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WATER UTILIZATION IN THE NOOKSACK RIVER, WASHINGTON

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By

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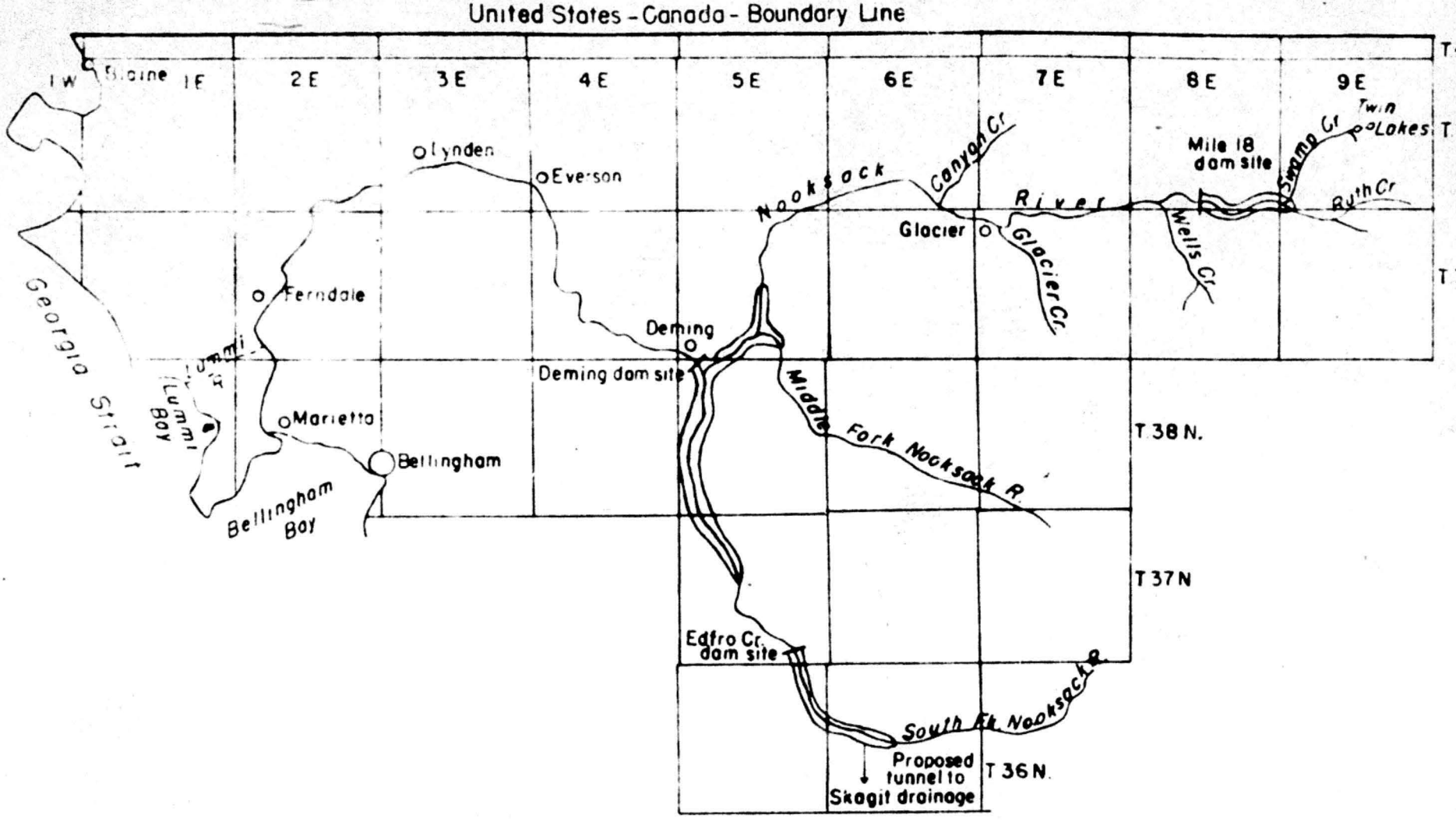
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KEY MAP

Nooksack River and Tributaries
showing reservoir sites

WATER UTILIZATION IN THE NOOKSACK RIVER, WASHINGTON

By R. O. Helland

PURPOSE AND SCOPE OF THE INVESTIGATION

The primary purpose of the investigation of the water resources of the Nooksack River was land classification. The Nooksack basin lies largely within the Mt. Baker National Forest and a considerable area of public lands will be involved in any plan for the ultimate development of its water power. Surveys on a scale of 1:24,000 and 1:31,680 were made from the mouth of the Nooksack River upstream to include such stretches of all streams in the basin as appear to have sufficient flow and head or storage possibilities to attract future power development. A dam site on the main stream and one on South Fork were mapped on a scale of 400 feet to the inch. A dam site on the main stream near Deming was mapped in 1938 by the U. S. Engineers. Areas within the basin not covered by these surveys are largely shown on quadrangle maps. The lower basin has been mapped on a scale of one inch to the mile, and the upper basin on a scale of one quarter inch to the mile (Mt. Baker district). These surveys and a brief record of discharge on the principal streams of the basin together with a general reconnaissance form the basis of this report. It outlines roughly a plan of development showing the potential power of the Nooksack River and its tributaries, and considers briefly the problems of flood control and irrigation within the basin.

SUMMARY

1. The Nooksack River has its source in the region of Mt. Baker, drains an area of about 800 square miles in northwestern Washington, a nd a small undetermined area in Canada, and empties into Bellingham Bay.

2. The upper basin of the Nooksack is one of strong relief, heavily timbered and well watered. The large area in the lower basin is relatively flat and is largely under cultivation.

3. The climate of the Nooksack basin is strongly influenced by the sea, is temperate and humid, the mean annual precipitation varying from 33 inches in the low coastal region to 102 inches in the higher elevations surrounding Mt. Baker. However, very little rain falls during July and August.

4. The Nooksack River has a well sustained flow due to its source in the snow-covered and glacial region of Mt. Baker. The mean annual run-off at a station located below the junction of South Fork near Deming for the five years 1935-1940 was 2,210,000 acre-feet. The maximum flow of record at this station (1935-40) is 33,200 second-feet (October 28, 1937), the minimum, 560 second-feet (November 9, 10, 1936).

5. Storage primarily for power development is possible at two sites in the Nooksack basin, one site on the lower South Fork and one site on the main river near headwaters. The two storage sites have a combined capacity of about 412,000 acre-feet that may be feasible of development for power primarily, 112,000 on the main stream and 300,000 on South Fork. Storage of 500,000 acre-feet for multiple purpose uses may be feasible at a site on the main stream near Deming.

6. The total potential power of the Nooksack River and tributaries is estimated roughly as follows:

	With natural flow, horsepower	With regulation, horsepower
Mean	294,000	
For 50 percent of time	220,000	220,000
For 90 percent of time	110,000	180,000
For 95 percent of time	90,000	170,000
For 100 percent of time	50,000	160,000

7. Should irrigation eventually be practiced in the Nooksack basin, it would probably not affect materially the potential power of the river since the rate of the release for irrigation would probably not be in excess of the rate of release for power, and since all but a very small part of the available water could be utilized for power development through all but a few feet of available head before diversion into irrigation canals.

8. Adequate flood control in the Nooksack basin may require a total storage capacity of 200,000 acre-feet in addition to revetments and other channel improvements.

GEOGRAPHY AND PHYSICAL FEATURES

The Nooksack River has its source in the region of Mt. Baker and Mt. Shuksan in northwestern Washington and flows westward to Bellingham Bay, draining an area of about 800 square miles within the United States and a small undetermined area in Canada. The upper basin is a region of strong relief, the

most prominent features being Mts. Baker and Shuksan, which are snow capped throughout the year. The river has three principal forks, the main stream, sometimes called the North Fork, the Middle Fork, which joins the main stream about 5 miles above Deming, and the South Fork which joins the main stream about one mile above Deming. All tributaries of the Nooksack have a steep gradient in the region of the headwaters, but level off as they reach lower elevations. Below Deming the main stream has a low gradient and follows a meandering course through a region of low relief to Bellingham Bay. A large part of this lower basin has been cleared and is now devoted to dairy farming. (See Sumas and Blaine quadrangles).

The Nooksack basin above Deming is generally timbered with the exception of the valley bottoms of the three forks which have been largely cleared in their lower stretches and now support a considerable number of thriving farms, principally engaged in dairying. Large areas in the upper basin have also been cut over, but few attempts have been made to farm this rough stump land. The upper basin is largely within the Mt. Baker National Forest. A number of small villages are scattered throughout the lower basin. Bellingham, a thriving city on Bellingham Bay is the trade center of the region. Although situated within 5 miles of the mouth of Nooksack River, this city is not within its drainage but is separated by a low divide.

CLIMATE

The climate of the Nooksack basin is tempered by the close proximity of the ocean. Summers are moderately warm and have a high percentage of clear days. Rains usually commence in early fall and winter and spring have a high percentage of cloudy or rainy days.

Although the average precipitation for the basin is comparatively high, there is a wide range between stations at which records have been kept, the higher elevations receiving a much greater precipitation than the lower. In the following table is summarized the monthly and annual mean precipitation for five rainfall stations in the basin:

Mean monthly precipitation in inches,
stations in the Nooksack River and adjacent basins,
Washington.

Month	Mt. Baker Lodge# El.4,200 ft. 8-yr.rec'd	Glacier* El.960 ft. 9-yr.rec'd	Marietta El. 10 ft. 27-yr.rec'd	Near Bellingham 19-yr.rec'd	Bellingham El. 60 ft. 36-yr.rec'd
Jan.	12.45	6.91	4.56	4.63	4.35
Feb.	9.91	4.86	3.03	2.96	3.18
Mar.	13.79	5.14	3.33	3.24	3.11
Apr.	7.64	3.51	2.16	2.23	2.14
May	6.19	2.70	1.51	1.82	1.81
June	5.21	2.89	1.65	1.60	1.72
July	2.84	1.59	0.89	0.85	0.92
Aug.	2.28	1.09	0.86	1.23	1.04
Sept.	6.00	3.05	2.08	2.20	2.15
Oct.	11.39	6.16	3.40	3.43	3.37
Nov.	12.03	6.57	4.03	4.35	4.29
Dec.	16.54	9.67	5.23	4.79	4.97
Year	101.54	58.07	32.58	33.36	33.05

*Record complete for 9 years; fragmentary for 9 additional years.
#Record complete for 8 years; fragmentary for 5 additional years.

This table shows that the headwaters region of the Nooksack River receives about three times as much precipitation as the coastal region. Since the season of heaviest precipitation is winter, this comes in the form of snow at the higher elevations and remains on the mountains until spring, when it is released by melting and greatly adds to the spring flood flow of the river. Some snow is carried over from year to year on the high elevations of Mt. Baker and is compacted into the glaciers of the region. These in turn supply water to the streams in the drier part of summer when the accumulation of snow at the lower elevations has melted. The glaciers therefore yield their maximum of water to streams at a season when other sources, rain, springs and melting snow, provide a minimum, and for this reason are of great value in contributing toward a well-sustained flow.

FACTORS AFFECTING HYDRAULIC STRUCTURES

Because of the temperate climate of the region, the Nooksack River should have no serious ice problem. However, ice has formed over the sluggish lower stretches of the river to such an extent as to cause jams which were a major factor in

floods. Logs and uprooted trees from the forests are carried down in large numbers by high water, and provision would have to be made for removing these from reservoirs. Another troublesome factor is the presence of a fine glacial silt in the river, especially on the North Fork. This fine silt gathers in a thick coat over water wheels and accumulates in forebays, tunnels, conduits and canals from which it must be removed. The quantity of silt in the water varies with the season, and is greatest during periods of warm weather when glacial water is released at the maximum rate. The normal surface run-off from rains and melting snow, contains very little silt.

WATER SUPPLY

The following records of discharge are available for stations in the Nooksack River basin:

Stream	Point	T. & R.	Sec.	Sq.mi.	Years
Nooksack River	at Deming	38N-5E	6	580	1935-1941
" "	near Glacier	39N-6E	2	195	1910-11 (frag.) 1934-1938
" "	above Cascade Cr.	39N-7E	1	105	1937-1941
" "	at Excelsior	40N-8E	31	96	1920-1921
S.Fk. " "	nr. Wickersham	37N-5E	26	103	1934-1941
Nooksack R.	at Saxon Bridge	37N-5E	21	129	Fragmentary 1920-1921 July, 1932 to Sept., 1934
Middle Fork Nooksack River	near Deming	38N-5E	13	70	1920-21, 1934-35

Monthly summaries for the periods of the records will be found in succeeding pages. Records for the water year 1940-41 are not included in the computations of this report.

The Nooksack River has a well-sustained summer flow because of its origin in the snows and glaciers of the Mt. Baker region. This is especially true of the main stream, or North Fork, which drains the greater part of the snow-capped area.

In the following table is summarized the record of discharge on the main stream near Deming, where the drainage area is 580 square miles:

Year	1935-36	1936-37	1937-38	1938-39	1939-40	1940-41*
Max. s.f.	12,100	20,100	33,200	23,000	14,200	12,200
Min. s.f.	600	560	782	625	612	692
Mean s.f.	3,063	2,848	3,133	3,183	3,030	2,444
Total A.F.	2,224,000	2,062,000	2,268,130	2,304,000	2,199,560	1,769,610

*Not included in computations of this report.

Records of discharge for Rogue River at Reygold, Oregon, complete since 1905, indicate that the period of the Nooksack River record (1935-40) is probably close to the long time mean.

An important record of discharge on Nooksack River is the record for the station above Cascade Creek since this station is located only a short distance below the Mile-18 dam site. In order to obtain an extension of this record based on probabilities, a factor has been applied to the record for the station on Nooksack River near Glacier (below Canyon Creek) for the years 1934-37. Both stations were maintained during the water year 1937-38. During this year the lower station recorded a total run-off of 847,690 acre-feet. The upper station recorded 530,170 acre-feet. Accordingly, the ratio 530,170/847,690, or 0.625, has been applied to the record near Glacier to obtain the probable run-off at the station above Cascade Creek. In the following table is given the annual run-off for the stations on Nooksack River above Cascade Creek (area 105 sq. mi.) and near Glacier (area 195 sq. mi.) actually recorded for certain years and as estimated for other years.

Annual run-off in acre-feet at stations on Nooksack River

Year	Above Cascade Creek Acre-feet	Near Glacier Acre-feet
1934-35	522,000 (est.)	835,400
1935-36	450,000 (est.)	720,500
1936-37	444,000 (est.)	709,050
1937-38	530,170	847,690
1938-39	549,360	880,000 (est.)
1939-40	536,540	860,000 (est.)
Mean	505,300	808,000
Per sq. mi.	4,812	4,143

In order to determine the probable mean run-off for subdivisions of the basin of Nooksack River above the junction of Middle Fork, the total drainage area has been sub-divided into minor areas, and the probable mean annual run-off for each minor area has been estimated from relative drainage areas, meteorological conditions, and a comparison of the parallel records on Nooksack River for the year 1937-38 at the station near Glacier (below Canyon Creek) and the station above Cascade Creek.

In the following table are given the estimated mean annual run-off for sub-divisions of the drainage basin above Middle Fork:

Estimated mean annual run-off for areas in Nooksack River basin (1934-40)

Stream and Area	Sq. Mi.	A.F. per sq.mi.	Total acre-feet
Nooksack River near Glacier (below Canyon Creek)	195	4,143	808,000*
Nooksack River above Cascade Creek	105	4,812	505,300 (a)
Nooksack River below Wells Creek (Mile 18 run-off area)	95	4,948	470,000#(a)
Glacier Creek at mouth	34	4,800	163,000#
Canyon Creek at mouth	30	3,333	100,000
Nooksack basin between Canyon Creek and Wells Creek, excluding Glacier Creek	36	2,083	75,000
Nooksack basin between Middle Fork and Canyon Creek	70	1,000	70,000

STORAGE

Storage on Nooksack River and its tributaries is necessary to complete power development, and would be a material factor in flood control. It would also have value for irrigation. There are only two points at which major storage primarily for power development may be feasible. One site is located on the main stream (or North Fork) at an altitude of 1,890 feet, the other on South Fork at an altitude of 400 feet. A large reservoir site on the main stream near Deming may have value for flood control and irrigation but, owing to its low altitude (203 feet), would have comparatively little value for power.

It seems probable that in the event that irrigation should eventually be practiced in the Nooksack basin the water utilized for this purpose could be abundantly supplied from diversions below the downstream area of probable power development, and from tributary creeks not brought into the power scheme. It seems probable that irrigation needs will never exceed the regulated flow proposed for power development. The bulk of the cultivable and irrigable lands in the basin are in the area below Deming, the approximate lower limit of feasible power development.

*Based on combined records 1934-40 at the two stations on Nooksack River.
#Based on run-off per sq. mi. for station above CascadeCr.(p.6)
(a) Overlapping areas.

STORAGE SITES

Mile 18 Reservoir Site - (12P5 2). At a point in what will probably be, when surveyed, sec. 34, T. 40 N., R. 8 E., or about a quarter of a mile above mile 18 at water surface elevation 1890 feet, as shown on Sheet B of the river survey, conditions may be favorable for the construction of a concrete dam. This dam site is formed by a series of four hills, densely timbered, which rise abruptly from the valley floor and extend in a chain from the left, or south bank, to a point near the right, or north bank, and there slope steeply into the river bed. This dam site was examined by J. C. Miller, geologist, in June 1939, who finds that the formation is a glaciated extrusive flow of undetermined thickness. This flow is in itself a strong, durable andesite suitable as foundation for a concrete dam, but drilling will be necessary to determine whether the flow lies on top of other rock suitable as dam foundation, or whether, if the flow overlies fill, it has a thickness sufficient to withstand the weight of a dam of the desired height. Mr. Miller's examination also indicates that drilling will be necessary to determine the extent of drift in the proposed abutments.

This dam site has possibilities for a natural spillway through a saddle near the left bank, but Miller found that geologic conditions indicate danger of serious scouring.

Although geologic conditions involved throw some doubt upon the feasibility of this site, the possibility seems fair that it may present no insurmountable obstacles to construction.

No discharge records have been obtained for the Nooksack at this site but a fair estimate of run-off may be had from study of discharge records at two stations downstream.

A 3-year record (1937-40) is available for a gaging station on the Nooksack at a point above Cascade Creek where the drainage area is 105 square miles. The drainage area above the Mile-18 site is about 67 square miles. It is proposed herein, however, to divert the flow of Wells Creek into the Mile-18 reservoir. This diversion would give the proposed Mile-18 reservoir a total drainage of about 95 sq. mi., or 90 percent of the total drainage above the gaging station. Hence the run-off for the Mile-18 reservoir site may be considered as roughly 90 percent of the recorded run-off. This estimate is probably somewhat low, since the snow and ice covered region of the headwaters probably has a higher run-off per unit area than the area immediately above the gaging station.

Assuming that the run-off at the Mile-18 dam site is equal to 90 percent of the recorded run-off at the station on Nooksack River above Cascade Creek, fig. 5a shows that a storage capacity of 110,000 acre-feet at this site would have been sufficient to equalize the flow in all 3 years of the record, and that a minimum flow of 630 second-feet might have been maintained.

The mean run-off for the 3 years of this record appears from a longer record near Glacier (1934-38) to have been about 6 percent above the 1934-40 mean.

Storage of 110,000 acre-feet in the proposed Mile-18 reservoir would require a dam 182 feet high. Since the lower 50 feet of dam would represent only 2,000 acre-feet of storage, however, this part of the dam could be more advantageously used for dead storage to create head. Storage of a total of 112,000 acre-feet would require a dam 183 feet high above normal water surface. A 183-foot dam would have a crest length of about 2,500 feet as roughly determined from a 1:31,680 survey. The dam would be in two sections, an overflow section 550 feet in crest length in a ravine on the left bank, and a non-overflow section of 1,950 feet in crest length. The two sections would be separated by a small hill. The volume of a concrete dam of gravity type, 183 feet high, as determined roughly from the 1:31,680 survey, is 220,000 cu. yds., not allowing for the sub-surface portion.

A dam 183 feet high would inundate a densely forested area of 1,460 acres. There are no improvements in the area except a graveled highway and a few cabins.

Mile 16 Reservoir site (12PB 3). In what will probably be, when surveyed, sec. 32, T. 40 N., R. 8 E., there is a narrow gorge which has possibilities as a dam site. This site is alternative to the Mile-18 dam site described above, and is located about 2 miles downstream or at Mile 16, as shown on the river survey. Rock is exposed to a height of more than a hundred feet above water surface, and small outcrops on both banks indicate that base rock is near the surface over the entire area of the site. If geologically suited, very little excavation would be necessary. The rock does not have a favorable appearance, however, and may not be geologically suited to dam construction. Much of it is dark in color, has a slaty appearance and may be easily pried loose. It is not uniform in appearance and appears to be a mixture of rock of various origin. Some carbonaceous shale is found near the proposed axis of the dam. This site has been examined by Chas. E. Erdmann, geologist, who states that conditions in the left abutment must be regarded as unfavorable for a high dam, the rock being structurally weak and highly permeable.

Storage of 112,000 acre-feet at this site would require a dam 256 feet high with crest length of 900 feet. Assuming that it could be built from concrete, a 256-foot gravity, overflow type dam at this site would have a volume of about 320,000 cubic yards, not including the sub-surface portion. This would represent a yardage-capacity ratio of 2.86 cubic yards to the acre-foot as against 1.97 at the Mile-18 site. Located at an altitude of 1,780 feet, it would command about 110 feet less of head than the Mile-18 site.

Wells Creek reservoir site (12PB 8). A small volume of storage or pondage could be developed on Wells Creek by the construction of a dam at mile 2.2 as shown on sheet B of the survey. Rock is exposed to a height of about 50 feet or more above water surface, and very little excavation would probably be necessary in any area of the site (See map on sheet B*). The site has been examined by Chas. E. Erdmann, geologist, who reports favorably on its geology. Although this storage site is small and would represent a high ratio of yardage to capacity (17 to 1), it has a peculiar value in the fact that it would enable almost complete diversion of the flow of Wells Creek into the proposed Mile-18 reservoir on Nooksack River. Such a plan of diversion would require about 4 miles of canal or conduit, or 1.6 miles of tunnel.

The volume of storage or pondage which would be required for complete diversion may be roughly determined from the record of flow on Nooksack River above Cascade Creek. Assuming that the flow in Wells Creek at the dam site is 25 percent of the recorded flow in Nooksack River above Cascade Creek, or proportional to relative drainage areas, a study of the run-off for the month of greatest discharge of the record (June, 1938) and for the month showing the greatest winter run-off for the record (December 1939), indicates that a storage capacity of 3,600 acre-feet on Wells Creek at mile 2.2, and a canal or tunnel of 480 second-feet capacity, would have been sufficient to have caught and diverted all Wells Creek flow during these months (see fig. 9a). It will be noted that the winter month (December 1939), although having the lesser run-off, has much the greater variation in flow. Summer flow, which is largely caused by normal melting of snow and glacial ice, is generally more uniform than winter flow, which may vary greatly as a result of rains and Chinook winds.

Allowing some margin for greater fluctuation and for the possibility that Wells Creek flow may be somewhat greater than estimated, a storage capacity of 5,000 acre-feet and a tunnel

*Not included in this report.

capacity of 600 second-feet are proposed to meet the probable maximum demand for complete diversion in the majority of years.

A reservoir of 5,000 acre-feet capacity at the Wells Creek site would require a dam about 115 feet high, with crest length of 1,080 feet. If built from concrete, and of gravity, overflow type, it would have a volume of 85,000 cubic yards, no allowance being made for the sub-surface portion. It would flood a forested area of 100 acres without improvements. Because of the great amount of gravel and drift carried by the stream during high water, the life of a reservoir at this site would probably be short.

Edfro Creek Reservoir Site (12PB 14). In sec. 35, T. 37 N., R. 5 E., on the South Fork of Nooksack River, at water surface altitude of 400 feet, is the Edfro Creek dam site, which offers the only opportunity for major storage on this fork. Geologic examination indicates a considerable depth to bedrock in the valley floor. This bedrock is described as a graphitic schist. A report on this dam site by Chas. E. Erdmann, geologist, is now available. The site has been drilled by the U. S. Army Engineers.

A 6-year record of discharge (1934-40) on South Fork near Wickersham (3/4 mile above Skookum Creek) may be used as the approximate record at the Edfro Creek dam site. The drainage area at the dam site is only slightly less than the drainage area at the gaging station. Based on this record, storage of 150,000 acre-feet would be required for complete equalization of flow at the dam site. If, however, geologic conditions at the Edfro Creek dam site are suitable for a high dam, the most feasible plan of power development on the South Fork may be through diversion by tunnel into the basin of Skagit River near Lyman. The lower 220 feet of dam would then be required to backwater to the elevation of the proposed tunnel intake, which would be at about 620 feet above sea level. Assuming storage of 150,000 acre-feet above this elevation, or a total storage of 300,000 acre-feet, a dam 305 feet high, rising to an elevation of 705 feet above sea level, would be required. A 305-foot dam at this site would have a crest length of 1,900 feet. The apparent great depth of valley fill may rule out a concrete dam at this site, and the feasibility of a flexible dam of any type will depend on the bearing power of this fill.

A 305-foot dam at this site would flood about 2,050 acres, of which possibly 40 percent may be sufficiently level for cultivation when cleared of stumps and timber. The rest of the area is too rough for cultivation and is partly timbered, partly cut-over stump land. A few small ranches have

been occupied at one time but are now abandoned. A few cattle range in the meadow lands of the area. No improvements have been made other than a few fences and shacks.

Should this site be utilized also for flood control, additional capacity would be required, and a higher dam constructed. The storage capacity could then be divided between the following uses: From 0 to 220 feet, dead storage for head. From 220 to 305 feet, storage for power, From 305 feet upward for flood control.

Deming Reservoir Site (12PB-16). Just below the confluence of the South Fork of the Nooksack River and about one mile above Deming, in sec. 6, T. 38 N., R. 5 E., is a constriction in the valley of the Nooksack that has possibilities as a dam site for the development of major storage. The U. S. Army Engineers made an investigation of this site in 1939, which included some exploratory drilling. If not suited to a concrete dam, it is believed that this site may be suitable for an earth or rock-fill dam.

The height of a dam at this site would be limited by the elevation of a saddle between the Nooksack and Samish River basins near Wickersham. The lowest point in this saddle is 322 feet above sea level. (See river survey of 1938). Whether or not it would be practicable to store water to the height of this saddle will depend upon the permeability of the valley fill in this area. Assuming construction of a dam rising to an elevation of 321 feet above sea level, a reservoir of 500,000 acre-feet capacity would be created, which would be sufficient for almost complete annual equalization of flow as determined from the 5-year record from 1935 to 1940. Such a dam would have a height of 118 feet above normal water surface. Normal water surface at this site is about 203 feet above sea level. A 118-foot dam would flood 9,800 acres, most of which is within the valley of the South Fork. The area is largely agricultural land. A part is woodland, timberland, and stump land. It is thickly settled, but most houses and farm buildings are relatively small.

The principal value of this site is for flood control, but some power could be developed in connection with such use. During the 5-year period from 1935 to 1940, which included a peak flow of 33,200 second-feet (Oct. 28, 1937), a 118-foot dam could have provided sufficient control to have maintained a flow varying from a minimum of 2,800 second-feet to a maximum of 3,100 second-feet.

POWER

The generation of electrical power is probably the most important potential value of water in the Nooksack basin. Concentration of head in the streams of the upper basin together with a well-sustained flow and the possibility of regulation through storage on the two larger forks, makes the Nooksack River a valuable power stream. Its proximity to Puget Sound with its growing cities and vast possibilities for future industrial and commercial expansion gives the power resources of Nooksack River a high potential value.

Ultimate power development on the Nooksack River may follow any one of several possible plans. There are, however, certain natural features of the basin which suggest a fairly well defined scheme for its fullest development. These may be listed as follows:

1. The Mile-18 dam site (or its alternative, the Mile-16 dam site) on the main stream (North Fork).

2. A minor dam site on the main stream near Maple Falls.

3. A dam site on the main stream near Deming.

4. A dam site on South Fork near Edfro Creek.

5. A narrow divide between South Fork Nooksack and Skagit River basin near Lyman, which would require a short tunnel for diversion into Skagit drainage.

If geologic conditions are favorable, these dam sites will probably determine the general plan of development in the basin. The size of the proposed structures will depend upon several factors, especially the degree of control which may be sought for floods. Development of all head in the basin not concentrated at these dam sites must be accomplished by canal, conduit or tunnel. The general pattern which this canal and conduit development may follow will depend to a large extent upon the feasibility of the proposed dam sites. It will also be determined to a certain extent by natural features which will permit the utilization at several points of a common power house for the development of flow from the main and tributary streams. The plan of development herein outlined assumes the feasibility of all proposed dam sites.

DEVELOPED POWER SITES

The only developed power site on Nooksack River is in sec. 31, T. 40 N., R. 8 E. This plant is owned by the Puget Sound Power and Light Co., and utilities a total head of 210 feet. The rated capacity of installed water wheels is 3,200 h.p. of generators, 1,875 h.p.

UNDEVELOPED POWER SITES

Swamp Creek power site (12PB 1). Swamp Creek and Ruth Creek enter the Nooksack so close together that it may be feasible to divert both at the same elevation and bring their flow into a common penstock discharging into a power house near the mouth of Swamp Creek. Both creeks have a steep gradient below an altitude of 3,020 feet, and the profile of both flattens for about two miles above this elevation. Diversion of both streams at an altitude of about 3,020 feet is proposed herein. No tributary of size enters either stream below the proposed point of diversion, and it seems probable that the flow in each for 90, 95 and 100 percent of the time would be very nearly as great at the proposed points of diversion as it is at their mouths. The flow for 50 percent of the time is probably only slightly less than at mouth.

Canal location is probably good, but some cliffs might be encountered. Both streams flow in deep gorges in certain stretches, and these gorges might make necessary some changes in the proposed diversion points, possibly to bring them further upstream. The area is densely timbered.

The elevation of the power house would be determined by the height of backwater from storage on the Nooksack, which, according to a plan proposed in this report, would approximate 2,073 feet. The available gross head is accordingly about 950 feet.

No opportunity for regulation of flow exists on these streams. Twin Lakes at the head of Swamp Creek are located so near the divide as to receive only a very small drainage and are probably of little value for storage. The natural flow is roughly estimated from the record on Nooksack River above Cascade Creek and direct drainage area ratio. Both streams were running a sufficiently strong current in the summers of 1931, 1932, and 1933, and both showed indications of a sufficiently heavy discharge to make the estimates thus obtained seem reasonable. In view of the fact, however, that the headwaters tributaries of the Nooksack differ widely in the relative percentage of water which they derive from

glaciers and snow, estimates based on drainage area must be regarded as very rough.

The following table gives estimates of potential power at the Swamp Creek site based on estimated flow:

Potential power at Swamp Creek power site (12PB 1)

Gross head 950 feet				70 percent efficiency			
Estimated natural flow (sec-ft)*				Horsepower			
For 50 percent of time Q 50	For 90 percent of time Q 90	For 95 percent of time Q 95	For 100 percent of time Q 100	For 50 percent of time	For 90 percent of time	For 95 percent of time	For 100 percent of time
90	40	30	10	6,800	3,000	2,300	700

*From record on Nooksack R. above Cascade Cr. and drainage area ratio.

Mile 18 power site (12PB 2). For a general description of this site see discussion under "Storage Sites." Based on the 3-year discharge record at a station above Cascade Creek (1937-40), annual equalization of flow at this site would require a dam 162 feet high assuming that the lower 50 feet were utilized for head. The period 1937-40 was a period of somewhat higher than normal flow. Water would be taken out at an elevation of 1940 feet. If carried by canal or conduit to the power house of the Puget Sound Power and Light Company 3 miles downstream a gross head of 605 feet would be available. On the basis of the 7-year combined records of discharge near Glacier (1934-38) and above Cascade Creek (1937-40) a continuous flow of 370 second-feet would be possible. This would give a minimum production at 70 percent efficiency of 18,000 horsepower. During 50 percent of the years of the record a continuous flow of 475 second-feet would have been possible with regulation, yielding 23,000 horsepower.

An alternative and more attractive plan of development at this site involves diversion of Wells Creek by tunnel into the proposed Mile-18 reservoir. This alternative plan has several advantages which might justify the higher construction costs. A tunnel 1.6 miles in length with intake at water surface elevation 2,300 feet on Wells Creek would conduct the flow of Wells Creek to a point on Nooksack River about 1/4 mile above the Mile-18 dam site. Diversion of nearly all of the flow in Wells Creek could probably be accomplished by construction of a dam at mile 2.2 on Wells Creek. (For a more complete description of the Wells Creek Reservoir site see page 10).

The combined run-off for the Nooksack at the Mile-18 dam site and at the Wells Creek dam site is estimated at 90 percent of the recorded run-off for Nooksack River above Cascade Creek at which station a record is available for the 3-year period, 1937-40. On the basis of this record and factor, storage of 110,000 acre-feet in the proposed Mile 18 reservoir would be sufficient to give almost complete annual equalization of flow (see fig. 5a). A minimum of 630 second-feet could have been provided throughout the 3-year period. If developed through the 605 feet of available head at this site, it would yield 30,500 continuous horsepower.

Storage of 110,000 acre-feet at the Mile 18 site would require a dam 182 feet high.

These estimates are given merely as descriptive of potentialities at this site assuming no development at sites down stream. Since, however, ultimate development contemplates also sites downstream, the release of stored water from the Mile-18 reservoir would be governed by the needs of the system of which it would be a unit.

A summary of potential power which follows on a later page (page 28) is based on the assumption that the proposed Mile-18 reservoir will be operated with the aim of securing highest yield of prime power from the series of sites on Nooksack River.

Potential power at Mile-18 power site (12PB 2)

Gross head 605 feet : Flow in second-feet(c)				70 percent efficiency : Horsepower			
For 50 percent of time: Q 50	For 90 percent of time: Q 90	For 95 percent of time: Q 95	For 100 percent of time: Q 100	For 50 percent of time	For 90 percent of time	For 95 percent of time	For 100 percent of time
(With natural flow(a))							
540	230	180	75	26,000	11,000	8,700	3,600
(With regulation (a)(b))							
630+	630	630	630	30,500+	30,500	30,500	30,500

(a) Includes Wells Creek diversion.
(b) Assuming no development downstream. These estimates are descriptive of potentialities only. Actual reservoir operation would probably result in wide variation in the rate of release.
(c) Estimated at 90 percent of flow above Cascade Creek.

Mile-16 power site (12PB 3). For a description of the Mile-16 reservoir site see discussion under "Storage Sites." The Mile-16 dam site has possibilities for power development comparable with the Mile-18 site, but is alternative to the Mile-18 site, which appears to be preferable. No further consideration will therefore be given in this report to the Mile-16 power site.

Wells Creek power site (12PB 7). The two forks of Wells Creek, a glacial stream, could be diverted at an elevation of 3,000 feet, and their combined flow carried by canal or conduit to a power house at the junction of the forks at an altitude of 2,435 feet. The flow of the two forks at the points of diversion, together with the flow which could be picked up along the course of the conduit, would almost equal for 90, 95, and 100 percent of the time the flow at the proposed Wells Creek dam site (mile 2.2). For 50 percent of the time the diverted flow would be somewhat less than the flow at the dam site. The flow at the dam site is roughly estimated at 25 percent of the recorded flow in Nooksack River above Cascade Creek. This estimate is based on drainage area ratio.

The proposed canal location is densely timbered, steep mountain side in which some cliffs occur.

Potential power at Wells Creek power site (12PB 7)

Gross head 565 feet :				70 percent efficiency			
Estimated natural flow, sec.ft.:				Horsepower			
For 50 percent of time Q50	For 90 percent of time Q 90	For 95 percent of time Q 95	For 100 percent of time Q 100	For 50 percent of time	For 90 percent of time	For 95 percent of time	For 100 percent of time
125	65	50	20	5,600	2,900	2,200	900

Tunnel power site (12PB 8). The lower 20 feet of the proposed Wells Creek reservoir would have a capacity of only 150 acre-feet and could therefore be used more advantageously for dead storage to create head. Assuming the tunnel to Mile-18 reservoir site on Nooksack River to have its intake at altitude 2,340 feet, and allowing a gradient of 2 feet per thousand, the tunnel would discharge at an altitude of about 2,323 feet. The maximum height of water surface in the proposed Mile-18 reservoir under the plan herein outlined is 2,073 feet. If the power house were built at this altitude, an effective head of 250 feet would be available.

The primary purpose of the proposed tunnel would be the diversion of Wells Creek flow into the proposed Mile-18 res-

ervoir, but a small degree of regulation could at the same time be effected, even with the small volume of proposed storage in Wells Creek (5,000 acre-feet). On the basis of the 3-year record of discharge on Nooksack River above Cascade Creek, and on the assumption that the run-off at this site is equal to 25 percent of the recorded run-off at this station, it is roughly estimated that a minimum flow of 80 second-feet could have been maintained throughout the period. This estimate is based on the record of January to March, 1938, and February and March, 1939, the periods of lowest flow. For 50 percent of the time an estimated flow of 120 second-feet would have been available. This small reservoir would probably be short-lived due to excessive deposits of gravel.

Potential power at Tunnel power site (12PB 8)

Head, 250 feet : Flow in second-feet*				70 percent efficiency : Horsepower*			
For 50 percent of time : Q 50	For 90 percent of time : Q 90	For 95 percent of time : Q 95	For 100 percent of time : Q 100	For 50 percent of time	For 90 percent of time	For 95 percent of time	For 100 percent of time
(Regulated flow)							
120	80	80	80	2,400	1,600	1,600	1,600
(Natural flow)							
150	65	50	20	3,000	1,300	1,000	400

*Mean flow is 185 second-feet, which would develop 3,700 h.p.

Glacier power site (12PB 4). The Nooksack River could be diverted below the power house of the Mile-18 power site at 1,335 feet and its flow carried by canal or conduit about 6 miles to a power house near Glacier picking up the flow of tributaries. If the power house were located near Glacier it might be used also to house the installation of the Glacier Creek power site, thus avoiding the necessity for an additional power house. A location in the NW¼SW¼ of sec. 5, T. 39 N., R. 7 E., at water surface 885 feet seems feasible.

Canal location for this site is heavily timbered steep mountain side.

The natural flow at this site would be roughly equal to the recorded flow at the station above Cascade Creek.

Potential power at Glacier power site (12PB 4)

Gross head 450 feet : 70 percent efficiency							
Estimated flow in second-ft.:				Horsepower			
For 50 percent of time Q 50	For 90 percent of time Q 90	For 95 percent of time Q 95	For 100 percent of time Q 100	For 50 percent of time	For 90 percent of time	For 95 percent of time	For 100 percent of time
(With natural flow)							
600	260	200	100	21,600	9,300	7,200	3,600
(With regulation)							
V a r i a b l e (See summary page 28)							

Glacier Creek power site (12PB 9). Glacier Creek is a glacial stream fed from the glaciers and snows of Mt. Baker. This creek has no possibilities for storage, but its glacial origin gives it a well-sustained flow. The stream splits into numerous tributaries above an altitude of 2,000 feet and this elevation may therefore be close to the upper limit of feasible development. Additional surveys, however, may show that diversion would be feasible at a somewhat greater elevation.

Assuming diversion at an altitude of 2,000 feet, or in sec. 33, T. 39 N., R. 7 E., the natural flow of this stream could be carried by canal or conduit to a point within 2 miles of the power house of the Glacier power site described above. The remaining 2 miles would require pressure pipe. This plan would give the site a gross head of 1,115 feet. The natural flow of Glacier Creek is estimated from the duration curve for Nooksack River above Cascade Creek (fig. 4), assuming that the two basins have roughly the same yield per square mile and that Glacier Creek has a regimen similar to that of the Nooksack above the gaging station.

Canal location for this site is steep, heavily timbered mountain side.

Potential power at Glacier Creek power site (12PB 9)

Gross head 1,115 feet : 70 percent efficiency							
Natural flow in second-feet :				Horsepower			
For 50 percent of time Q 50	For 90 percent of time Q 90	For 95 percent of time Q 95	For 100 percent of time Q 100	For 50 percent of time	For 90 percent of time	For 95 percent of time	For 100 percent of time
180	75	60	25	16,000	6,700	5,300	2,200

Warnick power site (12PB 5). Nooksack River might be diverted below the junction of Glacier Creek by a low diversion dam backing water to the power house above at altitude 885 feet, and its flow carried by canal or conduit over the 3-mile stretch to Canyon Creek near Warnick and there discharged into a power house in common with the development on Canyon Creek at an altitude of 730 feet. Separate turbines would be required since diversions on the two streams would be at widely different elevations. Canal location would be in steep heavily timbered mountain side.

The natural flow at this site would be somewhat less than the discharge recorded for the station on Nooksack River near Glacier (below Canyon Creek), especially for 50 percent of the time. The flow for 90, 95, and 100 percent of the time would be only slightly less.

Potential power at Warnick power site (12PB 5)

Gross head 155 feet				70 percent efficiency			
Natural flow in second-feet*				Horsepower			
For 50 percent of time: Q 50	For 90 percent of time: Q 90	For 95 percent of time: Q 95	For 100 percent of time: Q 100	For 50 percent of time	For 90 percent of time	For 95 percent of time	For 100 percent of time
700	325	250	125	8,700	4,000	3,100	1,500

*For regulated flow and power, see Summary.

Canyon Creek power site (12PB 10). Canyon Creek has a steep gradient from mouth to an altitude of 2,000 feet, proposed diversion point, above which there is a flattening of the profile and splitting up of the stream into numerous small tributaries. Only a small part of the total flow is contributed by the small tributaries entering below an altitude of 2,000 feet, especially during low flow periods, and a considerable percent of this discharge might be picked up. Diversion at 2,000 feet should therefore, utilize almost all of the flow for 90 percent, 95 percent, and 100 percent of the time as estimated for the creek at its mouth, and for 50 percent of the time only a small part of the total run-off should be lost. The flow in Canyon Creek is estimated from the record on the Nooksack River below Canyon Creek and drainage area ratio, allowing a much smaller run-off per square mile to the Canyon Creek basin than is shown by the record for Nooksack River (see page 6). Canyon Creek drains an area of lower general elevation than the Mt. Baker region, and probably therefore has a lower run-off per square mile than the Nooksack near headwaters.

The flow at the proposed point of diversion could be carried by about 4 miles of canal or conduit and pressure pipe to a power house in common with the proposed Warnick power site, giving it a gross head of 1,270 feet.

Potential power at Canyon Creek power site (12PB 10)

Gross head 1,270 feet				70 percent efficiency			
Natural flow, second-feet				Horsepower			
For 50 percent of time Q 50	For 90 percent of time Q 90	For 95 percent of time Q 95	For 100 percent of time Q 100	For 50 percent of time	For 90 percent of time	For 95 percent of time	For 100 percent of time
100	45	35	15	10,000	4,600	3,500	1,500

Kulshan power site (12PB 6). From its junction with Canyon Creek (water surface altitude 730 feet) to the limits of backwater from the highest dam that might be feasible near Deming, the Nooksack River drops through a head of 410 feet which could be developed for power by canal, conduit, or dams, in one or more units. Possibly 100 feet could be developed by construction of a dam at the Maple Falls site in sec. 31, T. 40 N., R. 6 E. The total length of this stretch of river is 12 miles.

The natural flow in Nooksack River near Kulshan is somewhat greater than the flowrecorded for the station on Nooksack River at Canyon Creek. The additional drainage is approximately 70 square miles, and its yield is roughly estimated at 10 percent of the recorded run-off from Nooksack River at Canyon Creek, at which point the drainage area is 195 square miles.

The Maple Falls dam site was examined by J. C. Miller, geologist, in 1939, who believes the site may be suitable for a low dam.

Potential power at Kulshan power site (12PB 6)

Gross head 410 feet				70 percent efficiency			
Natural flow in second-feet*				Horsepower			
For 50 percent of time Q 50	For 90 percent of time Q 90	For 95 percent of time Q 95	For 100 percent of time Q 100	For 50 percent of time	For 90 percent of time	For 95 percent of time	For 100 percent of time
900	400	300	140	29,500	13,000	9,800	4,600

*For regulated flow and power see Summary.

Clearwater Creek power site (12PB 11). The Middle Fork of the Nooksack River has its source in the glaciers on the west slope of Mt. Baker and because of the well sustained summer flow from this source and the steep gradient of the stream near headwaters, it appears feasible to divert water for power development at a point not far below the area of the glaciers. The Mt. Baker topographic map and the river survey indicate that the upper limits of feasible development may be at an altitude of 2,600 feet, since the stream appears to split up above this elevation into forks having very small drainage areas. Assuming diversion of the Middle Fork at a point about 2 miles above the confluence of Green Creek, or at an altitude of 2,600 feet, the natural flow would be carried by canal or conduit to the confluence of Clearwater Creek, an 8-mile stretch, and there discharged into a power house at an altitude of 1,170 feet through a half-mile length of pressure pipe, giving the site a gross head of 1,430 feet.

The site would be dependent on natural flow alone, since there is no opportunity for regulation. The drainage area above the proposed power house is about 35 square miles. The drainage area above the gaging station on Middle Fork is 70 square miles. The discharge record on the Middle Fork covers only 2 full water years, 1920-21 and 1934-35. The earlier record was made at a section just below the mouth of Heislers Creek, where the drainage area is 72 square miles. The later record was made at a section just above the mouth of Heislers Creek where the drainage area is 70 square miles. The discharge of Heislers Creek is so small, however, that the two records are closely comparable. The 2 years of the record appear from the long-time record on the Willamette River at Albany to have been higher than probable mean, and it is therefore estimated on the basis of the Albany record that application of the factor 0.83 to the values obtained from the duration curve for Middle Fork may bring these values closer to the longer term mean.

Application of the factor 0.83 to the duration curve (fig. 13) indicates rates of flow for the Middle Fork of the Nooksack River at Heisler's Creek as follows:

For 50 percent of the time ..... 323 sec.-ft.
For 90 percent of the time ..... 187 sec.-ft.
For 95 percent of the time ..... 153 sec.-ft.

Information is lacking on the variation of flow in the Middle Fork near its source. The period of lowest flow probably occurs during the sub-freezing temperatures of winter when little or no water is released by melting ice and snow.

However, the contribution from springs above the proposed diversion point will probably be sufficient to maintain a relatively strong flow throughout the winter.

The following estimates of probable discharge at the proposed power house site are based on the records of flow near Heislers Creek and drainage area ratio:

For 50 percent of the time ..... 160 sec.-ft.
For 90 percent of the time ..... 90 sec.-ft.
For 95 percent of the time ..... 75 sec.-ft.
For 100 percent of the time ..... 60 sec.-ft.

A large part of this total flow may not be capturable. Estimates of potential power, here given, are, however, based on the total flow.

Potential power at Clearwater power site (12PB 11)

Gross head 1,430 feet : 70 percent efficiency							
Natural flow in second-feet : Horsepower							
For 50 percent of time Q 50	For 90 percent of time Q 90	For 95 percent of time Q 95	For 100 percent of time Q 100	For 50 percent of time	For 90 percent of time	For 95 percent of time	For 100 percent of time
160	90	75	60	18,300	10,200	8,600	6,900

Kulshan-Middle Fork power site (12PB 12). The Middle Fork of the Nooksack River could again be diverted below Clearwater Creek at an altitude of 1,170 feet, and its flow carried by canal or conduit to a point near Kulshan, about 7 miles. Power house location for this site would be determined by backwater from the proposed Deming dam. The limit of this backwater is probably at an altitude of 321 feet. The Kulshan-Middle Fork site would accordingly have a gross head of 849 feet. The natural flow at the power house site is slightly greater than the recorded flow at the junction of Heislers Creek. There is no opportunity for regulation. A large part of this total flow may not be capturable. Estimates of potential power here given are, however, based on the total flow.

Potential power at Kulshan-Middle Fork power site (12PB 12)

Gross head 849 feet : Natural flow in second-feet :				70 percent efficiency : Horsepower			
For 50 percent of time : Q 50	For 90 percent of time : Q 90	For 95 percent of time : Q 95	For 100 percent of time : Q 100	For 50 percent of time	For 90 percent of time	For 95 percent of time	For 100 percent of time
320	180	150	130	21,800	12,200	10,200	8,800

Wanlick Creek power site (12PB 13). Wanlick Creek, tributary to the South Fork Nooksack River probably marks the upper limit of feasible power development on this river. The river splits up into many tributaries above this point and only a small amount of power could be developed without an intricate system of canals, conduits and syphons in which to collect the flow from the several small feeders.

The river survey of 1934 ends at Wanlick Creek, but the basin above this point is shown on the Mt. Baker quadrangle map, scale, ¼ inch to the mile. Assuming diversion of South Fork just below the mouth of Wanlick Creek at an altitude of 1,820 feet and power house in sec. 21, T. 36 N., R. 6 E., the power site would receive the flow from a drainage area of approximately 35 square miles, assuming all flow capturable. Based on drainage area ratio and the record obtained from 1934 to 1940 at a station near Wickersham, natural flow at the proposed diversion point is estimated as follows:

For 50 percent of the time ..... 165 sec.-ft.
For 90 percent of the time ..... 35 sec.-ft.
For 95 percent of the time ..... 30 sec.-ft.
For 100 percent of the time ..... 22 sec.-ft.

This estimate covers a period which, according to the record on Willamette River at Albany, was slightly wetter than normal. On the other hand, it is highly probable that the run-off per square mile from the South Fork above Wanlick Creek is considerably greater, especially for 90 percent, 95 percent, and 100 percent of the time, than it is at the gaging station, since the higher elevations of this headwaters region probably give it a heavier precipitation. Rough estimates of the probable discharge of South Fork of Nooksack River below Wanlick Creek based on the foregoing considerations are as follows:

For 50 percent of the time ..... 165 sec.-ft.
For 90 percent of the time ..... 45 sec.-ft.
For 95 percent of the time ..... 40 sec.-ft.
For 100 percent of the time ..... 20 sec.-ft.

Assuming development of the Edfro Creek reservoir site to a capacity of 300,000 acre-feet, the maximum under a plan for power only, backwater should not interfere with a power house at an altitude of 710 feet. Assuming a power house at this altitude in the NE¼ sec. 21, T. 36 N., R. 6 E., the Wanlick Creek power site would have a gross head of 1,110 feet.

A large part of the total flow in South Fork at the power house site may not be capturable, and accordingly, not feasible of development.

Potential power at Wanlick Creek power site (12PB 13)

Gross head 1,110 feet				70 percent efficiency			
Natural flow in second-feet				Horsepower			
For 50 percent of time Q 50	For 90 percent of time Q 90	For 95 percent of time Q 95	For 100 percent of time Q 100	For 50 percent of time	For 90 percent of time	For 95 percent of time	For 100 percent of time
165	45	40	20	14,700	4,000	3,500	1,800

Lyman power site (12PB 14). This power site would draw its water from storage in the Edfro Creek reservoir site through a diversion tunnel. For description of the Edfro Creek reservoir site see discussion under "Storage sites." The most feasible plan of power development from Edfro Creek storage may be through diversion into the Skagit River through a tunnel diverting at an altitude of 620 feet in sec. 20, T. 36 N., R. 6 E., and having its exit in the NE¼ sec. 32, of the same township. This tunnel would have a length of about 2 miles. An additional length of approximately 2⅝ miles of canal and 1 mile of pressure pipe would convey the water to a power house in or near sec. 17, T. 35 N., R. 6 E., on Skagit River near the village of Lyman. The site would have a gross head of about 560 feet and an estimated minimum flow with regulation of 625 second-feet as determined from the 1934-1940 discharge record near Wickersham, and assuming that the proposed plant is operated as an independent unit. Regulation to secure this minimum flow would require a dam 305 feet high storing 300,000 acre-feet, of which 150,000 acre-feet would be above the 620-foot level.

As determined from this 6-year record, the potential power at the Lyman power site is estimated as follows:

Potential power at Lyman power site (12PB 14)

Gross head 560 feet : Flow in second-feet				70 percent efficiency : Horsepower			
For 50 percent of time Q 50	For 90 percent of time Q 90	For 95 percent of time Q 95	For 100 percent of time Q 100	For 50 percent of time	For 90 percent of time	For 95 percent of time	For 100 percent of time
(Natural flow)							
500	110	90	65	22,400	4.900	4,000	2,900
(Regulated flow)*							
625	625	625	625	28,000	28,000	28,000	28,000

*Assuming regulation to s ecure highest yield of prime power at site 12PB 14.

A comparison with the long time record (1895-1940) on Willamette River at Albany, Oregon, indicates that the 6-year period on which the above esti.a tes of potential power are based, may be years of slightly greater than mean flow, and accordingly, that the potential power at the Lyman site that would be reasonably dependable over a long period of years, would fall somewhat under the given estimates.

Acme power site (12PB 15). As an alternative to the Lyman power site, the Acme power site could be developed to divert stored water from the proposed Edfro Creek reservoir at an altitude of 620 feet. This diversion could be carried by canal and syphon or flume to a point about 2 miles upstream from Acme, in sec. 16, T. 37 N., R. 5 E., to a power house at an altitude of 321 feet. This plan would require 5 miles of canal or conduit, and a syphon or flume crossing Skookum Creek. The regulated flow at this site would be roughly the same as that estimated for the Lyman power site.

Potential power at Acme power site (alternative)(12-PB-15)

Gross head 299 feet : Flow in second-feet				70 percent efficiency : Horsepower			
For [illegible] percent of time Q 50	For 90 percent of time Q 90	For 95 percent of time Q 95	For 100 percent of time Q 100	For 50 percent of time	For 90 percent of time	For 95 percent of time	For 100 percent of time
(Natural flow)							
500	110	90	65	12,000	2,600	2,100	1,600
(Regulated flow)							
625	625	625	625	15,000	15,000	15,000	15,000

Deming power site (12PB 16). For description, see Deming reservoir site (12PB 16). Although this site is of greatest value as a potential flood control reservoir, it also has potential value as a power site. The mean annual run-off at this site, as determined from a 5-year record, (1935-40) at a station located just below the junction of South Fork is 2,210,000 acre-feet. A dam 118 feet high, creating a reservoir of 500,000 acre-feet capacity, would provide almost complete regulation on the basis of this 5-year record, and would make possible a minimum flow of 2,800 second-feet. However, development of this site primarily for power would involve drawdown with variable head, and flow. During the 5 years of the record of discharge a constant power output of 20,000 horsepower could have been maintained, assuming operation of this site as an independent unit. Since there are no power sites downstream, re-regulation of flow at this site would probably be aimed at the highest yield of prime power for the site, unless storage to be developed upstream should be inadequate for satisfactory regulation. Since proposed storage at the Mile-18 and Edfro Creek reservoir sites is sufficient to give a high degree of regulation, it will be assumed in this report that the Deming power site would be operated as an independent unit.

If the South Fork Nooksack River is diverted into Skagit drainage, this would reduce the flow and power at the Deming site proportionately to the diverted flow.

Potential power at Deming power site (12PB 16)
(Assuming development primarily for power)

Head, 64-118 feet :				70 percent efficiency			
Flow in second-feet* :				Horsepower			
For 50 percent of time: Q 50	For 90 percent of time: Q 90	For 95 percent of time: Q 95	For 100 percent of time: Q 100	For 50 percent of time:	For 90 percent of time:	For 95 percent of time:	For 100 percent of time
(Natural flow)							
2,500	1,000	800	560	23,600	9,400	7,500	5,300
(Regulated flow)							
Variable				20,000	20,000	20,000	20,000

*If South Fork Nooksack River is diverted into Skagit drainage, flow and power at Deming would be reduced in proportion. The summary of potential power (table, page 28) assumes this diversion.

SUMMARY OF POTENTIAL POWER IN THE NOOKSACK RIVER BASIN, WASHINGTON

Index 12PB-	Site	Stream	Gross head (feet)
-1	Swamp Creek	Swamp and Ruth Creeks	950
2	Mile-18	Nooksack River	605
3	Mile-16 (Alternative)	do	-
4	Glacier	do	450
5	Warnick	do	155
6	Kulshan	do	410
7	Wells Creek	Wells Creek	565
8	Tunnel	do	250
9	Glacier Creek	Glacier Creek	1,115
10	Canyon Creek	Canyon Creek	1,270
11	Clearwater Creek	Middle Fork of Nooksack R.	1,430
12	Kulshan-Middle Fork	do	849
13	Wanlick Creek	South Fork of Nooksack R.	1,110
14	Lyman	do	560
15	Acme (Alternative)	do	-
16	Deming	Nooksack River	118

Index 12PB-	Natural flow (sec.-ft.) Q50	Q90	Q95	Q100	Mean	Horsepower .08HQ50	.08HQ90	.08HQ95	.08HQ100	.08HQm
1	90	40	30	10	100	6,800	3,000	2,300	700	7,600
2	540	230	180	75	650	26,000	11,000	8,700	3,600	31,000
4	600	260	200	100	800	21,600	9,300	7,200	3,600	26,000
5	700	325	250	125	970	8,700	4,000	3,100	1,500	12,000
6	900	400	300	140	1,200	29,500	13,000	9,800	4,600	39,000
7	125	65	50	20	170	5,600	2,900	2,200	900	7,700
8	150	65	50	20	185	3,000	1,300	1,000	400	3,700
9	180	75	60	25	225	16,000	6,700	5,300	2,200	20,000
10	100	45	35	15	140	10,000	4,600	3,500	1,500	14,000
11	160	90	75	60	240	18,300	10,200	8,600	6,900	27,500
12	320	180	150	130	480	21,800	12,200	10,200	8,800	32,600
13	165	45	40	20	230	14,700	4,000	3,500	1,800	20,000
14	500	110	90	65	700	22,400	4,900	4,000	2,900	31,000
16	2,000	900	700	465	2,300	19,000	8,500	6,600	4,400	22,000
Estim. total potential power*						220,000	110,000	90,000	50,000	294,000

Index 12PB-	Regulated flow, sec-ft: Q50	Q90	Q95	Q100	Horsepower .08HQ50	.08HQ90	.08HQ95	.08HQ100
1	90	40	30	10	7,000	3,100	2,300	700
2-6	(Variable flow)				80,000	80,000	80,000	80,000
7	125	65	50	20	5,600	2,900	2,200	900
8	120	80	80	80	2,400	1,600	1,600	1,600
9	180	75	60	25	16,000	6,700	5,300	2,200
10	100	45	35	15	10,000	4,600	3,500	1,500
11	160	90	75	60	18,300	10,200	8,600	6,900
12	320	180	150	130	21,800	12,200	10,200	8,800
13	165	45	40	20	14,700	4,000	3,500	1,800
14	625	625	625	625	28,000	28,000	28,000	28,000
16	(Variable flow)				15,000	15,000	15,000	15,000
Estim. total potential power*					220,000	180,000	170,000	160,000

*Assumes interconnection of all plants in one system. Assumes also that all flow above power house location is capturable. A proportionate downward reduction is necessary for flow not capturable. Assumes over-all plant efficiency of 70 percent. No allowance is made for friction head in conduits and canals.

FLOODS IN THE NOOKSACK BASIN

Introduction

The Nooksack River has three principal forks, the South Fork, the Middle Fork and the main stream, sometimes called the North Fork. The North and Middle Forks have their sources in the glaciers and perpetual snows of Mt. Baker and Mt. Shuksan. All descend rapidly through narrow mountain valleys to points not far above their confluence. Below their confluence, the main stream flattens out. The Middle Fork enters the main stream about 5 miles above Deming, and the South Fork enters about 1 mile above Deming. Except for an area in the lower basin of South Fork which is subject to overflow, there is no serious flood problem above the junction of the three branches.

Below Deming the river flows out upon a broad and conparatively flat valley floor in which the principal damage from floods has occurred. The total length of the river between Deming and Bellingham Bay is 36 miles and its total fall in this reach is 200 feet, an average of 5.5 feet per mile. Between Lawrence and Everson, a distance of 6 miles, the river follows a course which is roughly parallel to the course of the Sumas River, a small tributary of the Fraser River, and the two streams are nowhere much farther than a mile apart in this area. The intervening ground in much of this area is without perceptible relief, and it is reported that the Nooksack has on several occasions overflowed into Sumas drainage. The Sumas River flows northward into Fraser River in British Columbia. It is a flat, sluggish little stream and any considerable overflow from the Nooksack would probably overtax its capacity and flood a wide area of highly developed agricultural land around Sumas in British Columbia.

Little information is available on the extent and duration of floods in the Nooksack basin. The principal sources of this information are newspaper accounts and the older residents of the region. Rough estimates of discharge can be made from information regarding stage as supplied by these sources. These sources also provide valuable information regarding the causes which contribute to the floods and the character of resulting damage.

Major Floods of Record

In the memory of the "oldest inhabitant", which goes back to the early nineties, there have been possibly six periods of high water in the Nooksack River that could be classified as destructive floods. The earliest of these is alleged to have occurred in 1893, or approximately 1893. Later floods,

of which there is authentic record, occurred in 1909, 1917, 1921, 1932, and 1935, and such comparisons as may be had indicate that the flood of 1909 was possibly the greatest in volume. Later floods, however, may have caused more damage to property and improvements, as there has been a considerable degree of development in the lower basin since 1909. A brief resume of available accounts and other information on these floods is given in the following pages.

The Flood of 1893

Only the vaguest account of this flood is available. Even the date is a matter of some question. An old resident of Everson, who has lived in the vicinity since 1884, stated that he could remember a flood in the year 1893, or about that year, in which high water flowed through the Northern Pacific railroad grade near Everson from Nooksack to Sumas drainage. It appears from his account that the break through the railroad grade was effected by local residents who sought to relieve conditions on the Nooksack side of the grade, an effective barrier, and therefore cut the grade by pick and shovel. The water did not break through by its own action.

The railroad to which reference is made is a branch of the N. P. Ry. which follows the Nooksack-Sumas divide from Lawrence to Everson.

The Flood of 1909

The flood of 1909 appears from the Bellingham Herald to have reached its maximum severity about November 30. The immediate cause of this high water appears to have been a greater than normal precipitation accompanied by unseasonable temperatures causing snow to melt in the Mt. Baker area. Weather Bureau records show a total of 7.61 inches of precipitation in November for the Bellingham station. Later records show that this was a departure of +3.32 inches from the 35-year mean (1901-24, and 1929-40). Weather Bureau records also show that a total of 2.87 inches fell at Bellingham between November 27 and November 30. Temperatures at Bellingham in November ranged from a low of 24° F. on November 15 to a high of 73° F. on November 18.

A station at Mt. Baker Lodge (elevation 4,200 feet) shows a mean precipitation about 3 times as great as at Bellingham (see page 4). Precipitation in the upper basin in November, 1909, may have occurred largely in the form of rain due to unseasonably high temperatures. No weather station had been established in the Mt. Baker area in 1909. The Weather Bureau record for Bellingham station does not show daily temperatures for this year, but the maximum for the month of November, 73°, was recorded on November 18.

Describing this flood the Bellingham Herald of November 29, 1909, states that Saxon, Acme and Nugent bridges were "carried out." These bridges were apparently spans over the South Fork near Saxon and Acme and over the main stream near Lawrence.

The Bellingham Herald of November 30, 1909, states that "there is not a dry floor in Ferndale today and many are under 6 and 7 feet of water ..... A whole row of houses across the river has floated downstream ..... The middle of Alder Street, the highest point in town, shows for less than a block ..... There is a foot of water over the floor of the bank."

A picture in the Bellingham Herald of December 2, 1909, shows an area in the village of Ferndale under possibly 1 to 2 feet of water. Flood damage in Ferndale was estimated at $90,000. (Bellingham Herald, Dec. 2, 1909).

The Bellingham Herald of December 1, 1909, referring to the flood in the town of Sumas, states: "The water is from the Nooksack, which backed up below Everson and filled the big slough running northeast of that town and which is drained by Johnson Creek. Little damage has been done by the high water."

The postmaster at Deming interviewed by the writer in 1940, expressed his opinion that the flood of 1909 was the greatest on the Nooksack in his memory. He stated that the water rose to an elevation "even with the railroad track" at Deming and that the water from the Nooksack overflowed into Sumas drainage about half a mile east of Everson. He stated his belief that the channel of the Nooksack River was washed out and widened to such an extent by the flood of 1909 that it has since had a much greater capacity, and that this has reduced the danger of serious overflow.

Recalling the flood of 1909, an old-time resident of Lawrence, interviewed by the writer in 1940, stated that the high water from the Nooksack broke through the railroad grade about 2 miles below Lawrence and flowed into the Sumas River. He recalled that the surface of the flood waters dropped about 1 foot in the vicinity of Lawrence following the break in the railroad grade. This railroad grade is probably higher than any recorded flood, and would constitute an effective barrier to the passage of flood waters from the Nooksack to the Sumas basin as long as it stands.

The Flood of 1917

Little information is available on this flood. The American Reveille, Bellingham newspaper of December 30, 1917, states: "The Nooksack River is still rising and is reported to be at least 6 inches higher than it ever was before .... A stream of water more than a foot deep is racing through the streets of Everson and at the highest point in Sumas the water is nearly a foot deep ..... It is impossible to estimate the great damage."

A considerable damage was reported from a "silver thaw" which apparently preceded the flood peak.

Weather Bureau records show a higher than normal precipitation for December 1917. A total of 13.32 inches of rainfall, a departure of +8.35 inches from normal, was recorded at Bellingham for the month. The normal for December, as determined from a 35-year record, is 4.97 inches. A total of 3.53 inches fell during the 4 days of December 26 to 29.

A minimum temperature of 21° F. for the month was recorded at the Bellingham station on December 24. This day of lowest temperature for the month was followed by slowly rising temperatures which reached a maximum of 62° F. on December 31.

At Glacier a total rainfall of 24.81 inches was recorded for December and a total of 7.07 inches fell during the 4-day period from December 26 to 29. Normal precipitation at Glacier as determined from a 14-year record is 9.67 inches. The temperature at Glacier reached a low of 11° F. for the month on December 24, after which it climbed to a maximum for the month of 51° F. on December 31.

Weather Bureau records give this further information on the climatological conditions in Washington in December:

> "The total monthly precipitation was the greatest in many years, but a large proportion was rain, even at great altitudes. On the western slope of the Cascades the monthly snowfall was from 3 to 66 inches ... Owing to abnormally warm weather and excessive rain, the snow did not accumulate in depth, but acquired great density ..... A succession of excessive rains and abnormally high temperatures settled and melted the snow rapidly so that the ground was bare on the 31st in many localities for the first time on record at that date, and the heavy run-off caused almost unprecedented freshets in all streams on both slopes of Cascades, washing out many country bridges and roads as well as railway tracks and bridges, greatly delaying traffic."

The Flood of 1921

Little information is available. However, the Skagit River, draining an adjacent basin, reached its maximum discharge of record on December 12, 1921, when it attained a peak of 60,000 second-feet at Newhalem, Washington. This discharge record covers the 27 years from 1908 to 1914, and 1920 to 1941. The peak discharge of December 12, 1921, is probably the maximum for the 33-year period from 1908 to 1941.

Weather Bureau records (U. S.) give the following summary of conditions in Washington in December, 1921:

> "The month of December, 1921, although somewhat below normal in temperature, did not have the average snowfall, and much of what fell was melted off by the excessive rains and warm winds from the 10th to 12th. Through most of the western division ..... the precipitation of these three days, mostly from rain, was from 70 to 80 percent of the entire month's precipitation, which was slightly below normal. These rains and warm winds caused excessive floods in the river valleys west of the Cascades, and those heading in the Cascades and flowing to the Columbia. They caused disastrous losses to roads and bridges, dykes, stored crops, prospective crops by the flooding of the lowlands with salt water, and loss of live stock."

Precipitation records for the station at Bellingham show a total rainfall of 3.56 inches for the 3-day period from December 10 to 12, and maximum daily temperatures for the same period ranging from 52° to 57°.

In all probability the Nooksack responded to the same general climatic conditions that caused the flood on the Skagit River. The Army Engineers, in a report released in 1935 (H.D. No. 159, 74th Cong., 1st Ses.) state that during the flood of 1921 a portion of the flood waters of the Nooksack River discharged into the Sumas River.

A press dispatch from Bellingham, appearing in the Seattle Post-Intelligencer of December 14, 1921, indicates that damage in the Nooksack basin was probably light. The C. M. & St. P. Ry. bridge near Deming was partly washed out, as were two short stretches of track. Slight damage resulted to hay and other feed standing out. No live stock was lost. The dispatch makes no mention of any damage to towns in the area.

The Flood of 1932

The flood of 1932, appears to have reached its peak near Everson on February 27, 1932. The Bellingham Herald of February 28, states that the river had raised 8½ feet to reach the highest flood peak since 1917. Apparently observations were made of the river stage at Everson. The Herald of February 28, reports that Harkness Street and Main Street (in Everson) were covered with water at 5:00 a.m. on February 27, and that the water was 1½ feet deep in places on Main Street at 1:00 p.m.

According to newspaper accounts the flood appears to have subsided greatly on February 28. The Herald of February 28, states that a check on flood conditions made early February 28 showed that Everson was clear of water but Marietta was still under water.

The newspaper account describes the flood as "one of the most serious floods" in the history of Whatcom County. Several main highways were closed to traffic. Among these were the Ferndale Cutoff from the Pacific highway, the Lummi reservation road over Marietta Slough bridge, the Deming-Wickersham highway and the Lawrence highway.

The Bellingham Herald, official observer for the Weather Bureau station at Bellingham, in its issue of February 28, 1932, states: "Rainfall which ended at 9 a.m. yesterday closed the heaviest rainfall in the history of the Bellingham Herald observatory." The Weather Bureau record shows that 3.14 inches fell during the 4-day period from February 24 to 27. The total rainfall for the month was 5.51 inches. The normal for February, as determined from a 36-year record, is 3.18 inches.

Temperatures at a Weather Bureau station near Bellingham for the month ranged from a low of 7° F. on February 2, to a maximum of 59° F. on February 27. From February 23 to February 27 the temperature ranged from a low of 38° F. on February 23 to a high of 59° F. on February 27.

The Weather Bureau station at Mt. Baker Lodge recorded temperatures for this 5-day period ranging from a low of 27° on February 23 to a high of 45° on February 27.

The following is quoted from the Weather Bureau record of February 1932:

"Snow accumulated to great depths in the mountains during December, January, and the early part of February. Every watershed in the State was covered with its normal amount of snow, and in many places more than normal, for the first time in 10 years. During the last decade of February, the weather which had remained cool through the winter, suddenly turned warm. Abnormal temperatures were reported from all parts of the State, and on the 25th and 26th temperatures averaged from 10° to 20° above normal. Immeasurable quantities of water were released from the melting snows .....

"The melting of the snow and flood condition was augmented by extremely heavy rains which fell throughout western Washington from the 24th to the 27th."

Referring to damage from the flood in the Nooksack Valley the Weather Bureau report continues:

"About $10,000 worth of crops were lost, and $5,000 damage done to prospective crops where new seeding and pastures were covered with a deposit of sand, gravel, logs and stumps. Property damage, including highways, amounted to approximately $100,000."

No gaging station was in operation on the Nooksack River in 1932. Information submitted to the writer in June 1940 by a resident at a farmhouse located near the south end of the C. M. and St. P. RR. bridge above Lawrence indicates, however, that the stage reached by the Nooksack River on February 27, 1932, has probably been equaled during high water periods since that date. According to this source, the river has on several occasions between 1932 and 1940 reached a stage which permitted some flow across a low flat bench on the left bank of the river immediately below the railroad bridge. The elevation of this bench is roughly 7 feet higher than the surface of the adjacent river as observed by the writer on May 29, 1940. As nearly as can be estimated, the elevation of this bench was the approximate stage reached in February 1932. Rough slope-area computations indicate that the discharge of Nooksack River at a stage permitting flow over this bench would probably amount to about 30,000 second-feet, or somewhat more. The maximum discharge recorded at Deming gaging station since it was established in July, 1935, is 33,200 second-feet (Oct. 28, 1937). It seems probable that the flood of February 27, 1932, may have reached a peak at Deming of possibly 30,000 to 35,000 second-feet.

Photograph No. 2* shows the C.M.& St. P. Ry. bridge above Cedarville taken on the morning following the washout of the

*Not reproduced.

bridge. The washout appears to have occurred on February 27, 1932, which would date the photograph as of February 28, 1932. It was taken during the morning, and, it is believed, about 12 or 15 hours after the peak had passed Rough slope-area computations based on stage shown in this photograph indicate that the river was discharging on the morning of February 28th between 15,000 and 20,000 second-feet.

A comparison of the flood of 1932 with the highwater of October 28, 1937, brings out what appears to be a fact of much importance in connection with the carrying capacity of the river channel. On October 28, 1937, the gaging station near Deming indicated a peak flow of 33,200 second-feet. This peak appears to have passed down the river to the sea without any considerable overflow. The flood of 1932, on the other hand, with a peak probably little or no greater than the peak of October 28, 1937, caused great damage through overflow. This difference in the extent of overflow in 1932 and 1937 appears with little doubt to have been due to the longer duration of heavy discharge in 1932. The daily mean flow as recorded during the 4 days from October 26 to 29, 1937, was as follows: 1,590 second-feet on October 26; 7,300, 21,600 and 8,140 second-feet on the 3 following days. Although no record of discharge is available for 1932, it appears that conditions favorable to heavy discharge, rain, and abnormal temperatures, prevailed for several days in late February. The river channel between Deming and Bellingham Bay has sufficient storage capacity to take care of a heavy inrus of water for a few hours, but as soon as this storage capacity is overtaxed the water overflows.

The flood of 1932 also illustrates a characteristic effect of log jams during flood stages on Nooksack River. The formation of a log jam above the railroad bridge in February, 1932, acted as a diversion dam to guide a considerable flow of water into a shallow draw on the right bank, which spread out into a broad sheet near Cedarville and Lawrence, inundating a part of the town of Cedarville (see photograph No. 3*) while the river at Cedarville was well within its banks. Backwater from log jams has probably also been responsible for much of the debris lining the Nooksack River in various reaches, and the deposition of debris must accordingly be considered as questionable indication of true river stage from which discharge could be computed.

*Not reproduced.

The Flood of 1935

The flood of 1935 appears to have reached its maximum stage in the lower Nooksack valley on or about January 25. This appears to have been one of the most protracted floods of record in the basin. The Bellingham Herald of January 21, reports that Bellingham was "practically isolated except by water." The Herald of January 25, reports 7 inches of water on Main Street in Everson. This flood was caused by a number of contributing factors which combined to make it one of the most destructive of the floods which have visited the Nooksack basin. Weather Bureau records indicate that a greater than normal depth of snow covered the Mt. Baker region in January. Precipitation at Bellingham totaled 14.87 inches for January. The mean at this station as determined from a 35-year record, is 4.35 inches. Subnormal temperatures prevailed for several days during the middle of the month. An extreme low of 3° F., reported by the Bellingham Herald as the "coldest wave" since 1911, was recorded on 2 successive days (January 18, 19) at the station near Bellingham. Slowly-rising temperatures followed the extreme low, and on January 25th a maximum of 61° was recorded. During the cold wave ice formed over the Nooksack River. The Bellingham Herald of January 19th reports the Nooksack "frozen over to its mouth." (See photograph No. 1*). Heavy precipitation began on the 20th and 5.59 inches were recorded at Bellingham on January 21st. During the 5-day period from January 21 to 25 a total of 10.74 inches were recorded at this station. This precipitation was in the form of both snow and rain. The Bellingham Herald of January 21 reports that 10½ inches of snowfall preceded the rain. It also reports a wind velocity of 40 miles per hour.

No conclusive information is available regarding the peak discharge of the Nooksack River during this flood. Possibly the most reliable information is obtainable from a report prepared by C. E. Webb, District Chief Engineer of the Dominion Water and Power Bureau. In his report dated at Vancouver, B.C., March 12, 1935, he states that the flood stage in January 1935 was approximately 4 feet above the stage during a discharge measurement of the U. S. Geological Survey on January 29, 1935. The measurement on January 29th, 1935, indicated a discharge at Deming of 9,630 second-feet. A discharge of 9,630 second-feet corresponds with a gage height of 8.15 feet (1938-39 rating). Assuming in accordance with Webb's estimate of stage that the flood of 1935 reached the equivalent of a gage height of 12.15 feet, the flood would appear to have reached a peak of about 27,000 second-feet.

*Not reproduced.

No material change is believed to have occurred in the channel section in the vicinity of the gaging station since 1935. The relationship between gage height and discharge has not changed greatly since that year. If the difference in stage, as reported, is approximately correct, the discharge in January 1933, as estimated, should not be greatly in error.

Weather Bureau records give an estimate of $125,000 for damage in Whatcom County resulting from the flood and an accompanying ice storm.

High Water of October 28, 1937

At 1:00 p.m. on October 28, 1937, the Nooksack River at Deming reached a peak discharge of 33,200 second-feet (gage height, 13.21 ft.). This peak is the highest of record since the establishment of the gage in July, 1935. It also appears to be close to the highest flood crest of which there is reasonably conclusive evidence.

The high water of October 28, 1937, does not appear from available information to have caused any serious flood damage. Although a crest was reached which is comparable to that of any flood of which there is clear evidence, the duration of the peak discharge was brief. The mean discharge for the day was only 21,600 second-feet. The mean discharges for the preceding 2 days were 1,590 and 7,300 second-feet and for the 2 following days were 8,140 and 4,740 second-feet.

The cause of this brief flood discharge was a heavy downpour in the Mt. Baker region on October 26 and 27. The Weather Bureau station at Mt. Baker Lodge recorded 4.15 inches on October 26 and 6.51 inches on October 27, a total rainfall of 10.66 inches in 2 days. Temperatures at Mt. Baker Lodge on these 2 days ranged from a minimum of 47° to a maximum of 61°, a sufficiently high temperature to indicate that all precipitation was probably in the form of rain, or was quickly melted if any part fell as snow or sleet.

The heavy rainfall on Mt. Baker during October 26 and 27 was clearly a local storm. At Bellingham the total rainfall for the 2 days was only 0.65 inch. The total for the month of October at Bellingham was only 2.65 inches. The October mean for this station, as determined from a 36-year record, is 3.37 inches.

A REVIEW OF FLOODS OF RECORD IN NOOKSACK BASIN, THEIR CAUSES, MAGNITUDE, FREQUENCY, DURATION, AND RESULTING DAMAGE

Causes

The floods in the Nooksack basin have, in general, resulted from abnormal rainfall, usually accompanied by abnormal temperatures which have caused the release by melting of large quantities of water stored in the form of snow. Contributing to the destructive effect of these floods have been log and ice jams.

Magnitude

As gauged by the peak discharge of Nooksack River near Deming, the floods in the Nooksack Valley have reached a maximum of perhaps 35,000 second-feet, according to the best evience available. The magnitude of these floods, however, as gauged by the volume of water discharged during the flood period can not be satisfactorily estimated. The extent of overflow in the flat lower basin between Deming and Bellingham Bay depends not so much on the peak discharge as on the volume of water which pours out upon this flat lowland area. The peak discharge of 33,200 second-feet on October 28, 1937, appears to have passed through to the ocean without any serious overflow. If, as estimated in this report, the flood of 1932 reached a peak of from 30,000 to 35,000 second-feet, this was comparable in crest to the high water of 1937. The flood of 1932, however, caused much damage by overflow. The possibility that a flood peak rising well above the estimated maximum of 35,000 second-feet occurred at some time prior to 1935 is indicated in drift along the banks of the Nooksack near Deming as reported by C. E. Webb, District Chief Engineer of the Dominion Water and Power Bureau in his report dated March 12, 1935. Webb states that "marks of a previous flood in the nature of drift were found at an elevation of 9 feet above stage of the measurement (of January 29, 1935)". This measurement by the U. S. Geological Survey indicated a discharge of 9,630 second-feet. Comparisons with the rating tables for the existing station near Deming indicate that a peak discharge of about 50,000 second-feet would be necessary under present channel conditions to reach the stage indicated by drift. Drift deposits, however, must be regarded as somewhat uncertain evidence of discharge since these are frequently left by jams which temporarily dam the channel. This is especially true of the Nooksack, which is lined from source to mouth by logs and uprooted trees waiting for the next high water to pick them up and carry them on to the sea. (See photographs Nos. 5*, 6*, 8, 10*, 22*, and 25*).

*Not reproduced.

Frequency

According to the best evidence available to the writer there have been six periods of high water on the Nooksack River between 1893 and 1941 which could be termed destructive floods. These occurred in or about 1893, in 1909, 1917, 1921, 1932, and 1935, or one in an average of 8 years.

Duration

The average duration of the reported floods on the Nooksack appears to have been about 3 or 4 days. The maximum duration was probably about 8 days (1935). In the 36 miles of its course from Deming to the sea, the river has a total fall of 200 feet and abnormally high water subsides within a few hours after the causes cease to operate. The comparatively long duration of the flood of 1935 was probably due in large part to the obstruction of the channel by ice and debris.

Damage

No estimates of damage are available for the earlier floods on the Nooksack River. The damage resulting from recent floods has been estimated by the Weather Bureau as follows:

Flood of 1932	$100,000
Flood (and ice storm) of 1935 . .	125,000

Flood damage in the Nooksack basin as estimated includes destruction or injury to crops, lands, houses, highways, bridges, etc. Apart from these tangible damages must be considered the inevitable dislocations and personal hardships which result to individuals whose property is destroyed or whose dwellings are made unfit for occupancy even though this is only temporary. Assuming that the six major floods of record resulted in damages comparable to the damage of 1932, the total for 48 years (1893-1941) would be only $600,000. A certain amount of damage has resulted from minor floods during the period, but there is no information as to its extent. It seems probable that the damage from minor floods has been confined largely to bank cutting and to crop damage along the lower depressions in the valley floor. A conservative estimate of total damage from floods in the Nooksack basin during the 48-year period from 1893 to 1941 would probably not exceed $1,000,000. However, as population grows and improvements are made on increasing scales, the annual damage will be proportionately greater if floods are not controlled. In estimating damage it should also be borne in mind that lands subject to flooding would have a much greater value per acre if the threat of floods were removed.

Any estimate of flood damage must take into account both the tangible and intangible damage. It seems probable that the latter may be a more pressing consideration than the tangible damage. So long as there is no control of floods the threat of floods remains, and in the Nooksack basin this potential danger affects a wide area along the Nooksack from Deming to Bellingham Bay, and also in the basin of Sumas River in British Columbia. Another half-century may pass with no greater damage than was witnessed in the past half-century, but potential dangers from floods remain a constant threat to the security of property and lives. Flood control measures in the Nooksack Basin would be insurance against these threatening dangers.

One feature of flood damage in the Nooksack valley is so peculiar to this and geologically similar basins that it will be considered in detail in the following pages. This feature is the peculiarly destructive action of the river during high stages in undercutting its banks so that these cave in and wash away.

Bank Cutting by the Nooksack River

In order to describe the bank-cutting effect of Nooksack floods it will be necessary to consider briefly the geologic formation of the valley floor. The river emerges near Lawrence from the mountain area to flow out upon the comparatively broad flat plain of the lower valley shown in detail on the Sumas and Blaine quadrangle maps. This broad lower valley has been built up by drift and sediment carried down by the swift currents in the upper river and its tributaries and deposited by the more sluggish current in the lower valley. The maximum depth of this valley fill is not known, but drill logs for scattered wells throughout the area indicate that the drift is deep. Rough drill logs for a number of wells in the area were obtained. Overlying this deep deposit of sand and gravel is a layer of high grade soil of varying thickness. In a large part of the area this soil layer is comparatively shallow, in many places not more than 6 inches thick. In other parts of the area, especially along the present river course, the soil layer is deep. Depths of soil up to extremes of 10 feet were noted by the writer along the river banks in 1940. Large areas are covered by a soil layer 2 feet in thickness. This soil layer is rich in humus and contains enough sand to make it friable. It is rich in plant food and makes excellent hay and pasture land.

The deeper soil is found in the lower end of the valley. Examination of the river channel shows that the line of separation between soil layer and gravel layer is well above the

surface of the river at low stage from Deming to a point about 5 miles below Lynden where the line of separation between the two formations drops to low water line. Downstream from a point about 5 miles below Lynden the line of separation is in general below the water surface, and below Ferndale the river appears to be flowing over a well-compacted bed of fine silt. No coarse gravel is visible in the banks anywhere from Ferndale to the bay. This fact is highly important in its bearing on the feasibility of dykes. The deep soil and silt layer which forms the banks of the river in the lower valley is a secure foundation for dykes. The construction of dykes along the river in the upper valley would have little or no value since these would collapse with the bank whenever the underlying gravel is disturbed.

The soil layer above described has much greater stability than the underlying gravel. The soil layer is in general a mixture of fine sand, clay and humus which is held together by the roots of its grass covering in a well-bound sod. Water may overflow the river's banks and sweep over this grass and pasture land without any serious erosion, and without other damage than is caused by silting. If, however, this sod layer is undermined by the action of the river current in washing away the supporting gravel, the sod layer will sag as its support yields, and break off in more or less vertical lines of cleavage, dropping into the river channel where it is quickly disintegrated and washed away. A typical illustration of this process is shown in photographs Nos. 7 and 8. Note in photograph No. 7 the typical vertical cleavage of the resistant sod layer, and the sloping gravel bank beneath. The gravel layer is so unstable that it does not come to rest until it assumes a slope of about 45°. Photographs Nos. 8 and 10* show parts of an area of about 40 acres which are alleged to have been converted from high-grade pasture land to gravel bars and river bed by this form of erosion.

The relative stability of the underlying gravel varies with its silt content. This silt deposit is in part a fine clay which acts as a binding and stabilizing cement. The clay is carried a long distance in suspension and is not deposited in quantity until the stream reaches the flat gradient of the lower basin. On the other hand, the heavy gravel soon comes to rest on the channel floor and very little of it is carried by the river below Lynden except during high stage when the current is comparatively swift.

This grading and assorting effect of the river on the material it transports from the headwaters region is brought out quite clearly in photographs Nos. 12*, 13*, and 14*.

*Not reproduced.



7. Typical bank erosion. Nooksack River 2 miles below Lawrence. Note loam layer undermined by washing out of unstable gravel.



8. Result of bank erosion on Nooksack River below Lawrence.

It will be noted from these photographs that large sized rock is transported as far as Deming, that there is a gradual decrease in the size of transported material as the stream enters the flat lowlands, and that there is no perceptible gravel content in the exposed areas of the soil of the river banks near Ferndale. Below Ferndale the river banks are in general sodded to water line, which is indicative of a firm well-compacted soil, not easily disturbed by river erosion.

The characteristic under-cutting of the river is not a form of flood damage that draws much attention from anyone but the owner of the land that falls into the river. It does not create newspaper headlines such as a house floating away or a bridge out. Consequently, little information on bank erosion has come to the attention of the general public. Photograph No. 8, however, tells its own story. The owner of this land said he paid $125.00 an acre for it.

How much good land has been carried down river is not known, and how much has been carried down since the first settlement is a matter of conjecture. Varying tales come from the riparian owners.

Such information as can be had from riparian owners and from examination of the valley floor indicates that the total value of lands destroyed by river erosion since the first settlement may not be great. One of the larger and more recently eroded areas, part of which is shown in photographs Nos. 8 and 10*, measures approximately 40 acres. The soil is alleged to have washed away by degrees since 1919. Its original purchase price was about $5,000. This is apparently an extreme case, and probably represents the most severely eroded area of size along the entire river. Evidence of recent erosion in other areas along the river is confined to patches and strips within a few hundred feet of the existing channel. On the basis of such evidence it is the writer's opinion that possibly 500 acres or somewhat more of pasture and woodland in the Nooksack basin may have been destroyed by this form of erosion since the first settlements. The lands adjacent to the river are the best lands of the valley.

The total value of lands in the Nooksack valley destroyed by river erosion since the first settlement may not exceed $100,000. The threat of greater damage is, however, constantly present. If this threat were removed, land values would undoubtedly rise. Illustrative of the potential danger in this form of river erosion is a condition now existing at a point on the right bank of the river at approximately mile

*Not reproduced.

28.2, in sec. 17, T. 39 N., R. 4 E. At this point the channel of the Nooksack River is about 800 feet from Sumas River drainage at low water stage. At bank full stage the Nooksack River is within 300 feet of Sumas drainage at this point. Photograph No. 7 shows this point on Nooksack River and shows the characteristic undercutting in progress. Information submitted by the land owner indicated that the Nooksack had cut its way about a quarter of a mile in the general direction of Sumas drainage since 1919. The average rate thus indicated is about 60 feet per year. The area which still separates Nooksack River channel from Sumas drainage is probably of the same general geologic character as the area that has been eroded since 1919, about 2 feet of sodded soil overlying gravel. A high railroad embankment occupies the divide between the two rivers, but this embankment, while effective as a barrier to Nooksack overflow in the past, will offer no resistance to the undercutting process. Unless the Nooksack is deflected from its present course at this point either by artificial revetments or by log jams, it seems highly probable that future high water may eventually cut through to Sumas drainage. Should this occur during high water and should a log jam form in such manner as to cause major diversion, the Nooksack might discharge heavily into Sumas drainage. The effect of such a diversion during flood stage would be inundation of a wide area in the Sumas River basin on both sides of the Canadian boundary.

Such a possible shift in the drainage system of this region does not seem to be without precedent. There is much evidence both in present surface geology and topography and in the more or less legendary accounts of Indians to indicate that the Nooksack River at some time in the past may have flowed into Fraser River in British Columbia through the present channel of the Sumas River. There are similar indications that at one time it may have followed the present channel of Dakota Creek or California Creek to Drayton Harbor. Within the memory of living inhabitants, the river has been wholly diverted below Ferndale from its old principal channel, now known as Lummi River, to its present channel discharging into Bellingham Bay. The original main outlet, Lummi River, is now dry in its upper course (see photograph 33*) and its lower course is occupied principally by tidewater (Photograph 32*).

One principal factor in the undercutting erosion so characteristic of the Nooksack is the formation of log jams which act as diversion dams in deflecting the current. When the current is deflected by the formation of a log jam it attacks the adjacent bank much as the jet from a hose in hydraulic mining. The underlying gravel formation crumbles rapidly under

*Not reproduced.

action of the direct current and the overlying sod caves and breaks. A wide area may be disintegrated in this manner before the deflected current has completed a sufficient excavation to permit free flow around the obstruction.

Bank cutting is not alone destructive of the better soils of the Nooksack valley. It is a distinct threat of inundation to the Sumas valley in British Columbia.

History of Control Measures

Several measures have been tried in combatting erosion by the Nooksack since settlement of the valley. In the lower valley, principally in the area between Lynden and Bellingham Bay, low dykes have been built from time to time financed by county taxation and by individual enterprise. Piles have been driven as revetments and deflectors, and various types of shear walls have been constructed in the more critical areas along the river channel from Ferndale to points above Deming, and on the South Fork Nooksack River. Large sums, it is understood, have been appropriated for this work by the County from time to time.

The establishment of vegetative covering to reinforce the river banks by binding the gravel is being tried in several short reaches of the main stream and on the South Fork. This work was begun about 1934, and has been carried out under the supervision of the State Department of Conservation and Development. Various forms of brush mats and fascines are used to protect the banks from erosion while willows and other vegetation gain a foothold (see photographs 15*, 16*, 18*, 19*, 20*, and 21*).

PROPOSED CONTROL MEASURES

Such information as is available from the history of past floods in the Nooksack Valley indicates that any plan for the effective control of floods in this basin must embody three essential features:

(1) Sufficient storage to reduce the daily discharge to possibly 20,000 second-feet at Deming.

(2) Dams for collecting debris.

(3) Channel improvement.

*Not reproduced.

Storage for Flood Control

It is the writer's opinion that adequate protection against overflow in the valley of the Nooksack River below Deming could probably be had from storage sufficient to reduce the daily mean discharge of the river to 20,000 second-feet. Some bank erosion in the area above Lynden would probably result from a flow of 15,000 second-feet, but the existing channel as enlarged by existing dykes will probably carry 20,000 second-feet without serious overflow provided the channel is kept free from snags and driftwood.

This estimated capacity is based on statements of riparian land owners and on the discharge record for the Nooksack near Deming. It was the opinion of several residents along the river, as expressed to the writer in 1940, that no serious overflow has occurred since the flood of 1935. Discharge records at the station near Deming show the following daily means and peaks:

	Second-feet	
Date	Mean	Peak
June 21, 1937	18,600	---
October 28, 1937	21,600	33,200
January 1, 1939	19,000	23,000

The almost unanimous opinion of the down-valley residents that there had been no serious overflow on these dates indicates that the channel, as now enlarged and reinforced by dykes, will carry a mean flow of 20,000 second-feet for a 24-hour period without damage from overflow. Slope-area computations indicate that flow which may continue over a 24-hour period in the channel below Deming without overflow, may continue indefinitely without overflow. If the peak flow of 33,200 second-feet on October 28, 1937 had continued throughout the day it is probable that serious overflow would have occurred in the lower valley. The mean for the day was only 21,600 second-feet. The mean for the preceding day (October 27) was only 7,300 second-feet. With a flow of only 7,300 second-feet there was sufficient empty storage space in the down-valley river channel to accommodate the sudden inrush from the peak flow of October 28. The storage space in the channel between Bellingham Bay and Lawrence is estimated roughly at 11,000 acre-feet with existing dykes. This estimate is based on planimetric measurements of the river survey. Only a small part of this capacity is required to accommodate flow at low stages.

Rough slope-area computations indicate that the Nooksack

River at bank full stage will have mean velocities ranging from about 6 to 7 feet per second in the reach from Lawrence to Bellingham Bay. Assuming a mean velocity of 6 feet per second, the 30-mile reach of channel below Lawrence would empty itself every 7.3 hours. This rate of discharge would give the channel the equivalent of a daily storage capacity of 36,000 acre-feet. This indicates that the channel would accommodate a daily mean flow of 18,000 second-feet without overflow, which checks roughly with other information indicating a carrying capacity of perhaps 20,000 second-feet.

Assuming that the existing channel of Nooksack River will carry a daily mean flow of not more than 20,000 second-feet, required storage for flood control would have to accommodate any surplus flow over this daily mean. Past records or reports of discharge or stage contain no evidence indicating that a peak flow greater than 50,000 second-feet has occurred in the Nooksack River. The possibility of a peak flow of 50,000 second-feet at some time in the past has been suggested by evidence of river stage in the form of water deposited debris. This evidence is at best uncertain in a stream such as the Nooksack, which transports large numbers of logs and uprooted trees during high stage. These frequently jam and cause a temporary backing up of water.

In so far as may be estimated from indications of stage and duration as herein described in connection with history of past floods, it seems probable that no flood during the present century has exceeded a peak discharge of 50,000 second-feet at Deming, and during no high water period has the river remained at flood stage for more than possibly 5 consecutive days. The severe flood of 1935 was apparently prolonged by ice jams after the rate of discharge dropped. Assuming the possibility of a mean discharge of 30,000 second-feet at Deming over a 5-day period, a total run-off of 100,000 acre-feet in excess of the estimated carrying capacity of the channel would probably have to be stored.

Flood Control Storage Sites

Three potential reservoirs in the Nooksack River basin, if geologically suited, could be developed for flood control. These sites have been described herein under the discussion of "Storage Sites" (see page 8). They are as follows:

1. Deming reservoir site (12PB 16) on Nooksack River.
2. Mile-18 reservoir site (12PB 2) on Nooksack River (or North Fork).
3. Edfro Creek reservoir site (12PB 14) on South Fork Nooksack River.

Deming reservoir site (12PB 16). Development to capacity of the Deming reservoir site would obviate necessity for other flood storage space. This reservoir site has a capacity of 500,000 acre-feet if fully developed (see page 12).

Mile-18 reservoir site (12PB 2). If the proposed Deming dam is not built, development of flood storage space at the Mile-18 site on the North Fork of Nooksack River (or main stream), and, at the Edfro Creek site on the South Fork, might be feasible, and would give a substantial degree of protection against floods. The two sites have about the same mean annual run-off. This is estimated at 504,000 acre-feet for the Edfro Creek site on South Fork and about 455,000 acre-feet for the Mile-18 site on North Fork, assuming diversion of Wells Creek into the Mile-18 site.

The mean annual run-off at the Mile-18 site on North Fork including the area of the proposed Wells Creek diversion, is about 20 percent of the run-off at Deming. The mean annual run-off at the Edfro Creek site on South Fork is about 23 percent of the run-off at Deming. The combined mean run-off at the two sites is therefore about 43 percent of the run-off at Deming. However, the two forks have a widely different regimen, and flood peaks at the two sites are rarely, if ever, concurrent. The efficacy of the two reservoirs in reducing flood peaks at Deming would accordingly be less, probably much less, than a reservoir of equivalent capacity at Deming.

Assuming that a mean discharge of 30,000 second-feet at Deming were to continue for 5 days, it would then be necessary to store 100,000 acre-feet, the excess run-off over the estimated channel capacity of 20,000 second-feet. Assuming further that nearly all of the flood flow were contributed by only one of the two forks, and giving some weight to relative drainage areas, a storage capacity of 110,000 acre-feet at the Edfro Creek reservoir site and 90,000 acre-feet at the Mile-18 site would appear to be sufficient protection against floods such as have occurred during the past half-century.

If the entire space to be utilized for flood storage were reserved solely for this purpose, a total storage capacity of about 200,000 acre-feet would be necessary at the Mile-18 site under plans for power development herein described. A dam to store 200,000 acre-feet at the Mile-18 site would probably be about 240 feet high measured from water surface at the dam site. The river survey does not show topography to this full height. The estimated height of dam is obtained by projection of the capacity curve. A 240-foot dam would flood about 1,850 acres of timber land.

Edfro Creek reservoir site (12PB 14). (See description of this site on page 11). If this site were developed solely as a flood control project, storage of the estimated requirement of 110,000 acre-feet could be developed by construction of a dam 193 feet high, flooding 1,330 acres. If storage space required for flood control should be developed in addition to the full storage space proposed for power only, a total reservoir capacity of 410,000 acre-feet would be necessary. This would require a dam 354 feet high as measured from natural water surface at the dam site. A 354-foot dam would inundate 2,370 acres.

Debris Dams

The construction of a dam on the main river above Deming or dams in the lower reaches of each of the 3 forks would probably do much to reduce the damage from overflow in the lower Nooksack Valley, and would probably also reduce materially the damage from bank cutting. Drifting logs, caught in jams, have doubtless been major contributing causes in past inundations of parts of the valley.

The log jam which formed in February 1932, above the Cedarville railroad bridge illustrates this point. The river appears from the testimony of local residents to have been well within its banks at Cedarville, but the log jam at the railroad bridge about a mile above the town acted as a diversion dam to raise the river level until it overflowed its right bank. The overflow followed a shallow draw and spread out in a broad sheet in the vicinity of Cedarville. When the bridge was washed out and the log jam broke the water quickly receded from Cedarville. Had the log jam not formed at the bridge, the river channel would probably have accommodated the peak discharge, at least in the reach above Lawrence.

Not only do log jams contribute to overflow, but these also act to accelerate bank cutting by directing the river current into its banks. Residents along the river tell of seeing this process in operation. A drifting log is grounded in a shallows; another drifting log catches on the first, and another, and soon the jam effectively blocks the onward current, deflecting it at an angle into the river bank. The loose gravel of the bank yields and the more resistent soil layer on top buckles and breaks into clods which fall into the channel and wash away.

The character of debris transported by the Nooksack River is not such as to restrict the use of any dam to debris collection. Any dam on the Nooksack or its forks could serve the

multiple purpose of debris collection, storage for power and storage for reducing flood stage. Debris in the Nooksack River consists principally of logs and uprooted trees (see photographs 5*, 6*, 8, 10*, 22*, and 25*). The current also transports gravel and silt, but it is not believed that these latter would materially interfere with the use of the debris dams for the multiple purpose. Silt is carried to the mouth of the river. Coarse river gravel is carried by the channel as far as Lynden. Cobbles 6 inches or more in diameter are carried as far as Deming. Depositions of silt and gravel would limit the life of any reservoir, but would not seriously impair its value for power or other use.

Logs and uprooted trees would probably not accumulate to the extent that they would seriously interfere with reservoir operation. Their removal from reservoirs would entail some expense, but this could probably be reduced to some extent by salvage operations. A part of the drifting timber is suitable for lumber and could be collected at the reservoir and transported to mills at a comparatively low cost.

Sites suitable for debris dams could be found on the Nooksack near Deming or at Maple Falls. The Edfro Creek site on South Fork would be valuable for this purpose. The Mile-18 or Mile-16 sites on the main stream (or North Fork) would have some value for debris collection. The Middle Fork is without any reservoir site of value for any other purpose, but debris collection would probably be possible through construction of a low dam near Kulshan. Construction of a debris dam on the main stream near Deming would obviate the necessity for debris dams on any of the forks.

Any of the proposed dams on Nooksack River and its tributaries could be made to serve the purpose of debris collection without material change in proposed reservoir capacity, as estimated for power development and flood control.

The term "debris dam," as used above, is meant to designate any dam, the primary purpose of which would be debris collection. The design of such a dam for any site on the Nooksack River would not necessarily vary in any essential detail from the design of a power or storage dam. If, however, it were designed for debris collection only, it might be a comparatively low dam, creating only enough lake surface to float the maximum probable load of logs and driftwood until this material could be cleared from the lake surface. Material not worth salvaging could be hauled to the shore. The lake level could then be lowered, leaving the debris to dry before burning.

*Not reproduced.

Channel Improvement

To the extent that channel improvements, including dykes, revetments, vegetative covering and rerouting are possible, these will reduce the required storage space. To what extent funds expended for such improvements may be more effective than if expended for storage space depends on a number of factors regarding which there is at present inadequate information.

For a study of channel improvements the main river may be divided roughly into two parts, the reach from Lynden to Bellingham Bay, and the reach from Lynden to Deming.

Dykes could probably be constructed along the entire river course from a point a few miles below Lynden to Bellingham Bay. These could probably be built to a height that would retain within banks any rate of discharge that could be contained within the channel above Lynden where dykes are not practicable due to the unstable gravel. Dykes have been in progress of construction in the area below Lynden for many years, and have been heightened and strengthened from time to time as the necessity became apparent. Existing dykes with some addition to present height and the construction of new dykes in certain areas, would probably protect the lower valley provided storage is developed in sufficient volume to reduce flood discharge to 20,000 second-feet at Deming, and provided there is effective debris control. Vegetative covering along the channel below Lynden would strengthen the dykes and help to preserve them against erosion. A successful start has been made with willow plantings in several areas below Lynden.

In the area above Lynden the gravelly banks will prevent successful dyke construction unless the exposed edge of the underlying gravel stratum can be sealed by vegetative covering, or by artificial means.* Dykes can in no way prevent or retard the destructive undercutting action of the river current. Several areas along the river in the reach from Lynden to Deming have been planted to willows in recent years. This vegetative covering has made an excellent start, and may contribute greatly to a solution of the bank-cutting problem. Maintenance, however, is equally important to this vegetative covering as it is to artificial revetments, and the success of the projects will depend largely upon the care given to them in the future.

*A flexible concrete mat developed by the Army Engineers for revetment along the lower Mississippi River is described on page 125 of the Engineering News-Record of September 20, 1945. This type of mat might prove effective in those reaches of the Nooksack where gravel is too coarse and unstable to favor vegetative covering.

Piles, cribs, deflectors and most forms of revetments can have only a temporary restraining action on the current in the area above Lynden. Any deflection of the current starts trouble elsewhere. Piles and cribs hold until the current gradually works behind them. Eventually they are left standing in the middle of a new channel, isolated on dry ground or otherwise circumvented. (See photograph No. 25*). Many years of experience in combatting the Nooksack River in the reach above Lynden by revetments has shown that these structures do not afford permanent protection. It is necessary that they be supplemented from time to time by new structures as the old give way. By deflecting the current, revetments also create areas of erosion elsewhere. Revetments in some form will probably always be necessary, however, in the area above Lynden unless the channel can be rerouted through an area less subject to erosion. If, however, adequate storage is developed at proposed reservoir sites upstream, this should greatly reduce the necessity for new revetments and should help substantially to preserve existing revetments.

As a more lasting solution of the problem in the area above Lynden, it might be worth while to give some study to possible rerouting of the channel. Information now available is not sufficient to serve as a basis for anything but the most general suggestions with regard to possible channel rerouting.

A broad peat marsh extends with some discontinuity along the lower ground from a point on the south or left bank of the Nooksack near Everson to a point near the river several miles below Lynden. This peat formation has accumulated in what appears to have been river bed at one time. Fountain Lake and Wiser Lake now occupy shallow basins in this area. The depth and extent of this peat formation is not definitely known. A part of the area was examined by the writer in 1940, but no depth determinations were made. It was noted, however, that a newly dug ditch in this area, having maximum depths of about 5 feet was wholly in fibrous peat. Fibrous peat is resistant to erosion, and will withstand a considerable current before yielding.

Extensive surveys of the peat area along the left bank of the Nooksack below Everson will be necessary before any conclusion may be reached regarding the feasibility of routing the river through this area.

From Everson to Deming, the river has eroded a wide channel, and, although much of this channel is comparatively shallow, its average gradient of 10 feet per mile compares with an average gradient of only 3.2 feet per mile in the reach from Ever-

*Not reproduced.

son to Bellingham Bay. If storage of sufficient volume were available to reduce floods to 20,000 second-feet as measured at Deming, there would probably be no overflow in this area. This reach of the river presents the most serious problem of bank cutting and the solution must depend on revetments, or vegetative covering, or a combination of them. From Deming to Lawrence, however, the valley floor is comparatively narrow, and therefore offers a more restricted area to river erosion than is the case below Lawrence.

IRRIGATION IN THE NOOKSACK VALLEY

A detailed study of irrigation possibilities in the Nooksack valley is beyond the scope of this report. It is desired herein merely to call attention to these possibilities, and to show in a general way the relationship between irrigation from the Nooksack River and other possible uses of its water, especially power.

That irrigation will have its part in the future development of agriculture in the Nooksack valley, is generally accepted by many of those who have studied the problem. Several small projects in the valley have already demonstrated that irrigation will materially increase the yield of many of the standard crops. A farmer near Lawrence reported (1940) that he had more than doubled the yield of alfalfa and beans from a small field by irrigation. He pumped water from a well and applied it by a power spray.

It will be noted from the table of mean monthly precipitation (page 4) for stations in the Nooksack River basin that comparatively little rain falls in the lower valley during summer. The station at Marietta, located near the mouth of the Nooksack, shows a 27-year mean of only 4.91 inches for the period from May to August, inclusive. The 27-year mean for July is 0.89 inch, and for August it is 0.86 inch. A slightly greater precipitation probably occurs throughout the agricultural area from Marietta to Lawrence. The station at Glacier shows a considerably greater precipitation, but this station is located so far upstream that it does not represent conditions in the lower valley. The mean precipitation throughout the agricultural area probably ranges from 5 to 6 inches for the 4-month season of May to August, inclusive, and this area probably receives less than 1 inch of rainfall during each of the months of July and August.

A total rainfall of 5 or 6 inches during the 4-month period of May to August would be a limiting factor in crop production even though it fell under the most favorable conditions for plant use, and on the most retentive soil. Such favorable conditions, however, do not prevail in the Nooksack basin. Summer precipitation in the lower valley comes mostly in the form of light showers which do not penetrate the soil to any depth, and a large percentage of the moisture evaporates without reaching plant roots. After crops reach a certain stage of growth a large percentage of this light summer precipitation comes to rest on the leaves or blades of the plants, and is evaporated without even coming into contact with the soil. In much of the agricultural area of the Nooksack valley, moreover, the subsoil is not retentive of moisture, and water that percolates through the topsoil is rapidly drained away by the gravelly underlayer. Because of this low retentive capacity, the duty of water is correspondingly high.

As a fair measure of the shortage represented by 6 inches of rainfall in the 4-month period from May to August, comparison may be made with the probable requirement for full irrigation based on practice in other areas. The actual duty of water in the Nooksack valley, as elsewhere, can be determined only by trial. The region has the great advantage of a moderate summer temperature with little wind. Evaporation losses should accordingly be small. On the other hand a gravelly subsoil throughout most of the area conduces to low retentive capacity and a high resultant seepage loss. Soils in much of the area dry out early in the season, and grass in many localities turns brown by midsummer unless rain is above normal. In late June, 1940, the writer tested the subsoil in a wide area of the lower valley and found it comparatively dry, especially in spots where the topsoil was thin. Allowing for the more favorable summer temperature, the requirements for irrigation in the Nooksack valley would probably be somewhat less than in the vicinity of Medford, Oregon, where 4 feet of water is considered the normal seasonal requirement. Possibly 3 feet, inclusive of rainfall, would suffice for the Nooksack valley, of which at least 2 feet would normally be applied in the 4-month period from May to August. If 6 inches of water falls as rain during this period it would represent only 25 percent of the normal requirement for complete irrigation. In terms of irrigation it would represent a shortage of 75 percent, or 18 inches.

It would accordingly seem that the complete irrigation of lands in the Nooksack valley should supply a normal deficiency of perhaps 1.5 feet of water. The Sumas and Blaine topographic maps show that a maximum of perhaps 130,000 acres between

Deming and the ocean, including Drayton Harbor drainage, may be sufficiently level to be susceptible of irrigation either by gravity or by pumping. Assuming the feasibility of such irrigation, the maximum annual requirement would approximate 200,000 acre-feet. Of the total of 130,000 acres that may be sufficiently level to irrigate, possibly 70,000 acres could be reached by gravity canals. The remaining 60,000 acres would require pumping with lifts ranging up to 100 feet or slightly more.

The preparation of even the most tentative design for this irrigation project is beyond the scope of this report. The foregoing estimates are based on the possibility of two main canals diverting below tailwater from the proposed Deming power house at a water surface elevation of about 200 feet. One canal, following the right bank, would command the area shown on the Sumas quadrangle lying north of the Nooksack River and east of Johnson Creek. The other canal, following the left bank of the Nooksack, would command the greater part of the area shown on the Sumas and Blaine quadrangle maps lying south of the Nooksack River. A large part of this area could be supplied by a diversion near Lawrence at water surface elevation of about 100 feet or slightly higher. An additional area lying above the elevation of these canals could be reached by pumping, if economically feasible. This higher area, extending roughly from Bellingham north and east to Cedarville, could also be irrigated by gravity, assuming diversion of the Nooksack at an altitude of 300 feet. If a dam were constructed at the Deming dam site with crest at an altitude of 321 feet, a canal diverting at an altitude of 300 feet could be supplied from the reservoir by gravity so long as draw-down did not bring the reservoir surface more than 20 feet below crest, and a comparatively low lift would be all that would ever be required under normal conditions of reservoir operation. Assuming construction of a dam at the Deming site, a diversion at about 300 feet might be more economical than to depend solely on a pumping plant downstream. Any diversion for irrigation at an elevation higher than tailwater at the proposed Deming power house would mean a drop in the potential power at this site.

The large area, about 40,000 acres, lying north of the Nooksack River and west of Johnson Creek, will be dependent almost entirely on the feasibility of pumping.

The relative merits of pumping and gravity methods will need to be studied in great detail for the entire irrigable area before a plan can be worked out which will make the best use of advantages offered by topography. Detailed soil classification must also be made as a basis for satisfactory planning.

The soils in some areas of the Nooksack valley may not be of sufficient depth or fertility to justify irrigation. In other low areas the need will be for drainage rather than irrigation, except possibly for a brief period in July and August.

Assuming on the basis of the foregoing that the maximum annual needs for irrigation in the Nooksack valley will not exceed 200,000 acre-feet, this quantity of water could be considered as available either as natural flow or under any system of regulation involving storage. The schedule for distribution used by the Grants Pass Irrigation District in Oregon would probably be roughly applicable to the Nooksack valley. Over a 6-year period prior to 1936 the schedule followed at Grants Pass was approximately as follows:

Month	Percent
April	5
May	10
June	20
July	30
August	25
September	10

On the basis of this schedule the distribution of 200,000 acre-feet in the Nooksack valley between May and August would be made approximately as follows:

Month	Acre-feet
May	23,000
June	47,000
July	70,000
August	60,000

It will be seen from the record of run-off at Deming (page 59) that at no time since the establishment of the gaging station has the run-off fallen below the quantities required to meet this rate of distribution and that in nearly all months of the record the run-off was much greater than the estimated requirement.

Under a system of complete regulation the rate of release at Deming might possibly be geared to a power demand schedule, but it is not likely that this would interfere with the irrigation demand schedule as outlined. The mean annual run-off at Deming from 1935 to 1940 was 2,211,000 acre-feet, or a monthly mean of 184,250 acre-feet. It is highly improbable that operation of this reservoir for power from variable head and flow would result in any material shortage for irrigation. It seems probable, therefore, that an abundant supply of water

for irrigation in the Nooksack valley is assured, either from natural flow or from artificial regulation. Should the South Fork of the Nooksack River be diverted into the Skagit River, thereby reducing by about 25 percent the flow of the main stream at Deming, the margin of surplus flow would be reduced, but at no time during the period of the record could a shortage have resulted from such diversion. (See table of run-off for Nooksack River at Deming, page 59). The full estimated requirement of 60,000 acre-feet for August would have been met by only a narrow margin from natural flow during 5 of the 7 years of the record, but, under a system of regulation the margin would probably have been ample.

Assuming diversion of South Fork into Skagit drainage, and assuming a requirement of 60,000 acre-feet for irrigation in August, additional storage at Deming or at some site on the main stream (North Fork) would be necessary in order to assure a dependable supply for any additional purpose such as municipal or domestic use.

The foregoing does not take into account the loss of water in distribution. Irrigation canals dug in the gravelly subsoil of the Nooksack valley would probably leak badly unless lined with some waterproof material. It is probable, however, that in time the fine glacial silt carried by the river would settle in canals in sufficient quantity to reduce seepage losses materially. Since, under a plan for storage, much of the silt would settle in the upstream reservoirs, downstream canals might have to be in use for a long time before a sufficient quantity would settle in them to reduce seepage losses effectively. Effective sealing of the canals would take place in a much shorter time if water were not stored but were allowed to enter the canals with its full load of suspended silt.

DOMESTIC WATER SUPPLY

A discussion of this problem is beyond the scope of this report. It may be stated, however, that towns and rural homes in the lower Nooksack valley, and also the lower Skagit valley to the south, have a poor quality of water for domestic use. Analyses are not available, but such information as can be had indicates that the chief impurity is organic matter, much of it possibly decayed vegetable matter. Well drillers in the lower Nooksack valley have frequently encountered buried logs at considerable depth. A large area in the lower valley floor is covered with peat. Water from many farm wells in this area is slightly discolored and has a taste indicative of organic impurities. Several wells in the area have been sunk to con-

siderable depths (see well logs in appendix*) in search of pure water withoug success.

Any diversion from Nooksack River or its tributaries above the settlements in the lower basin would provide water for domestic use far superior to the water now in use over most of this area. The silt in the North Fork discharge during part of the year would have to be removed by settling or otherwise before the water were piped into residential areas. Organic impurities would probably be very low in water from any source above Saxon Bridge on the South Fork and above Heisler Creek on Middle Fork. The small scattered settlements along the main stream (North Fork) as far up as Glacier, would subject this stream to a slight degree of contamination.

It would be possible to supply many towns and some rural areas in the lower Nooksack and Skagit River basins with water from the Nooksack River or its tributaries. As a project primarily for domestic and municipal purposes, a distribution

Run-off in Acre feet, Nooksack River above Cascade Creek
(Area - 105 square miles)

Month:	1937-38:	1938-39:	1939-40:	1940-41*
Oct. :	45,850:	29,600:	37,680:	62,160
Nov. :	52,670:	23,950:	40,890:	24,130
Dec. :	42,060:	47,160:	83,240:	42,090
Jan. :	26,540:	39,830:	37,180:	26,340
Feb. :	10,210:	11,460:	26,630:	23,050
Mar. :	18,990:	20,610:	34,990:	21,640
Apr. :	36,340:	44,560:	33,750:	32,370
May :	67,400:	87,240:	78,690:	54,170
June :	89,610:	83,440:	60,570:	53,150
July :	71,200:	88,260:	44,570:	48,340
Aug. :	39,310:	47,640:	33,020:	29,090
Sept.:	29,990:	25,610:	25,330:	37,180
Year :	530,170:	549,360:	536,540:	453,710

*Not included in computations of this report.

Run-off in Acre-feet, Nooksack River at Excelsior
(Area - 96 square miles)

Month:	1920-21
Sept.:	52,700
Oct. :	73,200
Nov. :	30,500
Dec. :	23,000
Jan. :	20,800
Feb. :	29,800
Mar. :	20,000
Apr. :	20,500
May :	62,100
June :	118,000
July :	79,300
Aug. :	57,100
Sept.:	41,500

Run-off in Acre-feet, Middle Fork of Nooksack River near Deming
(Area - 70 square miles)

Month:	1919-20:	1920-21:	1933-34:	1934-35
Oct. :	:	78,100:	:	29,750
Nov. :	:	34,800:	:	54,950
Dec. :	:	34,400:	:	53,290
Jan. :	:	30,700:	:	53,340
Feb. :	:	47,500:	29,500:	37,240
Mar. :	:	22,300:	37,060:	15,190
Apr. :	:	22,600:	32,930:	12,360
May :	:	48,000:	42,300:	28,160
June :	:	71,400:	24,840:	30,090
July :	:	40,200:	27,040:	22,500
Aug. :	:	25,600:	20,420:	15,350
Sept.:	47,400:	25,800:	23,640:	20,840
Total:		481,000:		355,060

Run-off in Acre-feet, South Fork Nooksack River at Saxon Bridge (Area - 129 sq. mi.)

Month	1920-21	1933-34
July		68,900
Aug.		22,800
Sept.	107,000	56,000
Oct.	116,000	82,470
Nov.	60,700	66,550
Dec.		148,700
Jan.	71,300	130,600
Feb.		57,800
Mar.		72,310
Apr.		56,370
May	64,600	51,690
June	66,000	22,170
July		21,660
Aug.	15,000	11,460
Sept.	64,300	21,490
		743,300 (Water year)

Run-off in Acre-feet, South Fork Nooksack River near Wickersham,(Area - 103 sq. mi.)

Month	1933-34	1934-35	1935-36	1936-37	1937-38	1938-39	1939-40	1940-41*
Oct.		31,130	24,120	10,100	41,030	21,040	39,700	42,710
Nov.		86,230	27,490	7,520	98,780	37,340	52,690	37,100
Dec.		69,960	37,870	71,440	76,940	83,890	94,400	61,950
Jan.		103,800	55,800	11,910	51,500	76,130	40,430	58,290
Feb.		53,390	21,540	17,230	21,080	24,730	55,570	35,950
Mar.		32,650	45,780	47,580	35,340	38,310	72,980	35,300
Apr.		28,280	68,580	55,020	59,130	55,580	41,460	26,940
May	43,910	59,140	102,500	75,640	56,240	76,370	47,760	43,780
June	18,340	54,190	67,560	103,500	32,430	63,230	18,410	21,380
July	17,260	25,240	22,020	24,010	12,550	39,690	7,570	8,630
Aug.	8,460	8,670	8,140	11,660	6,300	11,140	5,880	6,370
Sept.	18,230	19,490	13,080	7,420	5,140	9,030	4,840	43,680
Total	106,200	572,200	494,500	443,000	496,460	536,480	481,700	422,080

*Not included in computations of this report.

GEOLOGIC RECONNAISSANCE

Maple Falls Dam Site
Nooksack River, Washington

By
J. C. Miller

The proposed dam site near Maple Falls is covered with a dense brush and second-growth timber so that it was rather difficult to make anything but a cursory examination of geologic conditions in the vicinity of the stream channel. The high water during the day when this examination was made and the lack of a boat prevented close inspection of the left or south bank of the river.

On the right or north bank the exposed rock may be classed as a greenish andesitic agglomerate, the highest part of which was observed at approximately 50 feet above water-level. Adjacent to this outcrop on the upstream side, gravel and alluvium extend from water level to the top of the slope and no andesite is exposed. On the left bank rock similar in appearance protruded from the brush at the same level as or slightly higher than that on the right bank to a height about 10 feet above water level. The length of both outcrops parallel to the stream is estimated not to exceed 200 feet before they disappear beneath the alluvium. The igneous rock on the right bank is similar in appearance to the agglomerate which occurs high on the right bank of the North Fork of the Nooksack River at the Mile 18 dam site, and perhaps older than the basalt or andesite with the columnar jointing which occurs farther upstream high on the left bank of the river at Mile 16.4 dam site.

No outcrop of sedimentary beds was observed at the Maple Falls dam site, and on the basis of the present examination the depth of alluvium and the thicknessof the extrusives cannot be estimated. If the northward dip of 67 degrees observed along the road cut in the SW-1/4 of sec. 27, T. 40 N., R. 6 E., W. M., persists in sec. 31 of that township beneath the andesite flow and the alluvium, sedimentary beds striking diagonally across the stream may be present at depth. A similar dip appears to have contributed to the rock slides on the north end of Slide Mountain. In the NW-1/4 of sec. 22, T. 40 N., R. 6 E., a thick limestone shows a steep dip to the north of approximately 80 degrees.

In view of the cover of alluvium and the apparent lack of solid beds more than 50 feet above water level, a dam at this location could not be very high. The rock on the left bank is probably firm and dense enough to support a moderately high dam

provided it is of sufficient thickness. Whether this extrusive merely covers old alluvium or immediately overlies sedimentary or metamorphic beds is not known, and either drilling or geophysical explorations will be necessary to determine the desirability of this site. A careful inspection of the left bank, however, and a detailed survey of the entire basin might reveal some merits of this location not observed during this brief examination.

GEOLOGIC RECONNAISSANCE

Mile 18 Dam Site
Nooksack River, Washington

By
J. C. Miller

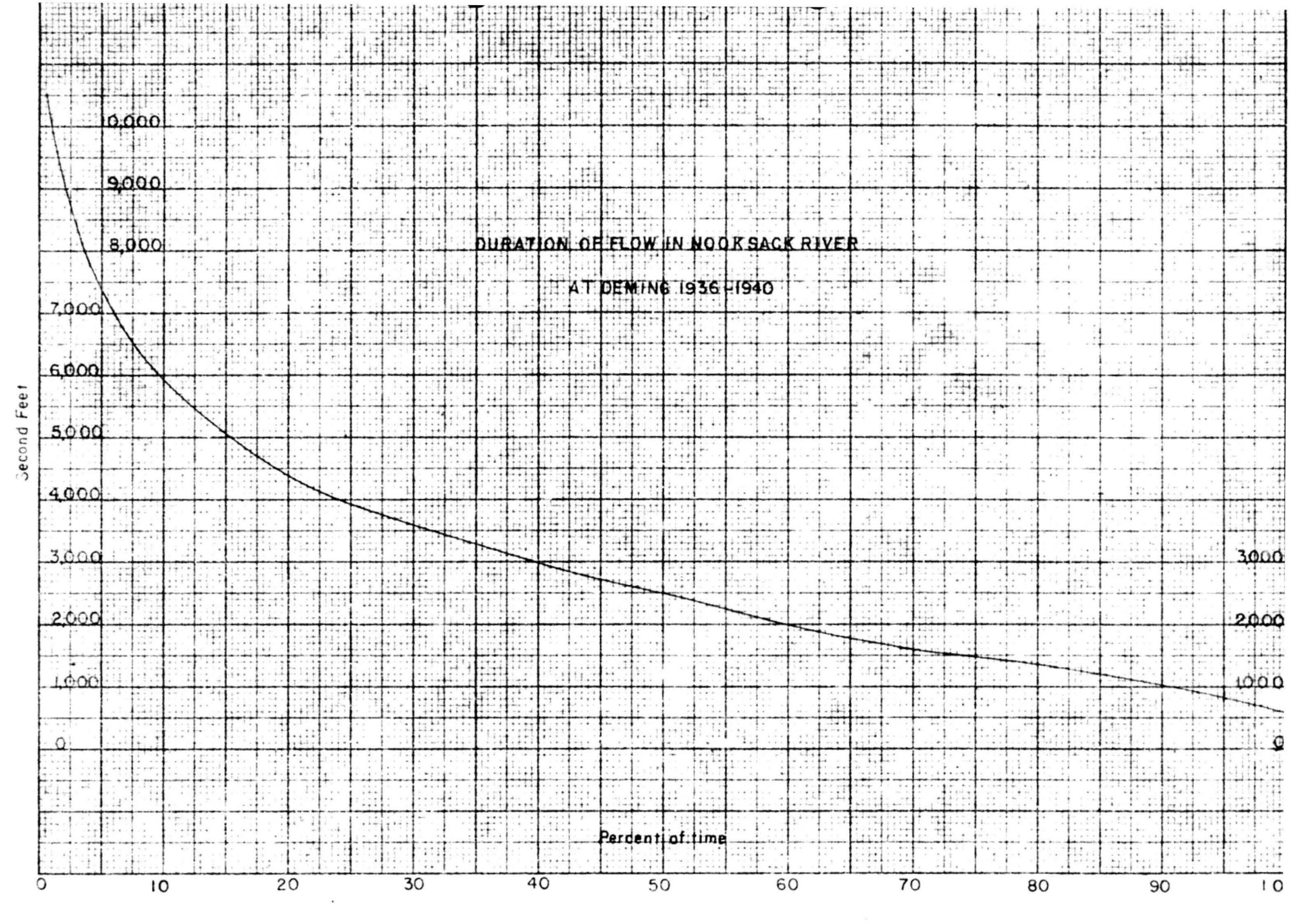
Except in the immediate vicinity of the Mt. Baker highway, the entire area of the proposed Mile 18 dam site on the North Fork of the Nooksack River is heavily wooded. No solid rock appears on the north or right bank of the stream below the highway until an elevation approximately 20 feet above water level is reached. This bed of broken, jointed rock presents the appearance of a solid mass extending about 150 feet upstream and probably 200 feet downstream from the site. This rock, which extends across stream from bank to bank, may be classed as an olivene andesite or a greenstone. No thin sections of any of the rocks exposed were prepared for petrographic examination. Downstream where the stream turns sharply southwest, the top or highest part of this bed stands at a height of 50 feet above water. Beneath the foot-bridge and elsewhere along the proposed site there are glacial striae on isolated exposures of andesite, the general direction of which striae is parallel to the stream. This very hard dense bed in the stream appears capable of supporting a dam if there is sufficient thickness below stream level.

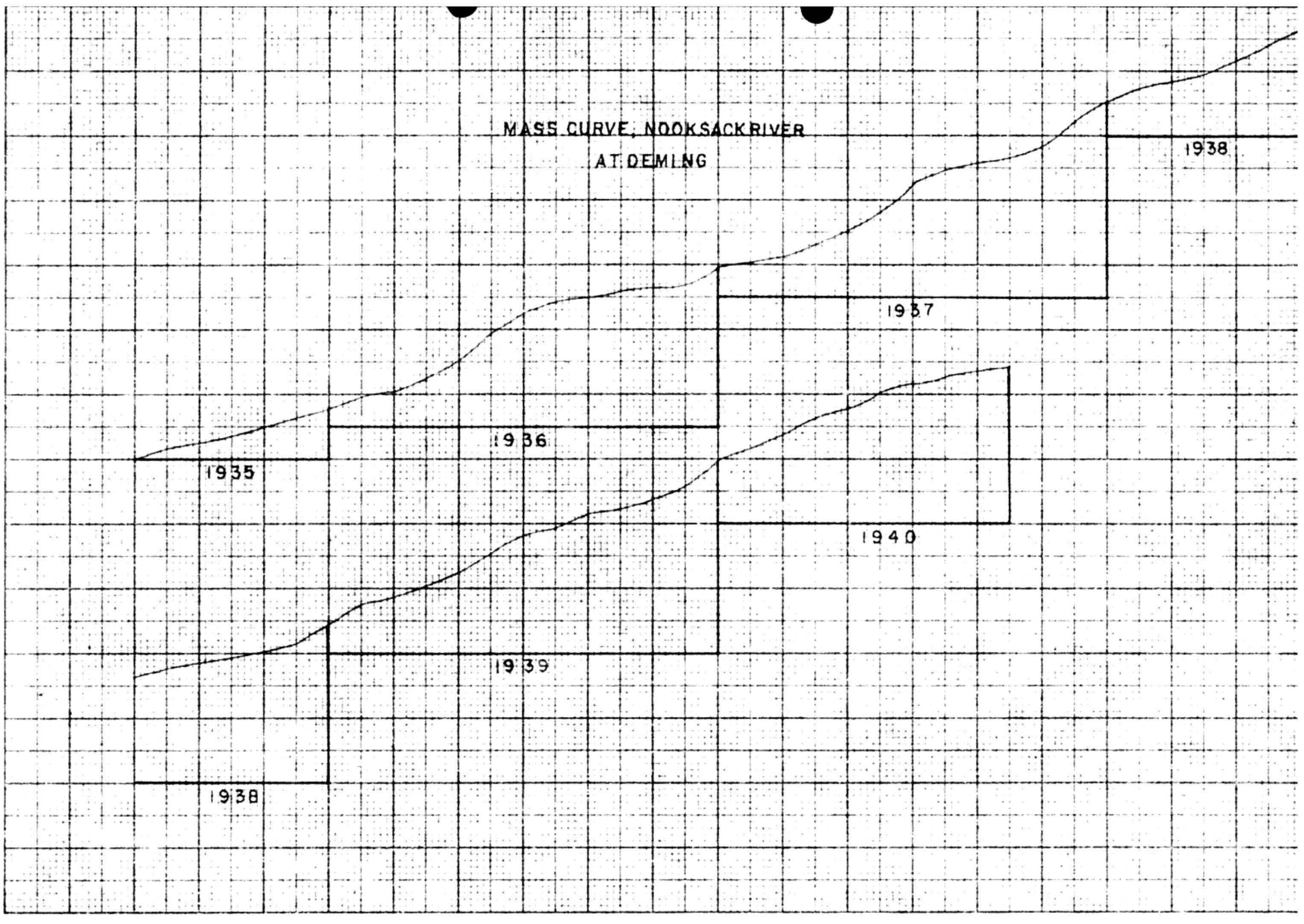
On the small creek proposed for a spillway the exposure of approximately 70 feet of andesite facing the creek has no counterpart on the south bank or abutment portion of the site although several very large boulders were observed. The left or south bank of this creek and that portion of the hill approximately 200 feet above it were covered with alluvium which may have obscured the outcrop. On the right or north bank of this creek, however, below the escarpment of andesite, no rock in place was observed. The conclusion reached is that the lower 75 feet of the spillway site would be subject to scouring unless the upturned edges of the older formations are present

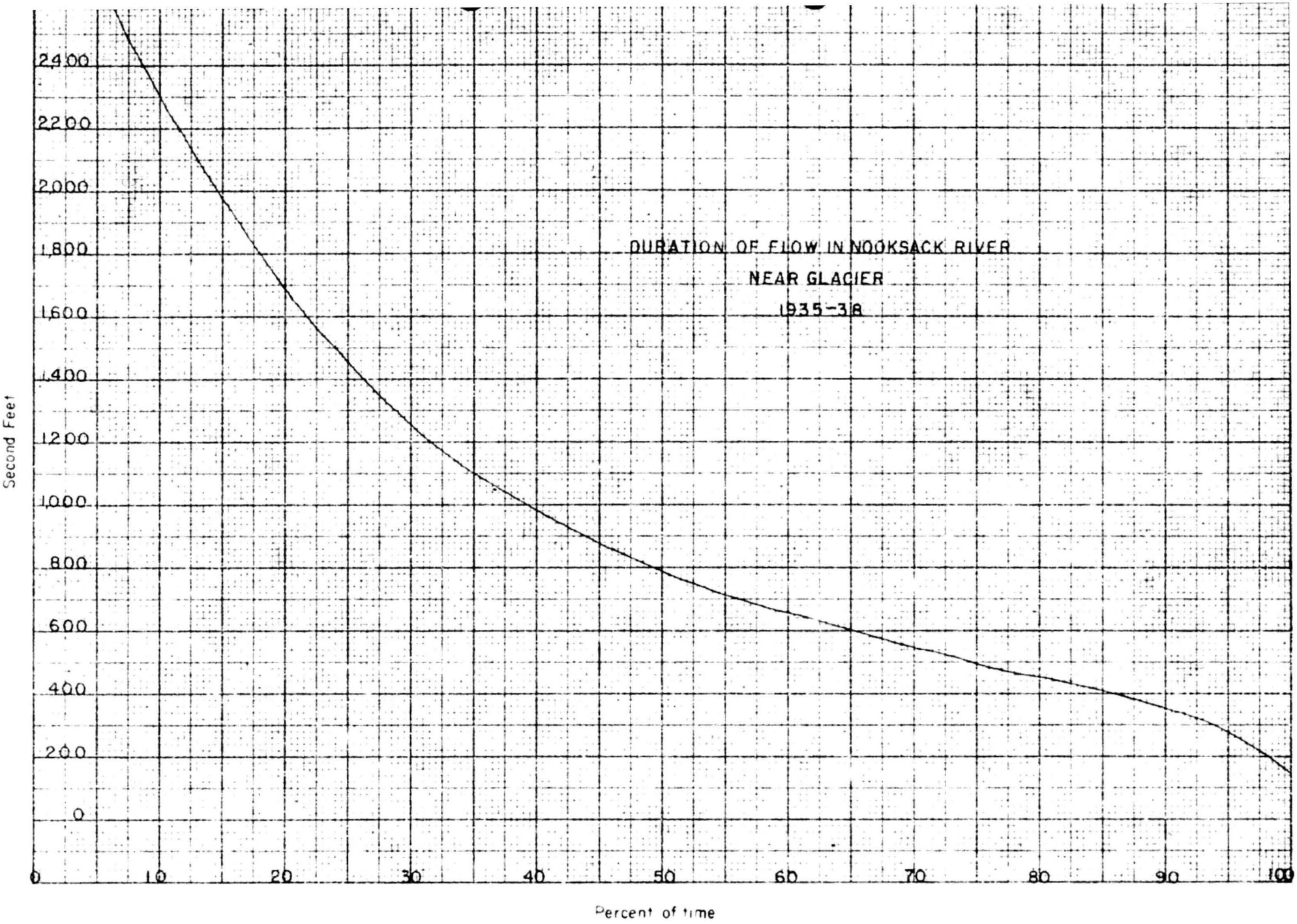
at relatively shallow depths. The few exposures observed along the dam site suggest the possibility that variations in the amount of andesite exposed may be due to variations in thickness of the flow.

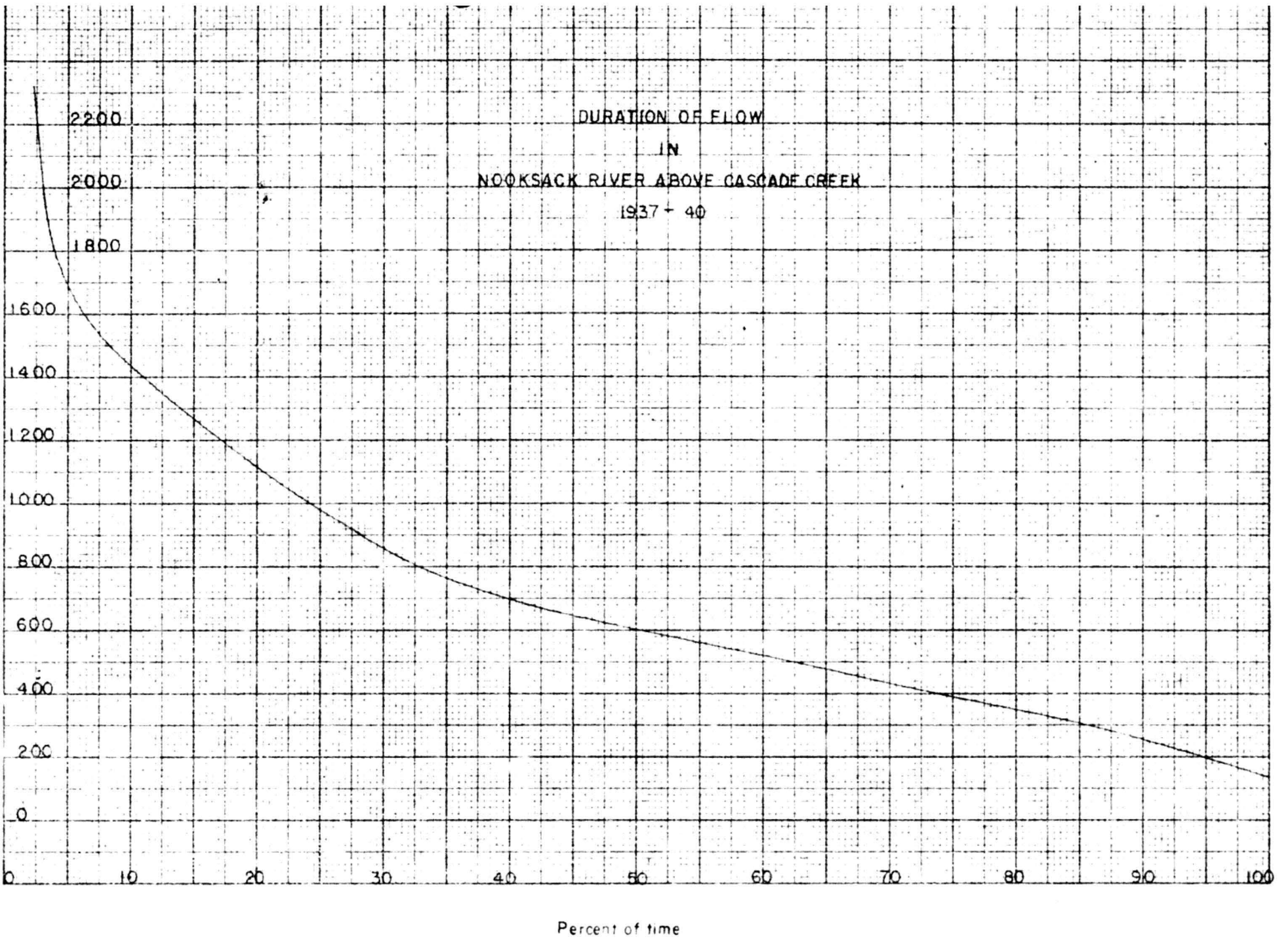
The proximity of these exposures to the flows shown on the areal map of the State suggests that the andesite flow or flows descended into the valley from the southeast tending to dam the stream and that sharp changes in gradient may be caused by the cascading of successive flows within the stream bed or by erosion of the stream headward along successive flows. Faulting and glacial action could have produced the same result. The precise width of the original stream valley, however, is not known as it was undoubtedly altered by lava flows and by glacial action. The thickness of the andesite at the site may be 70 feet or more. It is very hard and dense, but joints tend to make it susceptible to leakage. It occurs at an elevation approximately 100 feet above stream level, but the abutments of the proposed dam would terminate in glacial drift or alluvium on the surface unless this material is relatively thin. If the upturned edges of the sediments are not present within a depth of 50 to 100 feet, there would be leakage at least around the upper 70 feet of the dam. Moreover, if the andesite rock which forms the stream bed at the site is underlain by valley fill it probably would not sustain a dam of the desired height.

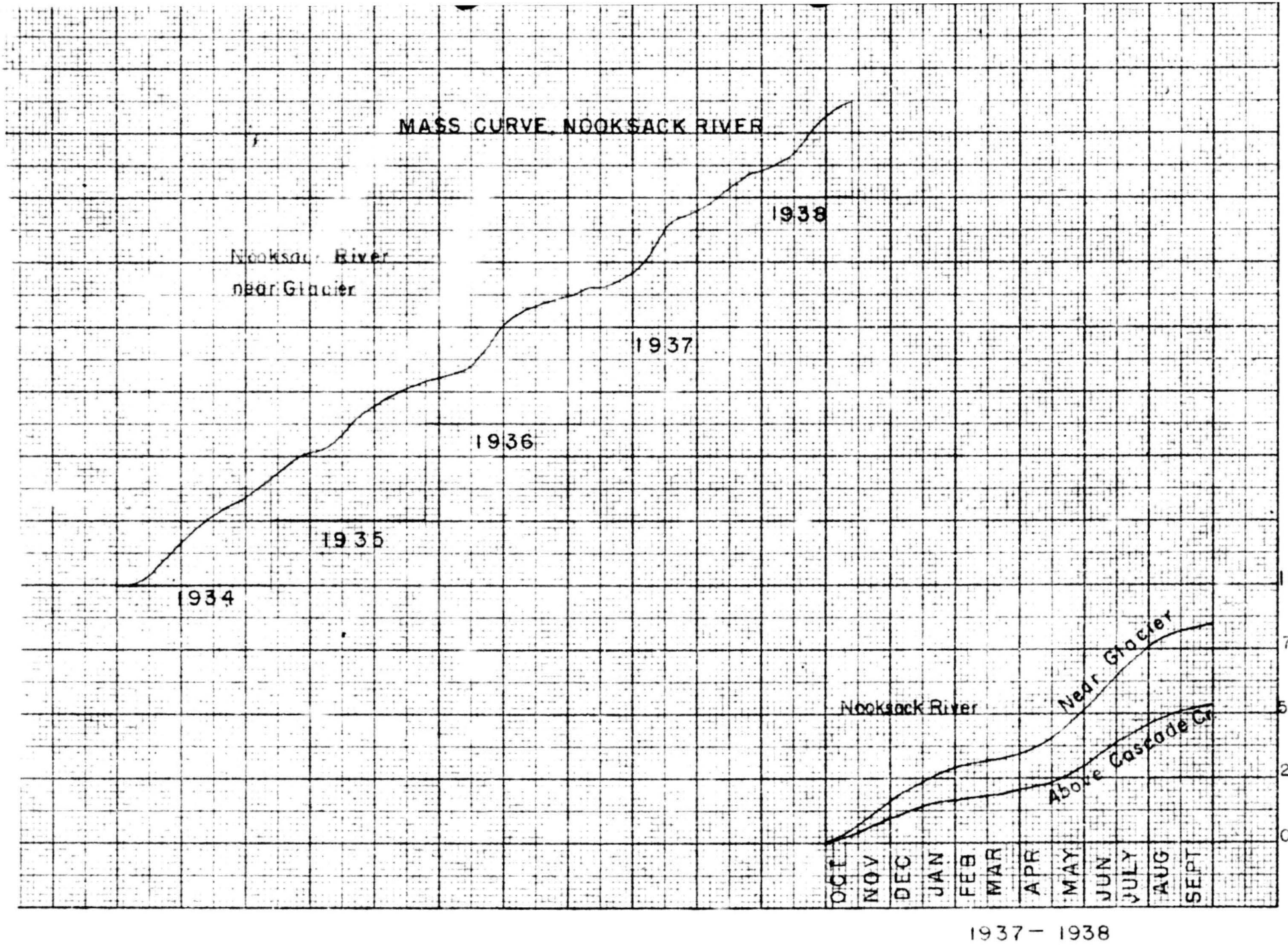
If further investigation of this site is attempted it is suggested that geophysical methods or drilling be employed to supplement the geologic examination. It is also suggested that a more detailed topographic map be prepared which would include an area approximately two miles upstream from the site and downstream as far as the Mile 16.4 site. Additional geologic investigations should include the entire basin and should probably extend beyond the limits of it by reason of the lack of exposures within the basin.

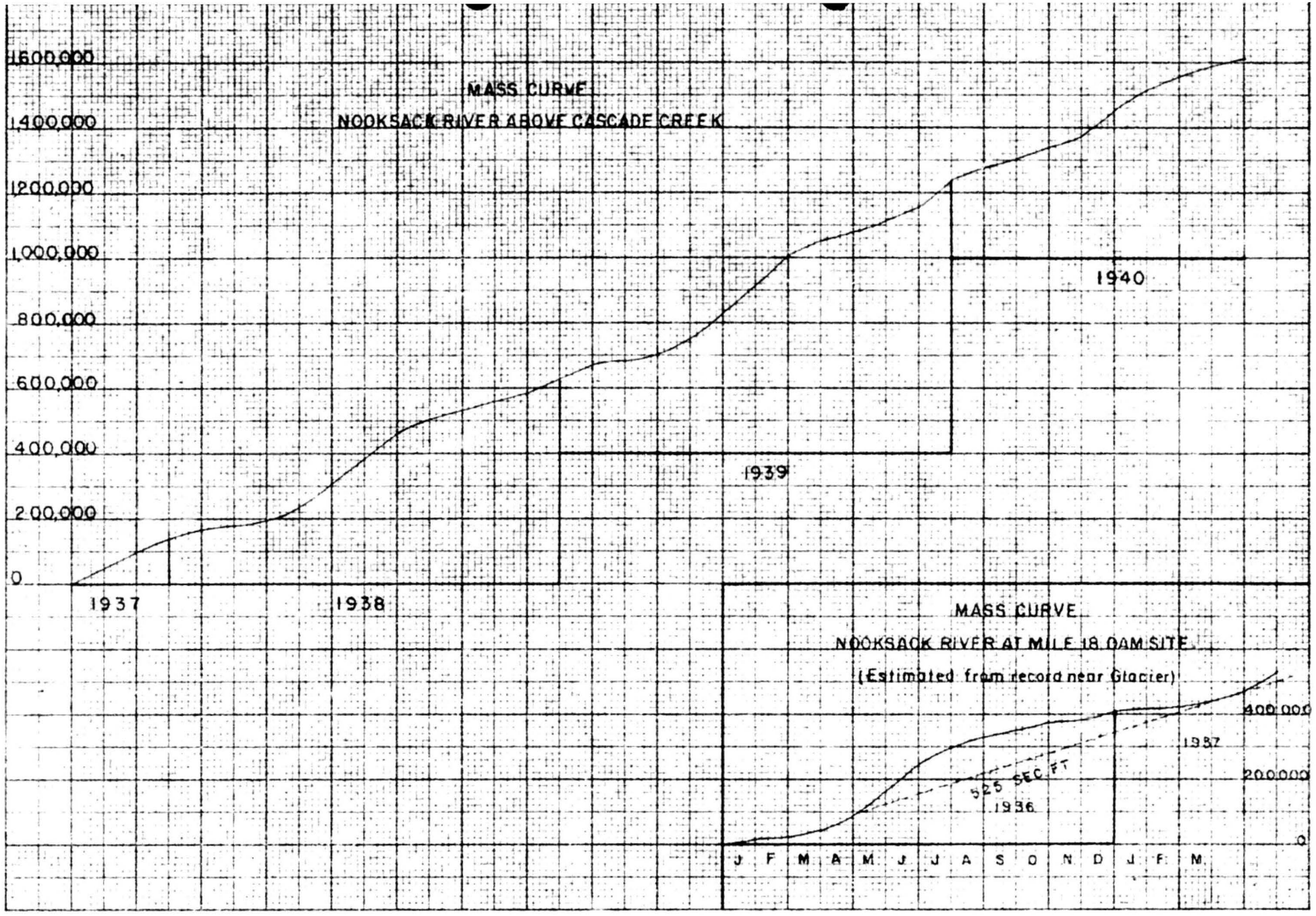

DURATION OF FLOW IN NOOKSACK RIVER
AT DEMING 1936-1940
Second Feet
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Percent of time
0
10
20
30
40
50
60
70
80
90
100


MASS CURVE, NOOKSACK RIVER
AT DEMING
1938
1937
1936
1935
1940
1939
1938
Acre Feet
Scale: 1 inch = 2,000,000 A F


DURATION OF FLOW IN NOOKSACK RIVER
NEAR GLACIER
1935-38
Second Feet
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time

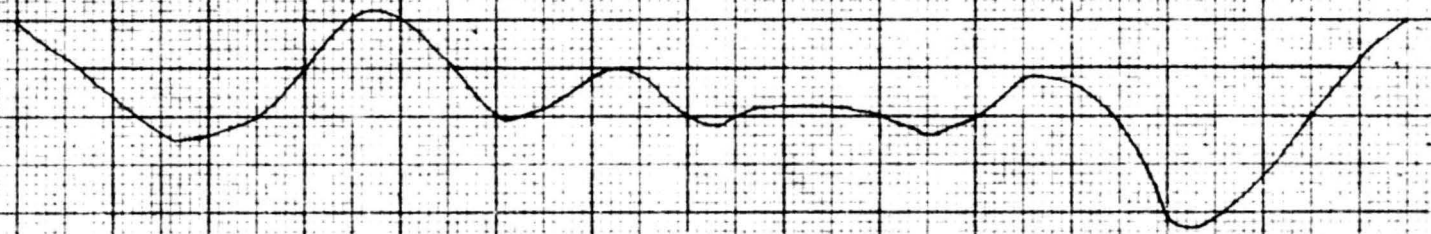

DURATION OF FLOW
IN
NOOKSACK RIVER ABOVE CASCADE CREEK
1937 - 40
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
10
20
30
40
50
60
70
80
90
100
Percent of time


MASS CURVE, NOOKSACK RIVER
1938
Nooksack River
near Glacier
1937
1936
1935
1934
Nooksack River
Near Glacier
Above Cascade Cr.
OCT
NOV
DEC
JAN
FEB
MAR
APR
MAY
JUN
JULY
AUG
SEPT
1937 – 1938
Cumulative Acre Feet (thousands)
100
750
500
250
0

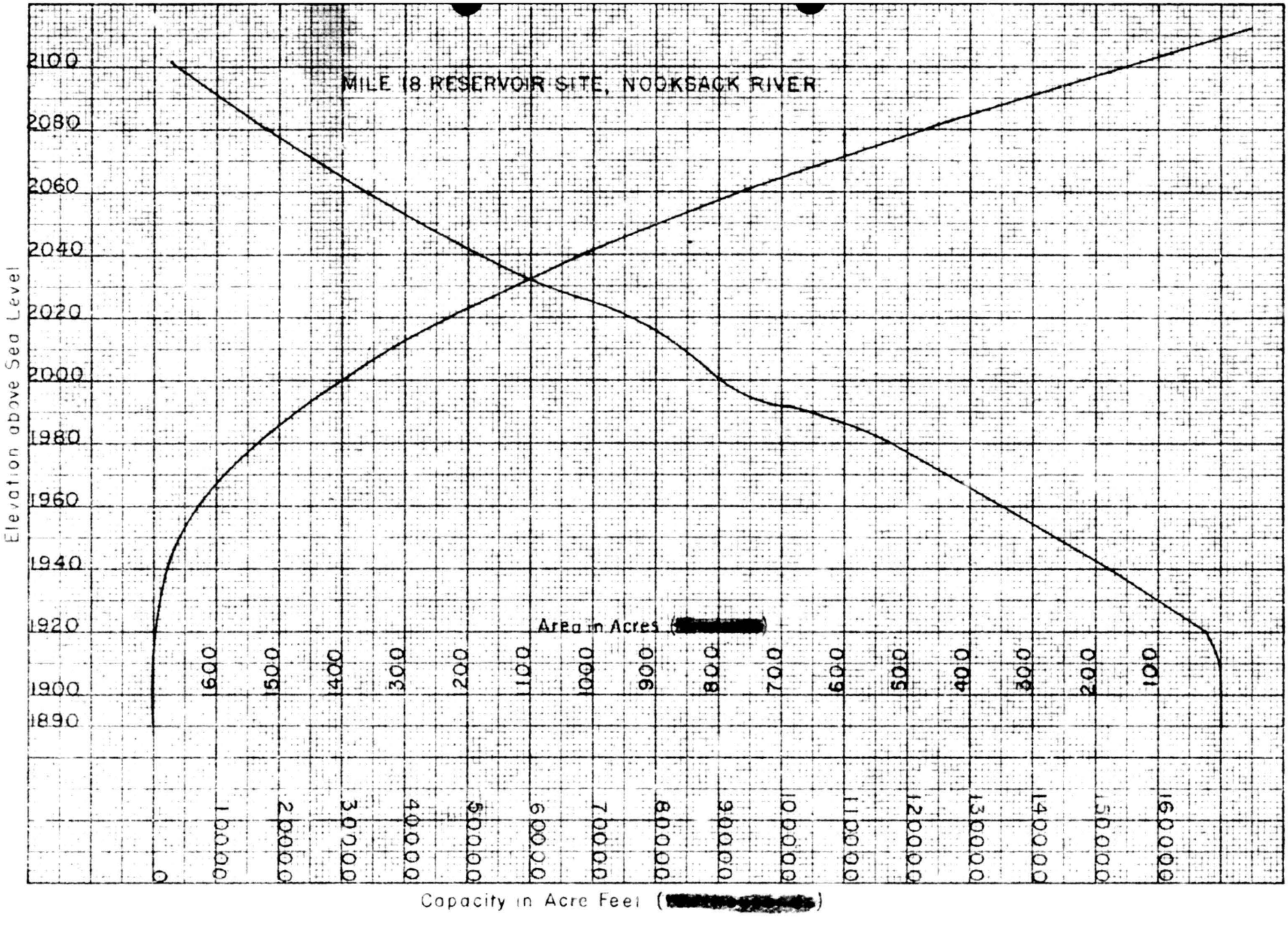

MASS CURVE
NOOKSACK RIVER ABOVE CASCADE CREEK
1600,000
1400,000
1200,000
1,000,000
800,000
600,000
400,000
200,000
0
Cumulative Acre Feet
1937
1938
1939
1940
MASS CURVE
NOOKSACK RIVER AT MILE 18 DAM SITE
(Estimated from record near Glacier)
525 SEC FT
1936
1937
400,000
200,000
0
J F M A M J J A S O N D J F M

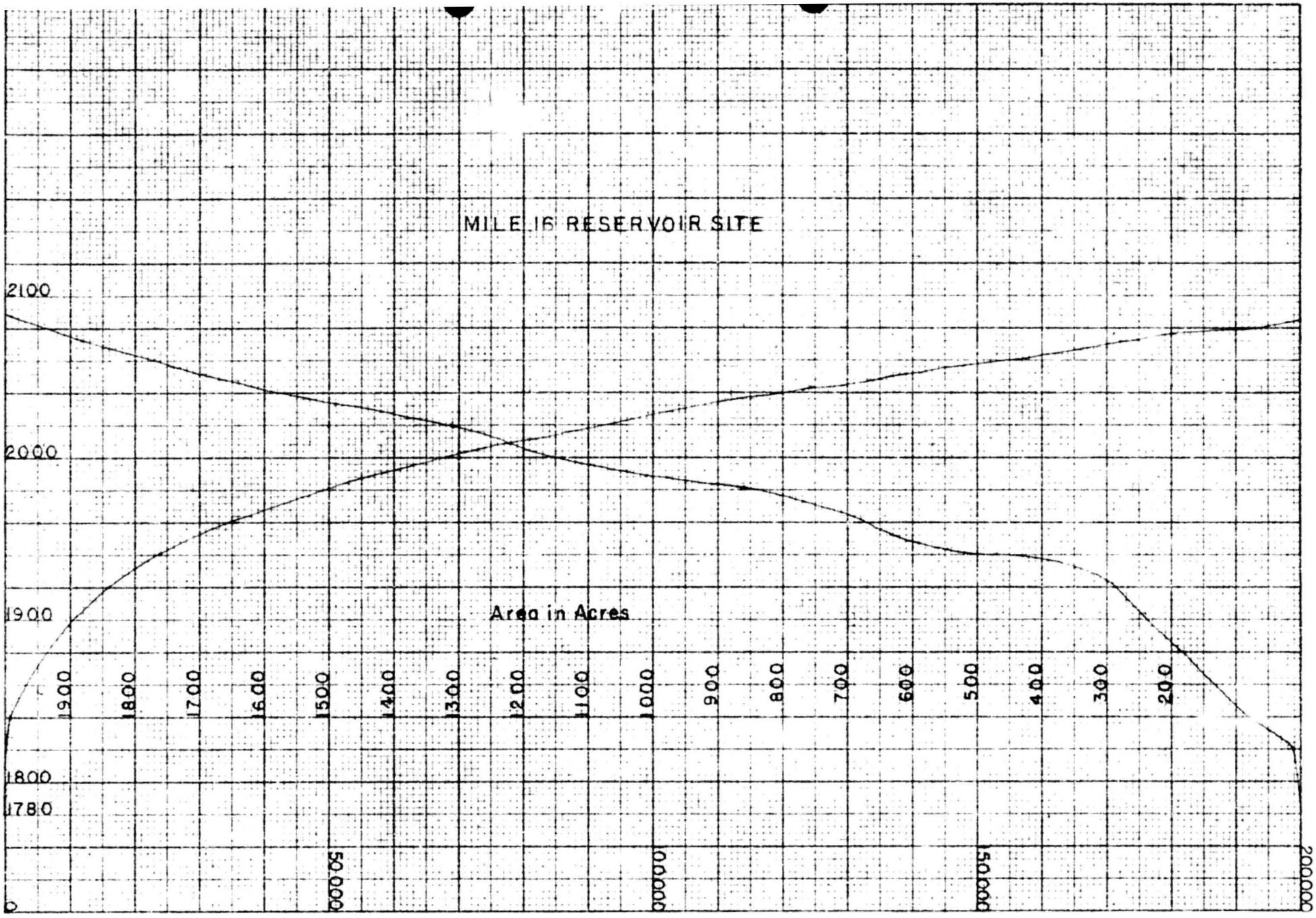
ELEVATION ABOVE SEA LEVEL

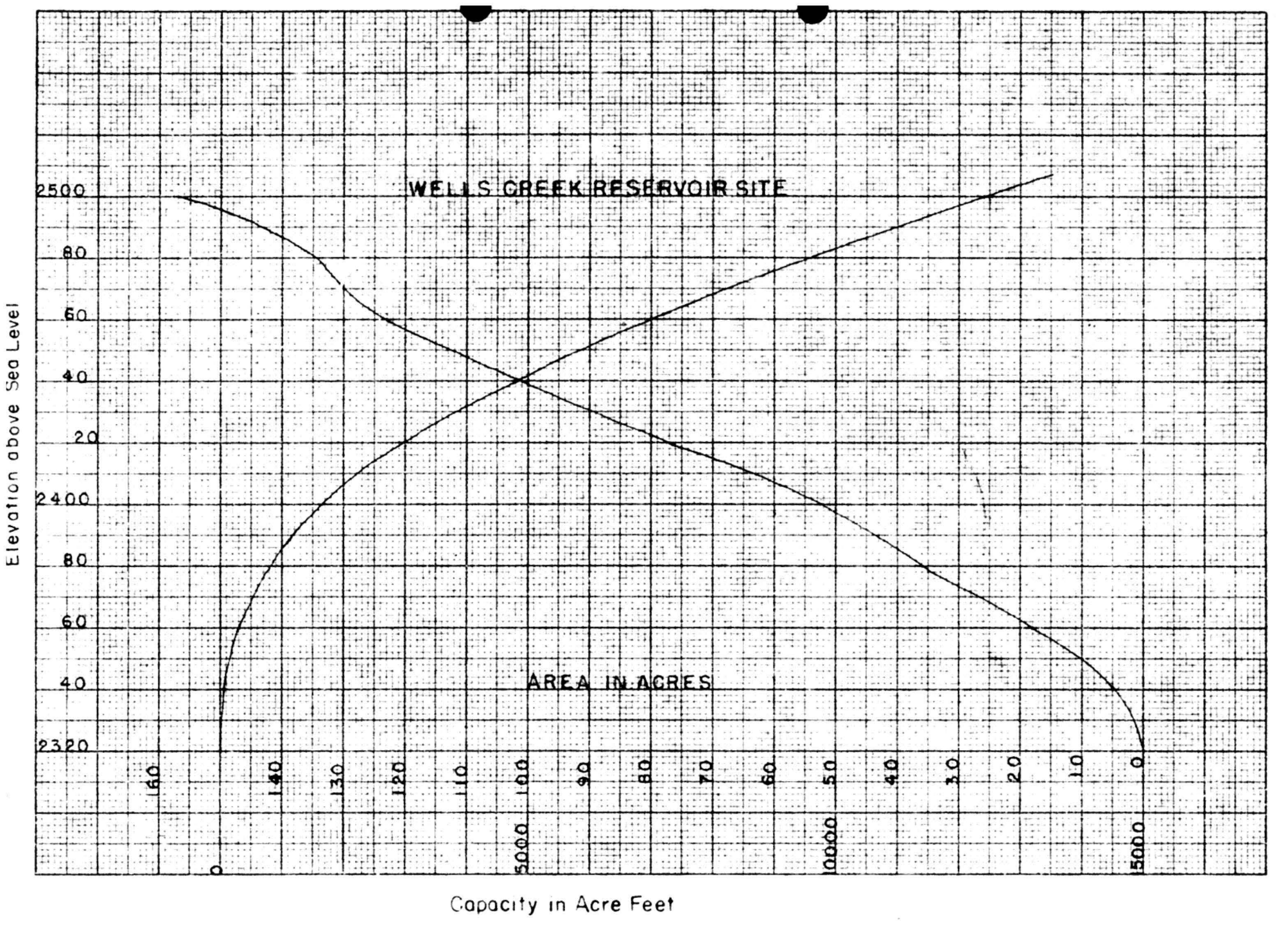
CROSS SECTION MILE 18 DAM SITE
NOOKSACK RIVER
(From I-31680 survey)

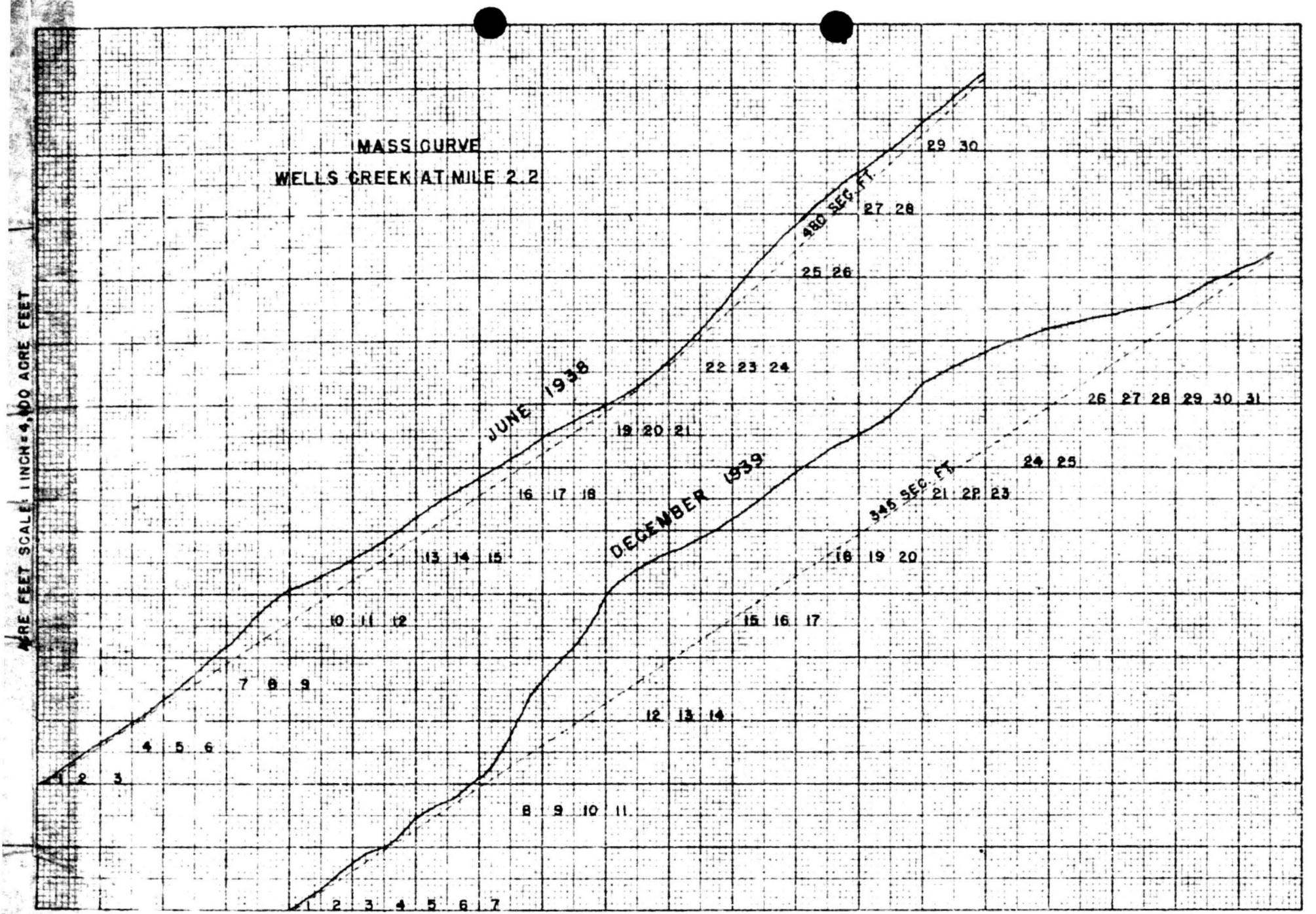


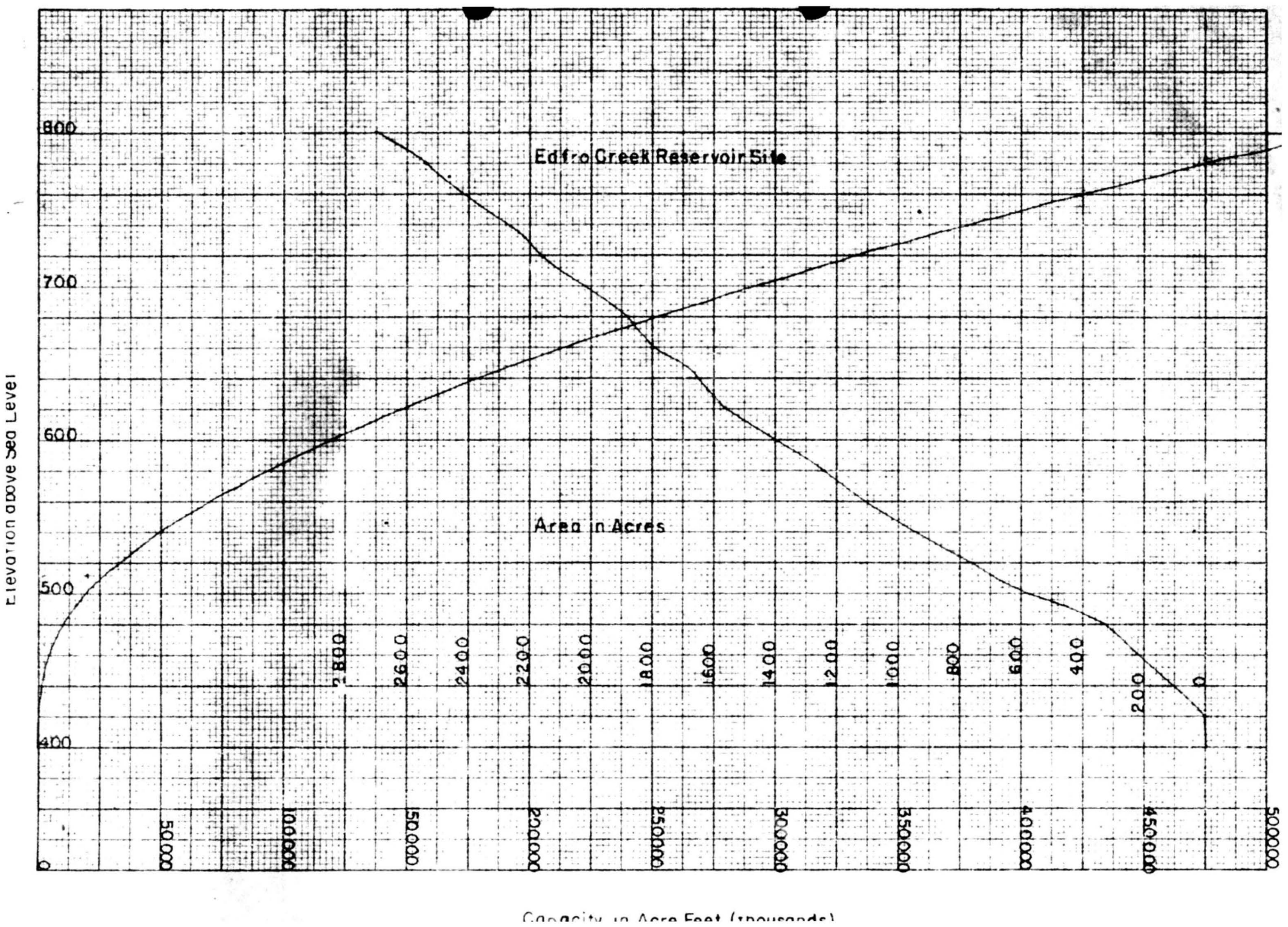
Scale: Vertical 1 in = 200 feet
Horizontal 1 in = 400 feet

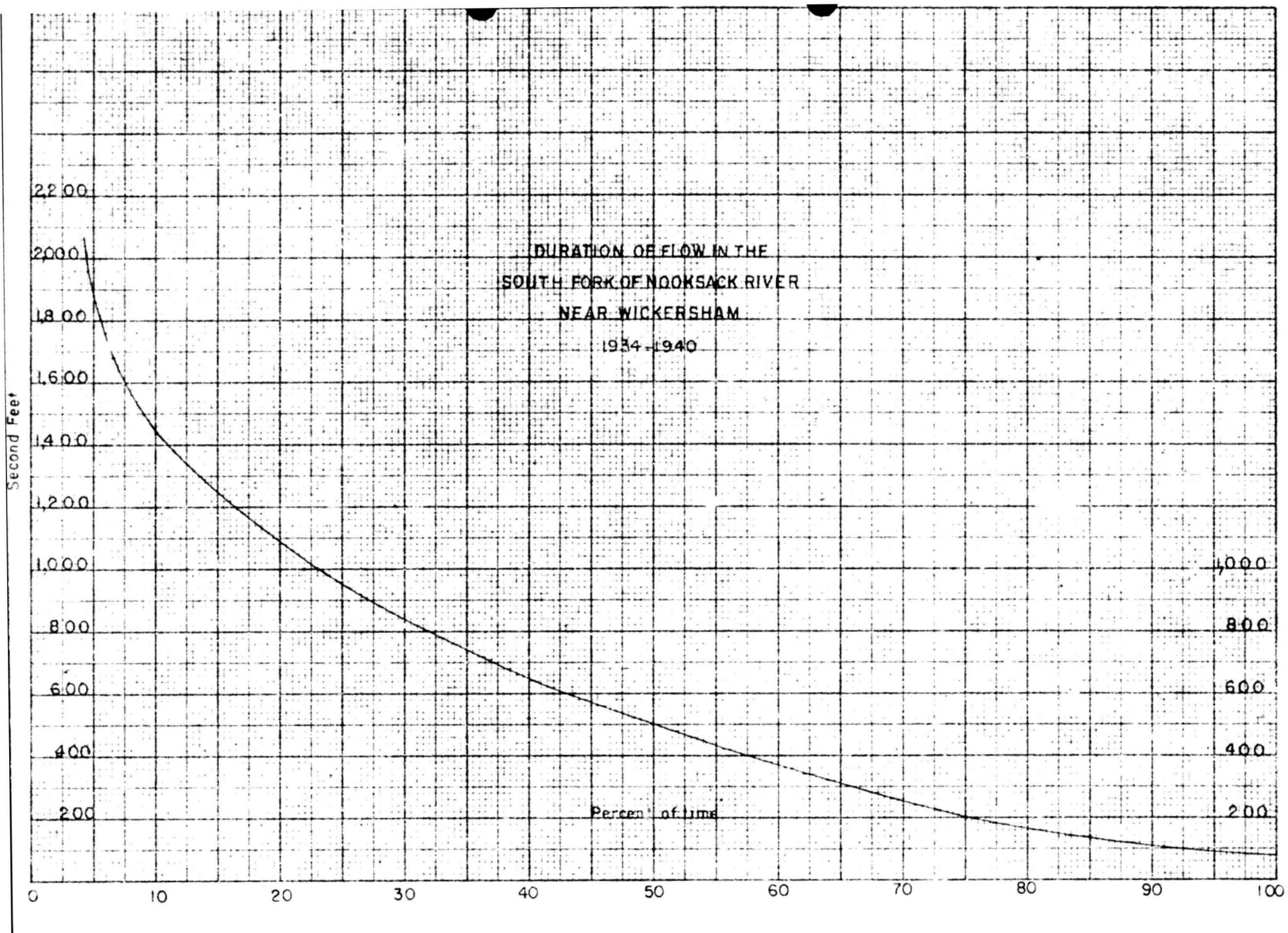

MILE 18 RESERVOIR SITE, NOOKSACK RIVER
Elevation above Sea Level
2100
2080
2060
2040
2020
2000
1980
1960
1940
1920
1900
1890
Area in Acres
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
100000
200000
300000
400000
500000
600000
700000
800000
900000
1000000
1100000
1200000
1300000
1400000
1500000
1600000
Capacity in Acre Feet

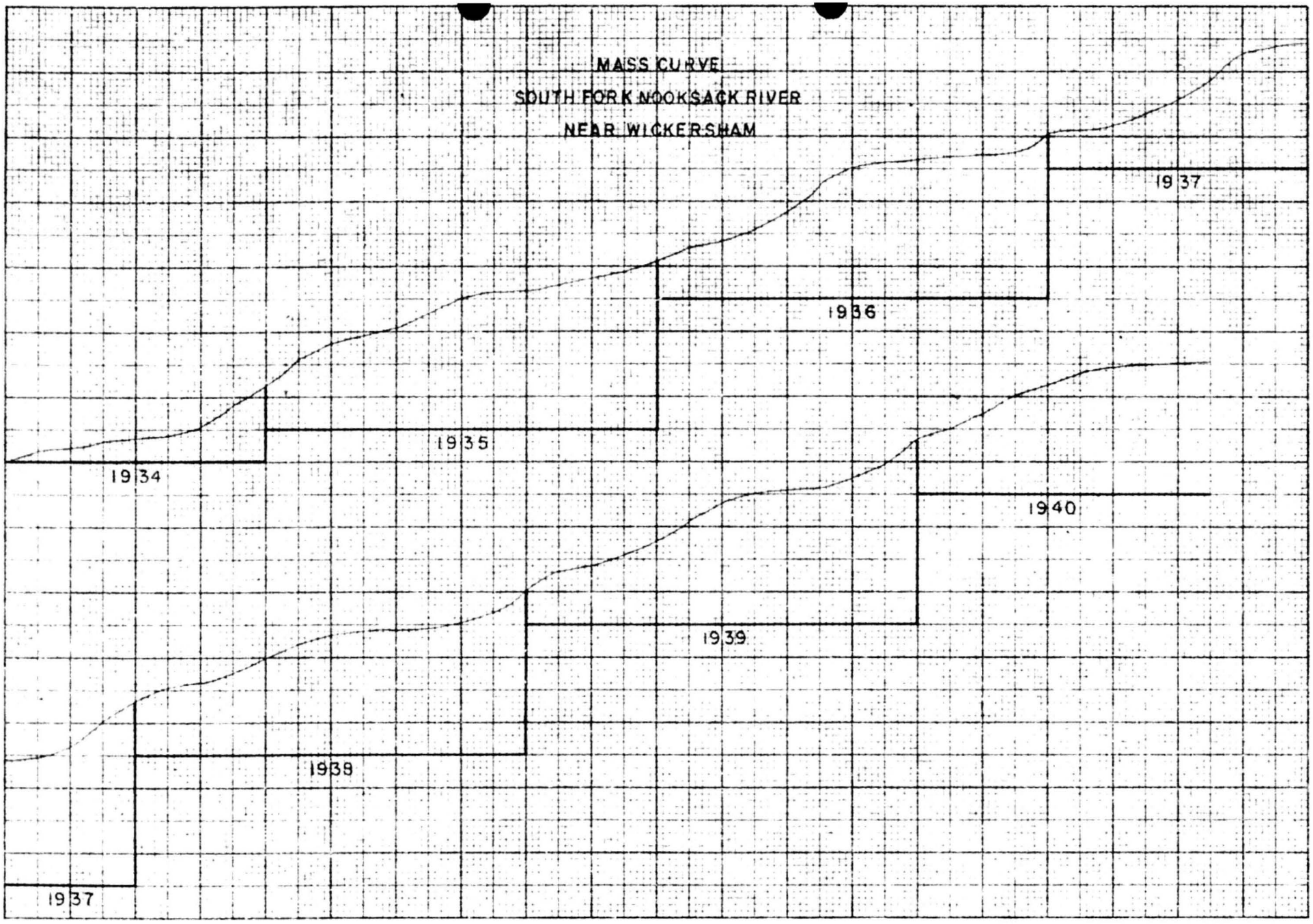

MILE 16 RESERVOIR SITE
Elevation above Sea Level
2100
2000
1900
1800
1780
Area in Acres
19.00
18.00
17.00
16.00
15.00
14.00
13.00
12.00
11.00
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
0
50000
100000
150000
200000
Capacity in Acre Feet

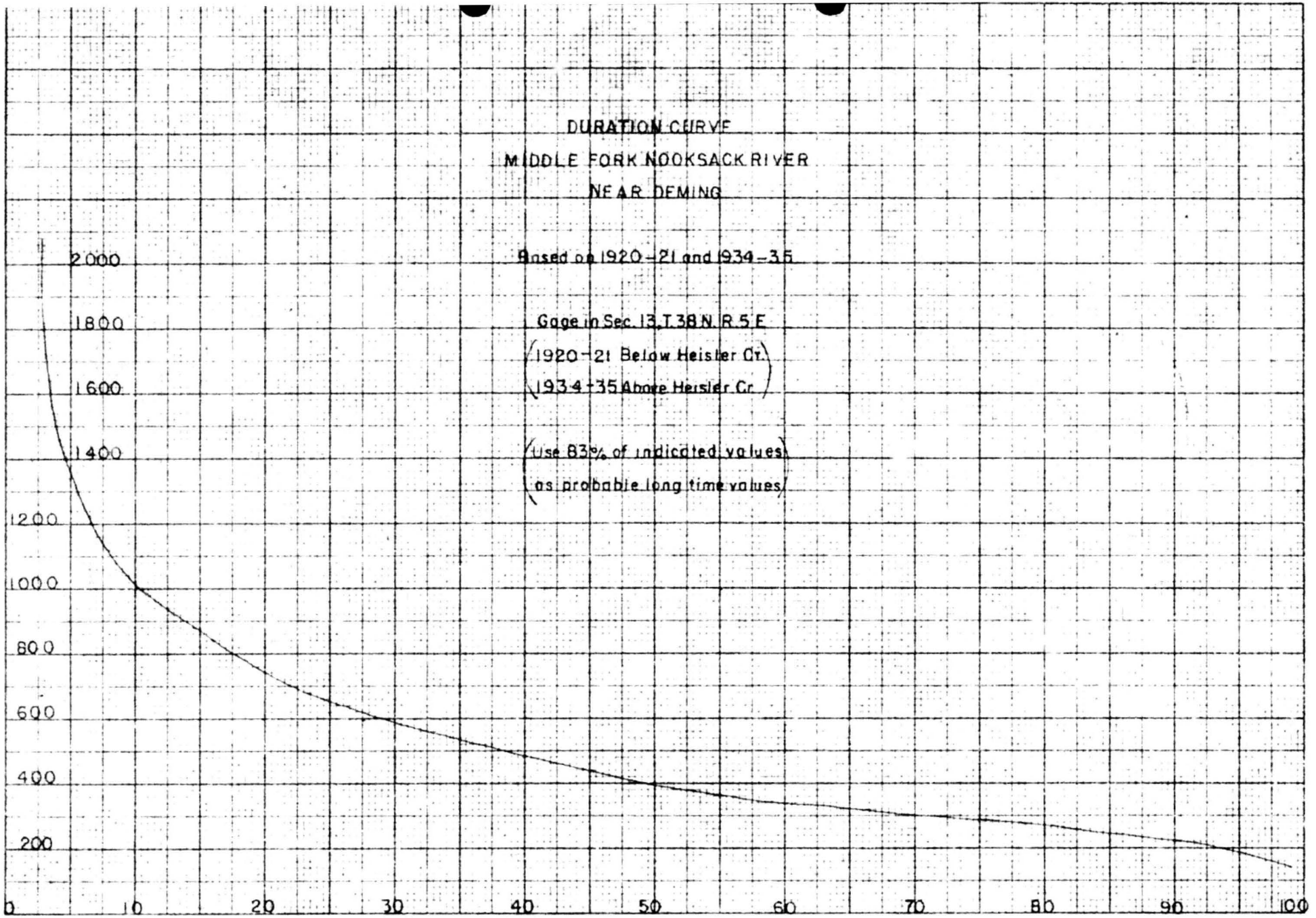

WELLS CREEK RESERVOIR SITE
AREA IN ACRES
Elevation above Sea Level
2500
80
60
40
20
2400
80
60
40
2320
160
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
5000
10000
15000
Capacity in Acre Feet

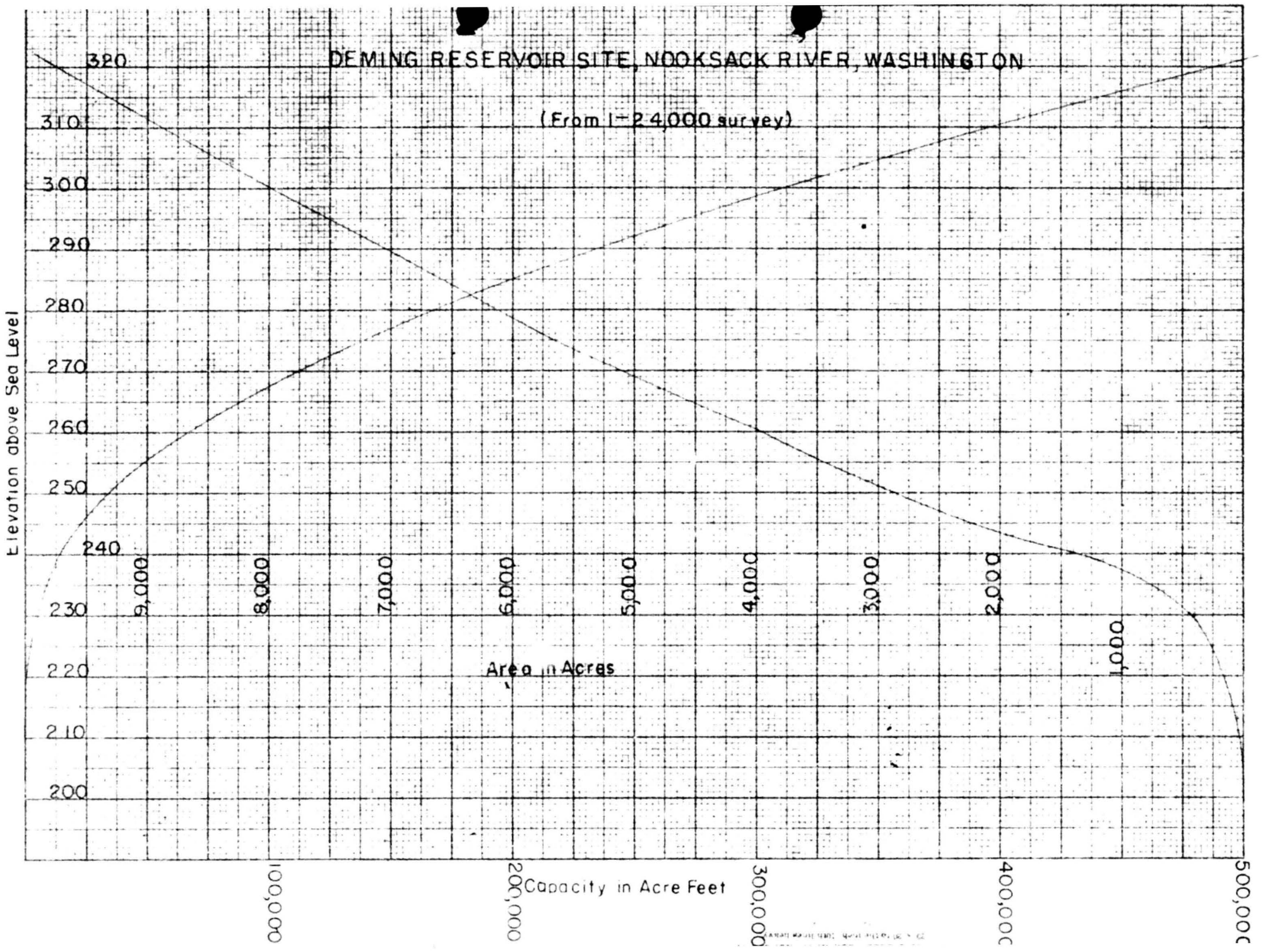

MASS CURVE
WELLS CREEK AT MILE 2.2
ACRE FEET SCALE 1 INCH = 4,000 ACRE FEET
JUNE 1938
480 SEC. FT.
DECEMBER 1939
345 SEC. FT.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

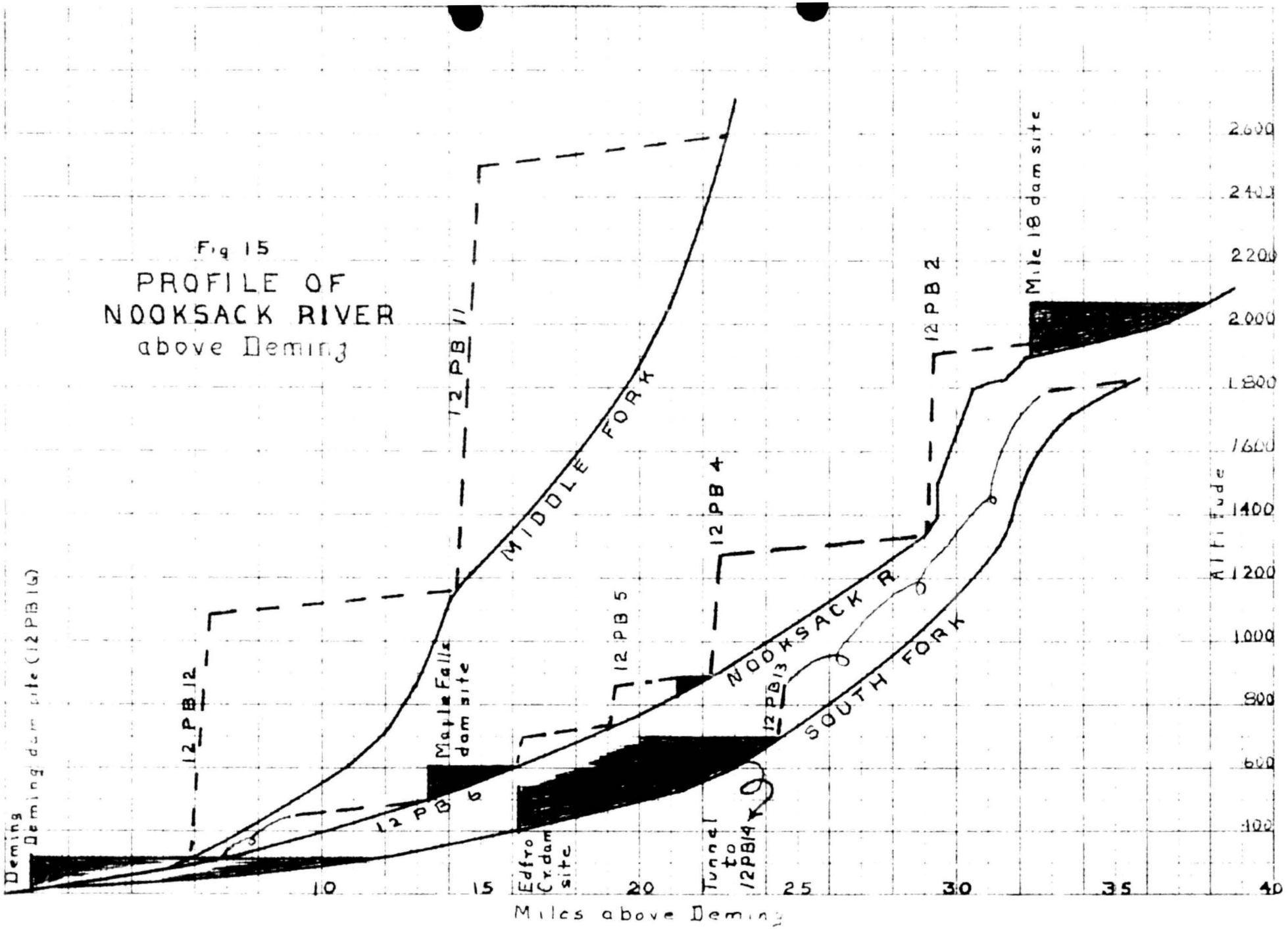

Edfro Creek Reservoir Site
Area in Acres
Elevation above Sea Level
800
700
600
500
400
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
50000
100000
150000
200000
250000
300000
350000
400000
450000
500000
Capacity in Acre Feet (thousands)


DURATION OF FLOW IN THE
SOUTH FORK OF NOOKSACK RIVER
NEAR WICKERSHAM
1934-1940
Second Feet
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
1,000
800
600
400
200
Percent of time
0
10
20
30
40
50
60
70
80
90
100


MASS CURVE
SOUTH FORK NOOKSACK RIVER
NEAR WICKERSHAM
1934
1935
1936
1937
1938
1939
1940
1937
Acre feet Scale inch = 500,000 Ac-ft


DURATION CURVE
MIDDLE FORK NOOKSACK RIVER
NEAR DEMING
Based on 1920-21 and 1934-35
Gage in Sec. 13, T.38 N. R.5 E.
(1920-21 Below Heisler Cr.
1934-35 Above Heisler Cr.)
(Use 83% of indicated values as probable long time values)
Flow in second feet
2000
1800
1600
1400
1200
1000
800
600
400
200
0
10
20
30
40
50
60
70
80
90
100
Percent of time


DEMING RESERVOIR SITE, NOOKSACK RIVER, WASHINGTON
(From 1"=2,000 survey)
Elevation above Sea Level
320
310
300
290
280
270
260
250
240
230
220
210
200
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
Area in Acres
100,000
200,000
300,000
400,000
500,000
Capacity in Acre Feet


Fig 15
PROFILE OF
NOOKSACK RIVER
above Deming
12 PB 11
12 PB 12
12 PB 4
12 PB 5
12 PB 6
12 PB 13
12 PB 2
MIDDLE FORK
NOOKSACK R
SOUTH FORK
Maple Falls dam site
Edfro Cr dam site
Tunnel to 12PB14
Mile 18 dam site
Deming Deming dam site (12PB16)
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
Altitude
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Miles above Deming