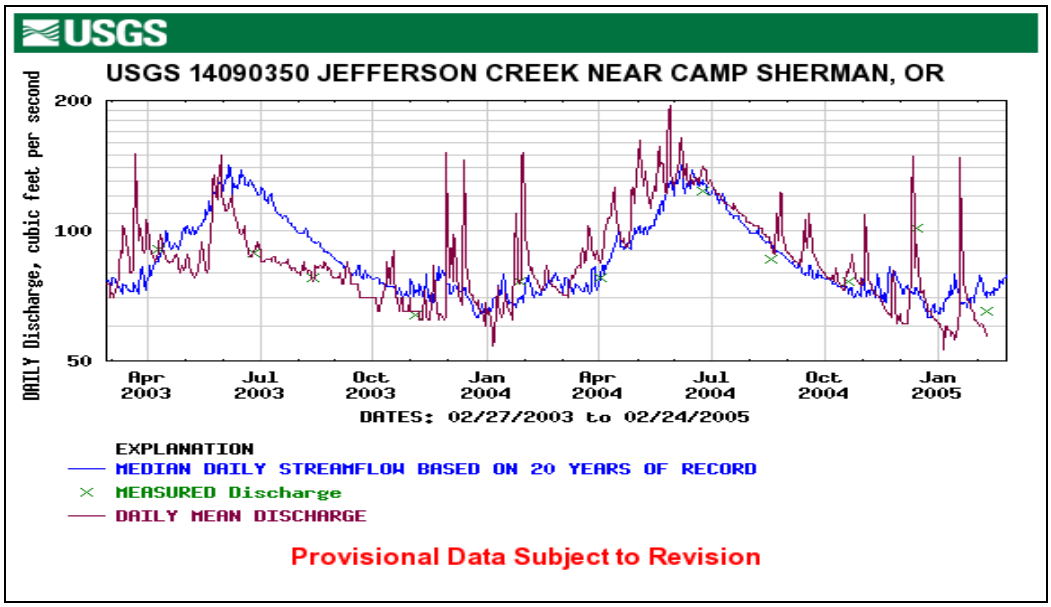

Figure 7. Comparison of Jefferson Creek Mean Daily Discharge for April 2003 through February 2005 with Median Daily Discharge based on twenty years of record.

If we use PRISM precipitation estimates and USGS stream gaging data, e.g., baseflow, as a proxy for antecedent soil moisture content, it appears that soil moisture content of hillslope soils during July 2003 were below field capacity or were unsaturated, i.e., precipitation did not satisfy soil moisture deficits. Thus, based on PRISM precipitation estimates and USGS stream discharge data for April through September 2003, it is unlikely that the July 2003 Rp of 0.6 was accurate. Even if the July 2003 Rp for the Jefferson Creek was 0.6, it is unlikely it was due exclusively to the effects of rainfall.

One mm of precipitation and 0.8 mm of runoff occurred in the Jefferson Creek watershed during July 2003. Most soils in the basin were not saturated during July 2003. Thus, it appears that other sources of quickflow may be present. Snowpack accumulated in the transient snow zone was probably melted during May and June 2003. However, melt-water from the permanent ice-fields and glaciers of Mt. Jefferson and/or groundwater inputs from adjacent basins probably contributed to baseflow during April through September 2003.

Similarly, these glacial melt-water and groundwater-inputs may have transiently satisfied riparian-zone soil moisture deficits causing local expansions of the VSA. Increases in VSA, due to presence of melt- or ground-water, may have increased the *efficiency* of the translation of rainfall to runoff during July 2003. It should be noted, however, that fluctuations of the VSA were not measured or observed during April to October 2003.

Alternatively, glacial melt-water and or ground-water inputs may have transiently increased quickflow during July 2003. It is apparent that Rp derived for Jefferson Creek may be affected by glacial meltwater and or groundwater inputs; in these instances, Rp values, based exclusively on rainfall-runoff relationships, derived for Jefferson Creek Oregon are probably not valid.

Mean annual Rp for WY 2004 (Rp = 0.05) is within the range of pre-fire annual Rp for WY 1985-2002. The mean annual PRISM precipitation estimate for WY 2004 is 2,056 mm (about 99 percent of the mean precipitation value based on data for WY 1985-2004). However, it is noted that July 2004 Rp was 0.2 or about twice the average July Rp value based on WY 1985-2002. The July 2004 PRISM precipitation estimate for Jefferson Creek is 4 mm; runoff is about 0.8 mm. Figure 7 shows that July 2004 mean daily discharge is nearly equivalent to the median daily discharge value based on twenty years of record.

Thus, based on the rainfall-runoff relationship of July 2003, the use of hydrological response ratios, e.g., Rp, (Equation 2) to quantify the effects of wildfire-induced changes in rainfall-runoff relationships for basins such as Jefferson Creek Oregon is problematic. Hewlett and Hibbert (1967) developed their methods based on data from small basins, i.e., less than 52 km^2 (20 mi^2), of the southeastern U.S. The use of Rp to quantify and compare larger basins, i.e., 72 to 700 km^2, of the Western U.S., has not been exhaustively explored in the literature.

For this research to proceed, it is necessary to determine if Rp derived for large basins of the American West are valid and accurately depict rainfall-runoff relationships. Work is ongoing to analyze rainfall-runoff data from other wildfire-affected basins, e.g., the Chetco River, Oregon at the 2002 Biscuit Fire and Vallecito Creek, Colorado at the 2002 Missionary Ridge Fire.

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Training and publications:

Kevin J. Spelts, 3rd year Graduate Student