

## SHORT RANGE SNOWMELT FORECASTS

By

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## INTRODUCTION

The Weather Bureau River Forecast Center prepares daily short range forecasts of snowmelt runoff for each of the principal Columbia River tributaries throughout the snowmelt season. These tributary forecasts are combined to yield forecasts of daily inflow to the principal reservoirs and, ultimately, daily stage forecasts for the Portland and Vancouver harbors and other downstream areas. Although several different methods are used, most tributary forecasts are based on a simple temperature index which varies proportionally with streamflow. The construction and use of the temperature index is described, together with a complementary contributing area index which may also be found useful in other methods of short range forecasting.

The methods will be illustrated on a portion of the Kootenay Basin in British Columbia. We have termed the 4100 square mile West Kootenay area between Porthill, Idaho and Corra Linn, B.C., shown in Figure 1, as Kootenay Lake Local Inflow. Temperature stations used are Crescent Valley and Old Glory Mountain. The 450 square mile Salmo basin, adjacent to the Kootenay on the Southwest, is used as an index in the second part of this paper.

## THE TEMPERATURE INDEX

The unit hydrograph is a common tool for the distribution of rainfall runoff, and it has also been used for many years to forecast snowmelt runoff. Because of the long time base characteristic of the snowmelt unit graph, its application by manual methods is rather tedious. By making several simplifying assumptions, the principle can be applied to temperatures to yield a quickly computed daily index which is proportional to daily streamflow.

In the large basins with which we deal, snowmelt unit graphs must usually be derived by trial and error, for it is impossible to isolate the runoff from a given day's melt. Likewise, the effectiveness of the previous days' temperatures, or the temperature weights we seek for our index must also be determined by trial and error.

Daily mean temperatures were plotted on the hydrographs for the ten years studied. The 1951 season is used for illustration in Figure 2. A comparison of temperatures and discharge shows several conservative characteristics of the basin. First, it discloses the proper base temperature, below which there is negligible melt and above which we compute degree days or temperature excess. The base temperature is dependent on the elevation of the temperature stations used, and it would preferably increase during the season with the increasing average elevation of the melting zone. For simplicity it has been held constant at 30 degrees in this study.

A consistent time difference between peak temperature and peak discharge will be found, and this indicates which antecedent day's temperature should receive maximum weight in the index.

When temperatures drop sharply so that no temperature excess occurs for several days, the hydrograph will exhibit the recession characteristics of the basin. Most streams will approximate a logarithmic recession over a reasonably wide range of flow, that is, one day's flow is a constant percentage of the previous day's flow. From this characteristic comes the simplification which makes the temperature index useful - the effect of all temperatures more than two or three days ago can be combined in a single number which declines each day by this same percentage, or recession constant.

After the foregoing characteristics have been determined, trials are made of various weights for the first several antecedent days' temperature excess to find the index which varies with discharge in the most nearly linear manner. For simplicity, weights should be those which can be applied mentally such as 1/2, 1, 2 or 3.

The computation method can be illustrated by following the example in Figure 3. The temperature index (TI) of 131 on the 8th is the sum of one-half ( $T_{E-1}$  (10) plus 2  $T_{E-2}$  (40) plus 2  $T_{E-3}$  (30) plus  $T_R$  (51), the temperature recession. This  $T_R$  value, in turn, is the sum of  $T_{E-4}$  plus .85  $T_{E-5}$  plus .72

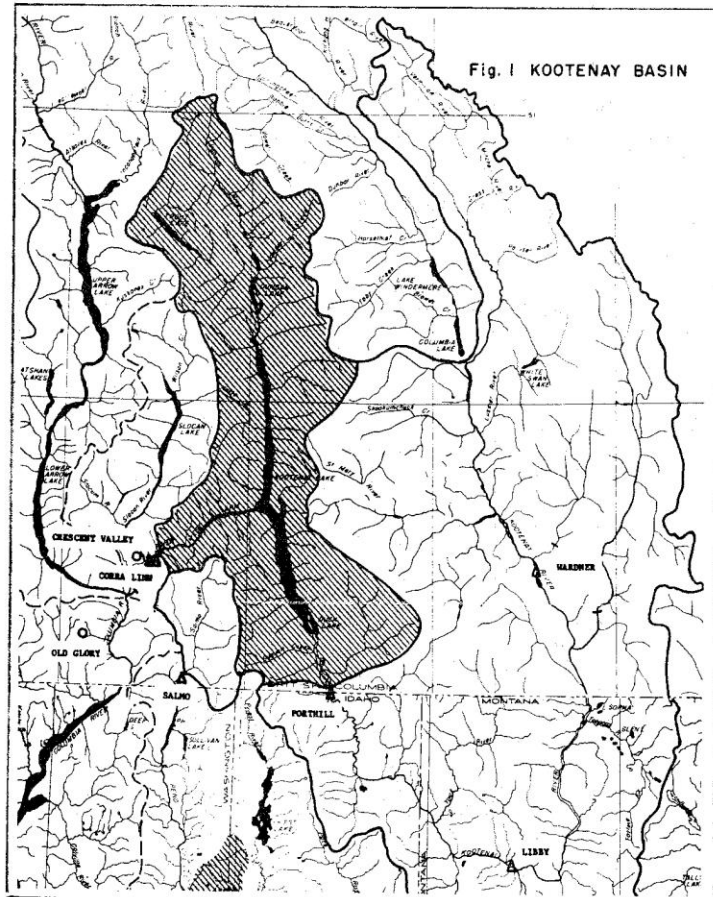
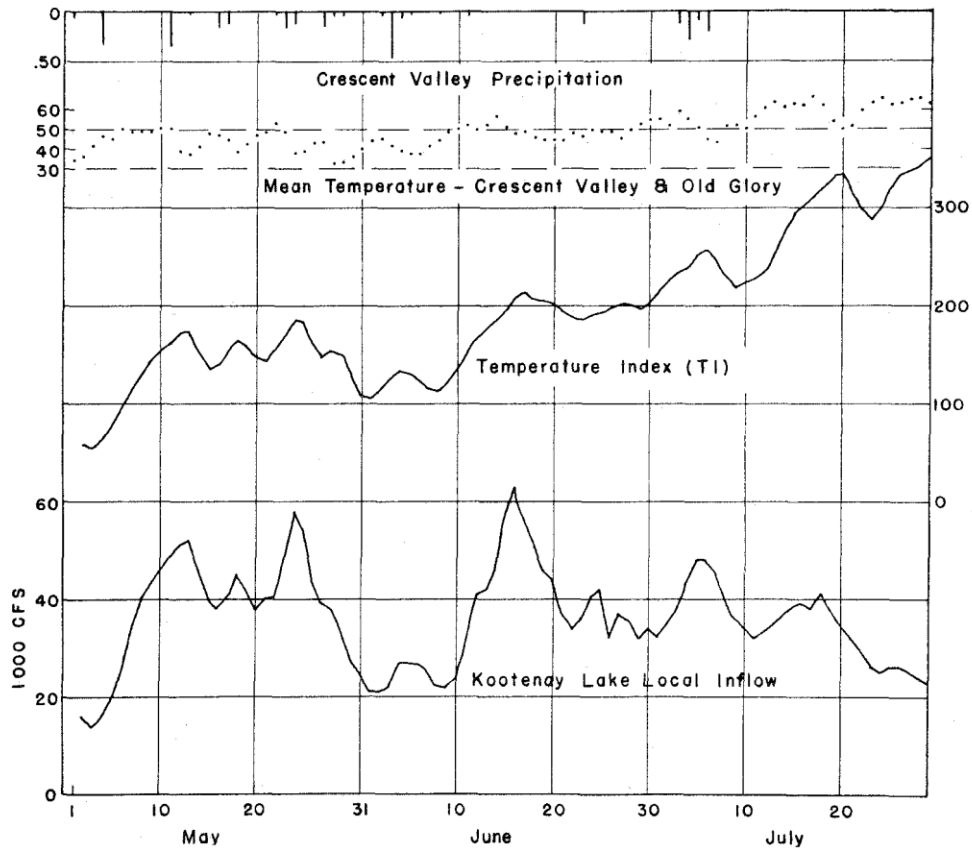


Fig.2 TEMPERATURE, PRECIPITATION and STREAMFLOW — 1951



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COMPUTATION AND TABULATION SHEET

Figure 3. Temperature Index Computation

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Computed by			Date		Checked by			Date					
			MAY, 1951										
Date:			1	2	3	4	5	6	7	8	9	10	11
Crescent Valley	Max		50	59	70	72	73	74	77	70	74	79	79
	Min		39	36	30	38	41	44	44	49	45	38	46
Old Glory	Max		24	29	40	40	40	43	44	42	45	49	44
	Min		21	19	25	33	26	38	35	34	33	35	31
	Sum		134	163	165	183	180	199	196	195	197	201	200
	Mean	T	34	36	41	46	45	50	49	49	49	50	50
Temp. Excess	T <sub>E</sub>		4	6	11	16	15	20		19	19	20	20
.85 YDA	T <sub>E</sub>		30	29	30	35	43	49	59	66	72	77	82
Temp. Recession	T <sub>R</sub>		34	35	41	51	58	69	78	85	91	97	102
	2 T <sub>R</sub>		8	12	22	32	30	40	38	38	38	40	40
	.5 T <sub>R</sub>		2	3	6	8	8	10	10	10	10	10	10
Temp. Index	TI			57	55	61	76	97	113	131	146	155	164
Hypothetical one day melt													
	T <sub>E</sub>		0	0	20	0	0	0	0	0	0	0	0
.85 YDA	T <sub>E</sub>				0	17	14	12	10	9			
	T <sub>R</sub>		0	0	20	17	14	12	10	9			
	2 T <sub>R</sub>		0	0	40	0	0	0	0	0			
	.5 T <sub>R</sub>		0	0	10	0	0	0	0	0			
	TI				0	10	40	40	20	17	14	12	10

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(.85<sup>2</sup>) T<sub>E-6</sub>, etc. The .85 YDA (yesterday's) T<sub>R</sub> values are quickly copied from an .85 factor table, and the four numbers composing the TI are outlined for easy addition by a template which covers all but the values shown in the boxes.

To illustrate that the TI has the characteristics we wish, let us examine the TI values computed from a hypothetical one day temperature excess, as shown in the lower portion of Figure 3. Adding in template order yields a series of TI values which clearly has the "unit graph" shape we would expect to see in the discharge hydrograph.

Referring back to Figure 2, we see that there is good general agreement between the shape of the TI curve and discharge. A closer check on the adequacy of the TI as a forecasting tool comes from plotting daily discharge against concurrent values of TI. Figure 4a shows the relation for the three principal rises of 1951 while Figure 4b shows several major rises of other years. Generally only the rising limb of the curve has been shown to avoid cluttering the graph, and because the recession is frequently distorted by rainfall runoff. A lengthy discussion of the latter is beyond the scope of this paper, but we should obviously avoid periods of significant rainfall in deriving the TI. In forecasting, rainfall runoff must be added to the computed snowmelt discharge. Small amounts of rain can be treated as an equivalent temperature excess and included in the TI. Intense rains usually cause more rapid runoff and are handled with the properly timed unit hydrograph.

Although the TI is not very sensitive to small fluctuations in temperature, it should be noted that the "wobbles" in the TI-Q curve are not all due to inadequacy of the TI. Daily discharges for this area are computed by subtracting the flow at Porthill from the total inflow to Kootenay Lake. The effects of wind on the lake stage add to the variations inherent in the residual from a subtractive process.

The slope of the curves is a function of the effective contributing area. It is low at the beginning of the season when the snow pack has not yet ripened. It rises to a maximum value, and then recedes with the decrease in snow covered area. The numerical slope values shown are with reference to a value of 1.0 for a 45 degree line, and are to be used in the next section of this paper. Because contributing area normally changes slowly, the TI-Q curve can be extrapolated successfully for the usual three day forecast without knowledge of the actual contributing area. The importance of snow cover knowledge increases with the extension of the forecast.

#### THE CONTRIBUTING AREA INDEX

Many different approaches to the determination of contributing area have been made.<sup>1/2/</sup> Perhaps the most satisfactory method is that of aerial reconnaissance as practiced by the several District Offices of the Corps of Engineers. However, an inexpensive method of continuous appraisal of snow covered area would be welcomed by both flood forecasters and those concerned with reservoir regulation and water management. I would like to suggest an approach which seems to have merit and warrant further study.

To introduce the method let us visualize two adjacent hypothetical basins, identical in every respect except the distribution of area with elevation. They will be affected by the same storms and each will receive a uniform basin-wide snow cover. Figure 5 (a) shows the respective area-elevation relations and (b), the relation between the two basins. If we now apply a gradually increasing amount of heat, just sufficient to cause melting over a narrow elevation-zone, a graph of the accumulated discharges from the two basins would follow a curve identical in shape to Figure 5 (b). We could simply re-label the scales and call them percent of accumulated seasonal runoff. The slope of the curve would indicate the elevation of the snow line or the effective contributing area throughout the season.

The illustration is far-fetched, but there are, nevertheless, natural basins which exhibit these characteristics to a useful degree. Figure 6 shows the accumulated April-July runoff relation between the Salmo River (See Figure 1) and adjacent Kootenay Lake Local Inflow. Years plotted include the largest (1954), and smallest (1958), of Salmo record, but all unplotted years fall within these envelopes.

If these basins were more nearly the same size we could use the slope of the curve in Figure 6 as an index to contributing area, but differing recession characteristics and the influence of rainfall runoff make it preferable to compare only periods of active snowmelt. In figure 7, the horizontal scale is the ratio of trough-to-peak rise in the Salmo River to rise in the Local Inflow for the previous period of snowmelt. (Units in the ratio of 10:1, compatible with Figure 6, are assumed.) The vertical scale is the slope of the TI-Q curve for the current rise as previously shown in Figure 4. Table 1 identifies the points.

Fig. 4 TEMPERATURE INDEX vs DISCHARGE (TI-Q)

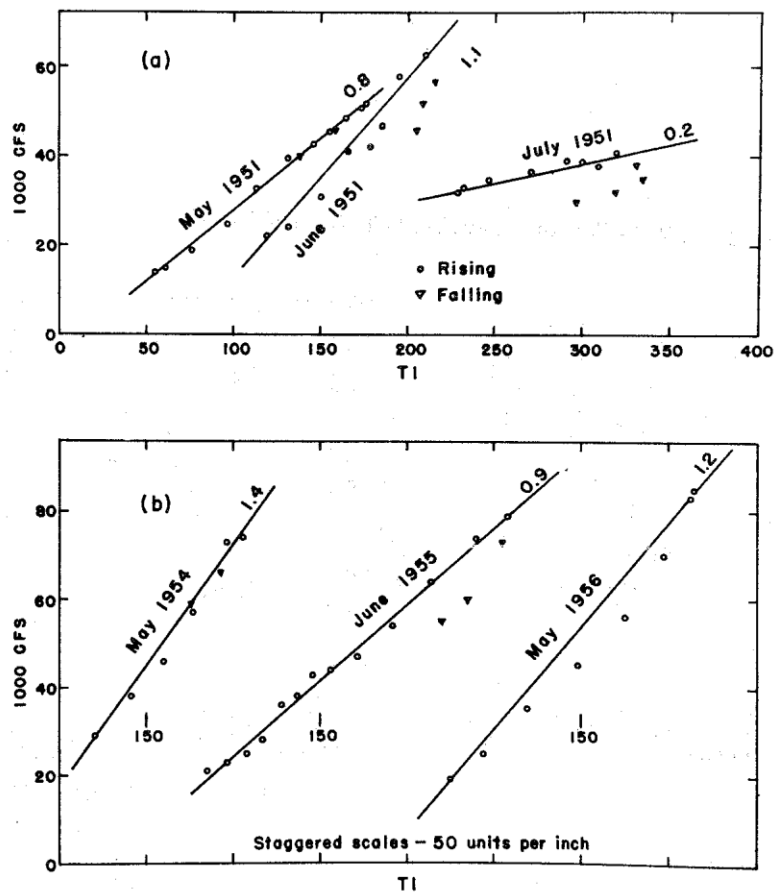


Fig. 5 HYPOTHETICAL AREA-ELEVATION CURVES

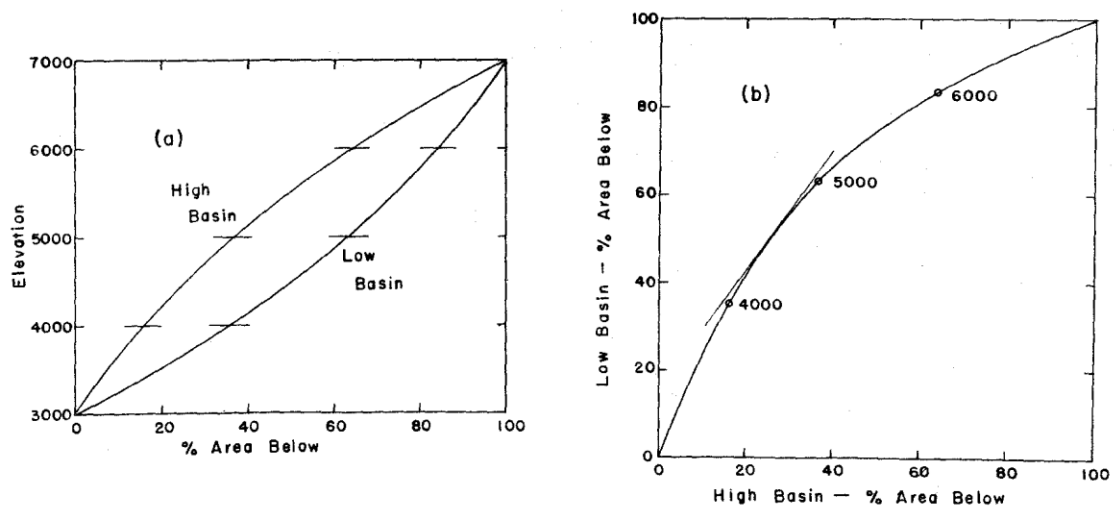


Fig. 6 ACCUMULATED APRIL-JULY RUNOFF

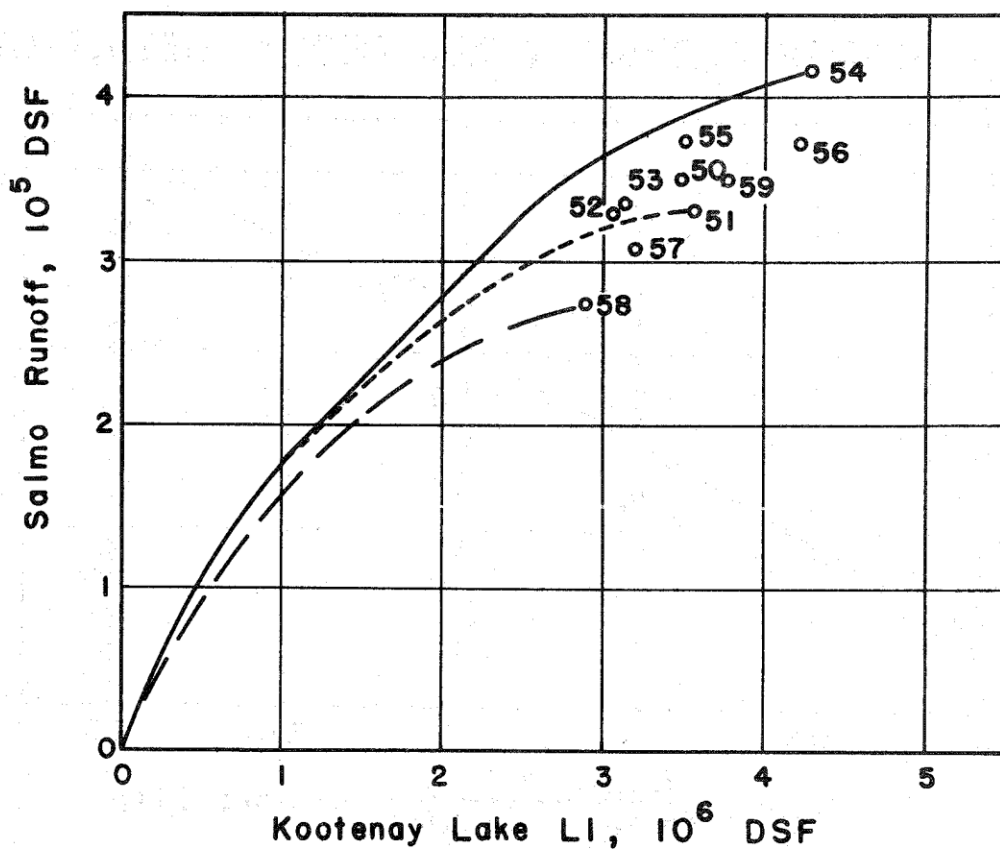
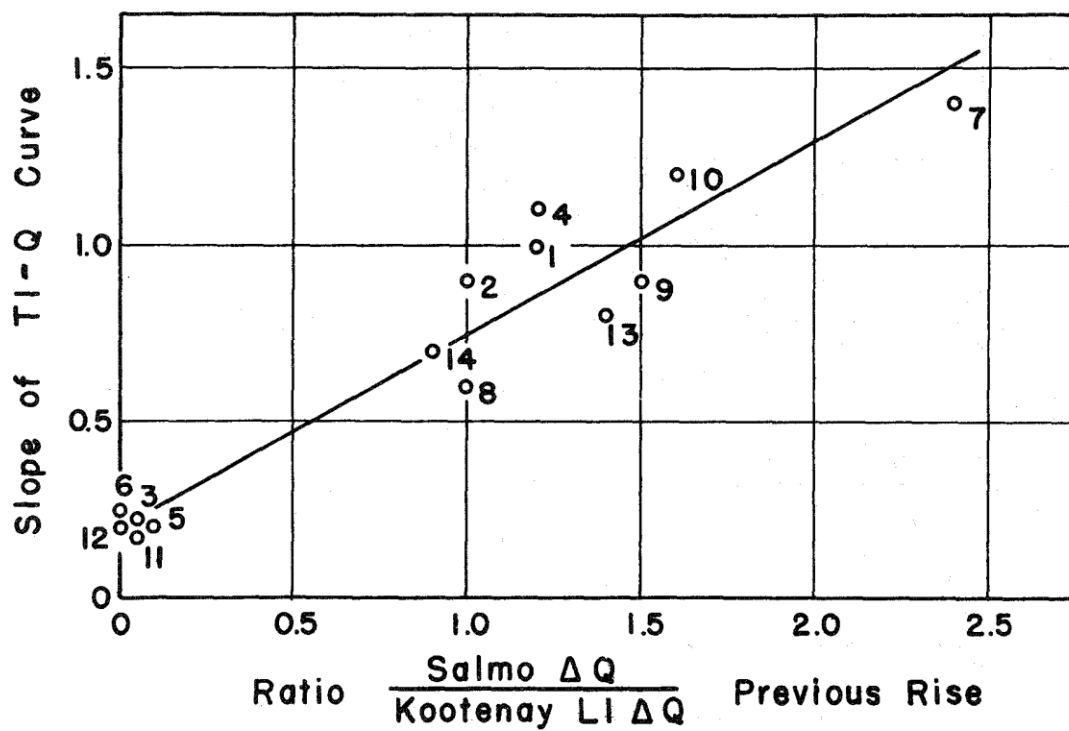


Fig. 7 CONTRIBUTING AREA INDEX RELATION



A general relation between the two values is evident, although the useable data are not uniformly distributed. Perhaps the most consistent feature is the apparent limiting slope of about 0.2 for a zero ratio. A zero ratio is computed when the Salmo flow remains steady or declines during a rise in Local Inflow. The condition indicates a depleted snow cover and has occurred as early as May. It imposes a limit on the extent of a subsequent snowmelt rise and should help to answer the perennial late season question, "Have we had the peak?" In other words, is there sufficient snow cover that the forecast temperatures, or any reasonably possible sequence of high temperatures can produce a peak flow higher than has already occurred?

#### SUMMARY

The temperature index is well suited to operations of the River Forecast Center where temperature reports and forecasts are available early in the morning and river reports come somewhat later. The three day forecast TI is ready and the TI-Q curve can be extended for a three day discharge forecast as soon as today's discharge is known.

TABLE 1  
CONTRIBUTING AREA INDEX DATA

<u>Point No.</u>	<u>Year</u>	<u>Dates of Current Rise</u>	<u>Dates of Previous Rise</u>
1	1950	June 10-15	June 1-5
2	1950	June 16-22	June 10-15
3	1950	June 27 - July 7	June 16-22
4	1951	June 9-16	May 21-24
5	1951	July 11-18	June 29-July 5
6	1953	July 6-15	June 29-July 5
7	1954	May 16-21	May 2-11
8	1954	June 21-28	June 10-14
9	1955	June 2-14	May 16-22
10	1956	May 15-22	May 6-10
11	1956	July 8-14	June 27-29
12	1957	May 26-June 7	May 7-10
13	1958	May 19-25	April 30-May 11
14	1959	June 19-23	June 12-15

While mean temperature excess was used in this study, the method imposes no restrictions. We have also used maximum temperature, a composite temperature and dewpoint function, and upper air temperatures in various other basins.

The contributing area index provides an independent check on other methods - it lets the basin tell its own story of snow cover depletion. If studies in other areas prove the index useful, by itself or in conjunction with other observations, then a reporting service from small index basins would be warranted.

#### REFERENCES

- 1/ Butson, K. D., 1953, U. S. Weather Bureau Snow Cover Observation Program, Proceedings Western Snow Conference, Boise, Idaho, pp. 5-6.
- 2/ Corps of Engineers, 1956, Snow Hydrology, North Pacific Division, Portland, Ore., pp. 262-267.