Analysis of peak flows on the Foothills Model Forest and methodology to estimate peak flows after harvest

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model *forest*
a growing understanding

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by

Robert H. Swanson
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Abstract

Timber harvest has been shown to increase streamflow. The effects of timber harvest on the peak yield that occurs during a year on the Foothills Model Forest area of Alberta was examined in this study. The Swanson and Hillman (1977) study was used to estimate the change after harvest in the magnitude of peak water yields occurring during the spring freshet and during various rain events throughout 1974. The results of a regional hydrology study (Hydroconsult EN3 Services, Ltd. 1997) was used to estimate probable annual peak water yields at 2, 10, 20, 50 and 100 year return periods (50, 10, 5, 2 and 1% probabilities).

The maximum increase in annual peak water yield that could be attributed to forest harvest in the Foothills Model Forest area was 3.64 mm/day. The WRNSFMF procedure was used to estimate peak water yields for harvested areas during the spring freshet. An analysis of the potential for daily changes in peak water yields after harvest indicated that 4-6 mm/day was the maximum change that could be expected. These changes were added to the estimated annual peaks which would occur at the various probabilities addressed by the regional hydrology study (Hydroconsult EN3 Services, Ltd. 1997).

The analysis reported here indicates that forest harvest has minimal impact on peak water yields. A theoretical maximum of 6 mm/day would increase the magnitude of 50% probable events by approximately 60%, of 10% probable events by approximately 15%, with lesser effects on the lower probability events. Realistically, an increase of 3-4 mm/day would be the most that forest harvest could cause, with comparably lesser effects on the magnitude of probable peak water yields.

Introduction

Timber harvest was shown to increase water yield from a number of watersheds in the Foothills Model Forest area by 39 mm or about 25% in 1974 (Swanson and Hillman 1977). In general, timber harvests within the Foothills Model Forest area were not planned as to intensity or frequency of watershed re-entry with regard to their possible changes to water yield and peak flows. One of the goals of the model forest program across Canada is to obtain better integration of forest operations with other legitimate users of the land and water resources. To this end, various land-use components should be addressed during the planning phase of timber extraction from the Foothills Model Forest area. The water yield component is to be addressed by a Watershed Assessment Model (WAM) that is currently being developed. This peak flow assessment is one part of the WAM.

Fisheries biologists have concluded that velocities critical to the movement of bed material can occur during approximately 25% - 30% of the incubation cycle (May through September) of rainbow trout in the Tri-Creeks watershed (Sterling 1992). From this, and perhaps other information, some fisheries biologists have suggested that the stream flow peaks that occur approximately every 10 years are responsible for much of the stream bed movement in streams within the Foothill Model forest area. Although there does not appear to be a definitive study relating flood recurrence and fish habitat condition, the above observations may provide a general criterion for examining the effects of timber harvest on streamflow in the Foothills Model Forest area. That is, the hydrology of a watershed with actual or predicted harvest causing an increase in the magnitude of any event to that of the 10-year event, or an increase in the frequency of events of the magnitude of the 10-year event should be examined in more detail.

Terms of reference

The purpose of the analyses reported here is to provide a means of estimating changes in peak flows following varying intensities of timber harvest. The ultimate goal of these analyses is to provide a methodology that can be used within the WAM to assist planners in designing harvest plans that consider the concerns of fisheries biologists for fish habitat and the needs of other water users, both instream and downstream. Since stream flow depends upon the amount of precipitation that occurs in a given year, which cannot be reliably predicted, responses to harvest will vary also, depending upon the precipitation regime and the current state of harvested areas within a given watershed and year. Thus, estimates of peak flow and peak flow change under varying intensities of harvest must necessarily be made within some given range of probability, rather than as absolute quantities.

General methodology

The changes in peak flows indicated by the Swanson and Hillman (1977) study of 18 catchments will be used as a measure of peak flow changes that have occurred following harvest on the Foothills Model Forest area. The WRNSFMF procedure (RH Swanson & Associates 1997) will be used to estimate changes in annual water yield accompanying various levels of forest harvest, and, if possible, these annual changes will be used to estimate changes in the magnitude of daily peak water yield and changes in the probability of occurrence of such flows.

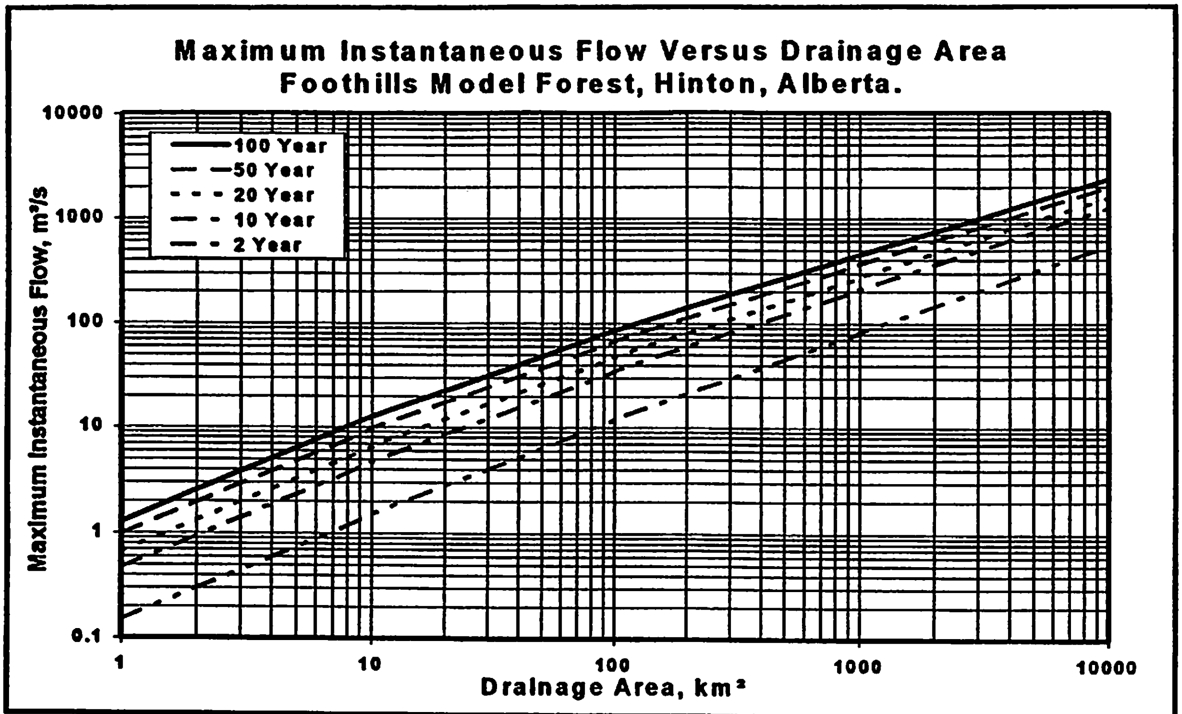

Figure 1. Regionalized curves for instantaneous annual peak flow, m³/s, as a function of watershed area (Reproduced from Hydroconsult EN3 Services, Ltd. 1997).

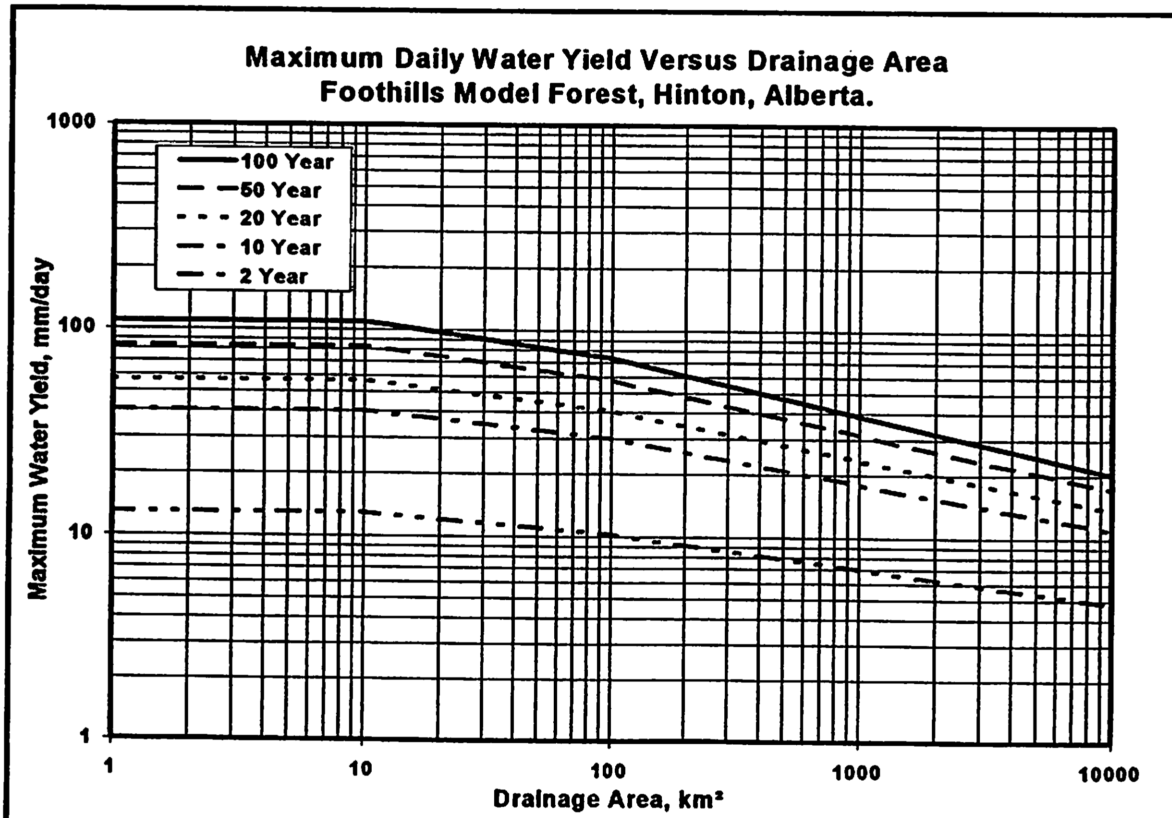

Figure 2. Regionalized curves for instantaneous annual maximum daily water yield, mm, as a function of watershed area (Derived from Hydroconsult EN3 Services, Ltd. 1997).

Table 1. Comparative statistics of water yield from unpaired composite and paired catchments on the Foothills Model Forest area, 1974. From Swanson and Hillman 1977.

Period 1974		Ppt	Comparison of water yield from catchments, mm					
			18 catchments, unpaired, df = 16				8 pairs, df = 7	
dd/mm	Event	mm	Logged	Unlogged	Difference	Confidence level %	Difference	Confidence level %
25/04-15/09	All	513	186.6	147.4	39.2	80	42.4	90
25/04-23/05	Spring freshet	278	98.9	62.3	36.6	90	34.2	95
09/07-14/07	Rain storm	43	11.9	10.0	1.9	n.s.	2.2	95
19/08-28/08	Rain storm	43	7.8	5.8	2.0	80	2.1	95
07/09-10/09	Rain storm	34	3.0	1.9	1.1	99	1.2	98

The probability of stream flows of various return periods has been estimated for the Foothills Model Forest area (Figure 1) by Hydroconsult EN3 Services, Ltd. (1977). Their analysis will be used within this report to estimate the probability of stream flows of various magnitude. In probability terms, the 2-year events have a probability of occurrence of 50%; their 10-year events, 10%; 20-year, 5%; 50-year, 2%; and 100-year, 1%.

In order to provide estimates of peak changes commensurate with the output of the WRNSFMF procedure, all analyses were conducted on unit-area flow basis (water yield data, expressed in mm/day, Figure 2). That is, for each watershed, the daily average stream flow in m^3/s was converted to total daily discharge and divided by that watershed area to eliminate the effect of differing areas on flow.[1]

The 18 study catchments of Swanson and Hillman (1977) were intended to be used as a composite whole, not as individuals. A comparison of differing water yields from individual catchment pairs is outside of their study design. However, Where the data from the combined pairs within a given working circle are statistically significant, these data will be used in this peak flow analysis *because it is the only such data available*. The difference in annual water yield between catchment pairs in the McLeod (95%) and Athabasca (80%) working circles were the only two pairs that were statistically significant (Table 5 in Swanson and Hillman 1977).

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[1] To convert mm/day to m^3/s: (mm/day) * (Watershed Area in km^2) $\div$ 86.4.
To convert from m^3/s to mm/day: (m^3/s) * (86.4) $\div$ (Watershed Area in km^2)

In order to use the water yield from the catchment pairs in this current peak flow analyses, it is necessary to make the assumption that the water yield from the logged and unlogged catchments were the same during the study year, 1974. This assumption can be questioned, as within-year variation in annual water yield among the adjacent catchments may be high. The Tri-Creeks catchments located adjacent to each other (Deerlick and Wampus, or Eunice and Deerlick) or only a few km apart (Eunice and Wampus creeks) can have annual water yields differing by 100 mm or more, e.g. 1977 water yield from Eunice and Deerlick creeks (Table 2). Such differences could completely mask any change in water yield caused by logging.

Table 2. Standard deviation (column 5) in annual water yield (columns 2 - 4), between collocated catchments on the Tri-Creeks watershed.

	Eunice	Wampus	Deerlick	Std Dev
Year	mm	mm	mm	mm
1971	253.5	313.9	293.2	30.7
1972	246.7	337.7	305.3	46.1
1973	233.9	322.1	226.0	53.3
1974	194.1	270.8	257.5	41.0
1975	97.4	122.8	149.6	26.1
1976	133.6	207.4	216.2	45.4
1977	349.2	403.3	455.7	53.3
1978	280.5	371.2	370.9	52.3
1979	119.8	175.4	181.7	34.1
1980	436.2	570.7	543.3	71.1
Mean	234.5	309.5	299.9	45.3

The design of the Swanson and Hillman (1977) study was to sample a sufficient number of catchments so that the null hypothesis that the mean of the water yield values from the cut and uncut watersheds were equal could be compared at a probability level of 80%. Variation, as estimated from the Tri-Creeks watershed, indicated that 9 logged and 9 unlogged catchments would provide a suitable statistical sample at the stated probability. The results from this study indicate that annual water yield from the logged catchments was 39.2 mm higher than that from the unlogged catchments at a probability of 90%. Eight of the logged catchments were paired with an unlogged catchment in the near vicinity. One additional logged and one unlogged catchment were selected without regard to location, were not collocated and therefore cannot be used as a pair. The water yield comparisons from the eight catchment pairs generally resulted in water yield differences similar to those from the unpaired grouping, but at somewhat higher level of confidence (Table 1).

Table 3. WRNSFMF-estimated and measured water yield change on McLeod and Athabasca watershed pairs.

	Measured			WRNSFMF	
Watershed pair	Unlogged mm	Logged mm	Increase mm	Unlogged	Logged mm
McLeod	82.3	143.2	60.9	86.1	140.0
Athabasca	105.4	151.8	46.4	95.4	151.5

I ran the WRNSFMF procedure on the paired data from the McLeod and Athabasca watersheds to see how closely it would simulate the measured water yields of their unharvested control pairs. If they were within ± 20 mm of each other, one might assume that their water yields in the unlogged state were not excessively different. The estimated water yields in the unlogged state are well within 20 mm (Table 3) of those measured and suggests that the assumption of equal water yield in their unlogged state was not unreasonable.

The data from the Swanson and Hillman (1977) study (abbreviated as S&H from here on) are unique, in that their evaluation of harvested and unharvested watersheds occurred during the same year. With this uniqueness comes the caution that there were no unlogged data for the logged catchments, these data represent only one year, and that year may or may not be typical of preceding or succeeding years.

Analyses conducted

Measured peak water yield changes

The average hydrographs from the 18 catchment S&H study during the ice-free season (Figure 3) indicates that there were four events during 1974 that produced reasonably significant

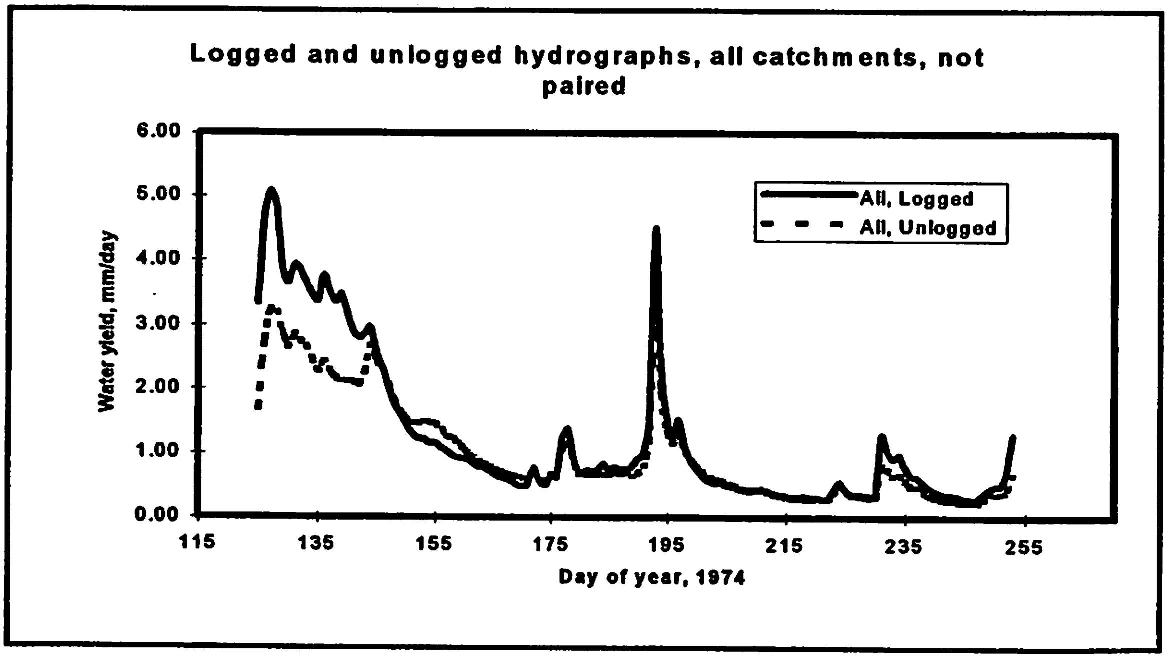

Figure 3. Composite hydrographs for the year 1974 from nine logged and nine unlogged catchments on the Foothills Model Forest area, Hinton, Alberta (from Swanson and Hillman 1977).

peaks: combined snowmelt and rain (April 25-May 23; days 115-143, spring freshet), and rain alone (July 6-16, days 187-197; August 19-28, days 231-240; September 7-10, days 250-253). The most significant peaks occurred during the spring freshet, which is a combination of snowmelt and rain, and during the July rain storm. The difference in the peak water yield during the spring freshet between the logged and unlogged catchments varies among the catchments within differing working circles. For the catchment pairs used in this analysis, those in the McLeod (Figure 4) produced the greatest peak difference, 3.64 mm , with smaller peak differences smaller (2.39 mm) for catchments in the Athabasca working circle (not shown). The peak water yield from the logged catchments in the Berland working circle (Figure 5) was lower than that from those not logged. This was not unexpected given the initial assumption that their unlogged water yields were equal, and the average deviation, of approximately ± 50 mm, from year to year that occurred between adjacent catchments (Table 2).

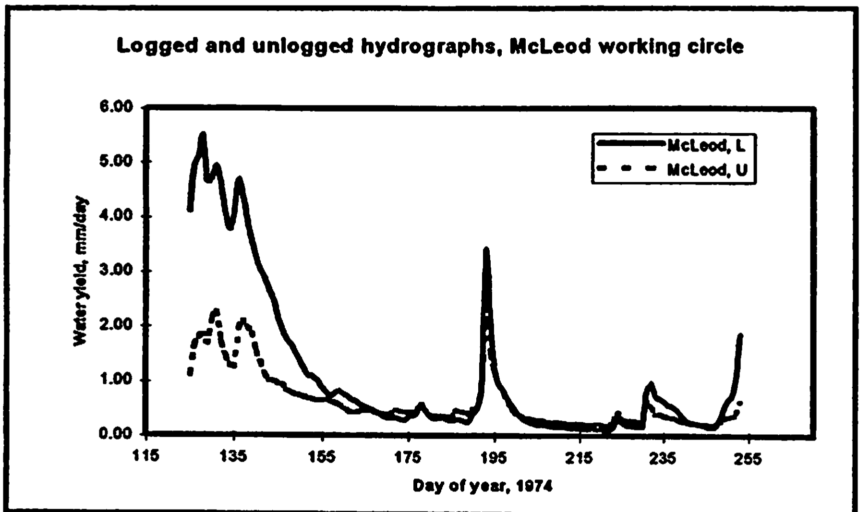

Figure 4.. Composite hydrographs from two logged and two unlogged catchments in the McLeod working circle, Foothills Model Forest area, Hinton.

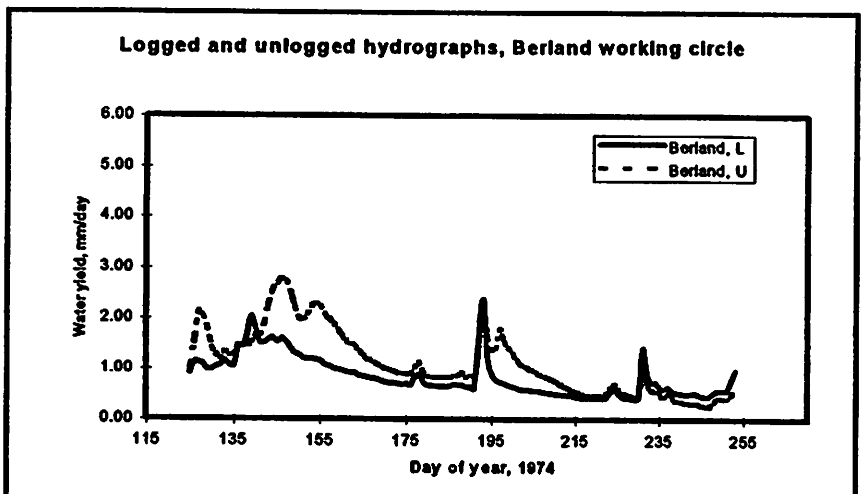

Figure 5. Composite hydrographs from two logged and two unlogged catchments on the Berland working circle, Foothills Model Forest area, Hinton.

The change in water yield during each peak event was extracted for the McLeod and Athabasca catchment pairs. A graph of the relationship between total annual water yield change for each of these working circle pairs, and the peak yield occurring during all events and each event was constructed (Figures 6 to 9). The correlation between annual water yield change and peak event magnitude becomes less as events get further in time from the spring freshet, where most of the change in water yield occurs. For events at specific time periods, correlation is best for peaks during the spring freshet (Figure 3), indicating that during 1974 most of the annual maxima occurred during the freshet. There was virtually no correlation between annual water yield change and the magnitude of peak increases from rain events in the summer (Figures 8 to 10).

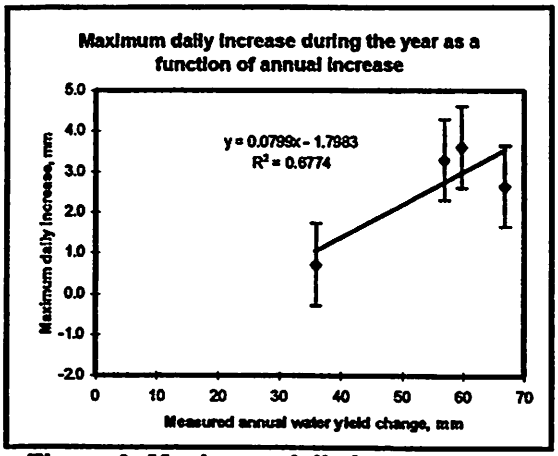

Figure 6. Maximum daily increase in water yield, all events, as a function of annual water yield increase. Data grouped within each working circle.

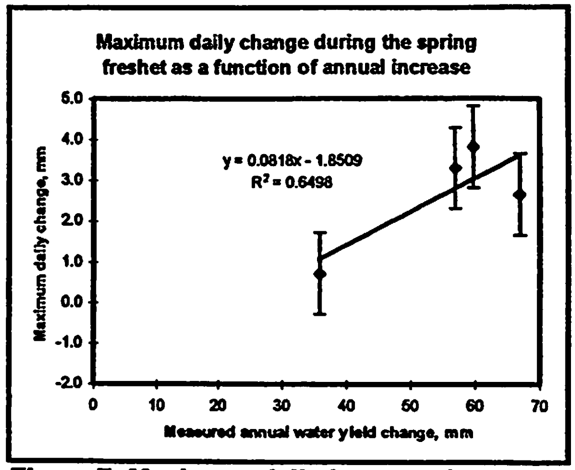

Figure 7. Maximum daily increase in water yield during the spring freshet as a function of annual water yield increase. Data grouped within each working circle.

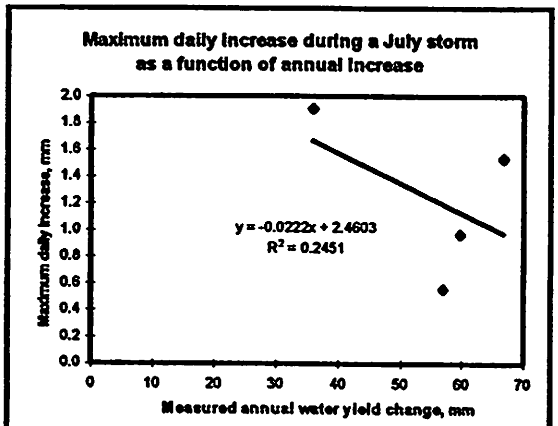

Figure 8. Maximum daily increase in water yield during a July rainstorm as a function of annual water yield change. Data grouped within each working circle.

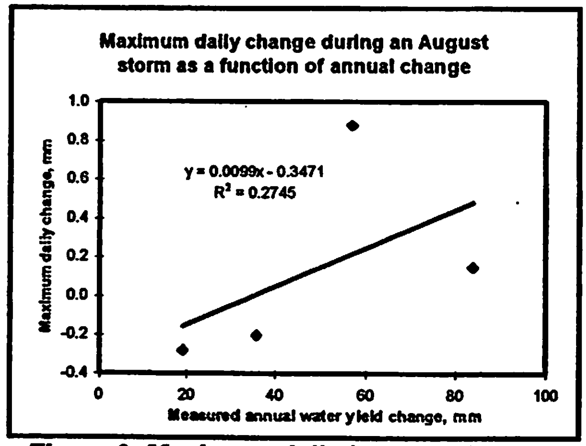

Figure 9. Maximum daily increase in water yield during an August rainstorm as a function of annual water yield increase. Data grouped within each working circle.

An important point evident from these relationships (Figures 6 to 10) is that the maximum increase in daily water yield due to forest harvest never exceeded 4 mm. This finding is supported by an examination of the daily potential evapotranspiration (PET) from forests in Northwestern Alberta (Table 4). These data obtained from analyses of growing season climate data in the Keg River, Grande Prairie and Valley View areas indicate maximum PET of approximately 6 mm per day. WRENSS estimates the maximum actual evapotranspiration (AET) at 0.4 of PET, or 2.4 mm/day (i.e., AET = 0.4 * PET) for WRENSS regions Rocky Mountain and Continental Maritimes (Figures III.46, III.47, III.48, and III.49, page III.91 in USEPA 1980). Assuming

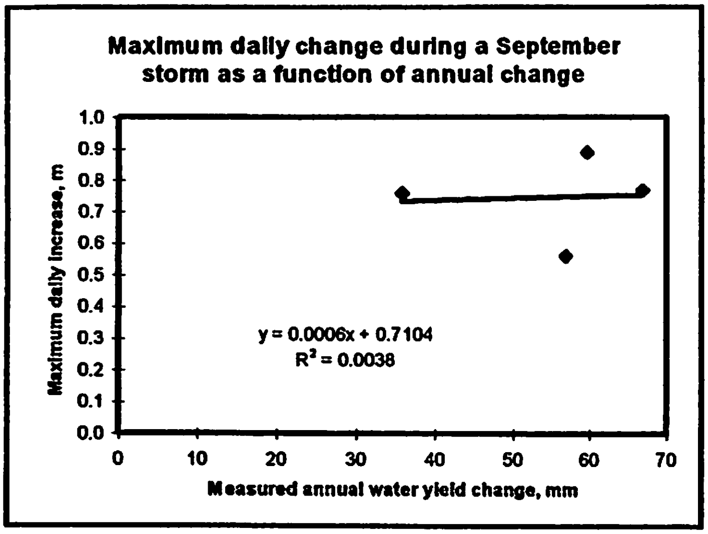

Figure 10. Maximum daily increase in water yield during a September rainstorm as a function of annual water yield increase. Data grouped within each working circle.

Table 4. Maximum daily potential evapotranspiration (Penman formula) data for 1995 from five sites in northwestern Alberta.

Climate Station Locations	PET mm/day
Grande Prairie 83	5.85
Grande Prairie 88	6.17
Keg River	6.67
Spring Creek 94	5.15
Spring Creek 96	5.15
Average	5.80

that all of this reduction in AET becomes water yield, i.e., (6 mm - 2.4 mm = 3.6 mm), the maximum increase in water yield that should result from forest harvest is about 3 to 4 mm/day.

Estimating peak changes with WRNSFMF

Estimating annual yield change from logged catchments

The WRNSFMF procedure was used to estimate the change in annual water yield for the logged catchment of each catchment pair including those where the results were not statistically significant (Figure 11). (The analysis of these data are included for information only.) In these estimations, the annual yield of the logged catchment prior to harvest was assumed to be the same as that from the unlogged catchment at the time of measurement. The site quality of the regeneration functions, and the

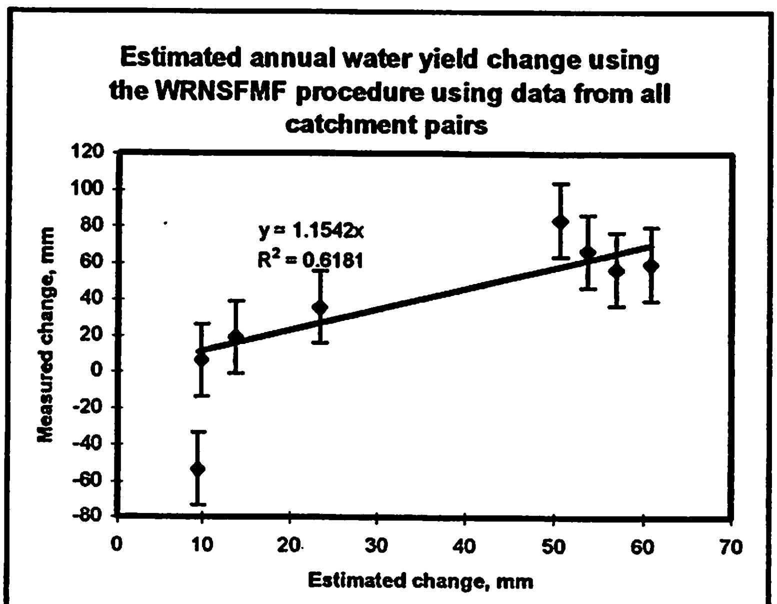

Figure 11. WRNSFMF estimated water yield for all eight logged catchments, including those with not statistically significant results.

WRENSS region in WRNSFMF, were selected to produce estimated yields as close to those measured as possible. An average age for the harvests was used (Table 2, page 21, In Swanson and Hillman 1977). Regrowth functions were selected from among those derived from the Alberta Forest Service, Phase 3 inventory (Alberta Forestry, Lands and Wildlife 1985) from fire origin stands. This procedure produced estimates of increased water yield generally well within the ± 20 mm that I assumed would be necessary to indicate reasonable equality of water yields from the logged and unlogged catchments prior to harvest. The major exception is one set of catchments from the Berland working circle where measured water yield from this Berland logged catchment was less than that from the unlogged catchment. This probably means that the water yield from the logged catchment was approximately 50 mm less than its unlogged pair prior to logging. A difference of this magnitude is well within that anticipated from the design analysis of the Tri-Creeks watersheds (Table 2).

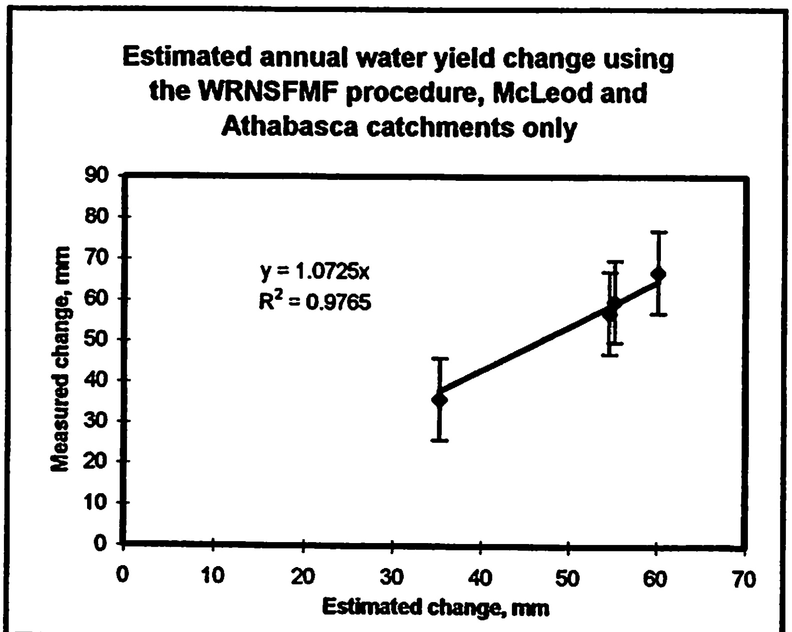

Figure 12. WRNSFMF estimated water yield for those catchment pairs in the Athabasca and McLeod working circles which produced statistically significant increases.

The relationship used in this peak flow analysis is that of WRNSFMF estimated water yield solely from those catchment pairs where there measured increases were statistically significant, e.g., the catchments from the McLeod and Athabasca working circles (Figure 12). All of these estimated water yield increases fall well within the ± 20 mm error band proposed as a criteria for use in this analysis (actually well within ± 10 mm).

Estimating magnitude of daily peak water yields from logged catchments

There was essentially no relationship between the change in daily peak yield magnitude during summer rain events and annual water yield (Figures 8 to 10). Therefore techniques to estimate these storm data were excluded from further analyses.

The increase in daily water yields that may be estimated are those occurring primarily during the spring freshet. To estimate these daily values I coupled the results of Figure 7 (change in peak water yield as a function of measured change in annual water yield) with that of

Figure 12 (measured change in annual water yield as a function of WRNSFMF-estimated change in annual water yield). Although one could use the results of Figures 6 and 12 in a similar manner, it is probably not advisable because Figure 6 includes the results from of the catchment pairs where the results were not statistically significant.

The results of Figures 7 and 12 are coupled in Figure 13. This indicates that WRNSFMF estimates of change in annual water yield can be used to estimate the change in daily peak water yield during the spring freshet within ± .75 mm, i.e., ± 20% of the maximum expected change in daily water yield due to forest harvest. Equation (1) is used for estimating daily maximum water yield change ΔQpeak.

$$\Delta Qpeak = 0.053 * (\Delta Qwrnsfmf) \ mm/day \qquad [1]$$

Equation (1) has been programmed within WRNSFMF to carry out the peak water yield calculations automatically. WRNSFMF has also been programmed to use the data from the Foothills Model Forest's regional hydrology study (Figures 1 and 2, Table 5) to estimate the peak water yield or streamflow at recurrence intervals of 2, 10, 20, 50 and 100 years from any watershed in the Model Forest's area. WRNSFMF produces a table (Table 6) for any given harvesting scenario describing the water yield at each of the above recurrence intervals, with and without harvest This table, and a graph of the harvest's effect on the 2, 10 and 20 year peak magnitude, can be viewed within WRNSFMF. The data (e.g. Table 6) can be saved in various spreadsheet or database formats for further analysis.

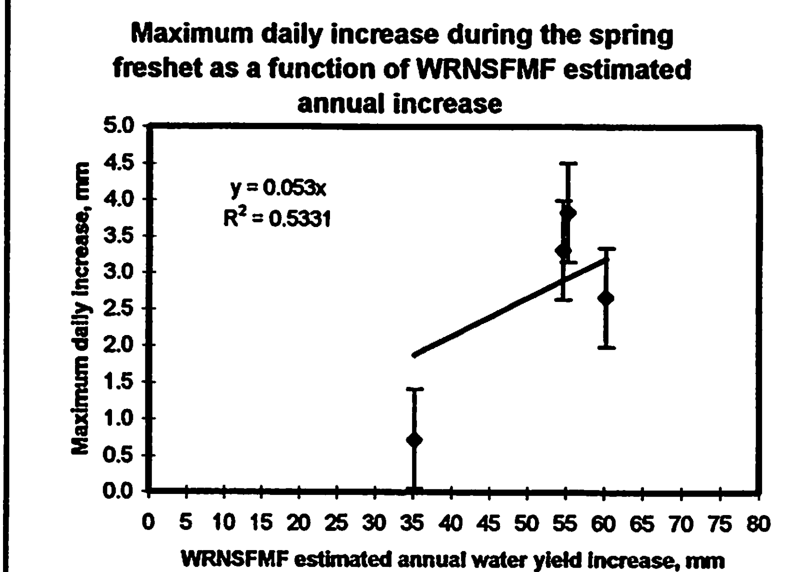

Figure 13. Relationship between WRNSFMF estimates of annual water yield increase and maximum daily flow during the spring freshet. The error bars on the daily increase represent a ± 10 mm error in WRNSFMF estimated annual yield increase.

Interpretation of peak events

The physical interpretation of peak events is beyond the scope of this paper. Peak events must be interpreted with respect to a water user, whether in the stream channel or on the flood plain at some downstream location. In general, one can anticipate that the events occur-

Table 5. Equations for maximum instantaneous flow (Q, m³/s) as a function of watershed area (WS Area, km²). Regional hydrology study, Foothills Model Forest, Hinton, Alberta (Hydroconsult EN3 Services, Ltd. 1997).

Recurrence Interval	Watershed Area < 25 km²	Watershed Area ≥ 25 km²
2-year	Q = 3.736(WS Area)/25	$Q = 0.255(WS\ Area)^{0.834}$
10-year	Q = 11.764(WS Area)/25	$Q = 0.945(WS\ Area)^{0.781}$
20-Year	Q = 16.448(WS Area)/25	$Q = 1.42(WS\ Area)^{0.761}$
50-year	Q = 24.047(WS Area)/25	$Q = 2.25(WS\ Area)^{0.736}$
100-Year	Q = 31.570(WS Area)/25	$Q = 3.12(WS\ Area)^{0.719}$

ring with a probability of 5 to 50%, i.e., those with 20, 10 and 2-year recurrence intervals, will be the most affected by forest harvest. However, one should not presume that any change in the magnitude or recurrence interval of an event will or will not have a favourable or unfavourable influence on instream or downstream users. That is something for the water or stream channel user to decide.

Describing changes in yearly maximum events

Forest harvesting increases the magnitude of annual streamflow peaks, but not by much. In this example (Table 6), the magnitude of the 2-year event has been increased by 20%. Even if the maximum potential increase of 6 mm were realized, the change in magnitude of the 2-year event would only be 60% higher than without harvest, and the 10-year event 15% higher than without harvest. Regardless of how it is described, the net effect is that peak streamflow will not be much higher than if the watershed was not harvested.

Procedures for estimating impact on peak flows

Even though the effect of harvest on streamflow peaks is not expected to be high, one may want to estimate it in order to counter claims to the contrary. Estimating the impact involves several steps outlined below. The last step is carried out automatically within the WRNSFMF program.

1. Identify watershed in question
2. Determine its importance of the stream channel to resident stream users and of flow levels to instream residents and/or downstream water users. If of no importance to either, you may be able to safely ignore hydrologic concerns, and you might not need to carry out the remaining steps!

3. Determine what data are available for that watershed.

   a) Are there any hydrologic characteristics that could be negatively impacted?

   b) What is the magnitude of peak flow events that are alleged to cause negative impacts?

   c) Precipitation data: Monthly averages are needed for WRNSFMF analysis. It is helpful if these data are from the actual watershed, but it can be interpolated from nearby stations.

   d) Water yield data: An annual value is needed for WRNSFMF analysis. It is helpful if this is from actual watershed, but it can be estimated from nearby stations.

   e) Anticipated regrowth: Are their functions available to estimate the rate of regrowth? If so these should be programmed into WRNSFMF to ensure the best possible simulation of the duration of harvest effects on water yield.

   f) Are there any time constraints on the harvest sequence in that watershed that must be met?

   g) Is there an existing planned harvest sequence that can be used as a starting point for further hydrologic impact analysis?

4. Do a WRNSFMF analysis on the planned harvest using best available water yield and precipitation data. "The Peak Flow Analysis" selector, accessible from the "Results" form within WRNSFMF will provide a quick look at the estimated absolute (tabulated) and percent change (graphed) in peaks that will occur over the duration of the harvesting scenario examined. The peak yield results can be saved in MS EXCEL™ or other formats for further analysis.

Discussion and Conclusions

The small sample of the effect of harvest on water yield change of the S&H study can provide only guidelines. The sample is too small statistically to provide a definitive method for determining the change in peak flows that harvest may cause. None-the-less, there are some general conclusions that can be drawn from this peak flow analysis.

Forest harvest will not likely increase peak daily water yield by more than 4-6 mm because this is the maximum reduction that is likely to occur in actual evapotranspiration. Even this change in generated yield may not be realized in actual yield from many watersheds because of the dampening effect of watershed storage. This is borne out by the S&H data where the maximum change in daily water yield was 3.8 mm.

Table 6. Results of peak flow analysis by WRNSFMF. The column headers have been edited in EXCEL to make the table more readable. The values in the first row (1961) are for the unharvested state.

	Change in Yield		Change in Peak Yield at Each Probability					Percent of Estimated Peak Yield		
	Annual	Peak	50%	10%	5%	2%	1%	Delta Percent		
Year	mm	mm	mm	mm	mm	mm	mm	50%	10%	5%
1961	0.0	0.0	9.8	27.9	38.0	53.3	68.0	100%	100%	100%
1962	3.5	0.2	9.9	28.1	38.2	53.5	68.1	102%	101%	100%
1963	12.2	0.6	10.4	28.5	38.6	53.9	68.6	107%	102%	102%
1964	15.5	0.8	10.6	28.7	38.8	54.1	68.8	108%	103%	102%
1965	24.8	1.3	11.1	29.2	39.3	54.6	69.3	113%	105%	103%
1966	32.9	1.7	11.5	29.6	39.7	55.0	69.7	118%	106%	105%
1967	36.1	1.9	11.7	29.8	39.9	55.2	69.9	120%	107%	105%
1968	34.1	1.8	11.6	29.7	39.8	55.1	69.8	119%	106%	105%
1969	32.6	1.7	11.5	29.6	39.7	55.0	69.7	118%	106%	105%
1970	32.1	1.7	11.5	29.6	39.7	55.0	69.7	117%	106%	104%
1971	31.8	1.7	11.4	29.6	39.7	55.0	69.6	117%	106%	104%
1972	31.8	1.7	11.4	29.6	39.7	55.0	69.6	117%	106%	104%
1973	31.3	1.7	11.4	29.6	39.7	54.9	69.6	117%	106%	104%
1974	30.0	1.6	11.4	29.5	39.6	54.9	69.5	116%	106%	104%
1975	28.3	1.5	11.3	29.4	39.5	54.8	69.5	115%	105%	104%
1976	26.3	1.4	11.2	29.3	39.4	54.7	69.3	114%	105%	104%
1977	23.7	1.3	11.0	29.2	39.3	54.5	69.2	113%	105%	103%
1978	21.3	1.1	10.9	29.0	39.1	54.4	69.1	112%	104%	103%
1979	18.4	1.0	10.7	28.9	39.0	54.2	68.9	110%	104%	103%
1980	16.9	0.9	10.7	28.8	38.9	54.2	68.9	109%	103%	102%
1981	16.3	0.9	10.6	28.8	38.9	54.1	68.8	109%	103%	102%
1982	15.6	0.8	10.6	28.7	38.8	54.1	68.8	108%	103%	102%
1983	14.9	0.8	10.6	28.7	38.8	54.1	68.7	108%	103%	102%
1984	14.2	0.8	10.5	28.6	38.8	54.0	68.7	108%	103%	102%
1985	13.2	0.7	10.5	28.6	38.7	54.0	68.7	107%	103%	102%
1986	12.1	0.6	10.4	28.5	38.6	53.9	68.6	107%	102%	102%
1987	10.9	0.6	10.3	28.5	38.6	53.8	68.5	106%	102%	102%
1988	9.7	0.5	10.3	28.4	38.5	53.8	68.5	105%	102%	101%
1989	8.5	0.4	10.2	28.3	38.5	53.7	68.4	105%	102%	101%
1990	7.3	0.4	10.1	28.3	38.4	53.7	68.3	104%	101%	101%
1991	6.1	0.3	10.1	28.2	38.3	53.6	68.3	103%	101%	101%

If we assume that 4-6 mm is the maximum increase in daily water yield that one should expect as a result of harvest, then *any* intensity of harvest will have a minor effect on peak streamflow at any probability of occurrence. Although in the S&H study peak water yield from the harvested watersheds was approximately 1.5 times that from the unlogged watersheds (5.08 mm logged

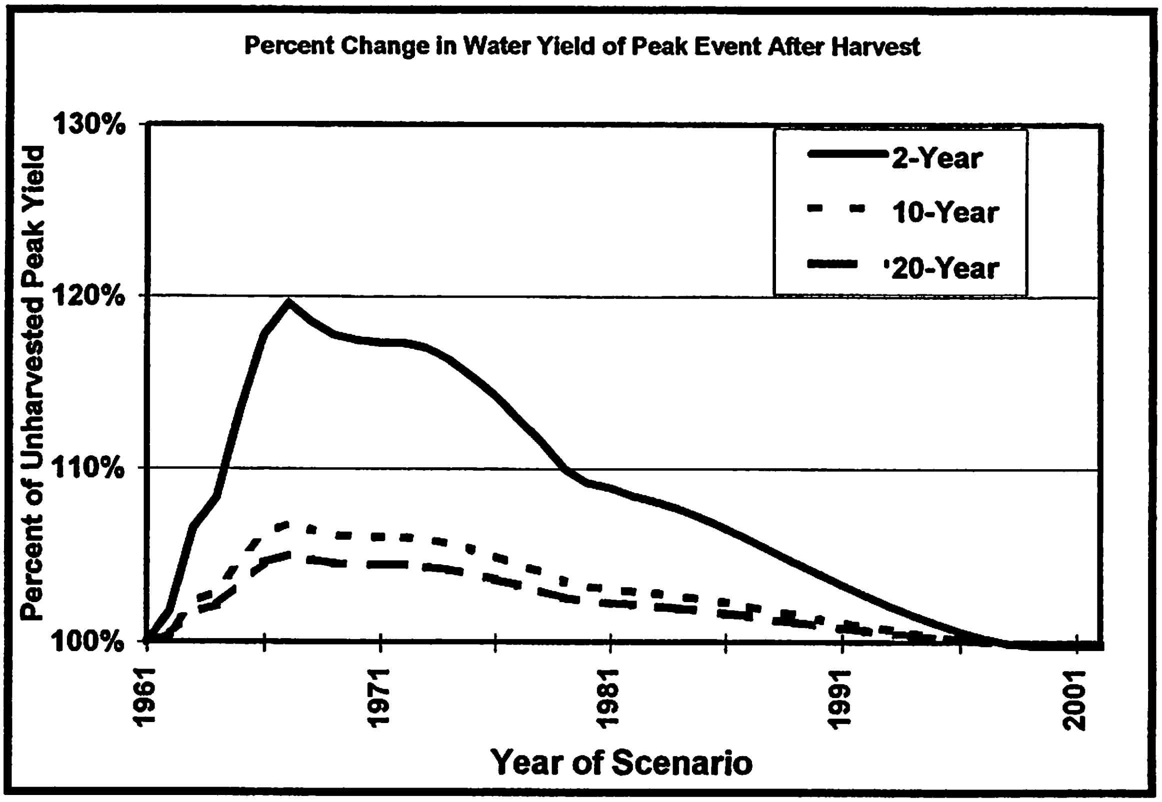

Figure 14. Percent change in peak daily water yield expressed as a percentage of estimated peak yield if not harvested. Harvested watershed data from Swanson and Hillman (1977).

versus 3.48 unlogged) during the spring freshet, the magnitude of this measured peak was less than 60% of the estimated magnitude (9.8 mm, see row for 1961, Table 6) that would occur with a probability of 50% (2-year recurrence interval) if not harvested. And even if the water yield from the unharvested catchments had been 9.8 mm, an increase in peak by the maximum possible of 4 or 6 mm to 13.8 or 15.8 mm from the harvested catchments would still be much less than the peak water yield (27.9 mm, see row for 1961, Table 6) estimated to occur at a probability of 10%. Therefore it is unlikely that forest harvest in the Foothills Model Forest area will have any physically significant impact on the *streamflow peaks* that have been suggested as damaging to fish habitat (approximately a 6% increase in the magnitude of that of the10-year recurrence interval. Figure 14). There still may be a physically significant impact due to the duration and magnitude of the augmented flow occurring during the spring freshet. However, this determination is beyond the scope of this present study.

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