ESTIMATING PRECIPITATION ON A REMOTE HEADWATER AREA OF WESTERN ALBERTA1/

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Introduction

The Saskatchewan River system rises on the east slopes of the Rocky Mountains (See Figure 1) and flows in an easterly direction through Canada's prairie provinces into Hudson Bay. It is the most important river on the semi-arid plains of western Canada, serving approximately 85 per cent of the population of Alberta and 42 per cent in Saskatchewan, and it derives most of its flow in the mountains and foothills of western Alberta. A large portion of this headwater area is the Rocky Mountain Forest Reserve, which is provincial public land managed primarily for water yield by a federal-provincial board, called the Eastern Rockies Forest Conservation Board, and the Alberta Forest Service.

In order to plan the management of this Reserve for optimum water yield, it was necessary at an early stage to initiate a network of climatological stations, for the purpose of defining the characteristics and distribution of precipitation and other parameters. The development of this network and the treatment of its preliminary data constitute the subject of this paper.

DESCRIPTION OF RESERVE

The Rocky Mountains Forest Reserve is steep and mountainous, rising from roughly 4,500 feet in the lower foothills on the east, through one or more mountain ranges to about 9,000 feet on the west. The southern half of the west boundary coincides with the Continental Divide.

The vegetation at lower elevations is of the aspen-grassland type. This merges with the spruce-fir forest which predominates between 5,000 and 7,000 feet. Above 7,000 feet the spruce-fir gives way to stunted alpine fir, larch and alpine tundra. Large tracts of lodgepole pine are common below 6,500 feet in areas which have been burned or logged.

Access is by Trunk Road which runs the length of the Reserve. Branches from this road penetrate the front range periodically and connect with roads on the plains. However, access in the Reserve is mainly by low-standard roads and trails.

STORAGE PRECIPITATION GAUGE NETWORK

The need for a precipitation measuring network was recognized by the Eastern Rockies Forest Conservation Board soon after this agency was formed in 1947. However, implementation of a network had two obstacles to overcome - relatively difficult access and few residents who could act as observers. The only people living in the Reserve were rangers of the Alberta Forest Service who were located at some 17 ranger stations in low valley locations.

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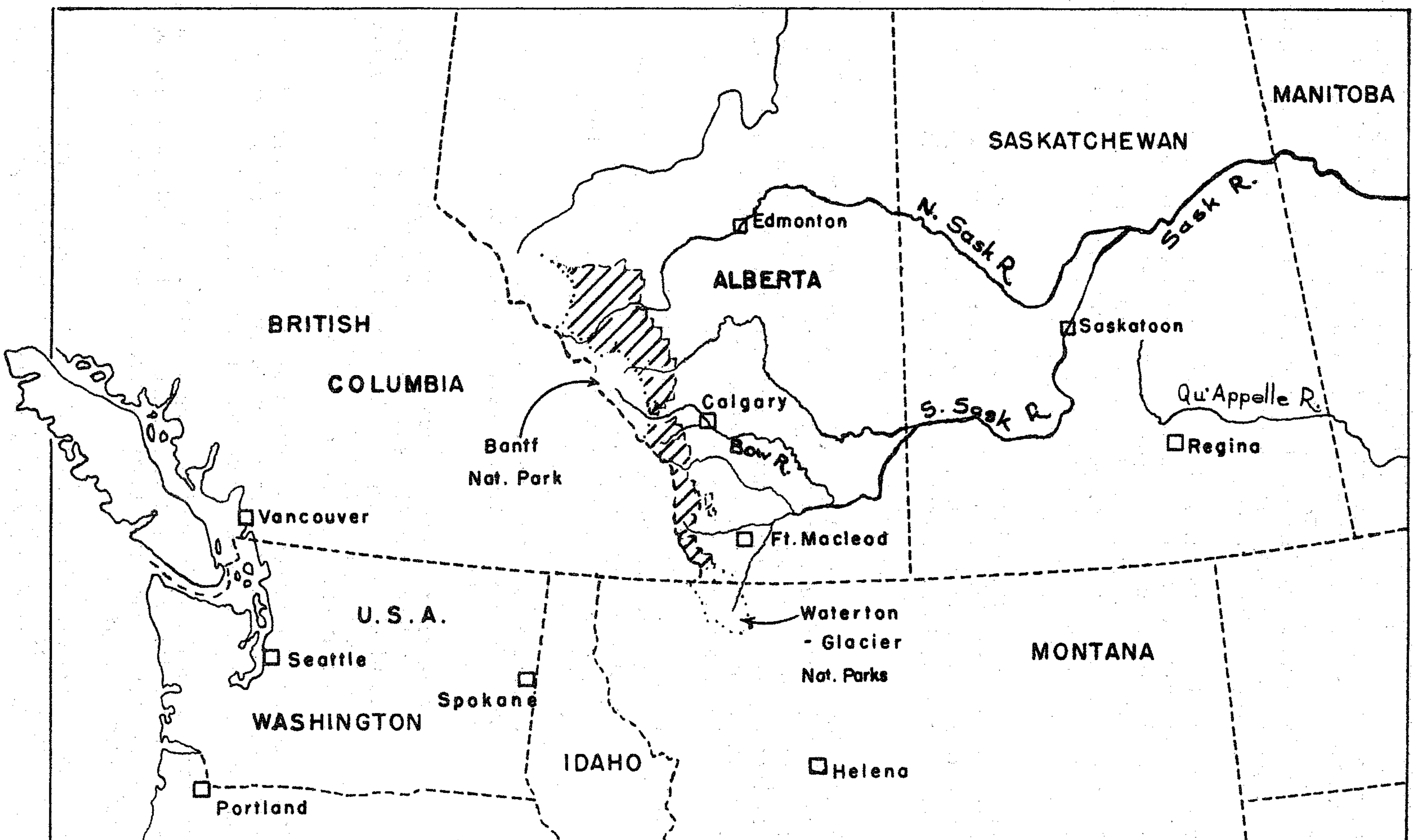

FIGURE I MAP SHOWING ROCKY MOUNTAINS FOREST RESERVE.

- Rocky Mt. For. Res.   Scale - 0 50 100 Mi.

Therefore it was necessary to select a relatively simple type of unattended gauge which could be readily distributed into remote areas and serviced at infrequent intervals by rangers. A slightly modified version of the Sacramento-type storage precipitation gauge was selected, and in the early 1950's nearly one hundred of these were installed throughout the Reserve, on front and back ranges, in interior valleys, and near the Continental Divide. Readings have been taken spring and fall of each year since that time. Overall direction of the network has been by the Eastern Rockies Forest Conservation Board although in recent years the Meteorological Branch of the Federal Department of Transport has taken an active interest in its development.

The gauges are conical in shape, of 100 inches capacity, steel, painted black and set on stands to keep the gauge clear of the snowpack. Orifice diameter is eight inches and standard Alter shields are used. The gauges are re-charged each fall with anti-freeze solution. Until 1961 the charge was calcium chloride solution but since that time, ethylene glycol has been used instead. Charges of two, three or four Imperial gallons (plus one quart of water in each case) are used, depending on the anticipated precipitation. One pint of No. 10 oil is added to suppress evaporation.

Measurements are made by dip-stick from the top of the gauge. An accuracy of one-sixteenth of an inch on the dip-stick is possible with this method which in terms of precipitation is three-tenths of an inch or less. Considering the magnitude of other possible errors such as under-catch due to wind, this is considered quite acceptable.

THE BROADER NETWORK

In 1962, the "East Slopes (Alberta) Watershed Research Program", involving a number of cooperating agencies of the Federal and Alberta governments, got under way, and established a climatological network sub-committee. Under this sub-committee the storage precipitation gauges became part of a broader network on the East Slopes. This broader network includes measurements of various climatic parameters, to obtain a better knowledge of the mountain climate. There are three orders of stations:

First order stations
- permanent, relatively few in number
- distributed low and high on the front range, in interior mountain valleys and near the Continental Divide.
- daily record of precipitation, temperature and other parameters.

Second order
- of several decades duration - in chains and groups to relate to first order stations - daily record of precipitation and temperature

Third order
- the Sacramento-type storage precipitation gauges - relied upon to give comparatively dense coverage for the main parameter, precipitation. - Many will be "satellite" in nature, remaining in place ten years or more until highly correlated with a longer-term station, then moving to a new location.

In addition, the broader concept includes snow courses co-located with some network stations, to relate snowpack characteristics to precipitation, temperature and elevation. Also envisaged are snow markers to be read from the air at inaccessible locations.

Some progress has been made in implementing the broader network. Last year, twelve ranger stations were selected as first and second order stations and commenced year-round, daily readings of precipitation and temperature, although they had already been taking summer records for a number of years.

However, progress has been slower in installing first and second order stations at points away from ranger stations. These must be of the unattended type and only one has been initiated thus far. Major improvements in this situation await increases in staff and further developments in instruments.

Of the third order stations (the storage gauges) a few "satellites" have correlated highly with long-term stations (r = about .90) after 10 years and have been moved to new locations where coverage was more sparse.

Also, ten snow courses have been set out during the past two years, in most cases co-located with storage gauges or the unattended station.

It will be seen from the foregoing that the broader network is only in its initial stages. However, the storage precipitation gauge network has existed for about one decade and the records have recently been used to prepare preliminary isohyetal maps, as described below.

PRELIMINARY ANALYSIS AND USE OF STORAGE GAUGE DATA

This analysis was confined to the portion of the Reserve lying south of the Bow River (See Figure 1), because the network is denser in that portion (40 square miles per gauge) than it is farther north (215 square miles per gauge). Also, the gauges south of the Bow are distributed more uniformly over the range of elevations.

The analysis was directed toward determining precipitation-elevation relationships, to be used in the preparation of isohyetal maps. However, before undertaking this, certain adjustments to the gauge records were considered advisable. Therefore, in the remainder of this paper, the adjustments are described first, followed by sections dealing with precipitation-elevation relationships and the preparation of isohyetal maps.

Adjustments to Records

1. Adjustments for normal under-catch were made to all records, for both summer season (Mid-May to Mid-October) and winter (Mid-October to Mid-May). The basis for these adjustments is developed below, beginning with summer season.

Over a period of eight summer seasons, 12 ranger stations throughout the Reserve provided 91 seasonal comparisons between the accumulated daily precipitation measured by a Meteorological Branch standard rain gauge and the corresponding precipitation caught in a co-located storage gauge. These comparisons produced an average ratio, standard, storage gauge, of 1.16:1, with about two-thirds of the comparisons falling between 1.06 and 1.26.

This was accepted as an indication of general under-catch by storage gauges. In support, under-catch had been commonly found in other studies (Wilson, 1954). Also, a general under-catch would be logically possible, in view of the likelihood of greater wind turbulence at a storage gauge orifice (8 - 9 feet above ground) than at the top of a standard rain gauge (1 foot above ground).

Therefore all the summer season storage gauge records were increased, for purposes of this analysis, by multiplying by 1.16; except at ranger stations, where the actual ratios determined for the respective stations were used.

For winter records, no comparison of storage and standard gauge catches could be made because the standard rain gauge is not used in winter. However, a few data were available from the Reserve comparing storage gauge catch with the corresponding increase in snowpack, and also a review of literature (e.g. Wilson, 1954) showed that under-catch for snow is generally greater than for rain. On this basis, a factor of 1.20 was selected, rather arbitrarily, and all the winter storage gauge records were adjusted upward by it.

2. In addition to the foregoing, further adjustments were made to the records from four severely exposed gauge locations, to eliminate the effects of excessive windiness, as follows.

After some years in the exposed locations, these gauges were moved short distances to more sheltered sites, because the excessive windiness was suspected as a source of under-catch. Subsequently this under-catch was made evident by double-mass analysis*, as may be seen in Figure 2, where the gauge caught distinctly less precipitation before it was moved than afterward, in comparison with other gauges in the general vicinity. Double-mass analyses were carried out for each of the four gauges, for both winter and annual precipitation, with results similar to those shown in Figure 2.

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* as described by Linsley, Kohler and Paulhus (1958).

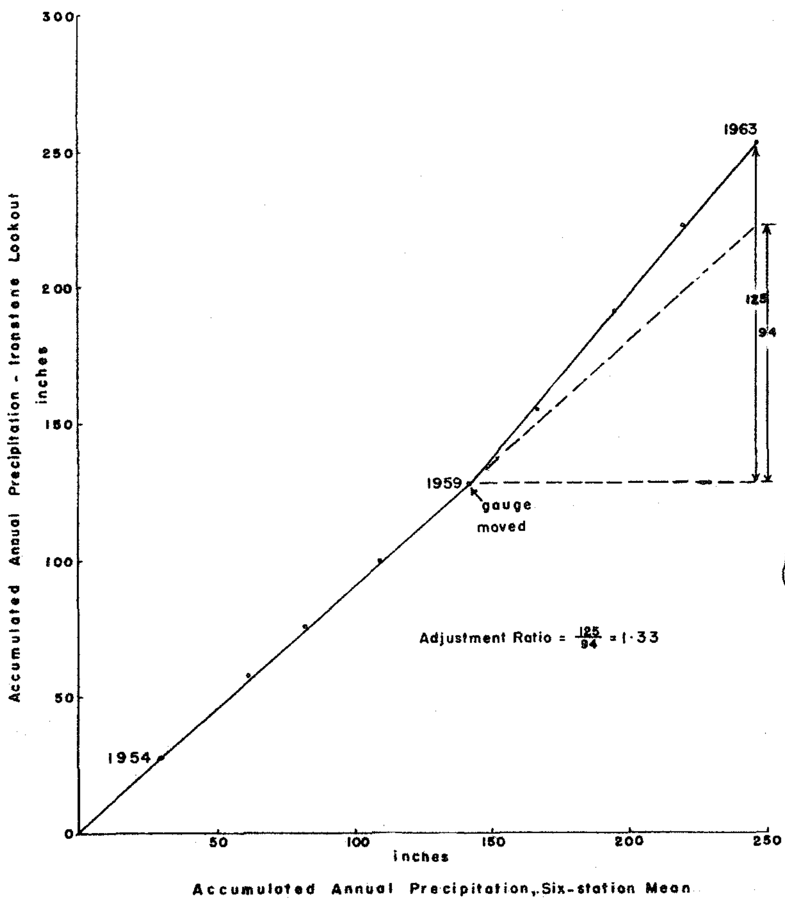

FIGURE 2 DOUBLE-MASS CURVE FOR IRONSTONE LOOKOUT STORAGE PRECIPITATION GAUGE.

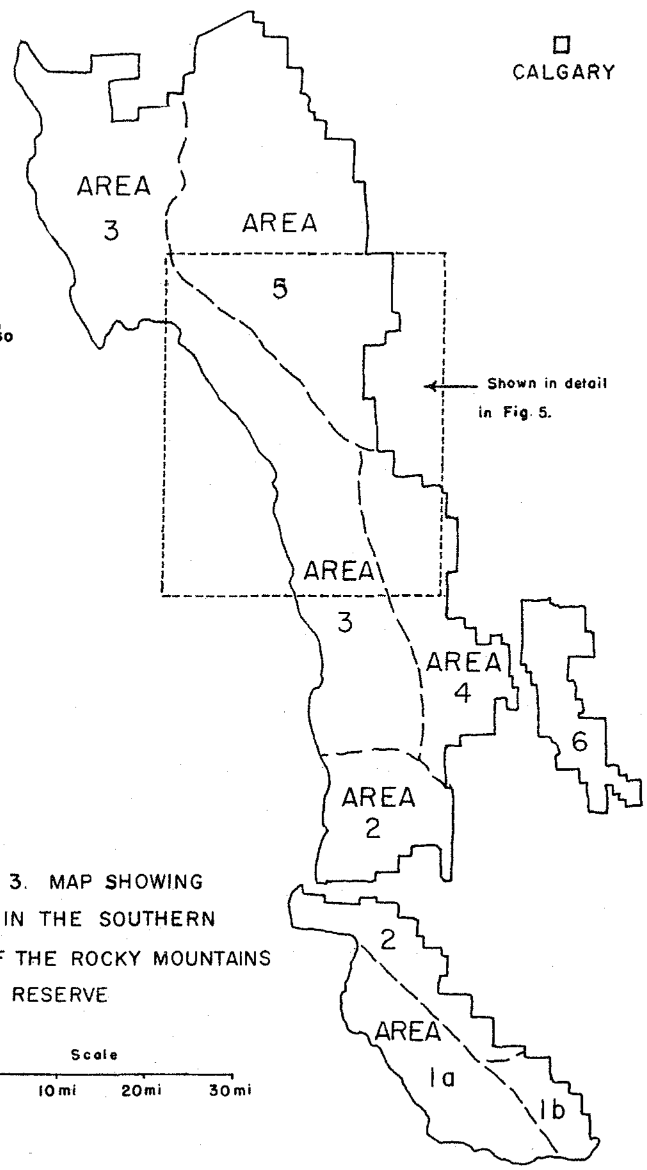

FIGURE 3. MAP SHOWING AREAS IN THE SOUTHERN PART OF THE ROCKY MOUNTAINS FOREST RESERVE

Then, to eliminate the effects of the excessive windiness, the records from the exposed locations (prior to the moves) were adjusted upward by multiplying by the respective adjustment ratios (1.33 in the case of Figure 2).

3. Another adjustment considered was that of altering the mean annual precipitation values for the various gauges to conform with 1931-60 "normals". However, to carry out this adjustment by usual methods was not advisable since the nearest stations with records dating back to 1931 were out in the plains to the east where the climate is different. Therefore, another approach was taken, as follows.

Streamflow records dating back, or almost back, to 1931 were found for the Oldman River in the vicinity of Fort Macleod, which is shown on the map in Figure 1, and for the Elbow River at Calgary. These long records made it possible to estimate closely the "normal" annual flow, 1931-60, at each of the two locations. These normal flows were compared with the average annual flows for 1954-64 (the period of storage gauge records) at the two locations, and on the Oldman River the 1954-64 average annual flow was found to be almost exactly "normal", while on the Elbow it was only three percent different from "normal".

Since more than 80 percent of the water flowing at these two stream gauges comes from the area under consideration (i.e. Reserve south of Bow River), the foregoing was accepted as indicating that the water balance, and hence precipitation, in that area were approximately "normal" for the period 1954-64. Therefore the mean values from the storage precipitation gauges were accepted as approximating normals, without adjustment.

Precipitation-elevation Relationships

A relationship frequently useful in managing mountain watersheds is that of precipitation with elevation. Therefore such relationships were determined in this study.

Firstly, the portion of the Reserve under consideration (i.e. south of the Bow River) was divided into six areas which were judged to differ climatically, on the basis of gauge records and topography. These areas are shown in Figure 3.

Area 1 was considered to receive considerably more precipitation than the other areas. This area was sub-divided into 1 (a), behind the front range, and 1 (b), which is on the east slope of the front range and rises very steeply from the plains. Area 2, which includes both front range and the east side of the Continental Divide, was considered to receive less precipitation than 1 but more than the other areas. Area 3 lies between the front range and the Continental Divide while areas 4 and 5 are front range. Area 6 is a range of hills east of the front range.

Precipitation-elevation relationships were prepared for the various areas, as illustrated in Figure 4. For each area, the points plotted were the mean annual, mean October-May and mean May-October precipitation values of each of its storage gauges.

The curves shown for area 3 are also typical of those prepared for areas 2, 4 and 5. These were all linear. The area 2 curves were similar in slope to those of area 3 but were higher, by about ten inches of moisture, for both October-May and annual precipitation. The curves for areas 4 and 5 were generally lower, by several inches of precipitation, than those of area 3, and exhibited slightly flatter slopes.

Included in Figure 4 are curves for area 1 (a), indicating the very large amounts of precipitation in that area, even at low elevations. These curves also indicate the probability of a curvilinear relationship in the future when gauges have been established at higher elevations in the area.

Areas 1 (a), 1 (b) and 6 included too few gauges (combined total of 13) to permit meaningful statistical analysis. However, statistical analysis of the precipitation-elevation relationships in the other areas was carried out, and selected data are presented in Table 1. Of particular interest are the values of r^2, which were, in simple language, the proportions of total variance attributable to elevation. The high value of r^2 were taken as a strong indication that elevation was the predominant factor influencing precipitation.

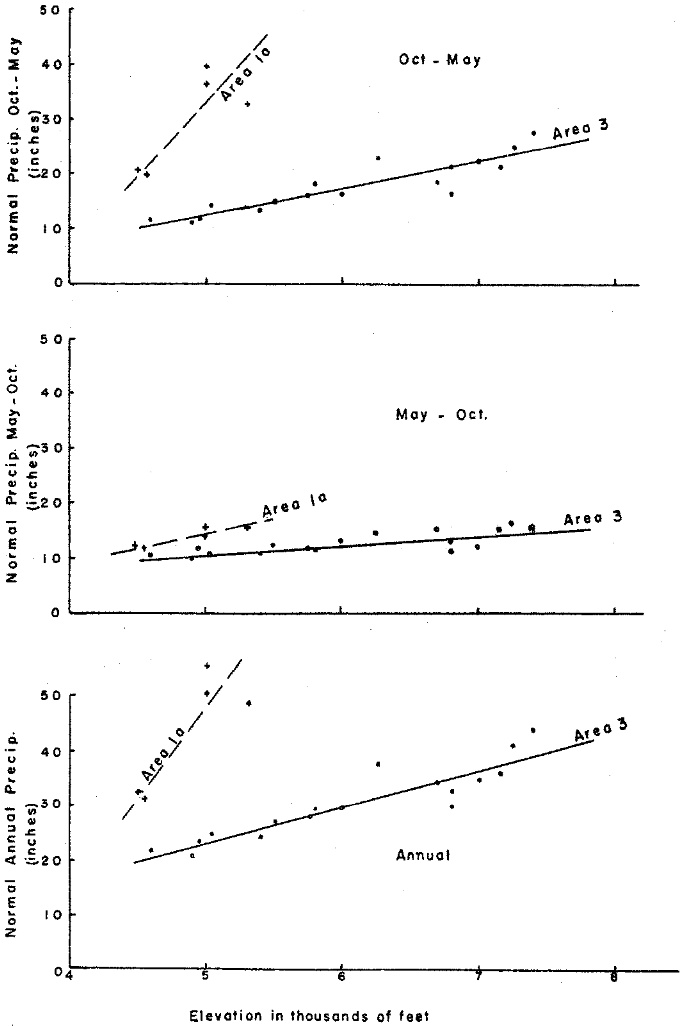

FIGURE 4. PRECIPITATION - ELEVATION RELATIONSHIPS, AREAS Ia AND 3.

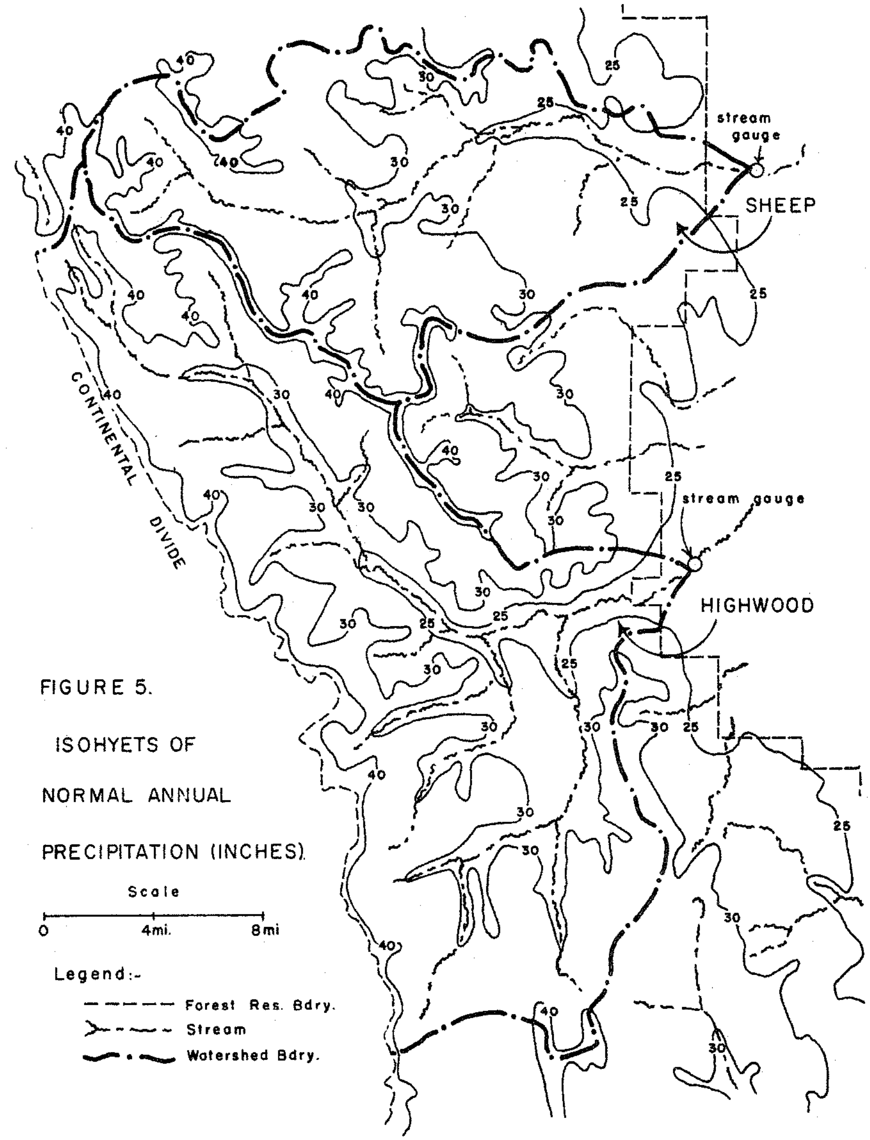

FIGURE 5.

ISOHYETS OF NORMAL ANNUAL PRECIPITATION (INCHES).

Table 1. Selected Statistical Data

Area	No. of Gauges	Range of Gauge Elevations	Mid-Oct. to Mid-May					Annual				
			Avg. Dist. of Points from Curve	% of Avg. Precipitation	Est. Std. Dev'n. from Curve	% of Avg. Precipitation	r^2	Avg. Dist. of Points from Curve	% of Avg. Precipitation	Est. Std. Dev'n from Curve	% of Avg. Precipitation	r^2
		FEET	INCHES		INCHES			INCHES		INCHES		
2	15	4500 -6800	2.1	8.8	2.7	11.3	.72	3.2	8.7	4.1	11.1	.63
3	17	4600 -7400	1.5	8.4	2.2	12.1	.83	1.9	6.3	2.8	9.0	.83
4	8	4600 -6650	0.6	4.7	0.9	6.9	.78	1.3	5.3	2.0	7.9	.77
5	17	4400 -7150	2.0	13.6	2.6	17.9	.71	2.6	9.3	3.4	11.9	.58
Average							.76					.70

Of the four areas, 2 to 5, area 3 exhibited the most rapid increase in annual precipitation per thousand foot rise in elevation (6.6 inches per thousand feet), while area 5 showed the least, (4.5 inches per thousand feet).

Isohyetal Maps

The high significance of the precipitation-elevation relationships has rendered them useful to management for the preparation of preliminary isohyetal maps. These have been prepared for a considerable part of the Reserve south of the Bow River, using mainly the precipitation-elevation relationships for the different areas in conjunction with contour maps. Figure 5 is an example of a map prepared for annual precipitation.

Figure 5 also helps to illustrate a type of check, which has been used wherever possible, on the validity of the isohyets. Average normal precipitation on each of the Sheep and Highwood watersheds was estimated with the aid of a dot grid. Also, average annual streamflow from each of the watersheds was calculated using the 1954-64 stream gauge records. Subtracting the latter from the former resulted in a difference of approximately eighteen inches for each watershed, which would be mainly due to evapotranspiration. This figure was considered reasonable and therefore constituted a rough overall check on the isohyets.

Isohyetal maps may also be preapred for October-May precipitation. These are useful in indicating the general distribution of winter precipitation occurring as snow. What this means in terms of spring snowpack is one of the "answers" anticipated from the co-located snow courses and gauges. The initial results show the April snowpack to be usually less than precipitation caught from mid-October to April, possibly on account of melting of early snow or evaporation by warm "chinook" winds in winter.

CONCLUSION

This paper has outlined a network, designed to gain knowledge of precipitation and related climatic parameters essential to the management of a very important but relatively remote headwater area. Relatively difficult access and small numbers of observers were two of the problems that had to be taken into account.

The paper has also presented some results from the storage precipitation gauges, which were the initial installations and have approximately one decade of record. The use of these results to prepare preliminary isohyetal maps has been described. Two problems that could be accounted for only approximately were gauge under-catch and the scarcity of long-term records.

New and improved results are anticipated with further development and the passage of time.

REFERENCES

1. Wilson, Walter T.: Discussion of "Precipitation at Barrow, Alaska, greater than recorded" by Robert F. Black. Transactions, American Geophysical Union, Vol. 35, April 1954, pgs. 206-7, 1954.

2. Linsley, Ray, K., Jr., Max A. Kohler and J. L. H. Paulhus; Hydrology for Engineers. McGraw-Hill Book Co., pgs. 33-4, 1958.

LIST OF FIGURES