THE COON CREEK WATER YIELD AUGMENTATION PILOT PROJECT

C.A. Troendle,[1] M.S. Wilcox,[2] and G.S. Bevenger[3]

ABSTRACT

The Coon Creek pilot project represents an attempt to verify that water yield augmentation technology, demonstrated to work on small-scale experimental watersheds, could be applied at an operational or landscape scale with similar results. Coon Creek, a 1673 ha (4133 a) catchment on the East Fork of the Encampment River was selected as the treatment watershed and Upper East Fork, an adjacent catchment, was selected as the control. Following an adequate calibration period, road building and timber harvest disturbed a total of 23.7 percent of the watershed area. Seasonal streamflow (April-October) significantly increased an average of 71 mm (2.8 in) for the first 3 years after harvest. Peak flows, expressed as either instantaneous maximum flow or as maximum mean daily flow, were not significantly increased although the duration of the higher, near bankful, discharges were extended. The findings at Coon Creek support and are comparable with documented observations on smaller experimental watershed studies in the snow zone.

INTRODUCTION

More than 80 years of watershed research throughout the United States, much of which is specifically oriented toward the West, has demonstrated that timber harvest, or vegetation removal, reduces net evapo-transpiration (ET) and results in increased streamflow (Bosch and Hewlett 1982, Callaham 1990). In the snow zone of the Rocky Mountains such increases have been documented following forest removal on experimental watersheds at Wagon Wheel Gap (Bates and Henry 1928, Van Haveren 1988) and at Fool Creek (Troendle 1983, Troendle and King 1985) and Deadhorse Creek (Troendle and King 1987, Troendle and Olsen 1994) on the Fraser Experimental Forest (FEF) in central Colorado. Other studies have shown similar responses occur following deforestation due to insect epidemics (Love 1955) and fire (Troendle and Bevenger 1996). The magnitude of the observed changes in flow is similar in nature to those observed to occur elsewhere in forested environments for similar levels of impact; although the distribution, or timing, of the flow change in the snow zone studies is more reflective of the dependence on snowmelt (Troendle and Leaf 1980). The subalpine environment is unique in terms of the timing of the flow change and the persistence of the increases.

Because of the limited supply of water in the Rocky Mountain West and because of the documented longevity of observed streamflow response to timber harvest, interest arose in the early 1980s in demonstrating that water yield augmentation technology, demonstrated to work on small-scale experimental watersheds, could be applied at an operational or landscape scale.

OBJECTIVES

As noted, the primary objective of the Coon Creek Water Yield Augmentation Pilot Project was to demonstrate timber harvest techniques known to increase flow from small experimental catchments could be scaled to the landscape, implemented under traditional forest management guidelines, and yield similar results. More recently, sediment transport (suspended and bedload) export has been monitored to further define treatment effect.

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[1] Hydrologist, US Forest Service, Fort Collins, Colorado, USA
[2] Hydrologist, US Forest Service, Bend, Oregon, USA
[3] Hydrologist, US Forest Service, Cody, Wyoming, USA

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STUDY DESIGN

Coon Creek, the treatment watershed, is a 1673 ha (4133 a) drainage located in the Sierra Madre Range on the Hayden District of the Medicine Bow National Forest (MBNF) in Wyoming. Coon Creek drains to the west at elevations ranging from 2,682-3,322 m (8,800 to 10,980 ft). Upper East Fork, a 908 ha (2,244 a) control watershed, drains to the southwest at elevations ranging from 2,682-3,322 m (8,800 to 10,090 ft). The post-glacial soils in both drainages are developing from alluvium and colluvium derived from weathering of igneous and metamorphic material. Soil depth varies between 50-150 cm (20 and 60 in) and is capable of absorbing water at rates well in excess of snowmelt and normal rainfall intensities (Bevenger and Troendle 1987). Surface erosion is minimal to non-existent on undisturbed soil surfaces.

The climate of the area is influenced by frontal systems and orographic storms during winter months and by orographic and convectional storms during summer months. Mean yearly precipitation and temperature on the catchments are estimated to be 100 cm (40 in) and 1° C (34° F) respectively. Approximately 70 percent of the precipitation comes in the form of snow. More than 95 percent of all streamflow is directly, or indirectly, the result of snowmelt, with flow generation primarily subsurface in nature (Bevenger and Troendle 1987). Summer stormflow, or the direct streamflow response to rainfall events, represents less than 4 percent of the event precipitation (Bevenger and Troendle 1987). Prior to harvest, forest cover on both catchments consisted of spruce-fir stands along stream courses, on north slopes, and at upper-slope positions. Lodgepole pine occurs on all low- and mid-elevation, southerly- or high-energy exposures. Alpine tundra occurs above timberline. Part of the area on the East Fork watershed was harvested for railroad ties in the early 1900s, but subsequent regrowth completely occupied the site, hydrologically, by the onset of the study in 1982.

In 1982, a 2.44 m (8 ft) Cipoletti weir was constructed on each drainage to monitor streamflow, and the gages are operated from April to October each year. Climatic parameters monitored include precipitation, temperature, and humidity at six sites, and a single solarimeter. In addition, snow courses (~500 stations) are located in both catchments to document peak water equivalent (PWE) in the snowpack at the onset of melt (Bevenger and Troendle 1987).

By 1987, a suitable calibration had been achieved (Bevenger and Troendle 1987) and design and implementation of the treatment began. Initially the intent was to harvest approximately one-third of the Coon Creek watershed; however, this was an operational effort and compliance with other constraints imposed by the MBNF Forest Plan (primarily for minimizing impairment of visual quality as well as riparian and old-growth protection) reduced the opportunity for harvest and resulted in 24 percent of the watershed area actually being impacted by either road construction or timber harvest.

IMPLEMENTATION

Construction of the main haul roads began in 1987 and were completed in 1989. Approximately 44 km (27.4 mi) of roads were built prior to harvest. The timber sale was laid out and sold in 1989 and harvesting began in 1990, after the snowmelt runoff season. In total, over 200 small clearcuts were created, ranging in size from 1.2 ha (3 a) to 4 ha (10 a). Including the area in haul roads, harvesting or tree removal disturbed a total of 23.7 percent of the Coon Creek watershed area (Figure 1). Approximately 22 percent of the watershed area was in harvested units while another 2 percent consisted of the main haul roads located outside the clearcut units but inside the drainage boundary (Erin O'Doherty, personal communication). Studies which monitored suspended and bedload transport were initiated in the late 1980's (Wilcox, *et al.* 1996). Although the sediment studies were not initiated early enough to document treatment effect, the observations are useful in characterizing the nature of the material being transported from each watershed; as well as, the relative similarity of export between the two catchments, only one of which has been impacted.

Because timber harvest did not begin until August 1990, after runoff occurred, the 1990 water year was included in the calibration (pre-treatment) period. Construction of the main haul roads in 1988 and 1989 resulted in disturbance of approximately 2 percent of the Coon Creek area and analysis of flow data through 1989 did not indicate the road influenced flow in any way. Both 1991 and 1992 are considered treatment years, and 1993 to 1995 represent the post-treatment period.

RESULTS

Effect of Timber Harvest on Snowpack Accumulation

Troendle and King (1985) noted a significant increase in snowpack water equivalent stored on the Fool Creek watershed following timber harvest. Similar analysis of the North Fork of Deadhorse Creek snowpack data did not indicate a detectable change at the level of the watershed, although the average in the opening was 22 percent higher than in the forest (Troendle and King 1987). A similar assessment was done for Coon Creek. Figure 2 presents the comparison between average PWE on Coon Creek plotted over that for East Fork. The yearly means are based on the 300 points in Coon Creek and 200 points in East Fork sampled about April 1 of each year at the time of maximum accumulation. In a separate covariance analysis of pre- and post-treatment PWE (SAS, General linear model procedure) the adjusted pre-treatment mean of water content in the snowpack is 573 mm (22.6 in), while the post-treatment mean is 578 mm (22.8 in). The 5 mm difference, or increase, is not significant ($p = 0.80$). Results to date indicate that treatment did not affect overall snowpack accumulation. However, Troendle and King (1985) noted 15 years of post-harvest record were needed to document change at Fool Creek, and only 5 years (1993-1997) of post-treatment record are available for analysis and presented in Figure 2. However, comparison of the individual sampling points, located in the forest and in clearcuts, indicated that PWE increased an average of 53 mm (2.1 in.) in the clearcuts as a result of timber harvest. The 9 percent increase was significant ($p=0.007$) at the level of the opening (forest vs. open) but was not great enough to alter the mean for the entire drainage. This is similar to the response at Deadhorse Creek (Troendle and King 1987).

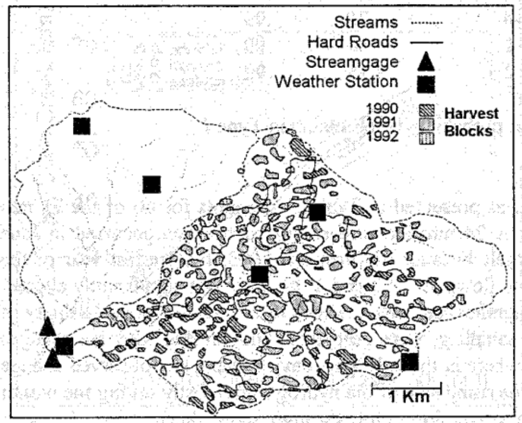

Figure 1. Coon Creek and East Fork catchments showing streamgage, weather station, stream net, road, and clear cut locations.

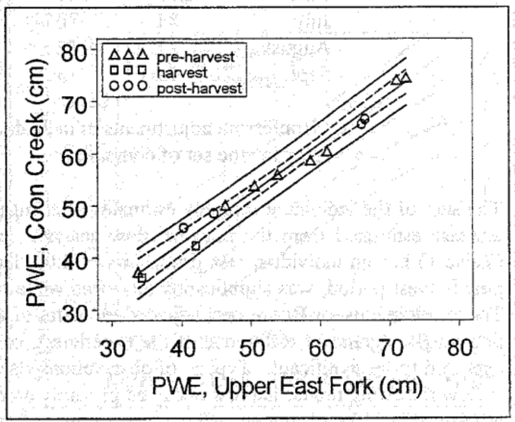

Figure 2. Coon Creek vs. Upper East Fork: average snow water equivalent (PWE) before and after harvest.

Effect of Timber Harvest on Streamflow

Seasonal flow. The pre-treatment calibration, or the least squares relationship between seasonal (April - October) flow on Coon Creek (Y) and that for East Fork (X), is presented graphically in Figure 3, and empirically by equation 1. Flow (mm) for Coon Creek is estimated as:

$$\mathbf{Q_{\text{Coon Creek}} = 79.0 + 0.8165\, Q_{\text{East Fork}}} \qquad \mathbf{(1)}$$

$$\mathbf{(R^2 = 0.99,\ p = 0.0001,\ SE = 0.14\ mm)}$$

Also included in Figure 3 are the yearly values for the treatment and post-treatment periods. The confidence band estimates about the regression line (mean) and those for individual and composite (3) predictions are also presented. One can evaluate the relative significance of all post-harvest observations using Figure 3, and it is apparent seasonal flow was significantly increased in all 3 years.

A separate covariance analyses (SAS, General Linear Models Procedure) indicated that for the 3-year period following harvest, the adjusted mean flow from Coon Creek increased an average of 71 mm per year (2.8 in. or 17 percent) from 427 mm (16.8 in) to 498 mm (19.6 in). Although the sample size is limited, with only 3 years of post-treatment record, the increases in flow appear to be flow related in that the largest increase occurred in the wettest year (1995). This preliminary assessment of response at Coon Creek is consistent with documented observations at Wagon Wheel Gap, Fool Creek (Troendle and King 1985), and Deadhorse Creek (Troendle and King 1987). The magnitude of the flow change, or absolute value of increase, is less than those observed in the Colorado studies, but proportional given the differences in areas harvested between the various studies.

Monthly flow. A covariance analysis, in a manner similar to the analysis of seasonal flows, was conducted on monthly flows for the April to October period and indicated that during the month of May, flow significantly increased in all years. (SE = 4.2 mm, p = 0.002). The increase in flow during May (Table 1), estimated to be 36 mm (1.42 in) accounts for 50 percent of the 71 mm (2.8 in) increase observed change in the total seasonal flow.

Table 1: Adjusted mean monthly flows before and after harvest.

Month	Flow (mm)			Probability	
	Expected	Observed	Change	Actual	Bonferroni[1]
April	10	12	2	.30	.99
May	80	116	36	.002	.01
June	217	241	24	.07	.40
July	84	80	-4	.30	.99
August	21	22	1	.44	.99
Sept.	14	16	2	.25	.99

[1] Bonferroni adjustments of individual probability levels maintain Type I error for the set of comparisons.

The sum of the individual monthly estimates of change, as presented in Table 1, accounts for 60 of the 71 mm increase estimated from the seasonal flow analysis. The 24 mm increase estimated to have occurred in June (Table 1) has an individual test probability of 0.07, largely because the flow for 1995, the wettest year of the post-harvest period, was significantly increased while the flows in 1993 and 1994 were not significantly altered. The simultaneous, or Bonferroni adjusted estimates of significance, which reflect an estimate of the probability of detecting a significant difference of the experiment, or sampling, were repeated. Only during May are changes expected to be significant. Typical of observations elsewhere in the subalpine environment, the observed change in flow following timber harvest occurred primarily on the rising side of the hydrograph, mostly during the month of May, with little subsequent effect on recession or late season flows (July through September).

Peak discharge. In an earlier analysis, Bevenger and Troendle (1987) documented that stormflow (response to summer rainfall events) averaged 4 percent or less of the storm precipitation falling on either Coon Creek or East Fork prior to harvest. Historically, it has been well documented that peak discharge from subalpine watersheds is the result of melting snowpack, and that although rain on melting snowpack may be a factor, peak flows (including major components of the partial series) are snowmelt driven (Jarrett 1993, Troendle and King 1985, 1987, Troendle and Olsen 1994). Snowmelt peaks are usually an order of magnitude greater than those summer rainfall peaks which do occur (Troendle and Bevenger 1996).

We analyzed the effect of timber harvest on peak discharge using two metrics; the annual, maximum instantaneous discharge and the annual, maximum mean daily discharge. Covariance analysis indicated the average maximum instantaneous flow, from Coon Creek, changed non-significantly from 1.2 $m^3.km^{-2}.s^{-1}$ (16.4 csm) to 1.3 $m^3.km^{-2}.s^{-1}$ (17.6 csm) for the three, post-harvest years. This represents an average change of 0.1 $m^3.km^{-2}.s^{-1}$ (1.2 csm) or 7 percent (p = 0.57). A similar analysis, performed on the maximum mean daily flow, produced a similar outcome (Figure 4). Maximum mean daily flow changed from 0.9 $m^3.km^{-2}.s^{-1}$ (12.3 csm) to 1.02 $m^3.km^{-2}.s^{-1}$ (13.9 csm); a 13 percent, but non-significant change (p = 0.15). The difference between the pre-harvest maximum mean daily flow and the maximum instantaneous flow of 0.3 $m^3.km^{-2}.s^{-1}$ (4.1 csm) is a reasonable index to the amplitude of diel fluctuation in discharge, during the melt period, associated with the snowmelt driven hydrographs, typical of this area. The range in daily flow (high to low) is almost 40 to 50 percent of the mean daily value.

In an effort to better define the flow components actually influenced, covariance and regression analysis was used to analyze various or discrete quantities of the annual flow frequency curve in an analysis format similar to that used for seasonal, monthly, and peak discharge analysis.

Flow duration. For each year of record, for both catchments, the flow duration curve was divided into 10 equally spaced bins. For each year, the lowest mean daily flow identified (the value-at-which 100 percent of all daily flows were equal to or greater than, for that particular year and watershed) is considered the zero quantile. The mean daily flow level associated with each successive 10 percent interval along the flow duration curve for the same year was also identified and matched with the comparable value for the other catchment (Coon Creek vs. East Fork). The 11th quantile is the mean daily flow exceeded 0 percent of the time in that year (this is also the maximum mean daily flow for that particular year as analyzed earlier as one of the metrics defining peak flow). In this manner, the duration curve for each year is approximated by the 11 discrete points, each equally spaced in terms of frequency of occurrence (but not flow). For each year, comparable quantiles for Coon Creek and East Fork were paired and covariance analysis was conducted on the pre- and post-treatment estimates, independently, for each of the 11 quantiles. In this way, the adjusted means for each of the 11 quantiles were estimated for pre- and post-harvest conditions and compared.

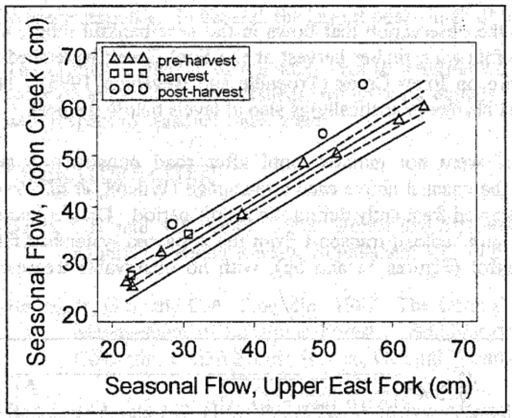

Figure 3. Coon Creek vs. Upper East Fork: seasonal flow before and after harvest.

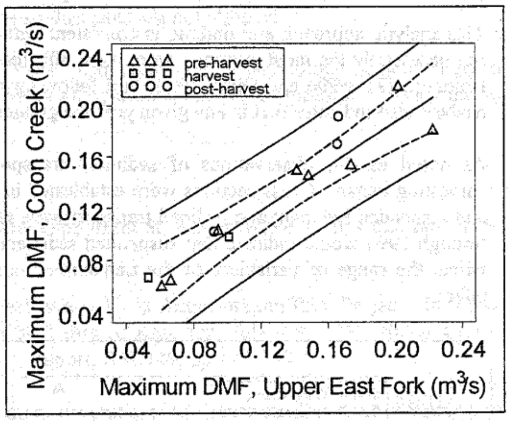

Figure 4. Coon Creek vs. Upper East Fork: maximum daily mean flow (DMF) before and after harvest.

Table 2 presents the expected flow levels for each of the quantiles, the change attributed to treatment, the probability of significance associated with the test for change. Two p-values are listed in Table 2: one that is uncorrected, or based on the discrete analysis at each quantile, and the other corrected for simultaneous comparison (Bonferroni). The uncorrected values indicate flows which occurred in the 70, 80, and 90 percent quantiles were significantly increased while the lowest (60 - 100) and highest (0) values for each post-treatment year were not significantly altered (at $p = 0.05$). The simultaneous, or Bonferroni adjusted, estimates of significance reflect an estimate of the probability of detecting a significant difference in similar comparisons with repeated sampling. These indicate that only the 80th and 90th quantiles have a significant probability of being different if the experiment were to be repeated.

Table 2

Quantile	Flow ($m^3km^2s^{-1}$)		Probability	
	Expected	Change	Actual	Bonferroni[1]
100	.904	.116	.15	.99
90	.596	.099	.002	.03
80	.352	.072	.005	.05
70	.201	.026	.05	.58
60	.126	.012	.42	.99
50	.085	.004	.63	.99
40	.055	.004	.48	.99
30	.043	.006	.26	.99
20	.036	.005	.38	.99
10	.029	.003	.61	.99
0	.023	-.003	.55	.99

[1] Bonferroni adjustments of individual probability levels maintain Type I error for the set of comparisons.

*Percent of time flow is equaled or exceeded

This analytic approach and finding, is consistent with the observation that flows in the near-bankful range, but not necessarily the most extreme, were most affected following timber harvest at the Fool Creek watershed in Colorado (Troendle and Olsen 1994) and following fire on Jones Creek (Troendle and Bevenger 1996). The analysis also indicates that in any given year the greatest change (statistically) is also at levels below the peak.

As noted earlier, observations of sediment transport were not initiated until after road construction and harvesting began. Cross sections were established in the channel above each streamgage (Wilcox, *et al.* 1996) and suspended sediment and bedload transport were sampled frequently during the runoff period. Data collected through 1995 would indicate that suspended sediment and bedload transport from the impacted watershed falls within the range of variability of the undisturbed control (Figures 5a and 5b), with no observable treatment effect.

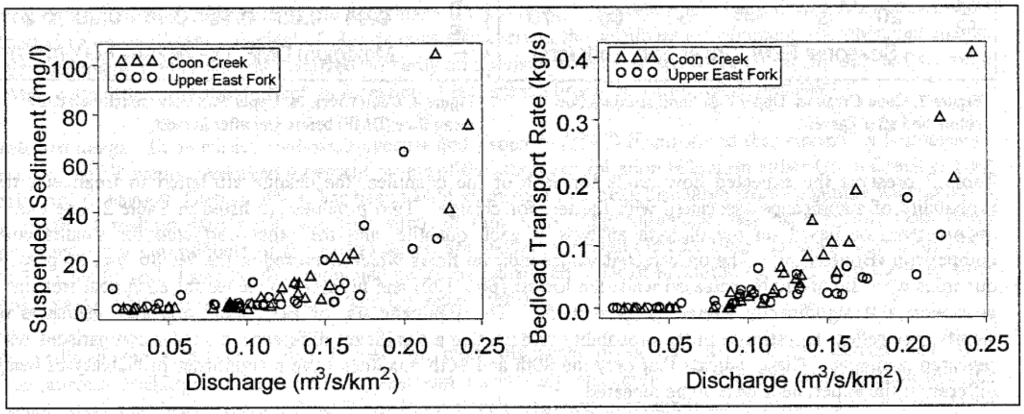

Figure 5. Comparison of suspended sediment (5a) and bedload transport (5b) from East Fork and Coon Creek for the harvest and post harvest period.

DISCUSSION

Although the length of the post-treatment record for Coon Creek is short, the impact the treatment has had on seasonal water yield is quite clear. Removal of vegetation from 23.7 percent of the area significantly increased flow by an average of 71 mm (2.8 in). The increase is proportionally consistent with what has been observed to occur on small experimental watersheds elsewhere and extrapolation of empirical estimates of change, based on process research at FEF (Troendle and Reuss 1997), compare well with the observed changes at Coon Creek.

The distribution or timing of the flow change observed at Coon Creek is equally comparable. All the small watershed experiments in Colorado, as well as the documented differences in flow from burned (Jones Creek) and unburned (Crow Creek) catchments indicate change in flow occurs on the rising side of the hydrograph and early in the runoff period. Similarly, analysis of Coon Creek data indicate that only during the month of May are flows significantly increased, accounting for 50 percent of the entire seasonal increase. June is the only other month during which the flow regime appeared to be altered.

The fact timber harvest increases stream discharge is well documented, as is the documentation that the increases are positively correlated with area harvested. Less well defined is the effect of timber harvest on peak discharges. Analysis of data from Wagon Wheel Gap (Bates and Henry 1928, Van Haveren 1988), Fool Creek (Troendle and King 1985), Deadhorse Creek (Troendle and King 1987) and Brownie Creek (Burton 1997) indicate peaks increase an average of 20 to 50 percent following timber harvest. Timber harvest on Coon Creek and post-fire comparisons on Jones Creek (Troendle and Bevenger 1996) did not demonstrate these increases, in average response. In general, the largest peaks in all of the studies cited are not affected.

The primary objective of the study was to determine if water yield augmentation technology demonstrated to work on experimental watersheds, would work equally well at an operational scale. It appears to have done so with respect to seasonal water yield.

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