HYDROLOGIC RELATIONSHIPS IN INTERIOR CANADIAN WATERSHEDS

Douglas L. Golding, Associate Professor
Faculty of Forestry
University of British Columbia
Vancouver, B.C. Canada[1]

ABSTRACT

The results of three studies in the Alberta Watershed Research Program are presented along with the treatment of two experimental watersheds based on these results and a proposed pilot project for water yield.

A one-year study in west-central Alberta showed 59% greater flow during the snowmelt freshet, 27% greater yield from April 25 to September 15, and an increase of 1 1/2-2 times in storm peaks on nine clearcut watersheds compared to nine forested watersheds. The James River study was carried out to determine snowtrapping efficiency and ablation rates in circular openings of 1/4-6 tree heights (H) in diameter. Snow accumulation was greatest in 2 H and 3 H openings and least in the uncut forest. Ablation rates were least in the 1 H and 3/4 H and greatest in the 3-6 H and uncut forest. A study of evaporation from the snowpack indicated that significant moisture losses occur along the eastern slopes of the Rocky Mountains during chinooks. From January 1 to March 30, 1976, calculated potential evaporation averaged 64 mm water equivalent at six sites above tree line and 33 mm at 13 sites in forest openings.

Treatments based on the James River snow accumulation results were applied to Streeter (in 1976) and Marmot Creek (in 1979) experimental watersheds to alter streamflow regime. These are described along with the Streeter results. Discussion is presented of a proposed pilot project of 300 km^2 to increase water yield by forest manipulation in the headwaters area of the Oldman River basin in southwestern Alberta.

Keywords: water yield, clearcut, snow accumulation, snow ablation, melt, storm flow, snow evaporation, forest openings.

INTRODUCTION

The Saskatchewan River supplies much of the water to the provinces of Alberta, Saskatchewan, and Manitoba. Much of that water originates on the east slopes of the Rocky Mountains of western Alberta. Because of the importance of this water supply, the governments of Canada and Alberta agreed in 1947 to cooperate in the protection and administration of 23,000 km^2 of mountain watersheds. A joint body, the Eastern Rockies Forest Conservation Board (ERFCB), was established to carry out these responsibilities. The Alberta Watershed Research Program (AWRP) began in 1960 as a cooperative program involving a dozen federal and provincial agencies. To some degree this program developed because of the awareness evoked by the ERFCB of the need for research in watershed management on the east slopes. Coordination of the program was assumed by the Canadian Forestry Service. In this paper I will deal with the results of some of the studies carried out as part of the AWRP and relate them to watershed management interests in the province. Because regulation of streamflow through watershed management is dependent on snowpack management in Alberta, much of the research reported here deals with that aspect.

SNOW IN FOREST OPENINGS

The size, shape, and orientation of clearcut forest openings have a profound influence on snow accumulation patterns and melt rates. Many studies have related snow accumulation to forest-opening size but the size of opening that acts as the best snow trap was in doubt. A study was carried out in the James River area of west-central Alberta to determine snow accumulation and ablation in circular forest openings of 1/4 tree height (H) to 6 (H) in diameter (Golding and Swanson 1978).

Method

The area is very flat with the foothills of the Rockies about 11 km to the west. The forest is a very homogeneous lodgepole pine (*Pinus contorta*) stand of 20-m height. Nine opening sizes (1/4, 1/2, 3/4, 1, 2, 3, 4, 5, and 6 H) plus the uncut control (0 H) were located on a 201 x 201 m grid. Beginning in 1969, openings were cleared and slashburned.

For all openings, and for the forest surrounding the openings, snow water equivalent (w.e.) was measured near the time of maximum accumulation and near the end of the melt season, in each of the years 1973-1976. The number of points measured per opening ranged from eight in the control to 52 in the 4, 5, and 6 H openings.

[1] The author wishes to acknowledge Water Survey of Canada for streamflow records, the Alberta Forest Service and Canadian Forestry Service for assistance, and the Natural Sciences and Engineering Council of Canada under whose grant (No. A6957) some of the work was done.

Results

Values given here are mean w.e., 1973-1976. All opening sizes had greater snow w.e. at maximum pack than did the uncut forest. Greatest accumulation was in the 2 H and 3 H openings, and least in the uncut control followed by the 1/4 H and 1/2 H (Figure 1).

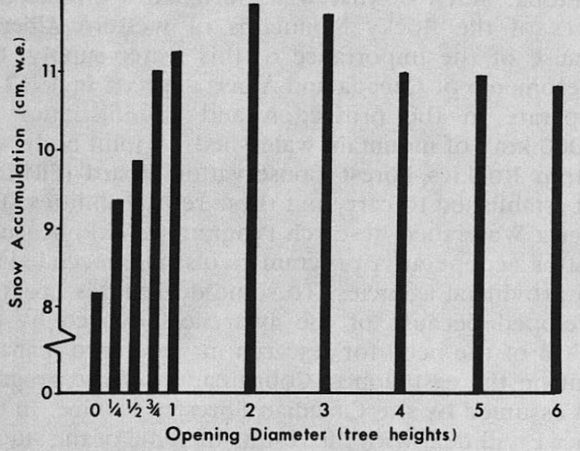

Figure 1. Mean maximum snow accumulation in forest openings at James River, 1973-1976.

There was less snow in the forest surrounding each opening than in either the opening or the control (Table 1). Snow ablation rates were lowest in 1 H (taken as 100%) and 3/4 H (103%), and greatest in 3-6 H openings (131-138%) and in the uncut control (131%) (Figure 2).

It is assumed that the 14.3% (1.2 cm) greater snow accumulation in the 1/4 H than in the 0 H could be attributed to elimination of canopy interception. A 1.2-cm increase should then be attributable to this cause for all opening sizes. Increases in excess of 1.2 cm must be due to the effects on air flow of the discontinuity in the canopy and to changes in wind speed within the opening. As opening size increases, more snow must be transferred from the surrounding forest to maintain the level of accumulation in the opening. This is accomplished either by greater removal of snow within a given distance from the opening edge or by removal from increasingly greater distances from the edge. Both factors likely work in combination as wind speed increases with increasing opening size. Horizontal wind speeds at 2 m height within the openings increase from 3% of above canopy winds for 1 H openings to 9% for 6 H openings and to 50% for 20 H openings (Swanson, personal communication). Swanson found that vertical wind velocities were generally less than about 0.1 m/sec in 1 and 2 H openings but increased to about 0.4 m/sec in 4 and 6 H openings.

Greater removal of snow from surrounding forest does take place as opening size increases. Snow w.e. in surrounding forest decreased from 8.4 cm adjacent to the 1 H opening to 6.3 cm adjacent to the 6 H (Table 1). As opening size increases, redistribution from surrounding forest cannot maintain the same level of accumulation in the opening so the level in the opening drops off also, from 11.9 cm (2 H) to 10.8 cm (6 H).

Table 1. Mean snow w.e. in forest openings and surrounding forest, 1973-1976.

Opening Size	Mean Snow w.e. Surrounding Forest	Opening
H	cm	cm
0	8.18[2]	8.18[2]
1/4	8.10	9.35
1/2	8.08	9.86
3/4	8.15	11.00
1	8.38	11.25
2	7.92	11.86
3	7.47	11.73
4	7.16	10.97
5	6.43	10.95
6	6.27	10.82

[2] This value is the mean snow w.e. for the uncut control, 0 H, and does not fit under either the "surrounding forest" or "opening" heading.

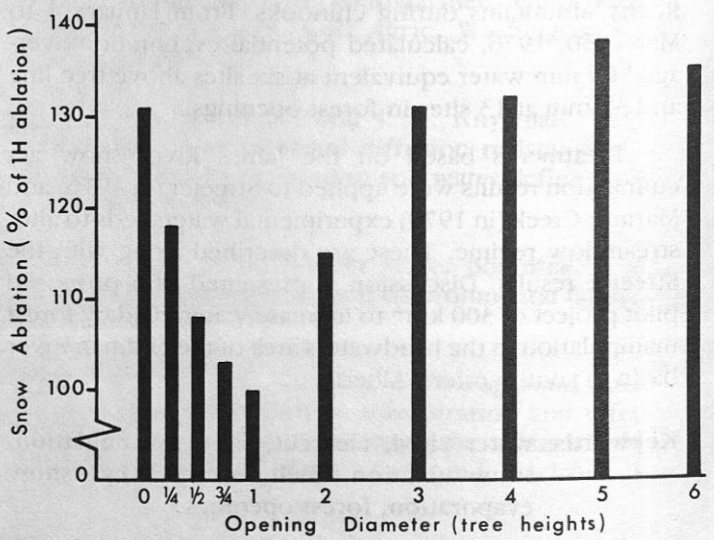

Figure 2. Mean snow ablation as a percentage of ablation in 1 H openings at James River, 1973-1976.

North-south profiles of snow w.e. showed a drop at the north edge of the openings (Figure 3). In 1973, four snow surveys were made, on February 1, March 1, April 12, and May 8, which showed the drop occurring as early as February 1 in 4-6 H openings. By March 1, the effect was obvious in 3 H openings and was just noticeable in

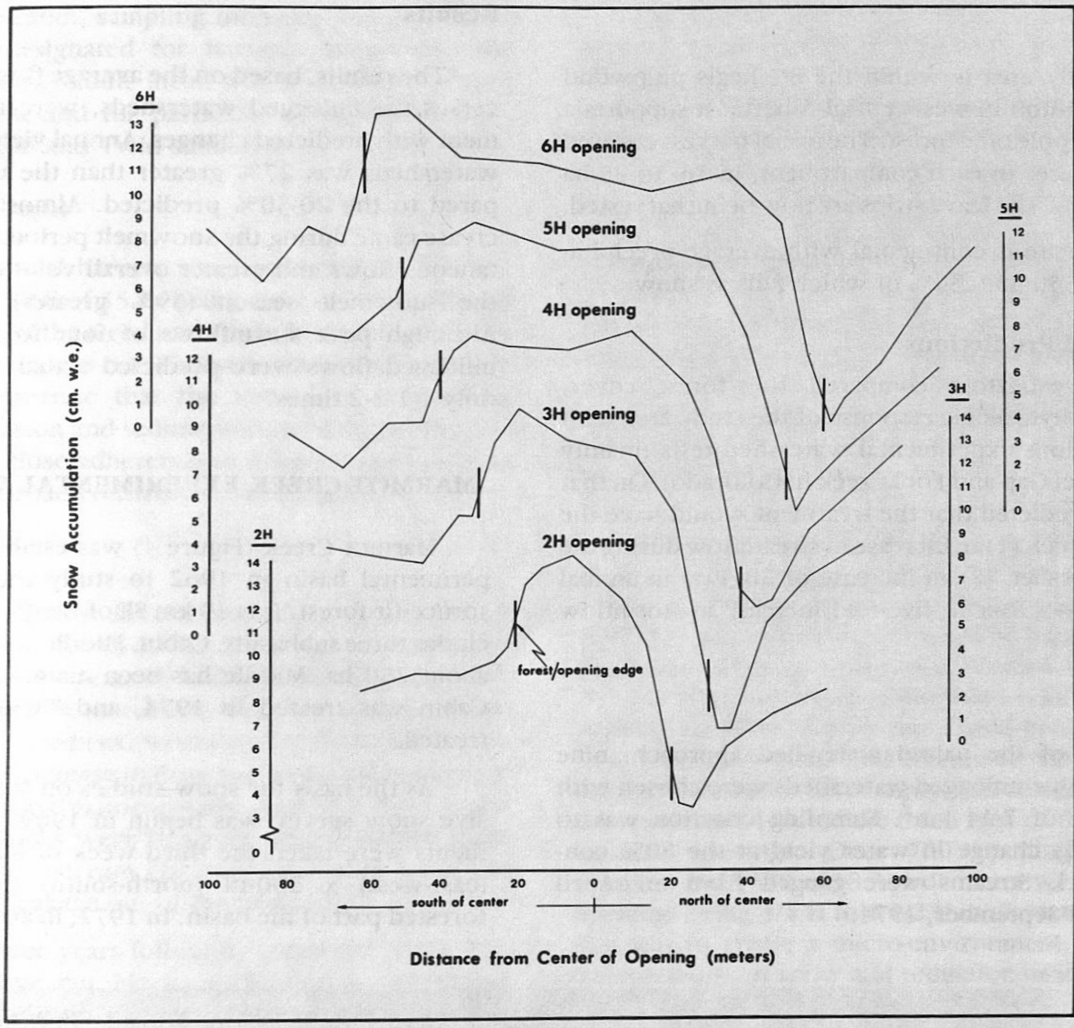

Figure 3. Mean north-south profile of snow accumulation at maximum pack in forest openings at James River, 1973-1976.

the 2 H. By April 12, the effect was obvious in 1 H openings. Apparently this is due to solar radiation reaching the north edge of the openings causing either snowpack evaporation or melt. On December 21, the day on which the sun's altitude is least, the north edge of openings 4 H and larger are in sunlight. Sunlight does not reach the north edge of the smallest openings, 1/4 H and 1/2 H, until long after snow has completely melted.

Wind directions are not so consistent that the low accumulation in the forest at the north edge of the openings can be attributed to wind. For 15 major snowstorms during the period of the study, winds were northwest for five of them, north for three, south for three, west for three, and south-east for one. Windspeeds were generally low, with nine storms being 2.2 m/sec or less, four between 2.2 and 4.0 cm/sec, and the remaining two storms being 5.7 and 11.7 m/sec. There is no evidence that redistribution of snow on the ground causes the drop in accumulation at the north edge either. During winter, highest winds occur from all directions, but predominantly from the south, west, and northwest.

It should also be noted that there is a slight tendency for snow scour to occur at the centre of the largest openings, the 4-6 H. As well, there is a ring of low accumulation just inside the forest surrounding the openings (Figure 3).

HINTON STUDY

The usual question of extrapolation was asked by resource managers in Alberta. Can the results of water-yield studies conducted elsewhere be applied to our situation? A study was carried out to demonstrate (1) that removing the forest will increase water yield, and (2) that the physical system is well enough understood to predict in quantitative terms the effect of treatment. This study was reported by Swanson and Hillman (1977).

Study Area

The study area is within the St. Regis pulpwood lease near Hinton in west-central Alberta. It supports a spruce-lodgepole pine forest. The initial harvest covered 50% of the area in each compartment, in 16- to 25-ha clearcut strips. The leave strips are now being harvested.

The climate is continental with average precipitation of 500-550 mm, 30% of which falls as snow.

Water-yield Predictions

The investigators compared the forest cover, climate, and hydrologic response of the study area with those of various experimental watershed tests (mainly Wagon Wheel Gap and Fool Creek in Colorado). On that basis they predicted that the treatment would have the following effect: (1) an increase in streamflow during the snowmelt freshet, (2) an increase of 20-30% in annual yield, and (3) a four to five-fold increase in stormflow peaks.

Method

Instead of the paired watershed approach, nine logged and nine unlogged watersheds were chosen with a size range of 7-14 km^2. Sampling criterion was to detect a 25% change in water yield at the 80% confidence level. Streams were gauged from mid-April through mid-September, 1974.

Results

The results, based on the average flow of the logged versus the unlogged watersheds, were in close agreement with predicted changes. Annual yield of the logged watersheds was 27% greater than the unlogged compared to the 20-30% predicted. Almost all of the increase came during the snowmelt period. Higher instantaneous flows and greater overall volumes occurred in the snowmelt season (59% greater) as predicted. Although peak stormflows of four to five times the unlogged flows were predicted actual increases were only 1 1/2-2 times.

MARMOT CREEK EXPERIMENTAL WATERSHED

Marmot Creek (Figure 4) was established as an experimental basin in 1962 to study the hydrology of spruce-fir forest. It is 40 km SE of Banff, Alberta, and includes three subbasins, Cabin, Middle, and Twin, each of about 250 ha. Middle has been maintained as control, Cabin was treated in 1974, and Twin has just been treated.

As the basis for snow studies on Marmot, an intensive snow survey was begun in 1969. Snow measurements were taken the third week of March on a 20-m (east-west) x 200-m (north-south) grid within the forested part of the basin. In 1972, in anticipation of the

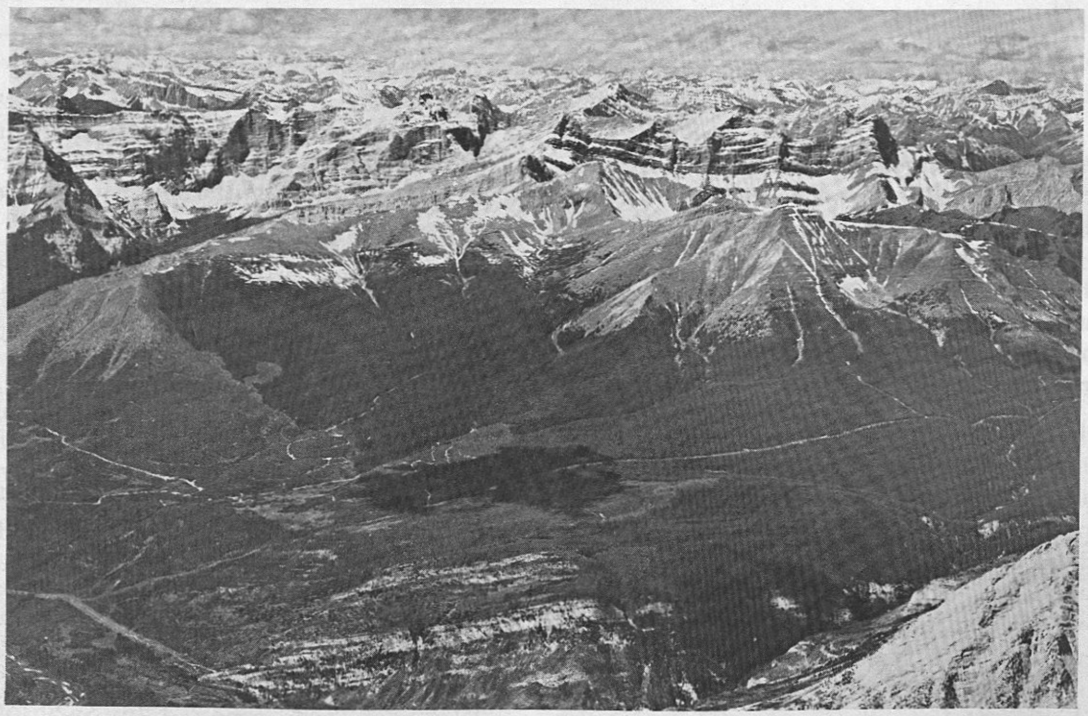

Figure 4. Marmot Creek experimental watershed showing snow in cleared patches.

treatment of Cabin, sampling intensity was doubled in those areas designated for harvest. Snow w.e. was calibrated, using Middle mean w.e. as control, for each sampling point and for particular groupings of these points on Cabin and Twin subbasins.

Cabin Treatment

A commercial harvest was conducted on Cabin in 1974, with a total of 55 ha being clear cut in six blocks. Forty percent of the treed part of the basin but only 20% of the total basin was cut. The basic aim of the treatment was to demonstrate that the impact of commercial harvest on erosion and sedimentation could be kept to a minimum by close adherence to Alberta Forest Service guidelines for road construction and logging.

Results

No increase in sediment production resulted from the treatment (Rothwell 1977). There was no increase in annual flow for the years 1975-78 but there were significant changes: a 24% increase in May flow, and maximum daily flow occurred two weeks earlier (from June 13 to May 31). Little increase in flow was expected because of the nature of the treatment: only 20% of the basin was logged, cut blocks were in upper and mid-slope positions away from stream channels, and because of the probability of leakage out of the basin.

For the three years following treatment (1975-77), four of the five cut blocks calibrated for snow accumulated significantly more snow than predicted and the fifth had more but not significantly so (Golding 1977). Of the five areas surrounding each of the cut blocks (i.e., within 60 m of the cut) none had significantly less snow than predicted, two having slightly more and three having slightly less. The mean observed accumulation of the five surrounding areas exactly equalled the predicted (15.7 cm). So the 22% additional snow in the cut blocks (18.0 cm observed compared with 14.7 cm predicted) was not due to redistribution from surrounding uncut forest. The increase may be due completely to lack of canopy interception. Large losses have been attributed to evaporation of snow intercepted by the canopy, e.g., for lodgepole pine in eastern Oregon a 24% loss (Miner and Trappe 1957); in Colorado, a 32% loss (Wilm and Dunford 1948); and a large proportion of a 56% increase in snow storage after cutting mixed conifers in Idaho is attributed to lack of interception (Haupt 1979). Other studies, however, show much smaller losses, e.g., 5% in Douglas-fir and white pine in Idaho (Satterlund and Haupt 1970), 10% in the central Sierra Nevada (Anderson 1967), and Hoover (1971) suggests that after strip cutting in Fool Creek, Colorado, the total pack was not changed although snow was redistributed.

On Marmot Creek it is unlikely that a significant amount of evaporation from the snowpack on the ground could result from radiation (Storr 1968). Satterlund and Eschner (1965) suggested that the differences in the energy and vapor balances between snow in tree crowns and on the ground are sufficient to account for considerably greater losses from intercepted snow. Evaporation from snowpacks on the east slopes can be significant during chinooks, at some locations exceeding 5.3 cm over the winter (Golding 1978). Seldom does intercepted snow remain in the tree canopy on Marmot for more than a day, because of winds. Also, snow in the canopy is quickly warmed at the initiation of chinook conditions and slides off to the ground.

Twin Treatment

The forest manager is generally limited to harvesting practices that speed up snowmelt and increase flow on the rising limb of the spring hydrograph. In many cases, however, it would be preferable to augment flow after the peak. A treatment carried out in 1979 on Twin subbasin of Marmot Creek was designed to delay the time of peak runoff and prolong recession flow from snowmelt. This treatment was based on the results of the James River study, and consisted of cutting the trees from 40% of the treed area of the subbasin in circular openings. Over 700 openings of 12.2-m diameter and 1372 of 18.3-m diameter were cleared, the openings being 3/4 H to 1 1/2 H in diameter. The objective was to create a micro-environment conducive to concentration of snow and reduction of its overall melt rate.

Snow surveys will be carried out on Twin subbasin and the control subbasin in March of 1980-82 to document the changes in snow accumulation in the openings, in the surrounding forest, and on the whole basin. Changes in streamflow regime will be related to snow accumulation changes.

SNOWPACK EVAPORATION DURING CHINOOKS

There are numerous accounts of how quickly snowpack disappears in particular locations along the east slopes of the Rocky Mountains during chinooks. There are few actual data, however, on their frequency, intensity, and the depth of snow evaporated or melted during chinook conditions. If forest cover is to be manipulated for snow accumulation and melt rate, the potential losses due to evaporation during chinooks must be considered.

A study was carried out to determine (1) potential snowpack evaporation during chinooks along a 160-km stretch of the Rocky Mountain foothills and (2) the frequency and intensity of chinooks at major mountain gaps along the flanks of the mountains (Golding 1978).

Method

The study area runs along the Rocky Mountain foothills from 30 km southeast of Banff to Nordegg, 185 km northwest of Banff. Three transects were established: one of five stations (three above treeline) from 1700 to 2360 m elevation in the Red Deer River valley, a major gap in the mountains; one of five stations (three above treeline) from 1410 to 2320 m elevation in the Bow River valley, another major gap; and one of nine stations from 1280 to 1690 m elevation along the flanks of the mountains. The six stations in the mountain gaps below tree line are in forest openings at least 150 m wide whereas the other nine stations below treeline are in large openings, at least 300 m from the forest edge.

Each of the 19 sites had a monthly recording hygrothermograph in a Stevenson screen at 1.7-m height along with maximum and minimum thermometers. Odd-numbered sites also had a battery-powered cup amemometer on a 6-m tower. Data were gathered for the period January to March, 1975 and 1976.

The potential snowpack evaporation, melt, and condensation were calculated using temperature and relative humidity as inputs to a nomogram by Boyd (1967). Boyd's nomogram assumes a wind speed of 20 m/sec so values were corrected for actual windspeed.

Results

Calculated potential evaporation averaged 1.2 mm/day for 19 chinook days in January-March, 1975 and 2.0 mm/day for 20 chinook days in the same period in 1976. Higher wind speeds accounted for greater evaporation in 1976: winds often exceeded the 1975 maximum of 22 m/sec and exceeded 45 m/sec on one occasion. Highest daily evaporation was 10.4 mm at a site above treeline during the chinook of January 16-22, 1976, when wind speed averaged 21 m/sec. Evaporation during chinooks from January to March in 1975 and 1976 averaged 25 mm and 33 mm below treeline, respectively, and 35 mm and 64 mm above treeline, respectively. Below-treeline values amount to about 15% of the average snowpack.

For a given elevation, calculated snowpack evaporation was neither greater at the two major mountain gaps than along the foothills nor did it diminish from south to north as was expected.

STREETER BASIN EXPERIMENTAL BASIN

Streeter Basin was established as an experimental watershed in 1963 to consider the problems of water supply on aspen-grassland areas cleared for grazing. The b[illegible]98 ha in area, is 100 km south of Calgary. The problem perceived was that as the forest was cleared the flow from springs diminished and often dried up completely towards late summer. Cleared areas retained little, if any, snow cover because of redistribution by wind into stream channels and evaporation during the frequent intense chinooks common to the area.

Vegetation is representative of the montane-aspen transition between mixed prairie and coniferous subalpine forest. The main tree species, aspen (*Populus tremuloides*), attains heights of 16 m on lower slopes but only 5 m on windswept ridges. Forest and shrub stands are interspersed with grasslands.

Treatment

During the summer of 1976 a treatment was applied to West Streeter subbasin to combine the goals of improving range for cattle and big-game animals while maintaining or prolonging summer streamflow (Figure 5). These goals were to be met by manipulating vegetation cover to (1) concentrate snow in given areas to retard evaporation and melt, and (2) enhance infiltration of snowmelt water by reducing accumulation in groundwater discharge areas and increasing accumulation in recharge areas.

The range goals included rejuvenating shrub stands to improve existing browse and herbage production for maximum wildlife use.

Treatment was based on James River study results and consisted of cutting patches in the aspen stands of 1 1/2-2 H width by 60-180 m in length. The long axis was oriented normal to the direction of the high-velocity winds that are responsible for redistribution of snow on the ground. Strips of equal width were left between openings, and trails were cut between cleared patches to facilitate movement by cattle and big game. Stems were sheared off at ground level to facilitate suckering.

Snow courses were established running through cut and uncut areas on the treated subbasin (West subbasin) and through treed and natural openings on the control subbasin (Middle subbasin). Courses were located on east-facing slopes and at the same elevational range on both subbasins. The natural openings on Middle subbasin are approximately 60 x 200 m.

Three soil-moisture transects were established on the treatment subbasin. Each transect consisted of 16 neutron probe access tubes installed at 6 m intervals across two clearcut strips and across two strips of intervening forest.

Results

Snow Accumulation. Only one snow survey has been carried out, in March, 1977. The cleared patches accumulated 35% more snow than did the uncut area and almost three times as much as the natural openings.

Figure 5. Streeter Creek experimental watershed showing snow in cleared patches.

Streamflow. Changes in streamflow were recorded for the following variables averaged for the three years after treatment (level of significance is given within brackets):

annual flow	—	52% greater (0.7%)
April flow	—	44% greater (3.7%)
May flow	—	39% greater (2.9%)
June flow	—	78% greater (1.3%)
maximum daily flow	—	78% greater (0.6%)
maximum 7-day flow	—	103% greater (0.2%)
half-flow date	—	17 days earlier (7.4%)

Soil Moisture. For the first year after treatment, soil moisture in the upper 150 cm of the soil profile was nearly always higher than for the forest sites. Differences of 4.2—9.9 cm of water were measured during summer and fall months. Differences were least about mid-May, gradually increasing to a maximum in September at which time the average difference was about 8 cm. Greatest differences were recorded in the upper 15 cm of soil, followed by the upper 90 cm, and finally the upper 150 cm.

MANAGEMENT IMPLICATIONS

Management of the publicly-owned forest lands in Canada is the responsibility of the provinces. The Watershed Management Division of the Alberta Forest Service has recognized three main water problems which might be dealt with by forest management: (1) water quality, (2) shortage of water in the southern part of the province, and (3) flooding in the northern part of the province (Alberta Forest Service, undated). The division has established a watershed management objective for Alberta: through land and vegetation management to supplement control over yield and timing of streamflow in areas facing shortage or surplus water, consistent with water quality protection.

Oldman River Basin

Of Alberta's water, 89% flows north; 11% flows through the southern areas of the province serving 85% of the population. The Oldman River in the southwest corner of the province rises in the east slopes of the Rocky Mountains and flows halfway across the province before joining the Bow River to form the South Saskatchewan River. Demands for water have been increasing rapidly in the basin for municipal, industrial, and irrigation needs. Water requirements have been projected at three times the 1975 level by 1985, and six times by 2005 (Alberta Environment 1976). At present, demand is greater than flow in low flow years and storage is no longer sufficient for prolonged low flows. Water quality problems exist also, with low dissolved oxygen and relatively high phosphorous and nitrogen concentrations during low flows. Public hearings have been held and special studies commissioned. One study was to determine the feasibility of increasing water supplies in the Oldman basin through watershed management (Northwest Hydraulic Consultants Ltd. 1977). The Oldman River at Lethbridge drains an area of about 17,000 km^2 from which the natural annual runaverages 2.3 million acre-ft. (2.8 billion m^3). The area available for forest manipulation, however, amounts to only 1300 km^2. The report concluded:

1. Watershed management for water yield on a scale appropriate to the needs of the Oldman basin has nowhere been attempted, despite fairly persistent advocacy by the forest hydrology community. Likely reasons include (a) scepticism by management about scale-up of small-basin results, (b) the modest scale of the potential increases compared to natural flows and their year-to-year fluctuations.
2. An average yield increase of 10 cm/yr applied to a managed area of 1300 km^2 produces only about 100,000 acre-ft. (123 million m^3), or 4% of the natural flow at Lethbridge—an insignificant amount.
3. It must be emphasized that there is no solid experimental evidence that yield increases can be obtained in the chinook-prone environment of the area.

Swanson (personal communication), however, made the following calculations for possible water yield increases through forest management of the Oldman basin, assuming 1248 km^2 of manageable forest: large clearcuts would produce an increase of 3%, small clearcut patches would produce a 10% increase if 50% of the basin were cut, and a 13% increase if 70% were cut (Table 3).

If the "protection" forest (above 1981 m elevation) were added to the manageable area (for a total of 1989 km^2 instead of 1248 km^2) the percentage increases rise to 4, 15, and 20 respectively.

In considering the consultant's report several points should be made. The report quoted snowpack evaporation losses during chinooks that were 2.54 times greater than actual because of an error in an early draft of the chinook study results. Also, the consultant's report suggests that the snowpack evaporation values were calculated for forest conditions whereas the meteorological data were gathered in extensive openings in the forest. Management of the forest for water yield would require smaller openings oriented perpendicular to chinook winds to minimize evaporation.

Table 3. Water-yield increase in Oldman River basin (1248 km^2) by forest treatment[3].

Forest Treatment	Yield Increase	
	Acre-ft.	% of Natural Flow
Large clearcut	65,500	3
Small clearings		
– 50% of basin cut	218,500	10
– 70% of basin cut	301,500	13

[3]Source: Personal communication from R.H. Swanson, Canadian Forestry Service, Edmonton, Alberta

Most of the experimental watershed studies reported in the literature deal with water yield increases from particular forest management schemes, not with schemes specifically designed to maximize yield. Therefore, a treatment designed to maximize yield should improve substantially on experimental watershed results. A final point is that Cabin Creek commercial cut on Marmot basin was not expected to significantly increase water yields for the reasons given earlier, but the consultant's report treated that study as one set of results representative of Alberta's conditions.

Oldman River Pilot Project

Regardless of the conclusions of the consultant's report, the Oldman River Basin Panel of the Environment Council of Alberta acknowledged that vegetation manipulation can increase water quantity (Environment Council of Alberta 1979). Further, the Panel recommended that by 1985 the various provincial agencies involved should decide the appropriate approach to watershed management in the Oldman River basin.

As a first step, the Alberta Forest Service has proposed a feasibility study of large-scale vegetation manipulation for water yield in the 300 km^2 Upper Oldman River basin (Alberta Forest Service 1979). The study would identify land use conflicts and management concerns, and given these constraints select an optimal treatment for water-yield improvement. Water-yield predictions for different treatments will be made using a simulation model. Alternatives will be chosen that are the most cost-effective, that will provide the greatest water-yield increase, and that will optimize multiple land-use benefits. Finally, a basin treatment will be selected and implemented, according to the proposal.

PRIME

The Prairie Rivers Improvement and Evaluation (PRIME) scheme was outlined some 10-12 years ago. The concept was the transfer of water from northern Alberta south and east by a series of diversions and reservoirs—south because of the need in southern Alberta, and east to satisfy the entitlement of Saskatchewan to designated flows or proportions of natural flows in the Saskatchewan River. For a short period PRIME generated a great deal of discussion generally focussing on environmental issues. The concept was recently raised again (although without reference to PRIME) by an Alberta legislator who proposed a dam on the Peace River in northwestern Alberta as a start to southward diversion. The diversion would amount to only 1 1/2-2% of the discharge, or 1.9 million acre-ft., almost equal to the mean annual flow in the Oldman River at Lethbridge.

When the proposal was announced there was consternation in northeastern British Columbia. It was realized that the reservoir behind the proposed Alberta dam would flood much of the Peace River valley's agricultural land in British Columbia, and that this land has been suggested as an alternative for agricultural land to be flooded by a proposed dam on the same river, but in British Columbia, near Fort St. John.

REFERENCES

Alberta Environment. 1976. Oldman river flow regulation—preliminary planning studies. Alberta Environment, Planning Division, Edmonton, Alberta. Vols. I-IV.

Alberta Forest Service. (Undated). Forests and water. Alberta Forest Service, Alberta Energy and Natural Resources, Edmonton, Alberta. 4 p.

Alberta Forest Service. 1979. Proposal for a feasibility study on large scale vegetation manipulation for water yield improvement in the upper Oldman River basin. Watershed Management Section, Alberta Forest Service, November, 1979. (Unpublished report). 12 p.

Anderson, H. W. 1967. Snow accumulation as related to meteorological, topographic, and forest variables in Central Sierra Nevada, California. Int. Assoc. Hydrol. Publ. No. 78:215-224.

Environment Council of Alberta. 1979. Public hearings on management of water resources within the Oldman River basin—report and recommendations. Environment Council of Alberta, Edmonton, Alberta. 245 p.

Golding, D. L. 1977. Watershed treatment to alter snow accumulation and melt rates. Proc. Alberta Watershed Research Program Symp., Fish. Environ. Can., North. For. Res. Cent. Inf. Rep. NOR-X-176. P. 237-255.

Golding, D. L. 1978. Calculated snowpack evaporation during chinooks along the eastern slopes of the Rocky Mountains in Alberta. J. Applied Meteor. 17(11): 1647-1651.

Golding, D. L. and R. H. Swanson. 1978. Snow accumulation and melt in small forest openings in Alberta. Can. J. For. Res. 8(4):380-388.

Haupt, H. F. 1979. Effects of timber cutting and revegetation on snow accumulation and melt in northern Idaho. U.S. Dep. Agric., For. Serv., Intermountain For. Range Exp. Stn. Res. Pap. INT-224. 14 p.

Hoover, M. D. 1971. Snow interception and redistribution in the forest. Proc. Internat. Seminar for Hydrol. Professors, West Lafayette, Indiana. 3:114-122.

Miner, N. H. and J. M. Trappe. 1957. Snow interception, accumulation and melt in lodgepole pine forests in the Blue Mountains of eastern Oregon. U.S. Dep. Agric., For. Serv. Pac. Northwest For. Range Exp. Stn. Res. Note 153.

Northwest Hydraulic Consultants Ltd. 1977. Watershed management for increased water yield. Oldman River Basin Study Management Comm., Environment Council of Alberta, Edmonton, Alberta. 62 p.

Rothwell, R. L. 1977. Suspended sediment and soil disturbance in a small mountain watershed after road construction and logging. Proc. Alberta Watershed Research Program Symp., Fish. Environ. Can., North. For. Res. Cent. Inf. Rep. NOR-X-176. p. 285-300.

Satterlund, D. R. and A. R. Eschner. 1965. The surface geometry of a closed coniferous forest in relation to losses of intercepted snow. U.S. Dep. Agric., For. Serv., Northeast. For. Exp. Stn. Res. Pap. NE-34.

Satterlund, D. R. and H. F. Haupt. 1970. The disposition of snow caught by conifer crowns. Water Resour. Res. 6:649-652.

Storr, D. 1968. An estimate of snow evaporation potential in Marmot Basin. Paper presented at the National Workshop Seminar on Snow Hydrology, Fredericton, N.B. 7 p.

Swanson, R. H. and G. R. Hillman. 1977. Predicted increased water yield after clearcutting verified in west-central Alberta. Fish. Environ., Can. For. Serv., North. For. Res. Cent. Info. Rep. NOR-X-198. 40 p.

Wilm, H. G. and E. G. Dunford. 1948. Effect of timber cutting on water available for streamflow from a lodgepole pine forest. U.S. Dep. Agric. Tech. Bull. 968. p. 1-43.