Summary furnished
Skagit County Commissioners

STAGE AND VOLUME OF PAST FLOODS IN SKAGIT VALLEY AND ADVISABLE PROTECTIVE MEASURES PRIOR TO THE CONSTRUCTION OF PERMANENT FLOOD CONTROLLING WORKS.

by

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See 143.82/55a for Geology

STAGE AND VOLUME OF PAST FLOODS IN SKAGIT VALLEY AND ADVISABLE PROTECTIVE MEASURES PRIOR TO THE CONSTRUCTION OF PERMANENT FLOOD CONTROLLING WORKS.

In accordance with an agreement between Skagit County and the United States Geological Survey, a study has been made of the flood flow in Skagit Valley. When neither extra time nor expense was involved, additional data were collected and possible remedial measures were studies as opportunity offered. The results of this study are being formed into a report which will not be completed for some time. The data concerning the volume of the floods, which was the basis of the agreement, was furnished in August of this year. But on the basis of levels by the Skagit County Engineer's office in September, there are slight corrections to the flood flows which were furnished for The Dalles.

The present study has been decided upon as advisable, in order that the corrected flood flow data may be furnished, and also to suggest inexpensive protective measures that need attention at present or in the near future.

Since the arrival of the first white people, about 1869, there have been six Skagit River floods whose discharge has exceeded 175,000 second-feet at Sedro Woolley. All of these six floods have occurred since November 15, 1896. The number of floods that exceeded 175,000 second-feet at Sedro Woolley prior to 1869 is unknown; but the occurrence of two great floods has been discovered. The exact dates of these early floods are not known, but their stages and volumes have been accurately determined.

The maximum floods which have occurred in the past have had about twice the discharge of the flood of 1921. A flood about 1815 was nearly a maximum but there had been, prior to that time, several floods approximately as large. This latter fact was determined at Reflector Bar, where alternate layers of flood sand and charcoal were found. The flood sand could have been deposited only by floods approximating the maximum size; while the charcoal could have been left only by forest fires which occurred during the time intervening between the maximum floods.

The essential information concerning the floods of known stage and volume are embodied in the summarized data below.

BASIS OF PEAK STAGE DETERMINATIONS.

The gage heights for all floods at all stations are based on the maximum height reached by the surging water. This proved necessary, for the height of all the earlier and some of the recent floods could be determined according to this method only. The resulting gage heights and discharges are somewhat greater than if the mean of surges were used as the U.S.G.S. does in obtaining gage heights. An idea of the difference in results can be obtained by comparing the maximum gage
(12 and 7.5) (14.1 [illegible])
heights for the 1917 and 1921 floods at Reflector Bar (published by the U.S.G.S.) with the heights for the same floods in this summary.

The peaks of surges are made up of at least two important factors. One factor is a more or less steady pulsation or seiche in the stream. This may be seen at its best in a steeply inclined and partly filled trough. The other factor is wave action due to the irregularities of the stream bed. The peak of the pulsations and the mean of the waves should be used in obtaining the true peak discharge. The true peak discharge, therefore, lies between the result obtained by using the gage height based on the crest of the highest surges, and the result obtained by using the gage height based on the mean of the highest surges.

SKAGIT RIVER AT REFLECTOR BAR,
NEAR MARBLEMOUNT, WASH.

DRAINAGE AREA 1,100 SQUARE MILES.

No. in order of magnitude	Date of flood	Gage height in feet	Discharge in second-feet	Discharge in second feet per sq. mile.	Accuracy in percent
1	?	21.0	120,000	109	20
2	1815	20.5	115,000	105	20
3	1856	18.5	95,000	86	15
4	Nov. 29, 1909	15.4	70,000	64	10
5	Dec. 12, 1921	14.5	63,000	57	10
6	Nov. 18, 1897	12.5	48,000	44	10
7	Dec. 29, 1917	12.5	43,000	39	10

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Notes: The flood dated 1814 probably occurred between 1804 and 1824. This is based on the age of an Indian interviewed in 1879 concerning that flood.

The flood dated 1856 did not occur after 1857 and probably not before 1850. This is known by precipitation data and by the age of trees on a bench which was cleared by the flood of 1856.

The flood of 1814 may have reached the stage given for flood No. 1. There are some slight indications, however, that it did not. It is certain that the peak stage of the flood of 1814 had been approximately reached several times prior to 1814. This is known from the alternate deposits of ground surface material and flood sand on a sand bar which was barely topped by the flood of 1856.

There is no flood sand above the stage reached by flood No. 1. The stage reached by that flood has not been exceeded, therefore, for thousands of years.

The stages of floods Nos. 2 and 3 were determined near the gage from the elevation of high water marks on canyon walls and from flood sand deposited by those floods.

The stage of flood No. 4 was determined from drift and flood sand at and above the gage.

The stage of flood No. 6 was determined from the stage one mile downstream in relation to floods Nos. 4 and 7.

SKAGIT RIVER AT THE DALLES
NEAR CONCRETE, WASH.

DRAINAGE AREA = 2,700 SQUARE MILES.

No. in order of magnitude	Date	Gage height in feet (Upper Dalles gage)	Discharge in second feet	Discharge in sec.ft. per.sq.mi.	Accuracy in percent
1	1815	56.6	500,000	189	10
2	1856	44.6	350,000	135	10
3	Nov.19, 1897	38.4	275,000	106	20
4	Nov.30, 1909	36.4	260,000	98	10
5	Dec.13, 1921	34.9	240,000	91	5
6	Dec.30, 1917	33.0	220,000	81	10

Notes: See notes for Reflector Bar concerning accuracy of date for floods of 1814 and 1856.

Floods Nos. 3-6 have been dated on the assumption that the flood occurred shortly after midnight in each case.

The stages for floods Nos. 3, 4, and 6 have been estimated from flood marks about one mile upstream. The stage for flood No. 3 was rather uncertain at the upstream point. The accuracy for the discharge of that flood has been reduced accordingly.

The stage for flood No. 1 was determined from the maximum height of flood sand opposite the upper Dalles gage.

The stage for flood No. 2 was determined from its highwater mark left on the Canyon wall in The Dalles.

There is no flood sand above the stage reached by flood No. 1. The stage reached by that flood has not been exceeded therefore, in thousands of years.

SKAGIT RIVER NEAR SEDRO WOOLLEY, WASH.

DRAINAGE AREA = 2,970 SQUARE MILES.

No. of flood in order of magnitude.	Date	?* Gage height in feet.	Discharge in second feet.	Discharge in second-feet per sq. mi.	Accuracy in percent.
1	1815	33.5	400,000	134	15
2	1856	30.0	300,000	101	15
3	Nov.30,1909	26.5	220,000	74	10
4	Dec.13,1921	24.3	210,000	71	10
5	Dec.30,1917	24.1	195,000	66	10
6	Nov.19,1897	24.9	190,000	64	15
7	Nov.16,1896	24.8	185,000	62	15
8	Nov.16, 1906	24.7	180,000	61	15

Notes: See notes for Reflector Bar concerning the accuracy of dates for floods of 1814 and 1856.

The stage for flood No. 1 has been estimated from the height of the flood plain, from the stage and discharge at the Dalles and by comparison with the stages of floods Nos. 2 and 3.

The stage for flood No. 6 has been obtained by its relation to the stage of flood No. 7 about one fourth mile up stream.

The stage discharge relation is shifting. The discharge for all floods except 3, 4, and 5, are based, to a large extent, therefore, on comparative stages at other points.

There were no floods from 1869 to 1895 as great as Nos. 7 and 8. This is according to the evidence of all the early settlers.

The stages of floods from 1814 to 1869, except that of 1856, are unknown. They were all, however, of a less crest stage than the flood of 1856. It is fairly certain, also, that the stage of any floods between 1856 and 1869 were less than that of flood No. 3.

It should be noted that the crest height of the maximum flood in the Sedro Woolley-Mt. Vernon district was about 7 feet higher than the crest of the 1909 flood. Due to the clearing away of the forests, the same flood at the present time might not be quite as high. This decrease in flood height should not be depended upon, however.

* [illegible] "Skagit R. near [illegible], [illegible] 1908-1922", [illegible]

A maximum flood, accordingly, would cover the highest points in Sedro-Woolley to a depth of nearly 2 feet. It would also carry away a great number of houses in Hamilton and Burlington. At the latter point, especially, a great loss of life would probably result. It is estimated that the total loss of life in the valley, without additional flood protection or warning, might easily be over 100. The prolonged exposure to winter rain, and the cold flood waters would cause untold suffering to many others.

Except for the Skagit River bridges, the monetary damage caused by a maximum flood would be difficult to estimate. The damage resulting to the bridges is fairly easy to forecast because drift and water would destroy most of the steel work and some of the piers. The loss in Skagit River bridges alone would be approximately $1,000,000. It is thought that the total monetary loss in the county, including bridges and excluding human life (which cannot be properly evaluated) would exceet $5,000,000.

The monetary damage caused by such a flood as 1856 would be approximately half as much as for the maximum flood. The loss of life, however, probably would not be proportionally as large.

The problem of climatic changes is still being investigated. It is hoped that the study will throw some light on the frequency of certain sized floods in the past and future. The investigation so far seems to indicate that time is only a secondary consideration in estimating the number of certain sized floods which may be expected. In the light of knowledge of past floods and the climatic conditions that caused them, it seems likely that a few floods corresponding to 1917 and 1921 may occur within 5 or 6 years, and, in addition, during that time there may occur such a flood as 1815 or 1856. In fact, it is likely that nearly this situation occurred in the early part of the nineteenth century, and again between 1850 and 1860. This corresponds somewhat with the well known fact that from 1869 to 1895 inclusive, there were no winter floods which approached the size of the floods of 1896, 1897, 1906, 1917, and 1921. The floods of 1815 and 1856, and the increase in the size of floods beginning with 1896 is due to climatic changes not fully understood as yet.

It would indeed be a serious matter if a flood the size of any of the six mentioned above should occur nearly every winter for a few years and in addition there should come enormous flood, such as that of 1815 or 1856. Skagit Valley, with such a rapid succession of floods, would be nearly financially destroyed, and bankers would hardly feel justified in making loans for protective measures.

It should be clear from the foregoing that the flood situation is more serious than the knowledge of the floods since 1896 would indicate. But no matter how serious the flood situation may appear, Skagit County should not be stampeded into any sudden action in constructing expensive flood protection works. The problem should br studied thoroughly from every angle, and then every effort bent to an early completion of what is decided upon.

The writer's complete study has proceeded far enough to indicate that diking the present river or flood spillway channels would have no value for a maximum flood except at an exceedingly high cost. Increasing the height of the proposed Ruby Reservoir would be helpful but this alone would not remove the menace.

Cut-off channels, river improvement, drift barriers, and detention reservoirs combined would give protection against maximum floods, but they will be expensive.

The writer will make several suggestions as to inexpensive protectice measures that should be carried out in the near future. They may be briefly outlined as follows:

1. INSTALL A FLOOD WARNING SYSTEM. pp 8-19
2. DELAY DIKING OFF THE NOOKACHAMPS DISTRICT. p 19
3. PROTECT CERTAIN DANGER SPOTS.
   a.- Remove drift from river channel below Hamilton and possibly near Lyman. 19-20
   b.- Build protective dike at Burlington and possibly at Mount Vernon. 21
4. OBTAIN ADDITIONAL HYDROGRAPHIC DATA. 22
5. FORM A CONSERVANCY DISTRICT. 25

The above items will be taken up in detail according to the order listed above.

INSTALL A FLOOD WARNING SYSTEM
METEOROLOGICAL AND HYDROGRAPHIC DATA.

An efficient flood warning system is essential but before deciding on the kind to install, all available data concerning past floods should be carefully studied with relation to the probable conditions during future floods. Fortunately, precipitation and temperature records were kept at the Skagit Power Camp for the 1909 flood, and at the Davis Ranch for the 1917 and 1921 floods. Data for floods earlier than 1909 are not available, and consequently only the three most recent floods can be studied. Meteorological data for the 1909 and 1921 floods are given in the following tables.

SKAGIT POWER CAMP 1909 FLOOD

Date	Temperature in degrees Fahrenheit			Precipitation in inches.
Nov.	Maximum	Minimum	Mean	
19	42	41	41.5	1.57
20	42	37	39.5	.42
21	41	37	39	.15
22	42	36	44	1.97
23	48	40	38.5	3.05
24	41	36	34	1.35
25	36	32	34	.12
26	38	33	35.5	.05
27	36	33	34.5	.40
28	40	33	36.5	4.00
29	52	39	45.5	3.85
30	40	36	38	.20

DAVIS RANCH 1921 FLOOD

Date	Temperature in degrees Fahrenheit			Precipitation in inches.
Dec.	Maximum	Minimum	Mean	
9	42	32	37	.20
10	49	37	43	2.59
11	45	38	41.5	3.92
12	51	36	43.5	3.70
13	48	35	41.5	0.00

The significant data in the above tables are those for November 28-29, 1909 and December 11-12, 1921. The total precipitation for the two days in 1909 was 7.85 inches, and for the two days in 1921, 7.62 inches. It is understood that all of the two day rain for the flood of 1921 fell between 8 a.m. of December 11 and 4 p.m. of December 12.

or a period of 32 hours. Probably the heaviest rainfall did not begin until sometime after 8 a.m. of December 11. It is possible that the two-day rain for the 1909 flood fell in about the same length of time or it is possible that it lasted 48 hours. If it lasted 48 hours, however, it must have fallen at a very slow rate during the later portion of that time, for it rained only 0.20 of an inch in the next 24 hours. Due to the very low temperatures on November 27, 1909, it is possible there was considerable hold-over run-off in the 0.40 of an inch precipitation of that date. Due to the high temperature on December 10, 1921, it is believed that the heavy precipitation of that date did not have any material effect on the final flood crest, other than to clear the snow out of the mountains to correspond to the same clearing out on November 23, 1909. It is probable that the maximum temperature in the Skagit Power Camp-Davis Ranch region was the same on December 12, 1921 as it was on November 29, 1909. The tables show 52 degrees Fahrenheit for 1909 and 51 degrees Fahrenheit for 1921. The difference however is probably due to the greater elevation of the Davis Ranch, causing about 1 degree Fahrenheight lower temperature there.

To test our rainfall problem, we will first assume that there was no hold-over rainfall from November 27, 1909, and that the precipitation of November 28 and 29 fell in 32 hours, and otherwise in the same manner as in 1921. The only appreciable difference, then, between the floods of 1909 and 1921 is the extra 0.23 of an inch of rain that fell during the two-day rain of the 1909 flood. Assuming that there was an even distribution of the extra rain over 1,100 square miles of drainage area above Reflector Bar, it would amount, in run-off, to a continuous

32-hour flow of about 5,000 second-feet. The extra 0.23 of an inch of rainfall for the 1909 flood would all run off up to the upper limit of any run-off for the 1921 flood, or an elevation of about 6,000 feet. There is very little area above an elevation of 6,000 feet, and the lack of the 0.23 of an inch run-off in that elevated region should be nearly balanced by the more than 0.23 of an inch precipitation and run-off at a high elevation, but below 6,000 feet; i.e., the maximum rainfall is at a considerably higher elevation than the Davis Ranch and the Power Camp.

During floods there is a pronounced diurnal fluctuation in discharge due to temperature. This would cause the actual difference between the peak discharge of the 1909 and 1921 flood to be greater than 5,000 second-feet even though the 0.23 precipitation occurred at a steady rate. The diurnal fluctuation, as far as the immediate precipitation is concerned, is caused by the night precipitation occurring as snow in high regions. Practically all of this night snow in the forested regions is deposited on the trees and is in an ideal state to be melted; consequently it all runs off the next day.

The minimum temperatures on the days of the floods of 1909 and 1921 averaged 14 degrees below the maximum temperatures. Topographic maps of that region have not been made, and accordingly, there is no way of ascertaining the proportional area lying below 6,000 feet elevation, and above the elevation of night rain. In addition, no hourly record of the flows for 1909 and 1921 are at hand. It may be assumed tentatively, however, that the maximum rate of run-off from the average of all ground surface below 6,000 feet elevation was nearly 150 percent greater than the minimum. Due to a great deal of this actual run-off being taken up temporarily by stream storage, the peak discharge at Reflector Bar would not be as much greater than the minimum discharge for the day, as the maximum hillside run-off was greater than its minimum. Probably, however, the Reflector Bar 1909 and 1921 peak discharges were 75 percent greater than the mean of the flow 12 hours preceding and succeeding the peak. Assuming that an average of the maximum and minimum flows gives the mean for the day, we would arrive at the conclusion that the minimum flow from the 0.23 of an inch precipitation was 3,600 second-feet and the maximum 6,400 second-feet. This 6,400 second-feet, therefore, according to rainfall, is the theoretical difference in peak discharge of the 1909 and 1921 floods. The actual peak discharge for the 1909 flood was 70,000 second-feet and for 1921 it was 63,000 second-feet. The difference, 7,000 second-feet, gives a remarkably close check on the 6,400 second-feet theoretical discharge based on rainfall.

If we assume that there was a 0.30 of an inch hold-over of the 0.40 of an inch precipitation on November 27, and that 0.30 of an inch rainfall occurred after 4 p.m. of November 29, we have a balance that leaves our problem the same as just worked out.

Any other assumptions than the two which have been considered would not work out well in a comparison of theoretical and actual discharge. These two assumptions are considered to be the most probable, however, and very likely they will be checked if further data is obtained on rates of 1909 and 1921 rain falls and on land surface areas between certain elevations.

From the above, we will estimate that each 0.23 of an inch of additional rainfall in 32 hours during large floods, disregarding stream storage, will cause 6,400 second-feet greater peak flow at Reflector Bar (one mile above the Davis Ranch). Eight times as much additional rain, or 1.84 inches would then cause 51,000 second-feet additional flow. The 32 hour rainfall in 1909 was 7.85 inches, and the peak discharge 70,000 second-feet. Adding the additional 1.84 inches rainfall and 51,000 second-feet flow, gives respectively 9.65 inches of rain and 121,000 second-feet flow.

The flood of 1815 had a discharge of 120,000 second-feet and the above study would indicate that the rainfall for that flood would have been about 9.65 inches in 32 hours. It seems likely, however, that there was a somewhat higher temperature, also, during that flood. If so, there would be more snow melting, and to obtain 120,000 second-feet flow there would not necessarily be quite as much rain as the study would indicate. The maximum temperature for 1815, probably did not exceed that for 1909 enough, however, to melt any material amount of snow. It is thought that 0.10 of an inch would be ample to allow for the higher temperature. It would be necessary also to allow about 0.40 of an inch rainfall for stream storage. The difference between these two corrections would amount to an additional 0.30 of an inch of rain or a total of 9.95 inches. The base data available does not warrant any great refinement, so it will be concluded that the 32-hour rainfall for 1815 was 10 inches. We may accordingly construct the following table for an 1815 type of flood at the Power Camp.

SKAGIT POWER CAMP 19---FLOOD

Date	Temperature in degrees Fahrenheit			Precipitation in inches
Nov. or Dec.	Maximum	Minimum	Mean	
?	38	34	36	.60
?	42	34	38	5.10
?	53½	41	47	4.90
?	41	37	34	.25

The following table is given to show the meteorlogical conditions at the time of the 1917 flood.

DAVIS RANCH 1917 FLOOD

Date	Temperature in degrees Fahrenheit			Precipitation in inches
	Maximum	Minimum	Mean	
15	39	35	37	1.28
16	43	34	38.5	1.38
17	43	33	38	1.05
18	51	34	42.5	3.05
19	49	33	41	.27
20	41	33	37	.28
21	37	33	35	.13
22	37	32	34.5	1.93
23	37	26	31.5	---
24	28	15	21.5	---
25	32	20	26	---
26	33	31	32	1.06
27	33	27	30	2.61
28	34	27	30.5	2.00
29	36	33	34.5	2.79
30	40	34	37	.08
31	40	35	37.5	2.02

There was snow on the ground and sleet on the trees at the Davis Ranch during the 1917 flood. The temperatures were therefore much below those in the hills where the snow was melted off. This table therefore illustrates the fact that dependence as a flood indicator cannot be placed on the thermometer readings as long as there is snow in their vicinity.

KIND AND LOCATION OF FLOOD WARNING STATION.

The present telephone system works fairly well for such floods as 1917 and 1921, but for a flood of the 1815 type, the telephone line would probably be broken in several places before the Skagit River reached a very high stage. The line breakage would be caused by uprooted trees, land slides, snow slides, and by drift and erosion in small tributaries. The flood would then descend on the doomed valley with little warning, except the general weather conditions and the rapidly rising river.

Two combined telephone and radio stations should be installed at points where the rate of raise and maximum stage of past floods are known. There are three points that are believed satisfactory and possibly there are others. The three points are the Davis Ranch, Skagit Power Camp, and Darrington.

A fl od warning system should be installed if possible before the 15th of November of this year. Due to the short time yet remaining the radio should if possible be installed at the Skagit Power Camp. Then next year, if it should be decided that the Davis Ranch is better, the equipment could be moved up there. A station could also be installed at Darrington next year, if that proved to be a good location. The radio stations should have the standard Weather Bureau equipment, consisting of a recording rain gage and the maximum and minimum thermometers. They should be made a Weather Bureau station and the meteorological data handled according to the U. S. Weather Bureau. These weather records will be valuable for flood study in the future, and in addition, the instrument will give a fairly accurate estimate of the coming flood even before it reaches the radio station.

The radio forecaster should be equipped with the daily discharge record at Reflector Bar, Skagit Power Camp (all stations) and Sedro Woolley. He should also have the hydrographs of the 1909 flood at the Power Camp, 1917 flood and the 1921 flood at Reflector Bar. All this data may be obtained from the U. S. Geological Survey at Tacoma.

With the daily discharge tables, flood hydrographs, climatological tables given above, and the meteorological instruments, a radio forecaster would be well equipped to give flood warnings.

After the start of chinooks, the rain gage should be considered the most reliable of early flood indicators. For Skagit Power Camp and Davis Ranch the meteorological tables indicate that a dangerous rainfall has occurred when an 8 a.m. reading shows 3.0 inches for the previous 24 hours or 4.5 inches in the previous 48 hours. In either of these cases, the cumulative precipitation should be determined hourly in case the rain continues. A preliminary warning should also be sent out for the dikes to be patrolled and for every one on the low lands to be ready to save their property. In addition to hourly precipitation readings the thermometer and the river gage should be watched closely. Warnings should be sent out according to the indications. If the rainfall readings indicate a probable total of 7 and one-half or 8 inches within 34 hours, a flood approximating that of 1909 or 1921 may be expected. If the rainfall readings indicate a probable total of around 10 inches within 34 hours, then a flood of the 1815 type may be expected. For a maximum flood, a warning should be sent out that a flood from 7 to 15 feet (accordingto the location) higher than that of 1921 might be expected. For a maximum flood the main effort should be to save human life, and until some adequate flood protection works are completed, the following places should be abandoned as soon as possible after the knowledge of such a flood has been received from the radio station.

1. All of Hamilton, Lyman, and Burlington.
2. Low lying portions of Concrete, Sedro Woolley, and Mount Vernon.

The above points should be abandoned mainly because of the danger of swift water and drift wrecking and carrying away houses. In some cases, however, it is because even in still water the second stories would be flooded.

For towns and ranches close to tide water, it would probably be safe for inhabitants to stay in the upper stories of their houses provided the second floors are six or more feet higher than the crests of the 1909 and 1921 floods. Other houses in the valley, where a six foot depth of water would occur on the surrounding ground, should be abandoned unless they are in locations where it would be impossible for an overland current from the river to strike the house and carry it away by drift and the force of the water. The high land in Sedro Woolley and Mount Vernon should be the main concentrating ground for refugees, but undoubtedly there are many houses on high ground which can be used.

A maximum flood has not occurred in approximately the last 100 years, and possibly it may be many years before another occurs. On the other hand it may occur in the next year or two. A radio station is the cheapest insurance that can be obtained against such a great catastrophe as a maximum flood could easily be. The radio station due to earlier warnings, would more than pay for its original cost and upkeep at the time of each of the smaller type of floods, such as 1909 and 1921.

If a radio station can be established at the Skagit Power Camp for the present season, the preferable method of handling would be for a county employee or other property holder to stay up there for two months. If this cannot be done probably a City of Seattle employee could every day take meteorological readings, test the apparatus, and send a bulletin to Mt. Vernon. A county employee could then go up at once on the inception of a chinook. With this last method it would be necessary to leave Mt. Vernon on the day previous to the morning of the critical precipitation reading.

2.- DELAY DIKING OFF THE NOOKACHAMPS DISTRICT.

The Nookachamps District, in its present condition, acts as a storage reservoir, and thus reduces the flood height in the surrounding and lower districts. This storage reservoir has been of material benefit in the past, and has doubtlessly decreased the number of breaks for the larger floods and prevented breaks for the lower floods. According to Mr. Robert Herzog, Assistant Engineer of the Great Northern Railway, the reservoir capacity of the Nookachamps District and other adjacent land is a flow of 150,000 second-feet for five hours. See 147.1/43 Herzog Report

3.- PROTECT CERTAIN DANGER SPOTS.

(a) REMOVE DRIFT FROM THE RIVER CHANNEL BELOW HAMILTON AND POSSIBLY NEAR LYMAN.

Drift is probably the main cause of channel changes and bank erosion, and is certainly the cause of higher river stages above the drift. At Hamilton a serious condition seems to have arisen due to drift lodging below that town. It is not known when the drift started lodging, but it has been assumed for convenience that it did not effect the 1909 flood crest, and that probably it came in during that flood. On the assumption that the 1909 stage was normal, a comparison with other points on the river would indicate that the drift and its accompanying effects had raised the stage for the 1917 flood 0.8 of a foot and the 1921, 1.0 foot above the normal stage to be expected for those floods. If this process continues, it is only a matter of time until the river erodes a channel around the drift and presumably to the northward. This erosion will probably occur gradually by making a bend, but it may occur suddenly by cutting a complete new channel. Hamilton is accordingly in a highly dangerous position.

Even though a new channel were not cut, a flood as great as that of 1856 might carry enough drift down through Hamilton to destroy most of the houses. There seems to be little doubt that a flood of the 1815 type would practically destroy the town. If the extreme floods should not occur and work some quick destruction, lower floods would erode the banks and gradually eat away a great deal of the town site.

The Skagit River can probably be induced to stay in its present channel at Hamilton by removing all of the drift in the present river channel for a mile or more below the town. By "channel drift" must be understood not only that drift lying on the surface, but also that drift portions of which show above the stream bed gravel. This process of removing surface drift and embedded drift would have to be repeated as new drift collected, and as stream erosion exposed more buried drift. It should be possible to reduce flood heights by this means at least 1 foot and possibly as much as 2 feet, and also hold the river to its present channel.

As a contributary but not a main factor in the danger at Hamilton, the logging road jetty opposite Hamilton should be removed from the river channel.

The work recommended above will not prevent great destruction by a flood of the 1815 type; but by lowering the flood crest and aiding drift to keep to the main channel it will reduce the losses somewhat.

At Lyman, the river has been shifting around over the valley floor due to the drift. If the damage to be expected from this shifting is considerable, then the removal of the drift for the purpose of forming a deep and more permanent channel would seem advisable.

(b). BUILD A PROTECTIVE DIKE AT BURLINGTON AND POSSIBLY AT MOUNT VERNON.

The city of Burlington is in a dangerous location both for position and elevation. Its position is such that floods have a tendency to pass through it when out of banks. It is located in the flood plain and hence is exposed to the full depth of the overflow water on that plain.

A flood of the 1815 type would probably be about 7 feet higher than the 1909 and 1921 floods would have been in Burlington without dikes. An examination of the Skagit 1921 flood profile furnished by the Great Northern Railway, would indicate that an 1815 flood would probably have reached a height of 143 or 144 feet, referred to the Great Northern Railroad datum. Assuming the town to lie at 131 feet elevation (the same as the Great Northern Railroad tracks) the 1815 flood would have been about 12 or 13 feet deep in the city.

Burlington, at the least, should have a semicircular dike to prevent destructive drift-laden currents from flowing through the city. This dike should reach to an elevation of at least 146 feet, (= 550 U.S.G.S.) Great Northern datum, and should be protected on the stream side by grass, brush, revetment, or other means to prevent destructive erosion by the swift water.

If funds can be raised, it would be far preferable to build a complete dike around the city of Burlington, and either raise the railroad tracks to the dike elevation or else put regular canal lock gate at each railroad opening. A correctly built dike around the entire city would preserve it against all damage during the greatest floods.

Dikes for full protection should be very wide in relation to their heights. Before constructing the dikes, all foreign materials would necessarily be removed from the land surface. All stumps would have to be removed completely enough to break up the continuity of the root system at the stump. This careful stump removal would be advisable for many dikes have been undermined by the water following decayed root channels. The ground should also be thoroughly broken with a plow after the clearing.

It is not likely that Mount Vernon, except for the highway bridge, would be sreiously damaged by currents and drift except at the time of dike breakage during an 1815 type of flood. This is due to the fact that as the flood passes the height of the 1909 and 1921 floods, it would tend to flow more and more past Burlington towards Padilla Bay. There would be some financial damage in Mt. Vernon due to swift currents and great damage due to slack water flooding. If therefore it can be proven that this damage will be great enough to warrant the cost of dikes, they should be built.

4.- OBTAIN ADDITIONAL METEOROLOGICAL AND HYDROGRAPHIC DATA.

In order that more definite information may be obtained in regard to floods, it is advisable that additional meteorological and hydrographic data be obtained.

METEOROLOGICAL DATA.

Under "Flood Warning System" was mentioned the need of obtaining climatological data at the warning stations. The data should be collected under the supervision of the U. S. Weather Bureau and the equipment should consist of maximum and minimum thermometers, recording and auxiliary rain gages, and a mercury barometer. In addition to the meteorological data obtained at the warning stations, other meteorological stations should be established in the mountains where they can be maintained throughout the year. Stations should be established at Ruby Inn, Marblemount, and Darrington unless there are U. S. Weather Bureau stations at these points already. A station should also be established as far as possible up Baker Valley. The Morovitz Ranch, U.S.Fish Hatchery or the Ranger cabin are good locations, but they may not be occupied continuously all the year. Probably the Bear Creek Power plant would be the most reliable station. All U. S. Weather Bureau stations now in operation in Skagit County should be equipped with necessary barometers. This includes Anacortes, Sedro Woolley, Davis Ranch stations, and probably others. All meteorological stations should have reliable telephone connections with the warning stations and with Mt. Vernon.

HYDROGRAPHIC DATA.

Continuous record of stream flow should be obtained on the Skagit River below the mouth of Baker River. The gaging station maintained at Sedro Woolley in past years has proved unsatisfactory, due to the shifting stage discharge relation.

The most suitable location for a new gaging station is at The Dalles one mile below the mouth of Baker River. Gages were installed at this point for the flood investigation during the winter of 1922-23. The Upper Dalles gage, near an old cabin belonging to Mr. H. C. Stiles, should be put into good condition. Regular readings should then be made twice daily on this gage. During winter floods special gage readings should be made every few hours at least, and every hour for stages above 25 feet.

It will be necessary to install a cable and cable car for making discharge measurements at The Dalles station. A suitable cross section can be found about one-fourth mile below the lower end of The Dalles. To make the cable safe against maximum floods, it would be necessary to install it so that the center of the unloaded span would be 10 feet above the maximum floods, or at an elevation of about 58 feet referred to the Dalles gage. For convenience in measurements, and to save cost in construction, it might be advisable to erect the cable with the center of the unloaded span at an elevation of 42 feet and chance losing the cable for floods higher than that of 1921.

In order to obtain the best results at a minimum expense, the gaging station should be handled in cooperation with the U. S. Geological Survey.

In addition to obtaining record of stream flow at The Dalles, samples of the water should be taken to determine the amount of suspended matter carried down the Skagit River. A sample should be taken daily during high water and oftener during floods. After the peak of the summer flood and during any low water a sample once a week should be sufficient.

A water sampling station should also be established at Mt. Vernon. Probably this could be handled by the County Engineer's office.

Data obtained on the amount of suspended matter in the Skagit River will give an indication as to how long it will take Skagit Bay and flood reservoirs to fill up.

5.- FORM A CONSERVANCY DISTRICT.

Before permanent and satisfactory flood prevention works can be installed, it will undoubtedly be necessary to form a Conservancy District. A Conservancy District properly formed by a majority of the people has powers to go ahead and complete flood works regardless of the opposition of a minority. In all probability, a Conservancy District can not be formed without an authorization act of the State Legislature. If so, Skagit County should start making their plans now for obtaining an authorizing act in the legislative session over a year ahead.

Notable instances of Conservancy Districts in the past have been those formed in Ohio and Colorado following the Dayton and Pueblo floods repsectively. As aid in forming a Conservancy District for Skagit Basin, the procedure followed in Ohio is given herewith as taken from "History of the Miami Flood Control Project".

FEATURES OF THE CONSERVANCY ACT.

"The conservancy act provides for the establishment of conservancy districts in Ohio, through petition of property owners to the court of common pleas of any county wholly or partly within the proposed district, for any or all of the following purposes:

(a) preventing floods;
(b) regulating stream channels by changing, widening, and deepening same;
(c) reclaiming or filling wet and overflowed lands;
(d) providing for irrigation where it may be needed;
(e) regulating the flow of streams;
(f) diverting, or in whole or in part eliminating water courses; and incident to such purposes and to enable their accomplishment, to straighten, widen, deepen, change, divert, or change the course or terminus of, any natural or artificial water course; to build reservoirs, canals, levees, walls, embankments, bridges, or dams; to maintain, operate, and repair any of the construction herein named; and to do all other things necessary for the fulfillment of the purposes of this act.

Organization of a district is affected by a majority decision of a court consisting of one common pleas judge from each county having land in the district. Upon organization of a district a court becomes ipso facto the conservancy court of that district. This court appoints a board of three directors to manage the district, who in turn may employ engineers, attorneys, and other assistants as deemed necessary. In constructing and maintaining the works of a district, the board of directors is authorized to cooperate with the federal government, with the government of any other state, with public or private corporations, with other conservancy districts, or with private parties.

A plan for the improvement is prepared by the chief engineer and passed upon by the board of directors. After a formal hearing of objections by affected property owners the plan is subject to the approval of the court. An appraisal of all benefits and damages accruing to properties affected by the execution of the proposed plan is made by a board of three appraisers appointed by the conservancy court. Due notice of the filing with the court of the appraisal roll and of the hearing thereon shall be published to give the property owners affected opportunity for filing exceptions to any part or all of the appraisal. After a hearing, the court must formally act on the appraisal record. Bonds can then be issued and sold to finance the construction of the proposed improvement. Any owner has the right to appeal from his award of benefits or damages, and may have his case heard before a jury in the county in which his property is located. No property can be confiscated, damage must be paid where damage is sustained, and no property owner can be unjustly assessed.

The following is a list of successive steps showing the operation of the conservancy act from the time the petition for the organization of the district is filed until the construction of the works is begun.

1. Property owners file petition for organization of district.
2. Property owners file bond to cover expenses.
3. Court publishes notice of hearing on petition.
4. Property owners file objections to organization of district.
5. Court holds hearing and decides to organize or not to organize the district.
6. Court appoints 3 directors and 3 appraisers.
7. Directors employ secretary, attorney, engineers, etc., and prepare plans.
8. Directors publish notice of hearing of plan.
9. Property owners file objections to adoption of the plan.
10. Directors hold hearing and adopt Official Plan.
11. Property owners file objections to approval of Official Plan.
12. Court hears and passes on objections to Official plan.
13. Appraisers appraise benefits and damages.
14. Appraisers file appraisal of benefits and damages.

15. Court publishes notice of hearing on appraisals.

16. Property owners file exceptions to appraisals.

17. Court holds hearing and issues decree on appraisals.

18. Property owners appeal on appraisals.

19. Directors prepare and file Conservancy Assessment Record.

20. Property owners have 30 days in which to pay assessments in full.

21. Directors issue bonds and have works constructed.

A district may be financed from three separate funds from which are provided for in the act:

1.- A preliminary fund, consisting of a tax levied upon the property in the district, not to exceed three-tenths of a mill on its assessed valuation.

2.- A bond fund, provided by the special assessment of benefits as approved by the court.

3.- A maintenance fund which is derived from a special assessment levied annually.

The preliminary fund is for defraying the cost of organization, surveys, and other expenses preliminary to the sale of bonds. The bond fund is for the construction cost of the proposed improvement. It is provided by an assessment levide on all real property against which benefits have been appraised. This assessment shall be levied on each property in proportion to the benefits appraised against that property. It shall not exceed the amount of benefits as approved by the court, and shall be only sufficient to pay for executing the plan. Any assessed property owner has the privilege of paying his assessment in full at any time within 30 days after the filing of the assessment roll in the office of the district. If not so paid, the assessment will be collected as an annual tax distributed over a period of years. The amount collected will go into a sinking fund to retire the bonds at maturity. This period shall not exceed 30 years. After the bonds have been sold the act does not permit an injunction against the collection of taxes for their payment or against constructing the works, as this would afford opportunities of obstruction and delay so great that little could be accomplished. It will be noted throughout, however, that appeal to the courts is provided for every important step, thus fully protecting the rights of the property owners.

The lands to be included in the Skagit Conservancy District need not be determined until after the passage of a Conservancy District Act by the State Legislature. The lands are however, about as follows: A large portion or possibly all of Skagit County, all of Whidbey and Camano Islands, and the river bottom land in Stillaguamish Valley, Snohomish County. The lands outside of Skagit County are essential to certain flood protection works. The flood protection works will be of some value outside of Skagit County and as the outside districts are merely brought in as a necessity, those outside districts should probably not be expected to bear any portion of the expense.

There is a great deal of detailed investigation necessary before any definite decision can be made as to just what permanent flood protection works to install. This detailed work will be somewhat expensive and probably more easily handled after the Conservancy District is formed.

James E. Stewart,
Hydraulic Engineer.

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NATURE AND SCOPE OF REPORT.

In accordance with an agreement between Skagit County and the United States Geological Survey, a study has been made of the flood flow in Skagit Valley. When no extra time or expense was involved, possible remedial measures were studied as opportunity offered. The results of this study have been formed into a report, which will be divided into the following chapters:

CHAPTER I.

SKAGIT RIVER DISCHARGE.

This chapter is devoted mainly to daily stream flow and to the date of occurrence, height, and volume of past floods.

CHAPTER II.

CLIMATE AND GEOLOGY.

This chapter discusses the past, present, and future climate with special reference to glaciers and floods, and the effect of glaciation on river drainage.

CHAPTER III.

THE SKAGIT DELTA AND ITS PROBLEMS.

CHAPTER IV.

SUMMARY OF THE RESULTS OF INVESTIGATIONS AND RECOMMENDATIONS FOR PROTECTION FROM FUTURE FLOODS.

CHAPTER I.

BASIC FLOOD EVIDENCE.

The first evidence that should be noted concerning great floods, is the maximum height of the flood plain. The significance of the word "flood plain" is often lost sight of even by engineers who are designing structures which are expected to withstand the maximum flood.

The normal way that a river which is not in solid rock erodes its valley, is by slowly working back and forth across its valley floor. In traveling back and forth across the bottom land, it works over all of the material, and carries away some of it. Manifestly, the valley floor is made up of washed-over material which could not be deposited higher than the maximum flood crest. Since the maximum floods occur at very rare intervals, the banks and highest points on the bottom land are, as a rule, several feet lower than the maximum flood.

According to certain physical and mechanical laws, stream-carrying capacity varies approximately as the sixth power of the velocity, i.e., if the velocity is doubled, the carrying power will be sixty-four times as great. A stream in flood has a relatively high velocity. It will usually be loaded to capacity with silt, sand, gravel, etc. At any point where the stream overflows the bank, the velocity drops, and the carrying capacity drops approximately as the sixth root of the velocity. A great deal of material is therefore dropped near the river, and natural dikes are formed. These dikes have a gentle slope away from the stream, and a downstream slope approximately the same as the slope of the flood crest.

In certain cases, a river is unable to follow its normal course in removing all of its material, as it gradually erodes its way downward. The following cases are known to occur.

1. If there has been a large and sudden geologic uplift, the river sometimes cuts below its banks and valley floor before it erodes all the material.

2. If a high dam in a river breaks, the stream cuts down through the material impounded above the dam without eroding, during the cutting, all of the available material. After a more normal grade has been reached, a great deal of the upper material cannot be eroded by under cutting. (The breaking of great ice dams on North Pacific coast streams, near the end of glacial epochs, were the cause of a great deal of river material being left at great heights along the stream).

3. Where a river in its upper or middle course suddenly debouches from a canyon, it is unable for some distance to work back and forth across the flood plain. As the river cuts lower, it leaves, close to the canyon mouth, banks of material higher than any of its floods can reach.

At Reflector Bar, there is a case of a sudden change from a canyon to a flood plain. There is flood sand on the North bank, however, which, due to its freshness and lack of humus covering, shows that the bank has been recently overflowed.

This north bank is a good illustration of the diking effect of streams. The slope of the bank downstream, and the gentle slope away from the stream are well marked.

The ground on which part of the Skagit Power Camp stands, is a good example of river banks which have been entirely abandoned by the river. Apparently, the banks have been abandoned due partly to the sudden debouch from the canyon above, and partly to the breaking of the ice dams in the lower Skagit River near the end of the last glacial epoch. Part of this camp site is still subject to floods.

There are many points on the valley floor between the Skagit Power Camp and the sea which have not been covered by the highest floods since the arrival of the first white settlers. By "Valley floor", it must be understood, is meant only those lands which have a deep soil similar to that soil which is known to have been overflowed. In Skagit Valley such lands probably all lie less than ten feet above the 1909 and 1921 flood crests. There are in places high gravel benches left after the breaking of glacial ice dams. These benches are, of course, never covered by floods. The Sedro Woolley town site is a good example of the low flood plain ground which has never been covered in the memory of the white man. There is no doubt, however, that the soil under Sedro Woolley was deposited by the river in recent time; and furthermore, there can be no doubt that there will be future floods which will cover the Sedro Woolley town site, and all other high points on the valley floor.

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OUTLINE OF FLOOD STUDY.

The problem upon which practically all of the field and office work was concentrated, was the determination of the flow of Skagit River. This work consisted of the following parts:

1. Ascertaining the elevation and date of all Skagit floods possible, at as many points along the river as the available time permitted.

2. Determination of flood discharges of the Skagit River near Concrete.

3. Determination of the 1921 flood discharge of the Skagit River in the Mount Vernon district.

4. Miscellaneous determinations of flood discharge of tributaries and of the upper Skagit River.

5. Determinations of daily and peak flood discharge at Sedro Woolley.

   A. Reestablishment of gaging station, and redetermination of rating curve.

   B. Determination of discharge outside of river channel and Beatty's Slough.

   C. Collection of all gage heights.

   D. Revision of back records on the basis of all available data.

KNOWN FLOODS IN SKAGIT VALLEY.

It took a great deal of time and patience to ascertain the heights of different floods in Skagit Valley. At times, efforts were well rewarded, but at other times they were barren of results. Marks of the 1909, 1917, and 1921 floods were fairly easy to obtain; the 1909 marks, because in general it was the heighest flood since the arrival of the white man; the 1917 and 1921 floods, because of their recent occurrence. Marks made by the settlers for the 1896, 1897, and 1906 floods are nearly all gone, and the natural marks of the 1896 and 1906 floods have been obliterated by higher floods. Many people have practically forgotten the large flood of November 16, 1906, which put the draw-span of the Great Northern Railway bridge out of commission, and took one span out of the Mount Vernon highway bridge. It was during the 1906 flood, that Mr. H. Peterson lost his life by running into the turning bar of the imperiled Mount Vernon bridge from which he was trying to escape.

The heights of the fall floods of 1879, 1882, 1883, and 1887 are not known accurately within about two feet, while the spring floods of 1880, 1882, and 1894 are known within approximately a foot. The heights of those fall floods prior to the flood of 1896 are known only at a few places, and merely in relation to the heights of the floods beginning with 1896.

The determination of the heights of floods prior to the arrival of the white man, proved one of the most interesting and valuable parts of the work. When the white settlers first came into Skagit Valley, the bark on all the fair sized fir and cedar trees, and all of the spruce over one and one-half feet in diameter, was stained up to a certain height. There were many speculations and arguments among the settlers as to the cause of this staining. The question was not entirely settled until they made inquiry of the Sedro Woolley Indians, in 1879. The inquiries were then proved fruitless until they interviewed one old Indian, whom they thought to be 70 years old. This Indian said that when he was about "so high" (indicating a boy of about 10 years of age) the stains on the trees were made by a very quick and terrible flood in the Skagit River, one winter night. The flood probably caught the Indians asleep; anyway, in this old Indian's camp, they barely escaped with their lives. He said that they had had no time to save their smoked salmon and dried venison. Apparently all the other Indian camps on the Skagit River had the same experience, for they nearly starved that winter. There was, doubtless, some loss of life, as there have been traditions handed down of drownings sduring the great flood.

The old Indian's statement that the trees were stained by flood water, agreed with the opinion of the more accurate thinkers among the settlers. The staining of live cedar bark has also been confirmed by the observations of different people after later floods.

In the floods since the coming of the white man, however, only a few trees have been stained. The cause of the staining is not known, but whether a tree will be stained or not probably depends on the condition of the tree, the length of time the tree is immersed and the percentage of the staining material, if any, in the water. The settlers accepted the old Indian's statement, and, according to their reckoning, the flood occurred about 1820. The settlers would be likely to underestimate, if anything, the old Indian's age. Assuming him to have been ten years old at the time of the flood, and assuming that he must have been between 65 and 85 years old in 1879, the flood would have occurred between 1805 and 1825. Taking all things into consideration, the mean year, 1815, should be within ten years of the correct date, and will be used in speaking of that flood in this report.

The old Indian was in error in ascribing to the flood of 1815 the flood stains seen by the early white settlers. It will be proven later than the flood stains seen in 1879 were from a flood of about 1856. There were only two locations found which still showed the marks of the flood of 1815. The 1856 flood, however, is well marked.

The story of the flood-stained cedar and spruce trees is practically the same as Mr. Hart, of Sedro Woolley, told it in June, 1918. Mr. Hart came to Skagit Valley in the summer of 1878, and was among those who obtained the information from the old Indian. In 1918, Mr. Hart was in excellent health, and had one of the most accurate memories that it has been the writer's privilege to encounter.

FLOOD OF 1856.

During the present investigations, the marks of the 1856 flood have been so easily and frequently found, that its crest can be traced throughout the valley much more easily than the crests of the 1896, 1897, and 1906 floods. In most places, the crest of the 1856 flood is marked only by sand in the deep crevices of the bark of old cedars. There is no mud in the bark of the firs, due to the rapid rate at which they shed their bark, Other trees were of no aid, due to their fairly smooth bark or their rapid growth. The stains formerly in the bark of the cedars has apparently all faded, due to the action of the sun, air, and precipitation, or has been dissipated by the growth of the trees.

The flood of 1897 was about 0.1 foot higher than the 1896 flood at Hart's Ranch. After one of the two floods, Mr. Hart measured from its high water mark up to the 1856 high water mark, and found the difference to be exactly 4.0 feet. Mr. E. J. Woods, the former gage reader at the Northern Pacific Railway bridge, saw a cedar on which the 1856 flood mark was 3.5 feet above the 1909 flood. In January, 1918, the writer found an old cedar, in the bark of which mud from the 1856 flood still remained 3.5 feet above the 1909 flood mark. The stain from the 1856 flood had disappeared but the 1909 and 1917 mud marks were clear, and the embedded mud of the 1856 flood easily found. The cedars observed by Mr. Woods and the writer were in the same vicinity, about two miles downstream from the Hart Ranch.

In addition to the mud and sand on the bark of the old cedars, there are a few other known marks, as follows:

1. A distinct high water line, 9 feet above the 1921 high water mark, is still visible on the north rock wall, close to the mouth of the "Dalles", near Concrete.

2. Below Canyon Diablo, between the Davis Ranch and Ruby Inn, fresh flood sand lies on top of Reflector Bar 5.0 feet above the crest of the 1909 flood.

3. A few hundred feet above the mouth of Canyon Diablo, in the first gulch on the north side, there is coarse wash sand up to slightly more than 5.5 feet above the 1909 driftwood. The top of this coarse wash sand marks the crest of the flood of 1856. The difference between the 1909 and 1856 flood marks in the gulch, show that the older flood overflowed Reflector Bar very little, and it has been assumed to have reached a gage height of 18.5 feet on the Reflector Bar gage.

4. About 1876, Mr. Charles Presentine settled on his ranch above Birdsview. He found the ground surface, where his buildings now stand, underlaid with very fresh looking leaves and grass. The leaves and grass had been covered by the silt deposits of a flood which had covered the flat to an unknown depth. No flood since 1876 has overflowed the flat.

5. At the Kemmerick Ranch below Birdsview, Mr. Kemmerick, an early settler, noted fresh flood sand inside of hollow logs. The logs were above any later floods, such as 1897. The fact that the logs were old and hollow when the sand was deposited, showed

the flood to be recent; for otherwise the logs would have been rotted away after the flood.

As before stated, the present investigation brought out the fact that the flood of 1815 was not the flood which made the high water marks seen by the white settlers in the late '70's. It was noted in 1918 and 1923 that the stains seen by the early white settlers could not be found. Not only that, but the mud adhering to the bark of the trees was more difficult to find in 1923 than in 1918. In fact, in 1923 the exact crest could rarely be determined, due to the scarcity of material near the crest of the flood. It is known that the stains on the trees in the late '70's were remarkably plain, and could be seen for long distances through the forest. In 1879, 65 years had passed since the flood of about 1815. If trees hundreds of years old were plainly stained 65 years after a flood, then the stains should be at least visible after 40 years more. Inquiry about the stains developed the fact that the coloring had dimmed fairly rapidly after they were first seen. About 1895 or 1900, seems to have been as late as the stains were noticeable. Mr. Hart had no particular trouble in finding the stained trees about 1897. Mr. Woods, however, after the 1909 flood, saw only one tree with the crest mark of the old flood on it, and it is not known whether the mark was mud or stain. It is certain that all stains had disappeared prior to 1918. The rapid dimming of the stains, and other evidences of the same flood, make it certain that the flood of 1815 did not make the stains which were seen by the early white settlers.

The evidence also indicates that the flood which had made the stain of the early white settler's tradition, had not occurred many years before the arrival of the white man. The Indians of about 1870 spoke neither of a disastrous flood occurring shortly before the coming of the white man, nor of the trees being stained by any recent flood. It seems certain, therefore, that the later flood was not as high as the first flood, and also that it rose much more slowly.

Some information has been obtained from the Indians concerning the approximate date of the last tree-staining flood. Johnny Towne, an old Sauk Indian, told one white man, during the 1909 flood, that when he was a boy he had seen a much higher flood. An old Indian thought to be nearly 90 years old, told Mr. James Cochraham in 1923, that he did not remember any flood which had drowned any of the Indians, but did remember a flood which was several feet higher than either 1909 or 1921. He stated, however, that in his younger days he had known old Indians who remembered a flood which had drowned some of the Indians.

The year of the occurrence of the 1856 flood was determined at the "Dalles." There is a sand bar bench on the north side of the head of the canyon. The highest of floods since the arrival of the white man have not covered this bar to a depth of more than two feet. On this bench are a number of young fir trees apparently of the same age, and all, very apparently, of a much younger age than the surrounding trees. The undoubted explanation of the uniform and youthful age of the trees, is that the sand bar was cleared of all trees by heavy drift, or a jam, during the flood of 1856. One of the trees was cut down in February, 1923, and found to have 62 rings at a stump height of 2.5 feet. A United States Forest Service official judged that it would have taken the tree four years to grow 2.5 feet. The assumed four years of growth plus the 62 years indicated by the rings, would give the tree an age of 66 years, with 1922 as the last year of its growth. If the tree started growing the first year after the flood and took four years to grow 2.5 feet, the flood must have occurred in 1856. Variations in the possibilities of time it took the tree to reach stump height might vary the year of the flood from the fall of 1854 to the fall of 1857. If a flood or floods as high or higher than the floods of 1897 and 1909 had occurred a few years after the tree staining flood, then the young trees would have been destroyed by this second flood, and a new crop of them started. Such a contingency is possible in the light of data in the next paragraph, and might even allow the date of the tree-staining flood to be as early as 1850, the year in which the Willamette River in Oregon had a great flood.

At Vancouver, Washington, precipitation records were started in 1849. There have been two gaps in the record: August 1868 to December 1888; and April 1892 to April 1898. There remains a total of 46 winters of precipitation record. The flood months are normal

November, December, and January (a possibility). During these 46 winters, there have been eleven flood months in which the precipitation has exceeded ten inches. Six of the eleven months were in the six-year period from 1852 to 1857. In other words, in 46 years' record there were more flood months of rainfall exceeding ten inches during the years 1852 to 1857 than in all the other years. In 1856, the rainfall in inches was as follows: October, 4.61; November, 6.62; December 15.37. The November and December rainfall was the heaviest ever recorded for two months, and the December rainfall was the heaviest recorded for any one month during the '50's. Vancouver is too far from the Lungit Valley to draw a definite conclusion from it's rainfall record concerning Lungit floods. In addition, heavy precipitation must be accompanied by high temperatures to cause floods. The remarkable precipitation at Vancouver from 1852 to 1857, however, is strong confirmation of the approximate time of the flood. Also, the great rainfall of November and December, 1856, checks the age of the tree and indicates that the flood occurred in December, 1856.

FLOOD OF 1815 AND MAXIMUM FLOODS.

As before stated, the old Indian who talked to the settlers in 1879, and ascribed the flood stains to the flood of 1815, was in error. The probable explanation of his error is this: The flood of his boyhood was higher than any which he saw before or after that time. Good evidence of its being an extremely high flood, is the fact that it stained all the fir, spruce, and cedar trees, and the fact that the Indians who survived barely escaped with their lives. Floods which have occurred since 1869 have stained very few trees, and would in no way have endangered Indians living as they did, near their canoes. Probably the Indians prior to the flood of 1815 had not seen more than a few cedar tree stains, just as we have seen very few stains today. The great catastrophe of 1815, therefore followed by the bright staining of all the cedar trees must have made a very vivid impression on all of their minds. As time passed by, and the stains did not seem to fade, the Indians must have considered them a permanent mark of the great flood. Possibly they considered the stain to be a mark left by the Great Spirit, in the same manner as in our biblical story the rainbow was considered a mark following the great deluge.

The tree stains probably dimmed fairly rapidly from about 1835 to 1856. The Indians had, very likely, not noticed this. After the flood of 1856, new stains were on the trees, which the white settlers of the '70's observed, and which the old Indian in 1879, ascribed to the flood of 1815. If he, or any of the other Indians took note of the stains after the flood of 1856, they were probably unable to remember whether or not the trees had been stained just before the flood. It may be, however, that some of the Indians were sure that if there had been any stains just before the flood, they were much dimmer than the stains seen afterward. In case the Indians did notice that there was a difference, then they must have ascribed the brightness of the stains to the fact that the trees had been washed by the flood waters.

It was, of course, advisable to find out the height of the highest flood, and determine whether or not the 1815 flood reached that height. The present investigation developed the fact that stains on trees are visible for scarcely 50 years after a flood. The investigation also indicated that flood crests can be determined accurately from sand in the bark crevices less than 75 years after a flood. There are, however, three other methods which can be used to supplement the determination of flood crests from trees. One method makes use of the fact that a flood crest sometimes leaves a mark, or line on the rock walls in canyons. The second method makes use of the knowledge that the heavily loaded flood waters deposit large quantities of sand in the dead or eddying water of small coves and gulches. The third method involves the study of cracks, holes, and crevices, in rock walls in locations protected from all except flood waters. The floods deposit silt, sand, sticks, and bits of bark in these rock crevices.

Method No. 1.- In narrow canyons, the water rushes through very rapidly and washes, wears, and polishes the walls up to the flood crest. In the course of time, canyon walls above flood heights become partly covered with moss, lichen, and various other vegetation. Where the rock faces are too smooth for anything to grow, there is likely to be at least some discoloration during the course of ages.

The line of demarkation between the flood-washed rock and the time above is therefore clear for a considerable length of time. It is not known how long such water marks will be visible under the most favorable conditions along the northwest coast. It would seem that 200 years, however, is probably the outside limit.

Method No. 2.- Other excellent spots to hunt for flood crests are the coves and gulches where sand is deposited, provided they are protected from wind and erosion, and have very little surface drainage into them. The highest flood sand in these favorable locations will remain as such until it disintegrates. In the course of time it will become covered with humus and aerial deposits, but even then it can be located by excavation. These sand deposits will probably show flood crests for thousands of years; in fact, as long or longer than they are of value. Flood crests finally lose their value, due to stream cutting or changes brought about by geologic uplift or subsidence.

Method No. 3.-In rock canyons there are often overhanging walls, or protected pockets where water never reaches except during floods. All deposits in the rock crevices in these protected locations are from decomposing rock, wind, and floods. If there are sufficient sticks and bark remaining from the floods, the flood heights can be determined, irrespective of the sand and silt. The sticks and bark of the maximum high water, left above the following next highest flood are always dry and do not entirely decay for a long time. The pieces of bark and wood are small, but might be expected to last for 100 or 200 years. If the wood and bark is all gone, the sand still remains, but is more difficult of interpretation. It is often difficult to distinguish between the decomposed rock and the flood sand. Unless the flood sand is very old (many thousands of years) however, the difference can usually be told by the appearance and texture of the two sands. The decomposed rock generally appears and feels lighter in weight and more angular in form than the flood sand. Microscopic examination of the two types of sand would doubtlessly be of great aid, but was not available in this investigation.

At Reflector Bar, the crest of the maximum flood was found by use of the various methods outlined above. In the first gulch on the north side of Canyon Diablo, a few hundred feet upstream from Reflector Bar, Mr. Frank Davis found flood sand deposited on the ground up to an elevation of 22 feet, referred to the Reflector Bar gage. The writer found a dim highwater mark on the south side of the canyon, opposite the gulch, at an elevation of 21.3 feet. In crevices of the rock wall at the mouth of Canyoh Diablo, the writer also found flood sand up to an elevation of 20.8 feet. A small piece of apparent drift bark was found in the rock crevices nearly as high as the flood sand. There is considerable drop in the water surface from points in and near the gulch to the crevices in the rock and a slight fall from the rock crevices to the gage. Elevations were taken with a hand level, and the flood crests, as witnessed by the different marks, were uncertain within a few tenths. Taking all factors into consideration, the following deductions have been made:

1. The faint high water mark on the rock wall marks the height of the maximum flood within the last 200 years (approximately).

   (a) The Indian tradition and the bark in the crevice of the rock indicate that the flood which made the faint high water line was the flood of 1815.

2. The highest flood sand on the ground in the gulch marks the crest of the maximum flood in thousands of years.

   (a) The highest of the flood sand may mark the crest of the flood of 1815, or it may mark the crest of some older flood. If an older flood, it could have been but little more than 0.5 foot higher than the flood of 1815.

The conclusion is that the flood of 1815 reached 20.5 feet, and that possibly an earlier flood (or floods) reached a gage height of 21 feet.

In 1918 an excavation was made on Reflector Bar near the Ranger Station, to determine if extremely large floods were unusual. It was found that there were several alternate layers of wash sand and charcoal from forest fires. This indicated that floods approximating that of 1815 were not abnormal, but have occurred occasionally. This is on the assumption that floods of the height of 1856 would not carry sand through the forest as far as the Ranger Station.

At the "Dalles", the crest of the maximum flood was found by means of the flood sand which had been deposited on the ground, in the small, north side gulch back of the old cabin at the head of the canyon. This sand is deposited up to an elevation of 56.6 feet referred to the upper gage at the "Dalles" as determined by Mr. L. J. Wright, Assistant County Engineer. The small amount of humus on the upper flood sand, despite the accretions from the heavy timber normally on the hillside, indicates the comparatively recent deposit of the flood sand. As shown by the study for Reflector Bar, the flood of 1815 may not have been quite the maximum. The difference would be small, however, and it will be assumed that the flood of 1815 was the maximum for "Dalles" and reached a gage height of 56.6 feet, referred to the upper gage.

It is an interesting point that the 1856 and later floods left coarse sand at Reflector Bar, while the flood of 1815 left a fine sand, at least near its crest. The significance of this difference in sand is not known, and may warrant further investigation.

The highest ground in Sedro Woolley is an elevation of about 53 feet, referred to the datum of the U. S. Geological Survey bench mark on the Nixon Hotel. To this datum the flood of 1909 reached an elevation of 47.5 feet, and the flood of 1856, an elevation of 51 feet. We see, therefore, that even the flood of 1856, which made

Flood of 1815 [illegible]

the tree stains of early settlers' memory, did not cover all of the Sedro Woolley town site. It is estimated that the flood of 1815 reached a stage of 54.5 feet (7 feet above the flood of 1909) and thus covered the highest points in Sedro Woolley 1.5 feet deep. At Mount Vernon, it is estimated that the floods of 1815 and 1856 were 7 feet and 3.5 respectively higher than the 1921 flood.

RECENT FLOODS.

Advantage was taken of many different methods of checking the heights of recent floods and this will be described later. It is obvious that the highest recent flood in any part of the valley obliterates most of the natural crest marks of all the preceding lower floods. A summary of the comparative size or recent floods is given below. The reader, from the descriptions of the floods, can readily make his own deductions concerning the obliteration of flood marks which have occurred in recent years.

From the description of early settlers, it is known that the flood of November 16, 1896, was the highest up to then, dating from the settlement of the valley and probably the highest from 1856.

The flood of November 19, 1897, was every where higher than the 1896 flood. It was especially high from the mouth of the Cascade River to a short distance below Birdsview.

In general, in this section of the river the 1897 peak has not been exceeded since the settlement of the valley. The 1897 flood rose with remarkable suddenness, due to a very warm chinook and heavy rain. The chinook and rain stopped very suddenly after about 36 hours. The Cascade, Sauk, and Baker rivers were very high and caused a high peak in the Skagit near the mouth of each stream. Due to the sudden starting and stopping of flood conditions, the peaks were rapidly reduced by river storage in traveling down the Skagit.

The flood of November 16, 1906 exceeded the flood of 1897 in the diked districts on the delta, due to the dikes. In all other sections of the river, however, the flood of 1906 was lower than that of 1897.

Of all the floods since the settlement of the valley, that of November 30, 1909 exceeded those previous and subsequent from the headwaters of the Skagit in Canada to the mouth of the Cascade River. It was also higher than the earlier and later floods, from a short distance below Birdsview to the sea, except where log jams forced the flood of 1897 and 1921 to higher elevations.

The flood of December 30, 1917, was remarkable for the length of time it remained high, rather than for its peak height. Evidence would indicate that it was a flood comparable to 1896 and 1906 floods in regard to height. The damage on the delta was due, partly to the long flood producing a great deal of over-flow after the dikes had broken.

The flood of December 12, 1921, was nearly as great as the flood of 1909, and was higher than that of 1917 everywhere except where abnormal conditions affected the flood height.

In determining recent flood heights, the following list covers most of the methods used:

1. Highwater marks made by inhabitants of the valley.
2. Oil marks left on the sides of buildings.
3. Mud marks left by the flood.
   (a) On trees, stumps, and logs.
   (b) Inside and outside of buildings.
      (1) On window panes of abandoned dwellings.
      (2) In cabinets and closets of abandoned dwellings.
      (3) On wall paper of houses.
      (4) On outside and inside walls.

4. Sand and mud deposits.

   (a) Sand in moss of tree trunks.
   (b) Sand and mud in crevices of tree's bark.
   (c) Sand and mud deposited on sills, beams, etc.

5. Small drift left along banks which were not over-topped.

6. Grass and small roots hanging in the limbs and on the bark of trees which were in a swift current.

7. Flood crest lines made by swift water scouring the loose material off of rock faces and tree trunks.

When they could be found, oil deposits were the most definite of all marks. The oil marks can usually be found around shop buildings, garages, etc. These marks are made by the oil which floats on the water surface, and attaches itself to everything it touches. At Concrete, on the outside of the galvanized siding of the old Washington Cement Plant shop building, the oil marks of the 1909 flood are 4.5 feet above the floor and as plain as though made yesterday.

Next to the oil marks in visibility, were the mud marks. The mud, or silt, often leaves a very plain horizontal line on the walls of buildings on the charred surfaces of stumps and trees, and also on canyon walls. Strangely enough, some board surfaces were free of the mark, while a few feet away lumber of a different kind, or of a different surfacing, or in closets or cupboards, would have a plain mark. The most striking of the mud marks are those found on window panes of old abandoned dwellings. Mud marks of the 1909 flood were found in many cases, and although not found, probably there are some mud marks remaining from the flood of 1897.

The mud marks of the 1909 flood were still visible on the Canyon Diablo wall in 1918.

Due to their availability, sand and mud deposits had to be relied upon to a considerable extent at the location where a flood height happened to be desired. For the 1921 flood, the most common mark of this type was the flood sand deposited in the moss which hangs on the barks of trees. Considerable care was necessary in determining the maximum flood height by this method. The flood crest usually lasted an exceedingly short time, and as a consequence, the peak of the flood left very little sand in the moss. When looking fo the 1921 crest, there was danger of obtaining a lower point than the flood crest. In general, all of the 1909 moss, or the flood sand existing on the moss had disappeared. In a few cases, however, it could not be determined whether the sand in the moss was from the 1909 or the 1921 flood.

Mud in the crevices of the bark of suitable trees was quite often helpful in determining the heights of 1909 and 1921 floods. Due to the elapsed time since the 1897 and 1909 floods, it was rarely possible to differentiate the deposits left by those floods from the deposits left by the flood of 1856. The large deposits of silt, below the flood crest, on beams and sills were very definite where they were undisturbed.

The recent floods previously mentioned all over-topped the banks in the rivers' lower course. The small drift found along banks was available mainly in the canyons above Marblemount. Due to the heavy snows, this section could not be visited advantageously during the winter of 1922-23. The 1909 drift had been noted, however, in 1918.

In the swift water in and below the "Dalles", the overhanging trees caught a large amount of grass, rootlets, leaves, etc. From checks by other methods, it was found that by these tree deposits, the 1921 flood crest could usually be determined within one or two tenths of a foot.

In and just below the "Dalles", the crest of the 1921 flood was easy to determine from the height to which some rock surfaces and tree trunks had been scoured.

High water marks were established by some inhabitants of the valley. These were quite often useful in tracing the flood crests. These marks had to be checked, however, due mainly to the fact that they were quite often a mark for the average water level at the crest of the flood. The average level is the better method, and the one used by the U. S. Geological Survey. All natural marks, however, are at the crest of surges and waves. It was necessary, therefore, to adjust some marks by settlers on the foregoing basis.

Recent floods

A profile map has been drawn, showing the floods of the following dates:

1815

1856

December 14, 1879

1880

1882

November 3, 1883

October 30, 1887

May 27, 1894

November 16, 1896 Highest up to that time since settlement of valley & probably since 1856

November 19, 1897 Everywhere higher than 1896 - especially high from Concrete [illegible] to [illegible] below [illegible]

November 30, 1909

December 30, 1917

December 13, 1921

This profile map is shown as Exhibit A, and completes Part 1, of the field and office work.

Part 2 deals with the determination of the flood discharge of Skagit River near Concrete. This work was largely technical and is given as Exhibit B. The results were very satisfactory, and show that the flood of 1921 had a discharge of 240,000 second-feet at that point, with a probable error in the final result of not over five percent. The accuracy would be as good for the floods of 1897, 1909, and 1917 if their correct flood heights were known at the "Dalles." The heights for 1909 and 1917 are known exactly, and 1897 approximately, only a mile upstream from the "Dalles." The exact heights of the floods of 1856 and 1815 are known at the "Dalles

The extension of the rating curve and the estimate of overflow for these two great floods, however, make the accuracy of estimate for them somewhat lower than for 1921. The discharge and accuracy for certain floods at "Dalles" is given herewith.

Date	Gage height upper Dalles gage	Discharge in second-feet	Accuracy within
1805-1825	56.6	480,000	10%
1856	44.6	350,000	10%
Nov. 19, 1897	38.4	270,000	15%
Nov. 30, 1909	36.4	260,000	10%
Dec. 30, 1917	30.8	220,000	10%
Dec. 13, 1921	34.9	240,000	5%

Part 5 deals with the determination of the flood discharge of the Skagit River in the Mt. Vernon district. This was again largely technical and is given as Exhibit C. The discharge of the 1921 flood was the only one which could be determined. The results were not very satisfactory due mainly to breaking dikes, bridge obstruction, small slope, etc. The discharge for the 1921 flood was found to be 140,000 second-feet in the river channel alone, the value being correct, probably, within 20 percent. The discharge through the breaks in the dikes is uncertain. Even with a fairly uniform stage in the river, the discharge through the dikes changed rapidly as the break deepened and widened. The discharge increased, of course, until the enlarging stopped, or until the enlarging was counterbalanced by decreased slope into the rapidly filling back area. It may be roughly estimated that the maximum combined discharge of river channels and the break across the Great Northern Railway grade was 190,000 second-feet. in 1921 - [illegible] to 210

Part 4 consists of miscellaneous determinations of discharge of tributaries and of the Upper Skagit. This is again largely technical and is given as Exhibit D. The discharges at Reflector Bar being especially accurate and of especiall value are given herewith:

Date	Gage height	Discharge	Accuracy
Unknown	21.0	120,000 (maximum)	20%
1805-1825	20.5	115,000	20%
1856	18.5	95,000	15%
Nov.18, 1897	12.5	48,000	10%
Nov.29, 1909	15.4	70,000	10%
Dec.29, 1917	12.5	43,000	10%
Dec.12, 1921	14.5	63,000	10%

Part 5 shows the determination of daily and peak flood discharge at Sedro Woolley. Section A, of part 5, deals with the re-establishment of the gaging station and redetermination of the rating curve. The U. S. Army Engineers established a gaging station at Sedro Woolley May 1, 1908. Beginning in 1910, the work was under the supervision of the U. S. Geological Survey. This station was maintained until September 2, 1919, when the observer, E. J. Woods, was killed. During the last three months of 1919, a record was obtained at the Sedro Woolley highway bridge. The station was then dropped, due to lack of funds. The Northern Pacific Railway kept a record of gage heights at the old gaging station from February 1, 1921 to November 21, 1922 for which period they have supplied the gage heights. Beginning with November 22, 1922, Skagit County has maintained the gaging station. Owing to the value of the record to the County, it is unfortunate that the station could not have been maintained continuously through 1920 and 1921.

By means of numerous discharge measurements made during the winter of 1922-23, it has been possible to work up a daily discharge record, except for the period of no gage heights, January 1, 1920 to January 31, 1921. The discharge record from February 1, 1921 to November 21, 1922 is somewhat deficient in accuracy, due to the fact that the station had been abandoned by the U. S. Geological Survey, and no discharge measurements obtained for that period. Rating curves for the Sedro Woolley gaging station are shown in Exhibit 2.

Section B, of part 5, is the determination of discharge outside of river channel and Beatty's slough. This problem proved difficult, due to the many obstructions and dead water in the overflow sections. The final and most satisfactory method of obtaining the discharge proved to be the calculation of the flow through the Northern Pacific Slough openings. These calculations are shown in Exhibit 3.

Section C, of part 5, is the collection of gage heights. As far as possible, all original gage heights were collected for scrutiny. In cases where the originals could not be obtained, copies by accurate engineers were available. The mean daily gage heights are shown with the daily discharges in Exhibit 1.

Section D is the revision of back records on the basis of all available data. Owing to the very shifting stage discharge relation and difficult measuring section at this station, this part of the work entailed a great amount of work. The work resulted, however, in obtaining a fairly good daily discharge record. This daily discharge record, in conjunction with the peak flood discharge, will prove very useful in further flood studies. The revision, study and discharge computations are shown in Exhibit H. The records of peak discharge are of particular interest, and are given herewith:

Sedro Woolley

Date	Gage height	Discharge	Accuracy
1805-1825	63.5	400,000	15%
1856	60.0	350,000	15%
Nov. 16, 1896	54.8	185,000	15%
Nov. 19, 1897	54.9	190,000	15%
Nov. 16, 1906	54.7	180,000	15%
* Nov. 30, 1909	56.5	220,000	10%
Dec. 30, 1917	54.1	195,000	10%
Dec. 13, 1921	54.3	210,000	10%

An examination of the preceeding data on floods at the "Dalles", Sedro Woolley, and Mt. Vernon, shows the great decrease in peak discharge, as the floods advance down the river. This decrease in peak discharge is due to the overflow of the banks. The overflow district acts as a storage basin, and cuts down the peak, but increases the length of the flood.

CHAPTER II.

CLIMATE AND GEOLOGY

BASIS AND NATURE OF THE STUDY.

In a study of floods and flood control, it is always well to take into consideration any unstable geologic and climatological features which may have a bearing on the problem. The study will be taken up according to the following outline:

I. Climate: Past, present, and future.

A. Glacial and inter-glacial epochs.
1. Minor climatic fluctuations.
(a) Winter floods--their cause and various factors on which they depend.

2. Effect of glaciation on river drainage.
(a) The capture of the Sauk and Suiattle by the Skagit
(b) The Baker River Balley.
(c) The Upper Skagit Valley.
(d) The Skagit River at the Dalles.

II. Uplift and subsidence of the land, and its effect on river drainage, taking into account glacial and inter-glacial epochs.

III. Conclusions.

Little is known of the quantitative uplift and subsidence in Puget Sound region, except for the last several hundred thousand years. Also include two, or possibly more, glacial periods. Item No. 2 must necessarily take into account change both in elevation and glaciation.

There have been vast changes in climate throughout the world during the past ages. This is proven first, by finding geologic evidence such as coal, that there was once a much warmer climate where it is now cold; second, by finding geologic evidence, such as glacial deposits, that there was once a much colder climate where it is now temperate.

CLIMATE: PAST, PRESENT, AND FUTURE.

Glacial and Inter-Glacial Epochs

Scattered all over the northern part of the United States is unmistakable evidence of very recent glaciation. The terminal morain of the last great continental ice sheet crosses, in addition to other states, Ohio, Indiana, Illinois, and Iowa. In the Puget Sound region there is a terminal morain completely across the gap north of Chehalis.

Prior to the last glacial epoch, Niagra River did not exist. The drainage of the Upper Great Lakes was then through drainage channels now buried. The Niagra Canyon, below the Falls, was therefore cut after the great continental glacier had retreated enough to allow the northward outlet of the water through the St. Lawrence River. According to the rate of retreat of the Falls since accurate records have been kept, there have elapsed probably not more than twenty-five thousand years since Niagra River started flowing.

The number of glacial epochs since the Cascade Mountains have had their present form is unknown. Two periods of glacial action are well marked, however, and there is some evidence of a third. Russel was the first to note two distinct periods, with a warmer period intervening. Willis later named the earlier glacial epoch "Admiralty", the inter-glacial period "Puyallup", and the last glacial epoch "Vashon". "The Glaciation of the Puget Sound Region" by J. Harlan Bretz, Bulletin No. 8, Washington Geological Survey, gives in great detail his findings in that basin.

It is logical to assume that glacial epochs occurred in the Puget Sound regions at the same time that they occurred east of the Rocky Mountains. At least two glacial epochs have been noted in the eastern Region. A brief but excellent description of the North American glaciation is given in "Hydrology" by Daniel W. Mead.

The glacial drift left by the Admiralty glacier exceeds by many times the drift left by the Vashon glacier. This greater amount of glacial drift indicates the correspondingly greater length of the Admiralty epoch. The greater length of the Admiralty epoch is shown by Gilbert's graphs of fluctuations of Lake Bonneville in the U. S. Geological Survey Monograph No. 1. Great Salt Lake is a remnant of Lake Bonneville. There were two great raises in Lake Bonneville which were, no doubt, synchronous with the Admiralty and Vashon Glacial epochs.

Most of the ice in the great Puget Sound glaciers came southward from the Cascades and Olympic mountains. These great glacial epochs were probably caused by a decrease in the amount of heat and an increase in the amount of precipitation at least over the glacial areas and adjacent territories. At present, we are emerging from one glacial epoch and the remnants of the great glacial sheet of ice are seen in the present continental ice sheets in Greenland

and Antarctica. The large glaciers in Alaska, and the various small mountain glaciers, such as are seen on Mt. Baker and Mt. Rainier, are still smaller remnants. In case the inter-glacial epoch into which we seem to be entering proves as warm as the previous one, the time will probably arrive, although a good many thousand years from now, when no glaciers will reach the sea any where in the world. The ocean water will gradually become warmer as the amount of glacial ice and water delivered to it decreases. The effect of the increasing warmth of sea-water on the Skagit Valley will be warmer winters and warmer chinooks. Warmer chinooks will cause greater floods, until it becomes too warm for considerable depths of snow to be collected in the mountains. The winter run-off will increase, and the summer run-off decrease. As the glaciers gradually disappear, the low water flow in the fall will gradually become much more pronounced.

MINOR CLIMATIC FLUCTUATIONS.

The general tendency towards a warmer inter-glacial climate, if such is the case, is so slow a process that account need not be taken of it in any present flood protection works. This general tendency of climate is obscured by minor fluctuations, the largest of which may cover several hundred years, and the smallest of which are embraced in what we term "hot and cold spells." We may, perhaps, roughly represent these different changes in climate by anology to the action of the sea. The tides on the open sea, invisibile to the eye, and undetected by instruments on a ship, are the glacial epochs.

The large waves are the fluctuations of climate lasting from a few years to several hundred years. The small wavelets animated by a local breeze are the especially warm or cold winters and summers, or merely hot and cold spells lasting for a short time. The variations of climate have been studied extensively by Ellsworth Huntington. The following books, written by him, are pertinent to the discussion here: "The Earth and Sun", "Climatic Changes, Their Nature and Cause", "The Secret of the Big Trees", "The Climatic Factor as Illustrated in Arid America", "The Pulse of Asia."

The minor fluctuations of climate lasting from a few, to several hundred years, have an important bearing on our flood problem. There is fairly clear evidence that the effective temperature for melting snow in the Cascade mountains has been higher during the last 30 years than in the previous 30. The Nisqually Glacier has retreated continuously from the time it was first observed in . It has retreated much more rapidly, however, in the last 30 years than during the previous 30. We know, also, that all the large fall floods on the Skagit have occurred since 1895.

Comparing our knowledge of the floods with the retreat of the Nisqually Glacier, it is seen that the two agree in indicating a milder winter climate during the last 30 years, than during the 30 years previous to that. This mildness of climate could be ascribed either to the Japan current being warmer or closer to the coast, or it might be attributed to the storms pursuing a different path as they come in from the ocean. If the Japan current is warmer, it would indicate an increase in the sea water temperature, at least over the portion of the Pacific Ocean from which the current comes.

WINTER FLOODS: THEIR CAUSE AND VARIOUS FACTORS ON WHICH THEY DEPEND.

Large winter floods are caused by strong and long continued winds bearing warm moisture from the Pacific Ocean to the Cascade Mountains. For the floods of 1909, 1917, 1921 and presumably all other floods, the winds blew towards and counter-clockwise around the area of extremely low pressures which were centered in that region of Canada bounded by Kamloops, Calgary, and Edmonton. The long continuance of the strong, warm winds (chinooks) was caused by the area of low pressure holding very closely to the same location for two or three days. This failure of the area of low pressure to change location was caused either by slow moving areas of pressure to the eastward, or by whatever prevented the eastward movement of those areas of high pressure.

The height and volume of all floods in the Skagit Basin depend on the following:

I. Amount and rapidity of precipitation in the Cascade Mountains, which depends on:

1. Amount of moisture transported from the Pacific Ocean to the Cascades, which in turn depends on

A. Amount of moisture lost over intervening land surface, depending on

(1) Length of air path from coast to Cascades.
(2) Temperature of air and exposed land surfaces along path from coast to Cascades.

B. Volume of warm air transported, depending on

(1) Velocity of air, depending on
(a) Barometric pressure at the center of low pressure.

(2) Time involved, depending on
(a) Length of time the area of low pressure stays in the Kamloops, Calgary, and Edmonton region.

C. Humidity of air.

D. Temperature of air, depending on
(1) Temperature of surface of Pacific Ocean, from where the air comes.

Note.- As stated before there are indications that there has been either an increase in temperature, or a change in location of the Japan current off the Washington Coast for the last 27 or 30 years.

(2) Reduction of air temperature on reaching the Cascades, which depends on
(a) Temperature of air reaching Cascades.
(b) Temperature of exposed land and snow surfaces in Cascades.

II. Total amount of water in snow (below the elevation of a freezing temperature) and the rapidity with which this snow goes off. This rapidity is dependent on No. I, and No. II, and the degree to which the snow on the ground is compacted.

Note.- Early in the winter this snow is loose and porous. Owing to this porous condition, it is much more easily carried off by rain. For a short time, though, it holds back the water, due to its absorptive powers. This holding back may increase the flood peaks.

III. Amount of snow, especially new snow, suspended in the trees of the forest.

Note.- This snow, especially if freshly fallen, will go off in a few hours.

It is probable that the chinook winds which have caused the disastrous floods during the last 27 years, have not been over two degrees warmer than the chinook winds which caused no disastrous floods between 1869 and 1895. The extra height of the late floods has probably been caused partly by increased precipitation and partly by increased run-off from the higher snow fields. In case the minor climatic fluctuation, in which we are apparently involved, should start a decreasing scale of temperature, then the winter floods will diminish in height, and a false sense of security will be developed. On the other hand, if the temperature increases, we may expect still more disastrous floods in the near future. There may be more disastrous floods even with no increase in temperatures. At the time of either of the 1909 or 1921 floods, if the area of low pressure had remained onemore day in the Kamloops, Calgary, Edmonton region, there would have been a flood of the 1856 height. If there had been another day of the 1897 hot chinook with plenty of snow in the mountains, there would have been a flood approximating the flood of 1815.

EFFECT OF GLACIATION ON RIVER DRAINAGE
THE CAPTURE OF THE SAUK AND SUIATTLE BY THE SKAGIT

In making a study of the effect of glaciation on river drainage, a remarkable case of stream capture was discovered. Since the Cascades had had their present form, and prior to the first glacial epoch, the Sauk and Suiattle rivers formed part of the Stillaguamish drainage basin. The advent of the first glacial epoch (possibly the Admiralty) was marked by the advancing into the Puget Sound region of a great glacier from British Columbia. This glacier dammed the Nooksack River and caused all its water to cut across the pass into the head of the Samish River, and thence into the Skagit Valley. Probably Frazier River water and other northwestern waters came also. A further advance of the glacier dammed the Skagit Valley. If Mt. Baker, was at that time, its present size, a glacier was also entering or had entered the Skagit Valley from Baker Valley. The dam formed by the Puget Sound Glacier or the Baker Glacier caused the confined Skagit water to break across a pass, now occupied by the lower Sauk Valley, into the Suiattle Basin. During the portion of the first glacial epoch when the ice dam held, the entire Skagit flow above Concrete poured across the Skagit-Suiattle Divide and thence down the Stilaguamish River. Probably the ice dam held from one to several hundred thousand years. The Skagit-Sauk Pass was, of course, rapidly cut down and formed into a regular river channel.

On the retreat of the Puget Sound Glacier, the ice dam at the mouth of the Skagit broke. The deposited material at the mouth of the Skagit was then rapidly eroded by Nooksack and the other waters coming through the Samish channel. Drainage from Concrete to Sedro Woolley, possibly including the Baker, gradually cleared that portion of the channel. The Skagit channel from Sauk to Concrete gradually cleared, after the retreat of the Baker glacier, until a high flood in the Skagit over-topped the remaining material and cut a channel for itself. This final step marked the recapture of the Upper Skagit.

The Skagit channel at Sauk, prior to the glacial period, had been cut lower in bed rock than the Stilaguamish at Darrington. This was due to its having over twice the drainage area, and a correspondingly greater flow. After the glacial epoch, and after the recapture of the Upper Skagit, the Skagit, owing to its greater flow and greater distance to bed rock, soon reduced its grade at Sauk to below the grade of the Suiattle-Sauk-Stilaguamish at Darrington. Meanwhile, small tributary flows to the Skagit in the new Sauk channel commenced clearing out that channel. Very probably before this had gone very far, some great flood on the Suiattle over-topped the fill, and the Suiattle was captured by the Skagit. The same process was repeated in capturing the Sauk. In the following glacial epoch or epochs the Skagit was, of course, rediverted to the Stilaguamish. After the glaciers retreated, however, the Skagit recaptured the stream in the manner already outlined.

The above theory, that the Suiattle and Sauk rivers were formerly tributary to the Stilaguamish, is based on various field investigations since 1913, and a study of the U. S. Geological Survey topographic maps. As far as known, this theory has never befo[re] been brought out in any geological study. Confirmation of the temporary diversion of the Skagit drainage to the Stilaguamish during glacial epochs, however, is given by Bretz, who says "The Sauk, Suiattle, and Skagit rivers formerly flowed out in the drift plain of Puget Sound."

THE BAKER RIVER VALLEY.

Prior to the first glacial epoch, the Baker River undoubtedly lay in a broad, deep valley. The river surface near Concrete was then a few hundred feet lower than its present surface in that section. The upper portion of the Baker River basin must have, at times, been invaded by lava flow from Mt. Baker. Probably there are in places many layers of alternate river deposits and lava. Possibly the upper portion of the valley is filled to a great depth with these layers.

At the beginning of the first glacial epoch, the glaciers from Mt. Baker forced the Baker River water over to the east side of the valley. During the Admiralty epoch, the Baker Valley was filled with glacial drift, as was the Skagit in the Concrete-Sedro Woolley region. On the regreat of the Admiralty ice, the east side of the Baker Valley was the first to be opened, just as it was the last to be closed at the beginning of the Admiralty epoch. The great outflow of water from the melting glacial ice, marking the end of the Admiralty epoch, cut a river channel along the east side of the old pre-glacial valley. In places, this valley cut into the bed rock on the east hillside of the valley.

During the Puyallup inter-glacial epoch, the valley was widened and deepened considerably. Erosion in the Admiralty till was greatly hindered, however, by the slow erosion in the new, highly elevated rock cuts on the east side of the valley. Probabl lava flows from Mt. Baker invaded the upper part of the valley.

Stetattle Creek glacier forced the Skagit River across a rocky point opposite the mouth of the Stetattle Creek. Thunder Creek glacier caused enormous changes in Skagit Valley opposite the mouth of Thunder Creek. The great Thunder Creek glacier, of which the present Boston glacier is only a tiny remnant, forced the Skagit against the north side of its valley. Changes in the glacier and the river caused such an amount of erosion that a great section of the country on the north side of Skagit River is a sort of plateau covered with hills and river channels. Since the Vashon glacial epoch, Thunder Creek for a portion of its course near its mouth, has been cutting a new rock channel. Its pre-Admiralty and Puyallup inter-glacial channels are, no doubt, buried under a great quantity of glacial materials.

THE SKAGIT RIVER AT THE DALLES.

The Dalles was formed by the Skagit River when it was forced across a rocky point by the Baker glacier. Elevated portions of this rocky channel are water worn in a downstream direction, indicating that the mouth of the Skagit was open at the time. The field investigation determined neither the glacial epoch during which the Dalles was formed, nor whether the channel was first cut at the beginning or end of a glacial period. The Baker River, however, at one time formed a dam across the Skagit River, while the mouth of the Skagit Valley was open. It seems likely, therefore, that the Baker River glacier, during each glacial period, dammed the Skagit, both before and after the Puget Sound glacier dammed the mouth of the valley.

UPLIFT AND SUBSIDENCE OF THE LAND, AND ITS EFFECT ON RIVER DRAINAGE, TAKING INTO ACCOUNT GLACIAL AND INTER-GLACIAL EPOCHS.

The Puget Sound region has experienced marked changes in elevation during and shortly prior to the last two glacial epochs. The following quotation from Bretz, at the end of Bulletin No. 8, is enlightening: "The very deep channels among the San Juan Islands attaining a maximum of 204 fathoms (1,224 feet) are largely the product of the glacial stream erosion, and demand a deep Pliocene Strait valley, as the Admiralty River demands a deep valley to the ocean during the Puyallup inter-glacial period." It may be explained here that the Cascades and coastal territory were at least a thousand feet higher during the pre-glacial and Puyallup inter-glacial epochs than they are now. With such an elevation there was, of course, no Puget Sound. What is now the Puget Sound was, during the Pliocene (pre-glacial period) occupied by North and South river valleys. The average slope of the Cascade river channels was of course much greater than at present. Stream cutting was very rapid and in most cases the stream channels were solid bed rock. Certainly this was the case in the Skagit canyon, above the City of Seattle Power Camp, and similar river stretches. At the time of the retreat of the Admiralty glacier, the elevation of the land was much the same as at present. It is a reasonable assumption that the elevation had been much the same during the Admiralty glacial epoch.

During the Admiralty glacial epoch, the valleys in the Puget Sound Basin had been filled with glacial drift. On the retreat of this glacier, or sometime thereafter in the Puyallup inter-glacial epoch, the land rose almost, 1,000 feet. This elevation of the land, caused most of the Skagit Basin streams to rapidly remove practically all of Admiralty drift and start cutting in the underlying bed rock. In this connection it is interesting to note the remains of valley drift fill on the north side of Skagit Valley between Concrete and Sedro Woolley. The bench can be seen in nearly all places where the hillside has been cleared by logging. From the valley floor in the neighborhood of Lyman, the long bench of glacial drift can be seen lying on the north hillside at an elevation of probably 500 or 600 feet. This long bench is very likely continuous on both sides of the valley from Concrete to Sedro Woolley. If the Baker River glacier dammed the Skagit Valley to a higher elevation than the Puget Sound glacier, then the slope of this drift fill is downstream toward Sedro Woolley, and indicates the slope of the water flowing westward between the Baker and Puget Sound glacial dams.. This bench was not examined, but is probably Admiralty till.

During the Puyallup inter-glacial epoch, great valleys were eroded in the Admiralty till in the main Puget Sound Basin. These valleys are now occupied by Puget Sound waters, except where they have been filled by drift during the Vashon glacial epoch and by later river deposits in the form of deltas.

A great deal of additonal cutting must have been done, during the Puyallup period, in the bed rock channel between the present mouth of the Suiattle River and the town of Sauk. As before stated, the flow was south through this valley during the Admiralty and Vashon epochs, and north during the Puyallup inter-glacial and past Vashon epochs. It seems likely that during the Puyallup inter-glacial epoch, this portion of the Sauk River bed was cut down to corredpond to the grade of the upper Sauk and lower Skagit. There is a possibility, however, that bed rock is much nearer the surface in this section of the river under the old Skagit-Suiattle Pass, than either upstream or downstream from there.

The great elevation of the Puget Sound region and of the Cascade Mountains, during the Puyallup inter-glacial epoch disappeared near the close of that epoch or at the beginning of the Vashon ice invasion. If the lowering was at the beginning of the Vashon glacial epoch, it may have been due in part, or entirely, to the weight of the Vashon ice. Streams in the region under discussion were rediverted by the Vashon ice as in the Admiralty glacial epoch. After a comparatively short stay, the Vashon glaciers retreated, and stream beds, to a large extent, were reoccupied. It may be estimated roughly that the Skagit Valley has been free from Vashon ice for somewhere between 15,000 and 50,000 years.

After the retreat of the Vashon glaciers, the Puget Sound region was at one time nearly 300 feet lower than at present. The time has been short since the last glacial epoch;.also the elevation of the land has been from 1,000 to 1,300 feet less than during the Puyallup inter-glacial epoch. For these reasons, the streams have not been able to cut down to the solid rock beds which they occupied during the Puyallup inter-glacial epoch. In the lower portion of the basin, the old stream beds are below sea level and of course cannot be reoccupied until the land is again greatly elevated.

From the foregoing, it can readily be seen why the stream valleys, even in rock canyons, are deeply filled with river material and glacial drift. It is probably nearly 1,000 feet to bed rock in the old river channel on the Skagit delta. It is known to be 111 feet to bed rock at the City of Seattle's Gorge Creek power site, and 30 feet at their Ruby Creek dam site. The City of Seattle's core borings, in conjunction with the probable depth of bed rock on the Skagit delta, show the gradual decrease in depth of material. This gradual decrease in depth of material may be expected in the Skagit and tributaries, except where original beds have not been reoccupied, such as Baker River, Thunder Creek, the site of the old Skagit-Suiattle Pass, now the lower Sauk channel, and the old Sauk channel underlying Darrington.

Conclusions.

The foregoing study indicates that, with one possible exception, there is no hope of placing flood protection dams on solid rock in the original channels of the lower Skagit, or lower portion of the main tributaries. The one exception is the lower Sauk canyon, the history of which has been taken up previously. In case bed rock were found within a reasonable distance of the surface in the lower

Sauk Canyon, there is still one feature that would make this site unfavorable for a storage dam. The former drainage of the Sauk and Suiattle out through the Stillaguamish, cut a channel that probably is, at Darrington, more than 300 feet under the present gound surface. Agreat portion, at least of the upper part, of the fill is Vashon deposits. The unfavorable feature is that leakage through this material down the Stillaguamish would probably be enormous. Due to the low gradient of the land surface in both directions from Darrington in the Stillaguamish and Sauk basins, however, it does not seem likely that the fill would cut out through seepage, at least, in any short period of time. Leakage does not eliminate the lower Sauk site as a flood storage reservoir or as a flood detention reservoir. Loss of water, of course, in these cases would be immaterial as long as it did not endanger the safety of the reservoir. The leakage, however, would practically eliminate the lower Sauk site as a power storage reservoir, and the cost of the construction for flood protection alone might be too great.

EXHIBIT B.

Computation of Discharge by "Slope" and "Contracted Opening" Method.

From the mouth of the Baker River to the mouth of the Skagit River, the best place to study the flood flow of the Skagit is at and near the Dalles. In this portion of the river, all floods since that of 1856, have been confined within the banks of the main channel. The further advantage of this section of the river is that two different methods of computing flow may be utilized to check each other. There is a pronounced drop in the water surface through the Dalles during floods. This drop at the crest of the 1921 flood amounted to over four feet in a distance of 560 feet. The major portion of this drop, however, occurred in 180 feet at the lower end of the Dalles in the most contracted section. This drop through the Dalles offers a good opportunity for measuring the flood flow by the "contracted opening" method. Below the Dalles, the 1921 flood flow of the river was confined between banks for about one mile, and that flood surface had a slope of over six feet per mile. The "slope" method can be used to advantage in this section below the Dalles.

The field data obtained for use in computation of the flood flow, may be summarized as follows:

Slope sections.

1. Three cross sections of the stream channel were taken.

No.1	618 feet along	right	shore	below the	lower end of	the Dalles
No.2	2,479 do	do	do	do		do
No.3	4,655 do	do	do	do		do

The river curves to the right between sections Nos. 2 and 3, so that the distance along the shore is somewhat shorter than mid-channel length. Correction has been made in the calculated distance for the center line of the river.

2. The crest of 1921 flood determined on both sides of the river for cross sections Nos. 1 and 3, and on right side of river only for No. 2. Determination of flood crest correct within 0.1 foot, for all points.

3. Difference in elevation of 1921 flood crest for the three cross sections determined by a closed level circuit on right bank. 1921 flood crests determined at each one of the cross sections. Difference in elevation of points correct within 0.1 foot.

4. Kutter's "n" determined at Sedro Woolley and used for the slope section below the Dalles.

Contracted opening.

1. Three cross sections of the channel were taken.

No.1 560 feet above mouth of and about 100 feet below upper end of the Dalles. About 50 feet upstream from lower end of flood whirl pools at the entrance to the Dalles.

No.2 180 feet above mouth of the Dalles (narrowest section in the gorge).

No. 3 At mouth of the Dalles (shallowest section in the gorge).

2. Crest of 1921 flood determined on both sides at cross sections Nos. 1 and 3, and on right side at cross section No. 2. Determinations correct within 0.1 foot on right side at cross sections Nos. 1 and 3, and both sides at No. 3. Probably within 0.2 foot at cross section No. 2 and 0.3 foot on left side at No. 1. Crest of 1921 flood also determined about 50 feet below cross section No. 1. This last determination is at lower end of right (north) whirl pool and at point of highest elevation of water surface in the Dalles. In addition the crest of the 1921 flood was obtained at several points on right (north) shore between sections Nos. 2 and 3.

3. Crest of 1856 flood determined at a point about 120 feet above lower end of the Dalles. The flood of 1856 had left a plain mark for a distance of about 15 feet along rock face of cliff.

4. Crest of maximum flood determined at the head of the Dalles. The floods have all left sand in the hollow gulch back of the cabin on the right (north) bank. The highest flood sand marks the crest of the highest flood.

The sections both for "contracted opening" and "slope" methods are considered very good for a stream of such slope and discharge. The points that prevent an extremely high degree of accuracy by either method are as follows:

"Slope" Method.

1. Flood channel does not maintain the same width, depth, and area throughout the slope sections. These variations cause changes in velocity. Consequently, in some stretches, velocity head is being gained, and in others being lost.

2. Coefficient of friction ("n") was obtained from Sedro Woolley. The material in the stream bed at the Dalles is somewhat coarser than at Sedro Woolley. In addition, the stream channel does not have quite the same characteristics.

3. Coefficient of friction ("n") may not be the same at flood stage as for low stages. During floods, the water is filled with silt, sand and drift, while rocks, gravel, and the heaviest of green drift are rolling on the bottom. In addition, the roots and limbs of large floating cedars, firs, and spruce are dragging on the bottom.

"Contracted Opening" Method.

1. The whirl pools at head of the Dalles cause average elevation of water and velocity of approach to most contracted sections to be somewhat uncertain.

2. A large portion of the solid rock bed in the Dalles is overlain with sand of unknown depth. This sand undoubtedly scours out during floods. The cross-sectional area of the flood channel is, therefore, from solid rock to flood surface. The computation of cross sectional area for the 1921 flood had been made from sand surface to flood surface. It is not believed that the sand averages more than a few tenths deep.

for the solid rock projects above the surface in several places.

3. Exact 1921 flood marks were hard to find between upper end and lower end of the Dalles, and on right side of upper end. This was due to the time that had elapsed since that flood. There may be a small error in drop, due to this difficulty.

It is believed that all of these factors, except No. 3 for the "contracted opening" method, are more or less compensating. Even if they are not, the effect on the result would be small in percentage.

In the case of the sand on the bottom in the Dalles, there is this to be said: The average depth of the water above the sand surface at the crest of the 1921 flood, was about 50 feet. If the sand on the bottom averages one foot deep, at low water, and if it was all washed out during the 1921 flood, the flow would be only 2 percent greater than computed.

The close check between the results by use of the two different methods, is an indication of the accuracy of both methods. It is believed that none of the results are in error over 8 percent, and the average of all results is within 5 percent of the true discharge.

In making the computations the following symbols have been used:

A = area of cross section of channel in square feet.

B = breadth of channel at cross section in feet.

C = Coefficient of roughness in Chezy's formula.

D = Distance between cross sections of channel, or distance between slope stations in feet.

g = acceleration of gravity 32.16 feet per second.

h = head of water or difference in elevation of water surface between two points in feet.

n = coefficient of roughness in Kutter's formula.

P = wetted perimeter of cross section of channel in feet.

Q = AV = quantity of water passing any given point in cubic feet per second.

R = A/P = hydraulic radius of cross section of channel.

S = h/D = surface slope of water surface.

V = average velocity of water throughout the cross section in feet per second.

Note.- Theoretically, S should be used for friction slope. Friction slope and surface slope are the same if the velocity is constant. Friction slope can rarely be determined accurately, so surface slope is used instead.

For the slope sections the discharge has been computed by use of Kutter's and Chezy's formulae. Kutter's formulae is used to derive C for use in Chezy's formula.

The formulae are as follows:

Kutter's

$$C = \frac{\frac{1.811}{n} + 41.65 + \frac{.00281}{S}}{1 + \frac{n}{\sqrt{r}}\left(41.65 + \frac{.00281}{S}\right)}$$

Chezy's.

$$V = C\sqrt{Rs}$$

The computations are as follows:

Determination of Kutter's "n" at Sedro Woolley.

(1) U. S. Army Engineers' measurement of June 12, 1908. Cross section taken at old ferry, present bridge site. Slope obtained by use of difference in elevation of water surface at ferry, and Northern Pacific Bridge, 1,520 feet downstream.

$h = 0.45$

$D = 1520$

$$S = \frac{0.45}{15.20} = .00029$$

$B = 840$

$P = 852$

$R = 11.4$

$Q = 40,200$

$A = 9,720$

$$V = \frac{40,200}{9,720} = 4.13$$

$$V = C\sqrt{Rs}$$

$$C = \frac{V}{\sqrt{Rs}} = \frac{4.13}{\sqrt{11.4 \times .00029}} = 71.$$

From Hoyt and Gover's "River Discharge", Plate VI, opposite page 62, example No. 4, $n = .033$.

(2) Flood of 1921.

Discharge in main channel taken as 160,000 second-feet (see curves and overflow data) cross section taken 1,190 feet above highway bridge. Slope taken from highwater marks, one, 970 feet above highway bridge; the other 1,430 feet below highway bridge.

$$h = 1.95$$

$$D = 2400$$

$$S = \frac{20}{2500} = .0008$$

$$B = 752$$

$$P = 762$$

$$A = 16500$$

$$R = \frac{16500}{762} = 21.7$$

$$V = \frac{160,000}{16,500} = 9.7$$

$$C = \frac{V}{\sqrt{Rs}} = \frac{9.7}{\sqrt{21.7 \times .0008}} = 73$$

From Hoyt and Grover's "River Discharge", Plate VI, opposite page 62, example No. 4, "n" = .034

<u>Note.-</u> The great change in slope for the two measurements is due to the effect of the Sterling Bend cut-off.

Slope Sections at the Dalles for 1921 flood.

1. Slope section between cross sections 1 and 2.

$h = 2.11$

$D = 1.860$

$$S = \frac{2.11}{1.860} = .00113$$

B Cross Section No. 1 = 610

P Cross Section No. 1 = 635

A Cross Section No. 1 = 18,000

B Cross Section No. 2 = 755

P Cross Section No. 2 = 780

A Cross Section No. 2 = 19,000

Mean A = 18,500

Mean P = 708

$$\text{Mean R} = \frac{\text{Mean A}}{\text{Mean P}} = \frac{18,500}{708} = 26.1$$

Assume n = 0.033

$$C = \frac{\frac{1.811}{.033} + 41.65 + \frac{.00281}{.00113}}{1 + \frac{.033}{\sqrt{26.1}}\left[41.65 + \frac{.00281}{.00113}\right]} = 76.9$$

$$V = 76.9\sqrt{26.1 \times .00113} = 13.2$$

$$Q = 18,500 \times 13.2 = 244,000$$ ✓

2. Slope section between cross sections No. 2 and 3.

$h = 2.62$

$D = 2190$

$$S = \frac{2.62}{2190} = .0012$$

B Cross Section No. 2 = 755

P Cross Section No. 2 = 780

A Cross Section No. 2 = 19,000

B Cross Section No. 3 = 691

P Cross Section No. 3 = 710

A Cross Section No. 3 = 16,900

Mean A = 18,000

Mean P = 745

$$\text{Mean } R = \frac{18,000}{745} = 24.2$$

Assume n = .033

$$C = \frac{\frac{1.811}{.033} + 41.65 + \frac{.00281}{.0012}}{1 + \frac{.033}{\sqrt{24.2}}\left[41.65 + \frac{.00281}{.0012}\right]} = 76.3$$

$$V = 76.3\sqrt{24.2 \times .0012} = 13.0$$

$$Q = 18,000 \times 13.0 = 234,000$$

3. Entire slope section from cross sections No. 1 to No. 3

$h = 4.73$

$D = 4050$

$S = \frac{4.73}{4050} = .00117$

Mean A = 18,200 Giving weight of one each to cross sections No. 1 and 3 and weight two to cross section No. 2

Mean P = 726 Weighted by same method as area.

Mean R = 25.1

$$C = \frac{\frac{1.811}{.033} + 41.65 + \frac{.00281}{.00117}}{1 + \frac{.033}{\sqrt{25.1}}\left[41.65 + \frac{.00281}{.00117}\right]} = 76.7$$

$V = 76.7\sqrt{25.1 \times .00117} = 13.2$

$Q = 18,200 \times 13.2 = 240,000$

244,000
234,000
240,000

3 | 718,000

239,000 Mean discharge for the three slope computations.

For computing discharge through the "contracted opening" the formula $V = \sqrt{2gh}$ has been used. The method and description of method has been partly adopted from "Calculation of Flow in Open Channels" by Ivan Houk, Technical Report No. 14 of the Miami Conservancy District, State of Ohio (see pages 53-56 of that report).

The method of obtaining the velocity head for the 1921 flood was as follows: An estimate of discharge was made from the average of computations for the slope sections. This discharge was divided by the area of cross section No. 1 at the Dalles. The estimate of discharge and equivalent velocity head were changed by successive computations involving the estimated friction head, until the final computation of discharge and friction head agreed with the estimates.

The friction head for the flood of 1921 was first estimated and subtracted from the total head (drop-off head plus velocity head). This gave an effective velocity head for the contracted opening. The velocity corresponding to this head was then obtained. By the use of an equation involving the friction head in the slope section, it was possible to obtain the friction head for the contracted opening. By successive approximations, involving the estimated discharge and velocity head, the friction head was made to agree with the estimated value.

The following symbols, in addition to ones previously given, were adopted for the "contracted opening" study.

V_h = velocity head at cross section No. 1

f_h = friction head loss between cross sections No. 1 and 3.

X_s = average friction head loss per feet of distance in slope sectio

X_1 = average friction head loss per feet of distance in upper 380 feet of 560 feet of contracted opening.

X_2 = average friction head loss per feet of distance in lower 180 feet of 560 feet of contracted opening.

V_s = average velocity in slope section.

V_1 = average velocity at cross section No. 1 contracted opening.

V_2 = average velocity at cross section No. 2 contracted opening.

V_3 = average velocity at cross section No. 3 same velocity as No.2.

R_c = mean hydraulic radius of contracted sections.

R_s = mean hydraulic radius of slope sections.

Assuming the coefficient of friction to be the same in "contracted opening" as in slope sections, we can write the following equations for the purpose of solving the friction loss in the "contracted opening."

$$f_h = 180X_1 + 380X_2$$

$$\frac{X_1}{X_s} = \frac{\dfrac{\overline{V_1}^2 + \overline{V_2}^2}{2} \times R_s}{\overline{V_s}^2 \times R_c} \quad \text{or} \quad X_1 = \frac{\dfrac{\overline{V_1}^2 + \overline{V_2}^2}{2} \times R_s \times X_s}{\overline{V_s}^2 \times R_c}$$

$$\frac{X_2}{X_s} = \frac{\frac{\overline{V_2}^2 + \overline{V_3}^2}{2} \times R_s}{\overline{V_s}^2 \times R_c} \text{ or (since } V_3 = V_2) \quad X_2 = \frac{\overline{V_2}^2 \times R_s \times X_s}{\overline{V_s}^2 \; R_c}$$

The final flood computations for the "contracted opening" section are given herewith:

Estimate Q = 246,000

Cross Section No. 1A = 14,000

Velocity of approach = $\frac{246,000}{14,000}$ = 17.6

Velocity head = $\frac{V^2}{2g} = \frac{\overline{17.6}^2}{64.32} = 4.8$

h = 4.2
Velocity h = 4.8

Total h = 9.0
Estimate fh = 1.2

Effective velocity h = 7.8

$$V = \sqrt{2gh} = \sqrt{64.32 \times 7.8} = 22.4$$

$$180X_1 = \frac{\frac{\overline{17.4}^2 + \overline{22.4}^2}{2} \times 25 \times .00117}{\overline{3.2}^2 \times 35} = 0.73 \text{ foot.}$$

$$380X_2 = \frac{\overline{22.4}^2 \times 25 \times .00117}{\overline{13.2}^2 \times 35} = 0.43$$

fh = 1.2 feet, which checks assumed avlue for friction head.

A = 11,000 x 22.4 = 246,000 which checks assumed value for discharge

A summary of the results for all slope sections and "contracted opening" computation is given herewith:

Section	Second-feet
Contracted opening	246,000
Upper portion slope section	244,000
Lower portion slope section	234,000
Total slope section	239,000
	4) 963,000
	241,000 = average of all computations. Use 240,000 as the discharge.

EXHIBIT C.

It is desirable to find the approximate channel capacity of the Skagit River at and below the Great Northern Railway bridge. To obtain this capacity, the following data was obtained:

1. Cross sectional area of the river at Riverside Highway bridge.

2. Cross sectional area of the river at Mt. Vernon highway bridge.

3. 1921 flood slope (north bank) between Great Northern Railway bridge and Mt. Vernon highway bridge.

4. Drop off (on west side) through Mt. Vernon highway bridge.

The material in this section of the river is very much finer than at Sedro Woolley. It is assumed, therefore, that the value of "n" is somewhat less than the .033 found at Sedro Woolley.

Riverside Bridge Slope Section: Assume

"n" = .030

A = 23,000

S = .00015

P = 930

$R = \frac{2,3000}{930} = 25$

C = 89 (From Kutter's Formulae)

V = 5.5 (From $V = C\sqrt{Rs}$)

Q = 23,000 x 5.5 = 126,000

Note: This is the copy as supplied by U.S.G.S. in 1925. Subsequently Mr. Stewart made some minor revisions & forwarded them to Tacoma. In Oct. 1925 Mr. [illegible] copied the revised passages and they [illegible] been incorporated in a revision of the report typed in this office [illegible]
Oct 2[illegible] 1925
S.R.W.

The area at Riveside bridge is probably not representative of the section covered by levels for slope. Therefore, result is not very accurate.

Contracted opening at Mt. Vernon highway bridge.

A = 15,900 (Part of area not effective. Estimate 14,000 net.

h = 1.2 (West side by Stewart)

h = .6 (By Great Northern Engineer)

Average h = 0.9

D = 27 feet

Friction h = Negligible.

Velocity of approach = 8.0 Estimated. No data available for obtaining velocity except velocity at Riverside bridge, and computed velocity through opening.

$$\text{Velocity head} = \frac{V^2}{2g} = \frac{8^2}{64.32} = \frac{64}{64} = 1.0$$

h = 0.9
Velocity h = 1.0

Total h = 1.9

$$V = \sqrt{2gh} = \sqrt{64.32 \times 1.9} = \sqrt{122} = 11.$$

$$Q = 15,000 \times 11 = 165,000.$$

The drop at this section is hardly sufficient for accurate results. Q = 14000 x 11 = 154000 ESP

126,000
154,000
2 | 280,000
140,000 = mean of slope and drop-off sections.

The figure of 140,000 second-feet is probably within 20 percent of the correct figure.

Beatty's Slough opening in Northern Pacific grade.

$A = 4,560$

$B = 270$

$P = 290$ (rough calculation)

$R = \frac{4,560}{290} = 16.$

$h = 0.23$

$D = 140$

$S = \frac{0.23}{140} = .00164$

$n = .045$ (estimated)

$C = 57$

$V = 8.5$

From Mead's "Water Power", page 49.

$Q = 4,560 \times 8.5 = 38,800$

Beatty's Slough always gets badly choked by drift during floods, and will not discharge ~~as much~~ as under open conditions assumed in computations. ~~Estimate~~ discharge ~~as~~ 30,000 second-feet.

Slough opening through Northern Pacific railroad grade, near Sedro Woolley. – North Slough

$A = 2,450$
$B = 227$
$P = 240$ (rough calculation)
$R = \frac{2,450}{240} = 10$
$S = .00164$ (From slope at Beatty's Slough opening).
$n = .050$ (estimated)

$C = 47$
$V = 5.7$ (From Mead's "Water Power", page 49.
$Q = 2,450 \times 5.7 = 14,000$

Summary of flow through slough openings at
Northern Pacific grade.

South Slough	=	13,000	
Beatty's Slough	=	30,000	
North Slough	=	14,000	
		57,000	
		7,000	Beatty's Slough discharge at County highway bridge.
		50,000	Discharge not accounted for in rating curve for river and Beatty's Slough channels at County road.

The 1917 flood was nearly the same height as the 1921 flood. It is estimated that overflow discharge was 50,000 second-feet in 1917 as well as 1921. The addition of this overflow discharge, therefore, determines a point on the true rating curves for 1917 and 1921. These points are 50,000 second-feet to the right of points at same gage height on each of these flood curves for the main channel and Beatty's Slough.

1908-1922. A File No. 913.

Exhibit E

SKAGIT RIVER NEAR SEDRO WOOLLEY

Revision 1908-1922

Skagit River at Sedro Woolley; Revision 1908-1922.

Observers.- May 1, 1908 to September 2, 1919, E. J. Woods (killed September 2, 1919) continuous record; one of the best observers in the district.

September 28 to December 31, 1919, Henry Batey; failed to get readings during ice period December 11-16, 1919; believed to be very conscientious however.

February 1, 1921 to date, W. H. Gale; careful and conscientious observer. Prior to November 22, 1922 he made the readings for the Northern Pacific Railway Company. Since that date he has been employed by Skagit County.

Ice.- The stage-discharge relation is seldom affected by ice. It has been affected however, during the following periods:

By ice jam half a mile below gage Jan. 17-21, 1916, and by ice in channel February 3-7, 1916, discharge interpolated.

December 11-16, 1919, December 10-18, 1922, and possibly during part of January and February, 1923.

Equipment.- Staff gage installed by Army Engineers about May 1, 1908. This washed out in the November, 1909 flood, probably November 29 or 30, but possibly during the high stage of November 24. New staff installed by observer to datum given by Army Engineers.

September 25, 1915 a temporary staff was installed by C. G. Paulsen on a dolphin in center of river on downstream side of one of a group of piles about 50 feet above third concrete pier of railway bridge from left bank. This temporary staff was used for gage heights below 37.00 feet due to water not reaching old gage satisfactorily. September 27, 1916 a chain gage was installed by J. E. Stewart and readings discontinued on old staff and temporary staff gages. September 25, 1919 a vertical staff was installed by J. McCombs on upstream inshore side of highway bridge draw span rest. This gage was about 1,500 feet above previous gages at the railway bridge.

Gage-height record.- Continuous from May 1, 1908 to September 2, 1919; from September 28 to December 31, 1919 (except when stage-discharge relation was affected by ice,) and from February 1, 1921 to September 30, 1922.

Gage-height corrections.-

Old Staff Gage.

Levels to 1909, 1917, and 1921 high water marks at the Hart Ranch, 1,200 feet upstream from the Northern Pacific gage, indicate that possibly the staff gage was re-installed in December, 1909, at 1.00 foot higher datum than prior to 1909 flood. The 1909 flood was 1.2 feet above the 1921 flood at the Hart Ranch, and the 1921 flood crest was 54.3 at the Northern Pacific staff. With unchanged stage discharge relation, the 1909 gage height should then be 55.5 at the Northern Pacific staff gage. There is, however, fair confirmation of the observer's 1909 reading of 56.5 at an old six-foot cedar tree on the south side of Beatty's Slough, just downstream from the Northern Pacific grade, and nearly opposite the Northern Pacific staff gage. At the cedar tree, the 1909 flood crest was at least 1.9 feet above the 1921 mark. The 1909 mud in the bark was nearly gone, especially near the flood crest, so that the exact crest was hard to determine. Assuming the 1909 flood to be 1.9 feet above the 1921 flood, the gage height would be 56.2 feet. With the tremendous surge during the 1909 flood, 0.3 feet difference, between the observer's reading and the estimate based on the cedar tree, is close enough agreement. The failure at the Hart Ranch of 1909 and 1921 flood crests to check the two crests at the Northern Pacific staff, and also the considerable variation in the difference between 1909 and 1921 at Hart's and the cedar tree, may be due entirely to two causes, as follows:

1. Prior to 1911 the river flowed around Sterling Bend in a much longer channel than thereafter. Hence the slope past the gage would be less than for the 1921 flood.

2. Choking effect of the Northern Pacific bridge was greater during the 1909 than during later floods because of the greater discharge. Log jams in Beatty's slough and sloughs south of the river also caused more obstruction than other floods.

The two causes mentioned would make the slope in 1921 much greater than in 1909. Cause No. 2 would make the difference between 1909 and 1921 floods greater just above the Northern Pacific embankment than just below it. The difference downstream from the Northern Pacific embankment was at least 1.9 feet. If we estimate the difference to be 2.2 feet upstream from the embankment, and add 2.2 to the 54.3 feet (gage height of 1921 flood) we have the 56.5 feet given by the observer for the 1909 flood.

The observer was very reliable and conscientious, and the data at the cedar tree nearly confirms his readings. It is deemed best, therefore, to accept his reading as correct, and to assume that the gage was reinstalled correctly in December, 1909 at the same datum as it had prior to the 1909 flood.

Levels have been taken as follows:

Corrections necessary to gage heights as indicated by levels.

Point on gage	H.K. 9-30-10	H.PG 4-22-11	WWC 9-15-11	JES 3-13-13	FBS 7-8-13	JES 10-19-13	GLP 5-5-14	ILC 5-5-14	CGP 9-25-15	JES 9-26-16	JES 1-22-23	LJW 2-21-23
61.46	---	---	---	---	---	---	---	---	---	-0.085	---	---
60.50	---	---	---	---	---	0.00	---	---	---	b( )	---	---
60.00	---	---	---	-0.065	---	---	---	---	-0.07	b(-0.08)	-0.12	-0.11
59.83	---	---	0.00	---	---	---	---	---	---	b(-0.08)	---	---
59.00	---	---	---	---	---	---	---	---	---	b(-0.08)	---	---
58.00	---	---	---	---	---	---	---	---	---	b(-0.08)	---	---
57.40	-0.19	---	---	---	---	---	---	---	---	b(-0.08)	---	---
57.29	---	---	---	---	-0.04	---	---	---	---	b(-0.08)	---	---
57.00	---	---	---	---	---	---	---	---	---	b(-0.08)	---	---
56.30	---	---	---	---	---	---	-0.02	---	---	b(-0.08)	---	---
56.00	---	---	---	---	---	---	---	---	---	b(-0.08)	---	---
55.81	---	---	---	---	---	---	---	-0.02	---	b(-0.08)	---	---
55.00	---	---	---	---	---	---	-0.04	-0.02	-0.06	b(-0.08)	---	---
54.00	---	---	---	---	---	---	---	---	a(-0.06)	b(-0.08)	---	---
53.00	---	---	---	---	---	---	---	---	a(-0.06)	b(-0.08)	---	---
52.00	---	---	---	---	---	---	---	---	a(-0.06)	b(-0.07)	---	---
51.00	---	---	---	---	---	---	---	---	a(-0.06)	Total distance O.K. and correction assumed to be -0.07.	---	---
50.00	---	---	---	---	---	---	---	---	a(-0.06)		---	---
49.00	---	---	---	---	---	---	---	---	a(-0.06)		---	---
48.77	---	---	---	---	---	---	-0.04	---	a(-0.06)		---	---
48.00	---	---	---	---	---	---	---	---	a(-0.06)		---	---
47.22	---	---	---	---	---	---	---	-0.02	a(-0.06)		---	---
47.00	---	---	---	---	---	---	---	---	a(-0.06)		---	---
46.00	---	---	---	---	---	---	---	---	a(-0.06)		---	---
45.00	---	---	---	---	---	---	---	---	a(-0.06)		---	---

a: Graduations checked with steel tape between 35 and 55 and found O.K. Corrections in parentheses supplied on this basis:

b: Graduations checked with steel tape 35-42 and 53-60; also total distance between 35 and 60 and found O.K. to nearest 0.01 ft. Slight batter to gage board causes difference in corrections at top and bottom. Corrections in parentheses supplied on basis of taping levels and batter.

Gage-height corrections.- Continued.

It would be very difficult to obtain equal back and foresights in checking this gage and possibly was never done. With the very small levels that were generally used it is likely that most of the discrepancies were due to the level or leveling. The general tendency of the corrections however indicate a settling of the gage. This settling probably amounted to between .02 and .04 from 1913 to 1916. The gage settled about .04 more from 1916 to 1923. This small settlement during the last period indicates that probably the settlement was nearer .02 than .04 for the first period.

Levels of April, 1911 were with a carpenter's level and tying to water surface. This was the same method as gage was set by observer in December, 1909. Levels of September 30, 1910 and September 15, 1911 do not agree but it seems likely that a gradual settlement was in progress from the installation of the gage. As this was at a very slow rate the balancing of the rating curve to the measurements and changing of rating curves will automatically take care of the gage height corrections and none have been made.

Temporary staff gage

This gage was installed to correct datum by C. G. Paulsen September 25, 1915. During the high water of June, 1916 the dolphin to which the gage was attached was struck by drift. The gage was on the lower side and doubtless the blows on the upper side of the dolphin settled the piles on the lower side. J. E. Stewart checked this temporary staff September 27, 1916 and found a correction of minus 0.055 to apply. This correction represents only 2.3 percent of the discharge at the lowest stage recorded while it was applicable. Correction was not made to gage heights for that reason when original 1916 computation was made and is not warranted at a station where changes in rating are so frequent.

Chain gage.

This gage was installed to correct datum by J. E. Stewart September 26, 1916. Chain lengthened as is usual with chain gages. It has been checked as follows:

Marker checked	9-25-16 Installed	5-15-17 Found	Left	8-15-17 Found	Left	12-23-17 Found	Left	1-2-18 Found	Left	3-9-18 Found	Left	6-18-18 Found	Left
60 ft.	0.00	-0.02	-.02	-.03	+.06	+.06	+.06	---		---		+.03	+.03
50 ft.	0.00	- .04	-.04	-.03	+.05	+.05	+.05	---		---		.00	.00
40 ft.	0.00	-.04	-.04	-.05	+.05	+.04	+.04	+.04	+.04			.00	.00
30 ft.	0.00	-.05	-.05	-.09	.00	.00	.00	---		-.01	-.01	-.06	.00

Marker checked	Found 10-4-18	Left	10-26-18 Found	Left	2-8-19 Found	Left	3-29-19 Found	Left	4-20-20 Found	Left
60 ft.	---		---		---		---		---	
50 ft.	-.03	+.02	---		---		---		---	Chain
40 ft.	-.03	.00	---		---		---		---	removed
30 ft.	-.05	.00	.00	.00	-.02	.00	.00	.00	.00	.00

Gage-height corrections.- Continued.

Gage heights have been corrected on the basis of this table as listed below. Considering the frequent changes in rating these corrections are scarcely warranted but as they were applied when original computations were made the same corrections were used in the revised computations.

Period	Correction	Marker used
1916		
Sept.27-Nov. 11	0.00	30
Nov. 12-Jan. 19	- .02	30
1917		
Jan. 20-March 31	- .04	30
April 1-July 22	- .05	40
July 23-Aug. 4	- .08	30
Aug. 5-Aug. 15	- .09	30
Aug. 16-Dec. 13	0.00	30
Dec. 14-Dec. 21	+.04	40
Dec. 22-Dec. 27	0.00	30
Dec. 28-Dec. 28	+.04	40
December 30	+.05	50
December 31	+.04	40
1918		
January 1	+.05	50
January 2-9	+.04	40
January 10-17	0.00	30
January 18	+.04	40
January 19-Mar. 24	0.00	30
March 25	+.03	40
Mar. 26-May 3	-.03	30
May 4-5	.00	40
May 6-30	-.04	30
May 31	.00	40
June 1-6	-.05	30
June 7-27	.00	40
June 28-July 31	.00	30
Aug. 1-31	-.02	30
Sept. 1-30	-.04	30
Oct. 1-4	-.05	30

No corrections made after October 4. Gage .02 long February 8, 1919 and corrected. Error considered negligible. Chain length O.K. April 20, 1920, indicating no correction during spring and summer of 1919.

For the sake of convenience observed gage heights were decreased 30 feet when entered on 9-192a; also rating curve and tables were made out on same basis.

Rating.- Between June 12, 1908 and January 22, 1923, eighty one discharge measurements (A-D and 1-76 including, 53A) have been made. Measurements are fairly well distributed over the period August 26, 1910 to September 1919. On the other hand there were no measurements made during the periods November 6, 1908, to August 25, 1910 and September 20, 1919 to November 20, 1922. Lack of measurements during the last period named was due to discontinuance of the station.

In looking over the old rating a serious error was discovered for the period November 30, 1909 to December 31, 1910. A study of the flood flow in the Skagit River makes it certain also that the high water extension of all the old curves are too small. Minor errors in curves were also noticeable, due usually to insufficient data being available at the time curves were drawn.

Although the control at this station is known to be shifting, the erratic plotting of some of the measurements seemed to indicate that part of the trouble might lay in the discharge measurements themselves. Examination of a few measurements made it clear that all measurements should be gone through systematically and examined along the following lines:

1. If soundings are not taken see that proper cross section was used.

2. If .2 and .8 method not used correct coefficients to 88 percent for 0.2 velocities and 90 percent for sub-surface velocities. These coefficients are the results of studies by J. E. Stewart in December, 1922. 89 percent might have been a little better for surface velocities.

3. If Beatty's slough not measured check amount, if any, added for it. Measurements Nos. 15-16 had been plotted without adding anything for Beatty's slough.

4. See that decimal point not in error for quantities near piers.

5. Check unchecked, partly checked and self checked measurements.

6. Correct measurements for non-standard hanging of meters in relation to weights. The correction of errors found made the measurements line up very much better and made some unexpected changes in interpretation of rating curves.

Rating.- Continued.

Measurements A-D were made by the Army Engineers by holding the meter at what they termed "top, middle, and bottom." Top and bottom meant one foot from the top and bottom respectively while middle meant mid depth. In case the water was 2 feet deep all three readings were in the same spot and the resulting mean velocity would be too great. Where the water was 20 feet deep the mean of the top, middle, and bottom would probably be somewhat low. The correction worked out for the measurements by F. F. Henshaw have been accepted as being as good as other doubtful features of the measurements warrant. These other features are:

1. Measurements made from ferry. Survey experience is that boat measurements are unsatisfactory.

2. Meter rating unknown.

3. Method and accuracy of obtaining width of river unknown.

The curve is fairly well defined below 50,000 second-feet and applicable May 1, 1908 to November 29, 1909. Rating table by A. C. Baldwin dated 3-14-23. Accuracy of daily discharge about D. Publish monthly values only May 1, 1908 to September 30, 1909.

Measurements 1-3 made during the fall of 1910 define the curve after the shift of November 29-30, 1909. This shift was caused by the greatest flood on the Skagit at Sedro Woolley since the arrival of the white man. It is likely that this flood nearly cut a channel through Sterling Bend below the Northern Pacific Railway bridge and that other high water flows partly went across this bend following the November 30, 1909 flood. This would account for the marked departure to the right of the upper portion of the curve based on 1-3. Another cause of the marked shift to the right of the upper portion of the curve might be a clearing out of log jams below the Northern Pacific bridge by the 1909 flood.

Although measurements 1-3 cover only a small portion of the total range of stage, the shape of the curve is well outlined by the succeeding curve. A study of the erratic plotting of measurements following the 1917 flood indicate that discharge based on a curve through measurements 1-3 may be rather unreliable for the month of December 1909 and January 1910. The curve is applicable November 30, 1909 to November 20, 1910, rating table by A. C. B. is dated 3-16-23.

Rating.- Continued.

Measurements 4-10 define a curve which is well defined between 4,000 and 70,000 second-feet and fairly well defined above 70,000 second-feet; curve is applicable November 21, 1910 to November 19, 1911. Rating table by A. C. B. is dated 3-17-23.

On November 20, 1911 the river cut completely across Sterling Bend making a decided shortening of the regular channel below the station. This resulted in a marked change in the rating. After this cut off the channel deepened at every small flood for exactly a year and at two large floods after that, the large floods being January 7, 1914 and April 3, 1915.

Measurements 11 and 12, when considered with succeeding curves outline a curve which is fairly well defined and applicable November 20, 1911 to January 29, 1912. Rating table by A. C. B. is dated 3-20-23A. This table is the same as table for succeeding curve, dated 3-20-23B above gage height 15.0.

Measurements 13-17, also 22-23 outline a curve fairly well defined and applicable January 30 to May 14, 1912. Rating table by A. C. B. is dated 3-20-23B.

Measurements 15-19, also 22 and 23 outline a curve fairly well defined applicable May 15 to November 18, 1912, rating table by A. C. B. dated 3-21-23. This table is the same as preceding table above gage height 12.0 feet. The change in low water part of curve is defined by measurements 18 and 19.

Measurements 20-25, also 15-17 outline a curve fairly well defined applicable November 19, 1912 to January 6, 1914. Rating table by A. C. B. 3-22-23. Table is same as preceding table above gage height 11.6 feet.

Measurements 26 and 27 indicate the shift caused by the Jan. 7, 1914 flood, the largest flood between November 1909 and December 1917. This flood indicates mostly a high water shift, probably due to widening the channel by cutting the banks at the Sterling Bend cut off. The cutting of the banks would have no effect on the low water curve. A slight grade reduction in the low water channel is shown, however, by measurement 27.

Rating curve is fairly well defined and is applicable January 7 to November 2, 1914. Rating table by A. C. B. is dated 3-23-23A.

Measurements 28-30 indicate a low water shift caused by the flood of November 3, 1914. This flood was not high enough to cut the banks so it is safest to assume that this curve merges with curve through measurement 26 at a fairly low gage height.

Rating curve fairly well defined and applicable November 3, 1914 to April 2, 1915. Rating table by A. C. B. is dated 3-23-23B and above gage height 9.6 is the same as preceding rating table.

Rating.- Continued.

Measurements 31-38, also 28-30 and 45-46, indicate the shift caused by the April 3, 1915 flood. The shift is greatest at a medium stage.

Rating curve is well defined below 1[illegible]0,000 second-feet and is applicable April 3, 1915 to September 26, 1916. Rating table by A. C. B. dated 3-13-23. From September 26, 1915 to September 26, 1916 for gage heights of 7.00 and above only. A temporary gage at a different location was used for stages below 7.00 for this period.

In the fall of 1915 water did not have free access to the gage. The temporary staff gage was therefore installed on a dolphin near the middle of the river. Measurements 33-39 were referred to this gage and a curve drawn up to be used for gage heights below 7.00 feet. Rating curve is well defined and is applicable September 26, 1915 to September 26, 1916. Rating table by A. C. B. dated 3-12-23.

Measurements 39-42 outline a curve for the chain gage. There was no shift between measurements 38 and 39. Also the chain and staff are at practically the same datum. The conditions however surrounding the staff gage at low water cause readings on it to be incomparable with the ~~staff~~ chain gage. Otherwise measurements 28-38 would confirm the same curve. Measurements at high stages such as 38, 45, and 46 have been used interchangeably for both the chain and staff. The curve for the chain gage is well defined and is applicable September 27, 1916 to December 18, 1917. Rating table by A. C. B. is dated 3-27-23A.

The flood of December 19, 1917 caused a small low water shift shown by measurements 43 and 44. A rating curve has been used which is defined also by measurements 48-55A and is applicabl[e] December 19 to 29, 1917. Rating table by A. C. B. is dated 3-27-23[B]

The flood of December 30, 1917 caused a large low water shift probably due to deposition of large quantities of sand and gravel at the lower end of Sterling Bend cut off. The lower end of Sterling Bend cut off is the location of the break in gradient between the steep valley gradient and the delta gradient as a consequence when the stream is loaded with material, to its carrying capacity in the upper section, it is forced to deposit at the break in gradient. This material may have washed

Rating.- Continued.

out gradually during the rise in stage January 18, 1918. Possibly this rise came primarily from the lower drainage and did not carry material to capacity so that the water could scour out all the deposit which had accummulated. It has been assumed, therefore, that the shift occurred January 18, 1918. The curve is outlined by measurements 45-47, is poorly defined and is applicable December 30, 1917 to January 17, 1918. Rating table by A. C. B. is dated 3-30-23.

Measurements 48-53A indicate the return of the curve to the position shown by measurements 43-44. Therefore same rating table is used as for the period December 19 to 29, 1917. It is applicable from January 18, to December 13, 1918. Rating table by A. C. B. is dated 3-27-23B.

Measurements 54 to 58 outline the curve after the shift of December 14, 1918. Curve is well defined and is applicable December 14, 1918 to December 12, 1921 for chain gage heights. Rating table by A. C. B. is dated 3-28-23.

The observer, E. J. Woods, was killed September 2, 1919. Henry Batey was hired to take his place. His readings began September 28, 1919 and taken from the staff gage at highway gage, which was installed by J. McCombs September 25. A curve of relations has been drawn using ~~my~~ readings by Stewart with January 1923 measurements and Kilgore's comparison of April 30 and May 3, 1920. By means of this curve of relations and the rating table for chain gage, December 14, 1918 to December 12, 1921 a rating table (by G4P 7-19-23) has been prepared for applying to highway bridge gage heights from September 28 to December 31, 1919.

Measurements 59 to 76 made from November 1922 to January, 1923 outline a curve following the December 13, 1921 flood. The results obtained by this series of measurements show that this is an exceedingly poor station, so far as rating is concerned, and should be abandoned.

All of this series of measurements with the exception of numbers 64 and 66 can be placed on two curves, one of which is applicable for falling stage and the other applicable for rising stage. The change in velocities from a rising to a falling stage were very noticeable in measurements made not over 18 hours apart. This would indicate that changes in gradient might be the sole cause. No other streams in Washington with such steep slopes are known to have shown this effect; nor can it be shown by past measurements at Sedro Woolley that a changeable gradient caused different ratings for rising and falling stages.

Rating.- Continued.

It is thought that there are several causes entering in the erratic results at Sedro Woolley as follows:

1. Change in stream bed gradient at lower end of Sterling Bend cut off. This causes deposition of material due to reduced velocity when the water reaches this section fully loaded with material. This material is cut out later when the water reaches there with extra carrying capacity.

2. The river channel on the delta does not have as much carrying capacity as the river down to Sedro Woolley. Due to lack of capacity the stage rises more rapidly than at Sedro Woolley and above. The water, after reaching the tops of the banks, floods the Nowhachamps country, in fact creates a vast reservoir. The backwater from the river channel and reservoir undoubtedly affects the rating at the Sedro Woolley station.

3. Tide effect. Whether an actual tide effect can be shown at Sedro Woolley is not known. The known tide effect only exists to about the Great Northern bridge. It seems very likely however, that since high tides must greatly reduce the outlet capacity of Skagit River that the effect is felt up to Sedro Woolley or above.

4. Change in gradient due to change in flow, the rapid change in discharge sometimes causes exceedingly rapid changes in stage. Changes of .5 foot per hour have been seen and 1.0 foot are said to occur in the vicinity of Sedro Woolley. A certain part of the rapid change in stage may be due to items 1, 2, and 3, but these are not thought to be large factors. It is reported that in the 1897 flood the Skagit River near Concrete rose about 3 feet in one hour and items 1 to 3 could not be effective that far upstream.

All the above causes are thought to assist in the peculiar results but as they are all more or less inter-dependent it is hard to say where one begins and another leaves off.

In drawing the rating curve it was decided to draw only one curve and give more weight to the falling stage measurements than those for a rising stage because the falling stage is usually of longer duration. Measurements at a steady or nearly steady stage, were given more weight than those made during rapid changes in stage. The rating curve is fairly well defined and is applicable December 13, 1921 to date. Rating table by A. C. B. is dated 3-30-23.

Rating.- Continued.

2. The trees, brush, stumps, houses, fences, etc., probably hinder flow more than estimated; that is the values assumed for Kutter's "n" were too small and increased wetted perimeter allowance was insufficient.

3. High banks, self dikes formed by river, prevent sufficient water getting to the back country to give the water the slope and flow estimated.

The conclusion, from these points, is that the slope and retarding effects are not correctly known.

The second method used in computing the overflow discharge was to obtain the cross section and slope of the 1921 flood, at the three slough openings through the Northern Pacific embankment. By this method the overflow discharge in excess of the river and slough at the highway bridge is 50,000 second-feet. Although this seems to be a great deal of water, it must be remembered that the total cross sectional area of the slough openings at the crest of the 1921 flood was slightly in excess of 10,000 square feet. The figure of 50,000 is assumed correct.

The estimated overflow derived from highway bridge cross sections was 34,000 second-feet or 68 percent of overflow determined by the second method. The total of river and Beatty's slough, and 50,000 overflow is 210,000 second-feet for the crest discharge December 13, 1921 at gage height 24.3 feet. If the 34,000 second-feet overflow had been used the total flow would have been 7½ percent less. On the other hand the overflow may have been greater than 50,000 second-feet for in computations through the slough openings the flow through the north opening was reduced 3,20[0] second-feet on the assumption that the slope found was too great. Beatty's slough was reduced 8,800 second-feet for possible obstruction by drift jams. Hence it will be readily understood that 50,00[0] second-feet is somewhat of a mean of several possible values for overflow. It is believed, however, that the crest discharge, estimated in these revised data, are within 10 percent of the correct figures for all floods subsequent to and including 1909.

The 1909 total discharge is based mainly on comparison of 1909, 1917, and 1921 stages between Concrete and Sedro Woolley where stage was not influenced by cut offs, jams or other causes.

J. E. Stewart, 3-13-23.
Reviewed and checked by G. L. Parker, 3-27-23.