HYDROLOGIC EFFECTS OF CLEAR-CUTTING AT MARMOT CREEK AND STREETER WATERSHEDS, ALBERTA

R.H. Swanson, D.L. Golding[1]*, R.L. Rothwell*[2]*, and P.Y. Bernier*

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[1] Associate Professor, Forest Hydrology, University of British Columbia, Vancouver, British Columbia.
[2] Associate Professor, Forest Hydrology, University of Alberta, Edmonton, Alberta.

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ABSTRACT

The Marmot and Streeter experimental watersheds were established to provide forest-cutting options to maximize water yield within the Saskatchewan River headwaters. Clear-cut harvesting of 21% of the area of the Cabin Creek subbasin of Marmot in 10-ha commercial-sized cut blocks increased annual water yield by 35.7 dam^3, 6% greater than predicted if left uncut. This represents an increase of 79 mm in the yield from the clear-cut patches. Erosion was not a problem on the stable soils of Cabin Creek; neither did suspended sediment load increase as a result of this timber harvest. Clear-cutting 50% of the vegetated portion of the West subbasin of Streeter in a pattern designed to augment snow accumulation and retention of snow on-site increased water yield from a small contact spring, during April through October, by 6.3 dam^3, 175% more than predicted if left uncut. More importantly, flow continued throughout the summer of 1977, the second-driest year on record in southern Alberta, even though predicted flow was zero if left uncut. These results, when coupled with those from similar experiments in Alberta and the United States, indicate that 1-ha clear-cut patches with maximum dimensions of 4-6 tree-heights across would maximize water yield from either subalpine or foothills forests.

RESUME

Les bassins expérimentaux de Marmot et Streeter furent établis au début des années soixante dans le but de fournir des stratégies de coupe permettant de maximiser les débits de la riviére Saskatchewan. La coupe à blanc effectuée par bloc commerciaux de 10 ha sur 21% de la surface du sous-bassin Cabin Creek a causé une augmentation de 35.7 dam^3 des débits annuels, ou 6% de plus que prévu sans coupe. Ceci représente une augmentation du débit provenant des aires coupées de 79 mm. L'érosion fut négligeable sur les sols stables de Marmot; les sédiments en suspension n'augmentairent pas non plus suite la coupe. La coupe de 50% de la surface boisée du sous-bassin Ouest de Streeter dans un patron destiné à augmenter l'accumulation et la rétention en place de la neige, a accru le débit d'avril à septembre d'une petite source de contact de 6.3 dam^3, ou 175% de plus que prévu sans coupe. Un fait significatif, le débit fut ininterrompu durant cet été 1977, le deuxième le plus sec jamais enregistré dans le sud de l'Alberta, bien que des débits nuls étaient prévus sans coupe. Ces deux résultats couplés avec ceux obtenus d'expériences semblables en Alberta et aux Etats-Unis, indiquent que des blocs de coupe de 1 ha, larges au plus de 4 à 6 hauteurs d'arbre, maximiseraient les débits des bassins sub-alpins et des piedmonts.

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NOTE

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INTRODUCTION

The eastern slopes of the Rocky Mountains in Alberta have long been recognized as an important watershed. The Eastern Rockies Forest Conservation Board (ERFCB) was constituted in 1947 in recognition of the special status of this area with respect to water supply in the Saskatchewan River, which is vital to the water needs of southern Alberta and Saskatchewan (Fig. 1). One of the ERFCB's principal functions was "the conservation, development, maintenance and management of the forests in such area [the eastern slopes watershed] with a view to obtaining the greatest possible flow of water in the Saskatchewan River and its tributaries" (Parliament of Canada 1947). The Eastern Rockies Forest Conservation area covered about 23 400 km² of the 287 000-km² watershed above the junction of the North and South Saskatchewan rivers near Prince Albert. The conservation area, plus an additional 9300 km² of mainly forested land above 1200 m elevation, constituted a manageable watershed area yielding 48% of the annual flow in the North and South Saskatchewan rivers (Laycock 1965). (Forty-two percent of the annual flow originates in Waterton, Banff, and Jasper national parks; 10% is from the remaining plains portion of this watershed.)

"How to manage this watershed for water production and water supply protection" was an issue addressed by the ERFCB. Upon its request, the joint provincial-federal Alberta Watershed Research Program (AWRP) was initiated during 1960–63 with the establishment of experimental watersheds at Marmot Creek and Streeter Creek (Fig. 1) to examine the effects of forest cutting on streamflow (Jeffrey 1964). This report discusses the progress made toward the ERFCB's goal of effective management. Watershed clear-cutting experiments on Marmot's Cabin Creek and at Streeter have been completed. The topics covered in this report are: 1) the experimental programs and expectations, which were different for each watershed, 2) the results, and 3) the authors' interpretation of those results in terms of their implications for watershed management in the Saskatchewan River headwaters.

THE MARMOT-CABIN CREEK COMMERCIAL HARVEST EXPERIMENT

Objectives

The principal objective of the Marmot-Cabin Creek experiment was to determine if the harvesting guidelines of the Alberta Forest Service (AFS) (Alberta Department of Lands and Forests 1971) for commercial cutting in spruce-fir forests were satisfactory for maintaining the volume of high-quality water that these watersheds yield. Data from Cabin Creek, which was to receive a commercial clear-cut, were to be compared with similar data from Middle Creek, which has been retained as an uncut control. The physiographic characteristics of both catchments are detailed in Table 1.

Vegetation

Cabin Creek is one of three subbasins on the Marmot experimental watershed (Fig. 2). Marmot is classified as part of the Subalpine Region (Rowe 1977), which places it in the same vegetation-climate classification as the better-known Fool Creek watershed on the Fraser Experimental Forest in Colorado (Alexander and Watkins 1977). Forest cover on Marmot's subbasins is generally greater than 200 years old and ranges in height from about 30 m near the confluence area to 5-10 m tall just below the tree line. The trees on north-facing slopes and all aspects at the higher elevations are mainly Engelmann spruce (*Picea engelmanii* Parry) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). A thin band of alpine larch (*Larix lyalii* Parl.) occurs just below tree line (approximately 2300 m) on all three subbasins. Old lodgepole pine (*Pinus contorta* Dougl. var *latifolia* Engelm.) occurs on southerly facing slopes and at lower elevations (Kirby and Ogilvie 1969). Fire destroyed the forest in the lower portion of the basin in 1936, and a replacement stand of young lodgepole pine (lighter-toned portion in Figure 2) occupies much of the confluence area.

Table 1. Physiographic characteristics of Cabin and Middle subbasins

Topographic classification	Cabin Creek subbasin	Middle Creek subbasin
Total area (ha)[a]	212	300
Maximum elevation (m)	2750	2800
Minimum elevation (m)	1730	1760
Area above tree line (%)	24.0	74.8
Length of streams (km)	6.7	5.7
Area clear-cut (ha)	44.9[a]	Nil

[a] Computed according to the "old" basin boundary in Figure 2, which places Block 4 outside of the basin. See Appendix 1 for details.

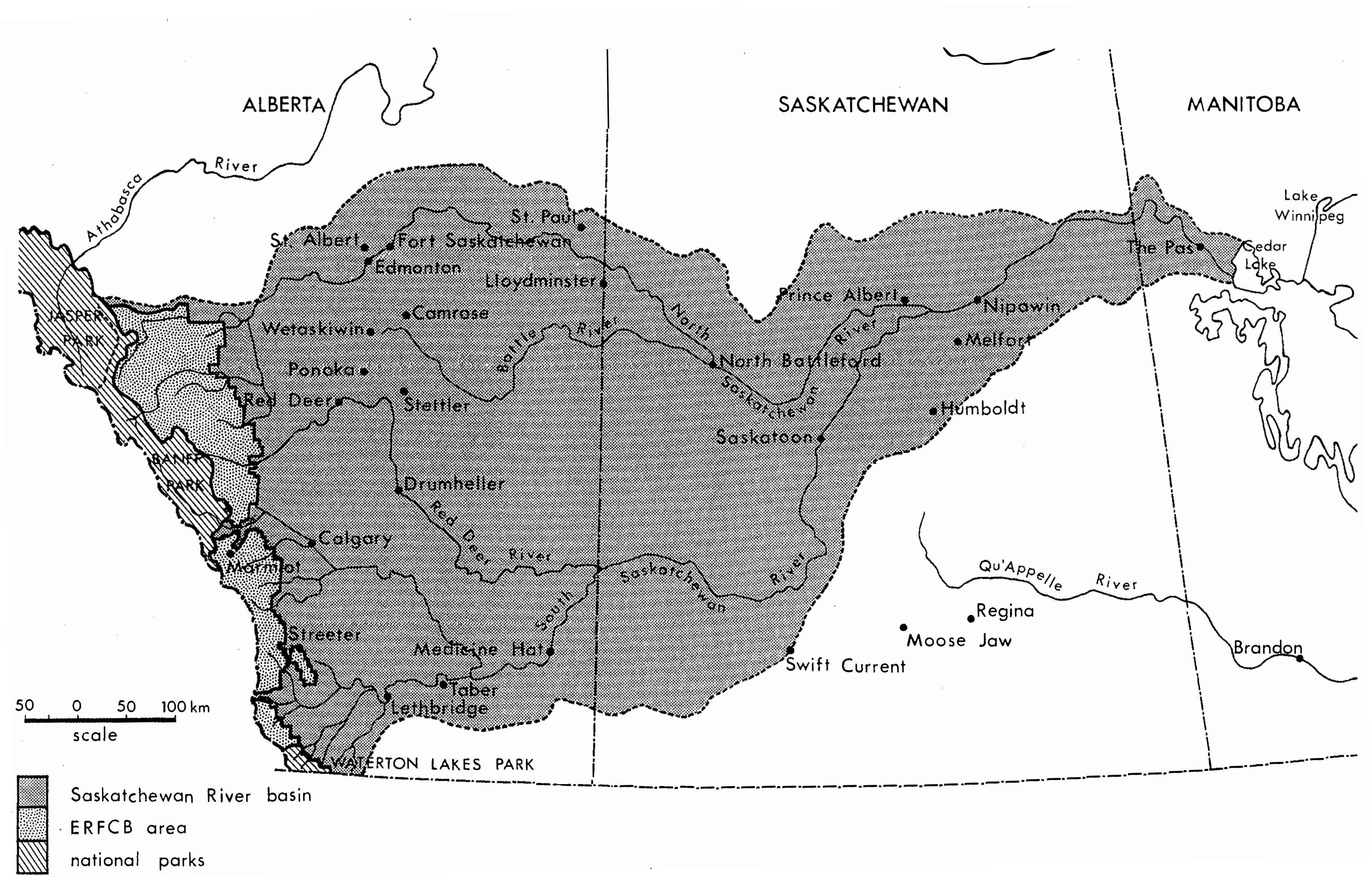

Figure 1. The Saskatchewan River basin and the locations of Marmot and Streeter experimental watersheds in southern Alberta.

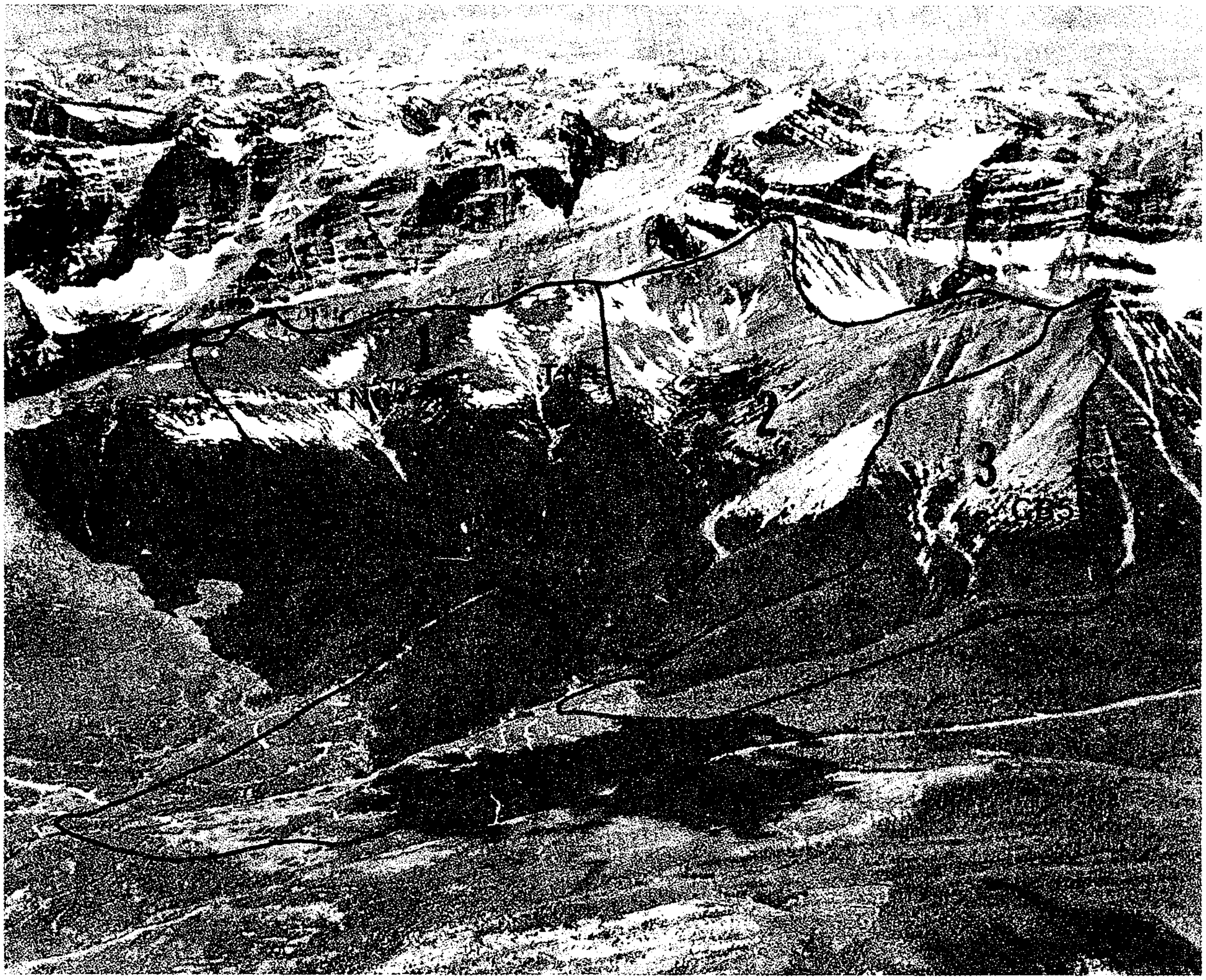

Figure 2. The three subbasins of the Marmot experimental watershed. Those with stream gauges are: 1) Twin, 2) Middle, and 3) Cabin. The area where the three streams join (4) is designated as confluence. The alphanumeric symbols indicate the location of the climatological stations that are currently in operation.

Soils and groundwater

The soils of Marmot are generally of glacial till origin and well-drained, with minimum infiltration rates higher than the reported maximum storm intensity (Beke 1969). The total depth of overlying unconsolidated coarse material ranges from 18 to 20 m in the lower confluence to nil on the alpine ridge. These deposits store water and dampen peaks (Stevenson 1967). When a standardized hydrograph separation technique (Hewlett and Hibbert 1967) is applied to the streamflow record, less than 2% of annual flow is classified as storm flow, which indicates that most water reaching the stream does so via a subsurface path.

Climate and hydrology

The climate of Marmot is characterized by long, cold winters and wet, cool summers. Mean monthly temperatures range from a low of −6°C in January to a high of 13°C in July. Annual precipitation varies from 660 mm at lower elevations to over 1140 mm at the highest station on Twin Creek subbasin. Mean annual precipitation for Cabin Creek is estimated at 840 mm, 70–75% of which falls as snow (Storr 1977). There are no permanent snowpacks or glaciers on Marmot.

Streamflow has been measured on Marmot since 1964 (Davis 1964). The gauging structure on Middle Creek is a sharp-crested, 90° V-notch weir; that on Cabin Creek is an H-flume with a laterally sloping floor to prevent sediment accumulation. At both structures water level is recorded in a stilling well with a Stevens A35 recorder, and both were enlarged from their initial capacity of 76 cm (head) to 91 cm (Cabin in 1970, Middle in 1971).

Average annual water yield on Cabin Creek is 310 mm, about 36% of annual precipitation. Peak streamflow of 170–250 L s^{-1} km^{-2} occurs in response to snowmelt, which often starts as early as the last week of April. June streamflow accounts for 39% of annual flow; that for May, June, and July combined is 76% of annual flow.

Marmot has a reputation as the most heavily instrumented experimental basin in Canada, though much of the data from these instruments is not directly relevant to the evaluation of the forest cutting treatments. Many sites were instrumented to meet the goals of particular climatological or groundwater studies and are no longer active. The placement of climatic instrumentation was such that there was an over-sampling of summer temperature and precipitation and an under-emphasis on the measurement of both winter precipitation in the alpine and microclimate parameters in the treed portions. Air temperature, relative humidity, incoming solar (short wave) radiation, precipitation, and wind speed and direction are currently recorded at four permanent stations (Fig. 2). Snow pillows are located near the Twin 1 (TN1) and Con 5 (CN5) stations. Ten snow courses have been read monthly (usually January through May) since 1964. In addition, the snow at each point on a 1500-point, 100 × 200 m grid covering the timbered portion of Marmot was sampled once each year in late March from 1969 through 1980.

Problems in evaluating yield change

In an early description of the Marmot project, Jeffrey (1964) indicated that a primary objective for the Cabin Creek treatment was an evaluation of the water yield and regime change that would occur. In 1971 this objective was relegated to a secondary position because the AWRP Research Coordinating Committee thought that it would be difficult, if not impossible, to evaluate the effect on either water yield or regime of clear-cutting only 21% of the subbasin.

The paired watershed approach, in which the hydrometric data from two physiographically similar catchments are compared by some statistical technique, is generally considered to be the most reliable to use in evaluating watershed harvesting experiments. Bosch and Hewlett (1982) indicated that even in the best of circumstances, however, the effect of reductions in forest cover of less than 20% cannot be detected by the hydrometric method.

A second approach to evaluation would be to model or compute the water balance for the preharvest and postharvest periods. The unavailability of alpine snow cover data, however, is a serious obstacle to evaluation of the water yield aspects of Marmot treatments by modeling (Dickinson 1982). At least 24% of the area of Cabin Creek lies above the timberline. Periodic visual observation indicates that this alpine portion is intermittently snow-covered and snow-free during some years; thus we do not know what precipitation input to attribute to a quarter of the area of Cabin Creek. This makes any calculation of Cabin Creek streamflow that is a function of precipitation an uncertain exercise.

Commercial harvest treatment on Cabin Creek

The harvest on the Cabin Creek watershed was designed to simulate a commercial clear-cutting operation. We could only simulate commercial logging because, under the ERFCB Act, all land in this portion of

Table 2. **Physical details of the Cabin Creek commercial treatment**

Block	Area (ha)	Approximate dimensions (H)[a]	Percent of total area			Slope (%)
			Skidroads	Access roads	Landings	
1	10.95	17 × 17	19.1	2.5	9.2	23
2	7.80	14 × 14	16.1	8.9	3.6	24
3[b]	2.59	8 × 8	—	11.8	—	—
5	10.84	16 × 16	18.4	4.5	8.3	10
6	12.70	18 × 18	18.1	6.5	2.0	16
Total	44.88					
Mean	8.98	15 × 15	17.9	6.8	5.8	18

[a] Considering the shape of each cut block as square, and 1 tree height (H) as 20 m.

[b] The timber from Block 3 was only partially removed although all of it was felled. Because its treatment differs from the others, it is not included in the statistics other than those for total area and access.

Alberta lying at an elevation above 6,500 ft. (1980 m), has been placed in a watershed protection zone where timber harvest is prohibited (Parliament of Canada 1947). Although no clear-cutting was allowed elsewhere above 1980 m in normal clear-cutting operations, it was allowed on Cabin Creek because there was no physical or physiological reason not to cut there and the additional cut area provided by blocks 2 and 3 (Fig. 3) was needed if we were to have any hope of detecting the effect on streamflow.

Six blocks ranging from 3 to 13 ha in area were marked for clear-cutting by AFS personnel (Table 2, Fig. 3). The primary criteria used in laying out the cut blocks were to locate areas to be cut well away from the stream channel and to avoid slopes greater than 45%. Cut blocks were shaped to reduce skidding distance and soil disturbance. One of these blocks, Block 4, was located in an area where the basin boundary was uncertain. Analysis of recent piezometric data (see Appendix 1) suggests that Block 4 is in fact outside of the Cabin Creek subbasin. Accordingly, it was left out of the present analysis.

Road construction occurred in 1971, 2 years prior to harvest. These roads were laid out during the spring of the year when the ground was wettest and the trouble spots most obvious. The main concerns during road layout were to minimize the number of road-stream crossings, to maintain a strip of undisturbed vegetation between the roadway and stream, to minimize cut-fill construction, and to avoid steep gradients. Temporary skid roads were constructed parallel to ground contours and used by rubber-tired skidders to bring tree-length logs from distant locations in each cut block to a landing site, where they were loaded onto trucks for transport to the sawmill. The proportion of each cut block area that is occupied by roads or landings is summarized in Table 2. Logging was done by Spray Lakes Sawmills Ltd., Cochrane, Alberta, from July to September 1974.

Evaluation of site disturbance and suspended sediment

Site disturbance

The occurrence and extent of soil exposure, surface erosion, and sediment transport from the roads and cut blocks were evaluated by preparing a map of the exposed soil in each of the cut blocks and by on-site reconnaissance during rainstorms or snowmelt to observe the presence or absence of overland sediment transport. Soil exposure was determined from upslope and downslope line transects established at 40-m intervals across each cut block. The width of roads and skid trails crossed by each transect was recorded. In addition, milacre (4-m^2) plots were established at 20-m intervals along each transect. Within each of these plots, the area of mineral soil exposure and the occurrence of erosion were visually estimated. These data were then grouped into soil disturbance classes of: high, 61-100%; moderate, 46–60%; low, 16–45%; and nil, <15%.

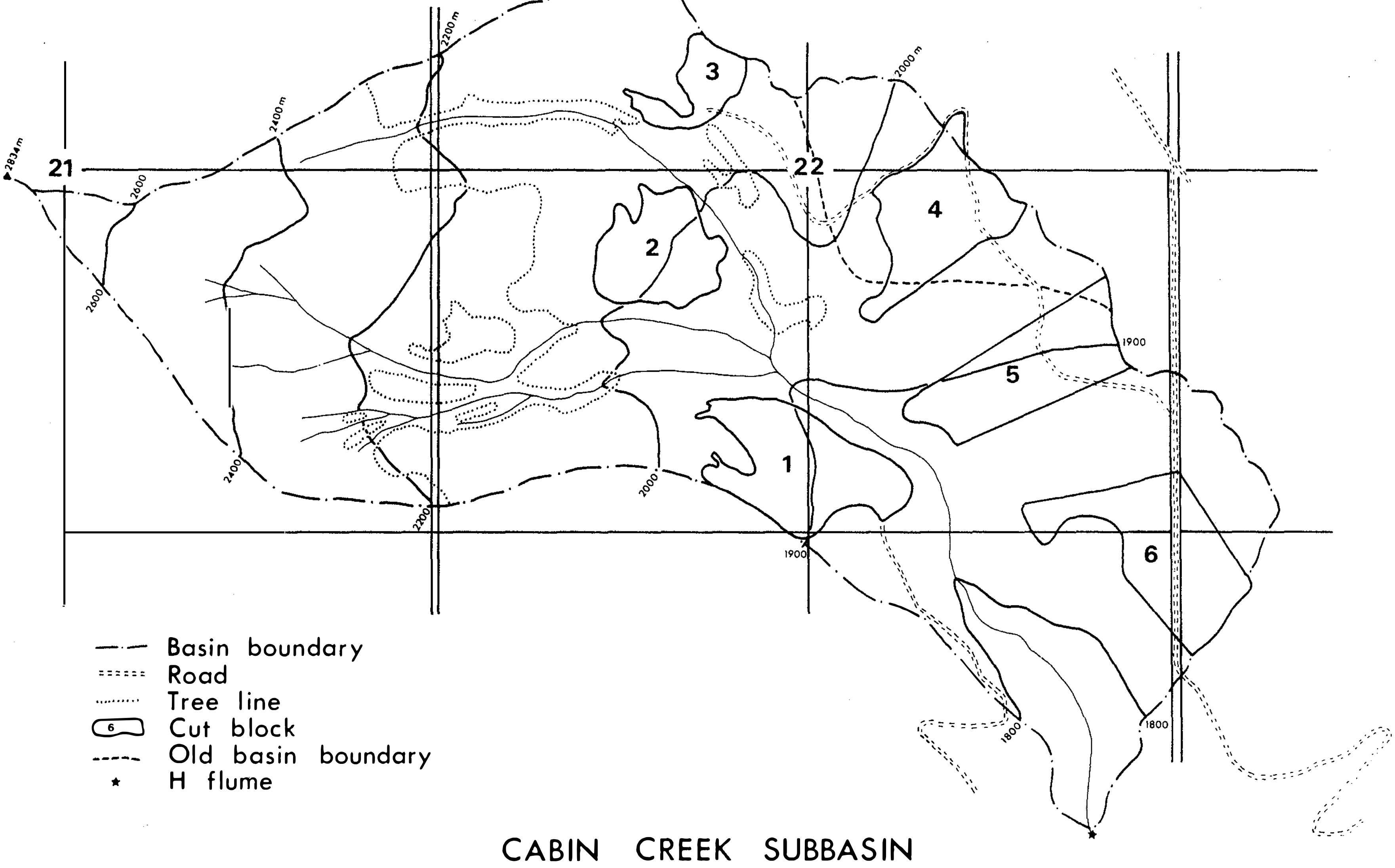

Figure 3. Map of Marmot's Cabin Creek watershed showing contours, roads, and cut blocks.

Table 3. Watersheds in the Spray Lakes area where commercial harvesting operations have taken place. Similar details for Cabin Creek (Marmot) are given for comparison.

Watershed	Total area (ha)	Harvested area (ha)	Elevation range (m)	Year harvested
Tributary 1 of Smuts	680	59	1860-3140	1968 and earlier
Tributary 2 of Smuts	1110	30	1860-3080	1975 and 1976
Ranger	930	66	1890-2990	1974 and earlier
Cabin	236	55	1740-2740	1974

A similar sampling technique was used to estimate the degree of disturbance occurring on commercial logging sites near Spray Lakes, approximately 15 km southwest of Marmot. Composite sediment samplers were also installed on three creeks draining them (Table 3).

Suspended sediment

Suspended sediment sampling was begun in 1969 by the Water Survey of Canada. Initial sampling was done with a depth-integrating USGS DH48A sediment sampler or by grab samples at the H-flume on Cabin Creek and at the Middle Creek weir. One or two samples were normally obtained each day during peak flows and snowmelt runoff, and one or two samples were collected each week during the summer and fall. Stream discharge was calculated for the time of each sediment sample.

In 1971 the Water Survey of Canada installed an automatic sediment sampler at the Cabin Creek flume; however, no comparable installation was made at Middle Creek. The frequency at which this sampler functioned was controlled by stream stage; during high flows samples were obtained every 4 to 6 hours, and once a day during low flows.

In 1975, after logging was completed, the Canadian Forestry Service established a network of eight automatic composite sediment samplers along the main channel of Cabin Creek, with paired samplers located upstream and downstream from each cut block. With these samplers, a small portion of stream water was collected once each hour into a single container. At the end of each week, the container held the combined water from 168 consecutive samples. These samplers were serviced weekly during the summers of 1975, 1976, and 1977 to obtain a 1-week harmonic mean value of sediment concentration. All sediment samples were analyzed by filtration and oven drying.

Results of site disturbance and sediment studies

The road surfaces and rights-of-way remained essentially bare of vegetation for 6 years after construction. A visual survey of the roads each spring and summer after 1971 revealed no major erosion or sediment transport. Detectable erosion was in the form of shallow rills on cut and fill slopes. Roadside ditches were slightly downcut. Sediment was usually stopped by logging debris and natural vegetation. No sediment was observed to reach the stream.

Exposure of mineral soil at access roads, skid trails, or landings was classified as high (20-30% of clear-cut area) on all of the cutover blocks at both Cabin Creek and Spray Lakes (Fig. 4). Shallow erosion rills were observed on these exposed areas, but sediment was usually trapped by vegetation and logging debris within 2-3 m of its point of origin.

No significant changes could be detected in suspended sediment concentrations either after road construction in 1971 or after harvesting in 1974 (Table 4). The peak concentration (239 mg L^{-1}) occurred during road construction.

The sampling of the waters of Cabin Creek upstream and downstream from the cut blocks did not reveal large increases in sediment load. Similarly, suspended sediments were low in the streams at Spray Lakes (Table 5). Suspended sediment concentration remained low throughout the study.

Discussion of sediment and erosion results

These results with respect to suspended sediment concentrations in the streams are somewhat surprising, especially because skidding and road construction in the vicinity of intermittent stream channels was not avoided at either Cabin Creek or Spray Lakes. These intermittent channels would ordinarily be expected to carry some sediment to the stream during the snowmelt period or during rainstorms. The most likely explanation for the low concentrations at both sites is not so much the rigid enforcement of the harvesting guidelines as the natural stability of these particular soils. The soils at both sites are of glacial till origin, are coarse, and contain carbonates that render soil particles resistant to detachment. Under such conditions, only areas that have been bared to mineral soil, are severely compacted, and provide a short, direct drainage path to the stream have any chance of yielding sediment. The low natural level of suspended sediment in Cabin (mean 2-12 mg L^{-1} prior to harvest, Table 4) is a good indicator of the stability and low erodibility of these particular soils.

Table 4. Average annual suspended sediment concentration and yield at the Cabin Creek flume

Year	Sediment concentration (mg L^{-1}) Mean	Sediment concentration (mg L^{-1}) Maximum	Sediment yield (kg ha^{-1})	Annual peak discharge (L s^{-1})
1969	4	49	41	325
1970	12	53	39	322
1971	6	239	37	577
1972	3	24	36	289
1973	2	47	16	170
1974	5	85	34	458
1975	2	24	6	144

The findings with respect to erosion and sediment movement on the cut blocks are not surprising when examined in the light of accepted forest hydrology principles. Most streamflow from forested lands originates as subsurface flow (Anderson et al. 1976). If the soils are not severely compacted during the logging operation, then one should expect little or no increase in overland flow to occur after harvest. Further, work done by Burns and Hewlett (1983) on erodible clays of the Georgia Piedmont indicates that the probability of soil particles being detached and transported to the channel is dependent on storm intensity, soil erodibility, slope, and position of the patches of bare soil with respect to the channel system. Because of high elevation and cool climate, neither Cabin Creek nor the Spray Lakes area experiences rainstorms of high intensity. Snowmelt, although yielding large amounts of water, occurs at a rate of about 10–15 mm d^{-1} and provides neither the kinetic energy necessary for particle detachment nor the intensity required to supply water at a rate greater than the normally high infiltration capacities of forest soils.

Table 5. Mean suspended sediment concentrations at Cabin Creek and in three small creeks draining logged watersheds in the Spray Lakes area, 1977

Creek	Sediment concentration (mg L^{-1})
Cabin	2.0
Tributary 1 of Smuts	4.2
Tributary 2 of Smuts	3.8
Ranger	3.2

Evaluation of streamflow change

Regression equations relating the streamflow on Cabin Creek to that of Middle Creek were established for the before- and after-treatment periods (Tables 6 and 7). The treatment effect was obtained by subtracting the predicted flow on Cabin (obtained using the appropriate time period's pretreatment regression equation) from that which actually occurred. The statistical significance was determined by covariance analysis of the pretreatment and posttreatment regression equation coefficients. A change in flow was considered significant if either the slope or intercept coefficient was different at a probability of 80% ($P < 0.2$). The monthly flow data for most years from 1964 to 1984 are given in Table 6. Data for 1969 were not included in the pretreatment regression derivation because the Middle Creek weir was overtopped for a portion of the spring runoff season. Also, those posttreatment years (1979 and 1982) when the flow data for May or June are partial or missing on either Middle or Cabin creeks have been omitted from the statistical analyses. These data were not estimated because the May-June period is when any expected flow change would be the greatest, and there are no independent measurements from which to make such estimates. Estimates were made for other time periods prior to 1980; these are indicated with the letter "a" in the tables and are based on regression against Twin Creek until 1980, when it too received a harvest treatment and could no longer be used as an undisturbed control.

Results of clear-cutting on water yield

A comparison of the predicted versus actual annual flows for the posttreatment period, 1975–83, indicates a

Table 6. Streamflow data (dam^3) for Marmot Creek watershed's Middle and Cabin creeks, 1964-83 (Water Survey of Canada 1983, 1984)

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Middle Creek (control)													
1964	11.3	8.5	6.8	11.7	147.7	899.4	343.8	62.0	92.2	105.4	39.7	22.5	1751.0
1965	14.8	10.6	9.9	26.9	130.3	682.3	468.4	181.5	145.3	202.2	63.5	30.0	1965.7
1966	19.6	13.5	14.8	22.4	301.6	495.2	280.6	96.5	49.4	40.2	25.7	17.8	1377.3
1967	12.2	8.4	8.1	7.9	172.5	747.7	314.3	85.0	33.0	24.3	17.8	11.6	1442.8
1968	10.7	7.5	8.0	10.4	174.0	505.4	283.9	142.0	105.9	92.3	34.0	23.3	1397.5
1970	9.3	5.9	5.4	6.6	159.2	585.8	181.6	50.1	31.9	29.5	19.1	12.1	1096.5
1971	7.1	4.9	7.9	14.5	282.4	701.7	222.3	67.7	31.9	29.7	20.0	12.4	1402.4
1972	9.3	6.9	6.5	9.4	221.6	763.9	333.2	127.7	68.9	56.6	30.4	18.5	1652.8
1973	13.7	9.6	8.5	11.6	249.7	583.1	245.0	68.4	84.4	40.2	27.5	19.1	1360.7
Treatment of Cabin Creek occurring during 1974; data not used in analyses													
1975	14.3	10.0[a]	8.9[a]	20.6[a]	86.6	452.7	268.9	148.0	75.6	46.9	28.7	19.5	1180.6
1976	15.8	11.2	6.8	21.6	390.3	394.2	281.2	203.3	156.7	69.4	30.4	23.0	1603.8
1977	16.4	10.9	11.0	35.3	200.7	236.7	86.1	156.8	127.6	73.8	35.6	23.3	1014.2
1978	14.3[a]	10.0[a]	8.9	17.5	176.4	618.0	268.9	118.9	86.6	77.1	38.2	24.4	1459.2
1980	8.6	7.5	6.0	51.4	350.1	456.3	116.4	109.4	145.1	100.1	32.2	24.5	1407.5
1981	18.5	11.3	12.3	25.0	395.8	521.5	439.1	173.2	48.9	29.2	19.9	13.3	1708.0
1983	14.1	13.0	10.4	24.8	228.4	356.4	251.6	67.0	39.3	30.5	20.0	17.8	1073.3
1984	9.6	7.5	5.7	15.6	105.0	475.0	176.0	55.7	51.2	75.3	28.3	16.9	1022.2
Avg. 1964-73	12.0	8.4	8.4	13.5	204.3	662.7	297.0	97.9	71.4	68.9	30.9	18.6	1494.1
Avg. 1975-84	14.0	10.2	8.7	26.5	241.7	438.8	236.0	129.0	91.4	62.8	29.2	20.3	1308.6
Cabin Creek (treated)													
1964	10.3	7.5	6.0	11.6	90.3	502.9	123.3	35.0	28.5	23.1	14.0	7.7	860.4
1965	5.2	4.1	4.6	22.1	90.5	316.2	201.3	96.1	69.8	117.9	47.7	25.1	1000.5
1966	17.3	12.3	12.9	15.6	131.6	244.1	111.8	40.3	22.4	22.5	16.7	12.7	660.2
1967	10.2	7.6	8.3	8.6	96.0	385.6	100.9	33.4	18.0	15.7	12.0	9.5	705.8
1968	8.4	6.6	7.0	7.6	72.0	210.2	100.0	50.4	36.7	34.5	22.1	16.2	571.8

Continued on next page

Table 6. continued.

1970	8.5	7.5	8.3	8.6	74.7	241.6	105.2	33.4	19.9	15.6	11.3	9.3	543.9
1971	7.6	6.4	6.1	11.3	151.4	382.2	80.2	30.3	19.9	15.9	11.5	4.3	727.0
1972	5.3	5.7	7.1	8.3	142.2	381.0	133.3	55.7	33.8	28.3	16.1	12.5	829.1
1973	12.1	8.8	9.1	10.3	125.7	293.9	109.6	40.2	31.9	24.6	18.2	14.0	698.1
Treatment occurring during 1974, data not used in analyses													
1975	8.5	5.9	7.7	8.0	72.4	204.8	104.4	63.5	39.8	27.3	18.8	14.3	575.3
1976	11.5	9.0	7.2	18.9	247.4	165.2	82.5	86.3	67.5	44.5	23.7	16.0	779.9
1977	12.3	9.3	8.5	22.7	93.1	79.8	42.1	50.3	51.9	38.7	23.3	16.5	448.5
1978	13.0	8.6	8.9	16.5	139.4	282.5	97.8	47.7	33.9	29.5	18.6	13.3	709.8
1980[b]	8.0	7.5	8.0	45.4	184.1	278.4	67.3	45.6	52.4	52.9	30.2	19.9	799.7
1981	14.8	11.8	10.5	24.5	262.5	338.3	191.2	116.8	41.5	25.8	16.0	12.1	1065.8
1983	9.9	6.9	8.0	15.4	108.6	126.4	123.9	49.8	29.1	20.1	16.6	8.8	523.6
1984	9.4	7.5	8.0	16.0	82.2	155.0	62.0	33.1	26.2	27.8	15.6	10.3	453.2
Avg. 1964-73	9.4	7.4	7.7	11.5	108.3	328.6	118.4	46.1	31.2	33.1	18.8	12.4	733.0
Avg. 1975-84	10.9	8.3	8.4	20.9	148.7	203.8	96.4	61.7	42.8	33.3	20.3	13.9	669.5

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[a] Estimated data.

[b] 1979 and 1982 streamflow data on Cabin missing prior to June; entire year omitted from analyses.

Table 7. Regression equations, covariance analysis statistics, and the predicted flow (dam^3) on Cabin Creek if the treatment had not occurred[a]

Statistic	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Slope	0.694	0.474	0.543	0.649	0.404	0.680	0.360	0.423	0.372	0.517	0.730	0.792	0.535
Intercept	1.1	3.4	3.1	2.8	25.7	−121.9	11.6	4.7	4.7	−2.5	−3.7	−2.4	−66.3
R^2	0.4766	0.2954	0.3720	0.9101	0.7037	0.9363	0.7504	0.8120	0.8336	0.8440	0.8324	0.6599	0.9019
90%[b]	1.5	1.1	1.1	0.8	9.2	13.4	9.8	5.1	3.7	7.3	2.7	2.0	25.7
F slope	0.12	0.26	0.65	0.67	1.21	0.05	0.06	0.02	1.55	0.85	1.32	0.23	2.94
F Intercept	0.03	0.05	0.46	0.13	3.25	0.79	0.01	0.14	2.28	0.35	1.22	0.03	2.66
n (years)[c]	>25	>25	>25	6	12	6	>25	>25	>25	>25	>25	>25	6
Predicted streamflow from Cabin Creek if not treated[d]													
Year													
1975	11.0	8.1	8.0	16.1	60.7	185.8	108.3	67.3	32.8	21.7	17.3	13.1	565.3
1976	12.1	8.7	6.8	16.8	183.4	146.1	112.7	90.7	62.9	33.4	18.5	15.9	791.7
1977	12.5	8.6	9.1	25.7	106.8	39.0	42.6	71.0	52.1	35.7	22.3	16.1	476.3
1978	11.0	8.1	8.0	14.2	97.0	298.2	108.3	55.0	36.9	37.3	24.2	17.0	714.3
1980	7.0	7.0	6.4	36.1	167.1	188.3	53.4	50.9	58.6	49.3	19.8	17.0	686.6
1981	13.9	8.8	9.8	19.0	185.6	232.6	169.5	77.9	22.8	12.6	10.8	8.2	847.4
1983	10.9	9.6	8.8	18.9	118.0	120.4	102.1	33.0	19.3	13.2	10.9	11.7	507.9
1984	8.0	7.0	6.2	12.9	68.1	201.0	74.9	28.2	23.7	36.4	17.0	11.0	480.5
Avg. predicted	10.8	8.2	7.9	20.0	123.3	176.4	96.5	59.3	38.6	29.9	17.6	13.7	633.8
Avg. actual	10.9	8.3	8.4	20.9	148.7	203.8	96.4	61.7	42.8	33.3	20.3	13.9	669.5
Change (%)	+1.1	1.2	+6.2	+4.9	+20.6	+15.5	−0.1	+4.0	+10.8	+11.3	+15.6	+1.3	+5.6

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[a] F values for tests at $P < 0.2$, slopes $F_{2,14} = 1.80$, intercepts $F_{1,15} = 1.79$ (Freese 1967).

[b] Confidence interval about predicted streamflow value at mean in cubic decametres.

[c] n = Estimated number of years of posttreatment streamflow data (based on pretreatment streamflow data) in order to achieve statistical significance with a 10% increase in annual yield at $P < 0.1$ (Kovner and Evans 1954).

[d] All values for a given year have been predicted using the comparable period's regression equation (above) and Middle Creek streamflow data from Table 6. The average predicted flow given in any column is the average of the individual predictions from the same column.

Table 8. Comparative results from studies in Cabin Creek and three other Rocky Mountain catchments where water from snowmelt dominates the hydrograph

Watershed	Area (ha)	Annual precipitation (mm)	Annual flow (mm)	Area cut (%)	Increase in yield	
					Total (mm)	On clear-cut (mm)
Cabin Creek, Alberta	212	840	310	21	17	79
Wagon Wheel Gap, Colorado[a]	81	536	157	100	25	25
Fool Creek, Colorado[b]	289	762	283	40	74	185
Hinton, Alberta[c]	1497	513	147	50	42	84

[a] Source: Bates and Henry 1928.

[b] Source: Troendle and Leaf 1981.

[c] Source: Swanson and Hillman 1977.

water yield increase of 35.7 dam^3 (17 mm), or 6% greater than if left uncut (statistically significant at $P < 0.2$) (Fig. 5, Table 7). Covariance analysis of each month's pretreatment and posttreatment regression equations indicates that the yield increase is statistically significant ($P < 0.2$) for May and September, although the actual flow is greater than predicted for all months except July. What is not clear at this writing is whether Marmot's status as an experimental basin will be continued long enough to achieve statistically significant results at any higher probability.[1] Table 7 contains estimates of time needed to reach statistical significance ($P < 0.1$) with a predicted flow increase of 10%. The annual increase is approaching significance at $P < 0.1$, and if the increase remains at its current level, it should be significant with 4-5 additional years of data.

Discussion of water yield change

The increased flow realized on Cabin Creek is reasonably high when considered in relation to the amount of area that was actually clear-cut. The 35.7-dam^3 increase over the entire catchment applied over the clear-cut area of 44.9 ha is 79 mm. This is not greatly different from the 84 mm experienced at Hinton, Alberta, but only one-third that of the 185 mm experienced at Fool Creek, Colorado (Table 8). It is considerably more than the 25 mm (Table 8) obtained after complete clear-cutting at Wagon Wheel Gap, also in Colorado.

According to Hoover and Leaf (1967) and Leaf (1975), the extraordinarily high water yield increase at Fool Creek occurs because the small clear-cuts with maximum dimensions of 1-6 tree heights provide traps for snow blown from the surrounding trees. Further, once deposited the snow in these small clear-cuts is sheltered from pickup and transport by wind. Golding (1981) found 33 mm more snow water equivalent in the Cabin Creek clear-cuts that average 15 tree heights across (Table 2), which represents an increase in snow of 21% over the adjacent uncut areas. Golding and Swanson (1978), however, found that clearings 2-5 tree heights in width accumulated 35-45% more snow than uncut areas. Troendle (1982) indicated that 5 tree heights across appears to be an approximately optimum dimension for maximum snow accumulation and redistribution effects in the Colorado subalpine forest. The position of the increase on Cabin Creek between that of Wagon Wheel Gap, with dimensions of approximately 45 tree heights, and Fool Creek indicates that the current commercial clear-cut blocks in Alberta are too large to influence snow redistribution and retention and to augment streamflow above that obtained through reduction in transpiration of the trees removed.

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[1] The Marmot experimental watershed has been chosen as the site of the 1988 Winter Olympic Games. The ski runs for the games themselves do not jeopardize the experiment; however, development of recreational skiing after the games has been planned in the area. Marmot's status as an experimental basin is guaranteed only until October 1986.

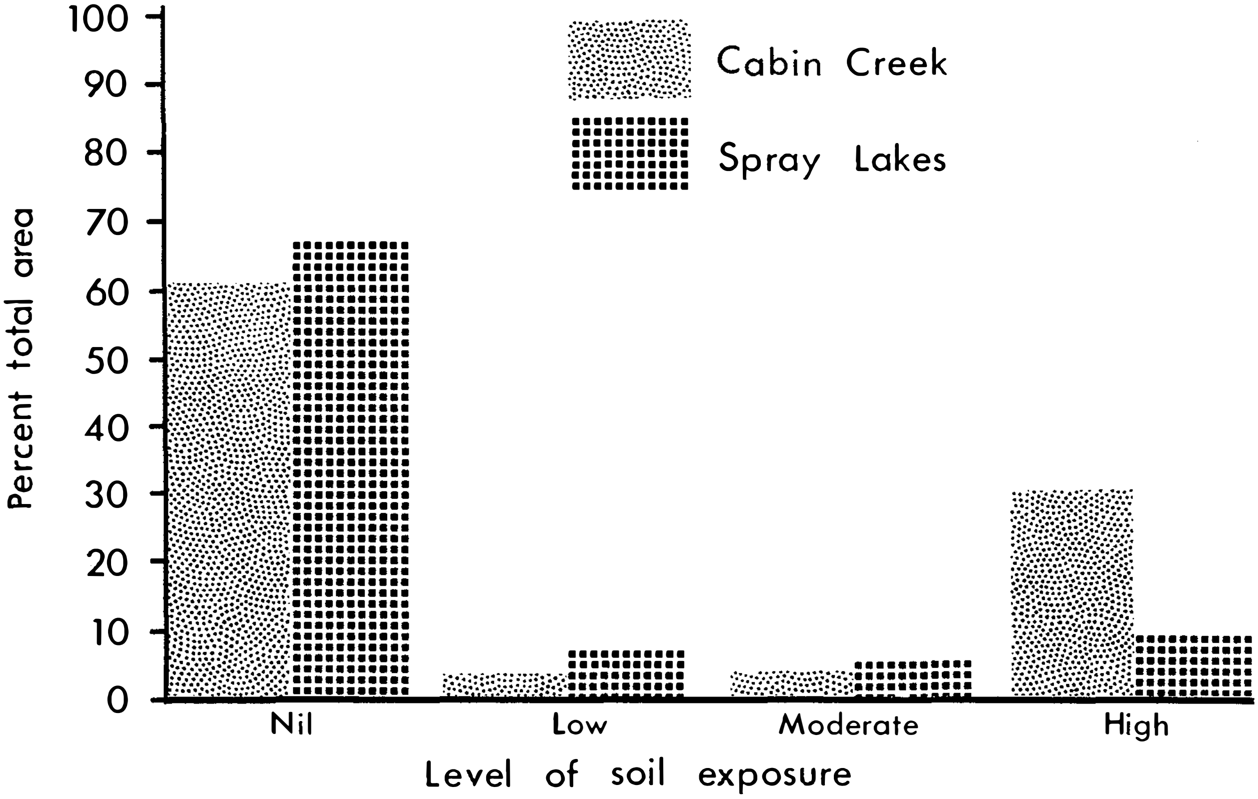

Figure 4. Soil exposure as a percentage of the area of any cut block at Cabin Creek and Spray Lakes.

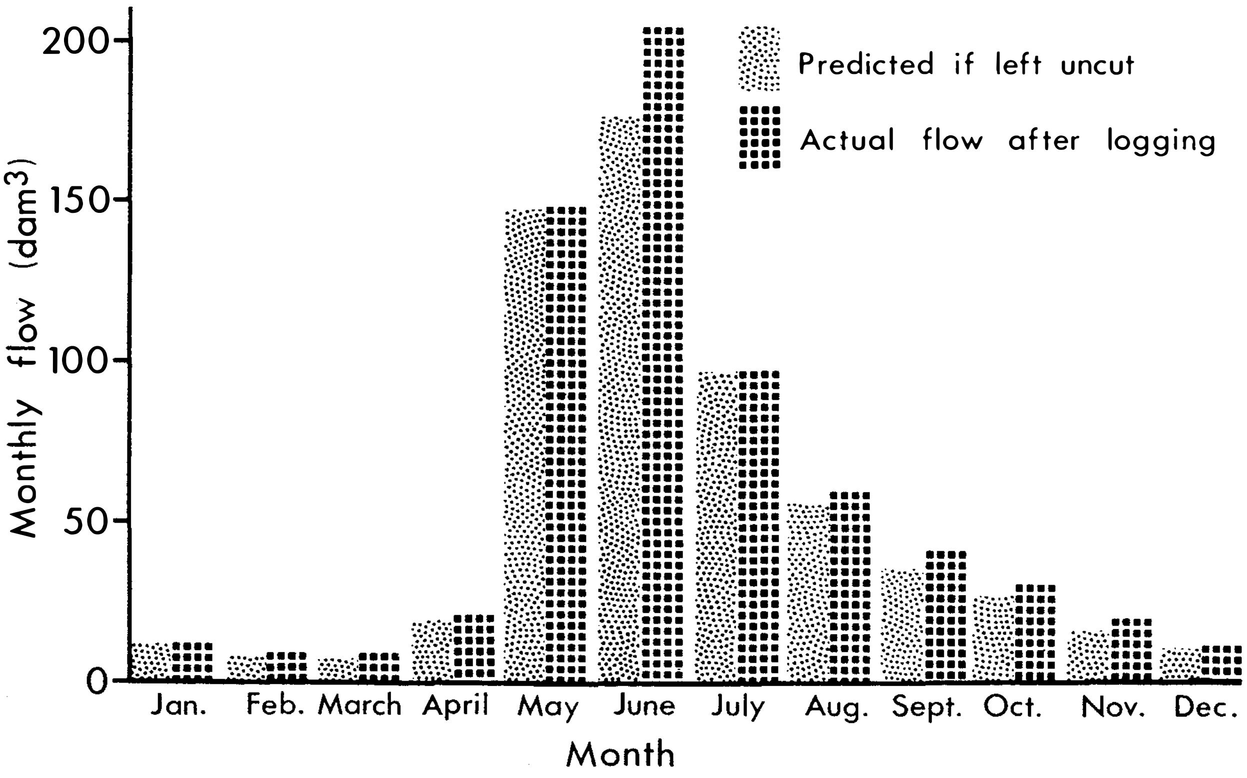

Figure 5. Time distribution of streamflow increases on Marmot-Cabin Creek.

THE STREETER BASIN GRASSLAND EXPERIMENT

Aspen grasslands are important to the ranching economy of the foothills of southern Alberta. These grasslands also occupy a significant portion of the Saskatchewan River headwaters. The woody vegetation (primarily *Populus* and *Salix* spp.) of the southern Alberta foothills has been periodically removed to allow greater grass production and more grazing capacity. According to Jeffrey (1964), the existing range areas were fully stocked at the then-present (livestock) management intensities. These clearing activities were thought to have a potentially serious impact on water yield, regime, and quality. Streeter Basin is the gauged watershed established for study of the montane aspen forests and associated grasslands of the southern foothills. It is located in the Porcupine Hills of southwest Alberta (Fig. 1) and was expected to provide guidelines to prevent hydrologic deterioration of watersheds undergoing cover change as a result of management for increased forage production. The shrubs and trees on the drier eastern portions of the southern mountains and foothills were being removed in 1965 to supply more grazing capacity (Jeffrey 1965). Because of economic pressures it is likely that this practice will continue.

Investigations of snow accumulation indicated that the most serious water supply problem associated with tree clearing might be the drying up of local springs that are formed by the surface contact of water-bearing strata. The recharge areas for these springs are often small portions of the ridge and slope positions above a defined stream channel. Time-sequence aerial and ground photographs taken during the winter revealed that, of the snow that initially accumulated on any portion of the basin, snow protected by trees or topography from the full force of the chinook winds common to southern Alberta remained in place, while that lying unprotected in large clearings disappeared between snowfall events. Our hypothesis was that after clearing trees from a recharge area, the snow that would normally accumulate and melt there might be directly evaporated or redistributed into topographic depressions such as the stream channel, especially during chinooks. If either evaporation or concentration in the stream channel occurred, meltwater would not be available to infiltrate the highly permeable soil and recharge the local groundwater system of a contact spring. This lack of recharge could result in springs drying up in summer when water for livestock may be in short supply. Thus complete clearing, as opposed to partial clearing to retain some protective canopy, could reduce range quality even though it would result in a larger area of grass.

Table 9. Annual water yield for Streeter (entire) and individual subbasins

Description	Area (km²)	Yield (mm)
West Streeter Creek	1.36	8
Middle Streeter Creek	0.90	54
East Streeter Creek	0.51	227
Streeter Creek Main Stem	5.89	76

The original research plan for Streeter, conceived in 1964, was to consider each of the three separate catchments of the basin as an experimental entity to determine the effect on streamflow of one or more range-clearing practices applied to the east and west subbasins, with the middle one being held as an untreated control (Jeffrey 1964). Preliminary investigations indicated considerable subsurface interchange between topographic entities with highly differing volumes of streamflow occurring from the three subbasins (Table 9). The yield increases about 30-fold from the west to the east subbasin. A hydrogeological cross section prepared from a few bore holes and surficial evidence (Swanson and Stevenson 1971) indicated that at least four local groundwater recharge and discharge systems were present in the basin. The complexity of this groundwater system and the amount of lateral subsurface interchange precluded the use of complete subbasins as either control or treated catchments in any reasonable experimental design.

The impracticality of evaluating the effect of any treatment on the hydrology of an entire subbasin simplified the approach to our research in Streeter basin. Because it was impossible to close quantitatively a water balance on any subbasin, the emphasis was shifted toward determining, at least in a qualitative sense, if a particular management practice would tend to improve or degrade the water regime of one of the many small contact springs that exist on Streeter Basin.

Objectives

The primary objective was to establish the effect of tree clearing above the West Streeter spring upon its water yield and regime. The effect of this clearing on sediment was not evaluated. Suspended sediment loads in the small contact springs evaluated are generally nil, and the existing surface drainage pattern would not have directed any overland flow into the spring gauging structures used in this study.

Description of Streeter Basin

Streeter Basin is in the Porcupine Hills of southwestern Alberta, about 115 km south of Calgary (Fig. 1). It lies in the Montane Forest Region (Rowe 1977) and constitutes a transition zone between the Mixed Prairie and Subalpine Forest regions. Thirty-seven percent of the basin's vegetation is herbaceous (including grasses), 11.7% is shrubs, 6.1% is open poplar forest, and 41.2% is dense poplar forest. The total area is 6 km^2, and there are three subbasins (West, 1.36 km^2; Middle 0.90 km^2; and East 0.51 km^2), and a confluence (3.23 km^2) (Fig. 6). The aspect is northerly, with elevation ranging from 1325 to 1660 m above mean sea level. The area is underlain by sandstone with a shallow covering of silty to sandy till (Jeffrey 1965). The basin is characterized by the dominance of black and dark gray chernozemic soils with regosols, eutric brunisols, and gray luvisols occupying lesser areas (Beke 1969). Saturated infiltration capacities range from a low of 14 mm h^{-1} to greater than 300 mm h^{-1} (Singh 1970).

Climate

Streeter's climate is best described as variable. Continental and Pacific air masses dominate the overall climate with frequent short fluctuations in temperature that are often accompanied by high westerly or southwesterly winds. Mean monthly air temperatures range from a low of −21.5° C in January to a high of 21.5°C in August; however, it is not unusual to experience above-freezing temperatures in any winter month. For example, on January 5, 1966, the average temperature was −30.8°C. The next day the temperature rose to 1.1°C, fluctuated near the freezing mark for 12 days, and reached a maximum of 8.9°C on January 17. Similar examples could be cited for the winter months of most years.

Mean annual precipitation is 560 mm, two-thirds of which occurs as rain. Convective storms are common during the summer months. In 1967 rainfall intensities during seven summer storms varied from 3 to 88 mm h^{-1}. Some snowmelt occurs during most winters, so that snow course data reliably portray only the current status at any given location.

Wind is a dominant feature of Streeter Basin's climate. Hourly wind run and direction were recorded at site 4 (Fig. 6) on the central ridge using a Meteorological Service of Canada Type 45B anemometer mounted at the top of a 10-m mast. Southwestern and western winds dominate during all months of the year. The average wind speed during 1967 was 5.0 m s^{-1}, with a peak 1-hour value of 26.8 m s^{-1} and a peak 1-day value of 15.3 m s^{-1}. Daily averages are highly variable, and days when the wind could be considered calm (perhaps a daily average less than 0.5 m s^{-1}) are few. The average winter wind speed was 5.8 m s^{-1}, with summer winds somewhat calmer at 4.0 m s^{-1}.

Hydrology

The average annual water yield from 1964 through 1968 was 76 mm, as measured at the main stream gauge (location shown on Fig. 6); however, this is probably not a good indicator of true water yield for this vegetation type. Channelized streamflow in Streeter Basin is intermittent and highly variable from year to year. Most of the water visible in stream channels arises from numerous contact springs. Between the points of influx from the springs, the reaches are often dry because of efflux to the local groundwater system. Four subsurface flow systems operate interdependently within Streeter Basin, with three discharging some of their water within the basin and the fourth likely discharging outside into Willow Creek, the topographic low in the vicinity (Swanson and Stevenson 1971).

Overland flow in Streeter Basin is rare. It has been observed only on undisturbed land during snowmelt, and that only in the vicinity of the stream channels at times when the soils there were saturated or frozen.

Treatment—West Streeter subbasin

The principal hydrologic goal was to maintain the least amount of vegetation necessary on the upslope recharge areas above contact springs and stream channels so that any snow that fell there would accumulate and be retained in place for subsequent melt and infiltration to the local groundwater system. All of the west subbasin was treated; however, our evaluation of the snow retention capability of this treatment is based on analysis of the flow data from the west spring, which drains only a tiny fraction of the area of the west subbasin.

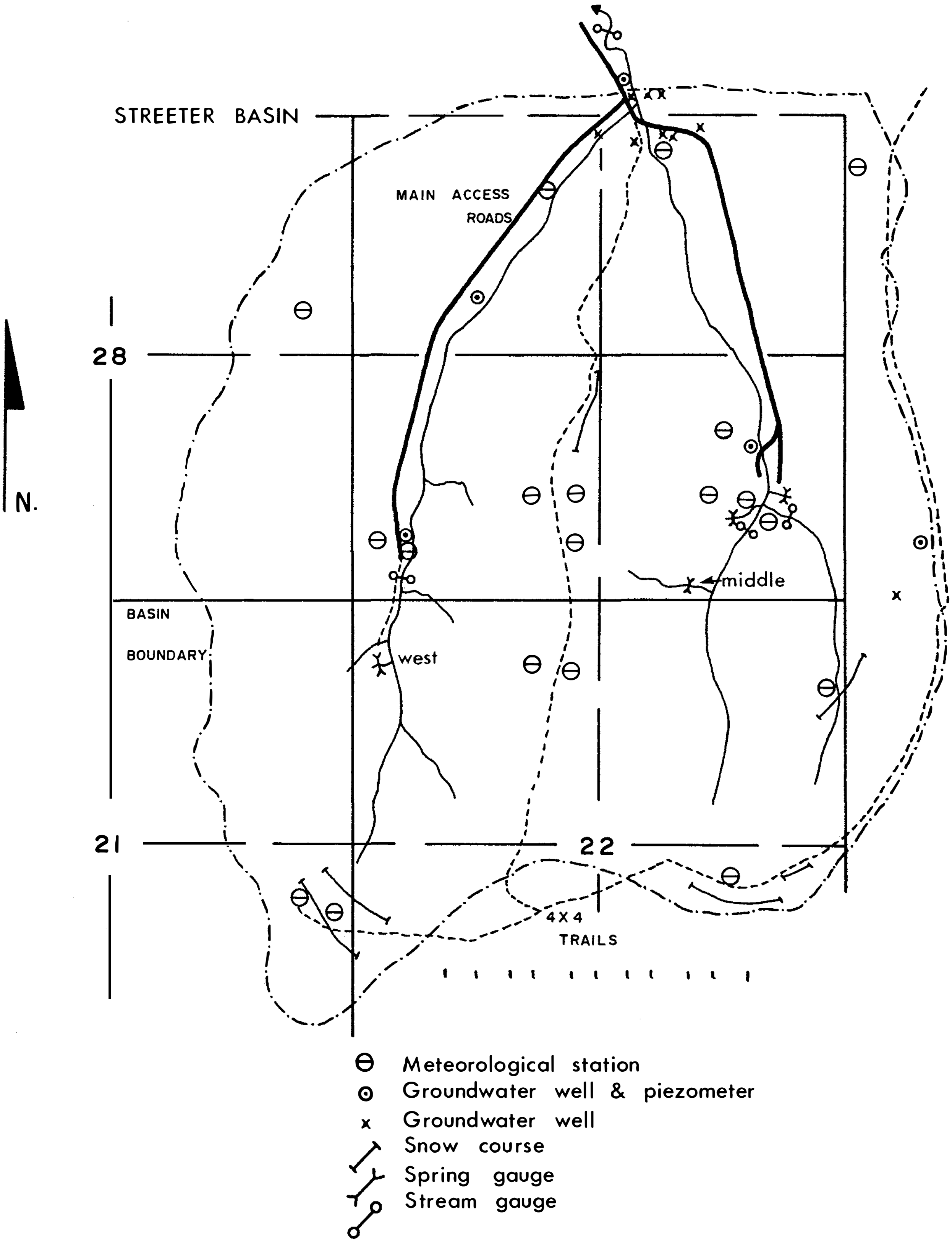

Figure 6. Location of meteorological and hydrometric stations on Streeter Basin.

The dimensions of the clear-cut patches were based on earlier findings with respect to snow accumulation and ablation in these poplar stands (Swanson and Stevenson 1971) and on results obtained in dense conifer forest (Golding and Swanson 1978). These studies indicated that clearings 1-2 tree heights (5-10 m) wide by 60-180 m long, with the long axis oriented perpendicular to the prevailing winter wind direction, would enhance snow accumulation and retention.

Areas of the indicated size and orientation were clear-cut on West Streeter subbasin (Fig. 7). Strips of trees of approximately equal width were left uncut between clearings, and trails were cut between openings to facilitate movement by cattle and big game. Strips 3-5 m wide were created in shrub stands. The total area cleared within each vegetation type is given in Table 10. All stems were sheared off at ground level. Slash was piled and burned in the patch cuts but left on the ground in the strips. All clearing was done during July and August 1976, and burning, if done, occurred during October to December of the same year.

Table 10. Area of vegetation types clear-cut on West Streeter subbasin in the Streeter experimental watershed

Vegetation type	Total area (ha)	Area clear-cut (ha)
Dense poplar forest	81.8	25.8
Open poplar forest	15.2	0.6
Shrubland	6.1	2.8
Herbs and grasses	38.5	1.4

Evaluation of snow accumulation

Snow courses were established in the cut and uncut patches on the treated subbasin and through treed and natural openings on the control (Middle Streeter) subbasin. Both snow courses were on an easterly aspect and at similar slopes and elevation (1400-1475 m). Measurement points were located at 20-m intervals by pacing along ribbon-marked lines; 20 measurement points were in the uncut and 17 in the cut patches of the treatment. Of these points, 13 were in the treed area and 32 in a natural opening 60 × 200 m on the control subbasin.

The snow courses were sampled on two occasions to ascertain that the treatment was having the desired effect.

Table 11. Results of snow surveys on the treated West Streeter subbasin and control Middle Streeter subbasin

Location	Number of samples[a]	Snow water equivalent (mm)
March 3,1977		
West subbasin		
Cut patches	17	58
Treed area	20	43
Middle subbasin		
Natural opening	32	20
Treed area	13	38
January 25,1978		
West subbasin		
Cut patches	15	69
Treed area	22	43
Middle subbasin		
Natural opening	18	45
Treed area	22	52

[a] The number of samples in each type differs between the two sample dates because a number of the samples were in neither treed nor open areas. The data from these samples have not been included in this table.

The results for both snow surveys were similar (Table 11). The small patch clearings of the treated subbasin always retained more snow than that in the large control opening. On both measurement dates, the treed areas on both the treated and control subbasins contained more snow than the large open (control) area.

Evaluation of water yield from cleared area

The water flow from Middle and West Streeter springs has been monitored since 1968 (Table 12) (Water Survey of Canada 1983). These springs are considered to be hydrogeologically independent of each other by virtue of their topographic locations. The gauging structures are 90° V-notch weirs with a capacity of 15-cm (head) tied into the rock outcrop that forces groundwater to the surface and causes the spring. The surface recharge areas for the perched water tables that discharge at each spring were considered to lie topographically directly above the point of contact of the

Table 12. Streamflow data[a] (dam^3) for Streeter basin's Middle and West springs, 1969-83

Year	Apr.	May	June	July	Aug.	Sept.	Oct.	Season
Middle Streeter Spring 2 (control)								
1969	10.73	11.96	10.36	13.94	5.06	3.21	2.34	57.60
1970	1.60	9.37	11.84	7.15	3.45	1.97	1.48	36.88
1971	1.85	3.82	8.51	4.32	2.34	1.48	1.36	23.68
1972	3.70	12.83	10.36	4.32	2.96	2.84	2.22	39.23
1973	2.71	11.10	8.51	4.32	2.10	1.48	1.48	31.70
1974	1.60	12.95	10.73	4.81	3.08	2.34	1.48	37.01
1975	0.74	12.09	14.06	8.39	3.70	2.47	1.97	43.42
1976	3.08	7.28	5.06	3.82	7.28	4.19	2.47	33.18
1977	1.15	1.97	2.34	1.60	1.12	0.62	0.69	9.50
1978	1.48	12.83	11.10	4.93	3.95	2.34	1.60	38.24
1979	1.36	11.10	6.29	3.21	2.22	1.02	0.75	25.95
1980	1.85	1.97	4.32	2.71	1.48	1.36	0.75	14.44
1981	0.59	8.51	10.73	7.52	5.43	2.71	0.95	36.45
1982	0.80	1.36	4.81	5.80	2.34	1.48	1.60	18.19
1983	1.02	4.44	5.92	3.33	1.85	1.15	0.75	18.47
Avg. 1969-76	3.25	10.18	9.93	6.38	3.75	2.50	1.85	37.84
Avg. 1977-83	1.18	6.03	6.50	4.16	2.63	1.53	1.01	23.03
West Streeter Spring (treated 1976)								
1969	10.36	8.51	6.66	13.82	1.85	0.74	0.75	42.69
1970	0.35	4.07	5.30	2.96	1.15	0.74	0.75	15.32
1971	0.85	1.85	3.45	1.48	0.59	0.00	0.42	8.65
1972	1.85	12.21	6.91	1.73	0.88	0.74	0.75	25.06
1973	1.60	8.26	5.18	1.73	0.75	0.74	0.69	18.96
1974	0.78	10.73	7.03	1.97	0.75	0.74	0.75	22.76
1975	0.12	12.21	11.22	5.06	1.60	0.80	0.75	31.77
1976	2.59	4.07	1.85	1.05	2.34	1.85	0.97	14.73
1977	0.67	0.75	0.74	0.75	0.25	0.00	0.02	3.18
1978	1.36	13.94	13.08	2.34	1.20	0.74	0.75	33.40
1979	1.17	11.72	3.82	1.23	0.75	0.59	0.00	19.29
1980	0.74	1.36	1.36	0.75	0.07	0.00	0.00	4.28
1981	0.17	8.76	9.25	3.95	1.85	0.90	0.75	25.63
1982	0.44	0.67	1.73	4.19	1.48	0.74	0.75	10.00
1983	0.57	1.60	2.10	1.23	0.75	0.07	0.07	6.40
Avg. 1969-76	2.31	7.74	5.95	3.72	1.24	0.79	0.73	22.49
Avg. 1977-83	0.73	5.54	4.58	2.07	0.91	0.44	0.34	14.60

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[a] The streamflow data in this table have been computed from records in ft.^{3} s^{-1} furnished by the Calgary office of the Water Survey of Canada. The published data are in m^3 s^{-1}, with the smallest unit being 0.001 (Water Survey of Canada 1983, 1984). Virtually all of the flow data for these springs are shown as zero in the metric data compilations.

underlying strata with the surface, but this was not verified experimentally. Thus, the exact portion of the surface area receiving precipitation for recharge of either the control or treated spring is unknown.

The effect of patch cutting on water yield was determined by using a pretreatment relationship between the flow of Middle and West Streeter springs to predict the flow of the west spring after treatment for comparison with what actually occurred. A regression equation was developed for each month's flow (April through October) based on data from 1968 to 1976 (Table 13).

The flow from the spring during April through October for 1977 through 1983 is almost double (1.75) that predicted if not treated (Fig. 8, Table 13). There has been a significant increase ($P < 0.05$) during most months. The 7-year average April-to-October water yield from the west spring was 14.6 dam^3, compared with the 8.33 dam^3 predicted. During 1977, a year with the second-lowest streamflow on record in southern Alberta (Water Survey of Canada 1983), the predicted flow for the west spring was nil from May through July, while the actual flow was 0.74 dam^3, and it continued throughout the summer at about 0.3 L s^{-1}.

Discussion of treatment effects on snow accumulation and water yield

The flow increase appears to be remarkably high in light of the small amount of treed area that was located upslope from the spring. The most important result from this study, however, is not so much the magnitude of the flow increase but the maintenance of snow cover on the recharge area and the continuance of flow during a very dry year. Both the snow course data and the water yield results demonstrate the effect that protection from wind can achieve. The creation of clearings that are sufficiently small to reduce wind speed at their surfaces below that required to relocate the snow (estimated by Tabler and Schmidt (1973) at about 6-7 m s^{-1} at 10 m above the surface) is probably the most important consideration if watershed management is to have a positive effect on streamflow from chinook-prone areas. Other studies (e.g., Swanson 1980) have shown that wind speed is reduced by a factor of at least 10 at the surface of

Table 13. Regression equations, covariance analysis statistics, and the predicted flow (dam^3) from West Streeter Spring if the treatment had not occurred[a]

Statistic	Apr.	May	June	July	Aug.	Sept.	Oct.	Season
Slope	1.05	1.14	0.94	1.21	0.35	0.45	0.23	1.04
Intercept	−1.10	−3.81	−3.43	−3.98	−0.08	−0.33	0.31	−17.00
R^2	0.9818	0.8311	0.8107	0.9549	0.8947	0.6719	0.4581	0.9139
F Intercept	6.0	10.1	8.3	1.7	0.2	0.1	0.0	14.4
F slope	0.8	0.1	2.4	8.0	0.0	0.1	6.2	0.0
Predicted flow, West Streeter Spring[b]								
1977	0.10	0.00	0.00	0.00	0.32	0.00	0.47	0.00
1978	0.45	10.75	7.06	1.97	1.31	0.72	0.67	22.91
1979	0.32	8.79	2.52	0.00	0.70	0.13	0.48	10.09
1980	0.84	0.00	0.65	0.00	0.44	0.28	0.48	0.00
1981	0.00	5.85	6.71	5.10	1.83	0.89	0.53	21.04
1982	0.00	0.00	1.12	3.02	0.75	0.34	0.67	1.99
1983	0.00	1.23	2.17	0.04	0.57	0.19	0.48	2.27
Avg. predicted	0.25	3.80	2.89	1.45	0.85	0.36	0.54	8.33
Avg. actual	0.73	5.54	4.58	2.07	0.91	0.44	0.34	14.60
Change (%)	+298	146	+158	+143	+107	+119	−62	+175

[a] F values for tests at $P < 0.05$, slopes $F_{1,10} = 4.96$, intercepts $F_{1,11} = 4.84$ (Freese 1967).

[b] All values have been predicted (constrained to ≥ 0) using the comparable period's regression equation (above) and Middle Streeter Spring flow data from Table 12. The average predicted flow is the average of these individual predictions from the same column.

Figure 7. View of West Streeter subbasin in February 1977, the first winter after treatment. This photo illustrates the loss of snow from the large, exposed clearings, which the small patch clear-cuts were designed to correct. The black object in many of the patch cuts is the residue from clearing that was piled but not fully burned.

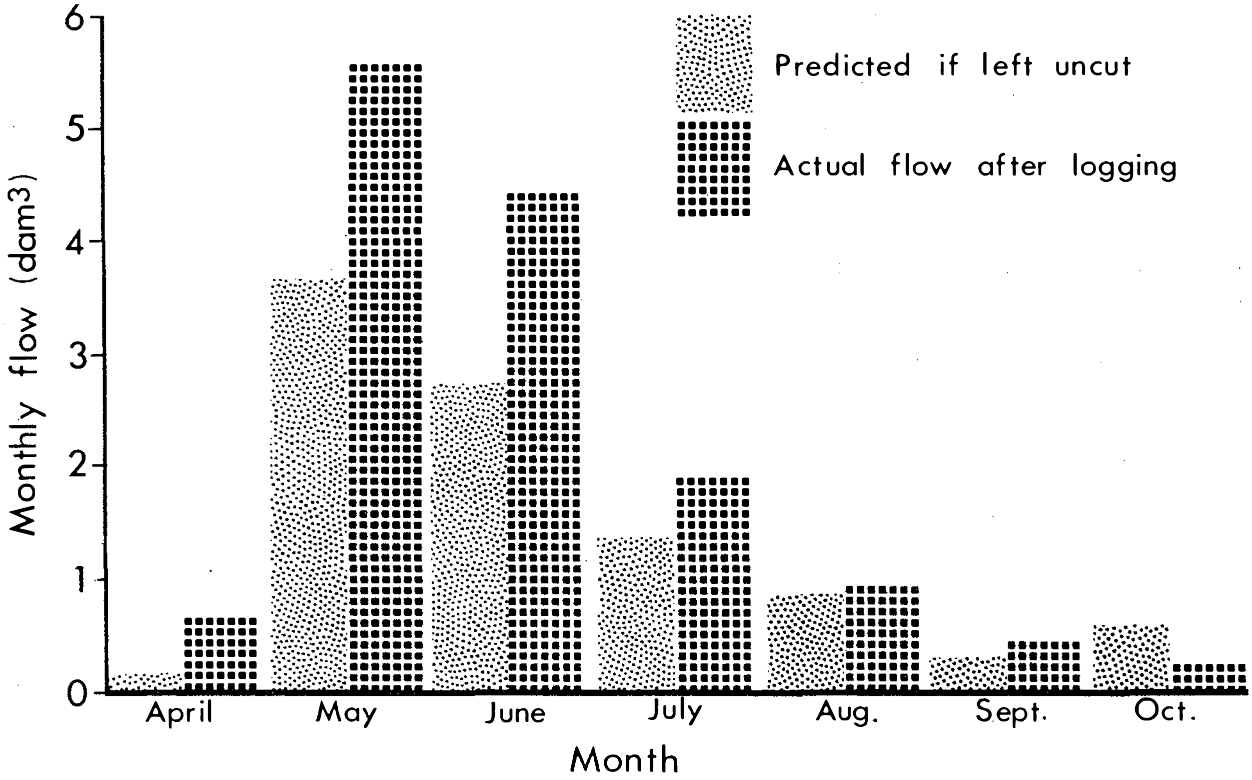

Figure 8. Monthly water yield from West Streeter spring. Actual is that which was measured; predicted is that which would have been expected in the absence of the treatment.

clearings smaller than 6 tree heights across, but hardly reduced at all at the surface of clearings 20 tree heights across. Between these extremes lies a critically sized clearing that should not be exceeded if the beneficial effects of snow accumulation and retention are to be realized when clear-cutting occurs in chinook-prone areas.

MANAGEMENT IMPLICATIONS

It is apparently possible to harvest timber from the subalpine portions of the Saskatchewan River headwaters watershed with little or no change in the normally low (generally less than 100 mg L^{-1}) suspended sediment loads. Further, such logging activity does not appear to have any significant impact on surface erosion. In this study's results, the low erosion and sediment loads are due primarily to stable soils. We know that these findings do not apply throughout the entire headwaters, as normal sediment loads in streams draining the lower elevation foothills catchments are generally greater than 100 mg L^{-1} (Rothwell 1983).

The results from Marmot-Cabin and Streeter, when coupled with those from a previous study at Hinton, Alberta (Swanson and Hillman 1977), and those from studies in similar timber-climatic types in the United States (Bates and Henry 1928; Leaf 1975; Troendle and Leaf 1981; Troendle 1982) are substantial evidence that it is technically feasible to use timber harvest to increase water yield from Alberta's east slopes watershed of the Saskatchewan River.

Our results from the Streeter experiment indicate that clear-cut patches 4–6 tree heights across would accomplish this in foothills poplar forests, whether or not these areas are subject to the drying influence of chinook winds. According to Troendle (1983), the recommended clearing size for optimum snow accumulation and redistribution effects in subalpine forests is one with dimensions between 3 and 8 tree heights maximum. Previous results of studies in the lodgepole pine forests of Alberta's foothills indicate that a clearing 2–3 tree heights across would accumulate the most snow (Golding and Swanson 1978). We consider that 5 tree heights would be a reasonable compromise between the extremes of 2 and 8, and therefore the size of clear-cut recommended to affect water yield increase in the Alberta subalpine and foothills forests (where the trees are approximately 20 m tall) is 1 ha, less than one-tenth the current commercial size.

We realize that land managers in the eastern slopes watershed must consider uses other than water production when making decisions. It is more expensive to harvest timber from the smaller clear-cuts that our results indicate to be most effective in enhancing water yield than from those currently used. An economical means to harvest timber in order to maintain a supply of logs for the wood products sector of the economy continues to be important in Alberta. It is likely that recreational use and the maintenance of wildlife habitat within the eastern slopes watershed will also assume increasing importance in the future. Many areas of the watershed that could have been managed for water yield improvement have already been harvested in the less-efficient (for water yield increase) larger clear-cuts, and a new stand of merchantable trees will not be available for 100 years or more. Other areas are being set aside for uses not compatible with any type of timber harvesting. Even though water yield improvement is technically feasible, because of these constraints the manageable area of the eastern slopes watershed is shrinking and the implementation of forest-cutting practices designed specifically to increase water yield, which was part of the Eastern Rockies Forest Conservation Board's mandate, may never occur.

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The Alberta Watershed Research Program is carried out in an informal cooperative way by federal and provincial departments concerned with water or watersheds. It consists of a Steering Committee, with membership restricted to department or service level directors, and a Research Coordinating Committee with membership open to anyone interested in participating in watershed research. The member agencies directly funded the clearing of West Streeter Basin.

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APPENDIX A

THE LOCATION OF THE PHREATIC DIVIDE ON THE NORTHEAST SHOULDER OF CABIN SUBBASIN

Marmot Creek basin occupies an area generally well defined by tall mountains and sharp ridges. On its northeast boundary, however, within the Cabin subbasin, the well-defined ridge coming down from Mount Colembola broadens into a wide, rounded shoulder where the true basin boundary is less evident. The initial survey of basin boundaries was performed by Alberta Water Resources. Later, the section of the boundary running on the northeast shoulder was resurveyed and was moved a few hundred metres to the north of the original boundary. The new boundary was thereafter used in the description of the basin. Figure A shows the location of both the old basin boundary, as originally mapped by Alberta Water Resources, and of the currently used boundary.

In the fall of 1984, Alberta Environment offered its services free of charge for the sinking of piezometers on Marmot Creek Basin. In an attempt to locate the northeast boundary of the Cabin subbasin, 11 wells were installed along two transects roughly perpendicular to the currently used boundary. Location of the wells was determined mainly by access to the site, because the fire-truck size drilling rig needed cleared and solid ground for access and operation. The two transects are shown in Figure A. Only one of these, the E to I transect, is actually located in the area where the boundary was moved. The elevation and depth of the wells are shown in Table A. Water levels in each of the wells was monitored almost weekly from October 14, 1984, to September 26, 1985.

Figures B and C show the relative elevation of the water table along each of the transects at various times throughout the year. Field readings show the distance between the top of the well and the water table. The relative elevations were obtained by subtracting a common value from all field data used in a particular graph, field data being readings of the distance from the ground surface to the water table. In other words, the analysis was done as if all wells were located along the same contour line.

It can be seen from Figure B that the phreatic divide appears to coincide with the old boundary originally proposed by Alberta Water Resources. The second transect showed in Figure C shows no evidence of difference between the phreatic and the surface mapped boundary. Although the determination of the actual phreatic boundary would require the installation of more piezometric transects, it seems that the original northeast boundary proposed by Alberta Water Resources is the most accurate of the two.

Table A: Elevation and depth of the 11 new wells.

Well	Elevation (m)	Depth (m)
E	1948.65	14.35
F	1945.15	11.20
G	1942.19	14.00
H	1933.61	12.61
I	1934.33	15.38
J	1890.04	12.13
K	1891.85	12.36
L	1888.81	11.99
M	1889.62	10.37
N	1889.32	15.64
O	1888.79	12.64

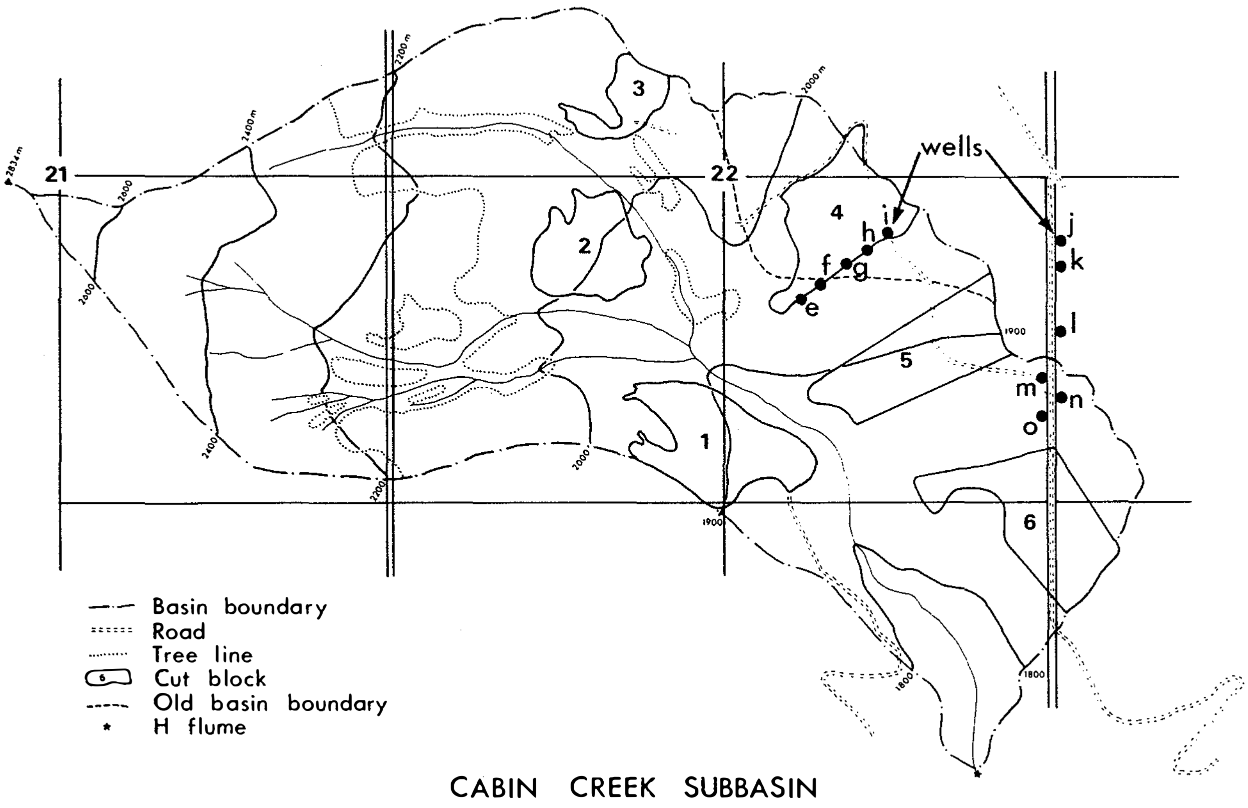

Figure A. Location of the groundwater wells on the Cabin Creek subbasin.

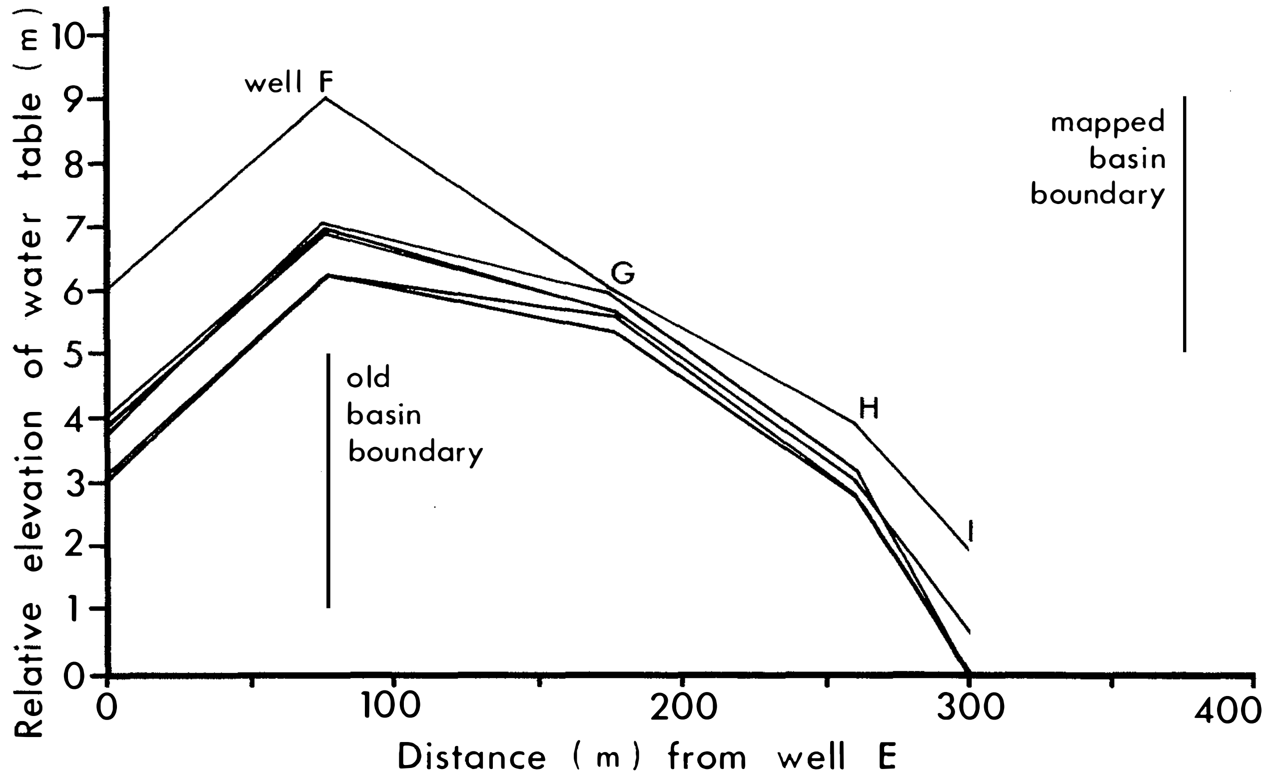

Figure B. Water levels along eastern well transect for various dates throughout the year.

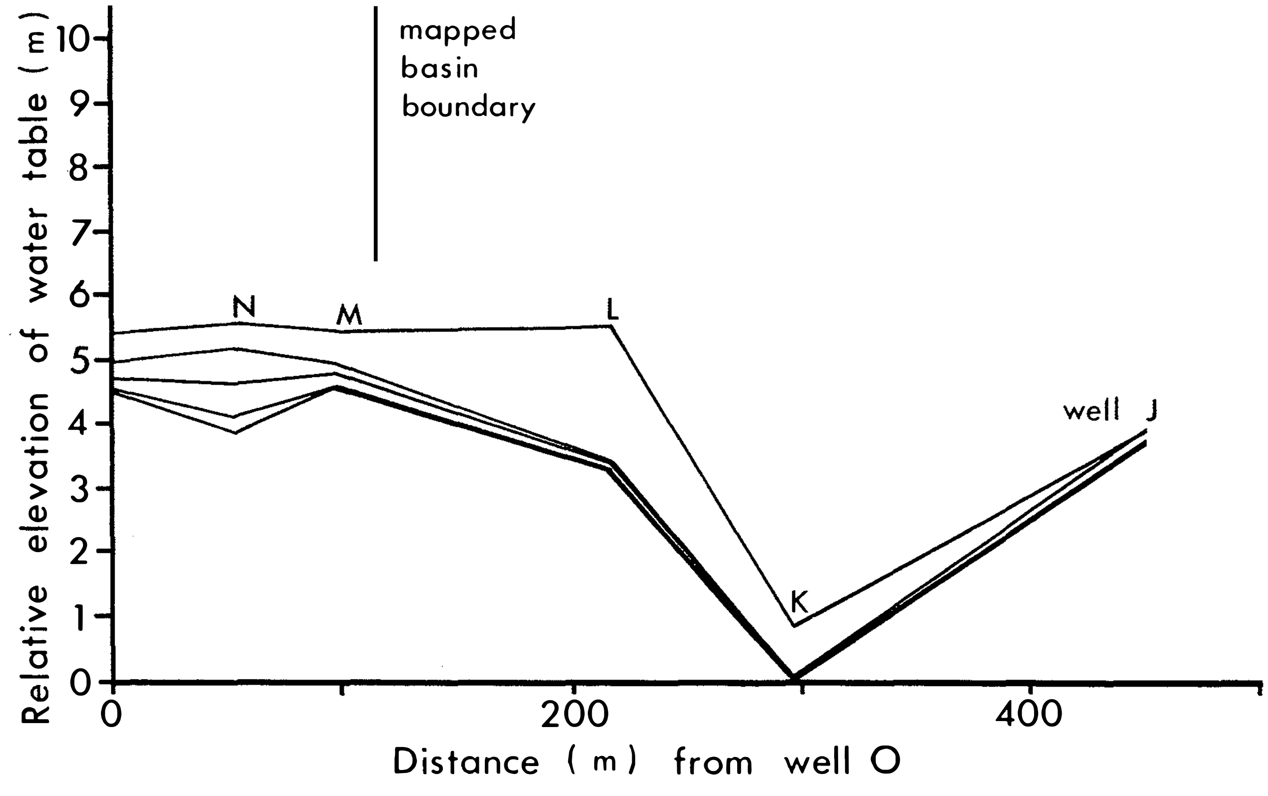

Figure C. Water levels along western well transect for various dates throughout the year.