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Subject: Standard Proj. Flood, Skagit River Basin, Washington
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NPS 800.5(Skagit River & Tribs.)51

NPDVG
NPD 824.02(Skagit Riv.)
Seattle Dist. - 50 3rd Ind.

Office, Division Engineer, North Pacific Division, Corps of Engineers 500 Pittock Block, Portland 5, Oregon, 22 March 1950.

TO: District Engineer, Seattle District, Corps of Engineers, 4735 E. Marginal Way, SEATTLE 4, WASHINGTON.

Forwarded for your information and files.

FOR THE DIVISION ENGINEER:

John P. Buehler
JOHN P. BUEHLER
Lt. Col., Corps of Engineers
Executive Officer

File
MJ

Derivation of Hydrograph of Inflow into Ross Reservoir During Standard Project Flood at Sedro Woolley

In obtaining the inflow hydrograph to Ross Reservoir during the Standard Project Storm at Sedro Woolley, a ratio of flows between the two locations was used. Streamflow records are available for only one major flood, that of December 1921, at both Skagit River at Ruby Creek (inflow into Ross Dam) and Sedro Woolley. However, flows have been derived for this site for the 1909 and 1917 floods from flows in Skagit River at Reflector Bar. The ratio of flood volume between Ruby Creek and Sedro Woolley for these floods varied from 12 to 22 percent. The ratio of peak flows varies from 16 to 22 percent.

A storm of sufficient severity to produce a flood of the magnitude of that of the standard project flood would probably not be concentrated over the upper Skagit Basin but would be a general storm over the entire basin. For this reason the volume of run-off at Ross Reservoir is estimated to be 18 percent of that at Sedro Woolley, with a crest of 22 percent of that at Sedro Woolley. The hydrograph of inflow to Ross Reservoir assumed to occur during the standard project flood at Sedro Woolley is presented on plate 4.

50.5 (Skagit Riv) 5/2

CORPS OF ENGINEERS, U. S. ARMY

OFFICE OF THE DISTRICT ENGINEER

SEATTLE DISTRICT

4735 E. Marginal Way

Seattle 4, Washington

Report on Derivation of Standard Project Flood

SKAGIT RIVER NEAR SEDRO WOOLLEY, WASHINGTON

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1 February 1950

CORPS OF ENGINEERS

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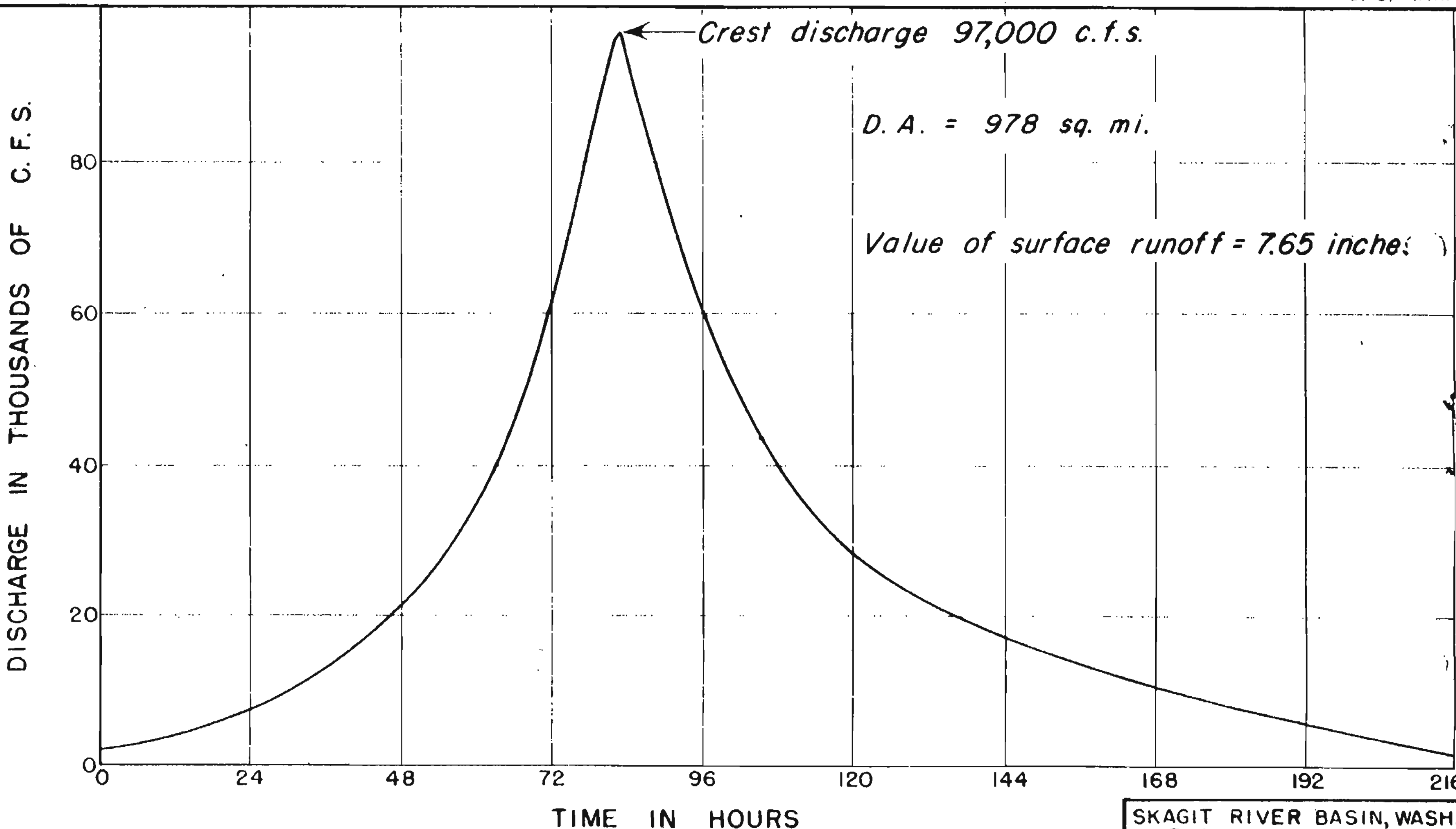

SKAGIT RIVER BASIN, WASH.

INFLOW TO ROSS RESERVOIR ACCOMPANYING STANDARD PROJECT FLOOD AT SEDRO WOOLLEY

Seattle District, Seattle, Wash.

Dwn: M.E.T.
Tr'd: A.N.I.
Chkd: F.C.M. File 6-6-74

Report on
Derivation of Standard Project Flood
Skagit River near Sedro Woolley, Washington

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REPORT ON DERIVATION OF STANDARD PROJECT FLOOD

Skagit River near Sedro Woolley, Washington

1. Authority. - This report has been prepared and is submitted for approval in accordance with circular letter No. 4262 (Civil Works No. 65) dated 20 November 1946 and paragraph 4208.11, Orders and Regulations, dated 1 September 1947.

2. Location. - The standard project flood discussed herein is derived for the site of the U. S. Geological Survey stream-gaging station Skagit River near Sedro Woolley, Washington. The project area extends downstream from Sedro Woolley to the mouth of Skagit River (see plate 1). A definite plan of improvement to be designed on the basis of this standard project flood has not yet been determined, but plans under consideration include levees combined with a by-pass channel and upstream storage. The by-pass channel would divert water from Skagit River at a point approximately 4 miles downstream from Sedro Woolley into Padilla Bay on Puget Sound.

3. Description of basin. - The Skagit River Basin is located in northwestern Washington and southwestern British Columbia, and drains an area extending from the crest of the Cascades to Puget Sound. The eastern sections of the drainage area are very rugged and mountainous, much of the higher area being barren rock. All of the higher summits as well as small areas of the basin upstream from Concrete, Washington, lie above the timber line and within the zone of perpetual snow and ice.

4. Altitudes within the Skagit Basin range from sea level to 8,000 feet at the crest of the Cascade Range, to 10,750 feet at the summit of

Mount Baker, 10,436 feet at Glacier Peak (Snohomish County) and 9,038 feet at Mount Shuksan.

5. Skagit River, the largest tributary of Puget Sound, drains an area of 3,140 square miles. The river heads in Canada, 28 miles north of the International Boundary, and flows southerly and southwesterly for 135 miles to Skagit Bay, on Puget Sound. About 10 miles above its mouth the river divides and passes through two main and several lesser channels into Skagit Bay.

6. The largest tributary of Skagit River is Sauk River, which drains an area of 729 square miles. The headwaters of Sauk River rise in the extensive glacial fields of Glacier Peak (Snohomish County) and in the rugged mountains lying southwesterly of that peak. Baker River, the second largest tributary of Skagit River, drains about 270 square miles and heads on the eastern slope of Mount Shuksan. The river flows southward, passing through Baker and Shannon Lakes, the latter an artificial reservoir crested by a power dam.

7. Typical flood. - Floods on Skagit River are typical of those occurring on the western slopes of the Cascades. Floods are experienced from October through February, with most frequent and severe floods occurring in November and December. These floods are the result of heavy rains frequently accompanied by warm winds which may cause considerable run-off from snowmelt by removing light to moderate snowpack up to elevations of 4,000 or 5,000 feet. The standard project flood would, therefore, be a winter flood resulting from the combination of high rates of precipitation and snowmelt.

8. Method. - The standard project flood was derived by application of unit hydrograph procedure to rainfall and snowmelt excess. The steps followed in this procedure were:

a. Derivation of unit hydrograph from major floods of record.

b. Determination of rainfall as half of maximum possible precipitation.*

c. Determination of snowmelt based on assumed rate of melt and temperature sequence patterned after storm of record.

d. Determination of losses based on those experienced in floods of record.

e. Determination of base flow patterned after that of floods of record.

9. Unit hydrograph. - A 6-hour unit hydrograph was derived for Skagit River near Sedro Woolley by analysis of rainfall run-off records for major floods. Stream-gaging stations were maintained near Sedro Woolley from 1908 to 1924; near Concrete from 1924 to date; and near Mt. Vernon from 1940 to date. The peak discharges of Skagit River near Sedro Woolley for the three largest floods since 1900 were 220,000, 195,000, and 210,000 second-feet, occurring in November 1909, December 1917, and December 1921, respectively. A medium flood used in this analysis, that of November 1910, had a recorded peak discharge of 114,000 second-feet at Sedro Woolley. Discharge hydrographs, basin precipitation, and losses for the November 1910, December 1917,

*As directed by Office, Chief of Engineers in paragraph 2 of the second indorsement to basic letter from Seattle District to North Pacific Division dated 8 July 1948, subject: "Submission of Method of Standard Project Flood Derivation for Levee Type Projects."

and December 1921 floods are shown on plate 2, figures 1, 2, and 3, respectively. The unit hydrographs derived from these floods are shown on plate 2, figure 4. Climatological records indicate that the November 1910 flood was caused primarily from rain at lower elevations. The December floods resulted from rain and snowmelt. The unit hydrographs derived from the December floods have higher crest discharges than the unit hydrograph derived for the November 1910 flood. Floods derived from a unit hydrograph similar to the December floods would show higher discharges than floods derived using a unit hydrograph similar to that of the November 1910 flood. Therefore, for design purposes, the composite unit hydrograph patterned after the unit hydrographs derived for the December floods was developed and is presented on plate 2, figure 4.

10. The composite unit hydrograph was checked by using it to reproduce the flood of November 1909. This is shown on plate 2, figure 5 where it can be seen that the reproduction is accurate enough for design purposes. Therefore, the composite unit hydrograph was adopted as the basic unit hydrograph which could be used to reproduce combined rain and snowmelt floods having discharges near Sedro Woolley of approximately 200,000 cfs. Hydrologic data for the four floods of record used in this study are shown in table 1, in order of ascending magnitude. Pertinent data concerning unit hydrographs derived from floods of record and the composite unit hydrograph are included in table 2.

Table 1. - Hydrologic data for major floods of record

Item	Nov. 1910	Dec. 1917	Dec. 1921	Nov. 1909	Standard project flood
Crest discharge, 1,000 cfs.	114	195	210	220	440
Storm duration, hours	48	72	78	66	120
Total storm precipitation, inches	5.98	7.30	12.50	6.69	10.8
Total storm snowmelt, inches	*	*	*	*	5.3
Surface run-off, inches	2.40	4.23	5.47	5.28	12.1
Precipitation and snowmelt minus surface run-off = losses in inches	3.58	3.07	7.03	1.41	4.0
Maximum 24-hr. precipitation, in.	4.40	3.59	5.60	3.60	5.0
Minimum 6-hr. loss**, inches	.47	.20	.58	.13	.2
Range of base flow, 1,000 cfs.	14-27	12-27	12-26	10-28	14-28

*Indeterminate

**Minimum loss for 6-hour period when rainfall excess was experienced

Table 2. - Unit hydrograph data

Item	Nov. 1910	Dec. 1917	Dec. 1921	Composite or basic	125 percent greater than basic
Crest of unit hydrograph, 1,000 cfs.	45.5	69.5	54.5	63.0	79.0
Hour of crest	32	45	46	45	42
Width at 75% crest, hours	19	12	15	12	9
Width at 50% crest, hours	32	20	27	23	17

11. Unit hydrographs derived for the two December floods show a marked similarity; yet the crests vary from 54,500 to 69,500 cubic feet per second. This difference is caused by variations in distribution of precipitation and contribution of snowmelt. To allow for these variations which are indeterminate, additional unit hydrographs having crests equal to 125, 150, and 175 percent of the basic hydrograph were derived. These four unit hydrographs are shown on plate 2, figure 6. Pertinent data for the basic and 125 percent crest of the basic unit hydrographs used in calculating the standard project flood are presented in table 2.

12. Precipitation. - The maximum possible precipitation for the Skagit River Basin was determined by the U. S. Weather Bureau* and is shown on plate 3 as figure 1. The maximum possible precipitation indicated on these curves for the drainage area upstream from Sedro Woolley (2,970 square miles) is 21.5 inches in 120 hours. The average precipitation over the basin above Sedro Woolley to be used for the standard project storm would be half of the above amount, or 10.8 inches in 120 hours (par. 8b). Precipitation rates for 6-hour intervals for duration of the standard project storm are shown in table 3.

13. Snowmelt. - Snowmelt contribution during the standard project flood is dependent upon many variables of which the most significant are distribution and amount of snow at the beginning of the storm, temperature sequence during the storm, and rate of melt. These conditions

*"Preliminary Estimate Maximum Possible Precipitation Skagit River Basin," by Hydrometeorological Section of U. S. Weather Bureau, 29 July 1946.

Table 3. - Standard project storm

Time hours	Maximum possible rainfall	Standard project storm: Rainfall: Total	Rainfall: 6-hour incremental	Rainfall: Most critical distribution	Snowmelt distribution	Rainfall and snowmelt distribution	Losses	Rainfall and snowmelt excess	Rainfall only: Loss	Rainfall only: Excess
	Inches									
0										
6	3.1	1.6	1.6	.1	.1	.2	.2	0	.1	0
12	5.9	3.0	1.4	.2	.2	.4	.2	.2	.1	.1
18	8.1	4.1	1.1	.2	.3	.5	.2	.3	.1	.1
24	10.1	5.0	.9	.3	.3	.6	.2	.4	.1	.2
30			.8	.4	.3	.7	.2	.5	.1	.3
36	13.0	6.5	.7	.5	.3	.8	.2	.6	.1	.4
42			.6	.6	.4	1.0	.2	.8	.1	.5
48	15.4	7.7	.6	.8	.5	1.3	.2	1.1	.1	.7
54			.5	1.1	.6	1.7	.2	1.5	.1	1.0
60	17.2	8.6	.4	1.6	.5	2.1	.2	1.9	.1	1.5
66			.4	1.4	.4	1.8	.2	1.6	.1	1.3
72	18.6	9.3	.3	.9	.3	1.2	.2	1.0	.1	.8
78			.3	.7	.3	1.0	.2	.8	.1	.6
84			.2	.6	.2	.8	.2	.6	.1	.5
90			.2	.4	.1	.5	.2	.3	.1	.3
96	20.4	10.2	.2	.3	.1	.4	.2	.2	.1	.2
102			.2	.2	.1	.3	.2	.1	.1	.1
108			.2	.2	.1	.3	.2	.1	.1	.1
114			.1	.2	.1	.3	.2	.1	.1	.1
120	21.5	10.8	.1	.1	.1	.2	.2	.0	.1	.0
Total		10.8	10.8	10.8	5.3	16.1	4.0	12.1	2.0	8.8

may vary widely in major storms and are difficult to analyze, as basic data are meager. The assumptions regarding amount, rate, and distribution of snowmelt contribution required for the standard project flood were made at, and in cooperation with, the Processing and Analysis Unit of the Snow Investigation Program, Oakland, California. Information available in that office under Office, Chief of Engineers Project CWI-171 was utilized.

14. The widely varying unit run-off from upper Skagit River and major tributaries such as Sauk and Baker Rivers during floods of record indicates that precipitation also must vary greatly throughout the basin. It is reasonable, therefore, to assume that distribution of snow cover would not be uniform but would vary with elevation and exposure. An attempt was made to determine the effect of these variables on snow distribution, but the meager data available made the determination impractical. However, the uneven distributions of snowmelt and precipitation have been reflected in floods of record and would therefore be reflected in the unit hydrographs derived from these floods. Therefore, to simplify computations, snow depth prior to the standard project storm is assumed to be evenly distributed throughout the basin for any given elevation.

15. Areas below 1,500 feet elevation rarely have a snow cover greater than a few inches during any storm. This snow is normally on the ground only a short time and usually disappears between storms. Less than 12 percent of the basin lies below elevation 1,500 feet;

therefore, snowmelt from this area is limited both with respect to areal contribution and volume. An area-elevation curve for Skagit River above Sedro Woolley is presented on plate 3, figure 2.

16. Approximately 25 percent of the basin area lies between elevation 1,500 and 3,500 feet. Light to moderate snowpacks may be accumulated between these elevations in November or December. Approximately 40 percent of the area of the basin has an elevation of from 3,500 to 5,500 feet. This area can, and frequently does, have a snowpack in excess of 2 feet by November or December when the standard project storm and resultant flood would most likely occur. Snow surveys have been made about 1 January at several courses in the upper Skagit Basin since 1947. Data obtained from these surveys are presented in table 4, and indicate that there may be a large potential snowmelt contribution to the standard project flood from areas above 3,500 feet elevation. The locations of the snow courses listed in table 4 are shown on plate 1.

17. <u>Temperature sequence</u>. - The best index to snowmelt is temperature and therefore it is necessary to adopt a temperature sequence for the standard project storm which will produce near optimum snowmelt for the type of flood under consideration. In order to produce near optimum snowmelt conditions, high temperatures should prevail at elevations of from approximately 3,500 to 5,500 feet. That area comprises 40 percent of the basin, and may have a moderate to heavy snowpack during or after October. A study of temperatures occurring

Table 4. - Snow surveys as of 1 January

Station	Elevation, (feet)	Average depth (inches)	Ave. Water equivalent (inches)	Density %
		1947		
Beaver Creek Trail	2,200	28	8.3	29.6
Beaver Pass	3,680	49	14.6	29.7
Freezeout Creek Trail	3,500	32	10.8	33.7
Freezeout Meadows	6,000	66	22.1	33.5
Granite Creek	2,500	30	7.7	25.7
Lightning Creek Trail	2,400	21	5.5	26.2
		1948		
Beaver Creek Trail	2,060	21	4.9	23.3
Beaver Pass	3,680	46	11.8	25.7
Freezeout Creek Trail	3,530	29	5.8	20.0
Freezeout Meadows	4,920	57	12.4	21.8
Granite Creek	2,820	9	2.1	23.3
Lightning Creek Trail	2,230	7	1.8	25.7
Meadow Cabins	1,900	6	1.6	26.7
Park Creek Pass	5,050	112	31.0	27.7
Thunder Basin	4,200	31	7.2	23.2
		1949		
Meadow Cabins	2,500	38	5.2	13.7
Three-year average				25.6

during several major storms showed that the storm of January 1935 was accompanied by unusually high temperatures. At Mount Baker Lodge, elevation 4,200 feet, a maximum temperature of 70°F. was recorded. An extreme temperature inversion was indicated during this storm because normal temperatures in this region decrease approximately 3°F. for an increase in elevation of 1,000 feet. However, a repetition of the storm of January 1935 with this temperature inversion would result in more nearly optimum snowmelt conditions for the area between 3,500 to 5,500 feet. The temperature sequence which occurred during this storm was therefore adopted as a pattern for the standard project storm.

18. Curves of mean daily temperatures for the storm period are shown in plate 3, figure 3A, for four stations in or near the basin, with elevations ranging from 38 feet to 4,200 feet. The curves shown in figure 3A are for observation stations and would not necessarily be the same for other points of equal elevation. Using the observed temperatures as a guide, curves representing assumed mean basin temperatures for the four elevations adopted for the standard project storm are presented in figure 3B, plate 3. Mean daily temperatures on the day preceding the 5-day storm, are 33°F., or below for all stations. These low temperatures prior to the storm assure that a snowpack deposited during a preceding storm would remain over the entire basin. Using the modified temperature sequence determined for the four stations as a basis, temperatures for all elevations

Table 5. - Standard project storm - Zonal temperatures and snowmelt

Elev. in feet	0 to 1,500	1,500 to 2,500	2,500 to 3,500	3,500 to 4,500	4,500 to 5,500	5,500 to 6,500	6,500 to 7,500	7,500 to 8,500	8,500 and above
Basin area in %	13.1	10.0	13.3	20.5	19.8	16.2	5.2	1.8	0.1
Day	Mean zone temperatures in degrees Fahrenheit								
1	33.5	36.5	41.0	45.0	44.0	43.0	41.0	39.5	38.0
2	36.0	40.0	47.0	52.0	50.5	48.5	46.5	44.0	42.0
3	38.0	42.5	52.0	55.0	54.0	52.0	49.5	46.5	44.0
4	32.5	34.5	38.5	42.0	41.0	40.0	38.5	37.5	36.0
5	31.5	32.5	35.0	39.0	38.0	37.0	36.0	34.5	33.0
	Zone degree days above 32 degrees Fahrenheit								
1	1.5	4.5	9.0	13.0	12.0	11.0	9.0	7.5	6.0
2	4.0	8.0	15.0	20.0	18.5	16.5	14.5	12.0	10.0
3	6.0	10.5	20.0	23.0	22.0	20.0	17.5	14.5	12.0
4	0.5	2.5	6.5	10.0	9.0	8.0	6.5	5.5	4.0
5	0	0.5	3.0	7.0	6.0	5.0	4.0	2.5	1.0
Total	12.0	26.0	53.5	73.0	67.5	60.5	51.5	42.0	33.0
	Total zone snow depth melted (assuming 30% density) in inches *								
Inches	4.0	8.7	17.8	24.3	22.5	20.2	17.2	14.0	11.0

* The zone snow depth melted is determined by assuming a melt rate of .10 inch per degree day, and 30% initial density. Example: Zone 0 to 1,500. (Total degree days above 32°F. = 12.0) (melt rate = .10 inch per degree day above 32°F.) ($\frac{1}{\text{initial density of snow}} = \frac{1}{.30}$) = (12.0)(.10)($\frac{1}{.30}$) = 4.0 inches.

P 000585

Table 6. - Standard project storm - Basin snowmelt

Day	Average snowmelt on basin contributed by each zone in inches*									
	0 to 1,500	1,500 to 2,500	2,500 to 3,500	3,500 to 4,500	4,500 to 5,500	5,500 to 6,500	6,500 to 7,500	7,500 to 8,500	8,500 and above	Total
1	0.020	0.045	0.120	0.266	0.238	0.178	0.047	0.014	0.001	0.9
2	0.052	0.080	0.199	0.410	0.366	0.267	0.075	0.022	0.001	1.5
3	0.079	0.105	0.266	0.472	0.436	0.324	0.091	0.026	0.001	1.8
4	0.007	0.025	0.086	0.205	0.178	0.130	0.034	0.010	0	0.7
5	0.000	0.005	0.040	0.144	0.119	0.081	0.021	0.004	0	0.4
Total	0.158	0.260	0.711	1.497	1.337	0.980	0.268	0.076	0.003	5.3

*This is the melt in each zone resulting from a melt of .10 inch per degree day, weighed by the zonal area or averaged over the entire basin. Example first day, zone 0 to 1,500 feet. (Degree days above 32°F. = 1.5)(melt rate = .10 inch per degree day above 32°F.)(zonal area in percent = .131) = (1.5)(.10)(.131) = .020.)

in the basin were derived for the 5 days of the storm, and the day preceding the storm. These curves are presented on plate 3, figure 4. A study of synoptic weather maps for January 1935 indicated that the assumed temperature sequence could have been experienced in the January 1935 storm.

20. Radiosonde data for upper air temperatures in Washington were not available when the snowmelt study was made at the Processing and Analysis Unit in Oakland, California. After the completion of the study in Oakland, data available in Seattle Weather Bureau Office were examined. These data showed freezing levels on 23 and 28 January 1935 at elevations of 8,800 feet and 7,200 feet, respectively. In order to follow the pattern of the January 1935 storm, temperatures at 8,000 feet should be approximately 32 to 35 degrees throughout the entire storm, instead of varying from 28 to 47 degrees as shown on figure 4, plate 3. The sequence adopted imposes higher temperatures at elevations above 6,000 feet. However, as only about 15 percent of the basin lies above 6,000 feet, and temperatures are conservatively high, no revision was made in the temperature sequence.

21. Rate of snowmelt. - No data are available on rate of snowmelt in Skagit or adjacent basins. However, information* on peak snowmelt rates at the Central Sierra Snow Laboratory indicates that the snowpack at 16 stations disappeared from 1 through 13 May at an average of 1.36 inches water equivalent per day, or about 0.13 inches per day degree. The basin on which this melt rate occurred

*Technical Report No. 5, Hydromet. Log of the Central Sierra Snow Lab published by the Processing & Analysis Unit of the Snow Invest. Program.

is 3.96 square miles in area, has a range in elevation of approximately 2,100 feet, and is relatively climatologically homogeneous. Skagit River above Sedro Woolley has a drainage area of 2,970 square miles, a range of elevation in excess of 10,000 feet, and widely varying characteristics. For these and other reasons the melt rate prevailing over the Skagit Basin could not be as high as that experienced during the peak of the snowmelt season at the Central Sierra Snow Laboratory. Therefore the assumption was made that a melt rate of 0.10 inches per degree day would be experienced during the standard project storm.

22. Computations to determine the amount of melt which would be contributed by 9 elevation zones and the entire area are presented in table 5. The melt thus determined using temperature sequence and melt rate assumed varied from 1.2 inches of water equivalent at elevations of less than 1,500 feet to a maximum of 7.3 inches at 4,000 feet, and decreased to 3.3 inches above 8,500 feet. The average snowmelt available for run-off for the entire basin for 120 hours was 5.3 inches, as shown in table 6. The daily contribution of snowmelt established in table 6 is further subdivided into contributions for 6-hour periods as shown in table 3.

23. The density of snow determined on 1 January surveys varied from 13.7 to 33.7 percent with the average density being about 26 percent (table 4). Assuming that the snowpack initially had a density of 30 percent, the depth of snow necessary to provide computed snowmelt

was determined and the results are shown on table 5, last line. Based on snowpack records it is very possible to have a snowpack varying from 4.0 inches below 1,500 feet to 24 inches at 3,500 to 4,500 feet. The snow below 1,500 feet could result from a single storm immediately preceding the standard project storm. At 3,500 to 4,500 feet, the 24-inch depth could be accumulated from one or more preceding storms. Above 4,500 feet, snowmelt decreases as temperatures are lower. However, the snowpack could be at least equal to that below 4,500 feet, and probably greater. The snowpack could in some cases be so great at higher elevations that it could absorb rainfall and snowmelt, and no run-off would result. However, the standard project storm would probably occur before such snowpacks were accumulated. These considerations indicate that a snow depth equal to that which would be melted during the storm could reasonably be assumed to exist at the beginning of the standard project storm.

24. Observations at the snow laboratories have shown that under certain conditions the snowpack retained no rainfall or melt after an initial retardation of run-off at the beginning of a storm. Therefore, in this study, it is assumed that precipitation and snowmelt would not be retarded by the snowpack.

25. Losses. - Losses are defined as the difference between total storm precipitation including snowmelt from previous accumulated snowpack and the run-off. Because of inadequate data, snowmelt contributions could not be determined for the storms

analyzed in the derivation of the unit hydrograph. The losses shown in table 1 are the difference between precipitation, only, and run-off. These losses are, therefore, too small, as no snowmelt was included with precipitation. This is particularly true of the relatively low losses shown for the November 1909 flood. During this flood all snow up to an elevation of 4,000 feet was melted, but not included in the analysis. Some snowmelt occurred during the December 1921 flood, particularly at lower elevation, and a smaller melt occurred during the December 1917 flood. Temperatures were so low during the November 1910 flood that little or no snowmelt occurred.

26. Losses accompanying the November 1909 flood were almost constant, and uniformly low, with a calculated minimum loss of 0.13 inch in 6 hours.

27. The inclusion of snowmelt in the standard project storm indicates that a minimum loss as determined in the November 1909 flood would be too small. It was recommended by the Processing and Analysis Unit that based on precipitation alone losses approximately double those computed for the November 1909 flood be used for the standard project storm. The minimum loss for the 1909 flood was 0.13 inch in a 6-hour time interval. A conservative comparable value of 0.20 inch per 6-hour time unit was adopted for the standard project storm.

28. <u>Surface run-off</u>. - Surface run-off was derived for rainfall and snowmelt excess using variable unit hydrographs as shown on plate 3, figure 5 as curves A and B, respectively. Unit hydrographs with

crests 125 and 150 percent of the unit hydrograph basic crest were derived because of possible higher rates of run-off for higher rates of precipitation during the standard project storm. The maximum 24-hour precipitation during the standard project storm occurs between hour 54 and 78 and totals 5.0 inches. During that period, 1.8 inches of snowmelt is contributed, giving a total snowmelt and precipitation of 6.8 inches in 24 hours. The December 1921 storm had a maximum of 5.6 inches of precipitation for 24 hours as compared with the 5.0 inches for the standard project storm. Snowmelt contribution is indeterminate for the December 1921 flood, and no comparison of snowmelt can be made. However, because precipitation rates are quite comparable, the use of the 150 percent unit hydrograph in deriving surface run-off for the standard project flood appears unwarranted. Therefore, the hydrograph of surface run-off developed by use of 100 and 125 percent unit hydrographs, curve B, plate 3, figure 5, is adopted for the standard project flood as being most representative of run-off conditions which could prevail.

29. In order to determine the effect of adding snowmelt to the standard project storm, a hydrograph resulting from precipitation alone was computed. Loss rates were assumed to vary from 0.3 inch per 6-hour period at the beginning of the storm to 0.1 inch per 6-hour period at the end of the storm. Unit hydrographs varying from 100 to 150 percent of the basic unit hydrograph were utilized, and the resultant hydrograph is presented as curve C, plate 3, figure 5.

This hydrograph is directly comparable to curve A, which includes run-off from snowmelt. In this case, the snowmelt increased the crest discharge approximately 33 percent, while increasing volume of surface run-off approximately 37 percent.

30. Base flow. - Because of the conditions which have been assumed to precede the standard project storm, the base flow cannot be excessive. In order to provide the snowpack assumed, precipitation during the storm prior to the standard project storm must have fallen as snow over the entire basin. The temperature sequence assumes that mean temperatures over the basin did not rise to above freezing until the first day of the standard project storm. Thus, low temperatures and snow would necessarily result in a low or not more than average base flow.

31. The base flow in floods studied varied from a minimum of 10,000 second-feet to a maximum of 28,000 second-feet (table 1).

32. The temperature sequence for the January 1935 storm was used as a basis for deriving the standard project flood. No discharge records are available for that period near Sedro Woolley. However, records are available for a station near Concrete, approximately 34 miles upstream from Sedro Woolley, drainage area 2,700 square miles. This station is below all major streams tributary to Skagit River. Prior to the storm of January 1935, the mean daily discharge at Concrete was less than 10,000 second-feet.

33. Because of assumptions of climatological conditions preceding the standard project storm, base flow could not be greater than that experienced during storms analyzed. Therefore, the base flow is assumed to vary from 14,000 to 28,000 second-feet and is presented as curve D, plate 3, figure 5.

34. Standard project flood. - The standard project flood is made up of two component parts, the surface run-off and base flow, curves B and D, respectively, of plate 3, figure 5. The crest discharge of the flood determined by adding the two components is 440,000 second-feet; this flood hydrograph is presented as curve E, plate 3, figure 5.

35. Discussion. - Records of stream flow for the gaging station, Skagit River near Sedro Woolley, are available for the period May 1908 to September 1924. The maximum discharge during this period was 220,000 second-feet on 30 November 1909. Streamflow records in the lower Skagit Basin indicate that the 1909 flood is the largest flood occurring in this locality since 1896. The standard project flood is, therefore, 200 percent of the 54-year maximum discharge at the site of the gaging station.

36. In the storm of November 1909, the maximum 24-hour precipitation was 3.60 inches; the amount of snowmelt contribution for the November 1909 flood is indeterminate; but the maximum 24-hour rainfall excess was 3.08 inches. The standard project storm maximum 24-hour precipitation is 5.0 inches, with a snowmelt contribution of 1.8 inches,

or a combined precipitation and snowmelt of 6.8 inches, the maximum rainfall-snowmelt excess for a 24-hour period is 6.1 inches. This is approximately double the maximum 24-hour precipitation of the November 1909 storm. However the maximum 24-hour precipitation of the standard project storm was exceeded in the December 1921 storm, and probably was equalled or exceeded in January 1935. The assumed snow cover is only nominal for this season of the year and was exceeded as recent as December 1948. The temperature sequence used for the standard project storm was patterned after that of the January 1935 storm.

37. Thus, each of the three major factors entering into the standard project flood, i.e., precipitation, antecedent snow cover, and temperature sequence, has been equalled, or exceeded, within the 50 years since 1900. All of the conditions were not experienced during the same storm and therefore the assumption that all conditions conducive to optimum run-off occur simultaneously makes this a rare flood.

38. Two large pre-record floods were estimated and an extensive study was made in an unpublished report by James E. Stewart, Hydraulic Engineer, U. S. Geological Survey, in 1923, titled "Report on Flood Control, Skagit River Basin." A summary of Stewart's report is contained in Geological Survey Water-Supply Paper 968-B. Mr. Stewart estimated the largest known floods to have occurred in 1815 and 1856, with magnitudes at Sedro Woolley of 400,000 and 300,000 second-feet, respectively. Mr. Stewart concluded that the 1815 flow was, or

almost equaled, the largest flood on the Skagit in thousands of years.

39. Although the 1815 flood may have occurred with the indicated magnitude, it may not have been from natural causes. The topography of the Skagit Basin is such that many reaches of the main river and numerous tributaries have narrow, steep canyons where timber, ice jams, or snow and rock slides could temporarily dam the river. Such dams would impound flows until they failed, at which time the resultant surges would cause extreme peak discharges in the lower river valley. Relatively large snow slides have occurred recently in the narrow box canyons near Ross Dam on the Skagit River temporarily blocking the river to a minor extent. The determinations of these floods do not seem conclusive. Therefore, the estimated peak discharges of the pre-record floods of 1815 and 1856 are not considered of much significance for comparison with the standard project flood.

40. Upstream regulation. - The Skagit River Basin has three reservoirs: Ross and Diablo on Skagit River and Lake Shannon on Baker River. These reservoirs are shown on plate 1. The usable capacities at Ross, Diablo, and Shannon are 1,204,000, 76,000, and 132,500 acre-feet, respectively.

41. The standard project flood was derived for natural river conditions, and assumes no regulation by these reservoirs, none of which are operated for flood control. Ross Dam has recently been raised to elevation 1,615 feet and 18-foot spillway gates will be

installed by the fall of 1952. The present license of the City of Seattle contains a provision for the reservation of 200,000 acre-feet of flood-control storage in Ross Reservoir. This space will be made available upon the installation of the spillway gates and will be entirely within their range of operation. The current Skagit River Report of this office will recommend an operation schedule for Ross Reservoir which will use this storage for flood control and will present the effect of such operation upon the standard project flood at Sedro Woolley.