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Appendix
to
Report on Survey
for Flood Control
of
SKAGIT RIVER AND TRIBUTARIES,
WASHINGTON

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APPENDIX TO
REPORT ON SURVEY FOR
FLOOD CONTROL OF SKAGIT RIVER
AND TRIBUTARIES, WASHINGTON

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SECTION I - HYDROLOGY

CLIMATOLOGY

1. General. - The Skagit River Basin is on the west side of the Cascade Range approximately 100 miles from the vast moisture supply of the Pacific Ocean. The influence of the maritime air masses is pronounced in both the precipitation and temperature regimes, producing a mild but wet climate. During the winter the Skagit Basin, lying directly in the storm path of cyclonic disturbances from the Pacific, is subject to convective showers which are frequently rather heavy and may follow in quick succession. On the mountain slopes, storm precipitation is heavy and almost continuous as a result of the combination of frontal and orographic effects. During the summer months the weather is warm and relatively dry as a result of the decreased activity of the semi-permanent Aleutian low and of the increased moisture-carrying capacity of incoming maritime air through land warming.

2. The U. S. Weather Bureau has maintained a total of 17 climatological stations in or near the basin, of which 10 are currently operating. Another climatological station is operated by the Department of Agriculture, Province of British Columbia, in the portion of the basin extending into Canada. The elevations of these stations vary from 30 feet at Anacortes to 4,150 feet at Mount Baker Lodge, with 13 of the 18 stations located below 1,000 feet and only 1 above 3,000 feet. The locations of these stations, together with their period of record, are shown on plate 1. A summary of precipitation and temperature data for 9 representative stations will be found in table A-1.

3. Temperature. - The mean annual temperature for stations in or near the basin varies from 40.6° F at Mt. Baker Lodge to 50.9° F at Concrete. Mean monthly temperatures vary from 27.4° F at Mt. Baker Lodge to 39.1° F at Anacortes in January, and from 55.2° F at Mt. Baker Lodge to 66.6° F at

Table A-1. - Summary of climatological data (through 1949)

Station	Elevation	Years of Record	PRECIPITATION, Annual: Mean	PRECIPITATION, Annual: 52-Year Normal 1/	PRECIPITATION, Annual: Max.	PRECIPITATION, Annual: Min.	SNOWFALL: Years of Record	SNOWFALL: Mean Annual 1/	TEMPERATURE: Years of Record	TEMPERATURE: Mean Annual	TEMPERATURE: Max. 1/	TEMPERATURE: Min. 1/	Average Length of Growing Season 1/
	Ft.		In.	In.	In.	In.		In.		°F	°F	°F	Days
Anacortes	30	56	26.60	26.7	37.82	15.89	48	5.3	43	50.6	95	6	236
Baker Lake	670	8	102.88	114.3	133.39	67.26	7	58.1	2/	2/	2/	2/	153
Concrete	270	35	60.79	65.0	80.45	43.45	33	29.5	33	50.9	106	-1	214
Darrington R.S.	550	31	1/ 76.54	82.4	102.93	51.45	14	42.7	26	48.8	105	-11	159
Diablo Dam	891	20	1/ 65.36	84.1	87.00	48.07	16	63.9	20	48.5	106	-10	209
Marblemount R.S.	330	8	1/ 71.44	73.8	82.11	60.19	2/	2/	2/	2/	2/	2/	2/
Mt. Baker Lodge	4150	14	109.49	147.4	141.97	74.13	10	504.0	14	40.6	91	-11	105
Sedro Woolley 1 E	56	52	45.50	48.2	64.35	28.18	34	7.9	52	50.4	99	-1	187
Skagit Power Plant	505	29	72.63	79.8	102.45	48.40	23	59.2	29	50.3	109	-4	207

Except as otherwise noted, data are taken directly from U. S. Weather Bureau Climatological Summaries.

1/ Computed by Corps of Engineers
2/ No record

Skagit Power Plant in July. The range in extreme temperatures recorded in the basin varies from 89° F at Anacortes to 116° F at Darrington Ranger Station and Diablo Dam, with the maximum recorded temperature of 109° F at Skagit Power Plant and the minimum of -11° F recorded at Darrington Ranger Station and Mount Baker Lodge. In general, the mean annual temperature varies from an average of approximately 50° F at elevations below 1,000 feet to 40° F at elevations 4,000-5,000 feet, dropping to the lower thirties at the highest elevations. The average length of growing season varies from 105 days at Mt. Baker Lodge to 236 days at Anacortes. Mean monthly temperature data for 7 representative stations are presented in table A-2.

4. Precipitation. - Precipitation over the basin normally varies greatly, with a range of approximately 150 inches. A normal annual amount of 40 inches or less falls in the vicinity of the mouth of the river and in that portion of the valley in Canada, which is located in a topographic rain shadow. A normal annual amount of 180 inches or more falls on the higher elevations of the Cascade range in the southern end of the basin and over the higher slopes of Mt. Baker. The normal annual precipitation over the basin above Mount Vernon is 92.2 inches, approximately 75 percent of this amount falling during the 6-month period, October through March. A normal annual isohyetal map based upon a computed 52-year normal annual precipitation at stations with 5 years or more of record, and drawn with due consideration for elevation and run-off regimes, is presented on plate 2. The mean monthly precipitation at stations in or near the basin varies from 0.67 inches in July at Anacortes to 17.38 inches in December at Mt. Baker Lodge. The maximum recorded precipitation for 1 month is 36.62 inches at Baker Lake in December 1933. Storm studies indicate that 5-6 inches of rainfall in 24 hours have occurred over much of the basin. Mean monthly precipitation data for 9 representative stations are presented in table A-3.

5. Snowfall. - The percent of the annual precipitation which falls in the form of snow in the Skagit Basin depends upon the elevation and the distance from the modifying influence of the Straits lying between the Pacific Ocean and the basin. The mean annual snowfall varies from 5.3 inches at

Table A-2. - Mean monthly temperature data (through 1949)

Station	Temperature in degrees F.												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Anacortes	39.1	41.5	45.1	49.6	54.3	58.6	61.4	61.6	57.8	51.9	45.4	41.2	50.6
Concrete	35.2	39.6	44.9	51.3	56.2	60.8	65.0	64.9	59.8	52.4	42.8	38.3	50.9
Darrington R.S. 1/	34.1	37.4	42.3	48.9	54.1	58.6	62.6	63.2	57.6	50.0	40.8	35.8	48.8
Diablo Dam 1/	30.7	34.6	41.0	48.0	54.2	59.2	65.3	64.8	59.6	50.0	39.2	35.0	48.5
Mt. Baker Lodge	27.4	29.9	32.6	36.8	43.3	48.1	55.2	57.8	49.2	42.8	34.6	29.0	40.6
Sedro Woolley 1 E	37.7	40.6	44.8	50.2	54.8	59.4	62.4	62.1	56.8	51.6	44.4	39.8	50.4
Skagit Power Plant	33.5	37.4	43.1	50.6	56.4	61.2	66.6	65.8	60.1	51.2	41.5	36.6	50.3

Table A-3. - Mean monthly precipitation data (through 1949)

Station	Precipitation in inches												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Anacortes	3.47	2.48	2.36	1.89	1.60	1.31	0.67	0.88	1.58	2.57	3.79	4.00	26.60
Baker Lake	15.60	10.88	12.66	5.91	4.96	3.56	1.93	1.43	6.10	11.16	12.02	16.67	102.88
Concrete	8.50	6.22	5.96	3.53	3.11	2.51	1.13	1.42	3.36	6.49	9.24	9.32	60.79
Darrington R.S. 1/	10.59	8.48	8.39	4.93	3.59	3.01	1.22	1.18	3.51	7.66	10.69	13.29	76.54
Diablo Dam 1/	8.95	7.50	7.20	4.01	2.60	2.24	1.28	0.89	2.90	7.40	8.90	11.49	65.36
Marblemount R.S. 1/	9.17	7.53	6.86	4.85	3.25	2.98	1.59	1.66	4.64	7.70	9.77	11.44	71.44
Mt. Baker Lodge	12.45	10.20	13.04	8.13	6.26	5.00	2.96	2.31	7.57	11.51	12.68	17.38	109.49
Sedro Woolley 1 E	5.54	4.11	4.37	3.19	2.78	2.51	1.36	1.47	3.07	4.63	6.12	6.35	45.50
Skagit Power Plant	10.72	7.37	7.33	3.90	3.20	2.31	1.29	1.33	3.63	8.26	11.29	12.00	72.63

1/ Computed by Corps of Engineers

Anacortes to 504 inches at Mt. Baker Lodge, with a maximum annual of 648 inches recorded at the latter station in 10 years of record. Snow surveys have been made at several courses in or near the upper Skagit Basin since 1927. The locations of these snow courses are shown on plate 1. These stations are in a portion of the basin that is in a topographic rain shadow and hence do not have the heavy snowfalls and snowpacks which occur in the southern portions of the basin and in the Baker River drainage area. The mean annual snowfall for 9 representative climatological stations is tabulated in table A-1.

6. Humidity. - The nearest station recording humidity data is at Seattle some 60 miles south of the basin. Relative humidity data have been taken at 4:30 a.m., 10:30 a.m., 4:30 p.m. and 10:30 p.m. in the past 10-year period at the Boeing Field Weather Bureau office. The humidity varies from a mean of 93 percent at 4:30 a.m. during the month of October to a mean of 48 percent at 4:30 p.m. during the month of July. The mean annual relative humidities are 88 percent at 4:30 a.m., 73 percent at 10:30 a.m., 61 percent at 4:30 p.m., and 80 percent at 10:30 p.m. The mean monthly and annual relative humidities for these hours of observation at Boeing Field will be found in table A-4.

Table A-4. - Relative humidity data Seattle, Washington, elevation 14 ft. (through 1949)

Month	Relative Humidity (percent)			
	4:30 a.m.	10:30 a.m.	4:30 p.m.	10:30 p.m.
January	86	81	72	82
February	87	79	68	83
March	86	70	58	79
April	87	66	54	78
May	87	63	50	75
June	88	64	51	75
July	87	63	48	72
August	89	68	52	76
September	92	73	58	82
October	93	81	69	89
November	91	84	77	88
December	88	84	78	86
YEAR	88	73	61	80

7. Wind. Surface winds over the basin are variable, especially at low velocities, depending upon the local topographic conditions. The prevailing wind over the basin is southwesterly, varying from west to south. There

are no stations in the basin for which wind velocities are available, however, it is estimated that the mean annual velocity in the basin at elevations less than 1,000 feet is 7-8 m.p.h. The estimated peak velocities for these elevations is in excess of 50 m.p.h. Mean velocities increase with elevation but no data are available to permit an estimate of their magnitude.

8. Storms. - All major floods in the Skagit Valley are produced by severe storms which occur chiefly during November, December, and January. The magnitude and intensity of a storm cannot always be used as an index to the resulting flood. Other factors such as temperature sequence, groundwater recharge, snow pack, etc., largely influence the rate of run-off as well as total run-off. Antecedent conditions may have been such that only a moderate storm may provide the required impetus to set in motion the related factors that collectively result in a flood. On the other hand, a combination of factors may be such that a very severe storm results in only minor high water. The following storms are described to illustrate the relationship between storm characteristics and the resulting flood.

9. November 1909. - The month of November 1909 was one of above normal precipitation over the Pacific Northwest with a period of moderate to heavy rains occurring during the last two weeks. Measurable amounts of precipitation occurred over the basin an average of 24 days during the month and approximately two-thirds of the monthly totals occurred after the 16th of the month. This period of heavy precipitation was a result of a series of low pressure systems which moved through the Pacific Northwest. The fastest moving storm was the last one of the series which moved into the region on the 26th of the month, causing copious amounts of precipitation on the 28th and 29th. The storm period which produced the flood of November 1909, the largest of record, was a 66-hour period beginning with 6:00 a.m. on the 27th and ending at midnight of the 29th. Total storm precipitations for this period were 9.2 inches at Goat Lake, 8.3 inches at Skagit Power Plant, 5.9 inches at Concrete and 2.5 inches at Sedro Woolley. Maximum 24-hour amounts were 5.6 inches, 5.8 inches,

3.8 inches, and 1.3 inches at these respective stations. Temperature sequences and the record at Goat Lake indicate that the precipitation fell as snow above 2,500 feet on the 26th and 27th, and mixed rain and snow fell on the 28th. On the 29th of the month, precipitation fell as rain up to elevations of 6,000 feet and melted off all snow to approximately 4,000 feet. The advent of a high pressure system brought a rapid decrease in storm activity by the 30th. The mean basin precipitation for this storm period was 6.69 inches and the mean basin maximum 24-hour fall, 3.60 inches. An isohyetal map for this storm and pertinent data are presented on plate 9.

10. December 1921 - The month of November 1921 was below normal in temperature while the precipitation was decidedly in excess. Mild weather with little or no precipitation prevailed until the 18th, when a sharp cold spell set it. Heavy snow fell on the 19th, 20th, and 21st to a depth up to 10 inches or more at stations west of the Cascades, being much heavier on high mountain slopes. It was the deepest snow on record for this early in the season with the exception of the extremely cold November of 1896. Mild weather with abundant rain marked the remainder of the month.

11. December, while cold, had less than the average amount of snowfall, and much of what fell was melted off by the excessive rains of the 10th to 12th. The storm period from 6:00 p.m. on the 9th to 12:00 p.m. on the 12th was the most critical in producing the flood peak of the 13th, the second highest flood of record. During this period, 14.2 inches of precipitation fell at Silverton, 10.2 inches at Davis Ranch, and 3.4 inches at Sedro Woolley. Maximum 24-hour amounts were 5.9 inches, 5.0 inches and 2.0 inches respectively at these stations.

12. December 1933 - The storms which produced the two largest floods of record have been analyzed above. The storm of December 1933 is an outstanding example of a major storm which did not cause a flood of damaging magnitude on Skagit River below Sedro Woolley; however, it did produce the largest flood in the last forty years on several of the other streams in western Washington. The month of December 1933 was one of unprecedented

rainfall over western Washington, including the entire Cascade Mountains. The total monthly precipitation was greater than for any month in previous years of record at the majority of stations. The average number of days recording measurable amounts of precipitation during the month was 28 for western Washington. The same average conditions prevailed over the Skagit Basin. The precipitation was unusually heavy during a number of periods within the month, the 6-day period from the 17th through the 22nd being the most critical. The storm period studied was from 7:00 a.m. on the 17th to 1:00 p.m. on the 22nd, a total of 126 hours. Total storm precipitations recorded in the basin varied from 2.50 inches at Anacortes to 11.41 inches at Darrington. It is estimated that nearly 25 inches fell over the high elevations in the southern portion of the basin. The maximum recorded 24-hour amounts were 3.55 inches at Darrington and 0.77 inches at Anacortes.

13. Although this was a very mild December, snowfall was above normal at most mountain stations. Because of the warm weather and rains, however, snow depths on the ground at the end of the month were less than usual with the snow remaining being wet and well packed. Mt. Baker Lodge reported 104 inches of snow fell during the month, with 56.0 on the ground on the 15th On the 31st only 59.0 inches were on the ground, which was 30.5 inches below normal.

14. This unusually wet month was caused by a low pressure disturbance of considerable intensity which remained fairly stationary off the Washington coast. Secondary frontal disturbance was constantly breaking away from this center and moving across the state, bringing the heavy rains as the result of a constant feeding of warm, moist, tropical air from the South Pacific.

15. While precipitation was much higher than normal for December 1933, none of the individual 2 to 5-day storms produced severe flooding in the basin. Station precipitation records indicate that 24-hour amounts were less than for the November 1909 and December 1921 storms. Much of the precipitation occurred as snow at the mountain stations, which reduced

direct run-off and also served to retard run-off from precipitation occurring as rain. These factors combined to produce high but non-damaging discharges throughout the basin.

STREAM FLOW

16. Discharge records. - Stream gaging in the Skagit River Basin was inaugurated in 1908 with the establishment of stations on Skagit River near Newhalem and Sedro Woolley. The station near or at Newhalem has been moved several times and not all of the record is entirely comparable, but it has the longest continuity of any station in the basin. The U. S. Geological Survey has published records for 57 stations, including lake and reservoir stations, of which 25 are currently operating. Many of the stations were operated for short periods of time or had intermittent records. The location of the 57 stations and pertinent data are shown on plate 1.

17. Stream flow characteristics. - The flow of Skagit River and its tributaries tends to be relatively low from August through October and subject to only minor variations reflecting storm run-off. During the months of November through March when temperatures, particularly at higher elevations, are at or near the freezing point and much of the precipitation occurs as snow, a low base flow is maintained. However, frequent sharp rises resulting from concentrated 2 to 5-day storms or series of storms are experienced in this period. The intense storms when accompanied by warm winds and resultant snowmelt produce a rapid run-off. During and following these severe storms river discharges may increase from a relatively low base flow to a discharge of damaging magnitude within 24 to 30 hours. Near crest discharges may be maintained for a few hours, followed by a recession almost as rapid as the rise. Two or three such rises may be experienced within a period of 2 weeks. Not all rises reach flood stages, however, and these usually are more frequent and reach higher stages in late October, November, and December.

18. In April or early May temperatures normally rise, causing the snowpack, accumulated at higher elevations during the winter, to melt. As temperatures continue to rise, snowmelt and run-off increase. Normally, the flow starts increasing from April or May through early June when the

peak discharge from snowmelt is reached. After approximately the middle of June, run-off starts to decrease. Although temperatures continue to rise the snowpack is normally too depleted to continue making high contributions to run-off. Snowmelt run-off decreases until the snowpack is exhausted and a low base flow is reached in July or August. Minor rises caused by storms have been experienced during the spring and early summer, but none have approached the magnitude of the major winter floods nor exceeded the safe channel capacity. A summary of discharge data and the variation of mean monthly run-off for representative stations are presented in tables A-5 and A-6. Daily discharge hydrographs for selected stations are included in plates 3 through 8.

19. The amount of run-off varies widely throughout the basin. The run-off from high areas lying nearer the coast, such as Baker River, exceeds 130 inches. The headwaters of Skagit River, particularly that area lying in British Columbia which is shielded from heavy precipitation by high mountains, yield an annual run-off of approximately 35 inches. A direct comparison of mean run-off in tables 5 and 6 reveals apparent inconsistencies because the various stream gaging stations have not operated for the same periods. A 52-year normal annual run-off was calculated for all stream gaging stations in the basin having at least 5 consecutive years of run-off prior to 1943, by double-mass-curve method. The normal annual run-off in inches so determined is shown on plate 2 for several representative stations in the basin. For comparative purposes, normal annual precipitation above the same stations was determined from the normal annual isohyetal map, shown on plate 2. The difference between normal annual precipitation and run-off is shown as losses which are attributable to transpiration, evaporation, etc. It may be seen that precipitation and resultant run-off varies greatly throughout the basin. The tendency for run-off per square mile at main stream gaging stations to increase as the drainage area increases is unique among rivers in the vicinity of Skagit River Basin.

Table A-5. - Summary of stream flow data
(through water year 1948)

Stream	Station	Drainage area in square miles	Period of Record	Annual run-off (cubic feet per second) Mean	52-yr. normal	Annual Max.	Annual Min.	Extreme discharge in cubic feet per second Instant Max.	Daily Max.	Daily Min.
Skagit River	At Newhalem	1,160	1908-14, 1920-	4,214	4,555	6,300	2,650	63,500	42,400	136
Skagit River	Near Concrete	2,700	1924-	13,980	15,080	19,740	9,629	147,000	129,000	2,360
Skagit River	Near Sedro Woolley	2,970	1908-24	16,200	16,150	19,600	10,700	220,000	198,000	2,830
Skagit River	Near Mt. Vernon	3,060	1940-	14,580	1/	17,460	10,510	94,300	88,000	3,050
Sauk River	Near Sauk	714	1911-12, 1928-	4,015	4,655	5,950	2,887	68,500	51,400	578
Baker River	Below Anderson Cr.2/ Near Concrete	210	1910-25, 1928-31	1,990	2,073	2,600	1,540	36,800	27,400	220

Table A-6. - Mean monthly stream flow data (through water year 1948)

Stream	Station	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Annual
Skagit River	At Newhalem	2,586	2,784	2,867	2,315	2,235	2,399	4,323	8,882	10,360	6,172	3,225	2,321	4,210
Skagit River	Near Concrete	10,340	11,720	13,740	11,810	10,160	10,220	14,540	24,080	26,960	17,280	9,158	7,563	13,980
Skagit River	Near Sedro Woolley	10,700	16,400	16,300	13,500	12,000	10,300	13,900	23,900	31,600	23,200	12,200	9,160	16,200
Skagit River	Near Mt. Vernon	11,540	12,190	15,240	12,160	11,080	10,030	14,100	22,960	26,830	17,920	9,230	8,470	14,580
Sauk River	Near Sauk	2,586	3,623	4,217	3,697	3,159	3,078	4,070	6,603	7,792	5,025	2,387	1,902	4,015
Baker River	Below Anderson Cr. Near Concrete	1,830	1,750	1,810	1,520	1,400	1,110	1,710	2,850	3,590	2,990	1,800	1,490	1,990

1/ Data unavailable
2/ Revised by Corps of Engineers

20. Regulation. - There are three reservoirs on Skagit River and its tributaries, operated entirely or primarily for production of power. Sinc their construction, they have effected some degree of incidental flood control. The first reservoir developed was Shannon Lake, operated by Puget Sound Power and Light Company. The dam was completed in June 1927, and controls a usable capacity of 132,500 acre-feet, however, there are no provisions for flood control reservations at this site. The normal operation of the reservoir for power results in water being stored during the spring snowmelt season and early winter rain season, while releases are generally made during the late summer, fall and winter. Because of this general operation the reservoir usually has a variable and small amount of space available to aid in regulating high discharges occurring in November and December. This reservoir was full prior to the peak of the November 1949 flood and therefore no reduction of flooding downstream was obtained.

21. The city of Seattle has developed Skagit River above Newhalem for the production of hydroelectric energy. Diablo Dam was completed in 1930. A usable capacity of 76,200 acre-feet is available between power operating levels of 1,205 feet and 1,040 feet. From 1930 to 1940 this reservoir provided incidental flood control, and was particularly effective during the flood of February 1932. Since the construction of Ross Dam in 1940, draw-down at Diablo has been limited insofar as possible to 15 feet. Future operation contemplates a limited diurnal fluctuation of approximately 3 to 5 feet required for power generation at peak load.

22. In 1940 Ross Dam was completed to elevation 1,400. Subsequent construction and the installation of spillway gates by 1952 will raise maximum operating pool level to 1,600 feet. The maximum draw-down contemplated for power is 100 feet, with a corresponding storage of 896,000 acre-feet.

23. Since the construction of these two dams on the Upper Skagit River, and until the installation of the gates is completed at Ross Dam in 1952, flood control regulation has, and will continue to be, incidental

and variable. Studies are under way to determine the amount of flood control storage reservation and the method of reservoir operation. At least 80,000 acre-feet of storage are required to effect the maximum amount of control possible for the largest floods of record. Final results have not yet been obtained, but for the purpose of this report to illustrate the effect of flood storage in Ross Reservoir 120,000 acre-feet of storage has been assumed. The effect of such storage in Ross Reservoir for the floods of 1909, 1917, 1921 and the standard project flood is shown on plate 9.

FLOODS

24. Flood characteristics. - Because of its geographic location, the Skagit River Basin is subject to floods of both the rain and snowmelt type. An annual high water is expected during the spring or early summer, caused by the seasonal rise in temperatures, with resultant melting of the accumulated snowpack. These high discharges may have a minor contribution from warm rains, but are caused predominantly by snowmelt. Rain-type floods occur usually in November or December, but may occur as early as October or as late as February. Antecedent precipitation serves to build up groudwater reserves and saturate the ground. Frequently, a light snowpack is then formed over most of, or the entire basin. A heavy rainfall accompanied by warm winds completes the sequence which produces major floods. The heavy rainfall and accompanying snowmelt result in a high rate of run-off as the ground is already nearly saturated from earlier precipitation. Two or more crests may be experienced within a period of a week or two when a series of storms moves across the basin from the west.

25. The high water caused by the spring snowmelt is characterized by its relatively slow rise and long duration. While this high water occurs annually, it has never reached a damaging stage. It is during this annual spring or early summer high water that power reservoirs are filling, and as a result the spring peak discharges are frequently reduced.

26. Rain floods occur during the fall or early winter months and have a considerably higher magnitude than the average annual spring high water. Since 1920 these floods have been reduced varying amounts by incidental control at the power reservoirs. However, the location of these reservoirs is such that they cannot effect any great amount of flood control because of the contribution from large uncontrolled tributary areas, of which Sauk River is the largest and most important.

27. Historical floods and floods of record. - The first white people settled in the valley about 1869. High-water marks since then have been recorded from time to time, with increasing accuracy. Prior to that time the record of floods depends upon testimony and tradition of the Indians, upon certain direct and indirect evidence of high-water marks, and upon flood records elsewhere. Gaging stations have been established only since 1908, and the records therefrom are not, in general, continuous for any particular station.

28. In 1923, Mr. J. E. Stewart, of the U. S. Geological Survey, collected data for, and partially completed, a report on Skagit River. After careful study and analysis of all data and evidence available he reached the conclusion that "a flood about 1815, was nearly a maximum, but there had been, prior to that time, several floods approximately as large." The 1815 flood had, he believed, about twice the discharge of the floods of 1909, 1917, and 1921, and he also found evidence of a flood in 1856, about 1-1/2 times as great as those more recent floods.

29. Flood discharges as determined by Mr. Stewart, together with data on the floods of February 1932, January 1935, November 1949, and February 1951, are shown in table A-7.

Table A-7 - Flood discharges of Skagit River

Station	Skagit R. at Reflector Bar		Skagit R. near Concrete		Skagit R. at Sedro Woolley	
Drainage Area	1,100 sq. mi.		2,700 sq. mi.		2,970 sq. mi.	
	Crest Discharge		Crest Discharge		Crest Discharge	
Date	cfs.	cfs/sq.mi.	cfs.	cfs/sq.mi.	cfs	cfs/sq.mi.
1815	1/115,000	105	1/500,000	185	1/400,000	135
1856	1/ 95,000	86	1/350,000	130	1/300,000	101
Nov. 16, 1896					1/185,000	62
Nov. 19, 1897	1/ 48,000	44	1/275,000	102	1/190,000	64
Nov. 16, 1906					180,000	61
Nov. 30, 1909	1/ 70,000	64	1/260,000	96	220,000	74
Dec. 30, 1917	1/ 43,000	39	1/220,000	81	195,000	66
Dec. 12-13, 1921	1/ 63,000	57	1/240,000	89	210,000	71
Feb. 27, 1932	2/ 45,000	39	147,000	54		
Nov. 13, 1932			116,000	43		
Dec. 22, 1933			101,000	37		
Nov. 5, 1934			131,000	49		
Jan. 25, 1935	2/ 30,300	26	131,000	49		
Nov. 27, 1949	2/3/14,000	12	3/158,000	59	3/135,000	45
Feb. 10, 1951	2/3/12,000	11	3/139,000	52	3/150,000	51

1/ Calculated by Mr. Stewart from all available information and high water marks.
2/ Discharge below Gorge power plant (D.A. 1,160 sq. mi.).
3/ Preliminary estimate by Corps of Engineers.

The discharge of floods at Sedro Woolley prior to and including 1921 was based partly upon the calculated discharge of the 1921 flood determined from slope area computations for the main channel and overflow in several sloughs. The discharge in the main channel for the observed gage height from rating curves was 160,000 cubic feet per second. The discharge of South, Beatty's and North Sloughs, not accounted for in rating curve for the river, and Beatty's Slough channel at County road, was computed to be 50,000 cubic feet per second. The total crest discharge was computed to be 210,000 second-feet, as shown in table A-7.

30. The discharge of the 1921 flood at Mount Vernon (drainage area 3,062 square miles) was determined by Mr. Stewart as approximately 190,000 second-feet, of which 140,000 second-feet was carried by the river channel below a break in the dikes just above the Great Northern Railway bridge. The crest discharge for this flood is given as 240,000 second-feet near Concrete and 210,000 second-feet at Sedro Woolley. This decrease in peak discharge as the floods advance downstream is caused by storage in the river channel and overflow areas. Mr. Stewart estimated the overflow discharge for the 1917 flood to be the same as for the 1921 flood, therefore 50,000 second-feet was added to the flow calculated for the main channel to determine the estimated total discharge. Mr. Stewart states the accuracy of crest discharges of the 1909, 1917, and 1921 floods at Sedro Woolley is 10 percent, and 15 percent for other floods prior to 1909. The limits of accuracy assigned to these discharges has been the subject of much discussion. However, data are too limited to permit a more accurate analysis than made by Mr. Stewart. As a result of Mr. Stewart's studies, the U. S. Geological Survey revised all discharge data for the period May 1, 1908, to September 30, 1921, for this station and these revisions were published in Water Supply Paper No. 552. The largest discharge actually measured at Sedro Woolley, prior to Mr. Stewart's study, was made on January 2, 1918, during the recession of the second and secondary crest of the December 1917 flood, and was determined as 91,100 second-feet. Thus, considerable extrapolation of the rating curve is required to obtain the calculated discharges for these early floods. A measurement taken at or near the peak of future flood, cf
(continued on next page)

comparable magnitude with those calculated by Mr. Stewart, will be of invaluable assistance in checking the calculations.

31. At the time Mr. Stewart made his report no gaging station had been established on Skagit River at The Dalles, near Concrete. His estimate of 240,000 second-feet for the crest discharge at this site is a mean of four calculated discharges, one made by contracted opening method and three by slope section. The 1917 and 1909 discharges were estimated by comparison of stage heights with that of the 1921 flood. Determination of gage heights of early floods was made from high-water marks. Mr. Stewart estimates the discharge of the December 1921 flood to have an accuracy within 5 percent; the 1917, 1909, 1856, and 1915 floods, 10 percent; and the 1897 flood, 20 percent at The Dalles. These values are also subject to question because of uncertainty of high-water marks, changing channel conditions tending to alter the rating curves such as clearing the bottom valley lands, erosion and deposition, and excessive extension of rating curves.

32. Flood frequency. - The records of the gaging station, Skagit River near Sedro Woolley, are used for the flood frequency study, as the gage is located at the head of the principal area for which protection has been considered. In addition, all flood damages in the lower Skagit valley have been related to flood discharges at this station. The flood frequency study utilizes annual peak flows from the winter months only, as the spring high waters have always been below damaging stage and are the result of a different set of meteorological conditions than those causing the winter floods.

33. Flood records are available in the basin since 1908 but they are not continuous at any single site for the entire period. As described previously, estimates have been made of crest discharges for historical floods occurring in 1815, 1856, 1897, 1898, and 1906. However, it was felt that the use of these flood peaks not in a continuous series and of questionable accuracy would decrease the over-all accuracy of the frequency curve, and so they were omitted from the study. As the period 1909 to 1950 is considered to be a relatively adequate sample for the determination of a flood frequency curve, a complete series of flood data was derived for this period from available stations to augment the recorded data.

34. Records are available at Sedro Woolley from May 1908 to December 1919 and February 1921 to December 1923.

35. The annual winter flood peaks for the period 1925 to date were estimated by comparison with Skagit River near Concrete and near Mount Vernon. Annual winter flood peaks for the years 1920 and 1924 are not available at either Sedro Woolley or Concrete, therefore the figures for these years were estimated from comparison with Cedar River near Landsberg. As these flows were near average, any error introduced would be negligible.

36. Crest discharges at Sedro Woolley have been affected by incidental regulation at Diablo Reservoir since 1930 and Ross Reservoir since 1941. Estimated observed discharges at Sedro Woolley since 1930 were revised to eliminate the effect of regulation by Diablo and Ross, either scheduled or incidental, and a curve was computed for Sedro Woolley representing natural conditions modified only by incidental regulation at Shannon Reservoir since its completion in 1927. This curve of "natural" flows is indicated on figure A-1 as curve A.

37. Upon the completion of the installation of the spillway gates at Ross Dam in 1952, storage will be made available at Ross Reservoir for flood control. The use of this storage will result in variable reductions in crest discharges at Sedro Woolley. Crest discharges near Sedro Woolley for the period studied were estimated assuming the operation of Ross Reservoir throughout the entire period in accordance with the proposed schedule of operation. Using these modified flows, a second curve representing frequency of discharges at Sedro Woolley as regulated by 1952 conditions at Ross Reservoir was computed, utilizing a maximum of 120,000 acre-feet of storage for flood control. This regulated curve of flood frequencies is shown on figure A-1 as curve B.

38. The flood-frequency curves for Skagit River at Sedro Woolley were calculated using Gumbel's method, which gives a straight-line curve according to the statistical theory of extreme values.

39. A summary of October through March peak flows for Skagit River at Sedro Woolley at various frequencies for natural and 1952 conditions is tabulated below:

Frequency in years	Natural	1952 Conditions
2	77,000	70,000
5	112,000	102,000
10	136,000	124,000
20	159,000	145,000
50	187,000	170,000
100	210,000	190,000

NOTE: Period of record for Skagit River near Sedro Woolley is from 1908 through 1919 and 1921 through 1923.
Flood crests for 1920 and 1924 estimated by comparison with floods on Cedar River.
Flood crests from 1925 through 1940 estimated from records at Skagit River near Concrete; 1941 through 1950 estimated from records of Skagit River near Concrete and Mount Vernon. Records subsequent to 1930 adjusted to compensate for operation of Diablo and Ross reservoirs to obtain natural conditions.

LEGEND: Curve A — Estimated natural flows without regulation at Diablo and Ross reservoirs.
Curve B — Estimated regulated flows based on 1952 operation of Ross with 120,000 acre-feet of flood control storage.
Curve C — Curve B modified by 140,000 A.F. of flood control storage at upper Baker site.
Curve D — Curve B modified by 300,000 A.F. of flood control storage at Faber site.

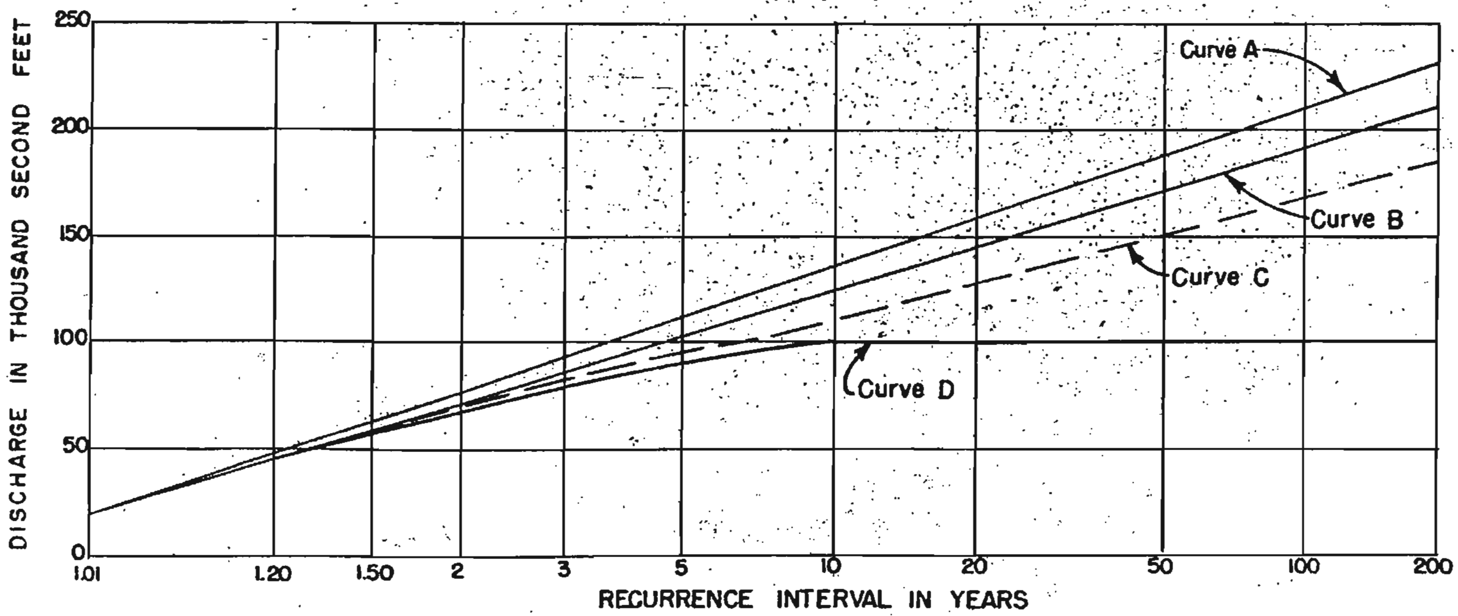

FIGURE A-1
FLOOD FREQUENCY
MAXIMUM ANNUAL WINTER PEAK DISCHARGE
SKAGIT RIVER NE[illegible] SEDRO WOOLLEY

FILE No. E-6-6-100

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STANDARD PROJECT FLOOD

40. Location. - The standard project flood is derived for the site of the U. S. Geological Survey stream-gaging station Skagit River near Sedro Woolley, Washington.

41. 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. 1/

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.

42. 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, and December 1921 floods are shown on plate 10, figures 1, 2, and 3, respectively. The unit

1/ 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 July 8, 1948, subject: "Submission of Method of Standard Project Flood Derivation for Levee Type Projects."

hydrographs derived from these floods are shown in 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 in figure 4.

43. The composite unit hydrograph was checked by using it to reproduce the flood of November 1909. This is shown on plate 10, 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 A-8, in order of ascending magnitude. Pertinent data concerning unit hydrographs derived from floods of record and the composite unit hydrograph are included in table A-9.

44. 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 10, 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 A-9.

Table A-8. - 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	1/	1/	1/	1/	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 in.	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 2/, inches	.47	.20	.58	.13	.2
Range of base flow, 1,000 cfs.	14-27	12-27	12-26	10-28	14-28

1/ Indeterminate
2/ Minimum loss for 6-hour period when rainfall excess was experienced

Table A-9. - Unit hydrograph data

Item	Nov. 1910	Dec. 1917	Dec. 1921	Composite or basic	Crest 125 percent of basic crest
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

45. Precipitation. - The maximum possible precipitation for the Skagit River Basin was determined by the U. S. Weather Bureau[1] and is shown on plate 11, 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 (par. 41), or 10.8 inches in 120 hours. Precipitation rates for 6-hour intervals for duration of the standard project storm are shown in table A-10.

46. 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 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.

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

Table A-10 - Standard Project Storm, Rainfall and Snowmelt Excess

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

47. 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.

48. 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 11, figure 2.

49. 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 A-11, 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 A-11, are shown on plate 1.

50. <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 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.

51. Curves of mean daily temperatures for the storm period are shown in plate 11, 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. Mean daily temperatures are 33°F. or below for all stations, on the day preceding the 5-day storm. 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 in the basin were derived for the 5 days of the storm, and the day preceding the storm. These curves are presented

Table A-11. - Snow surveys as of 1 January
(1947 through 1949)

Station	Elevation (feet)	Average depth (inches)	Average Water equivalent (inches)	Density %
		1947	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

P 0002(

Table A-12. - Standard project storm, 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	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 percent density) in inches 1/								
Inches	4.0	8.7	17.8	24.3	22.5	20.2	17.2	14.0	11.0

1/ The zone snow depth melted is determined by assuming a melt rate of 0.10 inch per degree day, and 30 percent initial density. Example: Zone 0 to 1,500. (Total degree days above 32°F. = 12.0) (melt rate = 0.10 inch per degree day above 32°F.) $\left(\frac{1}{\text{initial density of snow}} = \frac{1}{0.30}\right)$

$= (12.0)(0.10)\left(\frac{1}{0.30}\right) = 4.0$ inches

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Table A-13. - Standard prpject storm, basin snowmelt

Day	Average snowmelt on basin contributed by each zone in inches 1/									
	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	0.000	0.7
5	0.000	0.005	0.040	0.144	0.119	0.081	0.021	0.004	0.000	0.4
Total	0.158	0.260	0.711	1.497	1.337	0.980	0.268	0.076	0.003	5.3

1/ This is the melt in each zone resulting from a melt of 0.10 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 = 0.10 inch per degree day above 32° F.)(zonal area in percent = 0.131)= (1.5)(0.10)(0.131) = 0.020

on plate 11, 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.

52. Rate of snowmelt. - No data are available on rate of snowmelt in Skagit or adjacent basins. However, information[1] 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 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.

53. Computations to determine the amount of melt which would be contributed by 9 elevation zones and the entire area are presented in table A-12. 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 A-13. The daily contribution of snowmelt established in table A-13 is further subdivided into contributions for 6-hour periods as shown in table A-10.

54. 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 A-11). Assuming that the snowpack initially had a density of 30 percent, the depth of snow necessary to provide computed snowmelt

1/Technical Report No. 5, Hydrome[illegible] of the Central Sierra Snow Lab published by the Processi[illegible]lysis Unit of the Snow Invest. Program.

was determined and the results are shown on table A-12, last line. Based on snowpack records it is 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.

55. 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.

56. 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 A-8 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.

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

58. 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.

59. <u>Surface run-off</u>. - Surface run-off was derived for rainfall and snowmelt excess, using variable unit hydrographs as shown on plate 11, 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 11, figure 5, is adopted for the standard project flood as being most representative of run-off conditions which could prevail.

60. 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 11, 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.

61. 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.

62. The base flow in floods studied varied from a minimum of 10,000 second-feet to a maximum of 28,000 second-feet (table A-8).

63. 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.

64. 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 11, figure 5.

65. <u>Standard project flood</u>. - 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 11, 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 11, figure 5.

66. <u>Discussion</u>. - Records of stream flow for the gaging station, Skagit River near Sedro Woolley, are available for the period May 1908 to December 1919 and from February 1921 to December 1923. The maximum discharge during this period was 220,000 second-feet on 30 November 1909; the standard project flood has a peak flow equal to twice the maximum discharge of the largest flood that has occurred since the establishment of stream flow records in the basin.

67. 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 recently as December 1948. The temperature sequence used for the standard project storm was patterned after that of the January 1935 storm.

68. 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.

69. The standard project flood was derived for natural river conditions, and assumes no regulation by upstream reservoirs, none of which are currently operated for flood control.

SECTION II - FLOOD DAMAGES

70. Methods. - For the area west of Sedro-Woolley the first step in determining average annual flood damages was preparation of water-surface profiles for the appraisal of floods. Previous high-water marks are insufficient for defining flood profiles for major floods. It was therefore necessary to determine the high-water profiles by hydraulic computations. A few high-water marks from the 1921 flood are available and were used as an aid in the determination of overland flood profiles. Skagit River flood flows in excess of 150,000 second-feet at Sedro-Woolley would be split into three parts in the vicinity of Burlington (see report map, E-6-6-85) as follows:

a. The existing leveed river channel was assumed to carry nearly bank-full flows (120,000 cfs.). Scattered levee breaks would occur at unknown locations. Future flood damages from such breaks in left bank levees and in the area between the North and South Forks were estimated from the damage experience in the 1921 and 1949 floods.

b. Overland flow into the right bank Skagit section north and west of the main river channel and North Fork channel would occur both from levee failures and from outflanking of the upper end of the right bank levee at Burlington. Backwater computations aided by high-water marks were made to establish the overland flood profile which was then used for field estimates of future damage.

c. The third area of flooding would be in the Samish section from water crossing the low Skagit-Samish divide between Burlington and Sedro Woolley. Flood profiles in this area were computed by backwater methods in conjunction with the backwater computations in b. above. The flood profiles were then used for field estimates of future damage.

71. The flood flow distribution as described in the previous paragraph is a rational approach in reproducing the existing pattern of flooding in the Skagit Basin west of Sedro Woolley. This type of

flooding gives overland flood stages considerably lower than flood stages in the adjacent leveed river channels.

72. Estimates of the potential flood damage under existing conditions were made by comparison of predetermined floodwater stages with ground levels. The type and nature of damages are described in a later paragraph. Flood damage estimates were obtained in this manner for flood discharges at Sedro Woolley of 210,000, 300,000, and 400,000 second-feet. These appraisals were made a short time after the November 1949 flood so that it was also possible to obtain a very reliable estimate of the damages from this recent flood.

73. In the upstream area east of Sedro Woolley, flood damage estimates were not made from computed water surface profiles. A reconnaissance-type damage estimate was obtained immediately following the November 1949 flood. This estimate and the judgment of the appraisers familiar with the area were used for drawing an approximate discharge damage curve.

74. <u>Nature and type of flood damages</u>. - To illustrate the types of flood damage considered in the appraisals, the following tabulation shows the breakdown of appraised damages for a 210,000-second-foot flood in the diked section on the right bank of Skagit River.

Item	Damage (1951 prices)
Crop land	$ 755,000
Erosion	8,800
Weed seeding	158,000
Salt-water damage	197,000
Fences	17,400
Buildings and contents	1,195,000
Farm machinery	88,700
Loss of business and pay rolls	53,100
Restoration of levees	48,000
Repairs to drainage works	45,200
Repairs to wire lines	10,700
Repairs to city streets and sewers	15,000
Care of refugees	41,000
Flood fighting	31,500
Highway traffic interruptions	40,700
Railroad traffic interruptions	15,200
Damage to roads	13,200
Damage to railroad facilities	38,800
Loss of livestock	35,800

(Cont'd next page)

Item	Damage (Cont'd)
Loss of milk production	$ 8,800
Loss of automobiles and trucks	24,100
Silt and debris deposits	259,000
Total	3,100,000

75. The largest damage items are those for crop land and for buildings and contents. Approximately 60,000 acres of land used for pasture or such crops as corn, grain, peas, vegetable seeds, berries, and bulbs are subject to flooding. Damages vary greatly according to the type of land use, and the estimates were obtained by applying appropriate rates of damage to the various types and classes of land use. Annual field and grain crop lands suffer the least damage because the floods occur in the dormant season so that clean-up and debris removal represents the main kind of damage for such lands. Damage to perennial crop lands is much higher, sometimes amounting to both the net crop profit and the capital crop investment up to the time of flood occurrence.

76. Damages to buildings and contents are determined from the anticipated depth of water in the buildings. Detailed inspection of buildings and contents was not made, but rather, water depths are translated directly into damage from depth-damage relationships established for typical classes of structures.

77. Damage results to crop lands if the sea dikes are breached and high tides saturate the crop lands with salt water. The effect of salt water inundation is reflected in reduced crop yields over a period of several years. The amount of this kind of damage included in the estimate is in addition to the usual flood crop damage previously noted.

78. The other items of flood damage are self-explanatory. Monetary amounts have been determined from data obtained by interviews, correspondence with affected interests, and by field inspections and estimates.

79. <u>Average annual damages</u>. - From flood damage data as described in the preceding paragraphs, discharge damage curves have been drawn. The discharge is referred to flow at Sedro Woolley. Using the flood-frequency curve (figure A-1), damage frequency curves were then prepared from which average annual damages have been computed. The discharge damage curves and frequency damage curves are shown in figures A-2 to A-5-a.

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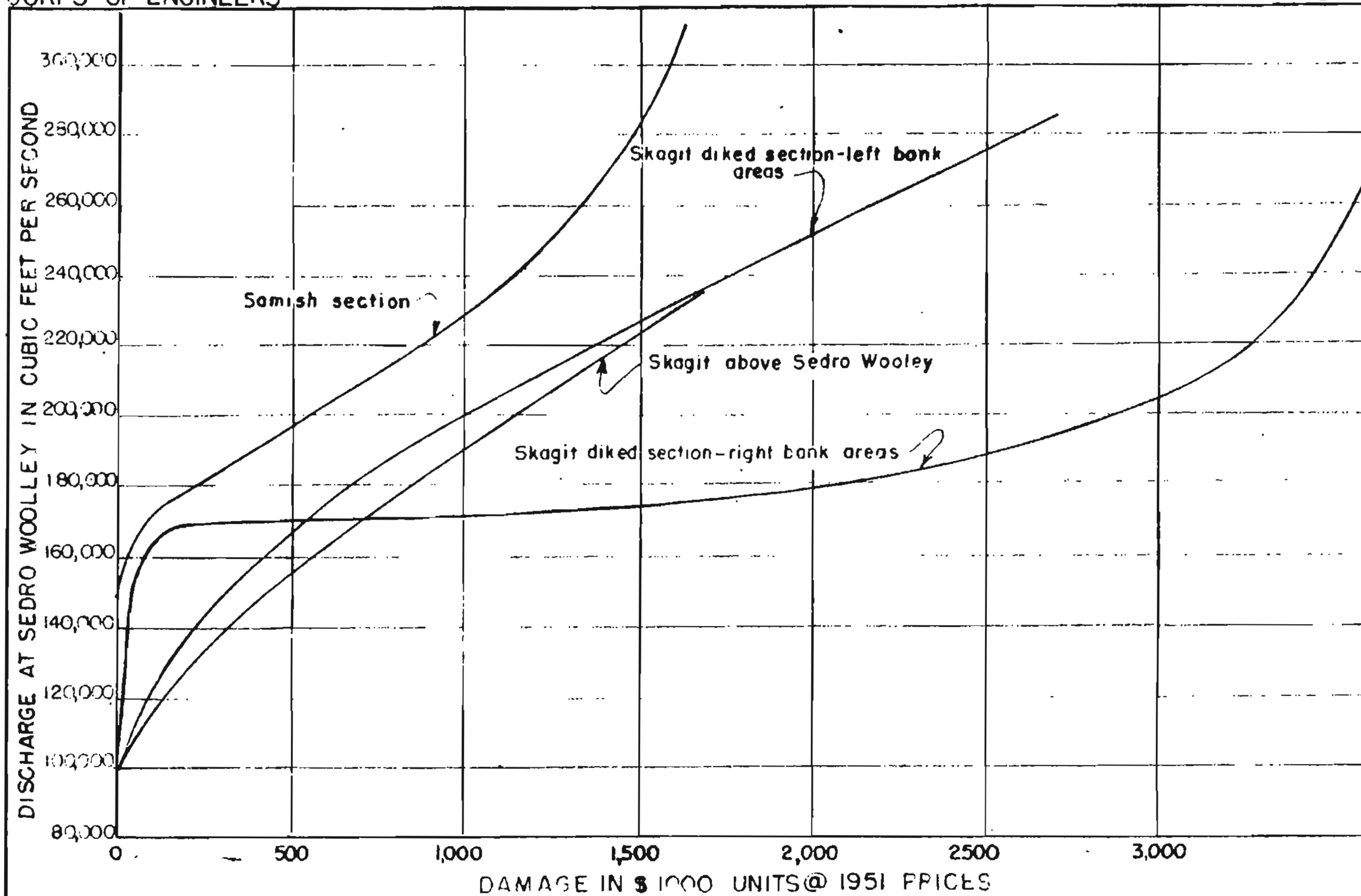

FIGURE A-2
DISCHARGE-DAMAGE CURVES
SKAGIT RIVER BASIN

FILE NO. E-6-6-101.1

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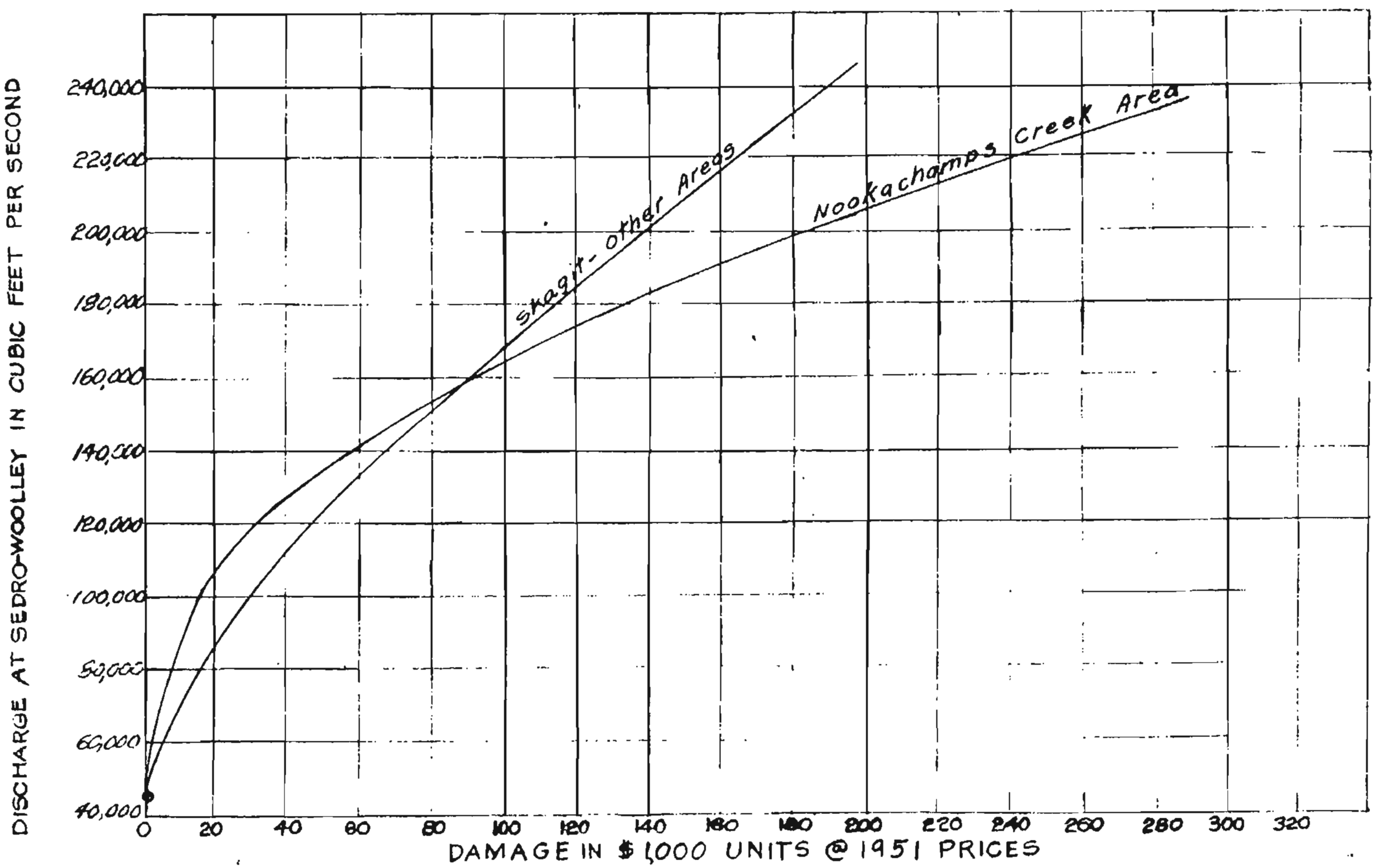

FIGURE A-3
DISCHARGE-DAMAGE CURVES
SKAGIT RIVER BASIN

FILE No. E-6-6-101.2

P 000277

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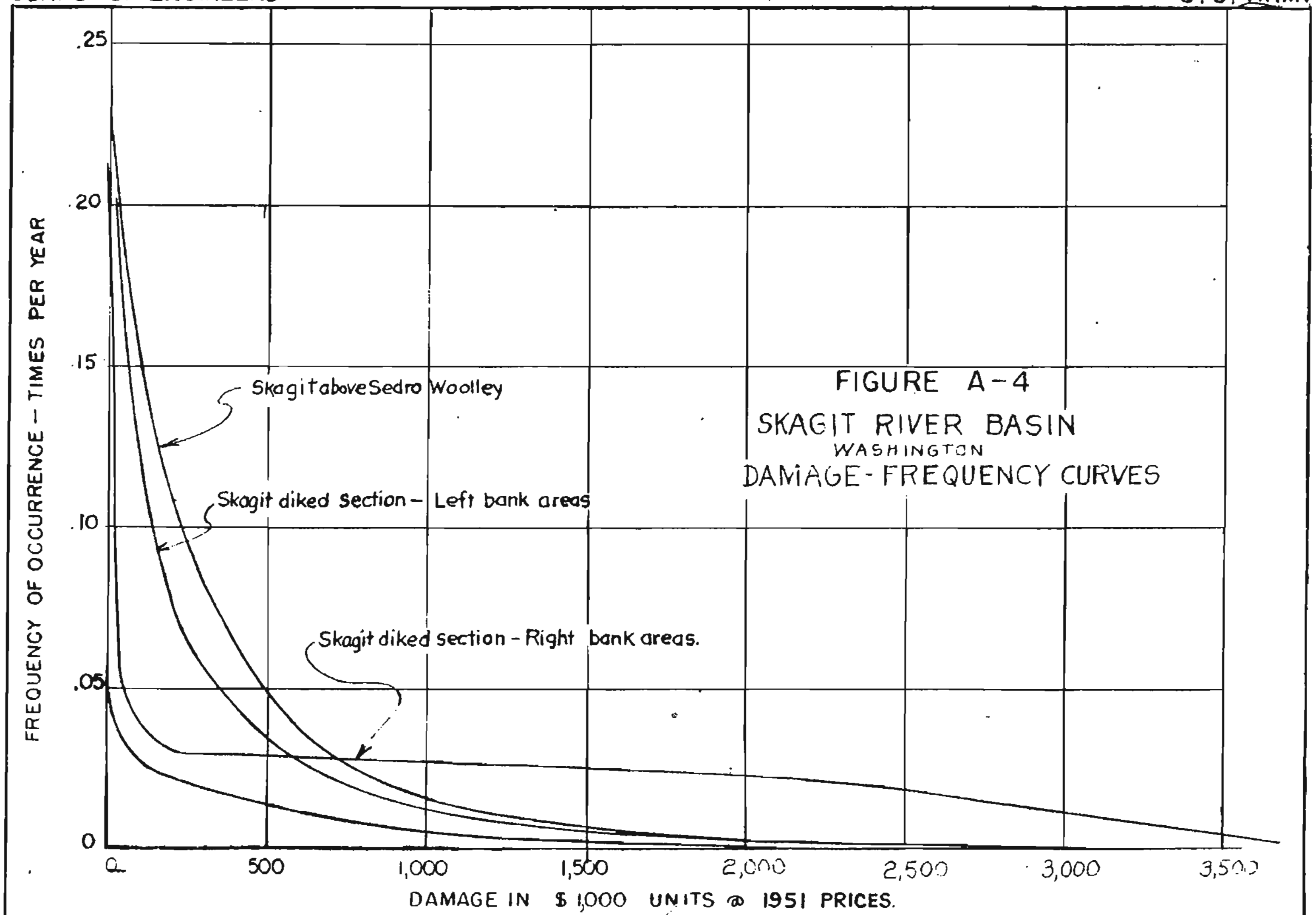

FIGURE A-4
SKAGIT RIVER BASIN
WASHINGTON
DAMAGE-FREQUENCY CURVES

FILE NO. E-6-6-101.3

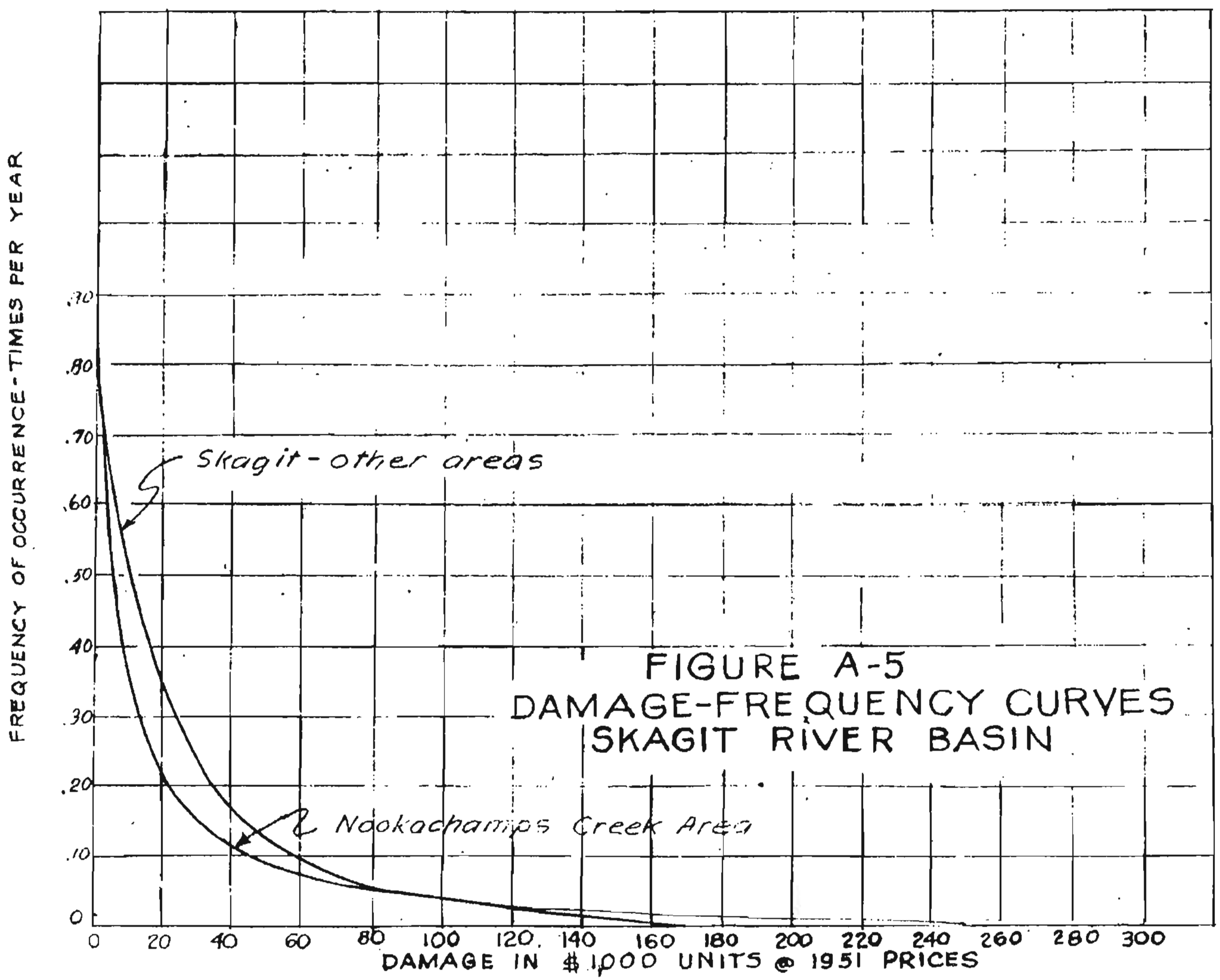

FIGURE A-5
DAMAGE-FREQUENCY CURVES
SKAGIT RIVER BASIN

FILE No.-E-6-6-101.4

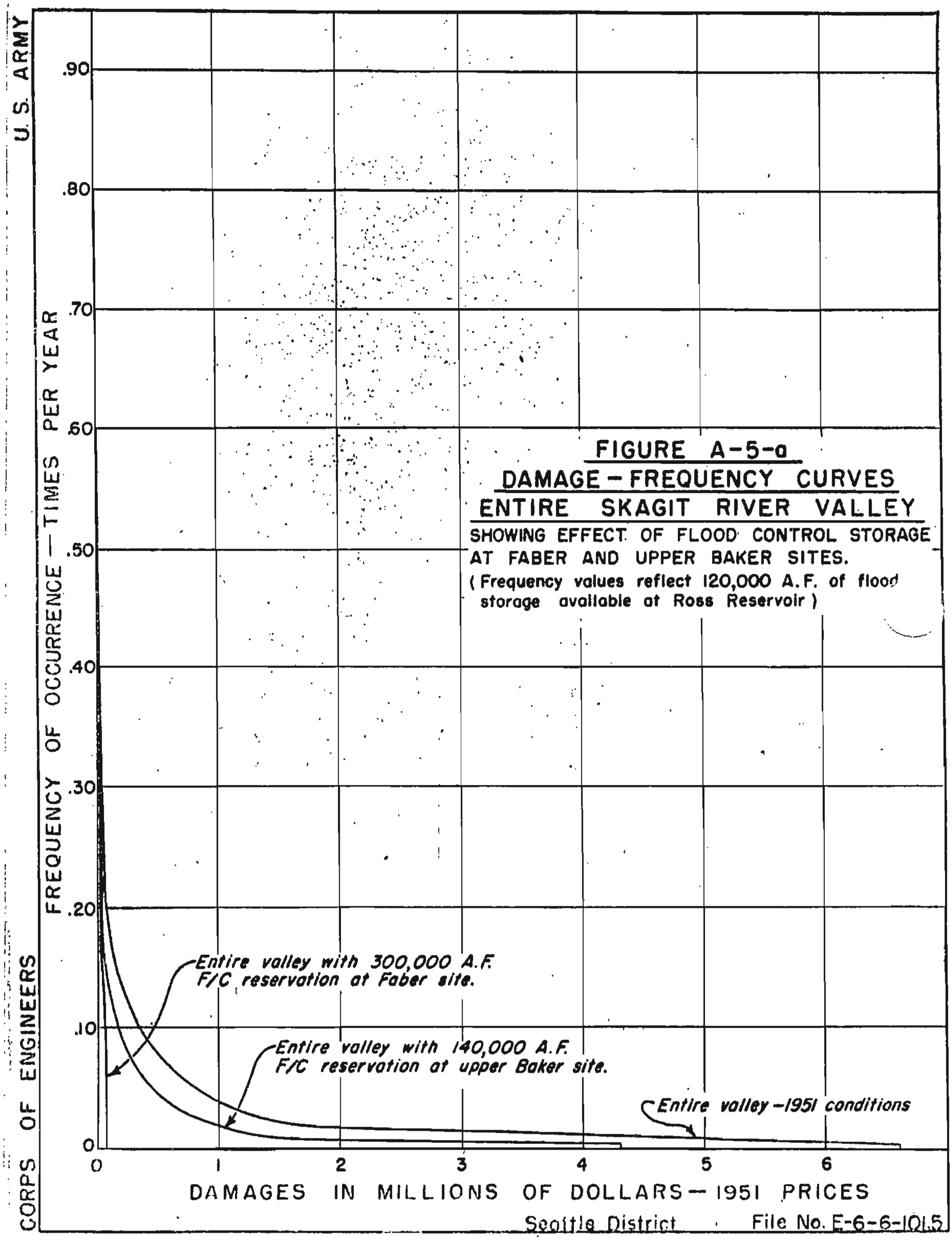

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FIGURE A-5-a
DAMAGE - FREQUENCY CURVES
ENTIRE SKAGIT RIVER VALLEY
SHOWING EFFECT OF FLOOD CONTROL STORAGE AT FABER AND UPPER BAKER SITES.
(Frequency values reflect 120,000 A.F. of flood storage available at Ross Reservoir)
FREQUENCY OF OCCURRENCE — TIMES PER YEAR
.90
.80
.70
.60
.50
.40
.30
.20
.10
0
Entire valley with 300,000 A.F. F/C reservation at Faber site.
Entire valley with 140,000 A.F. F/C reservation at upper Baker site.
Entire valley – 1951 conditions
0
1
2
3
4
5
6
DAMAGES IN MILLIONS OF DOLLARS — 1951 PRICES
Seattle District
File No. E-6-6-101.5

P 000280

SECTION III. - DAM AND RESERVOIR STUDIES

80. General. - The four principal dam sites remaining in the basin, at which substantial power and flood control benefits could be obtained, were investigated for this report. They are the following:

Faber site on Skagit River near Concrete

Cascade site on Cascade River

Upper Sauk site on Sauk River above Darrington

Upper Baker site on Baker River above Shannon Lake

The Skagit River and tributaries above Faber are rich in spawning area and have considerable value as fish producers. As brought out in the report, the fisheries interests are opposed to a dam at either the Faber site or a possible alternate on the lower Sauk. The fisheries interests are also opposed, though less vigorously, to the construction of dams at the Cascade and upper Baker sites.

81. Results of the report studies indicate that Federal construction of a dam and reservoir project is not justified at any of these sites at the present time. Benefits obtainable from the multiple-purposes of power production, flood control, and navigation are inadequate at the Cascade and upper Sauk sites; and, as shown in the report, construction by the Federal Government of reservoir projects at the Faber and upper Baker sites cannot be recommended at this time. A brief description and a cost estimate are given in the following paragraphs for each of the four reservoir projects that were investigated.

82. Faber dam site. - The site is on the main stem of Skagit River near Concrete and is below all important tributaries except Baker River.

The foundation is composed of sand, silt, and clay with sand and loam predominating. Maximum depth drilled is 387 feet, and the depth to bedrock is unknown. The right (north) abutment has many exposures of argillite, and except for varying depths of overburden this abutment consists of rock. The left (south) abutment has no bedrock and is composed of material similar to the foundation. On the downstream side of the left abutment a section predominating in clay shows surface evidence of slide conditions. These subsurface conditions point to an earth and rockfill type dam. The wet climatic condition of the region throughout much of the year might make a hydraulic fill a better means of construction.

83. The maximum permissible reservoir water surface elevation is about 500, which would require a dam about 300 feet high. The reservoir area would extend upstream on Sauk River to the town of Darrington, which lies at a general elevation of 500. In the vicinity of Darrington and at the same elevation is a low, wide divide into the Stillaguamish River Basin. For estimating purposes, an earth and rockfill dam with its crest at elevation 500 has been assumed. The spillway, powerhouse, and penstocks would be located on the right abutment. Extensive highway, railroad, and transmission line relocations would be required in the reservoir area.

84. About 8 miles downstream from Faber dam site is another site, locally known as The Dalles, at which a low dam could be constructed. A hydroelectric plant here could take advantage of increased river flows from Faber Reservoir and the existing Shannon Lake Reservoir on Baker River. In addition to producing power, The Dalles Reservoir would serve as a re-regulating reservoir to smooth out widely varying discharges from the Faber powerhouse if that plant were operated at a low daily load factor. Preliminary estimates for development of this site are based on a combined dam and powerhouse about 65 feet high with an adjoining gated spillway 500 feet long, a low nonoverflow section 550 feet long, and an emergency uncontrolled weir section 500 feet long.

85. Pertinent power data for the two sites are as follows:

	Faber	Dalles
Average continuous discharge (Phase C-2 Columbia R. critical period 1928-32)	11,027 cfs.	12,800 cfs.
Maximum pool elevation	490 feet	184 feet
Tailwater elevation	184 "	145 "
Average net power head	233 "	32 "
Storage at maximum level	4,650,000 a.f.	21,200 a.f.
Usable storage	2,790,000 "	pondage only
Average continuous power	188,000 kw.	31,700 kw.

86. A summary of principal cost items including contingencies is as follows:

FABER DAM (for 40 percent load factor, 728,000 kw. installed)

Item	Cost (1951)
General (power and telephone, reservoir clearing, etc.)	$ 10,230,000
Cofferdams, river diversion, and tunnels	10,030,000
Dam and spillway	47,500,000
Intake works, surge tanks, penstocks	42,060,000
Powerhouse and generating equipment	66,300,000
Government furnished housing and administrative facilities	2,900,000
Reservoir lands	2,479,000
Relocations	14,170,000
Indirect costs	23,131,000
Total	$218,800,000

DALLES DAM (for 80 percent load factor, 53,000 installed)

Item	Cost (1951)
General (rights-of-way, relocations, etc.)	$ 805,000
Spillway section	5,060,000
Nonoverflow section and weir section	805,000
Powerhouse and equipment	12,420,000
Indirect costs	2,310,000
Total	$21,400,000

87. The power dam proposed for the Faber site could provide 300,000 acre-feet of flood control storage during the months of December, January, and February, without material loss of power production. This reservation would make it possible to control all floods, having a recurrence interval of less than 200 years, to a regulated flow of 100,000 cfs. at Sedro Woolley; and would reduce the total average annual flood damages in the basin from about $188,000 to about $18,000 (1951 prices).

A storage reservation of 1,250,000 acre-feet would control the standard project flood and would eliminate practically all flood damages, but would provide only a small amount of incremental benefits and would reduce the power benefits materially. Faber Dam, in conjunction with a reregulating dam at The Dalles, would also provide some navigation benefits during periods of low natural flows. As the navigation benefits would be comparatively small, however, and very difficult to evaluate, no estimate has been made of their magnitude.

88. Operation of the Faber-Dalles project for power would be in conjunction with the Columbia River system, and the power benefits shown in table 6 of the report were computed on the basis of the following values:

Capacity ------------------	$16.16 per kw.
Energy --------------------	2.0 mills per kwh. at load center
Transmission cost ---------	$ 4.12 per kw.
Transmission line losses --	3 percent

The following is a sample computation of the total value of power with a 40 percent load factor:

$$\text{Capacity value} = \frac{(\$16.16 \times .97) - \$4.12}{.40 \text{ L.F.}} = \$28.90 \text{ per kw. yr.}$$

$$\text{Energy value} = .002 \times 8760 \times .97 = \underline{16.99} \text{ " " "}$$

$$\text{Total value of power} = \$45.89 \text{ " " "}$$

89. The transmission cost and losses of $4.12 and 3 percent, respectively, are about one-half of the values established for the Phase C-2 system and are believed equitable for Skagit River plants in view of their proximity to the Puget Sound load center. The values of energy and capacity are the same as those used in the 1948 Columbia River Review Report (H. Doc. 531/81/2). With average continuous power of 188,000 kw. at Faber, and 31,700 kw. at The Dalles, the total annual power benefits would be $9,617,000. With average annual flood control benefits at $170,000, the total average annual benefits would be $9,787,000. The annual costs are estimated at $12,030,000 and the benefit-cost ratio of the combined project would be .81.

90. Upper Baker Dam site. - The site is in a narrow rock gorge immediately above Shannon Lake and the existing private plant on Baker River. Other possible sites are found in the one-half mile section of river above the lake in the vicinity of Sulphur Creek, but the one used for estimating purposes appeared most promising from a ground reconnaissance. Foundation borings and explorations have not been made. Based on a geological reconnaissance, the left abutment is assumed to be entirely rock. The right abutment has exposed rock to elevation 690. A short distance beyond the face of this abutment the rock appears to dip away rapidly, leaving a saddle probably filled with glacial moraines and sediments. Maximum elevation of the saddle is 650 feet and at the 500-foot contour the seepage path is 1,000 feet long. The right abutment requires a dike for reservoir elevations above 650 and sloping of the existing glacial material to increase its stability.

91. Character of the foundation below the river bed is unknown, but for estimating purposes 70 feet of overburden was assumed. A considerable depth of overburden is not uncommon in the stream beds of rivers in this region that have been subject to glacial action, such as the Upper Baker River.

92. A concrete gravity dam with gated spillway has been assumed for estimating purposes. Maximum elevation of the dam would be 710 feet which appears to be close to the maximum height permitted by the glacial soils in the right abutment. Principal items in the cost estimate, including contingencies, are summarized as follows (40 percent load factor, 62,000 kw. installed at upper site):

Item	Cost (1951)
General	$ 2,900,000
Dam and spillway	7,800,000
Embankment	1,400,000
Powerhouse and intake works	10,500,000
Indirect costs	2,660,000
Total, Upper Baker	$25,260,000
35,000 kw. addition to existing plant	3,700,000
Total	$28,960,000

gorge in which rock is exposed to a high elevation on either side so that no practical limit to the height of a dam is imposed by the abutments. The principal geologic problem appears to be the depth to bedrock in the bottom of the river. Three exploratory drill holes indicated 75 feet of overburden, but it is questionable whether or not these holes reached the deepest portion of the valley. For estimating purposes, therefore, a maximum of 100 feet of overburden has been assumed.

98. Maximum power development of the area should utilize the steep fall below the dam site. The powerhouse site would therefore be located about 5 miles downstream and would be served by a pressure tunnel. Tunnel excavation would be through rock similar to the dam site abutments.

99. A concrete gravity dam with an uncontrolled spillway has been assumed. The Washington State Department of Fisheries has informally advised that a minimum release of 250 second-feet should be maintained below the dam, and outlet valves for this purpose have been included. The height of the dam has been determined by the power storage requirements so as to obtain the maximum power production from available river flows. Power production has been assumed to be coordinated with the Columbia River system.

100. The powerhouse would be on the right bank, 5 miles downstream from the dam, with water being supplied through a pressure tunnel 12 feet in diameter. In the reservoir area 2.2 miles of highway would have to be relocated and a new 200-foot steel bridge constructed. A summary of principal cost items, including contingencies, is as follows: (50 percent load factor, 66,000 kw. installed)

Item	Cost (1951)
General	$ 2,400,000
Gravity dam and outlets	28,500,000
Tunnels, surge tank, and gates	10,000,000
Powerhouse, penstocks, and operators' housing	6,300,000
Reservoir lands and clearing	1,100,000
Relocations	700,000
Indirect costs	5,000,000
Total	$54,000,000

101. Pertinent power data for the Cascade development are as follows:

Maximum pool elevation	1,186 ft.
Tailwater elevation	360 "
Net power head at mean reservoir level	735 "
Storage at maximum pool level	247,400 a.f.
Usable storage	240,000 "
Average continuous power	32,900 kw.

102. Using the power values shown in paragraph 88, the power benefits for this project would be $1,320,000. The annual costs would be about $2,700,000, and the project would not be feasible.

103. This site could control only 5 percent of the total Skagit Basin area at Sedro Woolley, and its effect on flood crests at Sedro Woolley is estimated to be not more than 10 percent. Assignable flood control benefits to Cascade Dam would therefore be small.

104. Fisheries interests have advised that they would not be able to make a definite statement regarding the effect of this project on migratory fish until further investigations had been made.

105. Upper Sauk dam site. - This site is about 9 miles upstream from Darrington and just below the confluence of Whitechuck and Sauk Rivers. No drillings or subsurface explorations have been made at the site, and information about the site has been obtained from ground reconnaissance. The left abutment appears to be solid rock while the right abutment is merely a low rock knob. Superimposed on the rock in the right abutment are large amounts of glacial debris and river-deposited material brought down by Whitechuck River. The right abutment and reservoir wall appear quite pervious from surface indications,

but as much of it is composed of the Whitechuck alluvial fan, presumably having a predominance of fine material, this important section of the abutment and reservoir wall may be satisfactory from the standpoint of seepage and stability. No information is available as to the depth of overburden in the river bottom, which shows no exposed bedrock.

106. Whitechuck River has its source on Glacier Peak as a consequence of which the river carries a heavy silt load that would gradually reduce the storage space in the reservoir. No estimates have been made of the loss of capacity from silt for this estimate. Sauk River does not head in any glacial fields and is relatively free of silt at the dam site.

107. Within the reservoir area are about 7 miles of secondary highway, a logging camp, and a logging railroad passing through the dam site to serve the camp, which is less than a mile from the dam site. Relocations of these facilities have been included in the estimate.

108. The dam site abutment conditions indicate an earthfill dam for which an ample supply of core and shell material is available within the reservoir area. A 17-foot diameter tunnel would supply the powerhouse located near Darrington on the right bank. Principal cost items, including contingencies, are as follows (50 percent load factor, 74,000 kw. installed):

Item	Cost (1951)
General	$ 900,000
Dam and appurtenances	15,400,000
Tunnel and surge tank	18,000,000
Powerhouse, penstocks, and surge tank	7,600,000
Reservoir lands and clearing	300,000
Relocations	300,000
Indirect costs	5,100,000
Total	$47,600,000

109. Pertinent power data for the Upper Sauk development are as follows:

Maximum pool elevation -------------	1,105 ft.
Tailwater elevation ----------------	520 "
Net power head at mean reservoir level ---------------------------	439 "
Storage at maximum pool level ------	137,000 a.f.
Usable storage ---------------------	133,000 "
Average continuous power -----------	37,000 kw.

110. Using the power values shown in paragraph 88, the power benefits for this project would be $1,485,000. The annual costs would be about $2,380,000 and the project would not be feasible.

111. This site also is objectionable to fisheries interests. For purposes of computing firm power a minimum flow of 250 second-feet for fisheries was assumed.

112. The drainage area above this site is only 8 percent of the Skagit Basin area at Sedro Woolley and assignable flood control benefits would probably not exceed 15 percent. Such flood control benefits would have a negligible effect on the feasibility of the project.

113. Lower Sauk dam site. - Estimates of cost and power production have not been made for this site. The firm opposition of fisheries interests to this site and the Faber site makes favorable consideration of either one very unlikely. The Lower Sauk dam site and reservoir area lie entirely within the Faber reservoir area, so that the Sauk site is merely an alternative to Faber. If there were no objections from the fisheries standpoint and if economic justification were favorable, first consideration for development of either of these sites would be given to Faber because it offers the possibility for the larger amount of power generation and would give the greater degree of flood protection. For these reasons, it is concluded that no useful purpose would be served at this time by the additional expense of making Lower Sauk studies.

Paragraphs 114 and 115 not used.

SECTION IV. - LEVEE IMPROVEMENT AND DIVERSION ESTIMATES

116. Possible means of flood protection for the areas west of Sedro Woolley include raising the existing levees, constructing a flood diversion channel, or some combination of these two methods. Field work and office studies were carried out to the extent needed to reasonably determine the feasibility of these proposals.

117. Levee estimates. - Field topographic surveys were made to establish the grade and cross section of the existing levee system. These survey data were used in making quantity estimates of raising the levees to various heights. A field soils examination was also made to determine the character of existing levees and sub-base, to locate sources of material, and to determine required levee cross sections. In all of the levee improvement plans estimated, the maximum height of levee would not exceed 20 feet, and most sections would have lesser heights. For estimating purposes, a levee cross section having a 12-foot top width and side slopes of 1 on 2.5 was used. Freeboard of 3 feet has been used. Cost estimates of various degrees of levee improvement were made and a curve showing cost versus capacity was drawn as shown on figure A-6. To illustrate the items considered in the levee estimate, table A-15 gives a summary of the estimate for a channel having a capacity of 170,000 second-feet.

118. Diversion estimates. - Previous cost estimates for the adopted flood diversion channel were checked and revised to bring to 1951 price levels. The plan layout and project works were also modified. Estimates of a flood diversion channel for this report include the following general features:

a. Intake between Burlington and the Great Northern Railway bridge.

b. Intake weir to have a fixed and uncontrolled crest set at such an elevation that flow would commence when the river discharge reached 40,000 second-feet.

Table A-15. - Levee improvement estimate, 170,000 cfs. capacity.

Item	Unit	Quantity	Unit Cost	Amount
Clearing and grubbing	acre	26	$250.00	$ 6,500
Stripping	c.y.	292,000	0.90	262,800
Embankment, load and haul	"	4,697,300	0.33	1,549,900
Embankment, place and shape	"	4,084,600	0.16	653,500
Seeding	acre	374	95.00	35,500
Flood wall, concrete	c.y.	1,530	42.50	65,000
Flood wall, excavation	"	600	1.00	600
Flood wall, backfill	"	2,000	0.50	1,000
Drainage culverts, new	l.s.			2,000
Drainage culverts, modification	"			20,000
Rights-of-way	acre	230	300.00	69,000
Rights-of-way, borrow	"	115	40.00	4,600
Road changes	l.s.			116,500
Highway bridge alterations	"			66,000
Railroad bridge alterations	"			158,300
Moving other structures	"			14,000
Contingencies				453,800
Indirect costs				417,000
Total				$3,896,000 (1950)
Increase 5% for 1951				$4,090,000 (1951)

c. Channel velocities approximately 5.5 feet per second, which will not scour a sodded channel. Somewhat higher velocities will obtain at the outlet, depending upon tidal stages.

d. Elimination of the tidal weir in the adopted project at the outlet to limit channel velocities. Estimates of scour based on frequency and duration of flow indicate channel deepening in tidal section would not be excessive.

e. Construction of only two bridges: one for the Great Northern Railway and one for U. S. Highway No. 99. Anacortes Branch of the Great Northern Railway to be relocated so as to use the main line bridge.

119. Comparative estimates were made to determine the most economical channel bottom width and it was found that for a diversion channel capacity of 100,000 second-feet the economical bottom width ranges between 1,100 and 1,500 feet. It was also found that the cost of diversion plans decreased considerably with increases in the allowed maximum flow in the existing river channel below the point of diversion. The reason for this relation is that diversion channel bottom excavation is reduced as the entrance water surface elevation is raised. The relationship between total cost of diversion plan and capacity is shown on figure A-7 by a series of curves, each one for a different river channel capacity.

120. Combined plans. - The costs of levee improvement shown by the curve on figure A-6 and the costs of flood diversion shown by the curves on figure A-7 can now be used for drawing other curves showing the cost of combined plans of levee improvement and diversion. These curves are shown in figure A-8 and have been constructed directly from figures A-6 and A-7. As an example, the curve for combined plans having a design flow of 200,000 second-feet was determined as follows:

Diversion flow	River flow	Diversion cost	Levees cost	Total cost
(cfs.)	(cfs.)	($)	($)	($)
0	200,000	0	5,900,000	5,900,000
20,000	180,000	1,250,000	4,650,000	5,900,000
40,000	160,000	2,750,000	3,550,000	6,300,000
70,000	130,000	5,500,000	2,000,000	7,500,000
110,000	90,000	9,600,000	0	9,600,000

121. From the curves of combined costs, it is apparent that for any design flow a major part of the improvement would be by raising the levees. Considering only the combined plan of least cost, the following tabulation has been taken from the data on figure A-8:

Design Q	Diversion Q From curve	River Q
180,000	0	180,000
200,000	10,000	190,000
250,000	40,000	210,000
300,000	95,000	205,000

This tabulation indicates that improvement of the levee system up to a capacity of about 200,000 second-feet is the most that should be done, and after that capacity is reached, the most economical means of additional flood protection would be by a diversion channel.

122. Economic feasibility. - The discussion of levee improvement and diversion plans have so far not considered whether or not such work is economically justified. From data previously presented, an economic analysis may readily be made. To achieve a project having the best chance for justification, protection of the Nookachamps Creek area by levees has not been considered. Because of natural storage in this area flood flows at Sedro Woolley are reduced as much as 30,000 second-feet in the reaches adjacent to Burlington where the considered improvements would begin. Left bank levees would start at the Great Northern Railway bridge, and the right bank levee would start at high ground between Sedro Woolley and Burlington so as to protect Burlington and also prevent overflow into the Samish section.

123. A comparison of several degrees of flood protection is shown in table A-16. Benefits have been determined from computations for average annual flood damages, using only those damages which would be prevented by the particular design flood selected. Benefits would be realized only in the Skagit diked area and the Samish section. This table shows that neither a levee project nor a combination levee-and-diversion project would provide a feasible means of flood protection in the valley below Sedro Woolley.

124. Nookachamps Creek area. - This section of flood plain does not have any kind of flood protection, and farming operations there are carried out with the expectation of frequent flooding. Average annual damages are consequently not large. Prevention of flooding by levees would not only involve local construction in the immediate area but would also require raising the levees of the entire lower river system to compensate for the loss of flood peak reduction from natural storage in the Nookachamps Creek area. As an example, consider the design flow project of 205,000 second-feet in table A-16. If the levees had to be raised to carry 205,000 second-feet instead of 184,000 second-feet, the project cost would be $6,300,000, which does not include the cost of Nookachamps area levees. For this example, Nookachamps levee costs will be ignored but the levee benefits will be included so that project benefits are increased by $15,000, giving a total annual benefit of $107,500. Project annual costs would be $315,000, and therefore the benefit-cost ratio would be 0.34 as compared to 0.38 if Nookachamps area were not protected.

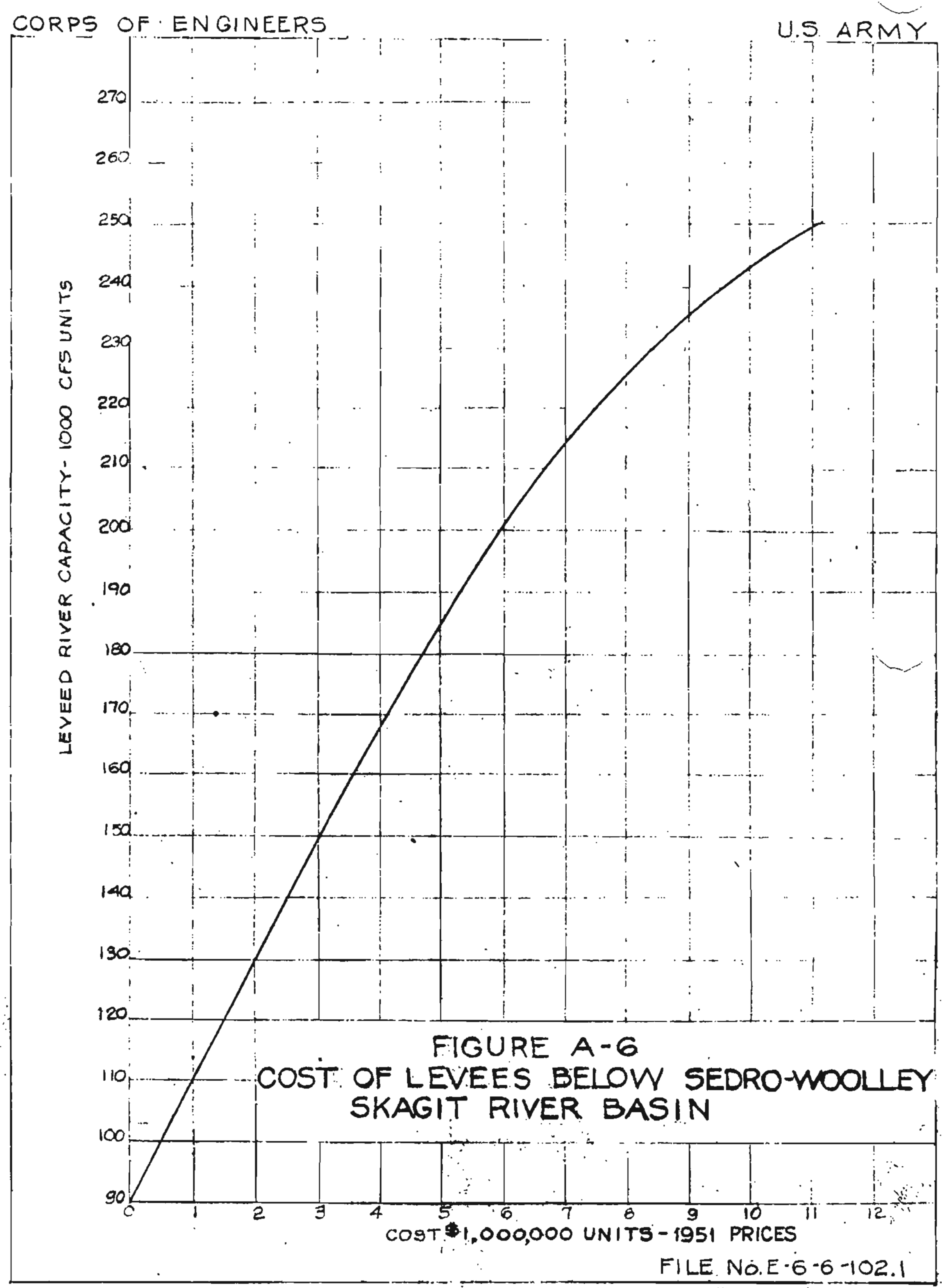
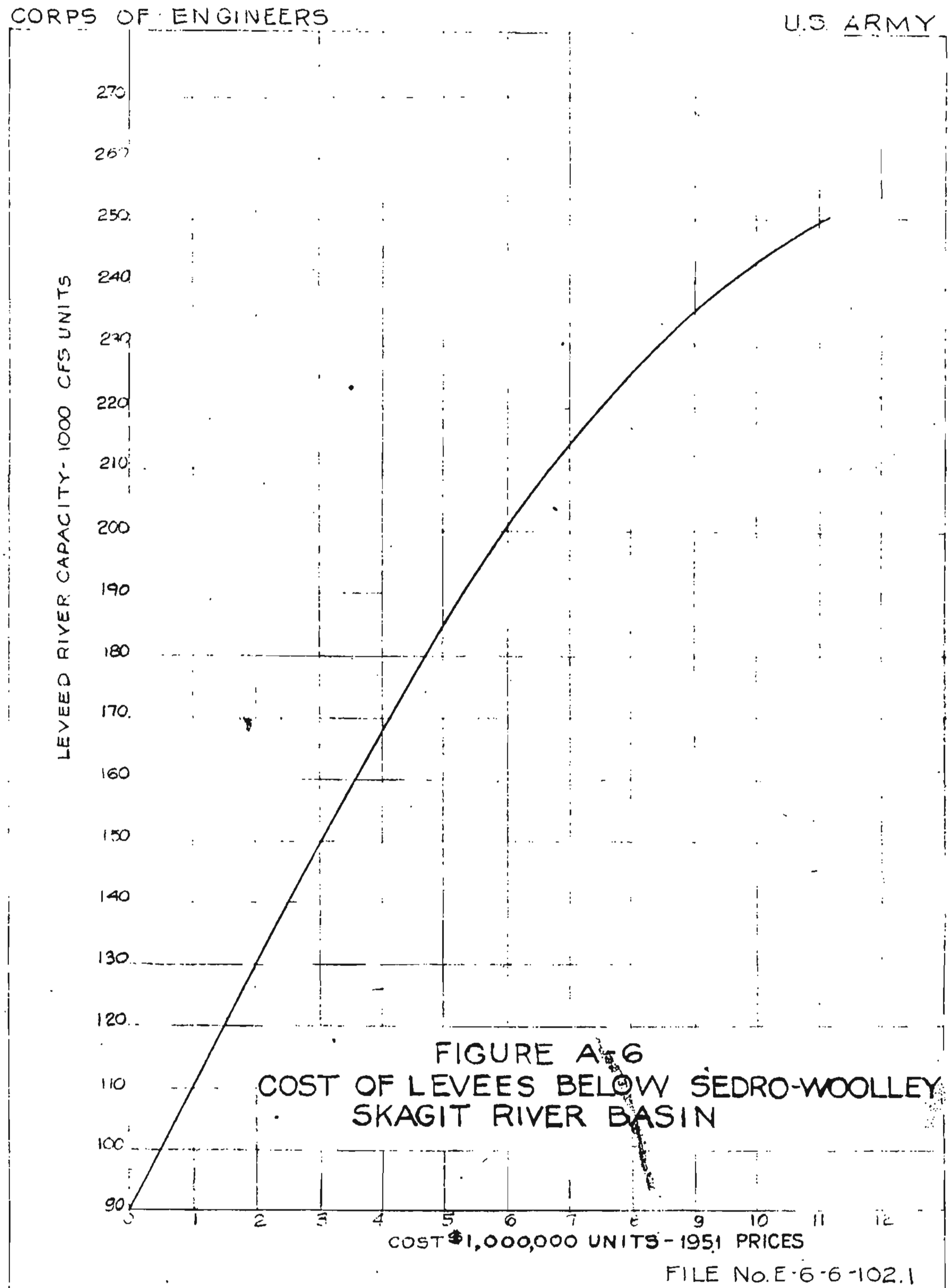


FIGURE A-6
COST OF LEVEES BELOW SEDRO-WOOLLEY
SKAGIT RIVER BASIN


CORPS OF ENGINEERS
U.S. ARMY
LEVEED RIVER CAPACITY - 1000 CFS UNITS
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
0
1
2
3
4
5
6
7
8
9
10
11
12
COST $1,000,000 UNITS - 1951 PRICES
FIGURE A-6
COST OF LEVEES BELOW SEDRO-WOOLLEY
SKAGIT RIVER BASIN
FILE No. E-6-6-102.1

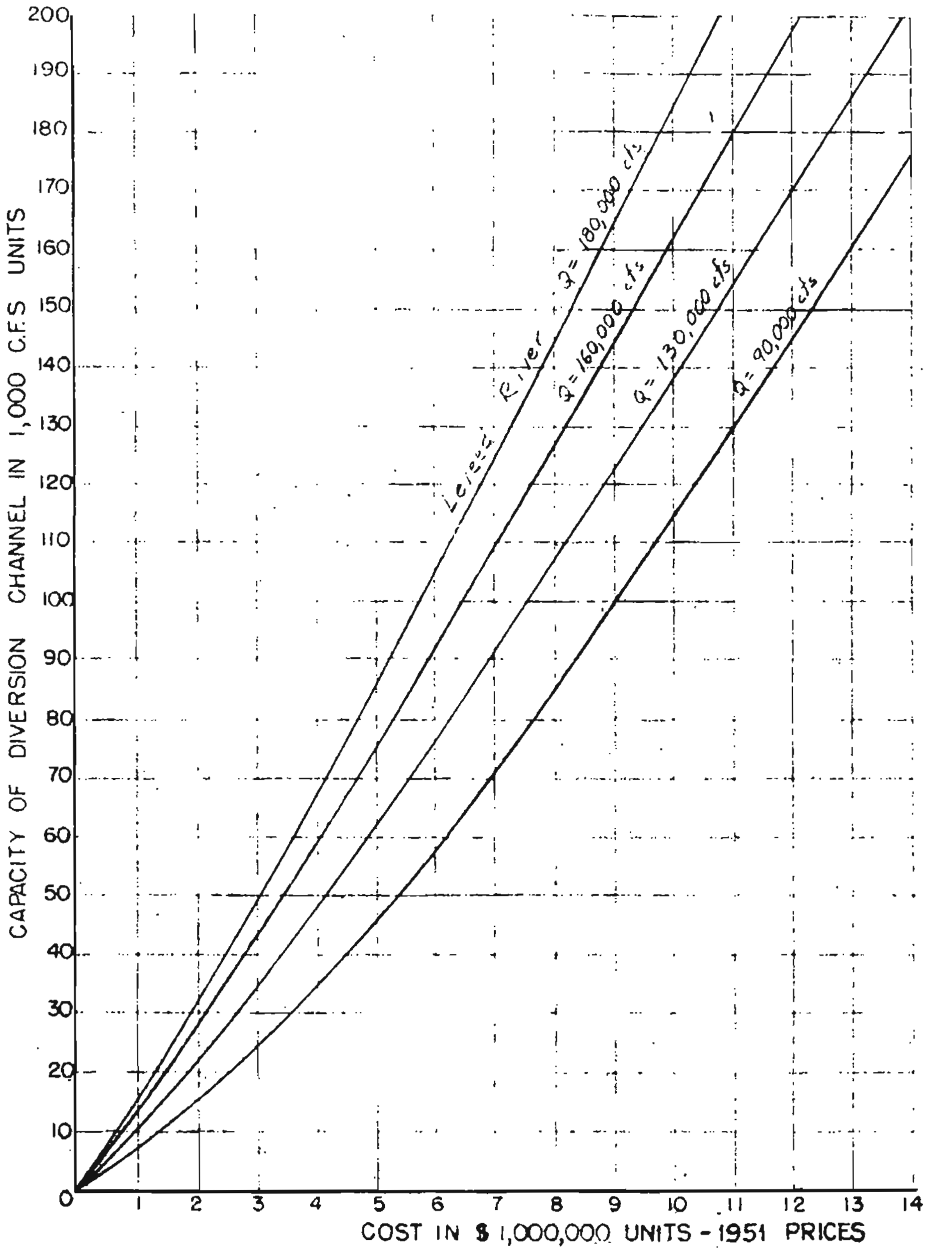


FIGURE A-7
COST OF FLOOD DIVERSION CHANNEL
SKAGIT RIVER BASIN

FILE NO.E-6-6-102.2

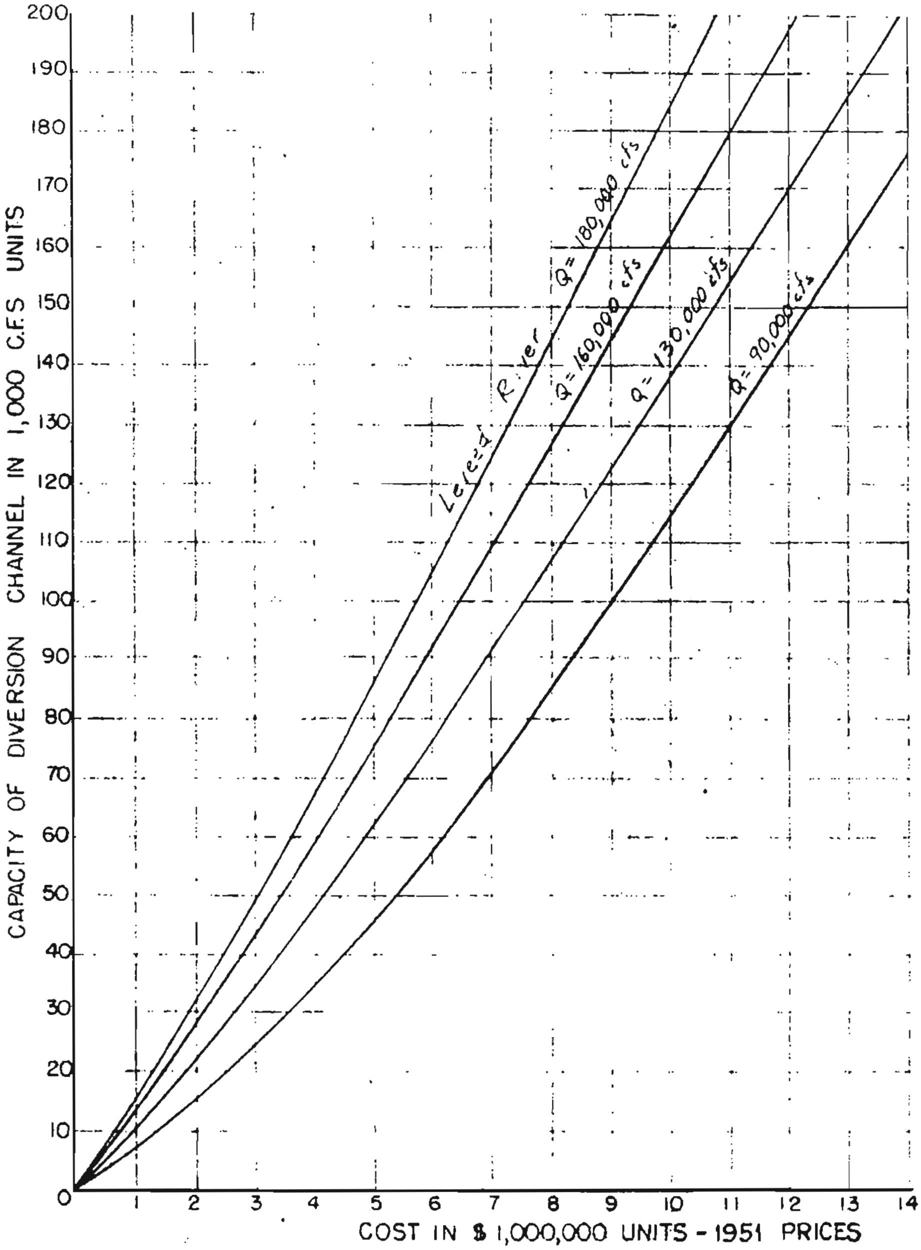


FIGURE A-7
COST OF FLOOD DIVERSION CHANNEL
SKAGIT RIVER BASIN

FILE NO. E-6-6-102.2

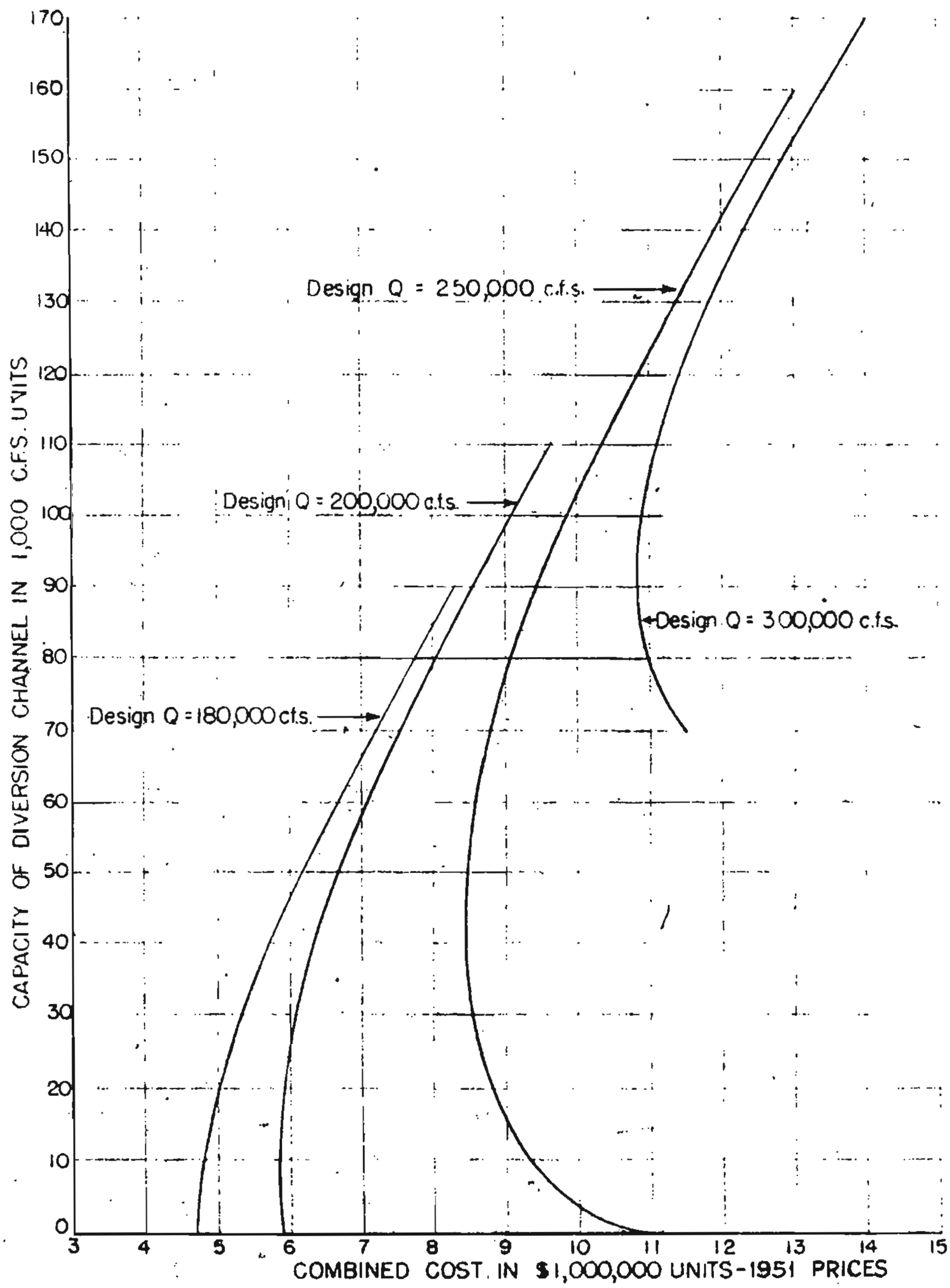


FIGURE A-8

COST OF COMBINED DIVERSION & LEVEE IMPROVEMENT

FILE NO. E-6-6-102.3

Table A-16. - Economic analysis of protecting Skagit diked areas and Samish section

(1951 Price Levels)

Flood flow at Sedro Woolley	Required capacity of Protective works 1/	Project cost	Annual cost at 5%	Approximate benefits	B/C ratio	Remarks
(cfs.)	(cfs.)	($)	($)	($)		
135,000	127,000	1,800,000	90,000	12,600	0.14	Improvement by levees only. Design flow equivalent to 1949 flood.
180,000	163,000	3,700,000	185,000	51,500	0.28	Improvement by levees only.
205,000	184,000	4,900,000	245,000	92,500	0.38	Improvement by levees only.
250,000	220,000	7,500,000	375,000	150,000	0.40	Improvement by levees only. Cost would theoretically be slightly less if combined plan with a small capacity diversion channel were used.
330,000	300,000	10,850,000	543,000	157,000	0.29	Levees 200,000 cfs.; diversion channel, 100,000 cfs. Because of low frequency design flow, benefits not significantly increased.

1/ Sedro Woolley flows reduced by storage in Nookachamps Creek area. Flow reduction assumed to vary from 0 cfs. at 90,000 cfs. Sedro flow to 30,000 cfs. at 250,000 cfs. Sedro flow.