

## Forests, snow, and water

### Forests

Forests are more than stands of trees. They are places in which to work and play and watersheds from which most of the water in our streams originates. A forest from which trees cannot be harvested is of limited usefulness. Timber must be harvested to supply lumber for our building needs. Trails

must be cleared to provide open slopes upon which skiers can maneuver without fear of collision with trees. Clear-cutting in patches increases the amount of water in streams that have forested headwaters—water for our homes, farms, factories, and hydropower needs.

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### HYDROLOGY

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**Marmot Creek experimental watershed in Kananaskis Country.** Mount Allan is the highest point on the watershed. The 1988 Winter Olympic Games' ski area *Nakiska* is located on the southeast shoulder of Mount Allan.



## Forests

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### Snow

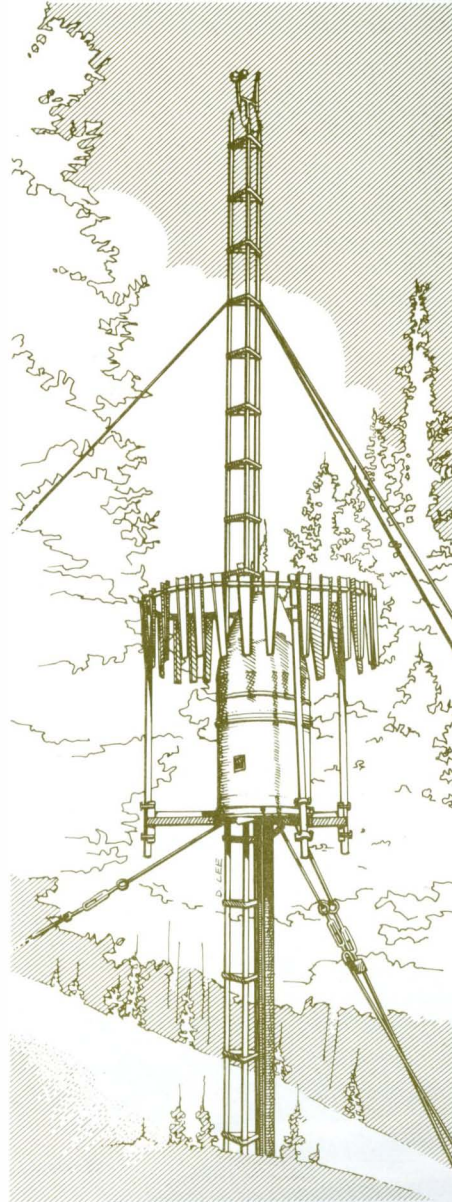
It is easy to wax poetic about snow. There is no denying the beauty of a landscape blanketed by snow. Snow is a great leveler, hiding the land surface and the dirty and unsightly from our view. It is an excellent material on which to ski. In our appreciation of the beauty and utility of snow on the ground, however, we must not lose sight of the fact that snow consists mainly of ice, that is, frozen water. The winter snowpack is a short-term reservoir for the water that waters our trees, irrigates our crops, and satisfies our thirst in the coming summer.

Who has not observed the feathery lightness of snow as it drifts, seemingly aimlessly, from sky to ground? It is this lightness, this buoyant property, coupled with its eventual melt in the spring that makes snow a manageable resource. Snow seldom falls vertically. Rather it is whipped about by wind and deposited behind obstacles, where the wind speed is suddenly reduced. The edge between a clearing and the surrounding forest induces more snow to fall in the clearing than under the trees. These edge-clearing combinations may exist naturally or can be created during timber harvest. We can use the uneven snow accumulation pattern that tree removal creates to improve skiing or to increase water supply.

If fallen snow is exposed to the wind at a later time, some snow crystals are picked up and carried by the wind for varying distances. The wind does not handle the crystals gently; they become more like ice particles than fluffy crystals by the time they are redeposited elsewhere. Some of the snow particles may even sublime (transfer directly from ice to vapor) while in transit and will never be deposited.

Regardless of whether snow is borne by the wind or deposited directly, once it has reached a resting place protected from the wind, it will rapidly lose its crystalline appearance. Within a few hours of deposition, the freshly fallen snow compacts to one-half or one-third of its original volume through a process called constructive metamorphosis, during which the surface-to-volume ratio decreases as individual snow particles become more spherical.

The snowpack continues to change in density and appearance throughout the winter. Destructive metamorphosis occurs because the bottom of the snowpack, at the ground, is normally warmer than the overlying air at the snow surface. Molecules of water vapor detach from crystals in or near the ground and move upward in response to this temperature difference, generally recrystallizing into different shapes. The bottom layer of the snowpack frequently



**Rain and snow gauge.** The bullet-shaped device is the gauge. Vertical louvers encircle the entrance to the gauge. Rain or snow enters the gauge through a 20.3-cm (8-in.) diameter circular opening in the top of the gauge and is captured in a bucket containing a mixture of water and antifreeze, which melts any incoming snow. The weight of the bucket is continually recorded on a paper chart located in the gauge housing. The difference in weight between time intervals is a measure of the amount of snow or rain that has fallen in that time interval.

develops as loosely structured depth hoar, which has very little mechanical strength. The depth hoar layer is often the one that gives way in snow avalanches.

A final change occurs just prior to melt. The snowpack becomes isothermal, that is, snow temperature stabilizes at 0°C from top to bottom. Shortly after this, meltwater from the surface fills many of the pores and the snowpack loses its mechanical strength. At this stage, the snowpack will not support the weight of a person on snowshoes and is said to be rotten.

### Water

Alberta's eastern slopes forests have a role in both recreation and water supply that extends far beyond the provincial borders. The selection of Mount Allan in the Kananaskis River valley as the site for the major downhill and slalom events of the 1988 Winter Olympics has provided a focus on the adjacent Marmot Creek experimental watershed. Snow measurements have been an integral part of the Marmot research program since its inception in 1963, and Marmot's data were used as justification for the selection of the Mount Allan site.

Marmot's principal use has been as a research area in which to design and test forest cutting practices to increase the supply of water from the eastern slopes streams. Most of the annual streamflow from Marmot comes from the winter snowpack.

The remainder of this *Forestry Report* discusses how snow is measured and how the snowpack has been managed to increase water yield from two watershed areas—Marmot Creek basin and Streeter Creek basin. First the techniques and equipment used for snow measurement are described briefly, with reference to the Marmot research program. The next section discusses an experiment to increase water flow following clear-cutting in the Cabin Creek subbasin of the Marmot watershed. The final section describes an experimental clear-cutting pattern that increased both the amount of snowpack retained and the summer water yield from a spring on the West subbasin of the Streeter watershed. It is hoped that these few pages will stimulate further reading about the measurement, properties, and management of this fascinating substance.

R. Swanson



# Snow measurements

Good snow measurements are essential to the success of the Marmot Creek experimental watershed research program, where snowpack management techniques are currently being tested or improved. About three-quarters of the 800–900 mm of precipitation that falls each year on Marmot comes in the form of snow.

From a hydrological standpoint, snow is manageable precipitation, because its arrangement on a watershed can be manipulated to some degree and it remains in place for days, weeks, or months before melting to become the water we find so useful in our homes and factories. Unlike the occurrence of rain, the timing of snowmelt in the spring and the amount of water that will be released (two of the crucial elements for the proper management of downstream reservoirs) can be predicted with relative accuracy.

Also, although we cannot alter the total amount of snow that falls on a watershed, we can harvest the forest in various sizes of clearings to alter the amount of snow that accumulates in them. This generally results in greater water yield from the same amount of snowfall because of the influence of clearing size on evaporation prior to snowmelt and the greatly reduced on-site use of snowmelt water by vegetation once the trees have been removed. Forest harvesting generally speeds up snowmelt rate because of the increased exposure of the snow surface to direct sunlight after clear-cutting.

Snow is measured for various purposes, but regardless of the end use of the data, the measurements fall into two categories: depth and water equivalent. Both are variable in time and space, but the depth of a given mass of snow is the more variable in time because there is a tendency toward a constant snowpack density of 0.2 to 0.3 g cm<sup>-3</sup> over time.

Snow depth is determined most simply with a ruler or other graduated device that is inserted vertically through the snowpack. It can also be determined from graduated stakes that were put in place prior to snowfall. The total snowfall for a year is the sum of individual measurements of the depth of freshly fallen snow; this is a value that will always be much greater than the actual accumulated depth of snow present at any given time.

The water equivalent of snow (SWE) can be measured by collecting snow in a precipitation gauge, where it is weighed or melted to obtain an equivalent water volume. It may also be obtained by measuring the depth and density or the weight of the snowpack that exists at any given place. The principal advantage of expressing snowpack in terms of water equivalent rather than depth is that SWE values represent the same amount of water as either snow or rain. Thus a snowpack containing 100 mm of snow water equivalent contains the same amount of water as a 100 mm rain storm (although its behavior in time and space is radically different!).

We emphasize the measurement of snow water equivalent in both time and space at the Marmot experimental watershed, although depth is generally determined at the same time because it does not require any extra effort. The SWE

present at any time during the winter or spring is important in forecasting the anticipated amount of spring runoff, not only from Marmot but from hundreds of similarly situated subalpine watersheds in the Saskatchewan River headwaters. The SWE present in and around both natural clearings and those that have been harvested is important in determining the effectiveness of forest cutting techniques in manipulating the snowpack to increase local or downstream water supply.

## Snow pillows

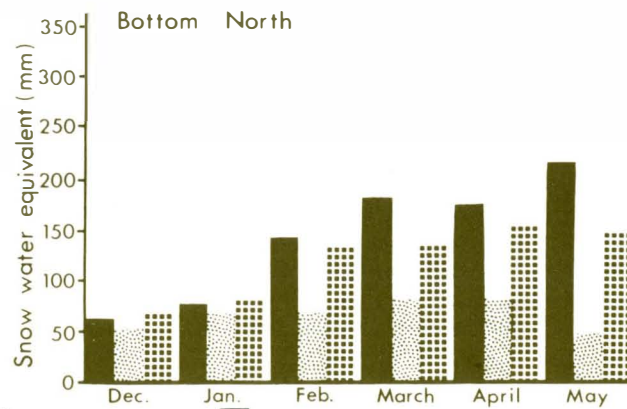
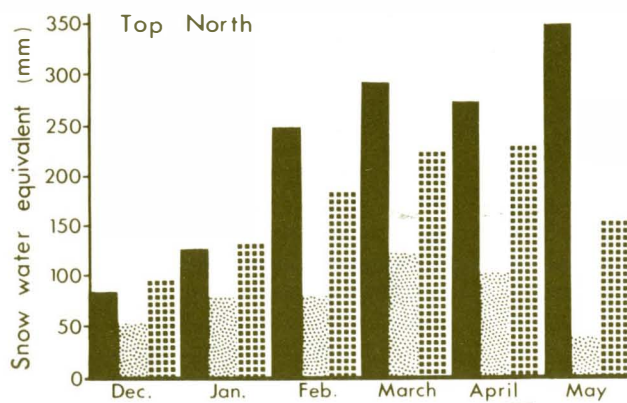
A snow pillow is a polygonal butyl rubber cushion, over 2 m in diameter and a few centimetres thick, filled with a methyl alcohol and water solution (to prevent freezing) and placed horizontally on the ground or on a low platform. As snow accumulates on the pillow surface,

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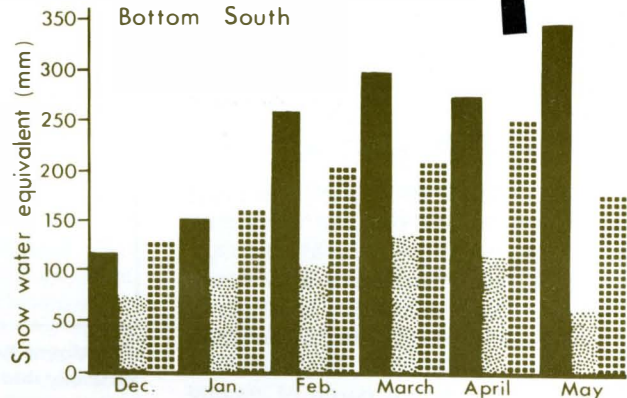
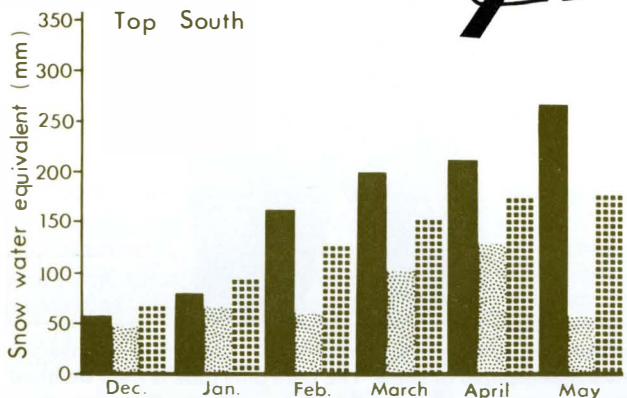
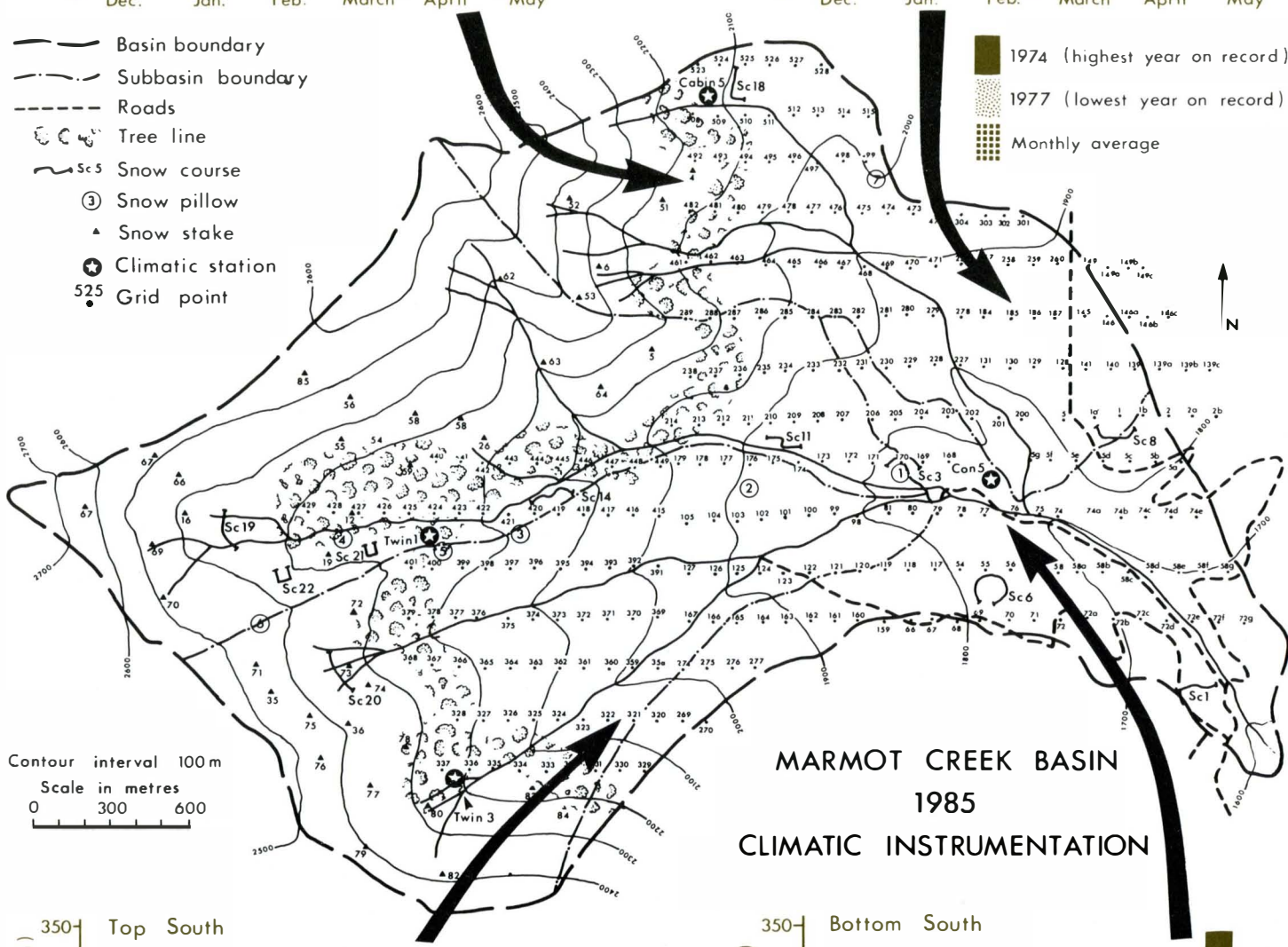


**The Mount Rose snow sampler.** The long tube (shown horizontal in the picture) is inserted vertically into the snow to extract a core sample of snow. The core plus tube is then weighed using a small spring scale. The difference between the weight of the core plus tube and the tube alone is the weight of the snow core. The diameter of the Mount Rose sampler is such that a core containing 25.4 mm (1 in.) of water weighs 28.4 g (1 oz.). The exterior of the snow sampler is marked at 12.5-mm (0.5-in.) intervals so that the depth of the snow can also be determined at the time the core is obtained.





- Basin boundary
- - Subbasin boundary
- - - Roads
- Tree line
- Sc 5 Snow course
- ③ Snow pillow
- ▲ Snow stake
- ★ Climatic station
- 525 Grid point



**Snow measurement grid on the Marmot Creek basin.** The map shows the location of snow pillows and measurement points on Marmot. Each measurement point in the timbered portion or above the timberline is numbered and permanently marked with a stake that is sufficiently long to be visible above the maximum expected snow depth. **Snow water equivalent within treed area.** Histograms illustrate snow water equivalent for several elevations and aspects in 1974 (a high snow year), in 1977 (a low snow year), and for the average of several years.



## Snow

*Continued from page 3*

the weight forces some of the fluid out of the pillow and into a vertical, clear plastic pipe located in a nearby shelter. The pipe is marked at 1-mm intervals so the level of the fluid can be read directly from it. The difference in level between any two readings is a measure of the weight change (snow accumulation or melt) that has occurred on the pillow during that interval. The water equivalence of the snow on the pillow is computed from either the fluid level in a manometer or the electrical output of a pressure transducer, both of which can be continuously recorded. The snow pillow data are good indexes of accumulation and melt over the basin.

### Snow courses

Snow courses are the best indicators of long-range variations of the accumulated snow pack on the Marmot Creek

watershed. At each course, the snow depth and water equivalence are measured at 10 fixed points marked with stakes. The 10 readings are averaged to obtain a single SWE value for the course. The snow courses have been sampled at the end of the month from February through May since 1963.

### Snow grid

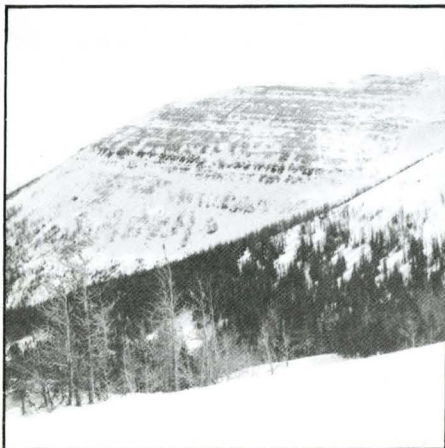
The areal distribution of snow in the forested portion of Marmot has been determined from measurements taken at preestablished grid points. The grid consists of east-west oriented parallel lines, 200 m (10 chains) apart, with permanent reference points located at 100-m intervals along each line. Once each year from 1969 to 1978 and in 1980, usually in the third or fourth week of March, snow depth and water equivalence were measured at 20-m (1 chain) intervals along each line. The data from two samples 40 m on either side of each permanent reference point were averaged as the reading for that point.

### Alpine snow cover

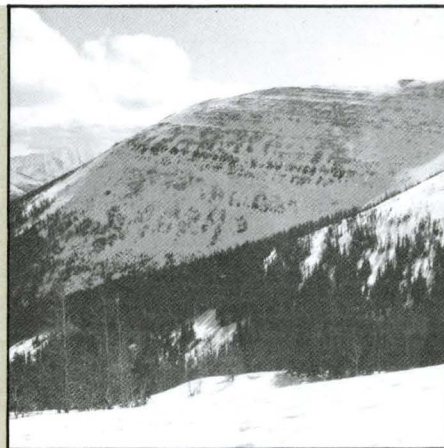
Graduated snow stakes located in the alpine portions of the basin have been measured monthly from February to June since 1974. Because of difficult and hazardous locations, readings are done by scope sighting. Only approximate snow depths can be obtained from this type of observation.

Snow cover in the alpine areas is very variable. The dry snow of early winter and midwinter is easily transported by the wind. During most winters, persistent snow cover occurs only in gullies or areas where the accumulated snow is protected from wind action by vegetation or rock obstacles. The snow that falls during the spring of the year is wetter and more cohesive and is better able to resist wind erosion. Snow-covered ridges are often a sign that spring has arrived.

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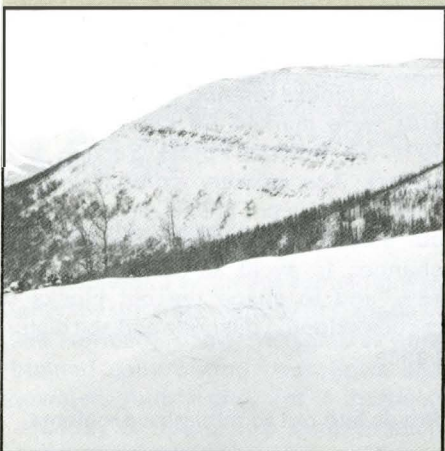
February 1975



March 1975



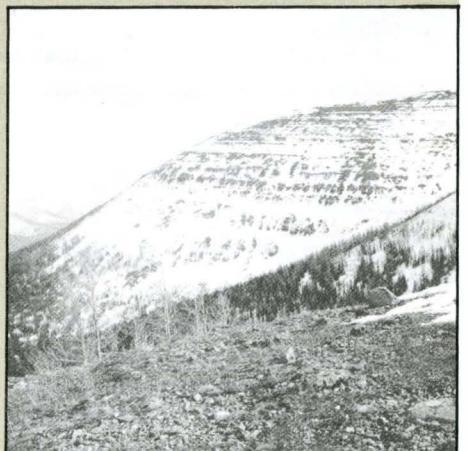
April 1975



December 1983



January 1984



April 1984

**Variability of snow cover above the timberline.** This sequence of photographs depicts the normal variation that occurs in snow cover where it is exposed to high winds. The area shown is the north-facing portion of Marmot's Twin subbasin, immediately north of the starting point for the men's downhill course, where wind speed frequently exceeds 100 kilometres per hour. A uniform-appearing snowpack in February is almost gone in March. The snow cover in April is typical of spring conditions, when snow falls at temperatures near freezing, is wet and sticky, and is not so prone to wind erosion as the dryer, colder snow of winter.



# Cabin Creek subbasin of the Marmot Creek basin

Cabin Creek is one of three sub-basins on the Marmot Creek experimental watershed. It was partially clear-cut in 1974 as part of an experiment to determine if the Alberta Forest Service's harvesting guidelines for commercial cutting in spruce-fir forests were satisfactory for maintaining the preharvesting volume of high-quality water.

The Marmot Creek basin is a sub-alpine catchment that is characterized by long, cold winters and wet, cool

summers. Mean monthly temperatures range from a low of  $-6^{\circ}\text{C}$  in January to a high of  $13^{\circ}\text{C}$  in July. Annual precipitation varies from 660 mm at lower elevations to over 1140 mm at the highest station on the Twin Creek subbasin. Mean annual precipitation for Cabin Creek subbasin is 840 mm, 70-75% of which falls as snow. About 50% of annual precipitation becomes streamflow. The pattern of streamflow is dominated by snowmelt, which often starts as early as the last week in April and continues into

late June. Summer or fall rain storms cause minor increases in the generally decreasing flow resulting from stored snowmelt. The soils of Marmot are in general of glacial till origin and well drained. Most of the streamflow from Marmot originates as subsurface flow.

Trees on the Cabin Creek watershed are generally greater than 200 years old and range in height from about 30 m near the confluence area to 5-10 m just below tree line. They are greatly sought after as saw timber for lumber. The trees on north-facing slopes and all aspects at the higher elevations are mainly Engelmann spruce (*Picea engelmannii* Parry) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). A thin band of alpine larch (*Larix lyltii* Parl.) occurs just below the tree line (at approximately 2300 m). Lodgepole pine (*Pinus contorta* Dougl. var *latifolia* Engelm.) occurs on southerly facing slopes and at lower elevations.

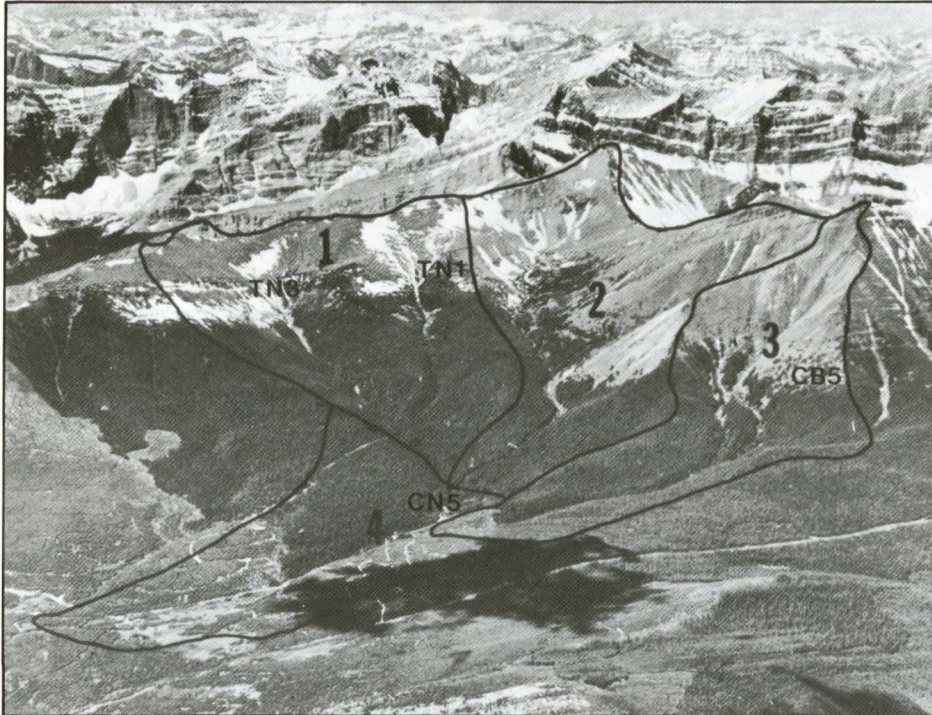
## Commercial clear-cutting operation simulated

The harvest on the Cabin Creek watershed was designed to simulate a commercial clear-cutting operation. We could only simulate commercial logging here because about one-third of the commercial trees were above an elevation of 1980 m (6500 ft), which in this portion of Alberta is a watershed protection zone in which timber harvest is prohibited. Although for this research program clear-cutting was allowed above 1980 m on Cabin Creek, it is not allowed in normal clear-cutting operations elsewhere in Alberta.

Six blocks ranging from 3 to 13 ha in area were marked for clear-cutting in 1974 by Alberta Forest Service personnel. The primary criteria used in laying out the cut blocks were to locate cut areas well away from the stream channel, to avoid slopes greater than 45%, and to shape the cut blocks to reduce skidding distance and soil disturbance.

## Roads laid out to minimize problems

Roads were laid out during the spring of 1971 when the ground would be at its wettest and the trouble spots most obvious. The primary concerns



**The Marmot Creek experimental watershed.** The three subbasins of the Marmot experimental watershed are 1) Twin, 2) Middle, and 3) Cabin. The area where the three streams join is designated as the confluence (4). Permanent weather stations are located at Twin 1 and 3, Cabin 5, and Confluence 5 (TN1, TN3, CB5, CN5). The site of the 1988 Winter Olympic Games (5) is shown on this photo before the ski runs shown on the cover photo were clear-cut.

## Snow

*Continued from page 5*

### Extrapolating snow grid data in time and space

The selection of Mount Allan (the actual ski area is immediately adjacent to the south border of the Marmot Creek watershed) as the site for the 1988 Winter Olympic Games has created a new use for our snow data. In the past, the amount of snow on the ground at or near the time when snowmelt started was all that we needed. Now it is important for the Olympic Games' organizers to know how much snow can be expected to lie on the

ground throughout most of the winter, especially December through March, the most important period for recreational skiing.

The snow grid data are a spatial description of the snowpack on the forested portion of the basin only on the date of measurement. Through statistical analysis, the data from the snow courses and the continuous record from the snow pillows have been combined to produce an estimate of the amount of snow at several locations on the watershed during December through May.

P. Bernier  
R. Swanson

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**Cabin Creek subbasin.** Clear-cutting of cut blocks occurred during July and August 1974.

## Cabin Creek

*Continued from page 6*

during road layout were to minimize 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. Logging operations started in July 1974 and were completed in September 1974.

### Suspended sediment sampled

Suspended sediment sampling was started by the Water Survey of Canada in 1969. Normally, one or two samples were obtained daily during peak flows and snowmelt runoff and at a reduced frequency of one or two samples each week throughout the summer and fall. In 1975 after the logging was completed, the Canadian Forestry Service established a network of automatic sediment samplers along the main channel of Cabin Creek upstream and downstream from each cut block. All sediment

samples were analyzed by filtration and oven-drying.

The extent and occurrence 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 rain storms or snowmelt to observe the presence or absence of overland sediment transport. Soil exposure was estimated and rated as high (61–100%), moderate (46–60%), low (16–45%), and nil (<15%).

A similar sampling technique was used to estimate the degree of disturbance and sedimentation that was occurring from normal commercial logging operations in the vicinity of Spray Lakes, approximately 15 km southwest of the Marmot watershed.

No significant changes could be detected in the Cabin Creek suspended sediment concentrations either after

road construction in 1971 or after harvesting in 1974.

### No major erosion detected

The road surfaces and right of way have remained essentially bare of vegetation since construction. A visual survey of the roads each spring and summer after 1971 revealed no major erosion or sediment transport.

Exposure of mineral soil at access roads, skid trails, and landings was rated high on approximately 20% of the cut-blocks on the Cabin Creek watershed and at Spray Lakes. 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.

The sampling of the Cabin Creek waters between cut-blocks did not reveal large increases in sediment load.

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## Cabin Creek

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Similarly, suspended sediments were low in the streams at Spray Lakes. The low concentrations at both sites likely are due not so much to the rigid enforcement of the harvesting guidelines as to the natural stability of these particular soils. Both are of glacial till origin, are coarse, and contain carbonates that make them resistant to detachment. Under such conditions, only the areas that have been bared to mineral soil and severely compacted, such as at road-stream crossings, have any chance of yielding sediment.

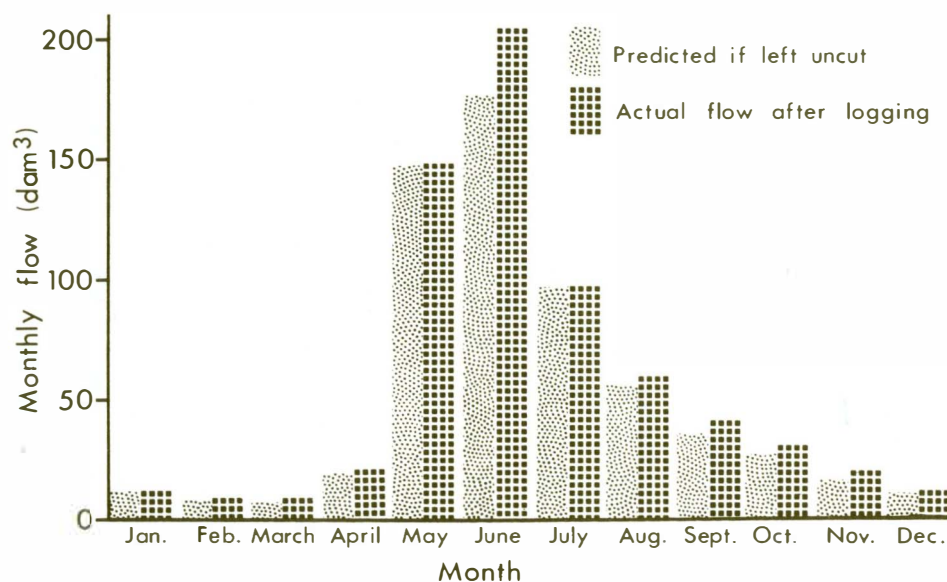
The findings with respect to erosion and sediment movement on the cut blocks are consistent with forest hydrology principles. Most streamflow from forested lands originates as subsurface flow. If the soils are not severely compacted during the actual logging operation, there should be little or no increase in overland flow after harvest. Because of the high elevation and cool climate, neither the Cabin Creek nor Spray Lakes areas experience rain storms of high intensity. Snowmelt, although yielding large amounts of water, occurs at a rate of about 10–15 mm d<sup>-1</sup> and does not provide either the kinetic energy necessary for particle detachment or the intensity necessary to provide water at a rate faster than the normally high infiltration capacities of forest soils.

### Water yield increased

Equations relating the streamflow on Cabin Creek to that of Middle Creek were established for the before and after treatment periods. The treatment effect was obtained by subtracting the predicted flow on Cabin Creek from that which actually occurred. These data indicate an increased water yield for 1975–83 of 35.7 dam<sup>3</sup> (cubic decametres)

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

| Year | Sediment concentration (mg L <sup>-1</sup> ) |         | Sediment yield (kg ha <sup>-1</sup> ) | Annual peak discharge (L s <sup>-1</sup> ) |
|------|--|---------|---------------------------------------|--|
|      | Mean   | Maximum |                                       |  |
| 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  |



**Effect of clear-cutting on streamflow.** A time distribution of streamflow increases on Marmot's Cabin Creek shows that the actual flow after logging is consistently higher than or equal to that predicted had the watershed not been clear-cut. Almost all of the water yield increase that results from logging occurs during the spring snowmelt; however, there is a small but consistent increase in late season flow as well.

(15 mm), which is 6% greater than if left uncut.

The increased flow realized on Cabin Creek is reasonably high considering that only 23% of the total area was actually clear-cut. The 15 mm

increase over the entire catchment applied over the clear-cut area of 55.3 ha is 65 mm. This is in line with results from similar watershed cutting experiments conducted elsewhere in North America.

R. Swanson

### 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                   | 236       | 840                       | 310              | 23           | 15                | 65                |
| Wagon Wheel Gap, Colorado <sup>1</sup> | 81        | 536                       | 157              | 100          | 25                | 25                |
| Fool Creek, Colorado <sup>2</sup>      | 289       | 762                       | 283              | 40           | 74                | 185               |
| Hinton, Alberta <sup>3</sup>           | 1497      | 513                       | 147              | 50           | 42                | 84                |

<sup>1</sup>Bates, C.G.; Henry, A.J. 1928. Forest and streamflow experiment at Wagon Wheel Gap, Colorado. Mon. Weather Rev. Suppl. 30.

<sup>2</sup>Troendle, C.A.; Leaf, C.F. 1981. Effects of timber harvest in the snow zone on volume and timing of water yield. Pages 231–244 in D.M. Baumgartner, ed. Watershed Manage. Symp. Coop. Ext., Washington State Univ., Pullman, Washington.

<sup>3</sup>Swanson, R.H.; Hillman G.R. 1977. Predicted increased water yield after clear-cutting verified in west-central Alberta. Can. Dep. Fish. Environ., Can. For. Serv., North. For. Res. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-198.



# The Streeter basin grassland experiment

Aspen grasslands are important to the ranching economy of the foothills of southern Alberta. These grasslands occupy a significant portion of the Saskatchewan River headwaters. The woody vegetation (primarily *Populus* and *Salix* spp.) has been removed periodically to allow greater grass production and more grazing capacity.

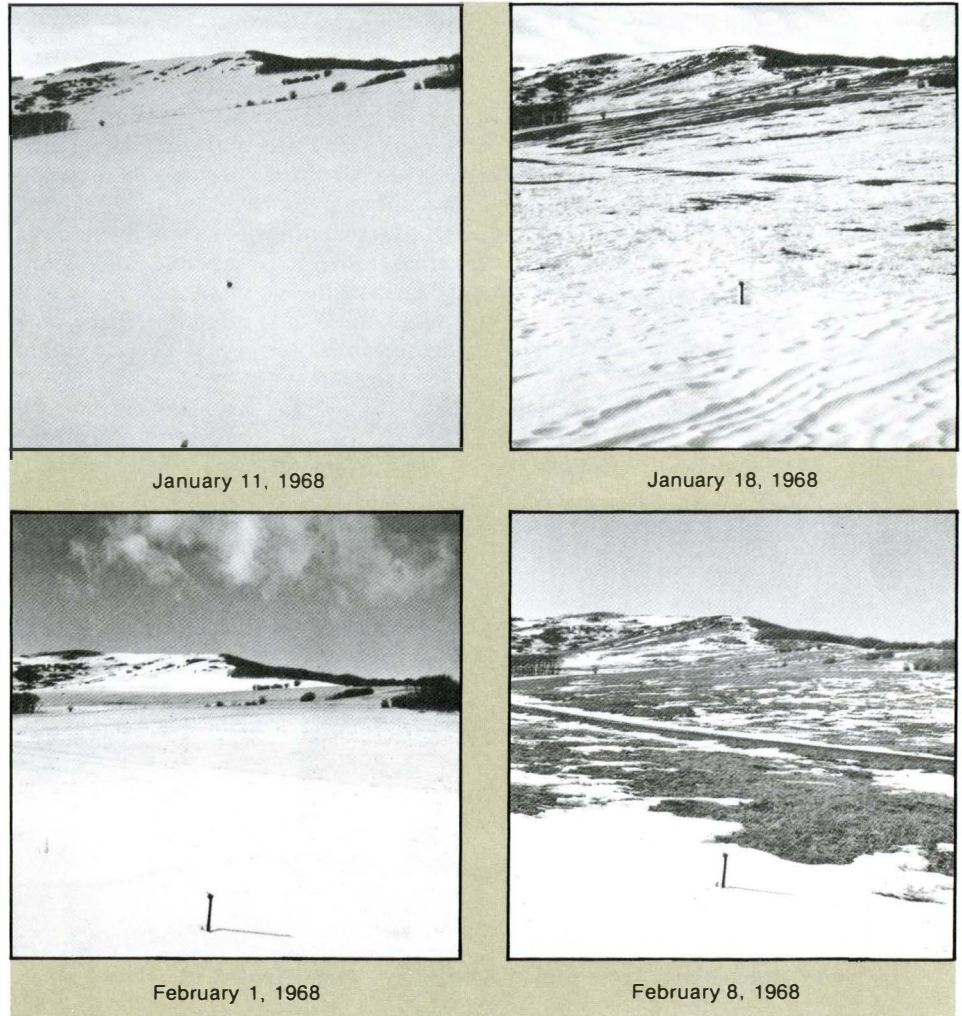
Streeter Creek basin, in the Porcupine Hills west of Nanton, is a gauged watershed that was established for a study of the effects of clearing on montane aspen forests and associated grasslands of the southern foothills. Streeter lies in a transition zone between the mixed prairie and subalpine forest. The primary objective of the Streeter basin clear-cutting experiment was to establish the effect of forest removal and conversion to grassland upon water yield and regime of a small contact spring formed by the intersection of an impervious layer of rock and the surface. The effects of range conversion on sediment were not evaluated, as suspended sediment loads in these springs are nil.

The basin, which has a northerly aspect, has three subbasins (West, 1.36 km<sup>2</sup>; Middle, 0.90 km<sup>2</sup>; and East, 0.51 km<sup>2</sup>) and a confluence (3.23 km<sup>2</sup>). The elevation ranges from 1325 to 1660 m above mean sea level. The area is underlain by sandstone with a shallow covering of silty to sandy till. Thirty-seven percent of the basin's vegetation is herbaceous, 11.7% is shrubs, 6.1% is open poplar forest, and 41.2% is dense poplar forest.

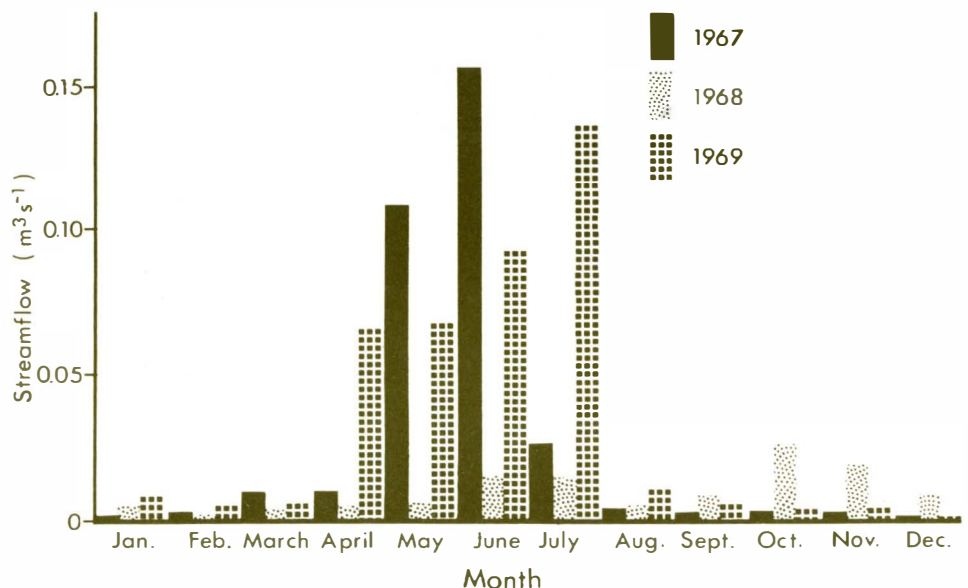
Wind is the dominant feature of Streeter basin's climate, with southwest and westerly winds dominating during all months of the year. The average wind speed during 1967 was 18 km h<sup>-1</sup>, and there was a peak hourly value of 97 km h<sup>-1</sup> and a peak daily value of 55 km h<sup>-1</sup>. Daily averages are highly variable, and days when the wind could be considered calm are indeed few. The 1967 winter wind speed averaged 21 km h<sup>-1</sup>, while that during the summer was somewhat calmer at 14 km h<sup>-1</sup>.

Streeter's air temperature and streamflow regimes are best described as variable. Average conditions are relatively meaningless because they occur only in transition from one state to another.

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**Intermittent snow cover in chinook country.** This series of photographs demonstrates the effectiveness of chinook winds in removing snow cover at Streeter basin.



**Streamflow at Streeter basin.** Streamflow at Streeter basin is highly variable from month to month and between years. Peak runoff occurred in June in 1967 and in July in 1968, but not until October (and that very reduced) in 1969.



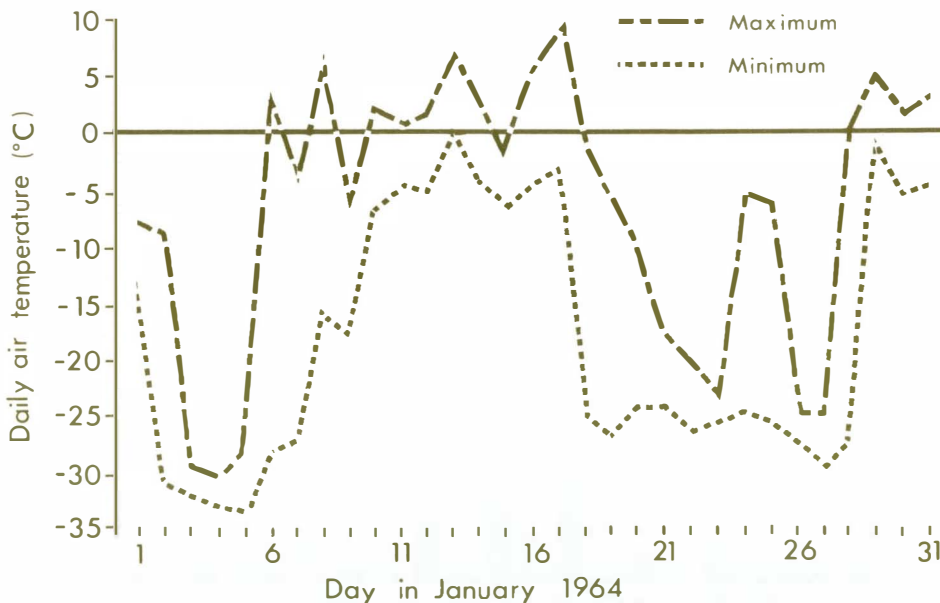
## Streeter

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Continental and Pacific air masses dominate the overall climate, and there are frequent short fluctuations in temperature that are generally accompanied by high westerly or southwesterly winds. Mean monthly air temperatures from 1966 through 1975 ranged from a low of  $-10.8^{\circ}\text{C}$  in January to a high of  $15.2^{\circ}\text{C}$  in August, and it is not unusual to experience above-freezing temperatures in any winter month. For example, on January 4, 1966, the average temperature

was  $-28.9^{\circ}\text{C}$ . On the 6th, it rose to  $1.1^{\circ}\text{C}$  and fluctuated near the freezing mark for 12 days, reaching a high of  $8.9^{\circ}\text{C}$  on the 17th. Similar examples could be cited for the winter months of most years.

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



**Air temperature at the Streeter Creek basin.** The monthly air temperatures of the top graph are misleading in that they suggest a stability in temperature that really does not exist. As the bottom graph shows, air temperature can fluctuate widely from day to day in response to chinook winds. Note that the maximum temperature was  $-29^{\circ}\text{C}$  on January 5 and  $+1^{\circ}\text{C}$  on the 6th. Such rapid changes are frequent occurrences in this part of Alberta.

Measurable streamflow is intermittent and highly variable from year to year in Streeter basin. The majority of the water visible in stream channels arises from numerous contact springs. Between the areas of influx from the springs, the stream reaches are often dry because of efflux to the local groundwater system. From 1964 through 1968 the average water yield measured at the main stream gauge was 76 mm, which is typical of the general surrounding area.

As observed on most forested watersheds, overland flow is rare. Saturated infiltration capacities on Streeter range from a low of  $14\text{ mm h}^{-1}$  to greater than  $300\text{ mm h}^{-1}$ . The only time overland flow has been observed on the undisturbed portions of Streeter is during snowmelt—and then only in the near vicinity of the stream channels when the soils were saturated or frozen.

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 underlying impervious materials. The recharge areas for these springs are small portions of the ridge and slope positions above a defined stream channel. Time sequences of aerial and ground photographs taken during the winter revealed that, of the snow initially accumulated on any portion of the basin, that which was 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, once the trees had been cleared from a recharge area, chinook winds would cause the snow that would normally accumulate and melt there to be evaporated or blown into depressions, such as the stream channel. In either event, 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 was 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.

Continued on next page





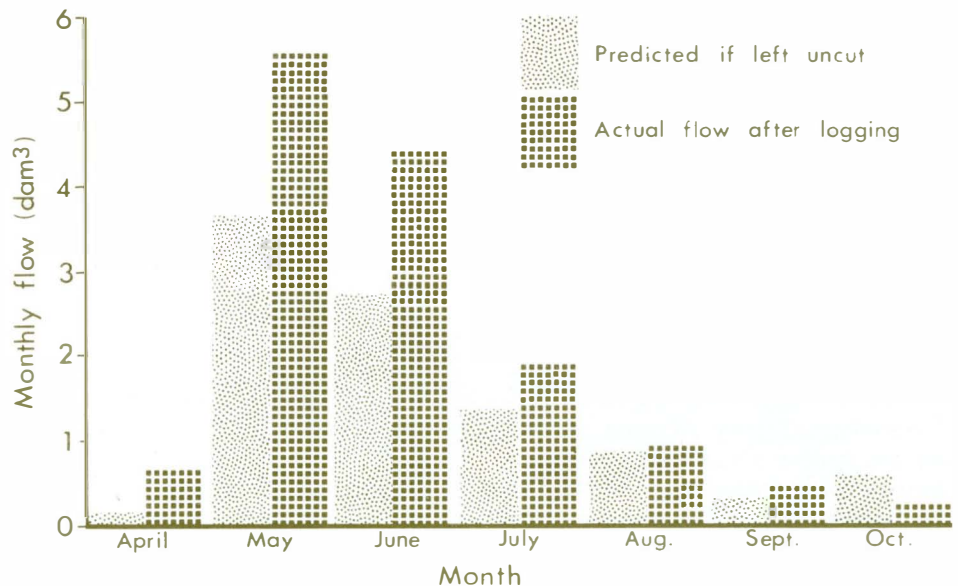
**Streeter basin in winter.** This view of the West Streeter subbasin in February 1977, the first winter after treatment, illustrates the loss of snow from the large, exposed clearings in the foreground that the small patch clear-cut treatment was designed to correct. The black object in many of the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

## Streeter

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The principal hydrologic goal of the cutting pattern imposed on Streeter basin was to maintain the least amount of vegetation necessary on the upslope recharge areas above contact springs and stream channels so that the snow that fell would accumulate and be retained 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 small portion of the West subbasin.

The dimensions of the clear-cut patches were based on earlier findings with respect to snow accumulation and disappearance in these poplar stands and on results obtained in dense conifer forest. These studies indicated that clearings one to two tree heights wide by 60–180 m long, with the long axis oriented perpendicular to the prevailing winter wind direction, would enhance snow accumulation and retain it where it fell. In shrub stands, strips 3–5 m wide by up to several hundred metres long were cleared. In trees stands, alternate clear and treed patches with widths of one to three tree heights were created, and trails were cut between clear-cuts to



**Effect of patch clear-cuts on monthly water yield from the West Streeter spring.** Actual is that which was measured; predicted is that which would have been expected in the absence of the treatment.

facilitate movement by cattle and big game. 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 occurred during October to December of the same year.

Snow courses were established in the cut and uncut patches on the treated subbasin and through the trees and a

large natural opening on the undisturbed Middle subbasin. Snow courses on both the treated and Middle subbasin were on an easterly aspect and had similar slopes and elevations (1400–1470 m). Measurement points were located at 20-m intervals. The small patch clearings of the treated subbasin always retained more snow than the large control opening, and the treed areas on either the treated

*Continued on next page*



## Streeter

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or control subbasin also contained more snow than the large open area.

The water flow from the East (undisturbed) and West subbasin springs has been monitored since 1968 by the Water Survey of Canada. The effect of the patch cutting on the water yield from one of the springs on the West subbasin was determined by using a pretreatment relationship between the flow in the East and West springs to predict the flow of the West spring after cutting. This was then compared with that which actually occurred. An equation was developed for each month's flow (April through August) based on 1968-76 data.

The effect of this patch clear-cutting on the flow from the West spring has been quite marked. April through October streamflow for 1977 through 1983 is almost double that predicted if clearing had not occurred. The 7-year average April to October water yield from the West spring was 14.6 dam<sup>3</sup> (cubic decametres) compared with 8.3 dam<sup>3</sup> predicted. During 1977, a year with the second-lowest streamflow ever recorded in southern Alberta, the flow predicted for the West spring from May through July was nil, while in actuality it was 0.74 dam<sup>3</sup> and continued to flow throughout the summer at about 0.3 L s<sup>-1</sup>.

The important result from this study is not so much the magnitude of the increase in flow, which is indeed high, but the maintenance of snow cover on the recharge area and the continuance of flow during a very dry year. This demonstrates that snow can be retained in place if given a reasonable degree of protection from the chinook winds. The creation of clearings that are sufficiently small so that the wind speed at their surface is significantly reduced is probably the most important consideration if forest clear-cutting is to have a positive affect on water yield from chinook-prone areas such as southern Alberta.

R. Swanson



**Aspen grasslands of southern Alberta.** Various-sized clumps or stands of poplars interspersed with open grassy areas are a frequent landscape in southern Alberta. A common range management practice is to clear-cut the poplar and reseed to grass.

### Results of snow surveys on the treated West Streeter subbasin and control Middle Streeter subbasin

| Date and location | Number of samples <sup>1</sup> | Average 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                                 |

<sup>1</sup> 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.

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