PRECIPITATION VARIATIONS IN A SMALL FORESTED WATERSHED 1/

By

D. Storr 2/

Introduction

Interest in watershed management in Canada has lagged behind that in the United States but has been increasing in Alberta since about 1960. As a part of a program set up to evaluate and improve land management on the east slopes of the Rocky Mountains for water yield, Marmot Creek Basin was instrumented to study the water balance in a typical sub-alpine spruce-fir forested watershed. Instrumentation began in 1962 and was mostly completed in 1964 although minor changes are still being made. This program has been described in detail by Jeffrey (1964, 1965). This paper is a preliminary report on the methods and first results of the precipitation measurement program, so the conclusions are somewhat tentative and may be subject to some future revision.

Marmot Creek Basin (Fig. 1) is located about 50 miles west of Calgary, Alberta in the narrow steep-walled Kananaskis Valley between the Fisher Range and the Continental Divide. Elevation in the basin ranges from 5200 ft. MSL to 9200 ft. MSL with tree-line at approximately 7500 ft. The general aspect of the basin is easterly. The topography is steeply sloping, averaging 39 percent for the basin as a whole (Fig. 2). This limits vehicle access to the lower portion of the basin and limits reading the upper precipitation gauges to once a week in the brief summer and about once or twice during the 8 - 10 month snow season.

Precipitation Gauge Network and Observing Procedure

Because of the steep terrain and the high proportion of convective type precipitation, a very dense network of raingauges has been installed. In this area of about 3½ square miles, there are now 30 sites at which summer rainfall is measured weekly, while 10 Sacramento storage gauges and one Leupold-Stevens recording gauge measure seasonal and annual precipitation (Fig. 3). The raingauge used is the standard Meteorological Service of Canada gauge, with an orifice of 10 square inches standing 12 inches above ground. Its capacity of 4.5 inches has proved adequate so far. A supplementary network of 10 small orifice gauges with a capacity of 18 inches guards against complete loss of data in case a weekly visit has to be missed in very wet weather. The standard MSC gauge measures rainfall to one one-hundredth of an inch while the Leupold-Stevens measures both rain and snow to the nearest tenth and the Sacramento to the nearest third of an inch. The MSC gauge is virtually useless for measuring snowfall. The gauges are exposed with the orifice horizontal. An exhaustive test (Storr, 1966) over a two-year period proved that gauges with the orifice parallel to the slope consistently catch less than those with the orifice horizontal in this valley on the lee side of the Rockies.

In addition to the gauge network, 20 snow courses have been laid out in the basin to sample the snow pack under various elevations, aspects and types of tree cover. They are read monthly from January to April, then weekly until the snow is gone in May or June.

The two main difficulties in the observing program arise first from the steep terrain which limits the frequency of gauge readings, and secondly from the frequent occasions in the Spring and Fall when rain falls in the lower levels and snow at higher elevations. This produces a situation where precise measurements are obtained in the lower areas, and less precise measurements in the area where the heaviest precipitation falls.

1/ This study was undertaken as part of the Meteorological Branch contribution to the East Slopes (Alta) Watershed Research Program.

2/ Research Hydrometeorologist, Meteorological Branch, Canada Dept. of Transport.

Summer Variations in Rainfall

Because the raingauge network is much denser than the Sacramento network and the gauges can be read much more frequently, the rainfall pattern over the basin can be delineated more precisely than that of snow. Charts of the total summer rainfall have been drawn for the three years 1964, 1965, and 1966 (Fig. 4, 5 & 6) and although the rainfall values naturally vary from year to year, the pattern is remarkably consistent. Even though a high proportion of the rain is caused by convective activity, over a summer season this variability smooths out as several studies have reported (McKay 1964, Linsley and Kohler 1951, Rainbird 1965). There is a progressive increase of amount with elevation, amounting on the average to about 1.5 inches per thousand feet (Fig. 7) but there is considerable scatter from this value, indicating the importance of such other factors as aspect and slope. This "Best Fit" line is obviously only a rough guide, and the next step in refining the rainfall map will be to use the graphical correlation technique as Spreen (1947) has done for western Colorado to relate rainfall totals to all three factors. It is interesting to note that the curve levels off by about 7600 MSL with a possible decrease near 8000 MSL. This requires further study.

Annual Variation in Total Precipitation

Assuming that the annual precipitation pattern will be similar to the consistent summer rainfall pattern, the rainfall pattern was used as a guide in the construction of the annual precipitation map. The annual Sacramento data were plotted and the summer pattern applied to them with only one discrepancy found. Fig. 8 shows the average annual precipitation for the three water-years October 1963 - September 1966 and it can be seen that the highest precipitation area is in the headwaters of Twin Creek instead of the headwaters of Middle Creek as on the rainfall charts. This difference is easily explained. The majority of heavy summer rains come with winds from the west or southwest, so slopes facing this direction will receive the largest amounts. This accounts for the heavy falls on the south-facing slopes in the headwaters of Middle Creek. In contrast, many of the heaviest snowfalls are caused by outbreaks of Arctic air bringing northerly winds to the basin, and dropping most of the falls on north-facing slopes such as those in the Twin Creek headwaters. Also some "blow-over" of snow from the next basin to the west has been noted visually in the Twin Creek headwaters and may contribute to the high precipitation area there. The previously mentioned assumption therefore seems justified.

Over the past three water years 25 - 30% of the annual precipitation has occurred as rain with the remaining 70 - 75% as snow or a mixture of rain and snow. This indicates the importance of snow to the water budget of the area and also the importance of studies in the fields of snow melt, snow accumulation, snow evaporation, etc., in the hydrologic investigation.

Accuracy of Measurement

The obvious question that must arise concerns the accuracy of the precipitation measurements. Most recent studies (McKay 1964, Allis et al 1963) conclude that "true areal precipitation remains unknown" but the degree of accuracy required depends on the purpose of the investigation (Hershfield 1965, Bruce and Clark 1966). An accurate estimate of the total volume of precipitation falling on an area is not as difficult as estimating the spatial and temporal distribution. Obviously the degree of accuracy of estimation depends on two factors; the accuracy of the devices measuring the point precipitation, and secondly the density of the gauge network in sampling the area adequately.

It is not the purpose of this paper to compare the relative performance of raingauges, but since the standard Meteorological Service gauge stands only 12 inches above ground it is felt to be at least as accurate as the standard U.S.W.B. gauge. Curry and Mann (1965) found that the Sacramento storage gauge undercatches rain by 15 - 20% but Bruce (1961) found no significant difference between the Sacramento and the MSC standard gauge. Some preliminary incomplete data for 1966 tends to support Curry's conclusion, but until more data are available the annual precipitation map will not be adjusted.

Gauge exposure in the basin is as uniform as possible, but with some gauges in clearings in the forest and some possibly over-exposed in the alpine area, there will be some difference in catch efficiency. It is a matter of continuing study to improve gauge exposure.

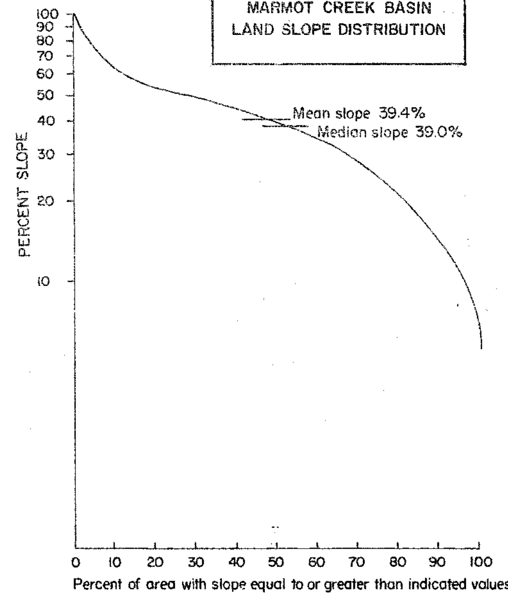
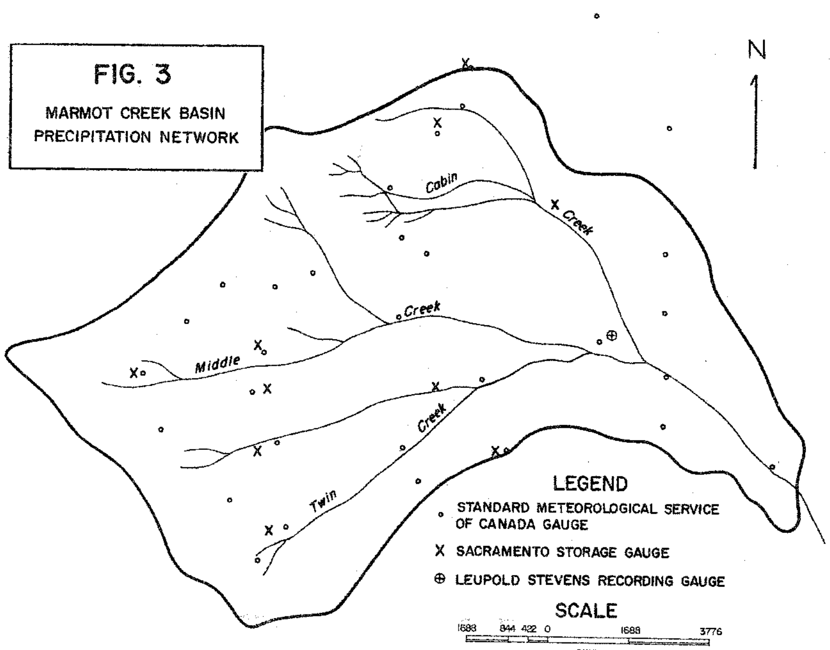


FIG. 2

MARMOT CREEK BASIN
LAND SLOPE DISTRIBUTION

FIG. 3

MARMOT CREEK BASIN
PRECIPITATION NETWORK



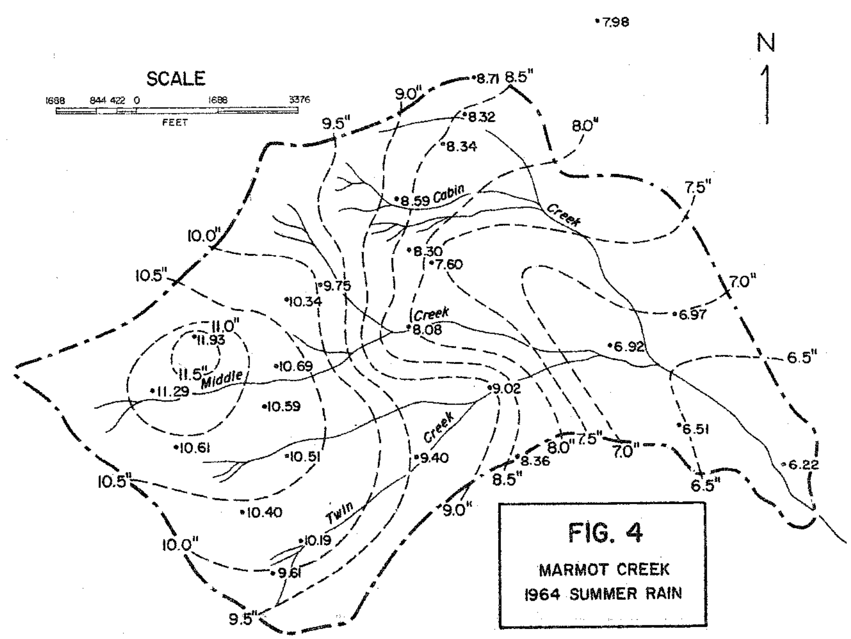


FIG. 4

MARMOT CREEK
1964 SUMMER RAIN

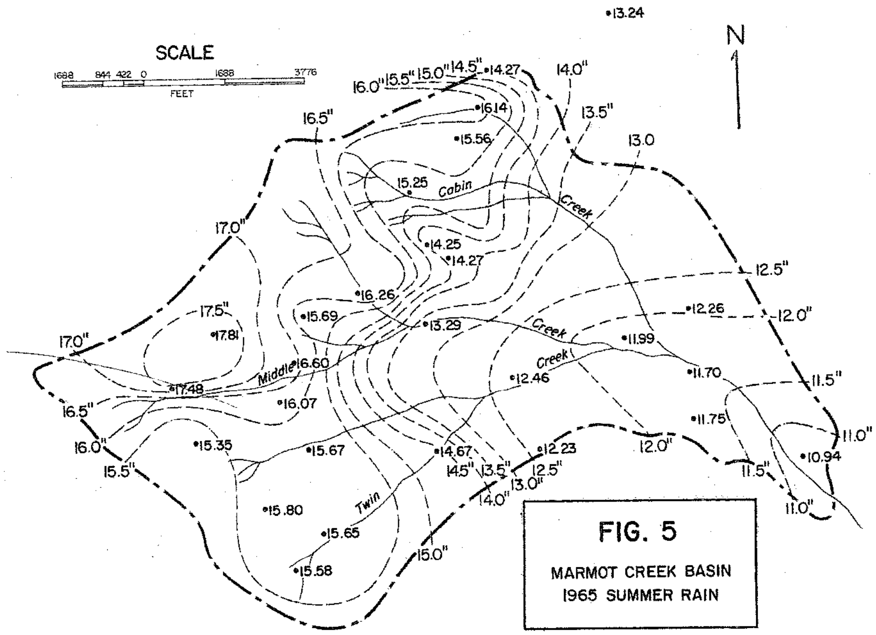


FIG. 5
MARMOT CREEK BASIN
1965 SUMMER RAIN

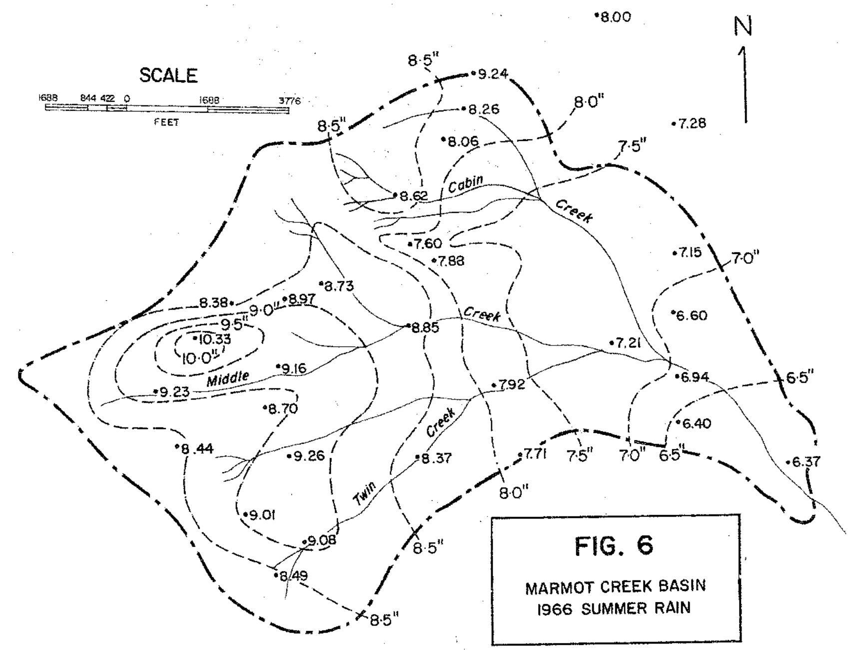


FIG. 6
MARMOT CREEK BASIN
1966 SUMMER RAIN

FIG. 7
RAINFALL-ELEVATION RELATIONSHIP

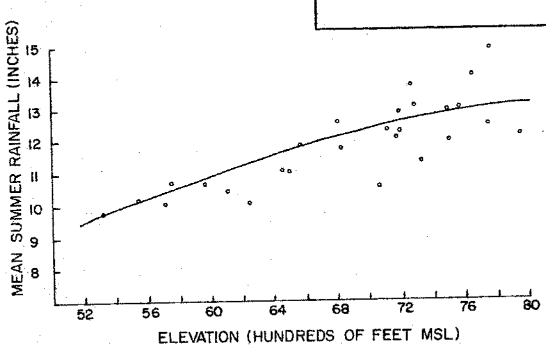
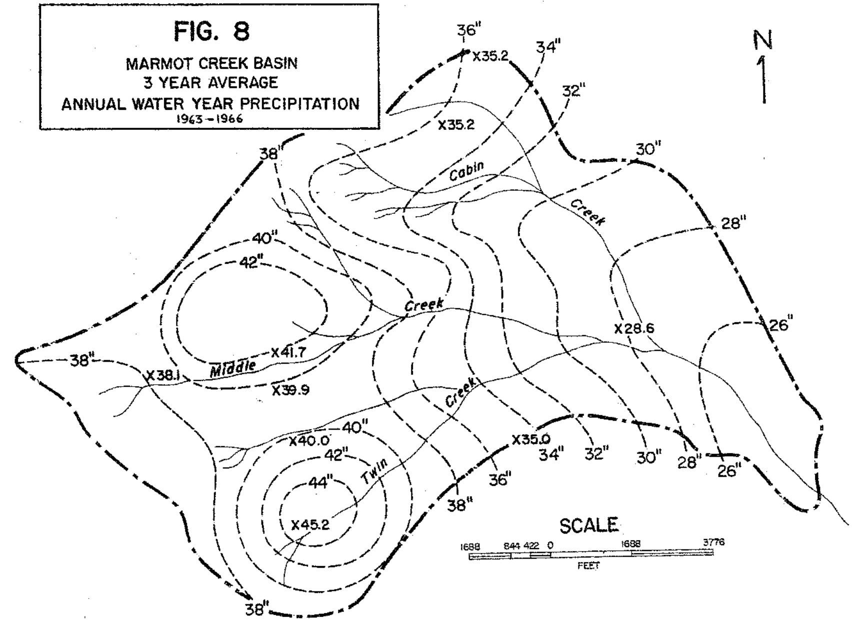


FIG. 8
MARMOT CREEK BASIN
3 YEAR AVERAGE
ANNUAL WATER YEAR PRECIPITATION
1963-1966



Concerning the network density, it was laid out to sample as adequately as possible, within the limits of access and available clearings, all ranges of elevation, slope and aspect as recommended by many investigators (Rainbird 1965, Neff 1965, Corbett 1965). The network density of 8.3 per square mile is the most dense in Canada, as far as can be ascertained, and is similar to that at Coshocton, Ohio. This is not to imply that the network is perfect, in fact there are a few areas of uncertainty remaining and three more standard raingauges will be installed this year. These however are mainly to improve definition of storm rainfall patterns and would affect seasonal or annual precipitation by less than 1 inch.

An indirect method of assessing the accuracy of the precipitation measurement is by comparison with surface run-off figures. The basic water budget equation: $P = Q + ET + \Delta gw + \Delta sm$ where P is precipitation,

Q is surface run-off,
ET is evapotranspiration,
Δgw is change in groundwater storage,
Δsm is change in soil moisture storage,

may be modified in the following manner for this purpose. Soil moisture storage in this basin is relatively minor because of the shallow mantle over most of the area, and because of its high percolation rate as shown by the rapid response of ground-water wells to precipitation (Stevenson*, personal communication). Also the groundwater wells and the surface run-off are on the "draw-down" phase each fall and tend to be comparable each year. Therefore, if the annual water-year (ending September 30) figures for P, Q, and ET are used, the terms Δgw and Δsm will be negligible in comparison and may be ignored. Any small error created by this step may be further minimized by taking average annual water year figures. Now, $P = Q + ET$.

TABLE 1

AVERAGE PRECIPITATION, RUN-OFF AND INDICATED EVAPOTRANSPIRATION AT MARMOT CREEK

	Precipitation (inches)	Run-off (inches)	Indicated Evapotranspiration (inches)
Total Marmot Creek Basin	35.26	19.63	15.63
Twin Creek Sub-basin	38.70	24.09	14.61
Cabin Creek Sub-basin	32.10	15.58	16.52
Middle Creek Sub-basin	38.28	23.44	14.84

A comparison of the indicated evapo-transpiration loss of 15.6 inches for the basin with the estimated annual lake evaporation of 22 inches (Bruce and Weisman, 1967) suggests three possibilities:

1. Actual evapotranspiration is less than potential evapotranspiration as estimated from the lake evaporation by 6.4 inches.
2. The estimate of lake evaporation may be too high.
3. The measurement of precipitation by storage gauges may be too low.

It is suspected that all three factors may be involved and each will be the subject of further study.

The sub-basin figures however are consistent. It can be seen that Cabin Creek has a higher evapotranspiration loss than the other two sub-basins, but this was expected since it has a much higher proportion of south-facing slopes and therefore receives more radiant energy and will lose more water as a result.

It is therefore felt that although the annual precipitation figures may have to be adjusted for an undercatch by the storage gauges as previously mentioned, the adjustment will not be great, and the basic pattern is correct.

* Stevenson, R.D., Groundwater Geologist, Alberta Research Council.

Intensity Variations

Precipitation intensity is measured at four locations in the basin with tipping bucket gauges, and eventually some conclusions may be drawn about variations in intensity with elevation, slope, aspect, etc. However, for a number of reasons (mainly mechanical failure) no significant amount of data has been collected from the two upper stations for analysis.

Applications and Discussion

This study has shown that, within limits, it is possible to measure with present instruments the precipitation pattern even in a complex mountainous watershed. The question of temporal variations is a matter of continuing study.

Improvements in instrumentation are needed to overcome the problems of measuring mixed rain and snow, and of frequency of observation.

The study also points up the importance of careful selection of gauge sites both for point measurement of precipitation and for network planning.

The wide variation in precipitation amount over such a short distance confirms the well known fact that researchers and hydrologists should not expect to measure the precipitation in mountainous watersheds using a single gauge without accepting the risk of a large degree of error. Experience in this and two other watersheds in Alberta would indicate that the more rugged the terrain the greater will be the precipitation variation.

Although the precipitation figures are tentative and subject to revision as noted, they do not indicate any major roadblocks to the attainment of a reasonably accurate annual water budget for the basin. Other studies are being undertaken to assess evapo-transpiration by the energy budget and Penman methods, and to enable the assignment of values for ground-water and soil moisture storage changes for shorter periods and smaller areas. When the water budget has been delineated, experiments in various forms of manipulation of vegetation will be carried out to determine the optimum means of improving or sustaining water yield, regime and quality.

ACKNOWLEDGEMENTS

The area-elevation curve (Fig. 2) was prepared by Mr. G. E. Curry while serving with the Eastern Rockies Forest Conservation Board.

The surface run-off data were collected and prepared by Mr. D. A. Davis, Hydrologist, Water Resources Branch, Canada Department of Energy, Mines and Resources.

REFERENCES

Allis, J. A., Harris, B., and Sharp, A. L., 1963: "A Comparison of Performance of Five Raingage Installations". Journal of Geophysical Research 68: 4723 - 4729.

Bruce, J. P., 1961: "A Note on Precipitation Measurements by the U.S.W.B. Storage Precipitation Gauge and Meteorological Service of Canada Standard Measurement Methods". Canada Department of Transport Technical Circular Series Cir - 3520 Tec - 366.

Bruce, J. P. and Clark, R. H., 1966: "Introduction to Hydrometeorology". Pergamon Press, London p 107.

Bruce, J. P. and Weisman, B., 1967: "Provisional Evaporation Maps of Canada". Canada Dept. of Transport, Technical Circular Series (in press).

Corbett, E. S., 1965: "Measurement and Estimation of Precipitation on Experimental Watersheds". Proceedings of International Symposium on Forest Hydrology, Pennsylvania State University, 1965, University Park, Pa.

Curry, G. E. and Mann, A. S., 1965: "Estimating Precipitation on a Remote Headwater Area of Western Alberta". Proc. 33rd Annual Western Snow Conference.

Hershfield, D. M., 1965: "On the Spacing of Raingauges". Proc. WMO-IASH Symposium on Design of Hydrometeorological Networks.

Jeffrey, W. W., 1964: "Watershed Research on the Saskatchewan River Headwaters". Proc. Hydrology Symposium No. 4, National Research Council of Canada.

Jeffrey, W. W., 1965: "Experimental Watersheds in the Rocky Mountains, Alberta, Canada". Publication No. 66 "Symposium of Budapest" of the I.A.S.H.

Linsley, R. K. and Kohler, M. A., 1951: "Variations in Storm Rainfalls over Small Areas". Trans A.G.U., Vol. 32, Apr. 1951 pp 245 - 250.

McKay, G. A., 1964: "Meteorological Measurements for Watershed Research". Proc. of Hydrology Symposium No. 4, National Research Council of Canada.

Neff, E. L., 1965: "Principles of Precipitation Network Design for Intensive Hydrologic Investigations". Proc. WMO-IASH Symposium on Design of Hydrometeorological Networks.

Rainbird, A. F., 1965: "Precipitation - Basic Principles of Network Design". Proc. WMO-IASH Symposium on Design of Hydrometeorological Networks.

Spreen, W. C., 1947: "A Determination of the Effect of Topography upon Precipitation". Trans. A.G.E., Vol. 28, No. 2 Apr. 1947.

Storr, D., 1966: "A Raingauge Comparison in a Mountainous Area". Canada Dept. of Transport, Technical Circular Series, Cir 4452 Tec. 617.