A PROPOSED SNOW COURSE AND METEOROLOGICAL NETWORK FOR THE COLUMBIA BASIN IN BRITISH COLUMBIA

By

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INTRODUCTION

The proposed storage and power development in the Columbia River basin which is to be operated under the Canada-United States Co-operative program will require additions to the present hydrometeorological network. These additions will include snow courses, river gauging stations and meteorological stations for use in detailed programming and operation of the proposed storage and power projects.

As the B. C. Water Resources Service is closely connected with the water resource problems of this province, including the collection of basic data, it was necessary to make an early assessment of those observational requirements that will most efficiently meet future Columbia basin operational needs. By making this assessment, it is hoped that the additional requirements can be incorporated into the overall Provincial network planning at the earliest possible date.

This paper outlines a plan for the establishment of a basic data network for the Columbia River Basin in British Columbia. In particular, it concentrates on a proposed network of snow courses and meteorological stations for both the Columbia and Kootenay drainage basins.

DESCRIPTION OF THE BASIN

Figure 1 is a map of the British Columbia portion of the Columbia River Basin. It shows both the main Columbia River, with locations of the proposed Mica and Arrow dams, and on its principal tributary, the Kootenay, the Duncan River storage dam has been indicated. The total area of the combined Columbia - Kootenay watershed at Birchbank is 34,000 square miles with 14,000 square miles of this total lying above the proposed Arrow Lake storage dam. Both rivers from source to confluence are about 450 miles long.

The Okanagan and Kettle Rivers, although part of the Columbia system join the main stream in Washington and are considered separate basins.

Four main mountain ranges, running in a NW - SE direction, form the watersheds which supply the Columbia and Kootenay runoff. These are the Rockies which form the basin's eastern border, the Purcell and Selkirks which are the backbone of the basin, and finally, the Monashee which forms it s western border. Valley floor elevation varies from 2600 feet at Columbia Lake to 1400 feet at Lower Arrow Lake. Mountain peaks rise as high as 12,000 feet, but generally most peaks are in the 8,000 to 10,000-foot range.

Forest cover is mainly coniferous: fir, spruce, pine, hemlock, balsam and cedar predominate, with this growth quite dense in the heavier precipitation areas. The tree line lies close to the 6,000-foot level, slightly higher than the mean elevation of the basin.

HYDROLOGIC CHARACTERISTICS

During the winter, the Columbia watershed receives its precipitation from Pacific storms passing from west to east across the basin. Occasionally, cold air from the Arctic pushes westward through the mountain passes, covers the basin and provides the

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necessary lift to produce many of the Columbia's heavier snow storms. The Pacific High is the dominant pressure system during summer with precipitation mainly convective in character.

A study of existing precipitation data shows that mean annual valley precipitation ranges from 16 to 20 inches in the East Kootenay and Columbia Lake - Golden regions, to 67 inches in Glacier National Park. At most valley locations, annual precipitation is shared more or less equally between the November through April and May through October periods. At higher elevations, where the bulk of the Columbia's stream-flow originates, the greatest proportion of the annual precipitation falls in the form of snow. On the Columbia's mountainous drainage, precipitation varies markedly with elevation and mean annual precipitation has been estimated well above 100 inches on the higher slopes. In 1948, the U. S. Corps of Engineers published an isohyetal map for the Columbia basin and Figure 2 shows precipitation amounts taken from selected Canadian cross-sections of that map.

Existing Columbia River snow courses have varying lengths of record with most of the higher elevation sites installed in the more recent years. Figure 3 shows results of the 1963 water equivalent measurements for those courses located near the 6,000-foot level. (For details and location, see Table I and Figure 7). The heaviest snowpacks are in the northern Selkirks, particularly Glacier National Park, with the lightest concentration on mountain slopes just to the south-east of Golden. May 1st water equivalents for similar elevation courses in these two regions vary from 56 inches to 9 inches respectively. The plots show that in 1963, the Columbia's 6,000-foot maximum snowpack occurred May 15th which is close to the usual date for this elevation's greatest annual snow accumulation. At lower elevations, however, maximum water equivalents were recorded April 1st.

The mean annual flow of the Columbia River at Birchbank near the International Boundary is 71,000 c.f.s. with the Kootenay River contributing a little less than half of this flow. At the proposed storage dams, Mica's mean annual flow is 19,000 c.f.s., Arrow - 37,000 c.f.s. and Duncan - 3,200 c.f.s. Of this annual flow, in excess of 80% occurs in the six-month period April through September indicating the importance of mountain snow to Columbia River runoff. Figure 4 shows the variation in preliminary estimates of average annual runoff in inches for many of the feeder streams in the basin. Highest runoff originates on the northern half of the basin with the lowest from drainages in the southeast and southwest.

Figure 5 shows the more important stream gauging stations now in operation, and indicates the percentage of the April-September flow originating on sub-drainages between stations above Arrow dam. Greatest contribution is the 7300 square mile watershed north of the Trans-Canada Highway between Revelstoke and Donald which provides 62% of the April-September Arrow Lakes inflow.

Frequency distributions in Figure 6 are for April-September inflow volumes for the Mica and Arrow Lakes reservoirs. In addition, it shows distribution of annual peaks for the Potlatch gauging site near Mica and dates of peak for the Twelve Mile Ferry gauging site near Revelstoke. Because of a high correlation with Twelve Mile Ferry flows, the short Potlatch record was extended backward in time to produce the longer record from which the distributions were developed.

The following tabulations are coefficients of determination for both April-September streamflow volumes and annual peaks. These are derived from correlations between succeeding downstream gauging stations above the proposed Mica and Arrow storage dams.

April-September Volumes

Gauging Stations	Coefficients of Determination
Nicholson and Donald	.92
Donald and Potlatch	.78
Potlatch and 12 Mile Ferry	.98
12 Mile Ferry and Inflow to Arrow Lakes	.94
Nicholson and Inflow to Arrow Lakes	.66

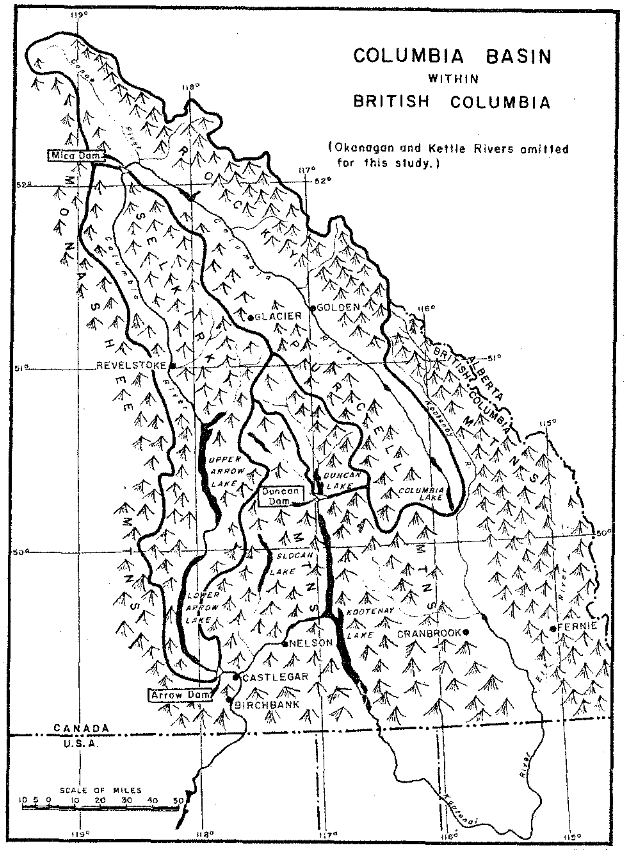


Fig. 1

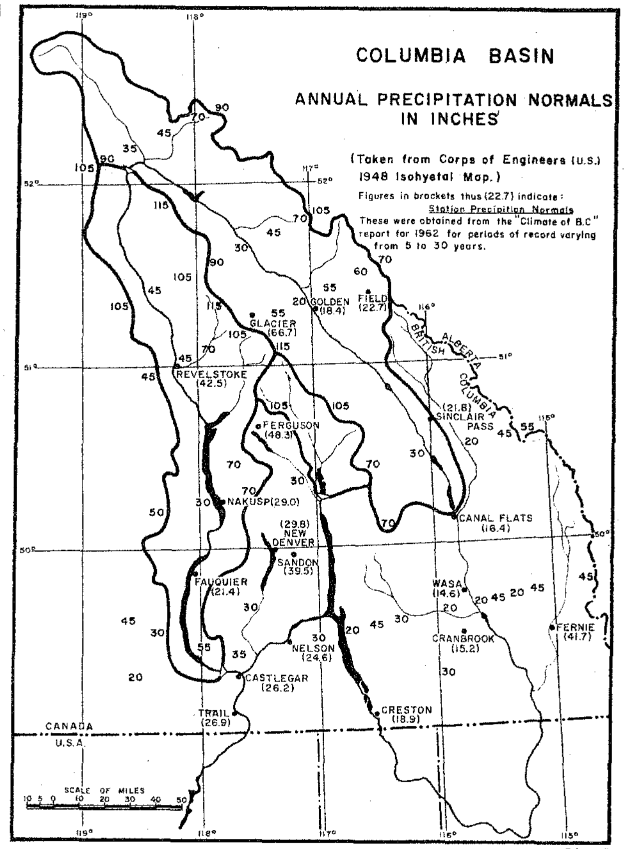


Fig. 2

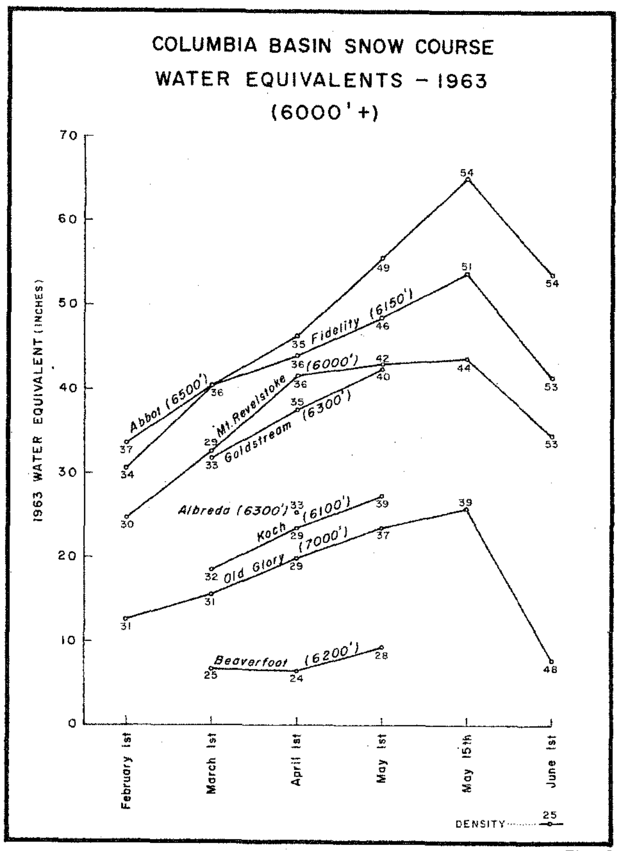


Fig. 3

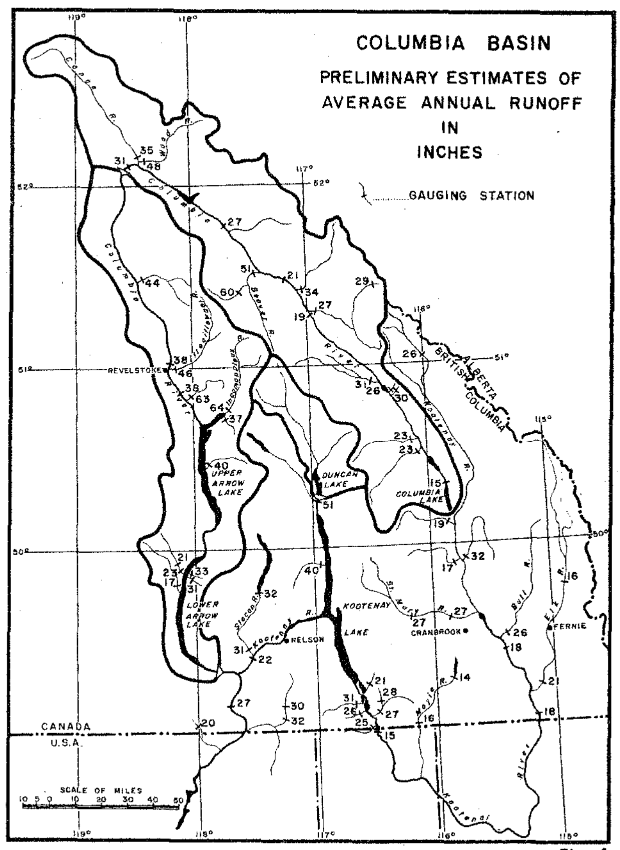


Fig. 4

Annual Peaks

Gauging Stations	Coefficients of Determination
Nicholson and Donald	.84
Donald and Potlatch	.79
Potlatch and 12 Mile Ferry	.92
Nicholson and 12 Mile Ferry	.56

The April-September volume tabulation shows that high correlations exist for all but the Donald and Potlatch relationship with this reflected further downstream in the Nicholson-Arrow Lakes correlation.

Annual peak correlations are not as significant as the volume correlations. They indicate that the Nicholson peak flow is no criterion of the expected peak at 12 Mile Ferry near Revelstoke.

The above coefficients suggest the precipitation and melt are not uniform over this large drainage.

BASIC DATA AND FORECAST REQUIREMENTS

Before proceeding further, an assessment should be made not only of the type of data required but also its specific application for operational use. This assessment leads to a need for two general types of streamflow forecasts; those for seasonal periods and those with a short-term time base. In the first category fall not only the long-range volumetric snowmelt forecasts but also the winter or low-flow forecasts which are both essential for long-range planning. The second category includes the short-term forecast which is often referred to as the synthesization of the hydrograph. This provides daily, weekly and even monthly estimates of streamflow and is particularly valuable in day-to-day flood forecasting, reservoir regulation and reconstitution studies which include the important design flood computations.

Since 1935, the B. C. Water Resources Service has been making quantitative seasonal volume snowmelt forecasts for streamflow stations on the Columbia River. During this period, variables known to have a physical relationship with snowmelt runoff have been tested. Those found significant are water equivalent, fall and winter streamflow and fall, spring and summer precipitation. Variables such as soil moisture and areal snow cover could also be important, but as yet these measurements are either not available or a sufficient record has not been established. Because of the importance of snow course, stream gauge and precipitation measurements in providing reliable seasonal forecasts, stations measuring these elements should be located so that they provide the representative information for the large drainage involved. In the case of snow water equivalent and precipitation measurements, stations should be established, not only climatically, but also at differing watershed elevations to define the variation of precipitation with elevation. Although the present network has provided quite good results, forecast accuracy could be improved by installing both snow courses and precipitation stations in those heavy water-producing regions where measurements are now not available.

The timing and distribution of the water yield is another matter; and in this regard, the short-range forecast plays an important role in day-to-day flood control and storage operations.

Hydrologic research has given a fairly good insight into the physical processes of snowmelt and it has been shown that snowmelt can be computed if the necessary meteorological and physical characteristics of the basin are measured or estimated. However, to be practicable, experience has shown that in day-to-day streamflow forecasting, melt should be based on an air temperature index and when combined with areal snow cover, precipitation, streamflow, reservoir and lake data, these measurements provide the information for forecasting streamflow on a daily basis. Stations measuring these elements should also be located so that they adequately represent the Columbia's large watershed.

Regular aeroplane flights should be made during the melt season, to provide areal snow cover information. This is done by air observers locating the snow line elevation and then using it with area-elevation data to provide a measure of the snow-covered area.

EXISTING SNOW COURSE NETWORK

At present, the B. C. Columbia-Kootenay snow course network consists of 32 courses with length of records varying from as long as 29 years to as short as one year, and elevations ranging from 1850 feet to 7000 feet. Most of the courses are located in accessible areas, that is, adjacent to mountain road passes or close to where people live. A good proportion of the Columbia's watershed is inaccessible and for this reason, courses have not been established in all regions and at elevations where they are needed, as is evident from Figure 7. Table 1 provides designators, elevations and periods of record for these courses,

Of the 20 courses on the watershed above the proposed Arrow Dam, nine of them provide a west-east cross-section of snow coverage along the Trans-Canada Highway between Revelstoke and Lake Louise. North of this highway, only the widely separated 6,000-foot Goldstream (No. 128) and Albreda (No. 53) measurement sites give middle elevation samplings of the Upper Columbia snowpack. A long-record valley-floor course (No. 9A) is located at the headwaters of the Canoe River in the extreme northern portion of the basin with a newly established one near Mica. These courses represent an area of some 7,000 square miles, and as mentioned previously, 62% of the Arrow Lake's snowmelt inflow.

Because of the accessibility problem, the Duncan River basin has no snow courses, but just to the west on the neighboring Lardeau watershed two courses are sampled each winter. On the remaining Kootenay drainage, a similar lack of snow courses is obvious with those in operation close to towns and main transportation routes.

PROPOSED ADDITIONAL SNOW COURSES

To provide adequate water equivalent coverage on the watersheds above the Mica and Arrow dams, key or master snow courses should be located near the mean elevation (approximately 6,000 feet) and in the geographic center of the following eight areas:

(a) East facing slope of the Purcell range between Columbia Lake and Golden (Horsethief Creek watershed).

(b) West facing slope of the Rockies between Golden and Mica (Bush River watershed).

(c) East facing slope of the Selkirks between Golden and Mica (Gold River watershed).

(d) West facing slope of the Rockies (Wood River watershed).

(e) West facing slope of the Selkirks between Mica and Revelstoke (Downie Creek watershed.)

(f) East facing slope of the Monashee Range between Mica and Revelstoke.

(g) West facing slope of the Selkirks between Revelstoke and Arrowpark (Halfway Creek watershed).

(h) East facing slope of the Monashee Range between Revelstoke and Arrowpark.

These courses have been identified by the above letters on Figure 7.

In order to secure information on the slope of the snow wedge in each area, it would be desirable to have supplementary courses installed in the vicinity of each course but at barying elevations. These would be located on the valley floor, the 4,000-foot level and if possible, the difficult 8,000-foot level. The priority course, however, should be located close to the tree line since little winter melt occurs at this elevation and experience has shown it to be a good indicator for snowmelt runoff. Lower level courses would be particularly valuable for assessing flood potential and for assessing snowmelt water supply during warm winter spells.

The suggested snow course location plan is based on the premise that snowpacks at key courses will be representative of large watershed areas, which, of course, is the basic principle in Western Snow Surveying. There are many sub-drainages that also warrant snow courses and these may have to be established if forecast requirements become more specific. On the other hand, after several years of sampling, correlations might show that some of these courses are not useful and can be discontinued. Proposed course locations are approximate and subject to revision depending on ground and aerial reconnaissance.

A glance at the existing snow course network shows that areas (b), (c), (d) and (e) should have first priority in any location plan as courses in these areas are virtually non-existent. This priority is particularly important when consideration is given to the large volume of water that these watersheds contribute.

The Duncan River should have two snow courses with one located on the eastern and the other on the western watershed. Proposed installations for the remaining Kootenay River drainage are shown in Figure 7. The remarks previously made for the Mica-Arrow dam network are applicable to both the Duncan and Kootenay networks.

ACCESSIBILITY

Accessibility was not considered in any of the proposed snow course locations. The assumption was made that access would be either by helicopter or a light ski-equipped plane. To assess the feasibility of flight operation in the Upper Columbia, the Canadian Meteorological Service has completed a machine tabulation of Revelstoke's ceilings and visibilities. Frequency studies show that probabilities of ceilings 6000 feet or greater range from a low of 39 percent chance of occurrence February 1st to a high of 70 percent June 1st. (See Figure 8). The probabilities of this ceiling occurring for the important March 1st, April 1st and May 1st samplings vary from 60 to 68 percent. A decision will have to be made as to helicopter operation in the upper Columbia and if not feasible, the suggested snow course plan will have to be revised and consideration given to accessibility and ground transport.

EXISTING METEOROLOGICAL NETWORK

Those meteorological stations located on Columbia River drainage above Arrow dam are listed in Table 2 and shown in Figure 9.

As in the case of snow courses, there is a definite lack of meteorological information in the northern portion of the Columbia basin in British Columbia. Also, temperature and precipitation stations are confined to valley floors and no information is available at higher elevations.

On the Duncan River watershed, no temperature or precipitation stations are available; however, just south of Duncan Lake are the recently established Lardeau and Argenta stations.

Kootenay meteorological stations are not listed in Table 2 but are shown in Figure 9. With the exception of the 7,700-foot Old Glory station, all are on the valley floor.

The only operative precipitation storage gauge is the Department of Northern Affairs and National Resources' stand pipe gauge located close to their Potlatch Creek streamflow station. It has been in continuous operation since 1952. In conjunction with the Potlatch A35 stream stage recorder is an air temperature recording attachment.

PROPOSED ADDITIONAL METEOROLOGICAL STATIONS

To assess the climatic variability of the Columbia basin, a base network of precipitation and temperature stations should be established at the same locations as the proposed snow courses. These stations are especially important for forecasting short duration changes in the flood hydrograph and for this reason, readings would be required

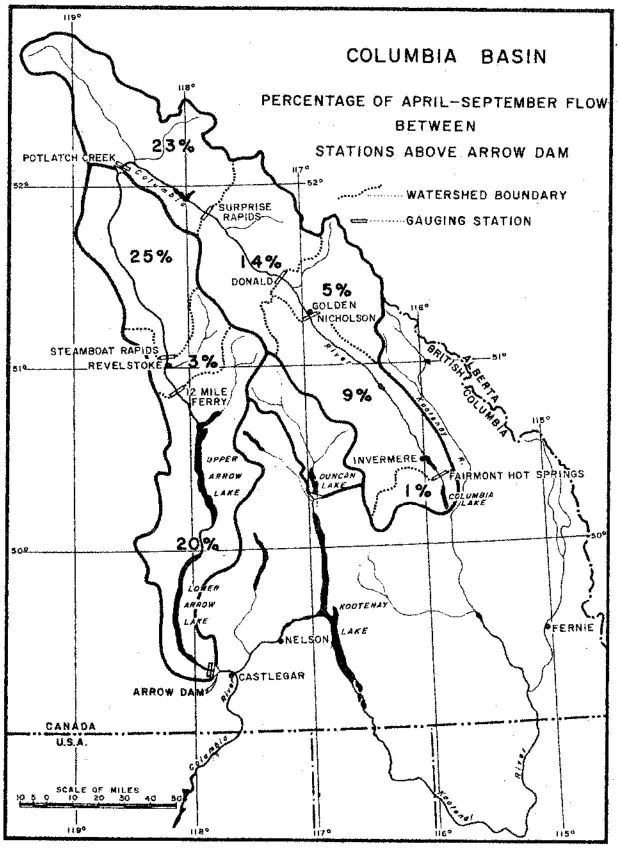


Fig. 5

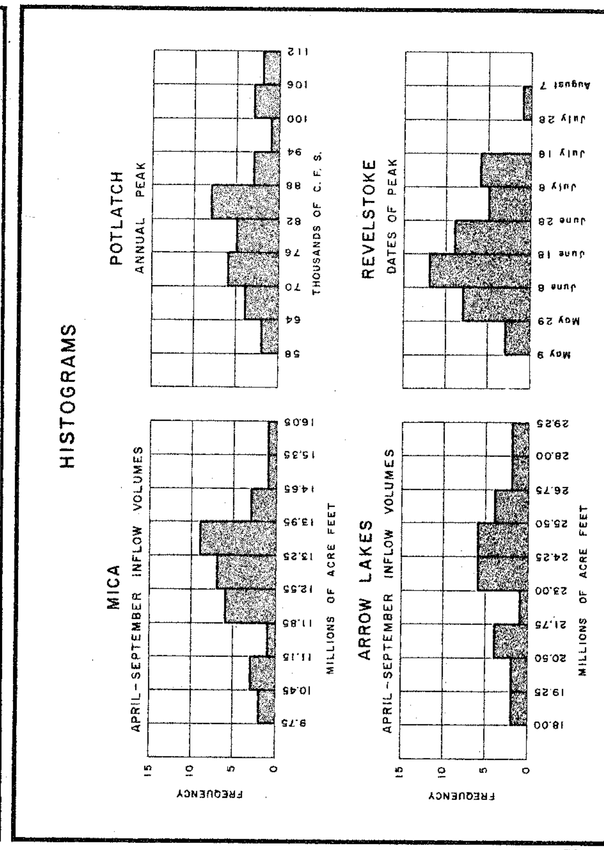


Fig. 6

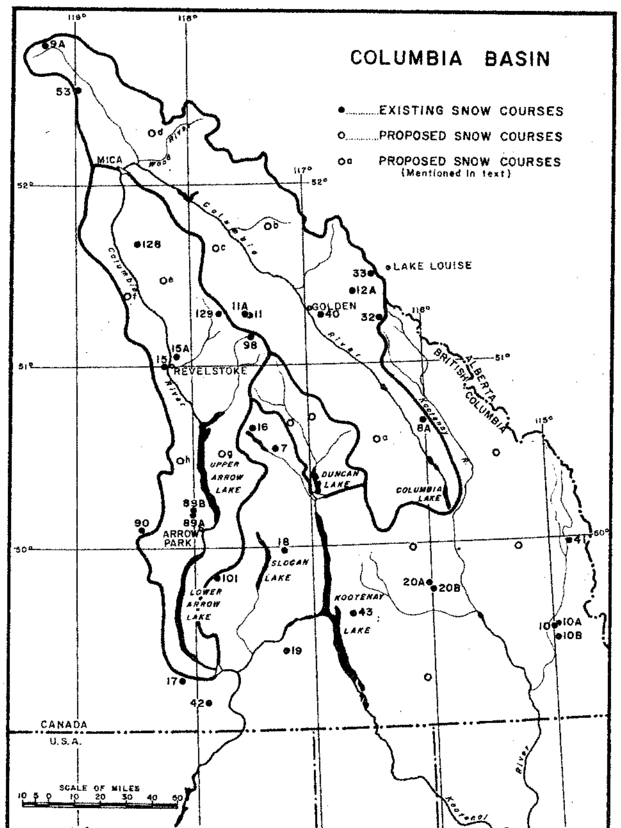


Fig. 7

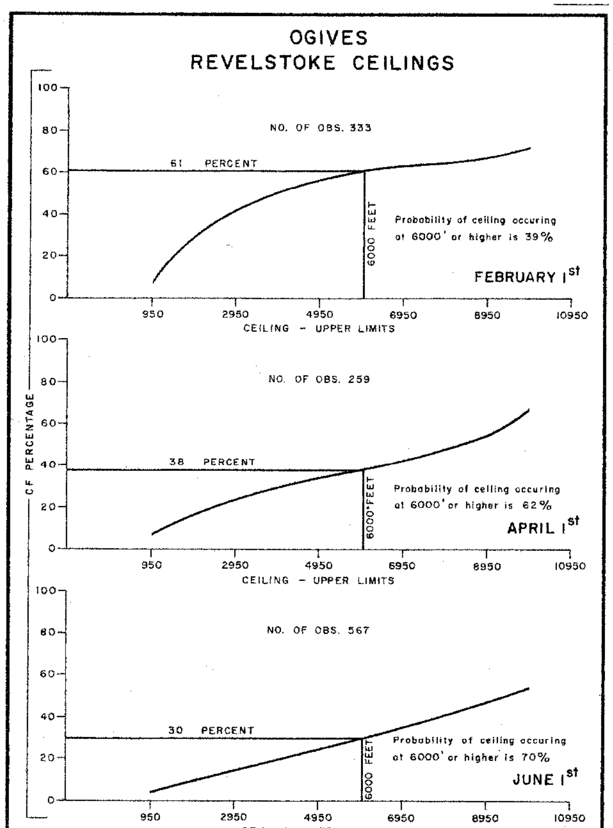


Fig. 8

on a daily basis. Unfortunately, the problems inherent in the continuous operation of such a network have not been entirely solved and as a result, its establishment is not practicable at the present time. Therefore, until dependable, automatic meteorological equipment becomes available, precipitation and temperature stations should be located at selected mountain sites which are accessible for servicing and which give a broad coverage of weather conditions in the Columbia basin.

A study of existing, higher-level access roads shows four possible sites which would provide the suggested coverage of mean elevation precipitation and temperature in the northern, central and southern portions of the Columbia-Kootenay basin. These are the Goldstream snow course site, the Avalanche Research Station on Mt. Fidelity, Idaho Peak near Sandon and the Fernie micro-wave site in southeastern B. C. (See Figure 9).

Instrumentation would include long-duration precipitation and temperature recorders with a suitable telemetering system for daily transmission of data to a base station.

Measurement of wind, humidity and radiation would also be desirable at these locations, but trouble-free automatic equipment is not available. However, these measurements can be made at Mt. Fidelity where a staff is available and the necessary co-operative arrangements should be completed at an early date for the gathering of this data. As Mt. Fidelity is representative of the severe climatic conditions of the northern Columbia, it would be a logical location for the testing of automatic equipment before placement at remote sites.

The valley floor meteorological station network should be expanded, particularly in the central and northern regions of the basins where stations are very few in number. Lack of readers is the chief deterrent to this proposed expansion but a determined effort should be made to recruit permanent residents in the sparsely populated regions to give sufficient precipitation and temperature coverate to the basin. Suggested installations are at Field, Donald, Downie Creek, Beaton, Gerrard, Nakusp, Duncan Lake and Slocan.

OTHER CONSIDERATIONS

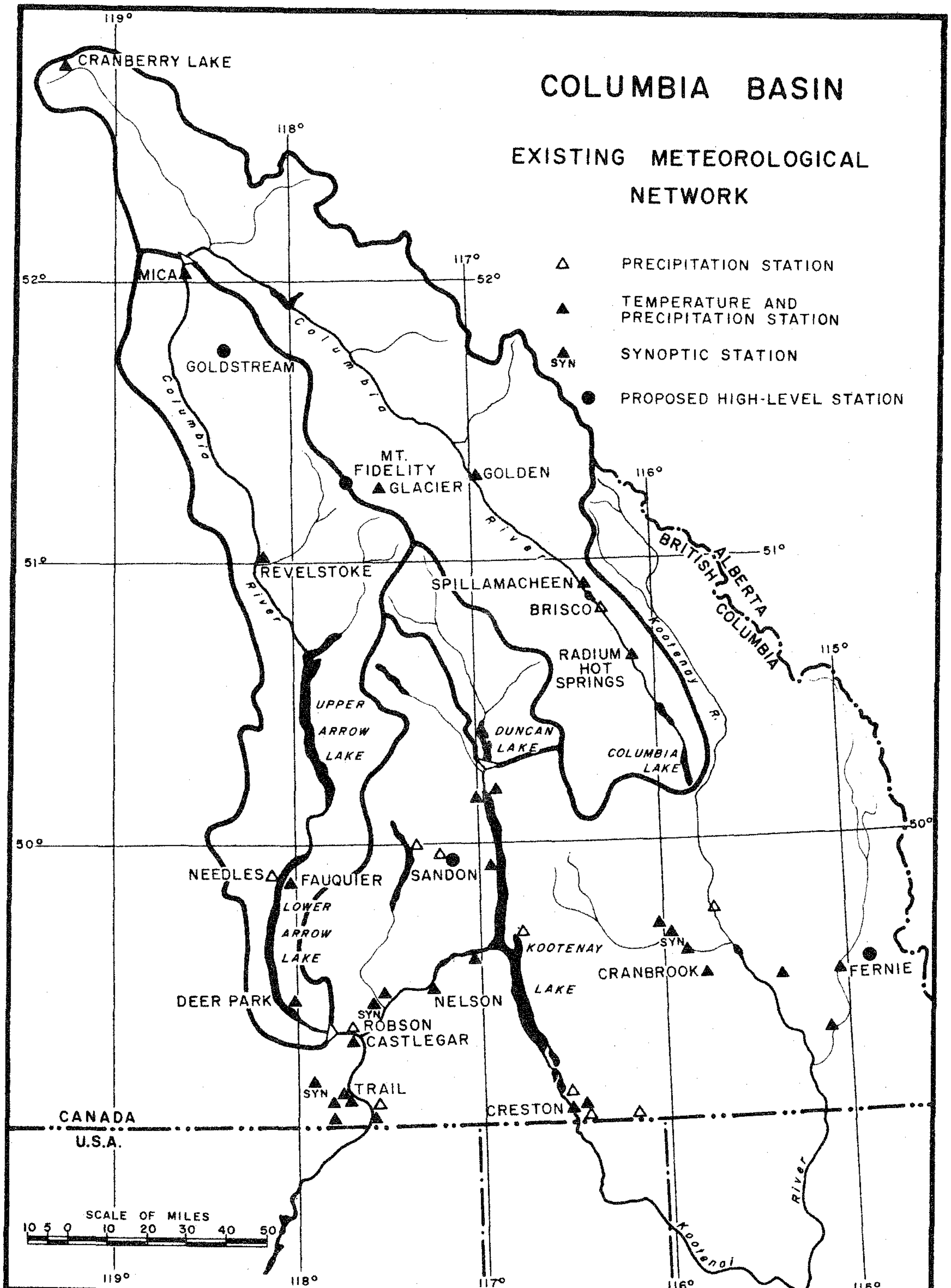
A few storage precipitation gauges should be installed close to snow course sites. This would provide another independent evaluation of winter precipitation. Evaporation was not discussed: it also plays an important role in runoff forecasting, however, and instrumentation will be required.

The very important existing and proposed stream gauging portion of the Columbia's hydro-meteorological network was mentioned only briefly and it is hoped that the discussion leader of this paper, who works for the Federal Department responsible for streamflow measurements in this Province, will elaborate and provide further information.

It should be mentioned that government and private agencies are working to perfect automatic sensoring devices for location in remote, rugged areas such as those of the Columbia basin. In the measurement of water equivalent, personnel of the U. S. Corps of Engineers think their proto-type radio-active snow gauges will soon become operational in basins other than their experimental Clearwater watershed. Similarly, U. S. Soil Conservation Service personnel appear optimistic about the pressure pillow measurements on Mt. Hood and at this meeting the promising radio storage gauge and its operation have been described. If and when these devices are adopted for operational use, winter accessibility will no longer be a problem. It is hoped this objective will be reached soon.

SUMMARY

Forecasting experience, hydrologic characteristics and knowledge of the basin were used as a guide in determining site locations for the additional stations required to build the suggested snow course and meteorological network just described. It is intended to be a base network which will provide hydrometeorological measurements for future operation of the Columbia River project.


COLUMBIA BASIN
EXISTING METEOROLOGICAL NETWORK
PRECIPITATION STATION
TEMPERATURE AND PRECIPITATION STATION
SYN
SYNOPTIC STATION
PROPOSED HIGH-LEVEL STATION
CRANBERRY LAKE
MICA
GOLDSTREAM
MT. FIDELITY
GLACIER
GOLDEN
REVELSTOKE
SPILLAMACHEEN
BRISCO
RADIUM HOT SPRINGS
UPPER ARROW LAKE
DUNCAN LAKE
COLUMBIA LAKE
NEEDLES
FAUQUIER
SANDON
LOWER ARROW LAKE
KOOTENAY LAKE
CRANBROOK
FERNIE
DEER PARK
NELSON
ROBSON
CASTLEGAR
TRAIL
CRESTON
CANADA
U.S.A.
BRITISH COLUMBIA
ALBERTA
Columbia River
Kootenay R.
Kootenai River
SCALE OF MILES
10 5 0 10 20 30 40 50
119°
118°
117°
116°
115°
52°
51°
50°
Fig. 9

REFERENCES

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TABLE 1

EXISTING SNOW COURSE NETWORK

See Figure 7

Columbia River Watershed

Course	No.	Elevation	Years of Record
Sinclair Pass	8A	4500'	29
Kicking Horse	33	5400'	17
Kield	12A	4200'	25
Beaverfoot	40	6200'	1
Glacier	11	4100'	27
New Glacier	11A	4100'	5
Abbot Mountain	98	6500'	5
Canoe River	9A	3000'	23
Mica		1860'	2 (temporary)
Upper Coldstream	128	6300'	1
Revelstoke	15	1850'	26
Revelstoke Mountain	15A	6000'	17
Fidelity Mountain	129	6150'	1
Upper Whatshan	89A	4850'	6
Lower Whatsham	89B	4100'	6
Barnes Creek	90	5300'	6
Koch Creek	101	6100'	5
Farron	17	4000'	26
Old Glory	42	7000'	16
Albreda	53	6300'	14

Kootenay River Watershed

Course	No.	Elevation	Years of Record
Marble Canyon	32	5000'	17
Upper Elk	41	4400'	16
Fernie	10	3500'	26
New Fernie	10A	4100'	13
Morrissey Ridge	10B	6100'	3
Kimberly	20B	3800'	26
Sullivan Mine	20A	5100'	18
Gray Creek	43	5100'	16
Ferguson	16	2900'	26
Gerrard	7	6000'	28
Sandon	18	3500'	26
Nelson	19	3050'	26

TABLE 2

EXISTING METEOROLOGICAL NETWORK

See Figure 9

Columbia River Watershed

Station	Elevation	Years of Record	Measurements
Radium Hot Springs	3570'	8	Precip., Temp.
Brisco	2750'	30+	Precip.
Golden	2583'	30+	Precip., Temp.
Glacier	3860'	4	Precip., Temp.
Cranberry Lake	2600'	30+	Precip., Temp.
Mica	1860'	1	Precip., Temp.
Spillamacheen	2617'	5	Precip., Temp.
Revelstoke	1497'	30+	Precip., Temp., Wind, Synoptics
Fauquier	1600'	30+	Precip., Temp.
Needles	1421'	7	Precip.
Deer Park	1460'	30+	Precip., Temp.
Castlegar	1425'	4	Precip., Temp.
Robson	1450'	9	Precip.