The Effects of Small Clearcuts on Water Yield from the Deadhorse Watershed; Fraser, Colorado

by

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Introduction

Timber harvesting reduces evapotranspirational demand, alters the soil moisture regime, and results in increased streamflow. Hibbert (1967) first summarized the effects of 39 worldwide watershed experiments, which addressed vegetation/streamflow relationships. Within the subalpine forests of the Rocky Mountain Region, three watershed experiments have determined the effect of timber harvest on water yield. The Wagon Wheel Gap Watershed was the first paired watershed experiment in the region and in the United States (Bates and Henry, 1928). The 81-ha aspen and conifer watershed was clearcut in 1921. The increase in flow, which was as much as 5-cm was diminished to pretreatment levels in only 5 years because of the rapid regrowth of aspen. Fool Creek, a watershed on the Fraser Experimental Forest was strip-cut in 1955. The first year average increase in flow following the clearcutting of 40 percent of the watershed was 8.9 cm. Twenty-five years later, regrowth of the lodgepole pine and spruce-fir had only reduced the initial effect by one-third (Troendle and Leaf, 1981). In a third, but less rigorous watershed experiment, Swanson and Hillman (1977) reported on a series of watersheds on the James river in Alberta that were harvested to differing degrees of intensity. Although a paired watershed approach was not used, comparison of cut and uncut watershed responses indicated an effect of treatment very similar to that for Wagon Wheel Gap and Fool Creek.

The Fool Creek Watershed Experiment and the associated supporting research in the nearby subalpine forests has led to accumulation of a large body of knowledge concerning the effect of timber harvest on snowpack accumulation and melt as well as its effects on streamflow.

The Deadhorse Creek watersheds, on the Fraser Experimental Forest, are being used as pilot demonstration areas to which optimal watershed, timber, and wildlife strategies can be implemented, responses predicted, and simulations evaluated. This paper examines the water yield improvement treatment applied to the North Fork drainage.

Watershed Description

Deadhorse Creek is a 270-ha watershed on the Fraser Experimental Forest, Colorado (fig. 1). It drains to the east at elevations ranging from 2880 m to 3536 m. Two subdrainages are the 41-ha North Fork, and the 78-ha Upper Basin. Adjacent to the Deadhorse Creek is Lexen Creek, the 124-ha control watershed for all three drainages in the Deadhorse Creek complex.

Snowpack accumulation and melt over and between the drainages is quite variable (Leaf, 1969). The combination of steep side slopes that average 40 percent, opposing north and south aspects, and the wide range in elevations (600+ m) all cause the energy load to be vary greatly. As a result, the snowpack on the North Fork of Deadhorse Creek (mostly mid-elevation, south facing) is melted well in advance of that for either the higher elevation Upper Basin of Deadhorse or the Lexen Creek watersheds (Leaf, 1969). The resulting flow from the North Fork peaks sooner and recedes faster than Lexen Creek (fig. 2).

Presented at the Western Snow Conference, April 20-22, 1982, Reno, Nevada

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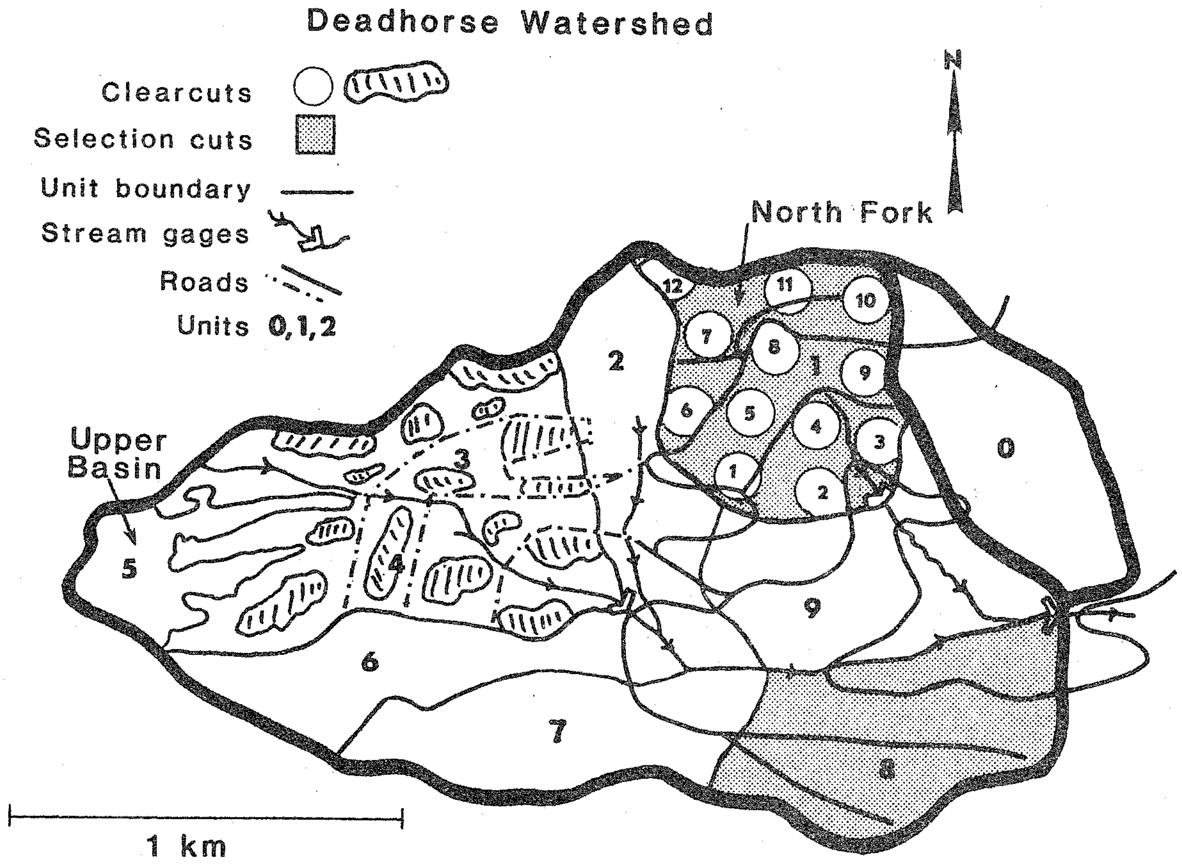

Figure 1.--The Deadhorse watershed complex showing proposed management alternatives for the North Fork, Upper Basin, and North Slope Units.

Forest cover on the watersheds consists of spruce-fir stands along the stream channels, on north slopes, and at upper slope positions. Lodgepole pine occurs on all low and mid-elevation southerly or high energy exposures. Alpine tundra is above timberline. There is an average of 168. $m^3 ha^{-1}$ of sawtimber on the forested portion of the watershed. The North Fork watershed, because of its mid-elevation southerly exposure, consists mostly of the lodgepole pine.

Treatment and Measurement Methods

The 120^o V-notch weirs on Main Deadhorse and Lexen Creeks were built in 1955. The weir on the North Fork of Deadhorse was built in 1970, the streamgage on the Upper Basin of Deadhorse Creek was constructed in 1975. All weirs have been operated from April to October of each year since construction.

In addition to obtaining long-term streamflow records; snow courses, to index peak water equivalent; precipitation; temperature and humidity; and annual sediment export have been continually monitored. Comparative snow course observations between the Deadhorse Creek and Lexen Creek were begun in spring 1967 and are used to estimate the mean water equivalent for each of the subdrainages. Samples are collected at 40-m intervals along transects that cross all major slope aspects and elevations. The estimate of mean water equivalent is used to index winter precipitation. Five rain gages (two recording and three standard) on Deadhorse and one standard gage on Lexen Creek are used to index the precipitation. Temperature and humidity are measured on two sites, one north and one south facing slope, on Deadhorse Creek.

Thirty-six percent of the forest was removed by clearcutting 12 small units, uniformly spaced through the drainage. The circular openings are about 122 m or 5-H in diameter and occupy about 1.2 ha each. Timber on 11 of the openings was harvested in 1977 and the remaining one was cut early in the summer of 1978. Harvesting consisted of felling

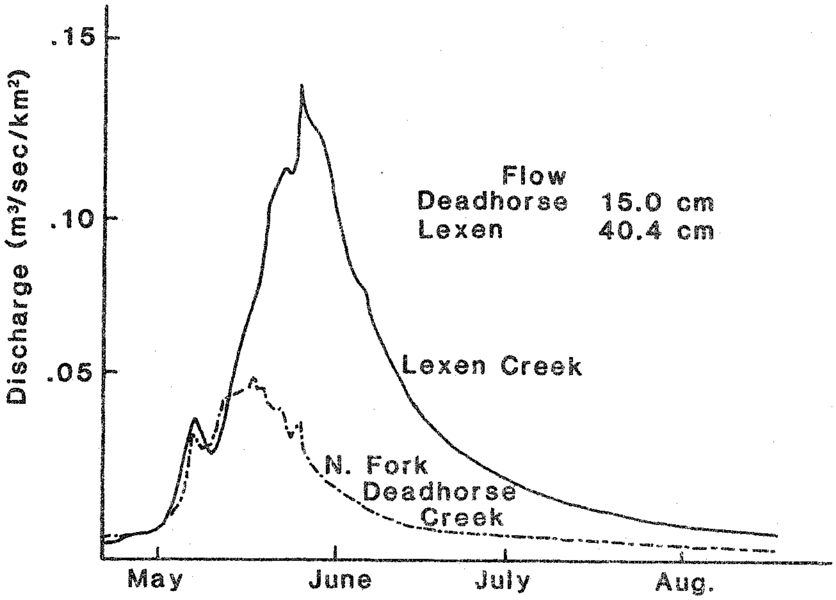

Figure 2.--Comparative hydrographs from North Fork and Lexen Creeks for an average year prior to harvest on the North Fork.

all trees 10 cm in diameter and larger and removal of all merchantable material from the site. All slash was lopped to a 10-cm top and scattered. Approximately 2450 m^3 of sawtimber was harvested from the North Fork watershed.

Response to Treatment

Effect on Snowpack Accumulation

Figure 3 demonstrates the pretreatment and posttreatment relationship of the peak water equivalent index for the control and treated watersheds. Based on covariance analysis, the observed relationships have not changed as a result of treatment. R^2 for the pretreatment relationship was 0.94 and was 0.97 for the 4 years since harvest. There was no detectable change in average water equivalent (measured about April 1 each year) on the watershed as a result of the treatment. It is assumed that the net precipitation input has not changed as a result of timber harvest. Its placement, stability, and melt characteristics have been altered but not the total amount.

In addition to the snow course observations, several of the openings, as well as the forest around them, have been sampled intensively. Snow tube samples were taken at 12 m intervals along transects that started in the forest, passed through the center of the openings, and continued into the forest to the next opening. In most cases, two transects per opening were made--one parallel to the prevailing winds, the other perpendicular to them. The mean water content for the samples taken in the forest was 40 cm while it averaged 52 cm for those taken in the openings. Because the overall watershed mean, as indexed by the snow course, did not change, it can be assumed that a redistribution occurred and that the increase in snowpack in the openings is a reflection of the change in depositional and redistribution patterns caused by the harvest. The water equivalents for the forest and the open samples were then area weighted and averaged to obtain a mean for the watershed as represented by the transects. The overall mean was 44.2 cm. The average of 52 cm of water observed in the openings reflects an 18 percent increase relative to the mean for all subsamples and is compensated by a reduction in the forest. This is somewhat less than the 30 percent increase expected in a 5-H opening using the Rho function developed by Troendle and Leaf (1980). However, of the 12 openings, 6 are spaced less than 3 H (at the closest point) from the next downwind opening and the spacing between openings should be at least 5 H to be optimal. Because of the less than optimal spacing and the

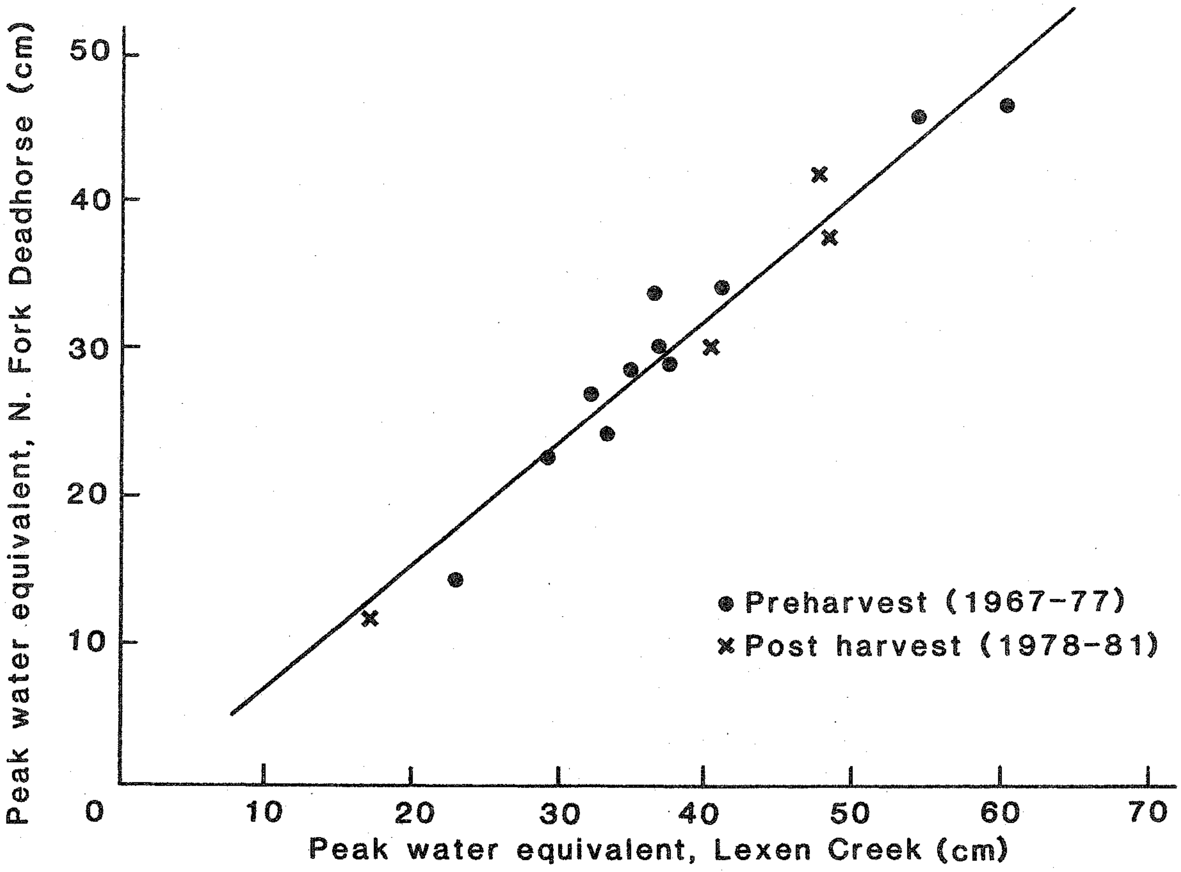

Figure 3.--The relationship of peak water equivalent on the North Fork of Deadhorse Creek with that for the control, Lexen Creek.

reduced redistribution efficiency, the observed redistribution estimate of 18 percent is reasonable. The greater amount of water equivalent in the openings is generally consistent with other observations made by Gary, 1981; Golding, 1981; Troendle and Leaf, 1981; and others.

Effects on Water Yield

Streamflow from the North Fork of Deadhorse was calibrated against that from Lexen Creek for a 7-year period (1971-77) prior to harvest. The least squares fit on total yield had an R^2 of 0.98 with a standard error of 1 cm. Table 1 presents observed flow from North Fork watershed and the change in flow attributed to treatment. Also presented is the precipitation for the 4 years involved. The latter is significant because the magnitude of the increase in flow strongly depends on annual precipitation. The wetter years produced the largest increases in flow (Fig. 4). Covariance analysis indicated that the 36 percent increase in flow observed during the 4 posttreatment years is significant at the $P = 0.05$ level and appears to be linear with volume of flow. This is similar to results on Fool Creek (Troendle and Leaf, 1981).

Figure 5 is a plotting of an annual hydrograph for Lexen and North Fork for water year 1980. Flow from Lexen Creek is comparable to that for the hydrograph shown in figure 2. As with the responses observed on Fool Creek and Wagon Wheel Gap in Colorado and at the James River in Alberta (Troendle and Leaf, 1981; Golding, 1981), the observed increase in flow appears on the rising side of the hydrograph. The increase results from a combination of advancing the spring melt by exposing the pack and smaller soil water

Table 1

The observed increase in flow following timber harvest on the North Fork of Deadhorse Creek

Year	Precipitation	Total Flow	Increase
	←	cm	→
1978	62.7	23.1	3.6[1]
1979	70.9	21.1	5.8
1980	71.9	23.1	6.6
1981	51.8	9.4	2.0
$\bar{x}$	64.8	19.3	4.6

[1] During harvest

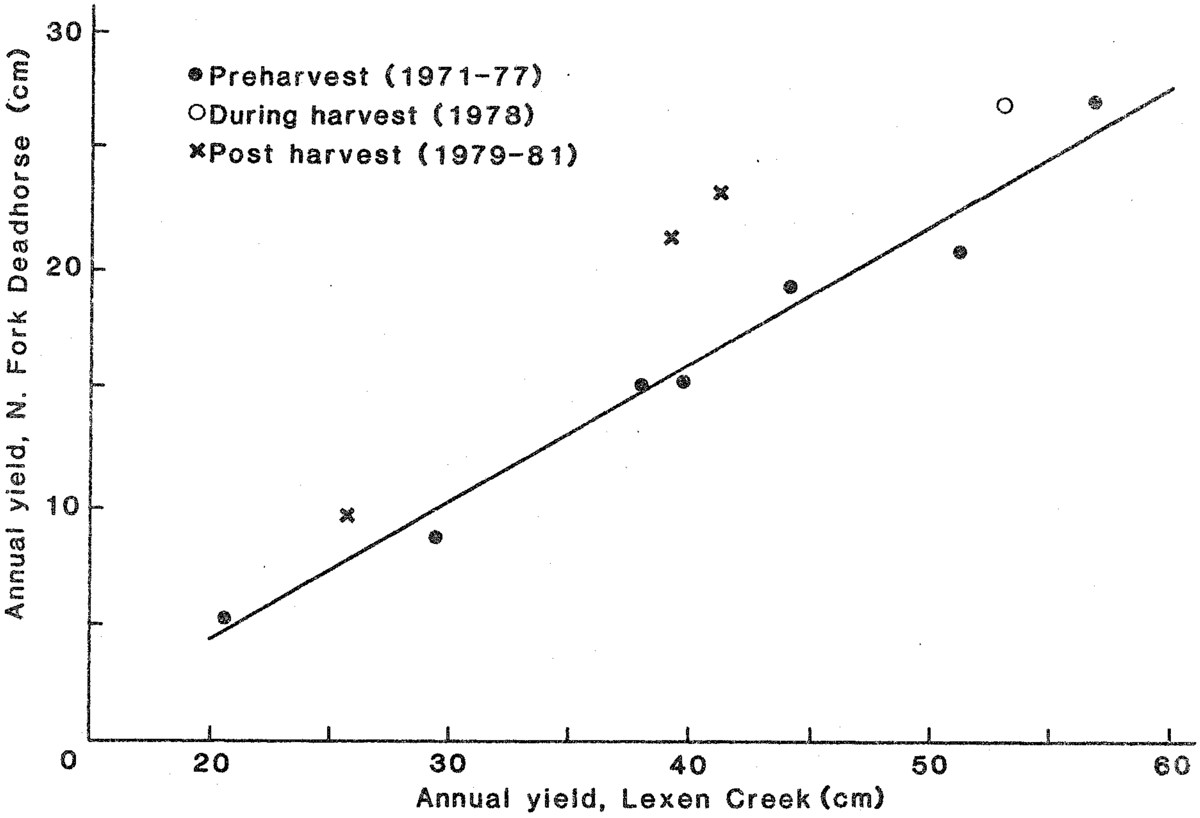

Figure 4.--The relationship between annual yield from North Fork of Deadhorse during the calibration period and for the four posttreatment years.

deficits from the previous growing season. The increase in flow for 1980 was 6.6 cm, figure 5, when compared with figure 2, presents a reasonable characterization of when and where the increase occurred.

The monthly flows for May to August were also calibrated for North Fork and Lexen Creek and individual confidence limits were placed on each of the monthly flows for the 4 posttreatment years to evaluate impact. May was the only month where flow differences were significant ($P = 0.05$). Total flow for May in both 1978 and 1980 was significantly

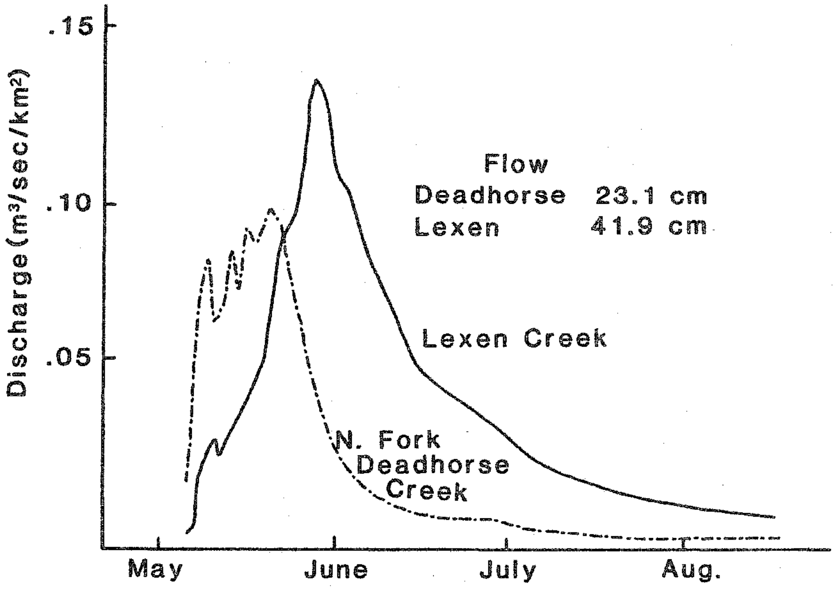

Figure 5.--Comparative hydrographs from the North Fork of Deadhorse and Lexen Creeks for an average water year during the posttreatment period.

increased; 1979 was of borderline significance. The analysis indicates that the total flow for May of 1980 was increased by 4.1 cm and represents more than half of the annual change. This is the largest single month increase in the 4 year post harvest record. None of the flows for months other than May were significantly affected. Subsequently, a covariance analysis was performed on the pre- and posttreatment streamflow data for the month of May. The multivariate analysis indicated that the adjusted mean flow for the month of May on Deadhorse Creek was 4.2 cm before harvest and 7.6 cm after harvest. The average 4 year increase of 3.4 cm is significant at the P = 0.05 level. The record is too short to support a more thorough flow interval analysis as was performed on the Fool Creek Record (Troendle and Leaf, 1981).

It has been generally noted that 20 to 30 percent of the watershed has to be harvested before a significant change in flow can be detected (Troendle and Leaf, 1980). In the case of the North Fork, 36 percent was harvested, and a significant change in flow was detected. However, the area harvested, on the North Fork, represents only 5 percent of the drainage gaged by the main weir downstream. The calibration relationship for the main weir and Lexen Creek is much longer, 1956-77, and has an R^2 of .98. Figure 6 represents a plotting of the calibration relationship that existed between main Deadhorse and Lexen Creek along with the four posttreatment observations. The treatment on the North Fork of Deadhorse has had no detectable effect downstream, at least as indexed by the main gage. This is a significant observation because the effect is established "onsite" and the increase is in the system, but the ability to detect it downstream is difficult because the increase is only part of the "noise". The main stream in Deadhorse is a second order perennial channel and there is no reason to believe the increase from the North Fork could be eroded or dissipated away in transit. The magnitude of change would not cause a significant increase in either the wetted or evaporative surface along the channel, seepage to groundwater, or an increase in consumptive use by vegetation. It is assumed that the increase has not been "lost" but is simply not detectable at the main gaging station.

Analyses of pre- and posttreatment observations of peak discharge of both North Fork and Lexen Creek indicated that no significant change occurred in the magnitude of the peak discharge of Deadhorse Creek following harvest. The error term on the peak flow relationship based on 4 posttreatment years is large, and a long period of record will be necessary to evaluate what may be a minor, if any, change in peak discharge. Covariance analysis indicated that the time of peak (number of days from May 1 on which the peak occurs) was not significantly (P = 0.05) affected by the harvesting. The mean of the average date of peak occurrence was advanced two days.

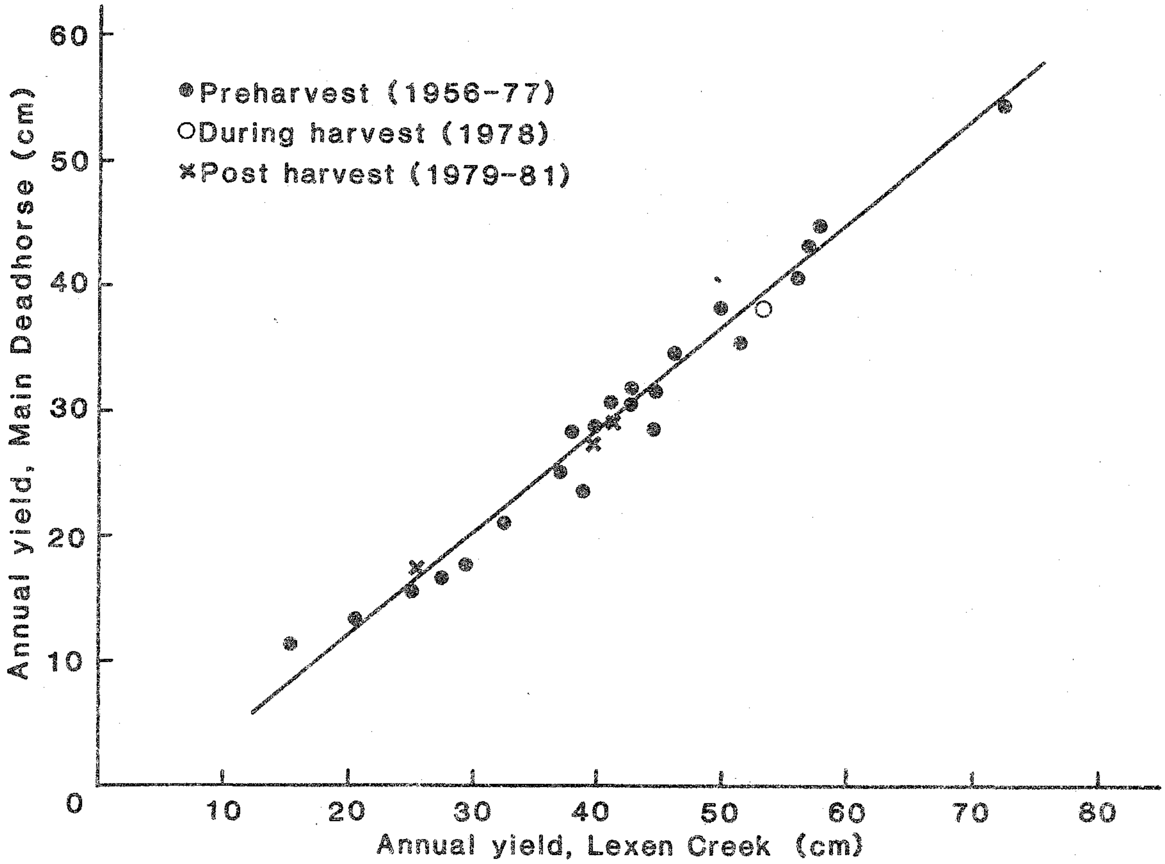

Figure 6.--The relationship between annual yield from Main Deadhorse and Lexen Creeks for pre- and posttreatment conditions.

A more thorough analysis of treatment effect is somewhat restricted because only 4 years of posttreatment record are available. Fortunately, those 4 years cover a range in climatic and flow conditions that equal the range observed during the calibration period. Although this supports the general conclusions on mean peak water equivalence in the snow pack, annual flow changes, and downstream effects, the precision makes detection of what can be no more than small changes in peak flows, timing of peak, duration of various flow levels, and other hydrograph descriptors less conclusive. For a thorough analysis of these descriptors, a longer posttreatment record is needed.

Effect of Treatment on Sediment Production

Water quality observations on Deadhorse and Lexen Creek have been minimal. Sediment export has been estimated based on the annual accumulations in the weir ponds. Leaf (1974) noted that the efficiency at which sediments settled out and into the ponds was quite high, even at peak flow rates. As a result, the annual accumulation of material in the ponds is a good index to the suspended and bedload export from the drainage.

The 7-year calibration of sediment production from North Fork to Lexen Creek was not particularly strong ($R^2 = 0.75$) but it does allow prediction of expected amounts for North Fork during the posttreatment years based on the export from the control watershed. The road system represents the primary disturbance to the North Fork.

Table 2 lists the expected sediment production from the watershed. This is estimated using the calibration period relationship or equation and applying it to the post treatment sediment production from the control watershed. The observed increase represents an estimate of the combined effect of the road building/harvesting operation on sediment production and is approximated as the difference between expected and observed sediment. The first year increase of 36.6 kg ha^{-1} is conservative relative to the increase observed

Table 2

Expected and observed sediment production from North Fork of Deadhorse Creek following timber harvest

Year	Expected Sediment	Observed Sediment	Increase
	<————	kg/ha	————>
1978	21.6	58.2	36.6
1979	15.0	29.7	14.7
1980	17.8	25.9	8.1
1981	13.2	2.6	-10.6

from the Fool Creek experiment (Leaf, 1974). However, the road system on Deadhorse is better designed, located, and drained than the system on Fool Creek, and it apparently has had a more minimal impact. The recovery during the 4 postharvest years seems to be quite rapid--as it was on Fool Creek. Longer record is necessary to assure that recovery has actually been achieved.

The activities within the drainage, while causing an effect "on-site" (such as at the North Fork weir) have not translated downstream to the main weir, so that the "offsite" effect of these activities has been minimal or at least undefinable. The sediment observations in this experiment, although quite limited, indicate that road construction and timber harvest had very little effect on sediment production from the treated watershed.

Summary and Conclusions

The initial phase of the Deadhorse Experiment resulted in a response that is consistent with other observations in the subalpine. As in the Fool Creek experiment, net water equivalent in the snowpack, and precipitation input to the watershed, did not significantly change. Secondary observations indicate snow was significantly redistributed with significantly more snow located in the open and less in surrounding forest. The resulting change in flow occurred early in the year, as it did on Fool Creek, but the magnitude of change is smaller relative to the proportion of the watershed area cut. This may partly result from the fact that the clearcuts on Deadhorse are discontinuous and not connected to the stream, allowing some loss of ET savings, "en route". The Deadhorse watershed appears to have shallow soils and, therefore, would present opportunities for extraction of the savings as the migrating water would more likely pass through a rooting zone. Another factor may be that the redistribution efficiency was reduced because of the less than optimal spacing of the openings.

Two other observations bear this out. In 1977, five-sixths of the patches were harvested late in the summer, with little apparent opportunity to reduce ET. In 1978, there was a significant increase in flow, implying that there had to be some reduction in normal recharge requirements the preceding year. This would be the result of a more dynamic, but minimal, hydrologic depth (or storage capacity on the watershed). The 1980-81 winter was a near record dry year with only 5 cm of water equivalent in the snowpack on March 1, 1981 whereas normally 25 cm would be expected. The spring precipitation was normal, while the summer (July-October) precipitation was above normal. As a result, summer flows were maintained at higher levels, causing a 2 cm annual increase. Because 1981 was the only year not to have a near significant increase in May, the increase must have been distributed through the entire season.

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