UNITED STATES

DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION

- - -

MEMORANDUM TO CHIEF DESIGNING ENGINEER

SUBJECT: BACKWATER INVESTIGATIONS

OF THE COLUMBIA RIVER RESERVOIR

- - -

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- - -

Denver, Colorado

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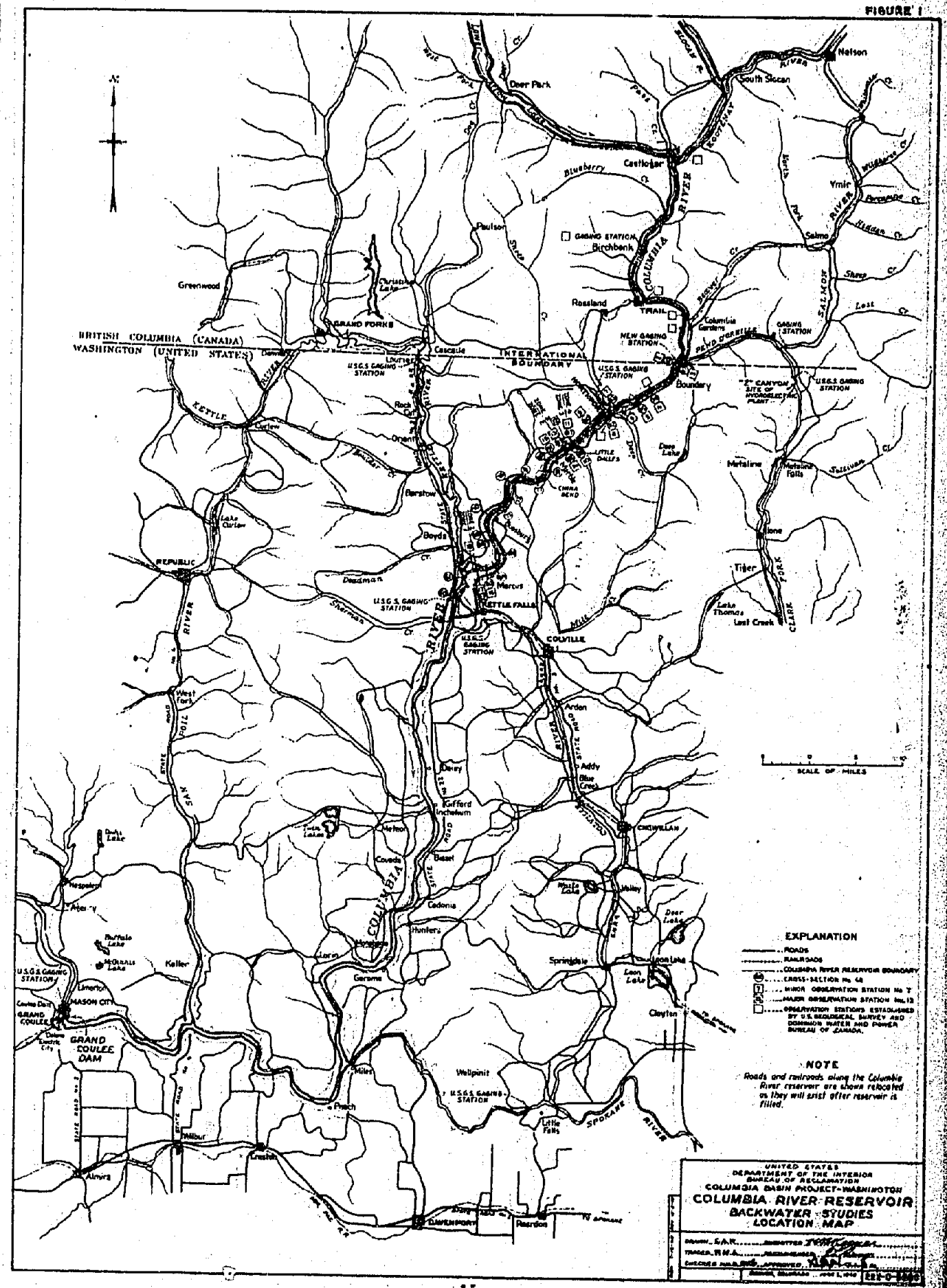
FIGURE 1


Nelson
South Slocan
Deer Park
Castlegar
Ymir
Salmo
Paulson
Birchbank
Rossland
TRAIL
Greenwood
GRAND FORKS
BRITISH COLUMBIA (CANADA)
WASHINGTON (UNITED STATES)
INTERNATIONAL BOUNDARY
Cascade
Laurier
Boundary
Rock Creek
Orient
Curlew
Barstow
Lake Curlew
Boyds
REPUBLIC
Deadman
Marcus
KETTLE FALLS
COLVILLE
Metaline
Metaline Falls
Ione
Tiger
Lake Thomas
Last Creek
Arden
Addy
Blue Creek
Daisy
Kettle Falls
Meyer
Covada
Bossburg
Cedonia
Hunters
Valley
Springdale
Deer Lake
Loon Lake
Clayton
Keller
Loomis
Germania
Hespeler
Ellensburg
Buffalo Lake
McDonald Lake
U.S.G.S. GAGING STATION
Limerick
MASON CITY
GRAND COULEE
GRAND COULEE DAM
Miles
Wellpinit
Fresh
Little Falls
Wilbur
Creston
Almira
Davenport
Reardan
COLUMBIA RIVER
KOOTENAY RIVER
SPOKANE RIVER
SCALE OF MILES
EXPLANATION
ROADS
RAILROADS
COLUMBIA RIVER RESERVOIR BOUNDARY
CROSS-SECTION No. 48
MINOR OBSERVATION STATION No. 7
MAJOR OBSERVATION STATION No. 13
OBSERVATION STATIONS ESTABLISHED BY U.S. GEOLOGICAL SURVEY AND DOMINION WATER AND POWER BUREAU OF CANADA.
NOTE
Roads and railroads along the Columbia River reservoir are shown relocated as they will exist after reservoir is filled.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT-WASHINGTON
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
LOCATION MAP

FOREWORD

The investigations on the backwater effects of the Grand Coulee Dam were made by the Bureau of Reclamation at Grand Coulee, Washington, and Denver, Colorado. At the Grand Coulee office, the backwater calculations and studies were made under the direction of F. A. Banks, Supervising Engineer, by J. C. Sharp, Assistant Engineer. The backwater studies at the Denver office were made under the direction of D. C. McConaughy, Senior Engineer, by W. M. Borland, Associate Engineer, and C. A. Wentz, Assistant Engineer. The hydraulic model of the Little Dalles was constructed and tested under the supervision of R. A. Goodpasture, Assistant Engineer, by direction of J. E. Warnock, Engineer. The investigations were under the general supervision of J. L. Savage, Chief Designing Engineer. All engineering work of the Bureau of Reclamation is under the direction of S. O. Harper, Chief Engineer, and all activities of the Bureau are under the direction of J. C. Page, Commissioner.

This report gives the amount of backwater that probably will exist at the International Boundary for various reservoir elevations for natural channel conditions or with the large rock island choking the entrance to the Little Dalles removed to elevation 1255 or with about 270,000 cubic yards of rock removed at the Little Dalles. The capacity of the spillway and the sluice outlets is given and the magnitude of the maximum expected flood is discussed. The program of reservoir operation is not definite at this time but an effort has been made to estimate its effect on the amount of backwater at the International Boundary.

COLUMBIA RIVER RESERVOIR

BACKWATER STUDIES

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SYNOPSIS

1. Introduction. The Grand Coulee Dam, located on the Columbia River about 150 miles downstream from the Canadian Boundary, will, when completed, form a lake which may rise as high as elevation 1290.0. At some discharges and reservoir elevations a small amount of backwater will exist at the International Boundary. The investigations presented in this report were made to determine the backwater conditions along the upper reaches of the reservoir and to develop some plan of channel improvement to prevent excessive backwater along the Nelson branch of the Great Northern Railroad, and to reduce such backwater as there may be at the International Boundary.

2. Field data. Major observation stations were established at critical points where water-surface elevations have been observed, especially at flood stages, since March 1930. These observations were made by the Geological Survey and the Corps of Engineers. In 1932 the Dominion Water and Power Bureau cooperated with the Geological Survey in taking observations, and this program has been continued to the present time. In 1935 several additional observation stations were established by the Bureau of Reclamation, making a total of 17 stations between Kettle Falls and the boundary (figure 1, frontispiece). Soundings of various river cross sections were made by the Washington Water Power Company in connection with a proposed power development at Kettle Falls. Later the Bureau of Reclamation took additional soundings at the Little Dalles and at the International Boundary. Altogether, 41 river cross sections are available along the upper end of the reservoir where they are most needed in the backwater computations. In 1937 the Bureau of Reclamation ran a line of precise levels between Grand Coulee Dam and the International Boundary and discovered an error of 1.7 feet in the difference of elevation which had previously been used between these two points. All field data have been corrected to conform to this line of precise levels.

The water-surface elevations were observed at the major observation stations indicated on figure 1 for discharges ranging from 17,800 to 420,000 second-feet. The magnitude of the discharge on the observation days was secured by deducting the discharge of the Kettle River as determined at the gaging station near Laurier, Washington, from the discharge of the Kettle Falls gaging station on the Columbia River. The tributaries of the Columbia River between the Kettle River and the Clark Fork River are all very small and do not materially affect the flow, so that the discharge obtained in the above manner is applicable throughout the reach being studied. This discharge was checked by adding

the flow of the Columbia River as determined at Trail or at Birchbank, British Columbia, to the flow of the Clark Fork below Z Canyon.

3. Analysis of field data. The rating curves at the major observation stations were accurately defined up to 420,000 second-feet (figure 5). These curves were extrapolated by various methods with the aid of meager field data to include the 1894 flood, estimated as 650,000 second-feet. With the discharge, the water-surface elevations, and the river cross sections given, the roughness coefficient (n) in the Kutter-Chezy formula was computed between observation stations for natural flow conditions. The roughness coefficient was then plotted against average water-surface elevation for each reach; it was found to vary with the discharge and stage. For discharges greater than 420,000 second-feet, the roughness coefficient versus discharge curves were extrapolated and so adjusted that they were in agreement with the extrapolated rating curves. As the stage of the river rises, the rough perimeter characterizing the low-water flow, evidenced by numerous falls and rapids, becomes an increasingly smaller part of the total; as a result, the value of n decreases with increasing stages. For a given backwater stage, a value of n for each reach may be determined from the n versus average water-surface-elevation curve. This coefficient is designated "backwater n's" while the coefficient obtained, assuming variation only with the discharge, is designated "natural n's."

4. Backwater calculations. Two types of backwater curves were calculated, one assuming n to vary only with the discharge (natural n), and another assuming n to vary only with the stage (backwater n). The difference between the two curves was small at large discharges where the change between natural and backwater water-surface elevations was relatively small (figure 29), but increased considerably for intermediate discharges. For example, at the boundary, a discharge of 100,000 second-feet gave 2.0 feet of backwater using natural coefficients and no backwater with backwater coefficients. The decrease of n for a considerable rise in the water-surface elevation for backwater conditions is quite large when taken from the n versus average water-surface-elevation curve. It is believed that the backwater surface profiles that will result from the operation of Grand Coulee Dam will coincide more closely with the backwater profiles computed with the use of backwater roughness coefficients than with the profiles computed with the use of natural roughness coefficients. The results of hydraulic model tests discussed later helped substantiate this belief.

The Kutter-Chezy and the Manning formulas are the two most frequently used for computing flow in open channels. Of these, the Kutter-Chezy formula has been more widely used than Manning's and was adopted for the backwater computations, except below the Little Dalles, where, due to the marked decrease in the slope of the backwater energy gradient, the Manning formula was used since it gave a greater energy loss. Accordingly, all computations upstream from the foot of the Little Dalles were conservatively based on the backwater rating curve at that point as given by the Manning formula. For the steeper energy gradients involved, the two formulas gave comparable results.

5. The Little Dalles. The Great Northern Railroad parallels the Columbia River for about 37 miles below the Canadian border (figure 1). Between the head of the Little Dalles and the International Boundary, the backwater at high-flood stages would cover the tracks in some places. Under natural flow conditions, a flood of 450,000 second-feet has done some damage to the track embankments. Because of this and to reduce the amount of backwater that would exist at the boundary, a location was sought where channel improvements, effective in reducing the amount of backwater at high discharges without a prohibitive amount of excavation, could be made. If, for a flood of 400,000 second-feet and maximum reservoir elevation, the natural flow stage could be restored where the railroad parallels the river above the Little Dalles, backwater would be eliminated both along the railroad and at the boundary for higher floods.

At the Little Dalles, 15½ miles below the International Boundary, the river is restricted to a very narrow, deep channel for a distance of 2,500 feet. For a discharge of 400,000 second-feet with the reservoir water surface at elevation 1290.0, there would be a head loss of 15.5 feet through these rapids (figure 29), but channel improvement at this location, according to plan 5 hereinafter discussed, would reduce this loss to only 8.5 feet, which is about 15.5 feet less than would exist under natural flow conditions with an unimproved channel. A topographic sketch of the Little Dalles is shown on figure 10.

6. Model studies of the Little Dalles. Because of doubt as to the applicability of energy-loss formulas to such an extremely rough river channel, an hydraulic model was built and tested to determine the losses through the Little Dalles with backwater conditions and to develop a plan for channel improvement. This model was built to a scale of 1 to 120 and represented the river between the major observation stations 11 and 13 at the Little Dalles (figure 32). The model was constructed from the field topography and from a careful study of prototype pictures.

The model was roughened by adding lumps of concrete to the bed and the walls of the channel so that, when natural flow conditions were reproduced at the foot of the Little Dalles, the upstream rating curves obtained from the model agreed reasonably well with those obtained from the prototype (figures 35 and 44).

After the model had been calibrated to simulate natural flow conditions, backwater conditions corresponding to a reservoir water surface at elevation 1290.0 at the dam were produced. To accomplish this, the rating curve as computed for backwater conditions at the lower end of the Little Dalles was reproduced in the model and the resulting water-surface elevations at the head of the Little Dalles were observed (figure 41). The backwater computations through the Little Dalles, using backwater coefficients, were found to give slightly lower water-surface elevations for a discharge of 200,000 second-feet than indicated by the model. For all other discharges, the model gave a lower elevation than that computed. The discrepancy was always less than or equal to 1.10 feet, or never greater than five percent of the total energy loss when there was any appreciable change in the water-surface elevation. These results from the model indicate that the use of backwater coefficients is justified.

Because of difficulties that accompany underwater excavation, especially if, as was shown by model tests to be necessary, the material must be broken up and removed, it was desired that the channel improvement should not extend below low-water level. To do this, excavation would have to be completed in winter months before the reservoir reached elevation 1240.0.

The channel improvement studies on the hydraulic model were made in steps by removing various portions of the simulated rock that noticeably disturbed flow conditions (figure 42). A rating curve for gage 11 at the head of the Little Dalles was obtained for each step or excavation plan (figure 41). The first plan was to remove the large rock island at the entrance to the Little Dalles to elevation 1255.0. Subsequent tests showed no additional improvement by further excavation to elevation 1250.0. A portion of the upstream left bank was next removed to improve entrance conditions (excavation plan 1, figure 40). Since this did not produce the desired improvement, a portion of the left bank was removed as far downstream as the cove. After several minor changes, a total of 270,000 cubic yards was removed above elevation 1255.0 (excavation plan 5, figures 40 and 65). This plan restored natural flow conditions above the Little Dalles at a discharge of 400,000 second-feet for reservoir elevation 1290.0.

7. Backwater with improved channel. Figure 41 shows that the recommended channel improvement will not only restore natural flow conditions at the head of the Little Dalles for a discharge of 400,000 second-feet, but also that some additional improvement would be obtained for all larger floods. This improvement would be greatest at the Little Dalles but would still be noticeable at the boundary (figures 66 and 67). Profiles of the backwater for natural and improved channel are shown in figures 59 and 60. The amount of backwater at the International Boundary with channel improvement is shown as curve No. 5, figure 63. These computations were based on natural roughness coefficients; using backwater coefficients, curve No. 10 is obtained, which is always below curve No. 7, giving less than 0.50 foot of backwater for discharges greater than 50,000 second-feet. Table I (end of synopsis) gives the water-surface elevations at the International Boundary for natural flows and for backwater conditions for both natural and improved channels with the reservoir water surface at elevation 1290.0, using either natural n's or backwater n's.

An inspection of table I shows that, for floods greater than 400,000 second-feet, the water-surface elevations above the Little Dalles will not be as high with full reservoir and channel improvement plan 5 as they are at the present time. Consequently, conditions along the railroad above the Little Dalles would be better than at present. Table I and figures 59, 60, and 63 show that, with the improved channel, the greatest amount of backwater at the boundary will be at small discharges, with an actual reduction in stage for floods above 400,000 second-feet. According to records for the past 27 years, a flood with a magnitude of 400,000 second-feet or larger is likely to occur on an average of once in about five years, or, on the basis of the 82-year record available at The Dalles, Oregon, a flood of this magnitude or larger is likely to occur on an average of once in about three years. If the reservoir surface is lowered 12 feet with channel improvement plan 5, there will be no backwater at the boundary for any discharge on the basis of backwater n's, but, with the reservoir at elevation 1290.0 at the dam, backwater with any discharge less than 335,000 second-feet will not exceed the water-surface elevation of ordinary high water for the past 27 years, the term "ordinary high water" being defined as the stage most likely to be reached or exceeded each year by the peak of the annual flood. For discharges between 335,000 and 400,000 second-feet, the backwater will be a maximum of about 0.4 foot above the present water surface on the basis of backwater n's or less than 0.6 foot on the basis of natural n's. The plan for reservoir operation is indefinite and is being studied at the present

time. From previous stream-flow records, it has been estimated that, when the Columbia Basin project is fully developed, for 35.8 percent of the time with unimproved channel and for 42.6 percent of the time with improved channel, the reservoir will be drawn down so low as to cause no backwater at the boundary, based on computations using backwater n's. Such draw-down would necessarily occur during the "lean" water years.

8. Analysis of excavation studies. Past experience has shown that the railroad, under present conditions, is safe against damage for discharges up to 400,000 second-feet. As shown above, channel improvement according to plan 5 will insure that the water surface above the Little Dalles after the reservoir is in operation will be lower than the natural water-surface elevation for greater discharges. A further study was made to determine whether it would be economically feasible to effect a greater improvement by reducing still further the stage above which the water surface with reservoir in operation would lie below the natural water surface. Accordingly, the amount of excavation for each excavation plan was plotted against the corresponding discharge at which natural conditions were restored upstream and an approximate extension obtained by logarithmic plotting (figure 43). The intersection of the natural rating curve at gage 11 with the backwater rating curve at gage 13 (figure 41) shows that no amount of excavation would restore natural conditions below a discharge of 297,000 second-feet. The channel improvement curve, therefore, must be asymptotic to this discharge as shown on figure 43. This curve indicates that plan 5 represents about the limit of economic excavation and that approximately 270,000 cubic yards of additional excavation would be required to reproduce natural conditions at a discharge of 350,000 second-feet. Plan 5 is accordingly recommended.

9. Velocities and effect of variations in elevation of reservoir. The losses through the Little Dalles with improved channel (plan 5) were obtained for various discharges and backwater stages (figures 48 and 49). These data allow the backwater above the Little Dalles to be determined for any reservoir elevation at Grand Coulee Dam. Water-surface profiles through the Little Dalles and velocities at selected sections were obtained at discharges approximating 100,000, 200,000, 300,000, 400,000, and 650,000 second-feet with the model representing reservoir elevation 1290.0 at the dam. The profiles are shown on figure 50 while the velocities are shown on figures 51 to 56. These data were obtained so that the possibilities of navigating the upper reaches of the reservoir might be studied in the future.

10. Conclusions and recommendations. It is concluded:

(a) That, without channel improvement and with a full reservoir, there will exist at the International Boundary from 0 to 2.75 feet of backwater for discharges below 100,000 second-feet but no threat of damage is involved thereby because the water-surface elevation for these will be from 0 to 12 feet below the natural flow stage for mean annual discharge. There will be about 1.5 to 1.0 feet of backwater at extremely high flows with about 1.00 foot at ordinary flood stages. These figures are based on backwater n's.

(b) That, without channel improvement and with a full reservoir, backwater along the railroad above the Little Dalles would be from 2 to 10 feet higher than at present for discharges ranging between 650,000 and 300,000 second-feet and that, for discharges in the neighborhood of 450,000 second-feet, which have previously caused some damage, the backwater surface will be about at the same elevation as the natural surface for discharges 75,000 second-feet lower.

(c) That, for discharges less than 50,000 second-feet, it is impossible to lower backwater at the International Boundary except by lowering the water surface of Columbia River Reservoir.

(d) That, by channel improvement plan 5 at the Little Dalles, the backwater for reservoir water surface at elevation 1290.0 can be so reduced that the water surface will lie below the ordinary high-water elevation of natural flow at the International Boundary for floods less than 335,000 second-feet, lie below the present water surface for floods greater than 400,000 second-feet, and will not be more than 0.6 foot above the present water surface for floods between 335,000 and 400,000 second-feet when natural roughness coefficients are used for computations.

(e) That, by this improvement and with a full reservoir, the water surface along the railroad above the Little Dalles will be no higher than under present conditions for a discharge of 400,000 second-feet and will be lower than under present conditions for greater discharges by amounts up to about 10 feet for a discharge of 650,000 second-feet.

(f) That channel improvement at the Little Dalles according to excavation plan 5 affords a satisfactory solution of the backwater problem and additional excavation is not economically justified.

It is recommended:

(a) That measurements of water-surface observations be continued at the established observation stations for the first few years of reservoir operation in order to obtain actual backwater profiles.

(b) That an automatic recording gage be installed at the head of the Little Dalles at observation station 11, river cross section 87. This gage would indicate the effectiveness of the channel improvement in reducing backwater at low flows and in improving natural flow conditions at large discharges. If the railroad should claim that they had suffered damages above the Little Dalles because of backwater caused by Grand Coulee Dam, water-surface elevations from an automatic gage at observation station 11 when compared with the natural rating curve at that point would show if there were any basis for such a claim. Such a gage, when used in conjunction with the gage at the International Boundary, could also be used to determine the discharge of the Columbia River under backwater conditions that would make the natural rating curves either at observation stations 11 or 2 useless. This method of determining river discharge when two gages are affected by backwater is discussed in Water Supply Paper 345.

Table I

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
WATER-SURFACE ELEVATIONS AT INTERNATIONAL BOUNDARY

Discharge sec. ft.	Natural flow	Backwater conditions*					
		Unimproved channel		Improved channel †			
				Plan No. 5		Island removed	
		Natural n's	Backwater n's	Natural n's	Backwater n's	Natural n's	Backwater n's
0	1284.2**	1290.00 (+5.80)	1290.00 (+5.80)	1290.00 (+5.80)	1290.00 (+5.80)	1290.00 (+5.80)	1290.00 (+5.80)
20,000	1289.80	1293.45 (+3.65)	1291.88 (+2.08)	1293.45 (+3.65)	1291.88 (+2.08)	1293.45 (+3.65)	1291.88 (+2.08)
50,000	1296.05	1299.02 (+2.97)	—	1298.98 (+2.93)		1299.01 (+2.96)	
100,000	1303.50	1305.59 (+2.09)	1303.50 (0)	1305.43 (+1.93)	1303.50 (0)	1305.48 (+1.98)	1303.50 (0)
200,000	1313.65	1315.43 (+1.78)	1313.98 (+0.33)	1315.02 (+1.37)	1313.79 (+0.14)	1315.21 (+1.56)	1313.91 (+0.26)
300,000	1321.70	1323.36 (+1.65)	1322.57 (+0.87)	1322.54 (+0.84)	1322.19 (+0.49)	1322.98 (+1.28)	1322.42 (+0.72)
400,000	1329.10	1330.78 (+1.68)	1330.32 (+1.22)	1329.10 (0)	1329.10 (0)	1330.05 (+0.95)	1329.84 (+0.74)
500,000	1336.00	1337.71 (+1.71)	1337.56 (+1.56)	1334.97 (-1.03)	1334.97 (-1.03)	1336.62 (+0.62)	1336.62 (+0.62)
650,000	1346.00	1347.01 (+1.01)	1346.95 (+0.95)	1342.90 (-3.10)	1342.90 (-3.10)	1346.30 (+0.30)	1346.30 (+0.30)

*Reservoir water-surface elevation 1290.00 at the dam.

**Water-surface elevation for zero discharge obtained by extending rating curve at the Boundary until it intersects the line of zero discharge. Lowest point in the river bed at this section is at elevation 1272.

†Based on model results for zone 3 and on either natural or backwater roughness coefficients for zone 4.

Figures in parentheses indicate backwater if plus and improvement if minus.

For the period from April, 1913, to Sept. 30, 1939, incl., the following discharge data are recorded for the Columbia River at Grand Coulee Dam:

Minimum discharge		15,300	second feet
Maximum "		492,000	" "
Maximum "	(mean for 27 yrs.)	358,148	" "
Average "	(26-yr. record)	107,700	" "

CHAPTER I - INTRODUCTION

The Columbia Basin Project

11. Introduction. The Columbia Basin "multiple-use" project in Washington will reclaim, within the next 25 to 50 years, 1,200,000 acres of land, regulate the flow of the Columbia River, and develop electrical energy to be used for irrigation pumping and other purposes. The first step in the development of the project was the construction of a dam at the mouth of the Grand Coulee in the Columbia River where it passes the northeasterly end of the well-known geological feature which gives the dam its name. The dam now being built will raise the water surface of the river 355 feet, and the reservoir formed will be 150 miles long, extending to the Canadian border. It will store about 10,000,000 acre-feet of water with a usable capacity of 5,200,000 acre-feet. The greatest width of the reservoir, except at tributary channels, is 2.4 miles at Marcus Flats. Submerged areas extend up the San Poil River 9 miles, the Spokane River 32 miles, the Colville River 2 miles, and the Kettle River 7.5 miles. (See figure 1.)

Irrigation water will be pumped from the Columbia River Reservoir to a regulatory reservoir formed by two dams 23 miles apart in the ancient river channel known as the Grand Coulee. The high-water level of this reservoir will be 280 feet above that of the storage reservoir behind Grand Coulee Dam. Since 360,000 acre-feet of storage will be available for regulation, only secondary power will be used for pumping. Lowering the Columbia River Reservoir by 80 feet to take advantage of the useful storage of 5,200,000 acre-feet will require pumping against a maximum lift of 360 feet. Twelve motor-operated centrifugal pumps, each with a capacity of 1,600 second-feet when pumping against a head of 295 feet, will be installed in the pumping plant. As two of the pumps are for emergency use only, the normal capacity of the pumping plant will be 16,000 second-feet.

While the development of the Columbia Basin project will extend over a period of 25 to 50 years, the construction of Grand Coulee Dam will be advanced to such a stage that the reservoir may be filled in the spring of 1941. It is estimated that it will be 22 years before there is a need for all of the power units and 20 years before ultimate capacity of the pumping plant is required. Construction work has not begun on the irrigation distribution system and the two dams across the Grand Coulee that will form the regulatory reservoir for the irrigation system. At present the dam will produce some electric power

and will stabilize the flow of the river, which will benefit existing power plants downstream at Bonneville and Rock Island.

12. Grand Coulee Dam. At the dam site, the river flows in a channel 700 to 850 feet wide at the bottom of a canyon a mile wide and about 1,600 feet deep. When completed, the dam (see figures 2 and 3) will rise 550 feet above foundation rock and will have a crest length of about 4,300 feet. It will be 30 feet thick at the top and 500 feet thick at the base. An overflow spillway with a gross length of 1,650 feet will be controlled by 11 drum gates, each 28 feet high and 135 feet long, and will have a capacity of nearly 900,000 second-feet, with the reservoir at elevation 1290.0. Sixty outlet conduits 8.5 feet in diameter, arranged in groups of 10 pairs at each of three elevations which differ by 100 feet, will regulate outflow from the reservoir during periods of low stream flow. When the reservoir level is above elevation 1185.0, it will be impossible to open the lower group of outlets because of the excessive head. Under ordinary conditions, 40 outlets will be available for regulation, having a combined capacity of 193,600 second-feet, for reservoir elevation 1290.0.

13. The power plant. The power plant will consist of two powerhouses, each 185 feet high, one being located on each side of the spillway section. The powerhouse at the east abutment will be 737 feet long and that at the west abutment 758 feet long. Present plans call for nine 150,000-horsepower units for each powerhouse, with a total capacity of 2,700,000 horsepower--the largest in the world both as to size of units and plant capacity. Only the west powerhouse is being completed at the present time. In addition to the main units, it will house three 14,000-horsepower station-service units, control room, offices, and general station operating facilities. At present only two of the station-service units and three of the main units will be installed. Two of the main units will be required for generating power for pumping and commercial purposes and the third will serve as a stand-by unit. The hydraulic turbines of the main units are designed to produce 150,000 horsepower at 120 revolutions per minute with a 335-foot operating head and will discharge 4,500 second-feet. The turbines will be supplied by 18-foot diameter penstocks, reducing to 15 feet for the short horizontal length at the downstream ends. They will be controlled by gates at the upstream face of the dam.

14. The Columbia River watershed. The Columbia River drains an area of about 259,000 square miles above its mouth, of which 39,000 square miles are in Canada. Its three principal tributaries are the Clark Fork, rising in Montana and flowing through

Idaho, Washington, and British Columbia, to its junction with the Columbia just above the Canadian Boundary; the Snake River, rising in Yellowstone Park and traversing Wyoming, Idaho, Oregon, and Washington to its confluence with the Columbia at Paroo, Washington; and the Kootenay, rising in British Columbia near the headwaters of the Columbia, flowing south into Montana and Idaho, and finally north, emptying into the Columbia above the Canadian line.

The Columbia River system above the Grand Coulee Dam drains a roughly triangular-shaped area of 74,000 square miles located in parts of British Columbia, Idaho, Montana, and Washington.

The combined effect of topography and prevailing winds produces abrupt changes in precipitation on the watershed so that the average yearly precipitation varies from less than 10 inches to more than 100 inches. The Columbia Basin contains a succession of mountain ranges and valleys running in a north and south direction. When a west wind from the ocean passes over the basin, the mountain ranges act as condensers and accumulators of moisture with varying effectiveness, depending upon the altitude of the range and other less important factors. Intervening valleys and easterly slopes of mountain ranges receive only a small part of the moisture and require irrigation for successful agriculture. This unequal distribution in precipitation causes a marked difference in run-off per unit of area, and the yield of tributaries varies widely, depending upon the side of the range on which they originate. For this reason, estimates of stream flow based upon drainage areas or on precipitation data at sparsely located observation stations are subject to considerable uncertainty.

The climate in the eastern part of the basin is cold and predominantly of the rigorous continental type, tending to cause an abundant accumulation of snow and ice at the higher altitudes on the western slope of the Rocky Mountains and on the Selkirk and Bitterroot Mountains. In the western part of the basin, the climate is modified by the adjacent ocean, producing rain and fog. Because of a range in latitude of 7½ degrees, the snow in the southern part of the basin starts melting and increases stream flow much earlier in the season than that in the northern part. The later yield of the northern part is a decided advantage as it produces an increased run-off during the hot and dry summer months.

Lakes located near the headwaters tend to regulate the flow of the river naturally by storing large volumes of water, thus decreasing the flood peaks and furnishing water for release when river and lake stages recede after the flood run-off. These

lakes have a combined area of at least 1,100 square miles and a capacity of 9,000,000 acre-feet below low stage and flood stage. The larger lakes are the Kootenay, upper and lower Arrow Lakes in British Columbia; Flathead Lake in Montana; and Pend d'Oreille, Priest, and Coeur D'Alene Lakes in Idaho.

Since the source of stream supply is melting snow and because of the stabilizing and equalizing effect of the large lakes, the hydrograph of the Columbia River at Grand Coulee Dam has no high, steep peaks but is regular, holding up well in the dry, hot, summer months, until the last of August (figure 4, end of chapter II). The annual flood period usually extends from May to July, inclusive, reaching a rather flat peak during June. It has a comparatively large range of maximum yearly discharges, which vary from 250,000 to 735,000 second-feet at the Grand Coulee Dam.

The low-water period occurs in the winter, from October to March, when precipitation is in the form of snow, during which time the discharge is about 30,000 second-feet. The extreme minimum flows are caused by rapid formation of ice during a sudden and severe freeze. The gaging station near Grand Coulee Dam has been in operation since April 1913, and, during this period, the minimum discharge may have been less than 15,300 second-feet, the stage-discharge relation probably having been affected by ice. The maximum discharge of record at this station was 492,000 second-feet, on June 15, 1913.

At The Dalles, Oregon, a stream-flow record has been kept since 1878. The maximum flood of record occurred about the first of June 1894. This flood was estimated by the Geological Survey to have reached a magnitude of 725,000 second-feet at Grand Coulee Dam. From high-water marks left by this flood over the Columbia Basin, it is known to have been the severest experienced by any of the principal tributaries since that time. High water on the Columbia River is not dependent upon rainfall but rather on the amount of snow in the basin and upon the sequence and length of the snow-melting period in the tributary basins.

The valley of the Columbia within the United States above the mouth of the Snake River is not subject to inundation. The banks are high enough to confine flood waters except during extreme conditions which might occur only once in 400 years or longer. Then only small isolated areas would be flooded. The tributaries are likewise free from flood damage, except for lands adjacent to lakes.

The mean annual discharges of the Kootenay and the main stem of the Columbia above the mouth of the Kootenay are nearly equal, being about 35,000 second-feet each. The Clark Fork contributes a mean annual discharge of 26,000 second-feet while the Kettle River yields only about 3,000 second-feet. These river basins are not as likely to be subjected to warm rains following an accumulation of snow as the Spokane Basin, which reached its known maximum discharge of 48,000 second-feet in December. The mean annual discharge of the Spokane is 8,000 second-feet. Regardless of its time of occurrence, a large flood in the Spokane Basin does not appreciably affect the Columbia River as the maximum flood of the Spokane is about equal to the low-water discharge of the Columbia.

The mean annual flow of the Columbia at the Grand Coulee Dam is 108,000 second-feet. This gives a mean annual run-off above the dam of 79,000,000 acre-feet, or about 20 inches over the basin. Full development of the project will require 6,000,000 acre-feet for irrigation. Even when the annual run-off is low and with a large increase in irrigation above the dam, this requirement can easily be fulfilled. The storage capacity of the Columbia River Reservoir is 10,000,000 acre-feet, and, with an average run-off, it could be filled nearly eight times in an average year. The useful storage is 5,200,000 acre-feet. When used for stream-flow regulation, it is large enough to double the firm power of plants between Grand Coulee Dam and the mouth of the Snake River and to increase by 50 percent the firm power output of other plants below that point, including the Bonneville plant. Release of stored water will maintain low-water levels in the lower river two feet higher than those of the uncontrolled river, providing a deeper navigable channel and reducing the dredging required.

The Columbia River above the Snake has a stable channel, being generally confined by rock banks and having a bed composed of solid rock, boulders, and cobbles, material not easily transported by even the high current velocities existing in this river. Between the International Boundary and the mouth of the Snake, the river falls about 980 feet in a distance of 425.3 miles, or an average of 2.3 feet per mile. This slope is not uniform but is concentrated at rapids and falls. A plan submitted by the Corps of Engineers contemplates the utilization of 96 percent of the 891 feet fall from the foot of Priest Rapids to the Canadian line, a distance of 352 miles. Grand Coulee Dam will develop 355 feet, or about 27 percent of this fall at low water, and about seven dams below Grand Coulee will utilize the remainder.

15. Investigations and reports. Irrigation possibilities in eastern Washington from rivers in the Columbia River Basin were investigated in 1904 and again in 1914 and 1915 by the Bureau of Reclamation cooperating with the State of Washington. A Columbia Basin Commission of the State of Washington was formed and investigated a number of plans which were reviewed by a board of engineers of the Bureau.

A comprehensive investigation of the Columbia River and minor tributaries was made by the Corps of Engineers of the War Department from 1928 to 1931. The results of this investigation were published as House Document No. 103, 73d Congress, First Session. The Corps of Engineers in 1930 established a few observation stations for determining the natural stage of the Columbia River, and some measurements were taken each succeeding year, especially during the annual flood period. Later more observation stations were established and data were collected between Kettle Falls, Washington, and Revelstoke, British Columbia, by various Federal Government agencies cooperating with the Dominion Water and Power Bureau of Canada and various water power companies. The Army report consisted of two volumes and five appendixes, one of which was prepared by the Bureau of Reclamation. As a result of this report, the Federal Emergency Administration of Public Works, on July 27, 1933, provided an initial allotment of $15,000,000 for the first year's operations at Grand Coulee Dam. The construction of this dam has been carried forward continuously from that date.

16. Property within the reservoir. Backwater in the main stream of the Columbia, which amounts to less than four feet at the International Boundary for extremely low flows, will decrease with an increase in river discharges. Such backwater as exists at the boundary will diminsh gradually in the first 15 to 20 miles above the Canadian line. Overflow rights to land on both sides of the Columbia River from the dam to the foot of the Little Dalles, a distance of 135 miles, have been acquired to elevation 1310.0. All buildings, fences, and improvements are being removed and all timber and brush lands are being cleared. The area submerged within the reservoir will be about 80,000 acres, of which less than one-half is of value. This comprises wheat land, irrigated tracts, and timber. The towns of Marcus and Kettle Falls are within the proposed submerged area and have been abandoned.

About 84 miles of state highway and 43 miles of county highway have been relocated on ground above the reservoir level. The railroad bridge at Marcus and the highway bridge across the Columbia River below Kettle Falls will be removed, and in their

place two new bridges will be built above reservoir level just below Kettle Falls. The branch of the Great Northern Railroad to Nelson, British Columbia, will require relocation and reconstruction for a distance of 15 miles between Kettle Falls and the foot of the Little Dalles.

The Washington Water Power Company has made extensive investigations of a power site located at Kettle Falls. In connection with its application for a permit to the Federal Power Commission, it made topographic surveys and foundation explorations. Topographic maps and river cross sections made by this company have been used extensively in backwater calculations.

17. Backwater studies. The report of the Corps of Engineers, War Department, on "The Columbia River and Minor Tributaries," published as House Document No. 103, volume 3, 73d Congress, First Session, has a plate, No. 147, opposite page 1058, entitled "Upper Columbia River, Comprehensive Plan-Profile." On this drawing the normal forebay level of Grand Coulee high dam was originally set at 1287.6 feet. A notation in the upper right-hand corner states, "Grand Coulee high dam would not cause backwater in Canada at any river stage." However, an error amounting to 1.7 feet at the Canadian Boundary was found near Kettle Falls in the earlier level circuits made by the Geological Survey, and the top of the spillway gates for the dam as constructed is at elevation 1288.0, the maximum reservoir elevation being at 1290.0. The increase in forebay elevation and the error in levels, found in 1937, have the effect of increasing the backwater. Raising the water-surface elevation of the reservoir to 1290.0 at the dam would increase the backwater at the boundary only about three inches for discharges greater than 100,000 second-feet; but the error in levels had the effect of lowering the river gage and all lands at the International Boundary with respect to the dam and maximum reservoir level, which naturally resulted in 1.7 feet more backwater at all river stages.

Below Kettle Falls, the Columbia River Reservoir water surface will be practically level for any river discharge on account of the large channel cross section and consequent insignificant friction losses. The 36 foot rise in the river bed at Kettle Falls and Grand Rapids materially reduces the channel cross section and, although not large, the friction losses are many times larger. The computation of the backwater curve below the foot of the Little Dalles offers no unusual problem, and the amount of backwater can be predicted with a considerable degree of accuracy up to this point. It would amount to less than 15 feet for discharges up to 650,000 second-feet. The first calculations were reliable enough to set the upper limit of the submerged

area at elevation 1310.0 from the dam to the foot of the Little Dalles. This limit included an allowance for freeboard.

The Little Dalles is located 135 miles upstream from Grand Coulee Dam and 15.5 miles downstream from the International Boundary. At this point the Columbia River, normally about 1,000 feet wide, is restricted to a narrow, deep channel about 300 feet wide and 200 feet deep for a distance of 2,500 feet. This natural barrier in the river channel constitutes a control section and, under natural flow conditions, backs water upstream, except during low-water periods. In addition to the extreme roughness of the channel surface at the Little Dalles, there are solid rock pinnacles and islands which rise 75 feet from the bed of the river. There are also deep holes and large bays which cause enormous eddies, whirls, and rollers not found in ordinary river flow. Backwater calculations for this section of the river are difficult and the results uncertain. Even under backwater conditions, the rise in reservoir water surface through this reach is twice as great as the friction loss in the 135 miles of reservoir between the foot of the Little Dalles and the dam. The amount of backwater that might exist at any point above the Little Dalles depends to a great extent on the results of computations for this section of the river. Above this reach, the railroad parallels the river and in many places is not much above ordinary high-water level. Backwater will extend into Canada, although in small amounts.

18. Channel improvement at the Little Dalles. The most promising method of reducing the amount of backwater is to improve the river channel at the Little Dalles since it forms a control section which for large discharges backs water up to the International Boundary. If channel improvement eliminates backwater--that is, restores natural flow conditions for a discharge of 400,000 second-feet with a maximum reservoir elevation--then, for any discharges above this amount, there will be a decrease in the natural stage of the river which will improve present conditions along the railroad and at the International Boundary. General plans of channel improvement were studied, but there was considerable uncertainty in computing the resulting decrease in stage at the head of the Little Dalles since it was difficult to select roughness coefficients that would be applicable to the proposed plans of channel improvement.

19. The use of an hydraulic model. Past experience has indicated that an hydraulic model is of assistance in solving problems of river-channel improvement where it is desired to develop the most economical plan of channel excavation. It is unnecessary to compute the backwater surface profile when using a model since the profiles may be measured directly for the natural river

channel or for any plan of channel improvement. Thus, a model offers a means of checking the difficult and uncertain backwater computations made through the Little Dalles with unimproved channel and defines directly without computation the backwater profile for any plan of channel improvement.

SPECIFICATIONS No. 757

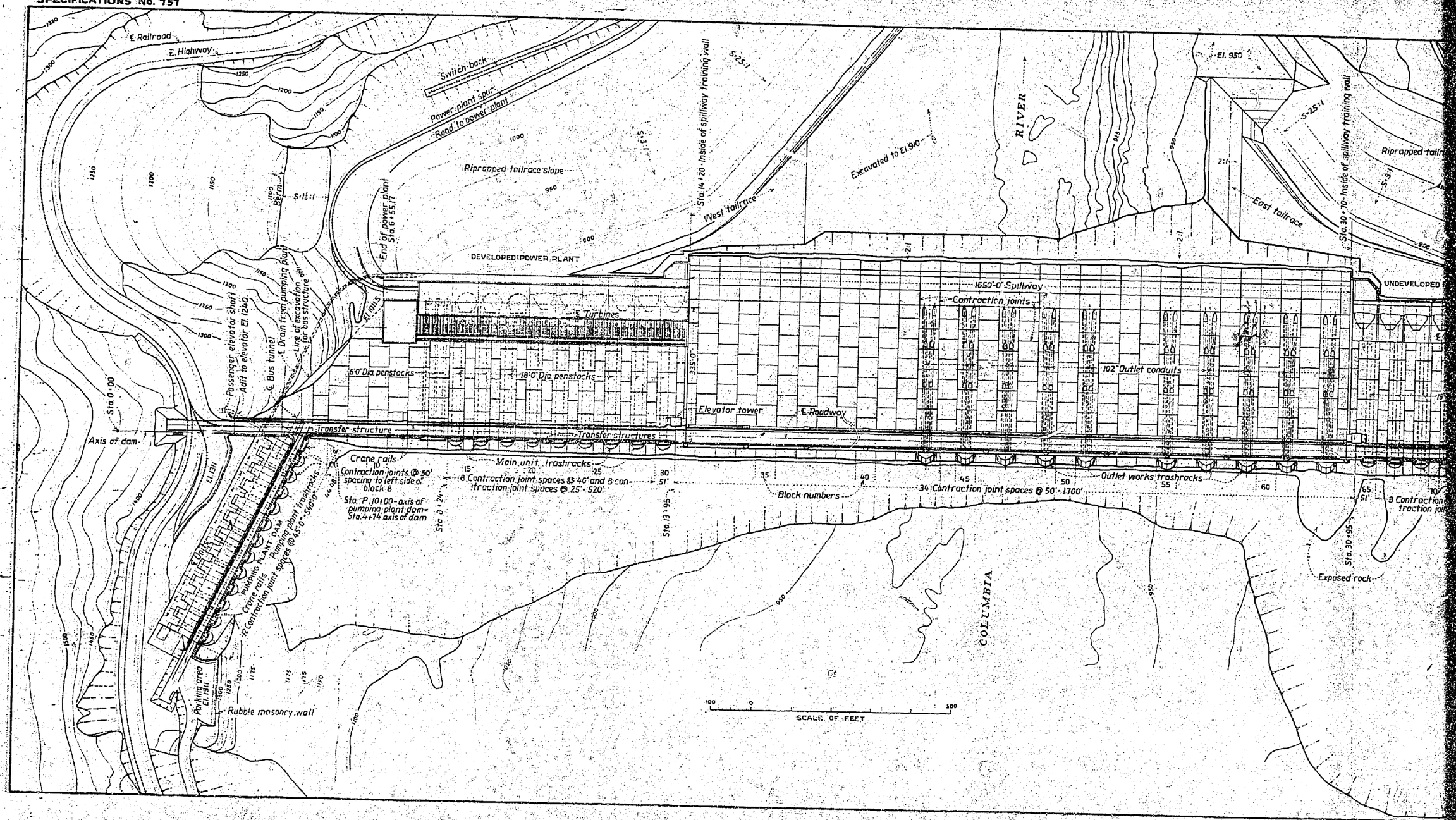
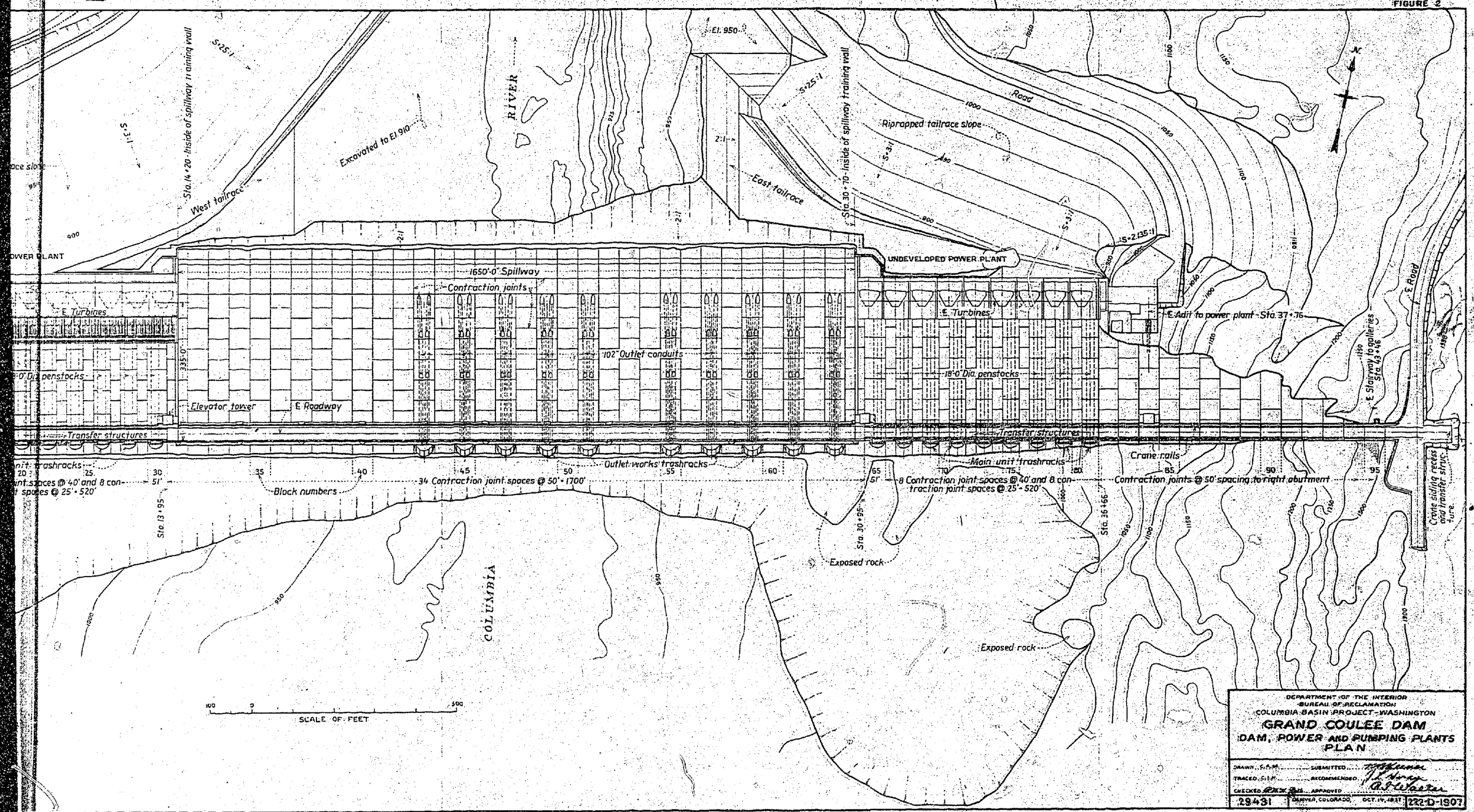


FIGURE 2


RIVER
COLUMBIA
Sta. 14+20 inside of spillway training wall
Sta. 30+70 inside of spillway training wall
West tailrace
East tailrace
Excavated to El 910
El. 950
Riprapped tailrace slope
Road
UNDEVELOPED POWER PLANT
1650'-0" Spillway
Contraction joints
℄ Turbines
℄ Adit to power plant Sta. 37+76
102" Outlet conduits
18'-0" Dia. penstocks
Elevator tower
℄ Roadway
℄ Stairway to galleries Sta. 43+46
℄ Road
Transfer structures
Outlet works trashracks
Main unit trashracks
Crane rails
Block numbers
34 Contraction joint spaces @ 50' = 1700'
8 Contraction joint spaces @ 40' and 8 contraction joint spaces @ 25' = 520'
Contraction joints @ 50' spacing to right abutment
Crane siding recess and transfer structure
Sta. 13+95
Sta. 30+95
Sta. 36+66
Exposed rock
SCALE OF FEET
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON
GRAND COULEE DAM
DAM, POWER AND PUMPING PLANTS
PLAN
DRAWN C.F.M.
TRACED C.I.P.
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
29431
DENVER, COLORADO, OCT. 14, 1937
222-D-1907

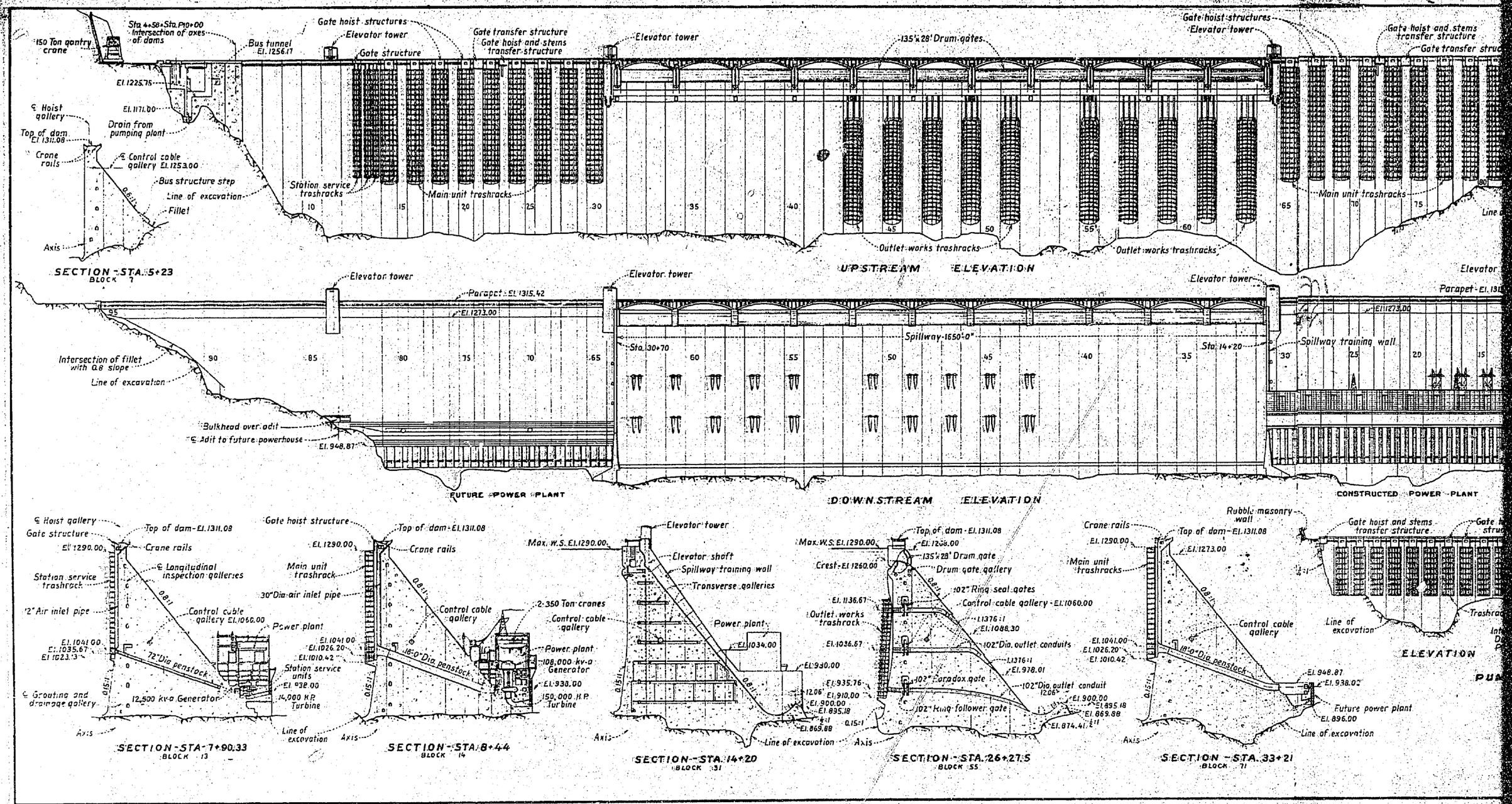
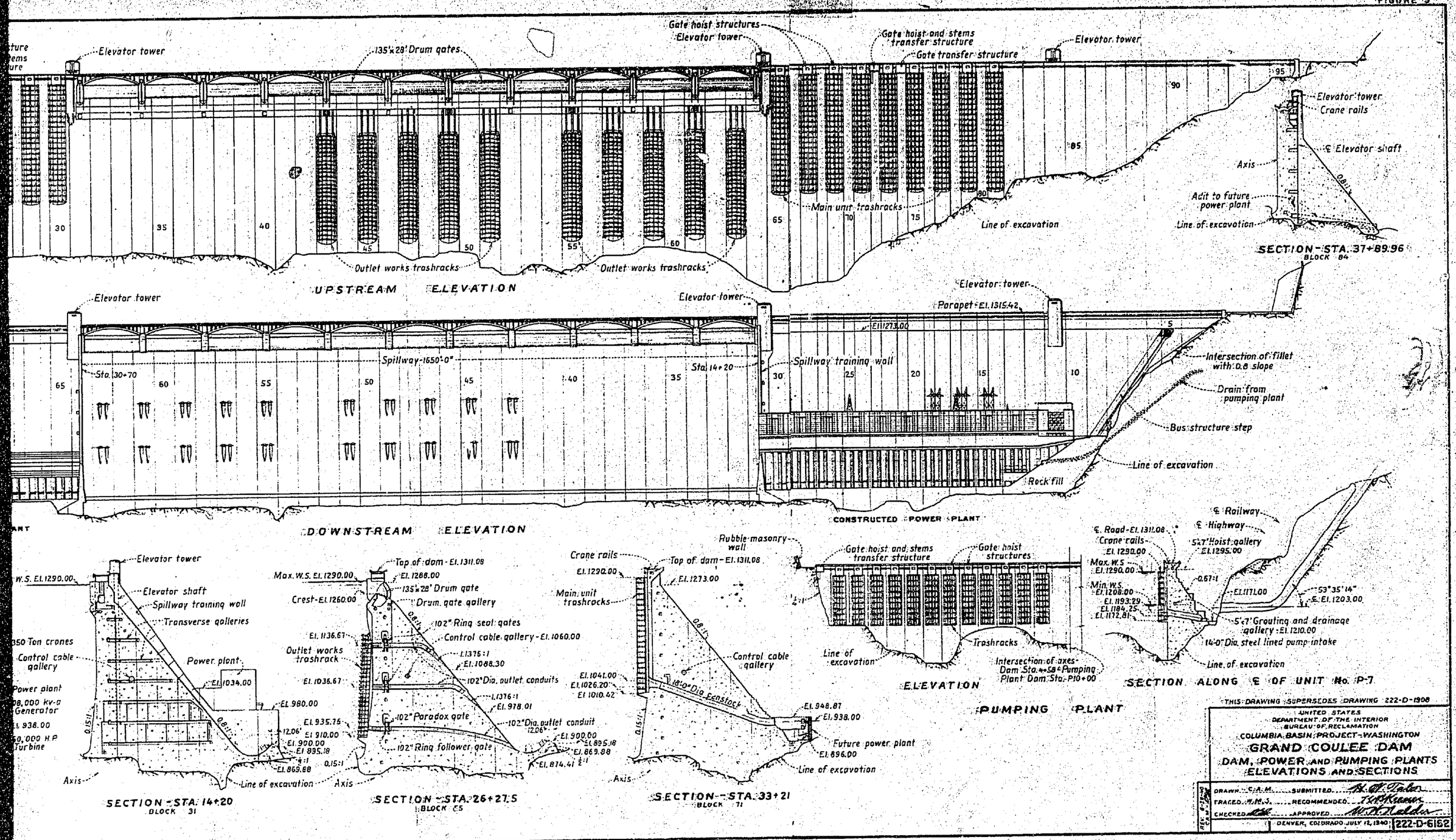

150 Ton gantry crane
Sta. 4+58=Sta. P10+00 Intersection of axes of dams
Bus tunnel El. 1256.17
Gate hoist structures
Elevator tower
Gate structure
Gate transfer structure
Gate hoist and stems transfer structure
Elevator tower
135'x28' Drum gates
Gate hoist structures
Elevator tower
Gate hoist and stems transfer structure
Gate transfer structure
El. 1225.75
El. 1171.00
℄ Hoist gallery
Top of dam El. 1311.08
Crane rails
Drain from pumping plant
℄ Control cable gallery El. 1253.00
Bus structure step
Line of excavation
Fillet
Axis
Station service trashracks
Main unit trashracks
Outlet works trashracks
Outlet works trashracks
Main unit trashracks
SECTION - STA. 5+23
BLOCK 7
UPSTREAM ELEVATION
Elevator tower
Elevator tower
Elevator tower
Elevator
Parapet - El. 1315.42
El. 1273.00
Parapet - El. 1311
El. 1273.00
Spillway - 1650'-0"
Sta. 30+70
Sta. 14+20
Spillway training wall
Intersection of fillet with 0.8 slope
Line of excavation
Bulkhead over adit
℄ Adit to future powerhouse
El. 948.87
FUTURE POWER PLANT
DOWNSTREAM ELEVATION
CONSTRUCTED POWER PLANT
℄ Hoist gallery
Gate structure
El. 1290.00
Top of dam - El. 1311.08
Crane rails
℄ Longitudinal inspection galleries
Station service trashrack
12" Air inlet pipe
Control cable gallery El. 1060.00
Power plant
El. 1041.00
El. 1035.67
El. 1023.13
72" Dia. penstock
℄ Grouting and drainage gallery
12,500 kv-a Generator
Axis
Line of excavation
SECTION - STA. 7+90.33
BLOCK 13
Gate hoist structure
El. 1290.00
Top of dam - El. 1311.08
Crane rails
Main unit trashrack
30" Dia. air inlet pipe
Control cable gallery
2-350 Ton cranes
Control cable gallery
Power plant
El. 1041.00
El. 1026.20
El. 1010.42
18'-0" Dia. penstock
Station service units
El. 938.00
108,000 kv-a Generator
El. 938.00
150,000 H.P. Turbine
14,000 H.P. Turbine
Axis
Line of excavation
SECTION - STA. 8+44
BLOCK 14
Max. W.S. El. 1290.00
Elevator tower
Elevator shaft
Spillway training wall
Transverse galleries
Power plant
El. 1034.00
El. 930.00
El. 935.76
El. 910.00
El. 900.00
El. 895.18
El. 869.88
Axis
Line of excavation
SECTION - STA. 14+20
BLOCK 31
Max. W.S. El. 1290.00
Top of dam - El. 1311.08
El. 1268.00
135'x28' Drum gate
Crest - El. 1260.00
Drum gate gallery
102" Ring seal gates
Control cable gallery - El. 1060.00
El. 1136.67
Outlet works trashrack
El. 1036.67
1.376:1
El. 1088.30
102" Dia. outlet conduits
1.316:1
El. 978.01
102" Coradox gate
102" Dia. outlet conduit
El. 900.00
El. 895.18
El. 869.88
102" Ring follower gate
El. 874.41
Axis
SECTION - STA. 26+27.5
BLOCK 55
Crane rails
Top of dam - El. 1311.08
El. 1290.00
El. 1273.00
Rubble masonry wall
Main unit trashracks
Control cable gallery
El. 1041.00
El. 1026.20
El. 1010.42
18'-0" Dia. penstock
El. 948.87
El. 938.00
Future power plant
El. 896.00
Line of excavation
Axis
SECTION - STA. 33+21
BLOCK 71
Gate hoist and stems transfer structure
Line of excavation
ELEVATION

FIGURE 3


Elevator tower
135'x28' Drum gates
Gate hoist structures
Elevator tower
Gate hoist and stems transfer structure
Gate transfer structure
Elevator tower
Elevator tower
Crane rails
℄ Elevator shaft
Axis
Adit to future power plant
Line of excavation
Main unit trashracks
Line of excavation
Outlet works trashracks
Outlet works trashracks
UPSTREAM ELEVATION
SECTION - STA. 37+89.96
BLOCK 84
Elevator tower
Elevator tower
Elevator tower
Parapet - El. 1315.42
El. 1273.00
Spillway - 1650'-0"
Sta. 30+70
Sta. 14+20
Spillway training wall
Intersection of fillet with 0.8 slope
Drain from pumping plant
Bus structure step
Line of excavation
Rock fill
DOWNSTREAM ELEVATION
CONSTRUCTED POWER PLANT
Elevator tower
W.S. El. 1290.00
Elevator shaft
Spillway training wall
Transverse galleries
350 Ton cranes
Control cable gallery
Power plant
Power plant
108,000 kv-a Generator
El. 938.00
50,000 H.P. Turbine
El. 1034.00
El. 980.00
El. 935.75
El. 910.00
El. 900.00
El. 895.18
El. 869.88
Axis
Line of excavation
SECTION - STA. 14+20
BLOCK 31
Top of dam - El. 1311.08
Max. W.S. El. 1290.00
El. 1288.00
135'x28' Drum gate
Crest - El. 1260.00
Drum gate gallery
102" Ring seal gates
Control cable gallery - El. 1060.00
El. 1136.67
Outlet works trashrack
El. 1088.30
102" Dia. outlet conduits
El. 1036.67
El. 978.01
102" Paradox gate
102" Dia. outlet conduit
El. 900.00
El. 895.18
102" Ring follower gate
El. 869.88
El. 874.41
Axis
SECTION - STA. 26+27.5
BLOCK 65
Crane rails
El. 1290.00
Main unit trashracks
Rubble masonry wall
Top of dam - El. 1311.08
El. 1273.00
Control cable gallery
El. 1041.00
El. 1026.20
El. 1010.42
180"-Dia. Penstock
El. 948.87
El. 938.00
Future power plant
El. 896.00
Line of excavation
Axis
SECTION - STA. 33+21
BLOCK 71
Gate hoist and stems transfer structure
Gate hoist structures
Line of excavation
Trashracks
Intersection of axes Dam Sta. 4+58 & Pumping Plant Dam Sta. P10+00
ELEVATION
PUMPING PLANT
℄ Railway
℄ Highway
℄ Road - El. 1311.08
Crane rails
El. 1290.00
5'x7' Hoist gallery
El. 1295.00
Max. W.S. El. 1290.00
Min. W.S. El. 1208.00
El. 1193.29
El. 1184.25
El. 1172.81
El. 1171.00
53°35'14"
℄ El. 1203.00
5'x7' Grouting and drainage gallery - El. 1210.00
14'-0" Dia. steel lined pump intake
Line of excavation
SECTION ALONG ℄ OF UNIT No. P-7
THIS DRAWING SUPERSEDES DRAWING 222-D-1908
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON
GRAND COULEE DAM
DAM, POWER AND PUMPING PLANTS
ELEVATIONS AND SECTIONS
DRAWN C.A.M.
SUBMITTED
TRACED W.M.S.
RECOMMENDED
CHECKED
APPROVED
DENVER, COLORADO JULY 12, 1940
222-D-6162

20. Level datum. Primary levels were run by the Geological Survey northward along the branch line of the Great Northern Railroad from Meyers Falls to the Boundary in 1905. This leveling was done for the International Boundary Commission. A notation on page 36, United States Geological Survey bulletin 674, states, "Part of line from Deer Park to Meyers Falls, unadjusted, closing - 3.89 feet." This would seem to indicate some uncertainty in the elevation of the bench mark from which levels were started at Meyers Falls in 1905.

The Geological Survey ran third-order levels up the Columbia River to the boundary in 1929-1930. The results indicated that revisions were desirable in previous elevations of bench marks at the boundary and other bench marks southward along the Columbia. The level datum used in the report of the Corps of Engineers, War Department, on the "Columbia River and Minor Tributaries" was [redacted] in agreement with the 1929-1930 surveys.

In making surveys for the Columbia River Reservoir, the Bureau of Reclamation discovered that the earlier level circuits by the Geological Survey joining Grand Coulee Dam with the Columbia River at the Canadian Boundary gave elevations too great at the boundary. In 1937 the Bureau ran a precise-level line up the Columbia River to the boundary from an initial bench mark established by the Geological Survey near Grand Coulee Dam site. Adjustments were made on each closed level circuit and wherever possible a check was made with bench marks by the Geological Survey. A break of 2.9 feet was found in the Geological Survey levels at a point 20 miles below Kettle Falls. This difference in elevation diminished gradually toward the International Boundary, at which point the error was 1.72 feet. The Geological Survey bench mark at the boundary line has a recorded elevation of 1352.50 while the Bureau of Reclamation gave the same bench mark an elevation of 1350.78 when referred to their datum at Grand Coulee Dam.

In Canada all observations are referred to the Geodetic Survey of Canada datum, publication No. 24, "Precise Levelling in British Columbia," published in 1930, and to secondary lines of levels by the Geodetic Survey of Canada-- in 1930, from B. M. No. 470J at Castlegar to the International Boundary--in 1931, from B. M. No. 523J at Nakusp to Edgewood. Bench marks referred to the Geodetic Survey of Canada datum have an elevation that is 2.03 feet lower than they have when referred to the Bureau of Reclamation datum. In backwater calculations, it is important that all elevations be correctly referred to the reservoir water-surface level at the dam. The Bureau of Reclamation levels meet

this requirement, regardless of whether the actual elevation above mean sea level is correct. The Bureau of Reclamation datum is used in this report and water-surface elevations obtained in Canada are reduced to this datum.

21. Maps. The first maps of the Columbia River were made in 1891 by Captain T. W. Symons, Corps of Engineers, United States Army. These maps were made as an aid to navigation and show the locations of reefs in the Little Dalles.

The only topographic maps that include all of the area that will be submerged by the Columbia River Reservoir are those furnished by the United States Geological Survey. These maps show a narrow strip on each side of the Columbia River from Rock Island Rapids (below Wenatchee, Washington) to the International Boundary. Ten sheets, 28 inches by 22 inches, on a scale of 1 to 31,680 or 2 inches to the mile, are used to cover this area with a contour interval of 20 feet on land and 5 feet on the river surface. The topography was obtained from aerial photographs made in 1930. The topography is no doubt in error to the same extent as the 1929-1930 levels, but, as these maps were used only for the purpose of obtaining cross sections below Kettle Falls, a small difference in level datum is of no consequence on account of the small scale and large contour interval.

Maps showing the Columbia River from just below Kettle Falls to the International Boundary were prepared by the Washington Water Power Company of Spokane in connection with an application submitted to the Federal Power Commission for a permit to operate a power plant at Kettle Falls. This series of maps, dated June 1931, was made to a scale of 400 feet to the inch and a contour interval of 10 feet where the ground surface had considerable slope and 5 feet where the ground was more nearly level. These maps were referred to the U. S. Geological Survey bench marks of 1905, being tied into a bench mark located at Marcus, designated as 1263-J and described in U. S. Geological Survey bulletin 457, page 25. At the foot of the Little Dalles, a Washington Water Power Company brass tablet was found to have an elevation 3.932 feet higher than that given by the Bureau of Reclamation datum. The Geological Survey bench mark just east of boundary monument No. 181 on the east bank of the Columbia River is given an elevation of 1354.138 by the Washington Water Power Company's maps and the Geological Survey of 1905. When referred to the Bureau of Reclamation datum, the elevation is 1350.779; that is, the elevations given on the map in this vicinity are 3.359 feet higher than the Bureau of Reclamation datum. Accordingly, a deduction of 3.6 feet is made from the elevations found on all maps and data obtained from this source.

Because of the extremely rough and jagged character of the Little Dalles, it was necessary to have more accurate information for studying the river channel than was given on the Washington Water Power Company's maps. Soundings were taken of the river channel at 13 sections which were completed by levels above low water to an elevation that would not be submerged by the reservoir. This information, supplemented by data from the power company maps, was used to make a map of the Little Dalles region on a scale of 50 feet to the inch with contour interval of 5 feet, elevations being wased on Bureau of Reclamation datum.

Incidental to a survey of the R. S. Wells mine property, a map was made, in 1939, of a portion of the Little Dalles above low water on a scale of 100 feet to the inch and with a contour interval of 10 feet, elevations being referred to the Bureau of Reclamation datum.

22. Photographs. During the high-water period of 1938, a series of photographs was taken of the Little Dalles region when the discharge was 330,600 second-feet; several photographs were taken in December 1939, with a river discharge of 50,000 second-feet. Prints of the aerial views of the Columbia River from the foot of the Little Dalles to the International Boundary, taken by the Geological Survey in connection with their topographic maps made in 1930, were obtained. An enlargement of the aerial view of the Little Dalles region was very useful in aiding workmen to mold and shape the topography for the hydraulic model.

23. Stream gaging stations. The Governments of the United States and Canada in 1928 developed an international investigation program of major streams and boundary waters between the Lake-of-the Woods and the Pacific Coast. This program included gaging stations on the Columbia at Trail, British Columbia, on the Clark Fork below Z Canyon near Metaline Falls, Washington, and on the Kettle River near Laurier, Washington. The location of these stations is shown on the map, figure 1. The data collected at a gaging station consist of records of stage, measurements of discharge, and general information of aid in determining the daily flow. The term "observation station" is used in this report to designate a place at which only the stage of the river is obtained; it is necessary to estimate the discharge from the records of one or more gaging stations located either upstream or downstream, correcting for flow from tributaries if necessary.

In computing a backwater profile, the properties of the river channel at the upper end of the reservoir have much more influence on the final result than those near the dam. For this

reason the stretch of river from the mouth of the Kettle River to the International Boundary is most important, with sections nearest the boundary having the most influence on the final result. Since there are no large tributaries joining the Columbia River within this stretch, the discharge was assumed constant from the mouth of the Kettle River to the International Boundary. The largest creek emptying into the Columbia River in this stretch is Sheep Creek, and its discharge is usually less than one percent of that of the Columbia River.

When the discharge obtained at a gaging station is to be used at some other locality, the variation in stage should be considered. The portion of the Columbia River which is subjected to backwater from Grand Coulee Dam has a very steady rate of flow, changing gradually from day to day because it is some distance from its source and, as already pointed out, is fed by melting snow and has a large lake area to stabilize its rate of flow. Figure 4 shows the hydrograph of the Columbia River at Grand Coulee Dam from 1913 to 1939. It will be noted that there are no sharp flood peaks. At the Kettle Falls gaging station, the change in the rate of discharge from day to day is rarely over five percent, is usually less than three percent, and, in eight hours, is less than two percent. To prove that the variation in discharge between the International Boundary and Kettle Falls for any day was not large, table II was prepared, which shows for each stream gaging station the drainage area, the average discharge computed from the available record, and the discharge for certain days. At the bottom of table II are shown the results of several comparisons of discharges as given by the tributary gaging stations and that at Kettle Falls. The maximum variation in discharge found was less than three percent. The tendency for the tributary stations to give a higher discharge than Kettle Falls when the stage is rising and a lower discharge when the stage is falling is very small. Since all the observation stations were between Trail, British Columbia, and Kettle Falls, to obtain the discharge that was applicable to any observation station it was necessary to correct only for the discharges from intervening tributaries.

The gaging station at Trail, British Columbia, was affected at flood stage by backwater caused by large discharges in the Clark Fork emptying into the Columbia 10 miles below Trail; some backwater may also be caused by the restricted channel at the Little Dalles at very high flood stage. Because of the unfavorable location, the gaging station at Trail was moved seven miles upstream to Birchbank in October 1937, where it was beyond the effect of backwater from the Clark Fork. There probably was a

tendency to estimate discharges from the rating curve of the Trail gaging station too high, as is indicated by the fact that the total average discharge of the tributaries is greater than that at Kettle Falls. Also, for the flood peak of June 22, 1933, the tributary stations showed a larger discharge than the Kettle Falls station.

To obtain the discharge of the Columbia at any point between the International Boundary and the mouth of the Kettle River, it is necessary to subtract from the discharge at the Kettle Falls gaging station the discharge of the Kettle River as given by the Laurier gaging station. This discharge may be checked by adding together the discharge of the Columbia at Trail or Birchbank, the discharge of the Clark Fork below Z Canyon, and the discharge of the Salmon River near Waneta; but, since the Salmon River contributes only about one-half of one percent of the flow in the Columbia, it may be neglected. This check was used for several large discharges and was always found to substantiate the results of the first method to within five percent or less. As previously stated, the only large creek emptying into the Columbia between the mouth of the Kettle River and the Canadian Boundary is Sheep Creek, which usually contributes less than one percent of the flow in the Columbia.

To obtain direct measurements of the backwater caused by the filling of the Columbia River Reservoir, the Dominion Water and Power Bureau of Canada, in cooperation with the U. S. Geological Survey, installed an international gaging station on the Columbia River at the Canadian Boundary during the winter of 1938-1939. An automatic recording gage is located on the left bank of the river at the boundary line. The cable measuring station is located about 6,000 feet downstream from the recording gage. Nine sets of current meter measurements, table VIII, have been made at this station for a range of discharges from 29,700 to 255,000 second-feet. These measurements checked the discharge obtained by deducting the discharge of the Kettle River at Laurier from the discharge of the Columbia at Kettle Falls by less than five percent.

24. Observation stations. The Corps of Engineers, in 1928-1931, established four observation stations where the water-surface elevations of the river were determined on certain days. These stations have been designated as major observation stations since they were located at the most critical points along the river and have a longer record than those located later by other Government agencies. The locations of these major observation stations are shown on figure 1. The water-surface elevations obtained at these stations were referred to the Geological

Survey datum of 1929-1930, and the equation between this datum and that of the Bureau of Reclamation was determined when precise-level circuits were made in 1937. All water-surface elevations have been reduced to the Bureau of Reclamation datum. Table III gives these data.

In May and June of 1933, the U. S. Geological Survey, in cooperation with the Dominion Water and Power Bureau of Canada, selected 10 locations for observation stations where the elevations of the water surface could be determined prior to and after placing the Grand Coulee Dam in operation. Four of these observation stations have the same location as those used by the Corps of Engineers, designated as major observation stations. The data obtained at those observation stations, which are at different locations from the observation stations of the Bureau of Reclamation, are given in table IV. These stations were spaced on an average of 3.4 miles apart on a stretch of the Columbia extending 17.5 miles upstream from the boundary and 17 miles downstream from the boundary. The map on figure 1 shows the location of these observation stations, and table V gives the distance between stations and the distance from Grand Coulee Dam. It was desirable to obtain the water-surface elevations at the observation stations simultaneously; however, this was not practicable, and, because of difficulties in traveling and time required for leveling, a complete set of observations could seldom be made during a single day. An average of four river profiles was obtained each year, with at least one of the profiles each year being taken during flood stage. This program of river-profile observations is being continued and will furnish important data when the Columbia Reservoir is filled; it will also serve to determine the effect of any channel improvement undertaken. Future data collected under those conditions can be used as a prototype check on model results obtained at the present time.

Additional observation stations on the Columbia River were established by the Bureau of Reclamation until there was a total of 17 stations which were located between the mouth of the Kettle River and the International Boundary (see figure 1). Four of these stations were identical with those established by the Corps of Engineers and designated as major observation stations. Twelve stations are located in the 16½ miles between the foot of the Little Dalles and the boundary, where the hydraulic characteristics of the river channel are very irregular and give a wide variation in the roughness coefficient. Five stations are located below the Little Dalles; three are near the town of Marcus, 22 miles below the Little Dalles; and two are adjacent to the Little Dalles. Twenty-six sets of water-surface elevations were obtained during the year 1936 for the entire range of flow from

flood to extreme low water. These elevations, together with the corresponding discharge, are given in table VI.

All observation stations are accessible from the highway along the river, and a bench mark is located near each station. Elevations are obtained along the bank by using a surveyor's level. As a consequence, any variation in water-surface level across the river channel is neglected, and all water-surface elevations given are applicable to the left (east) side of the river. Observation stations were never located on river bends and were always placed on the main river channel so that the water-surface elevations determined in the manner described above represented, as nearly as possible, the average elevations of the water surface at that section, except near and through the Little Dalles, where large eddies are known to affect the water level near the left bank.

In order to have a more reliable check on the performance of the hydraulic model, 12 additional observation stations were established through the Little Dalles. Water-surface elevations were determined on the left side of the channel for a range of discharges from 25,000 to 240,000 second-feet (see table VII). Through the Little Dalles, the water-surface elevation varied from point to point across the river cross section; in comparing model and prototype, the water surface in the model was measured on the left bank at points which corresponded to those observation stations used in the prototype.

25. River cross sections. Representative cross sections of the channel were taken by soundings below low-water level and by leveling above low water. Areas of these sections were obtained by planimeter, and the wetted perimeters determined. Curves of area and hydraulic radius were plotted against water-surface elevation.

For the purpose of backwater studies, it was convenient to divide the length of the reservoir into four zones. Each zone has different characteristics of topography, a different type of channel flow, and required different methods of analysis. The extent of each zone is shown on the map, figure 1. The locations and lengths of zones are as follows:

Zone 1 from Grand Coulee Dam to above Kettle Falls observation station 17 (at Marcus) ..... 111.0 miles.

Zone 2 from above Kettle Falls observation station 17 to foot of Little Dalles ..... 22.0 miles.

Zone 3 from foot of Little Dalles to head of Little Dalles ..... 0.9 miles.

Zone 4 from head of Little Dalles to the International Boundary ..... 15.3 miles.

In zone 1, the area and the hydraulic radius are very large and the mean velocity is very low; consequently, the friction loss is very small, being only a little over one foot for a discharge of 650,000 second-feet. The friction loss in this zone does not have much effect on the amount of backwater in zone 4 or at the International Boundary. In view of this fact, it was sufficiently accurate to determine the river cross section from the aerial topographic maps made by the Geological Survey.

The maps made by the Washington Water Power Company extend from below Kettle Falls to the International Boundary. Three river cross sections had to be determined from these topographic maps, one at the Kettle Falls highway bridge, section 60, and two between the falls and the town of Marcus. These maps give the topography in fair detail down to low-water level, but the bottom of the river bed had to be assumed. This assumption is relatively unimportant and would not cause any serious error since the area below low water is small compared to the area of the cross section with a full reservoir, and the slope of the energy gradient just above Kettle Falls with the reservoir full or partly full is very flat.

The Washington Water Power Company obtained a series of river cross sections by soundings and surveys between the town of Marcus and the International Boundary. These cross sections, together with their areas and hydraulic radii, were obtained from the power company and corrected to the Bureau of Reclamation datum. There are 24 of these cross sections in the 38 miles of river, the maximum distance between sections being 20,300 feet, or 3.85 miles, near the Canadian Boundary where the river channel flows uniformly and has a constant channel cross section for 4 or 5 miles. With this one exception, the distance between cross sections is less than 13,250 feet. Care was exercised in locating the river cross sections so that they would be representative of the river channel with no marked change in flow conditions or shape of channel taking place between them. None of the cross sections was located at a bend in the river, nor did any of them cut across bays or abnormally wide portions of the river. The cross sections were taken at right angles to the flow of the river under both natural and backwater conditions.

The Bureau of Reclamation took 13 additional river cross sections along the Little Dalles between the two cross sections of the Washington Water Power Company. Seven of these were located within the 500 feet of entrance section to the restricted gorge, where the shape of the channel was fast changing from the normally broad, shallow river section to the narrow, deep, restricted section of the Little Dalles. This change in shape of cross section was made more complicated by the large island of solid limestone that choked the entrance and split it into two channels. Five other cross sections were obtained where the shape or size of the channel changed through the deep gorge of the Little Dalles. Below the deep gorge, the river channel widens out, becoming shallower. Several intermittent rock ridges or reefs tend to divide the main channel into two or three parts. This condition extends for about 2,000 feet and considerable energy is expended, as is shown by waves and white water around the points of rock jutting out of the water. One cross section was taken at the lower end of this section of reefs. This point is known as the foot of the Little Dalles, and, downstream from it, the river becomes normal, being perhaps a little wider for a short distance where the boils and rollers originating in the Little Dalles dissipate themselves.

To obtain these river cross sections, a cable was stretched between the steep banks of the river from which a line was suspended to a boat. A 40-pound weight attached to a small steel cable was used for making the soundings. These cross sections were obtained at low water when the discharge was about 25,000 second-feet. Even at these low discharges, velocities were high and considerable difficulty was experienced in handling the sounding weights. Several weights were lost in the deeper portions of the channel. Below the restricted section of the Little Dalles where the river widens out, running over the rocky reefs, it was impossible to stretch a cable because of the greater distance and the flatter river banks. Consequently, the use of a boat would have been very dangerous because of the swift currents and rocky reefs, and no sections were obtained.

The Bureau of Reclamation took a river cross section 280 feet above the boundary line at the site of the major observation station No. 2. In the winter of 1938-1939, a permanent automatic recording gage was located at this cross section on the left bank of the river. All backwater conditions and measurements at the International Boundary will be referred to this river cross section.

26. Coincidence of river cross sections and observation stations. The cross section of the river channel at the observation station must be known if the roughness coefficient

is to be computed accurately. At most river cross sections, water-surface elevations were unknown. In some instances the cross section at the observation stations were unknown, which complicated the work of computing the roughness coefficient.

For those observation stations located above the Canadian border, there are no river cross sections available; however, no backwater computations were made in this region. Below the boundary there are no river cross sections for the following observation stations:

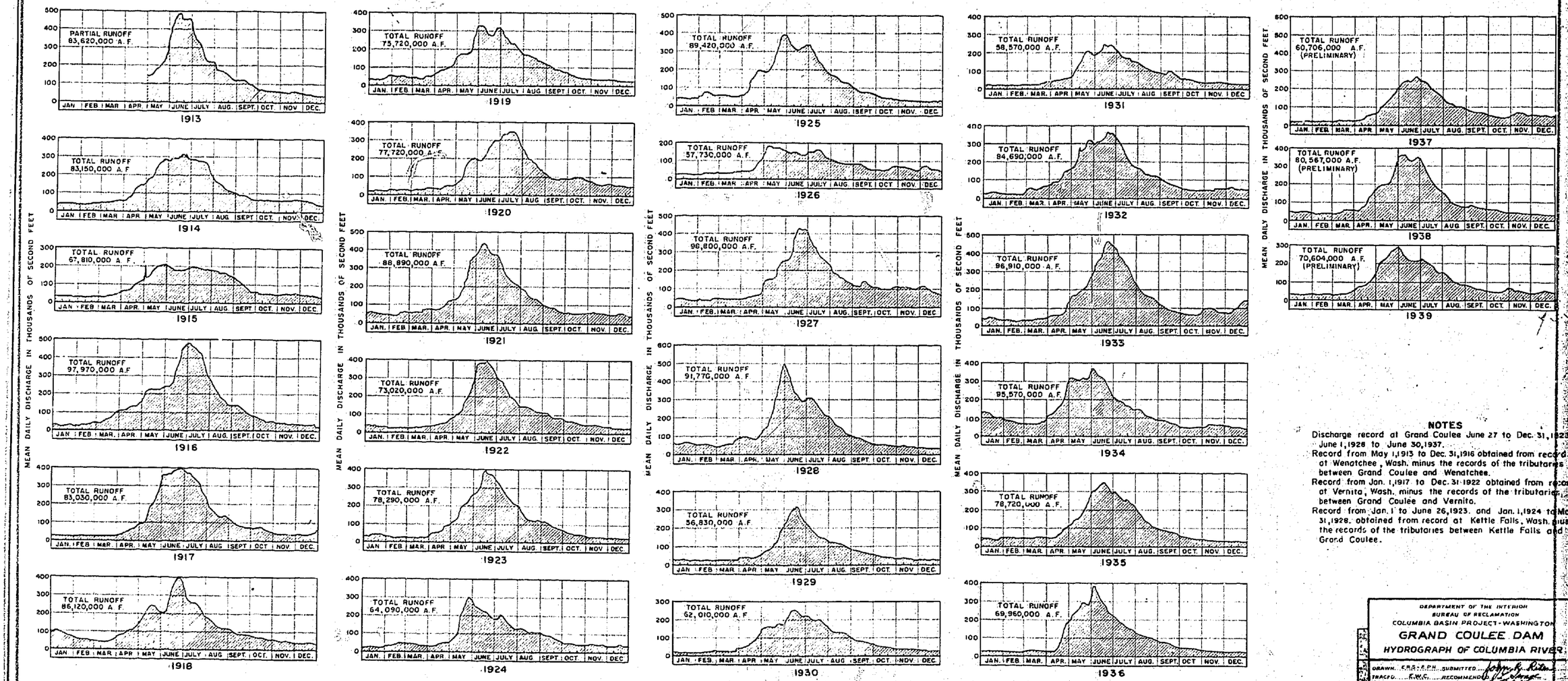
Orchard - 4.0 miles downstream from International Boundary.
Northport Bridge - 10.8 miles downstream from International Boundary.

These stations were of no value in ascertaining the roughness coefficients, but the data for them are listed in table IV.

Some of the observation stations established by the Bureau of Reclamation were located a short distance from a river cross section, but the data from these stations were used to compute the roughness coefficients since they were so near the river cross sections and there were no other data available. The following is a list of these stations and their distances to the nearest river cross section:

Observation station 7 -	1,000 feet downstream from river cross section 93.
Observation station 10 -	900 feet upstream from river cross section 88.
Observation station 12 -	260 feet upstream from river cross section L.

FIGURE 4



NOTES

Discharge record at Grand Coulee June 27 to Dec. 31, 1923; June 1, 1928 to June 30, 1937.

Record from May 1, 1913 to Dec. 31, 1916 obtained from record at Wenatchee, Wash. minus the records of the tributaries between Grand Coulee and Wenatchee.

Record from Jan. 1, 1917 to Dec. 31 1922 obtained from record at Vernita, Wash. minus the records of the tributaries between Grand Coulee and Vernita.

Record from Jan. 1 to June 26, 1923. and Jan. 1, 1924 to May 31, 1928. obtained from record at Kettle Falls, Wash. plus the records of the tributaries between Kettle Falls and Grand Coulee.

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON

GRAND COULEE DAM

HYDROGRAPH OF COLUMBIA RIVER

DRAWN. E.R.S.-E.P.H. SUBMITTED John R. Riter
TRACED. E.W.C. RECOMMENDED [illegible]
CHECKED. G.L.M. APPROVED A. F. Walle

29426 DENVER, COLORADO, OCT 16, 1937 222-D-1302

COLUMBIA RIVER RESERVOIR

BACKWATER STUDIES

HYDROLOGIC DATA FOR COLUMBIA RIVER BASIN

River	Gaging Station Location	Drainage Area above Station Sq. mi.	Records Available: From Month Year	Records Available: Total years to 1937	Average* Discharge: Second-feet	Average* Discharge: Percent	Discharge June 22, 1933: Second-feet	Discharge June 22, 1933: Percent	Discharge June 25, 1937: Second-feet	Discharge June 25, 1937: Percent	Discharge August 15, 1937: Second-feet	Discharge August 15, 1937: Percent	Discharge June 1894 Sec.-Ft. Estimated
Columbia	Trail, B. C.	34,000	April 1913	24	70,940	70.64	287,000	65.64	183,000	72.59	84,300	84.41	
Clark Fork	Birchbank, B.C. Z Canyon, Washington	25,200	Oct. 1912	25	26,180	26.07	137,000	31.33	56,800	22.53	14,800	14.82	
Salmon	Waneta, B. C.	-	Mar. 1936	1	630	0.63	-	-	2,350	0.93	206	0.21	
Sheep Creek	Northport, Wash.	225	June 1929	8	195	0.19	424	0.10	940	0.37	50	0.05	
Kettle	Laurier, Wash.	3,800	Sept. 1929	8	2,481	2.47	12,800	2.93	9,010	3.58	506	0.51	50,000
	TOTALS	63,225			100,426	100.00	437,224	100.00	252,100	100.00	99,862	100.00	
Columbia	Kettle Falls, Wash.	64,500	April 1913	24	99,500	92.69	435,000	95.12	255,000	97.16	103,000	98.70	700,000
Colville	Meyers Falls, Wash.	-	Oct. 1922	1	159	0.15	224	0.05	312	0.12	59	0.05	
Spokane	Little Falls, Wash.	6,380	Oct. 1912	25	7,693	7.16	22,100	4.83	7,130	2.72	1,300	1.25	25,000
	TOTALS	70,880			107,352	100.00	457,324	100.00	262,442	100.00	104,359	100.00	
Columbia	Grand Coulee, Wash.	74,100	April 1913	24	108,000		464,000		270,000		107,000		725,000

Note: Data from U. S. Geological Survey Water Supply Papers.

*For records available to 1937.

River	Gaging Station Location	Discharge (Second-feet) Rising stage: 6-10-33	5-20-35	5-10-36	5-20-37	5-31-37	6-10-38	Falling stage: 7-10-33	6-30-35	7-31-35	6-10-36	7-20-37	7-31-38
	Totals ‡	332,600	151,500	215,700	129,900	192,100	335,200	357,300	282,200	215,900	315,000	165,700	144,100
Columbia	Kettle Falls	337,000	156,000	212,000	133,000	190,000	339,000	366,000	287,000	215,000	322,000	168,000	148,000
Percent difference		-1.3	-2.9	+1.7	-2.3	+1.1	-1.1	-2.4	-1.7	+0.4	-2.0	-1.4	-2.6

‡ Summation of discharge of Columbia River at Trail plus discharges of tributaries between Trail and Kettle Falls.

Table II

COLUMBIA RIVER RESERVOIR

BACKWATER STUDIES

Observed Water Surface Elevations by U. S. Geological Survey, U. S. Engineering Corps, and Dominion Water and Power Bureau of Canada

Date	Discharge in thousands of cubic feet per second	Elevation of water surface: Observation Station No. 2	Elevation of water surface: Observation Station No. 6	Date	Discharge in thousands of cubic feet per second	Elevation of water surface: Observation Station No. 11	Elevation of water surface: Observation Station No. 13
3-14-30	20.7	1290.0	1270.6	3-13-30	21.1	1246.4	1243.3
10-13-30	42.7	1294.7	1274.4	10-13-30	42.7	1252.0	1246.6
1- 7-31	18.9	1289.8	1269.8	1- 8-31	18.9	1245.9	1242.5
5-31-32	266.0	1316.9	1299.3	6- 1-32	265.4	1289.3	1269.7
6- 6-32	280.0	1320.3	1301.0	6- 7-32	288.0	1291.9	1271.3
6-14-32	306.0	1322.5	1303.7	6-14-32	306.0	1294.9	1273.1
6-18-32	341.1	1325.0	1307.1	6-18-32	341.1	1298.8	1275.6
7- 6-32	297.1	1321.3	1302.2	7- 6-32	297.1	1293.1	1272.2
8-19-32	117.4	1305.6	1283.5	8-20-32	116.7	1266.7	1256.5
11- 3-32	40.8	1294.2	1274.0	11- 4-32	39.5	1251.2	1246.2
11-22-32	43.0	1294.6	1274.3	11-22-32	43.0	1251.9	1246.7
6-15-33	346.4	1325.4	1307.4	6-15-33	346.4	1299.4	1276.1
6-21-33	420.2	1330.9	1314.3	6-22-33	422.5	1306.5	1281.0
7- 4-33	395.4	1328.5	1310.6	7- 6-33	381.6	1302.1	1278.0
10-13-33	58.4	1297.5	1275.9	10-14-33	57.7	1255.3	1249.1
2-26-36	16.3	1288.8					
2-27-36	16.7		1268.8	2-27-36	16.7	1244.9	1242.0
5-23-36	259.6	1318.2	1298.3	5-23-36	259.6	1288.0	1268.9
6- 5-36	363.2	1325.9	1307.8	6- 5-36	363.2	1299.8	1276.2
8-24-36	92.2	1302.5	1280.6	8-24-36	92.2	1262.3	1253.6
				6- 7-37	215.8	1282.6	1264.7
6- 7-37	215.8	1314.8	1294.2	6-18-37	226.3	1284.4	1266.6
				11-11-37	59.3	1255.9	1249.4
6-18-37	226.3	1315.6	1295.4				
				1-26-38	34.5	1250.0	1245.3
11-11-37	59.3	1297.7	1276.8	4- 8-38	43.5	1252.3	1246.8
1-26-38	34.5	1292.9	1272.8				
				6-17-38	311.3	1294.3	1272.8
4- 7-38	43.5	1294.2	1274.1	12-14-38	29.3	1248.3	1244.2
				4-26-39	84.7	1261.3	1252.8
6-17-38	311.3	1322.0	1303.0	6-20-39	195.1	1279.9	1263.9
12-13-38	29.3	1291.8	1271.2				
4-26-39	84.7	1301.6	1279.8				
6-20-39	195.1	1313.1	1292.1				

The following are designated as major observation stations:

Observation station 2 located at International Boundary level adjustment was -1.7.
Observation station 6 located at Sheep Creek Bend level adjustment was -1.8.
Observation station 11 located at Head of Little Dalles level adjustment was -2.1.
Observation station 13 located at foot of Little Dalles level adjustment was -2.1.

Notes: Discharge of Columbia River above Marcus obtained by deducting discharge of Kettle River at Laurier from discharge of Columbia River at Kettle Falls on date of observation.

Water surface elevations are reduced to level datum of adjusted circuit of April 1937, run by U.S.B.R. from Grand Coulee Dam to International Boundary.

Table III

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

Water Surface Elevations at Selected Observation Stations
on the Columbia River* - U.S.B.R. Datum

Date	Northport Bridge, Wash.	4 miles below International Boundary	Columbia Gardens, B. C.	Beaver Creek, B.C.	Trail, B.C.	Birch-bank, B.C.	Castlegar, B. C.
5-31-32			1328.6		1343.7		1388.2
6- 4-32					1344.8		1389.7
6- 6-32	1295.9	1310.6	1329.5	1333.1	1345.6		1390.8
6-13-32					1347.9	1375.9	1392.9
6-14-32	1298.9	1313.0	1332.3	1335.9	1348.4		1393.8
6-17-32					1351.3		1396.9
6-18-32	1302.5	1315.8	1335.4	1339.1	1351.6	1380.4	1397.4
6-20-32					1351.3		1396.9
6-21-32	1301.9	1315.3			1351.0		1396.6
6-22-32					1351.2	1379.8	1396.6
7- 4-32					1349.7	1378.1	1395.9
7- 6-32	1297.3	1311.8	1332.3	1336.3	1349.1		1394.9
8-15-32				1323.3		1361.8	1385.4
8-17-32			1318.8		1336.9		
11- 2-32			1308.8	1313.1	1326.9		1375.4
11- 3-32	1268.5	1287.3					
11- 6-32					1326.7		1375.3
11-22-32	1268.8	1287.7	1308.4	1312.8	1326.5		1374.5
6-14-33			1332.5	1335.7	1347.7	1375.5	1391.9
6-15-33	1303.0	1316.1			1348.4		1392.7
6-21-33	1308.8	1322.2	1339.6	1342.5	1354.2	1383.0	1399.0
7- 4-33		1319.0	1338.0	1341.5	1353.5	1382.5	1399.0
10-12-33			1311.5	1315.8	1329.8	1352.1	1377.6
10-13-33	1270.9	1289.9					
2-26-36			1303.6	1308.8	1322.0	1344.2	1370.8
2-27-36	1264.3	1283.4					
5-22-36			1327.6	1331.5	1343.9	1370.8	1389.0
5-23-36	1292.8	1308.7					
6- 4-36			1336.3	1340.6	1352.9	1382.0	1399.3
6- 5-36	1303.6	1316.4			1352.8		
8-22-36			1316.8	1321.2	1334.4	1358.8	1383.9
8-24-36	1274.9	1294.0			1334.2		
6- 6-37			1325.2	1329.0	1341.9	1368.7	1387.3
6- 7-37	1288.2	1305.5					
6-17-37			1326.4	1330.4	1343.4	1370.4	1389.0
6-18-37	1289.6	1306.1					

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

Water Surface Elevations at Selected Observation Stations on the Columbia River* - U.S.B.R. Datum

Date	Northport Bridge, Wash.	4 miles below International Boundary	Columbia Gardens, B. C.	Beaver Creek, B.C.	Trail, B.C.	Birch-bank, B.C.	Castlegar, B. C.
11- 9-37				1316.3	1329.9	1352.8	1378.4
11-11-37	1271.1	1290.0				1353.0	1378.2
1-26-38	1267.5	1286.3				1346.5	1372.2
1-27-38			1306.2	1311.0	1324.4	1346.5	1372.3
4- 7-38	1268.6	1287.4	1306.8	1311.4	1324.8	1346.7	1372.3
6- 8-38	1300.3	1313.8	1332.8	1336.7	1349.1	1377.2	1393.6
6-17-38	1298.3	1312.4	1331.8	1335.7	1348.2	1376.2	1393.2
12-12-38			1306.3	1311.0	1324.4	1346.4	1372.7
12-13-38	1266.7	1285.6					
4-26-39	1274.2	1293.1	1312.4	1316.7	1330.0	1353.0	1375.8
6-20-39	1286.1	1303.6	1324.2	1328.3	1341.4	1367.7	1387.4

* From report by G. L. Parker, U. S. Geological Survey, 1939, and from report by C. E. Webb, Dominion Water and Power Bureau of Canada, 1939.

COLUMBIA RIVER RESERVOIR

BACKWATER STUDIES

DISTANCE BETWEEN RIVER CROSS SECTIONS AND/OR OBSERVATION STATIONS

River Cross Section or Observation Station	Distance in feet	Miles from Grand Coulee Dam
Section 60, highway bridge below Kettle Falls		106.652
	12,580	
Section 61		109.035
	8,730	
Observation station 18		110.688
	1,820	
Section 62, observation station 17 W.W.P.Co. section 37 (End of Zone 1, beginning of Zone 2)		111.053
	5,770	
Section 63, observation station 16 W.W.P. Co. section 12		112.126
	5,650	
Section 64, (W.W.P.Co. section 13)		113.196
	8,130	
Section 66, (W.W.P.Co. section 14)		114.736
	8,750	
Section 68, (W.W.P.Co. section 15)		116.393
	7,160	
Section 69, (W.W.P.Co. section 16)		117.749
	7,870	
Section 70, (W.W.P.Co. section 17)		119.240
	9,180	
Section 72, (W.W.P.Co. section 18)		120.979
	5,590	
Section 73, (W.W.P.Co. section 19)		122.038
	10,500	
Section 75, (W.W.P.Co. section 20)		124.027
	9,670	
Section 76, (W.W.P.Co. section 21)		125.858
	7,290	
Section 77, (W.W.P.Co. section 22)		127.239
	7,570	
Section 79, (W.W.P.Co. section 23)		128.673
	5,650	
Section 80, (W.W.P.Co. section 24)		129.743
	6,180	
Section 81, observation station 15 W.W.P.Co. section 25		130.913
	5,380	
Section 82, observation station 14 W.W.P.Co. section 26		131.932
	1,750	

COLUMBIA RIVER RESERVOIR

BACKWATER STUDIES

DISTANCE BETWEEN RIVER CROSS SECTIONS AND/OR OBSERVATION STATIONS

River Cross Section or Observation Station	Distance in feet	Miles from Grand Coulee Dam
Section 83 or M, observation station 13. (End of Zone 2, beginning of Zone 3)		132.263
	2,170	
Section L		132.674
	260	
Observation station 12 (no cross section taken)		132.723
	255	
Section K		132.771
	765	
Section J		132.920
	160	
Section I		132.950
	220	
Section H		132.992
	65	
Section G		133.004
	220	
Section F		133.046
	108	
Section E		133.066
	70	
Section D		133.079
	118	
Section C		133.101
	100	
Section B		133.120
	100	
Section A		133.139
	172	
Section 87, observation station 11 W.W.P.Co., section 27. (End of Zone 3, beginning of Zone 4)		133.172
	2,790	
Section 88, (W.W.P.Co., section 28)		133.700
	900	
Observation station 10 (no cross section taken)		133.870
	11,200	
Section 90, observation station 9 W.W.P.Co., section 29		135.991
	12,340	
Section 92, observation station 8 W.W.P.Co., section 30		138.328
	3,590	

COLUMBIA RIVER RESERVOIR

BACKWATER STUDIES

DISTANCE BETWEEN RIVER CROSS SECTIONS AND/OR OBSERVATION STATIONS

River Cross Section or Observation Station	Distance in feet	Miles from Grand Coulee Dam
Observation station 7 (no cross section taken)		139.008
	1,000	
Section 93, (W.W.P.Co., section 31)		139.197
	3,210	
Section 94, observation station 6 W.W.P.Co., section 32		139.805
	13,250	
Section 95, observation station 5 W.W.P.Co., section 33		142.314
	9,050	
Section 96, observation station 4 W.W.P.Co., section 34		144.028
	20,300	
Section 97, observation station 3 W.W.P.Co., section 35		147.873
	2,870	
International Boundary (Canada-United States)		148.417
	280	
Section 98, observation station 2 (End of Zone 4)		148.470

Notes: W.W.P.Co. is an abbreviation for Washington Water Power Company. River cross sections having this designation were originally made by the Washington Water Power Company and later were traced by the Coulee Dam office, being given a new section number which is given first in the table.

River cross sections from section A to section M and also section 98 at the International Boundary were prepared from measurements and soundings taken by the U. S. Bureau of Reclamation engineers. The points where the elevation of the river water surface are determined are noted as observation stations. The distances between sections and/or observation stations were scaled from maps prepared by the Washington Water Power Company except in the Little Dalles region, Zone 3, where the distances were scaled from map R_2-1999-8 prepared by the Coulee Dam office.

COLUMBIA RIVER RESERVOIR

BACKWATER STUDIES

Observed Water Surface Elevations by U.S. Bureau of Reclamation

Date	Discharge in thousands of cubic feet per second	Observation Station																
		Zone No. 4									Zone No. 3			Zone No. 2				
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
12-4,5-35	25.8	1291.1	1290.8	1285.0	1281.4	1271.2	1270.0	1266.5	1257.3	1247.6	1247.6	1246.5	1243.8	1243.8	1240.2			
1-9,10-36	22.1	1290.5	1290.1	1284.3			1269.3	1265.9	1256.8	1246.7	1246.8	1245.6	1243.2	1243.2	1239.5			
2-14-36	17.8	1289.2	1289.0	1283.2			1268.2	1264.9	1255.9	1245.6	1245.5	1244.3	1242.2	1242.3	1238.4			
3-11-36	22.5	1290.5	1290.1	1284.4	1280.9	1270.5	1269.3	1265.6	1256.9	1246.8	1246.9	1245.8	1243.4	1243.3	1239.6			
4- 6-36	21.7	1290.1	1289.9	1284.1	1280.7	1270.3	1269.2	1265.7	1256.2	1246.2	1246.9	1245.7	1243.0	1243.2	1239.5	1207.8	1205.5	1205.0
4-17-36	39.4	1294.4	1293.9	1287.5	1283.7	1273.9	1272.4	1269.4	1259.2	1252.0	1252.3	1250.1	1246.9	1246.8	1243.4	1211.5	1210.6	1208.9
4-23-36	88.0	1302.2	1300.7	1294.0	1288.7	1280.9	1278.9	1275.3	1264.4	1262.5	1262.4	1257.1	1253.6	1253.4	1250.9	1217.5	1216.4	1214.8
4-29-36	138.2	1307.9	1306.3	1298.1	1294.2	1286.0	1284.0	1280.6	1274.3	1271.7	1271.1	1263.3	1258.9	1258.8	1256.7	1221.5	1220.1	1218.6
5- 9-36	195.2	1313.4	1312.1	1302.9	1299.8	1292.2	1289.8	1287.0	1282.7	1281.0	1280.0	1269.7	1264.4	1264.4	1262.5	1225.3	1223.9	1221.2
5-16-36	234.5	1316.6	1315.1	1306.3	1303.3	1296.4	1293.9	1291.4	1288.3	1286.4	1285.5	1273.9	1267.6	1267.5	1265.8	1227.9	1226.3	1224.9
5-23-36	258.6	1318.1	1316.7	1308.0	1305.1	1298.1	1296.0	1293.5	1291.0		1288.2	1275.1	1268.9	1269.0	1267.4	1228.7	1227.0	1225.9
6- 1-36	312.0	1322.8	1321.1	1312.3	1309.4	1302.2	1301.1	1299.7	1297.4	1295.5	1294.8	1280.2	1273.1	1273.3	1271.6	1231.5	1230.2	1228.4
6- 4-36	361.5	1325.8	1324.5	1315.7	1313.4	1307.9	1305.6	1304.0	1302.4	1301.2	1299.9	1283.9	1276.4	1276.3	1274.8	1233.8	1232.1	1230.8
6-13-36	288.6	1320.3	1318.9	1309.8	1307.4	1300.9	1298.6	1296.4	1294.3	1292.8	1291.4	1277.9	1271.1	1271.2	1269.6	1230.2	1228.5	1227.2
6-20-36	251.6	1317.6	1316.3	1307.4	1304.5	1297.6	1295.6	1292.9	1290.1	1288.7	1287.4	1275.1	1268.8	1268.5	1266.9	1228.4	1226.7	1225.4
6-27-36	219.8	1315.3	1314.0	1304.9	1302.0	1294.5	1292.3	1289.5	1286.0	1284.0	1283.2	1272.2	1266.0	1266.0	1264.2	1226.5	1224.9	1223.7
7- 6-36	187.9	1312.4	1311.1	1302.1	1298.8	1291.0	1288.8	1286.0	1281.3	1279.2	1278.5	1268.8	1265.2	1263.3	1261.4	1224.3	1222.8	1221.6
7-15-36	158.9	1309.6	1308.6	1299.1	1296.5	1288.3	1285.9	1283.1	1277.2	1275.0	1274.3	1265.6	1261.0	1260.8	1258.9	1222.5	1220.8	1219.9
7-27-36	137.0	1307.5	1306.3	1297.7	1294.3	1285.9	1283.7	1280.5	1274.1	1271.2	1270.8	1263.2	1258.5	1258.8	1256.4		1219.4	1218.3
8-10-36	107.5	1304.0	1303.1	1295.0	1290.9	1282.4	1280.6	1277.5	1269.1	1265.5	1265.2	1259.3	1255.4	1255.5	1253.0		1216.9	1215.9
8-24-36	91.6	1302.1	1301.2	1293.7	1289.4	1280.9	1279.1	1275.9	1267.0	1262.8	1262.6	1257.3	1253.8	1253.8	1251.2		1215.6	1214.8
9-10-36	72.4	1300.1	1298.9	1291.4	1287.1	1278.6	1276.8	1273.5	1264.0	1258.9	1258.7	1254.6	1251.2	1251.2	1248.4		1213.8	1212.9
9-24-36	47.6	1295.6	1294.9	1288.2	1284.4	1275.2	1273.5	1269.9	1260.2	1253.3	1253.2	1250.7	1247.5	1247.5	1244.3		1210.7	1209.7
10-12-36	39.1	1294.0	1293.4	1286.2	1283.4	1273.7	1272.2	1268.8	1259.0	1251.2	1251.1	1249.2	1246.0	1246.2	1242.6		1209.4	1208.5
11- 8-36	29.8	1292.0	1291.6	1285.5	1282.0	1272.1	1270.8	1267.2	1257.8	1248.6	1248.9		1244.7		1240.6		1207.9	1206.7
12- 1-36	22.0	1290.2	1289.9	1284.3	1280.7	1270.3	1269.2	1265.7	1256.4	1246.4	1246.6	1245.5	1243.0		1239.5			1204.9

Notes: Discharge of Columbia River above Marcus obtained by deducting discharge of Kettle River at Laurier from discharge of Columbia River at Kettle Falls on date of observation.

Level datum from adjusted circuit of April 1937 run by U.S.B.R. from Grand Coulee Dam to International Boundary.

Table VI

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
OBSERVED WATER-SURFACE ELEVATIONS AT LITTLE DALLES
BY
U. S. BUREAU OF RECLAMATION
(U. S. B. R. DATUM)

Cross section	Obs. sta.	Nov. 9-16, 1936 Q = 25,000 s.f.	April 1, 1940 Q = 62,000 s.f.	April 30, 1940 Q = 95,000 s.f.	May 24, 1940 Q = 205,000 s.f.	June 7, 1940 Q = 240,000 s.f.
87	11		1256.5	1263.1	1281.6	1286.3
A		1247.7	1256.2	1263.1	1281.3	1286.3
B		1247.5	1256.4	1263.0	1281.3	1286.3
C		1247.0	1256.3	1263.0	1281.3	1286.3
D		1246.9	1256.3	1263.1	1281.3	1286.3
E		1246.9	1256.3	1263.0	1281.1	1286.4
F		1246.8	1255.4	1260.9	1281.1	1286.5
G		1246.8	1253.7	1259.3	1275.1	1279.9
H		1246.3	1253.8	1259.1	1274.9	1279.1
I		1246.2	1253.5	1258.6	1274.4	1278.0
J		1246.1	1253.7	1258.6	1272.9	1276.8
K		1246.0	1252.9	1257.5	1270.7	1272.9
L		1245.9	1252.9	1257.2	1270.5	1272.0
83 - M	13	1243.8	1249.8	1253.9	1264.9	1267.5

Notes: Discharges were obtained from the rating curve for Obs. Sta. 11.
Water-surface elevations were observed on left bank of river.

CHAPTER III - ANALYSIS OF FIELD DATA

27. Determination of value of n for natural flows. There are available about 50 water-surface profiles as well as cross sections of the river. The profiles were determined by water-surface elevations at the 4 major observation stations from 1930 on, supplemented by elevations taken at the 13 minor observation stations during 1935 and 1936. In determining values of n the first step was to plot rating curves (discharge versus elevation) for each major observation station. From these rating curves the differences of elevation between adjacent major observation stations were obtained, the stations involved being Nos. 2, 6, 11, and 13 (figure 1) proceeding downstream. These differences were plotted against corresponding discharges. The rating curves and the difference of elevation curves were then adjusted so that the sum of the differences between adjacent stations was equal to the total fall, as determined by the rating curves, between stations 2 and 13. These major observation stations, being of longer record, were used as a control for adjustment of the difference of elevation curves for minor observation stations which were similarly treated. There being no major station below station 13, just below the Little Dalles, minor stations between there and Kettle Falls were adjusted in the same way to minor observation station 17. This adjustment was necessary because of the dispersion of the points from which each curve was plotted.

After these curves were plotted, the value of n for each reach was computed for several values of the discharge and the values so determined were plotted against the discharge, giving curves from which the value of n for natural flow for any desired discharge in any reach could be determined.

28. Rating curves for major observation stations. Table III shows water-surface elevations and the discharges for major observation stations as determined on certain days. These data were used to construct the rating curve for each of these stations shown in figure 5, which curves are well defined up to a discharge of 420,000 second-feet. No difference can be detected in the rating curves for rising and falling stages of the river. This confirms the previous conclusion that it is unnecessary to correct the record for difference in time of observations and distance between stations.

Nine current meter measurements were made at the new gaging station located below the International Boundary about 6,000 feet downstream from major observation station 2, where the elevation of the water surface is measured. These data, table VIII, are plotted on the rating curve for this station. The points agree

very well with the curve as originally drawn when based only on the data from the observation station.

29. Difference in water-surface elevation between observation stations. Except in one or two cases, the sets of observations giving the water-surface levels at the observation stations were collected on the same day or at least on two consecutive days so that practically the same discharge was flowing in the river at any two neighboring stations when the elevations of the water surface were observed. Differences in water-surface elevations between major observation stations are shown by table IX and the data are plotted on figure 6. As with the rating curves, the curves for differences in water-surface elevations are well defined up to a discharge of 420,000 second-feet, the largest discharge for which measurements were made.

The river between major observation stations was divided into several reaches, either by minor observation stations or by points where river cross sections were taken. The minor observation stations were established by the Bureau of Reclamation in December 1935, and the data for these stations are shown by table VI. Rating curves were not drawn for the minor observation stations; instead, curves of the difference of elevation in each reach plotted against discharge were used since only this difference was needed for the calculation of the roughness coefficient. These curves of differences of water-surface elevation between successive minor observation stations were adjusted so that the total fall between major observations obtained from these curves agreed with that obtained from the rating curves previously drawn for the major observation stations. When these curves, figures 7 and 8, were completed, they defined accurately the difference in water-surface level within any reach for any discharge up to about 400,000 second-feet; also these curves were consistent with each other and with the rating curves obtained for the major observation stations.

30. Formulas used to determine energy loss. Field data were obtained only to medium flood stage and it is necessary to extend these data so that they will cover high flood stages, in order to obtain values of the roughness coefficient for all stages for later use in backwater computations. While various formulas for computing flow in open channels have been proposed, only two, Kutter's and Manning's, have been widely used, and all computations were based on one of these two formulas; values of n for natural flow were computed for each of them. The field data were carefully analyzed to give as accurate and true a picture as possible of conditions as they actually exist under natural flow conditions without the introduction of any safety factor.

31. Enlargement loss. There are several losses that occur in open-channel flow besides that due to friction, but no attempt was made to correct for any of these losses other than enlargement. Usually the change from kinetic to potential energy, which occurs during enlargement, involves a loss which is sometimes expressed by the formula

$$h_e = K_e \frac{V_2^2 - V_1^2}{2g}$$

For irregular river channels, the evaluation of the portion of the energy that is lost is very difficult. There are few data available as guides in selecting a value of K_e. The value of this factor increases where numerous whirls and eddies accompany the enlargement of the stream. A commonly used value of K_e is 0.50; however, values vary from 0.50 to 0.75. Because of the difficulty in selecting a proper value, Borda's formula for sudden enlargement was used:

$$h_e = \frac{(V_2 - V_1)^2}{2g}$$

For sudden enlargement this formula is theoretically correct, and its accuracy has been demonstrated by numerous experiments. It is doubtful if it is strictly applicable to the type of enlargement found in the river flow, yet, since no better formula has been found or developed, it is believed that its use is justified. Since the total energy loss is composed of enlargement and friction loss, the roughness coefficient will be smaller than it should be, if the enlargement loss is computed too large. When the backwater curve is computed, the error introduced, if any, is to some extent compensating if the same friction and enlargement loss formulas are used.

32. Computing the roughness coefficients for zone 4. Table XI is a sample computation sheet used for determining the roughness coefficient, by either the Manning or the Kutter formula, for zone 4 from the International Boundary, major observation station 2, to the head of the Little Dalles, major observation station 11. Computations are started at one of the major observation stations, which have rating curves, so that the water-surface elevation for any discharge is known; in this case 400,000 second-feet is used as an illustration. The roughness coefficients were computed for discharges of 20,000, 100,000, 200,000, 300,000, and 400,000 second-feet for all reaches of the river which had an observation station and a river cross located at both ends of the

reach. Figure 9 shows the cross sections at the lower and upper ends of a typical reach, section 96 to section 97, and also shows the curves that are developed and used in computing the roughness coefficient.

As noted on page 43 there were two observation stations in zone 4 that did not coincide with river cross sections, affecting four reaches arranged in pairs. In each pair, three observation stations are available, one at the upstream end of the upstream reach, one at the downstream end of the downstream reach, and one at an intermediate point. Sections are available at the two former and there is also a section within about 1,000 feet of the latter. Some adjustment is necessary in order to determine the roughness coefficient for these reaches. The intermediate river cross section might be assumed to be the same as that at the observation station and might be used as if it were located at the observation station; thus, a general idea of the roughness coefficient for each reach could be obtained. However, the river cross section may be much larger or smaller than the actual cross section at the observation station, in which case the velocity head is incorrectly computed and the energy gradient will be in error, causing the roughness coefficients to be incorrect. The total drop in water surface or in the energy gradient in each pair of reaches is definitely known. The difficulty is in dividing the loss in energy gradient between the two reaches.

A roughness coefficient was first computed, assuming the intermediate cross section and observation station to coincide. Then, using this coefficient, the water surface at the intermediate cross section was computed. The process was repeated until the computed water surface between sections, assumed as a straight line, passed through the known point at the intermediate observation station. When the elevation of the water surface at the intermediate cross section had been determined, the roughness coefficient for the other reach could be computed in the usual way. The drop in water surface between river cross sections instead of between observation stations was plotted from these computations and is shown on figure 8, for the two cases referred to.

33. Computing the roughness coefficients for zone 2. Below the Little Dalles, at the beginning of zone 2, the river widens and forms a natural pool in which the eddies, whirls, and turbulence originating in the Little Dalles are dissipated. As a result, the two reaches between sections 81 and 83 below the Little Dalles have higher values of the roughness coefficient than are normal for zone 2. The roughness coefficients for these two reaches were determined in the manner previously outlined for zone 4.

With the exception of these two reaches comprising 1.4 miles, the river flows smoothly in a uniform channel for 25 miles to Kettle Falls so that for zone 2, except for the upper 1.4 miles, the roughness coefficient may be regarded as constant for a given discharge. One major and five minor observation stations were located in zone 2. These were considered enough because of the uniform flow conditions and also because any error that might be made in the roughness coefficient would not materially affect the amount of backwater computed above the Little Dalles. Below the two reaches mentioned above (section 81 to section 83) there is a reach 19.1 miles long between minor observation stations 15 and 16 with twelve intervening cross sections at which water-surface elevations are unknown, except that approximate profiles are available for the low water flow of 18,000 second-feet and for the 1936 flood of 361,000 second-feet. Data for these profiles are shown in table XII. It was desired to use the twelve intervening cross sections to avoid having to depend only on the average of the two end sections for values of the area and hydraulic radius, but to do this it was necessary to know the water-surface elevation at each section. This was estimated as follows: The ratio of the drop between adjacent sections to the total drop in the reach was computed for the two approximately known profiles, and these ratios were applied to the known total drop between the observation stations to determine the water-surface elevation at each section. Having the approximate level of the water surface, the area and the hydraulic radius at each section were determined. Each cross section is assumed to be representative of the river channel for one-half the distance to adjacent cross sections. Accordingly, the velocity and the hydraulic radius of each section were multiplied by the ratio of the distance represented to the total distance (19.1 miles) and the products added to give mean values for the total reach. The total drop in water surface for the 19.1-mile stretch is known, and the total drop in energy gradient is computed. The enlargement losses, computed from the change in velocity between intervening river cross sections, are deducted from the total change in energy to give the over-all friction drop and thus the over-all friction slope "S". The coefficient C in the Chezy formula, $C = \frac{V_m}{\sqrt{R_m S}}$, may then be computed, and from the coefficient (C), the roughness coefficient (n) obtained by either the Manning or the Kutter formula. Coefficients for discharges of 20,000, 100,000, 200,000, 300,000, and 400,000 second-feet were computed. An alternative method would have been to assume a constant value of n for the 19.1-mile reach and, starting at one observation station with a known water surface to compute water surfaces at each successive cross section to the other observation station, arriving by trial and

error at a value of n which would give the known drop between observation stations. To check the value of n (0.037), obtained by the method used, the water-surface profile was computed for 400,000 second-feet for natural flow condition, using the alternative method and the resulting difference in water-surface elevation compared with that obtained from the rating curves and the difference in water-surface elevation curve, figure 8, which were accurate up to this discharge. The same value of n was obtained showing that this mean roughness coefficient gave satisfactory results. The coefficients for the 1.5-mile reach, below that just discussed, were computed from the data for observation stations 16 and 17 and approximately the same values of n were obtained as for the long reach.

Two of the observation stations were established in zone 2, one on each side of the present bridge at Marcus, but there were no river cross sections at or close to them; also, this bridge and its piers will be removed before backwater conditions are brought about, so the data from these observation stations were of very little practical use. Consequently, the value of n derived as just described was used for the whole of zone 2 except the two reaches just below the Little Dalles.

34. Computing the roughness coefficients for zone 3. The Little Dalles is divided into two physically different parts. That part which is below the cove (see figure 10), or river cross section L, has a fairly wide channel which is shallow and contains numerous rock reefs. The energy loss through this portion of the Little Dalles is much greater than in a normal channel but is not nearly as large as in the narrower portion of this zone. The portion above the cove, or section L, is very deep and narrow, having many changes in cross-sectional shape and size. The energy loss through this section is enormous. A check on the narrowest section of the Little Dalles reveals that at all discharges the velocity is less than critical.

In zone 3, from the foot to the head of the Little Dalles, there are 14 river cross sections and three observation stations. Two of the observation stations, 11 and 13, are located at the head and foot of the Little Dalles, coinciding with river cross sections. The third observation station is located in a cove on the left bank of the river where there are large eddies and whirls which interfere with obtaining mean water levels that are representative of this section of the river. There are no river cross sections located in the cove nor at the observation station; even if there were, they would be of very little value or use since they would not be representative of the river channel.

The determination of the roughness coefficient for the upper portion of the Little Dalles, section 87 to section L, is a difficult problem because there are 13 river cross sections and only two observation stations, one at each end of this reach. It might be thought that the roughness coefficient could be computed in the same way as was used for zone 2, by obtaining a mean velocity and a mean hydraulic radius for the multiple reach. If the friction slope and the size and shape of the channel cross section had been more nearly uniform, this method might have given satisfactory results, as it did in zone 2. It was concluded, however, that it was probable that a different value of the coefficient should be used for each reach between cross sections, but in the absence of water-surface elevations at each cross section, the determination of these coefficients was impossible. As the best approximation to this method available, for a given discharge, a constant value of the coefficient between observation stations was found which would give the energy loss which actually occurred. In order to do this, a roughness coefficient was assumed and the water surface computed in the usual way, subject, however, to the condition that the computed and observed water surfaces at the opposite ends of the reach must agree. If they did not, a new value of n was assumed and the process repeated.

Table XIII gives the computations for a discharge of 300,000 second-feet. Using an assumed roughness coefficient "n" of 0.217, the total drop in water surface from section 87 to section L is determined to be 15.73 feet. Since observation station 12 is between sections K and L, assuming the water-surface profile to be a straight line between these sections, the drop to observation station 12 is $15.73 - (\frac{260}{515}\ 2.63) = 14.40$, but from the rating curves, figure 5, it should be 14.09. Thus the assumed roughness coefficient is too large and, as shown at the bottom of table XIII, gives 0.31 foot of friction loss too much, or, correcting the tabular totals for the difference between stations 12 and L, the friction coefficient should be reduced to $\sqrt{\frac{13.06}{13.34}(0.217)^2} = 0.214+$. Since the value of the assumed coefficient is so close to the value of the correct one, it will not be necessary to make the computations with $n = 0.214$. A similar case was tried for $Q = 400,000$ second-feet and it was found that when the roughness coefficient used for the computations gave results less than 5 percent in error it was possible to compute the roughness coefficient in the manner outlined above.

The roughness coefficient for the lower portion of the Little Dalles, section L to section M, is now computed. The water-surface elevation is established at section L by correcting the drop in

water surface from section 87 to section L by the percent that this drop was in error when it was computed with the assumed value of $n = 0.217$ as shown by the notes at the bottom of the table. The water surface at section M, observation station 13, is found from its rating curve. Computations are then carried out in the usual manner to determine, first, C in the Chezy formula and then n in the Kutter formula. These computations are shown at the bottom of table XIII.

The roughness coefficient was computed for the two reaches of the Little Dalles in this manner for discharges of 20,000, 100,000, 200,000, 300,000, and 400,000 second-feet, and these values of Kutter's n for natural flow conditions are listed in table XIV.

35. Variation of roughness coefficients. An inspection of table XIV, giving the values of the roughness coefficient for zones 2, 3, and 4 computed from field data up to and including a discharge of 400,000 second-feet, shows that n for natural flow conditions is not a constant for any reach but that its value changes with the discharge. It is usually considered that for any channel with the same degree of roughness on the bottom as on the sides the roughness coefficient is constant. Four possible causes for this variation in n with the discharge are: first, the formula may not be correct, that is, the relation of the variables, namely friction, slope, hydraulic radius, and velocity may be improperly expressed by either formula used; second, some of the secondary losses such as contraction, enlargement, and bend loss may not have been properly accounted for and may have been included in the loss attributed to friction; third, the roughness of the sides may not be as great as that of the bed, or the roughness of the sides may decrease with elevation; and a fourth possible cause is the decrease in the ratio between the dimensions of the channel and those of the projecting points or protuberances of rock along the perimeter and the boulders which no doubt are present in the bottom of the channel. A further cause, but one not applicable to this river channel, is the scouring of the bed material, to which variations of n with discharge have been attributed by some.

The roughness coefficient "n", for each reach, was plotted against the discharge, figure 11. In nearly every case there was a decrease in "n" as the discharge increased. Where there is an exception to this condition, the reach is adjacent to the Little Dalles. The reach below the Little Dalles, section 83 to section 82, forms a sort of stilling basin for the eddies and whirls originating in the Little Dalles. These eddies increase in size and energy content with an increase in discharge, and when they dissipate themselves in this reach, all the energy that they contain is lost. This accounts for the increase of n with the increase in

discharge. The reach above the Little Dalles, section 87 to section 88, is affected by the island at the entrance to the narrow channel. It is believed that the local flow condition due to the presence of this island causes an incorrect measurement of the change in water-surface elevation between these two sections, resulting in an incorrect slope and consequent value of n which is too low at low flows; but that this effect disappears at higher discharges, causing the value of n to increase with discharge.

The variation of the roughness coefficient with the depth of flow in the river channel was studied. Several factors which were functions of the stage were suggested as ordinates against which the roughness coefficient could be plotted as abscissas. The average water surface in the reach seemed to be the most satisfactory factor, although the hydraulic radius and the wetted perimeter were also used. (See figures 12, 13, and 14.) One objection to using the hydraulic radius as the ordinate is that when a channel contains a shelf or bench, the hydraulic radius decreases when the stage rises above the elevation of the bench, so that there are two stages which give the same value of the hydraulic radius. This is well illustrated by section 96, shown in figure 9, where a minor channel on the left bank causes a marked decrease in the hydraulic radius at elevation 1337.0. This causes a break in the curve of average hydraulic radius for this reach. This break in continuity was troublesome, especially when trying to extrapolate the n curves. When the mean wetted perimeter was used as the ordinate for plotting the roughness coefficient, the resulting curve did not show any sudden break but did not give as satisfactory results as when the average water-surface elevation was used. The value of the roughness coefficient decreased with the increase of average water-surface elevation, wetted perimeter, and hydraulic radius for all reaches except those joining the Little Dalles, as previously discussed. Since the discharge is a function of the depth and the factors used as ordinates for the roughness coefficient curves are also functions of the depth; these curves are very similar in general shape to those obtained where the discharge was used as the ordinate, yet, when used in connection with backwater computations, they give different results.

36. Determination of water-surface profile for maximum flood. The largest flood for which water-surface elevations were obtained at any observation station was that of June 22, 1933, with a discharge of 420,200 second-feet at the Little Dalles. The maximum known flood was that of 1894 with an estimated discharge of 650,000 second-feet at the Little Dalles. Since it is necessary to compute backwater curves for discharges equal to or greater than the maximum known flood, the value of the roughness coefficient, n, should be known for natural flow conditions up to and including a discharge

of 650,000 second-feet or more. Also it is necessary to know the water-surface profile for maximum discharge under natural flow conditions, so that it may be used as a basis of comparison with the water-surface profile that will exist after the construction of Grand Coulee Dam.

There are three methods of estimating or computing the water-surface profiles for discharges above those which were accurately measured. These methods are: first, an extension of the roughness coefficient-discharge curves to a discharge of 650,000 second-feet and the use of these values of n to compute the water-surface profile with the extension of at least one rating curve; second, the extension of the curves showing the relation of difference in water surface to discharge, also with extension of at least one rating curve; third, the extension of the gage discharge or rating curves for all observation stations to cover the maximum flood. The application of these methods will usually result in slightly different profiles, yet, obviously there is only one correct profile for any discharge. This brings up the question of which method is the most reliable and accurate. Logically, a method which takes into account the greatest number of known variables should give better results than one which neglects factors which might affect the water-surface profile. The extensions of the difference in water-surface curve, or of the rating curves for all observation stations, beyond the last observed point probably give the least accurate results, since there is no method of taking account of the effect of changes in shape of the river channel above the highest observed water-surface profile.

With any method used, it is necessary to extend the rating curve for at least one of the observation stations in order to have a starting point. The change in water surface for the several reaches may then be computed by a friction-loss formula, having obtained the proper roughness coefficient by an extension of the n discharge curves. This method was considered the most reliable and was accordingly used, the results being checked by extending the difference in water-surface curves. Extensions of the rating curves at the major observation stations were used to make minor adjustments in the values of n. The rating curve or curves to be extended should be the most reliable available, with a maximum number of water-surface observations and taken at a section without abrupt changes in shape below high water. High-water marks of the 1894 flood aided in fixing accurately the extension of the rating curve for observation station 2 at the International Boundary and this curve was therefore used as one starting point.

The rating curves for all the major observation stations were extended, by logarithmic plotting as well as by two other methods.

The first of these was developed by J. C. Stevens (31) and is usually known as the $A\sqrt{R}$ method. The Chezy formula is $Q = AC\sqrt{RS}$; if $C\sqrt{S}$ is considered constant,

$$Q = \text{constant} \times A\sqrt{R}, \text{ or } Q = K_1 (A\sqrt{R})$$

which is the equation of a straight line when Q is plotted against values of $A\sqrt{R}$. The observed water-surface elevations at the observation stations are then used to determine the area and hydraulic radius from which the values of $A\sqrt{R}$ are computed and plotted against the corresponding discharges. See tables XV, XVI, XVII, and XVIII and figures 15, 16, 17, and 18 for examples of the extension of rating curves. If $C\sqrt{S}$ is not a constant the observed values of $A\sqrt{R}$ when plotted against discharge will not give a straight line but will show a slight curvature such as is evident for low discharges in the graphs. It is the property of the curve to become a straight line at high stages that makes its extension beyond the last observed point easy. The auxiliary curve of water-surface elevation versus $A\sqrt{R}$ is drawn beyond the upper limit of stage observations by computing the value of $A\sqrt{R}$ from the properties of the river cross section. It should be noted that this curve is determined only from the properties of the river cross section, entirely independent of the discharge, and can be plotted to an elevation equal to that to which the cross section is surveyed. To determine the water-surface elevation for any large discharge one enters the abscissa of the $A\sqrt{R}$ discharge curve, follows up vertically to this curve, moves horizontally with the determined value of $A\sqrt{R}$ until the water-surface elevation versus $A\sqrt{R}$ curve is encountered and then proceeds downward reading the water-surface elevation that corresponds to the discharge. The water surface is determined for several large discharges and the rating curve may then be extended.

Another common method of extending the rating curves is the mean-velocity method. The mean velocity is computed by determining the area from the river cross section corresponding to the observed water-surface level and then dividing the discharge by this area. Manning's formula is $V = \frac{1.486}{n} R^{2/3} S^{1/2}$. If n and S are considered constant, then $V = K' R^{2/3}$ or $K' = \frac{V}{R^{2/3}}$. The value of K' may be computed for each observed water surface and plotted against the water-surface elevation. See figures 15, 16, 17, and 18. The curve defined by these points usually approaches a vertical straight line for high

discharges and is therefore easy to extend with accuracy. If the discharge is desired for a high stage, K' is found from the extension of the curve, and R and A are found from curves constructed for the river cross section which are not shown on the figures. R, A, and K' are, of course, found for the same assumed high water surface. The mean velocity may be found from the formula $V = K' R^{2/3}$, and the discharge from $Q = AV$, or $Q = K' AR^{2/3}$ may be used to determine the discharge in one operation. Several high water-surface elevations are chosen, and the corresponding discharge is computed in the manner outlined above. The rating curve may now be extended through these computed points.

Figures 15, 16, 17, and 18 show the extension of the rating curves at the major observation stations by the two methods just described. The extension for observation station 2 at the International Boundary was very important, as it was used to establish the initial water surface from which to begin computations for the maximum flood profiles in zone 4. Also, this rating curve was used as a basis for measuring the amount of backwater or improvement caused by the operation of Grand Coulee Dam and the proposed channel improvement at the Little Dalles. The new U. S. Geological Survey station established at observation station 2 has confirmed the rating curve for discharges up to 255,000 second-feet. The high water of the 1894 flood at its peak is reported to have been at the floor level of the store as at present located, practically on the boundary line. The floor elevation of the store is 1345.8, and the water level at this point was probably the result of pondage entering from a point below the boundary and may have been somewhat lower than the water surface at the boundary. The water-surface elevation in the main channel of the river is estimated to have been at 1346.0. The discharge of the 1894 flood is estimated to have been 650,000 second-feet at the International Boundary. The rating curve is extended to this high water mark, see figure 15. This extension of the rating curve at 650,000 second-feet is about three-quarters of a foot higher than the extension of the rating curve by either the mean velocity or the $A\sqrt{R}$ method. The high water mark was well established as the storekeeper, who witnessed the 1894 flood, showed the survey party where the high water line had been, but the flood may have been underestimated; however, this extension is used hereafter in this report. It will be later demonstrated that had one of the lower extensions been used, either the amount of backwater or the lowering in stage at the International Boundary due to channel improvement would have been nearly the same.

The data for major observation station 13 at the foot of the Little Dalles gave a better-defined rating curve than those for any other station and the extension of its curve is consequently the most accurate and the least likely to be in error. Figure 18 shows the extensions of this rating curve by both methods which differ by less than a quarter of a foot for a discharge of 650,000 second-feet. Water-surface elevations were taken from this curve to compute the maximum flood water-surface profile for zones 2 and 3.

The extension of the rating curve at observation station 11, head of the Little Dalles, figure 17, was uncertain because of the influence of backwater from the Little Dalles. High water marks at the town of Northport, 5.5 miles upstream indicated that for a discharge of 650,000 second-feet the water surface at the observation station should be at about elevation 1324.4; however, extension of the rating curve by both methods used gave water-surface elevations 3 to 5 feet higher than this. The profile of the water surface computed from the reliable rating curve at observation station 13, the foot of the Little Dalles, indicated a water-surface elevation at observation station 11 of 1327.5; since one of the extensions checked this figure, this extension was adopted; later model tests gave a curve perhaps a foot lower at maximum flood flow (see figure 44).

The extension of the rating curve at major observation station 6, figure 16, was used only as a check on water-surface profiles computed from the extension of the n versus discharge curves. The river cross section at this observation station shows a shelf at elevation 1305.0 which causes a break in the curves at this point and illustrates the danger of attempting to extend a rating curve without considering the properties of the river cross section.

To find the roughness coefficient, n, for each reach that was applicable to the natural flow with maximum discharge, the curve of n versus discharge was extended on logarithmic paper. By plotting the curves for each reach on this paper, they were somewhat straightened out, and also the extension was shorter than it would have been on natural coordinate paper. These curves are shown on figure 11. For natural flow conditions it is believed that n varies more properly with discharge than with stage, hence, no attempt was made to determine values of n by extending the curves of n plotted against mean water-surface elevation, wetted perimeter or hydraulic radius; however, after the adjusted values of n were obtained for the maximum flood, they were plotted on these curves as a check to ascertain if any sudden breaks in curvature were caused by the use of the extrapolated values. See figures 12, 13, and 14.

To compute the water-surface profiles for zone 3 for flows higher than those observed, the initial water-surface elevation was taken from the extended rating curve for observation station 13, foot of the Little Dalles, and for zone 4 the initial water surface was taken from the extended rating curve for observation station 2, International Boundary. The values of the roughness coefficient n found from the extension of the n versus discharge curves were used for each reach, and computation proceeded upstream or downstream using a trial-and-error method to determine the energy loss, composed of friction loss and sometimes enlargement loss. Computations were similar to those shown on tables XIII and XXII. The water-surface change or difference in elevation for each reach was plotted on the curve of difference of water-surface elevation versus discharge, to insure that the extensions of these curves were consistent with the computed values of difference of water-surface elevation (see figures 7 and 8). The rating curves at observation stations 6 and 11 were used to check the computed water-surface profiles. Some adjustments had to be made in the extensions of the n versus discharge curves, and the extensions of the rating curves at observation stations 11 and 6 were also changed so that they would be in agreement with each other. After all adjustments were completed, a water-surface profile was obtained which was consistent and in agreement with the several curves and was believed to be more likely to be correct than if determined by only one of the methods given on page 64. All water-surface profiles at and below the highest observed discharge for which field data are available are in agreement with these curves, namely, the rating curves at major observation stations, the change in water-surface curves and the n discharge curves for the various reaches; investigations have indicated that computed water surfaces which are consistent with reasonable extensions of all three of these curves must be uniquely determined for all practical purposes. The values of n for each reach used in the extensions of the curves, for discharges of 500,000 and 650,000 second-feet, are listed in table XIV. Careful analysis and computation of natural water-surface profiles were very necessary, for all backwater computations had to be based on the roughness coefficients obtained and the amount of all backwater measured from these water-surface profiles.

37. Maximum flood probability. The highest flood of which there is an authentic record is that of June 1894. This flood was caused by the unusual simultaneous occurrence of hot weather on the watersheds of the Snake River and the Upper Columbia River, combined with an exceptionally heavy snow cover. The highest stage of the flood was recorded on June 6 at Cascade Locks, and, by rating curves later prepared, the discharge was estimated as

1,160,000 second-feet. The peak discharge of this flood at Grand Coulee Dam has been estimated by both the Army Engineer Corps and the Geological Survey as 725,000 second-feet. Some of the water-supply papers of the Geological Survey give the discharge for this flood at Kettle Falls as 700,000 second-feet "based on information from several sources." The maximum discharge of the Kettle River at Laurier for a 9-year period (1929 to 1938) is given as 23,800 second-feet on June 17, 1933. It may well be that the discharge of the Kettle River was much higher and that Sheep Creek and Deep Creek contributed enough so that the flood peak of the 1894 flood was reduced to 650,000 second-feet at the International Boundary. However, a more probable distribution of the flood discharge is that the 725,000 second-feet estimated peak at Grand Coulee was made up of 50,000 second-feet from the Spokane River and 25,000 second-feet from the Kettle River, thus leaving the discharge of 650,000 second-feet in the Columbia River above the mouth of the Kettle River. While the estimate of the 1894 flood of 650,000 second-feet at the International Boundary may be questionable, it is believed to be the best that can be obtained. Table XIX gives the maximum discharge of the Columbia River at The Dalles, Oregon, and at Kettle Falls, Washington, for each year from 1858 to date.

The records of the annual flood peaks for the past 82 years (1858-1939, inclusive) at The Dalles, Oregon, were analyzed in accordance with the methods outlined by H. Alden Foster (37), and the results are plotted on probability paper, figure 19(a). The computed coefficient of skew is 0.3 and this curve, shown dotted on figure 19(a), approximates the plotted points fairly well with the exception of the point for the 1894 flood. Foster recommends the use of a coefficient of skew equal to twice the coefficient of variation which in this case is 0.28. The use of a coefficient of skew of 0.5, slightly less than twice the coefficient of variation, gives a curve which comes much closer to the point for the 1894 flood. This curve shown as a solid line, figure 19(a), has been adopted. The ratios of the maximum annual flood at Grand Coulee to that at The Dalles for the years of record at Grand Coulee, 1913 to 1939, inclusive, are plotted on figure 19(b). There is quite a dispersion of the points, but it is possible to draw a curve which will approximate the relation. On figure 19(a) directly below the corresponding discharges at The Dalles are plotted the discharges at Grand Coulee for those years of flood record. By means of these points and the relation between maximum annual flood at Grand Coulee and that at The Dalles the duration curve is drawn for Grand Coulee Dam.

The available flood record at Grand Coulee for the past 27 years (1913-1939, inclusive) was also analyzed by the Foster

method, figure 19(c), but because of the shortness of the record and because the past 27 years have been very dry when compared with the 82-year record at The Dalles, this duration curve does not give results as high as those obtained from the longer record at The Dalles. This curve is not as conservative as that obtained from data for The Dalles.

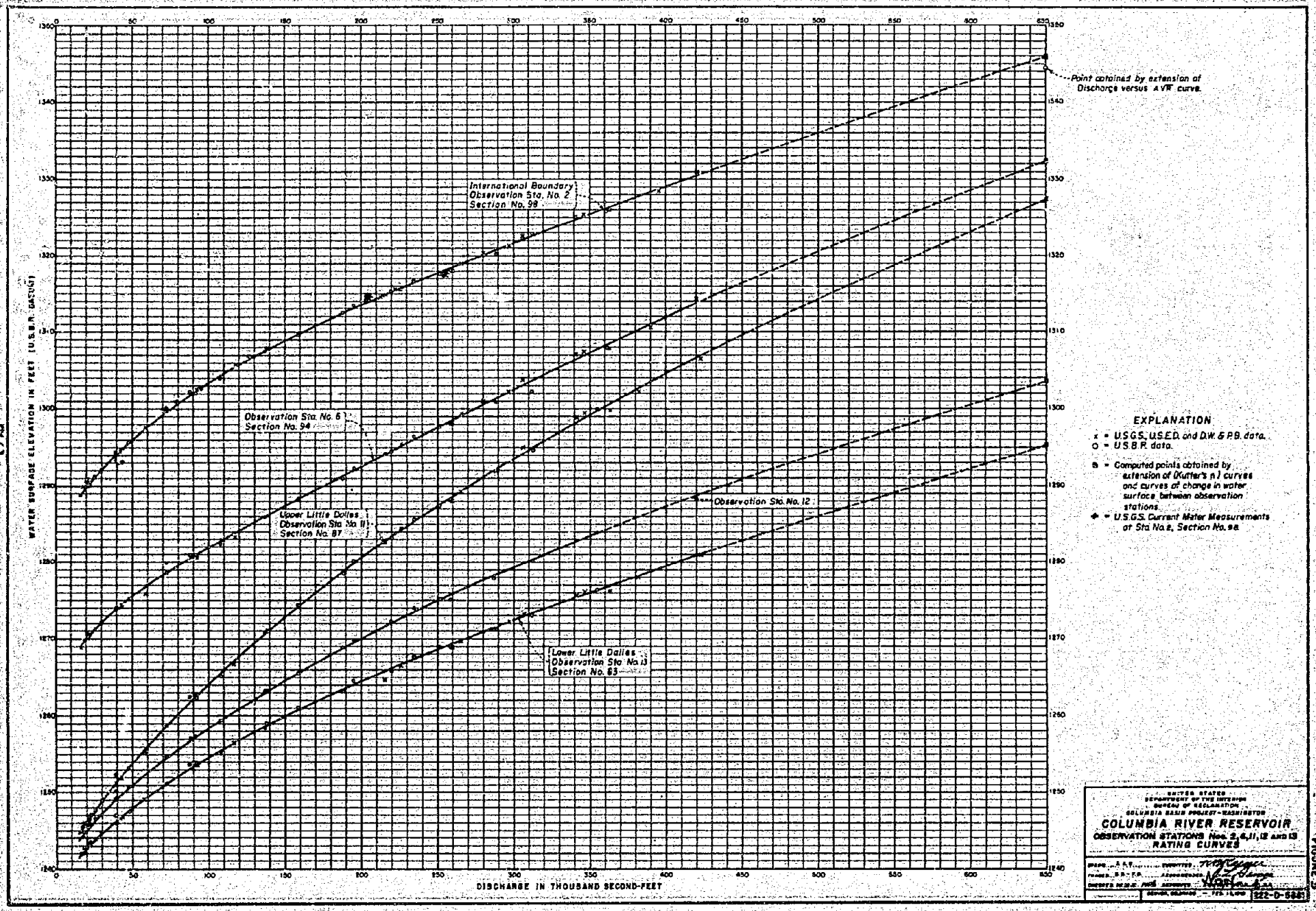
A study was made of the relation between the discharge at the Little Dalles or International Boundary and that at Grand Coulee. It was found that on a basis of annual run-off the discharge at the Little Dalles was about 90 percent of that at Grand Coulee. Further studies showed that the ratio of discharge at the Little Dalles to that at Grand Coulee varied with the season of the year, being as low as 0.70 in the early spring and as high as 0.98 in the late summer and early fall; however, when only the annual flood peaks were considered the ratio was about 0.94. This ratio of 0.94 and the previously described probability studies were used to construct the flood duration table XX. on page 132

The duration curves, figures 19(a) and 19(c), can be extended to the left indefinitely, whereas there probably is a definite limit beyond which it should not extend. This limit is unknown and the maximum flood at the Little Dalles might reach a magnitude greater than the 1894 flood estimated at 650,000 second-feet; however, this flood was the largest experienced since the country was settled by the white men. To consider a discharge in the river larger than the 1894 flood would require extrapolation of the rating curves, roughness coefficient curves, and difference in water-surface curves so far beyond the last observed points that their accuracy would be very doubtful. Probably as accurate a result can be obtained by taking the computed amounts of backwater at the International Boundary, plotting the curve of backwater versus discharge, and extending this curve to the magnitude of the desired flood (figure 63). The trend of this curve is such as to give less backwater for higher flood discharges (indicating no backwater for floods over 800,000 second-feet), so there is very little interest in the water-surface profiles for higher floods.

The magnitude of the flood peak may be taken as the maximum rate at which water would have to be discharged at Grand Coulee Dam. The reason for this is that the hydrographs of the Columbia River at Grand Coulee, figure 4, have no sharp peaks from flash floods; the maximum flow occurs after the passage of about one-third of the flood run-off due to melting snow, and the flow increases gradually from day to day for 20 to 30 days until the peak flow is reached. Such a flood has tremendous volume and, by comparison, the volume of reservoir storage is very

small. By the time the peak inflow of a flood occurs, the reservoir will be full and discharging over the spillway and there will be very little difference in the rates of inflow and outflow in the reservoir. For very large floods extending over a period of 80 days, as do all large floods analyzed, the reduction in peak discharge in passing through the reservoir is only about 2 percent.

To determine the elevation of ordinary highwater at the International Boundary it is necessary to determine the magnitude of the normal maximum annual flood. The actual record of flood flow at the International Boundary is too short to be of use, so the record at Kettle Falls adjusted so as to be applicable to the International Boundary is used. On figure 20 are plotted the maximum annual flood discharges of the Columbia River at Kettle Falls for the period 1913 to 1939, and directly below the corresponding discharges at Kettle Falls are plotted the computed discharges at the Little Dalles for the years 1930 to 1939, inclusive (records available of Kettle River discharge at Laurier since 1930). The curve defined by these points is applicable to the Columbia River anywhere above the Kettle River and below the Clark Fork. The normal maximum annual flood is determined by the point of inflection on this duration curve, which in this case occurs at 45 percent of the total time, giving a discharge of 345,000 second-feet. At the International Boundary this discharge corresponds to water-surface elevation of 1325.0, which, on the basis of the 27-year record, is the stage which most probably will be reached or exceeded by the annual flood and hence may be termed the ordinary high water mark at this point. If the longer flood record at The Dalles, Oregon, for the past 82 years (1858-1939, inclusive) had been used, the normal maximum annual flood would have been about 355,000 second-feet, because the years 1913 to 1939 have been drier than the years 1858 to 1913.


WATER SURFACE ELEVATION IN FEET (U.S.B.R. DATUM)
DISCHARGE IN THOUSAND SECOND-FEET
Point obtained by extension of Discharge versus AVR curve.
International Boundary
Observation Sta. No. 2
Section No. 98
Observation Sta. No. 6
Section No. 94
Upper Little Dalles
Observation Sta. No. 11
Section No. 87
Observation Sta. No. 12
Lower Little Dalles
Observation Sta. No. 13
Section No. 83
EXPLANATION
x = U.S.G.S., U.S.E.D. and D.W. & P.B. data.
o = U.S.B.R. data.
■ = Computed points obtained by extension of (Kutter's n) curves and curves of change in water surface between observation stations.
◆ = U.S.G.S. Current Meter Measurements at Sta. No. 2, Section No. 98.
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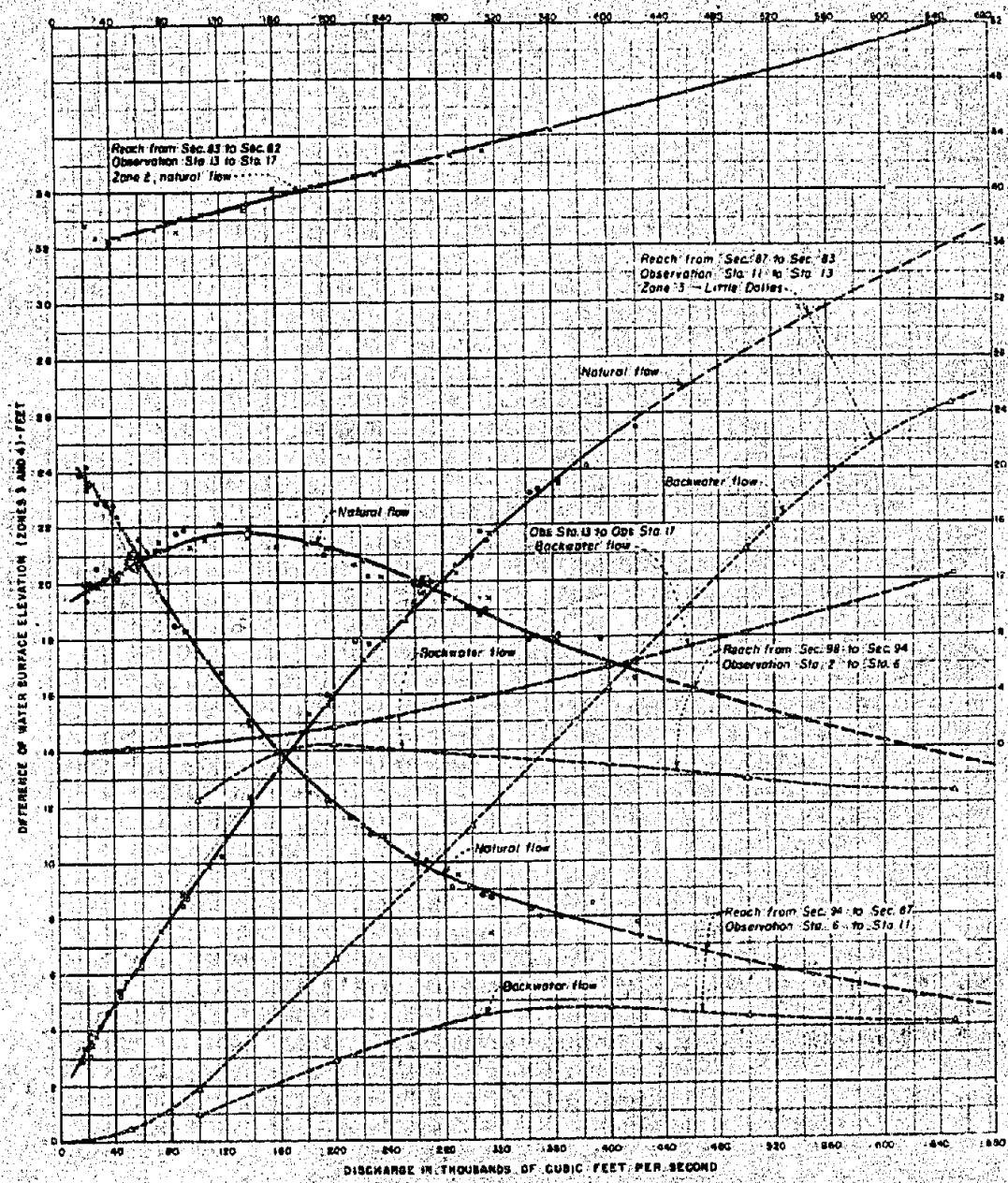
COLUMBIA BASIN PROJECT-WASHINGTON
COLUMBIA RIVER RESERVOIR
OBSERVATION STATIONS Nos. 2, 6, 11, 12 AND 13
RATING CURVES
222-D-5881

FIGURE 15

FIGURE 6



EXPLANATION

o-From observations made by U.S. Geological Survey, Dominion Water and Power Bureau of Canada and U.S. Army Engineering Corps

x-From observations made by U.S. Bureau of Reclamation.

△-From computations for unimproved channel, for reservoir W.S. El 1290.0 at dam, and using natural flow n's.

□-From computations for reservoir W.S. El 1290.0 at dam.

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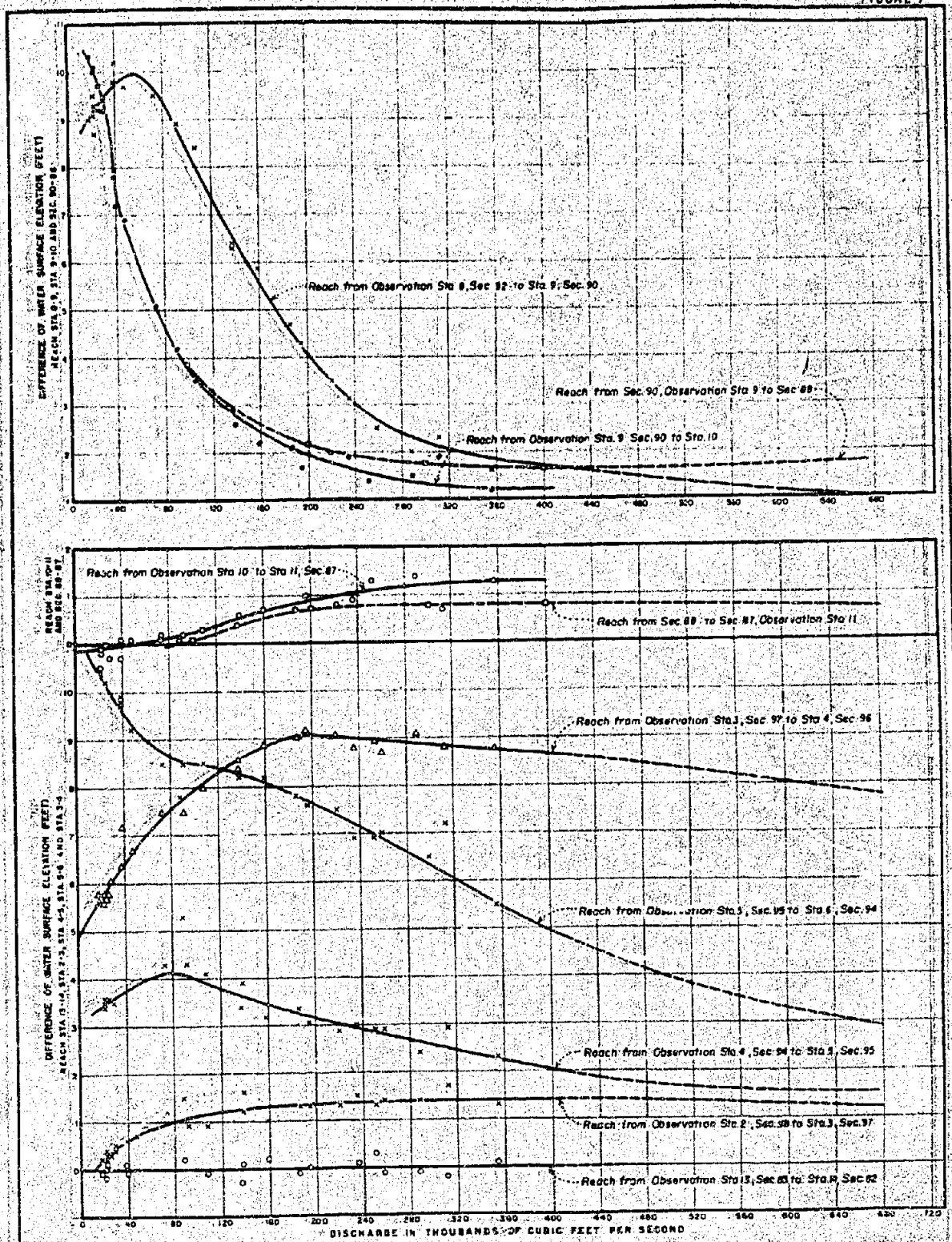
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
DIFFERENCE OF WATER SURFACE ELEVATION
BETWEEN MAJOR OBSERVATION STATIONS

FIGURE 7



EXPLANATION

X ✱, O, Δ From observations made by Bureau of Reclamation, natural flow.

—□— Difference of water surface elevation between river cross-sections computed from difference of water surface elevation that existed between observation stations, natural flow.

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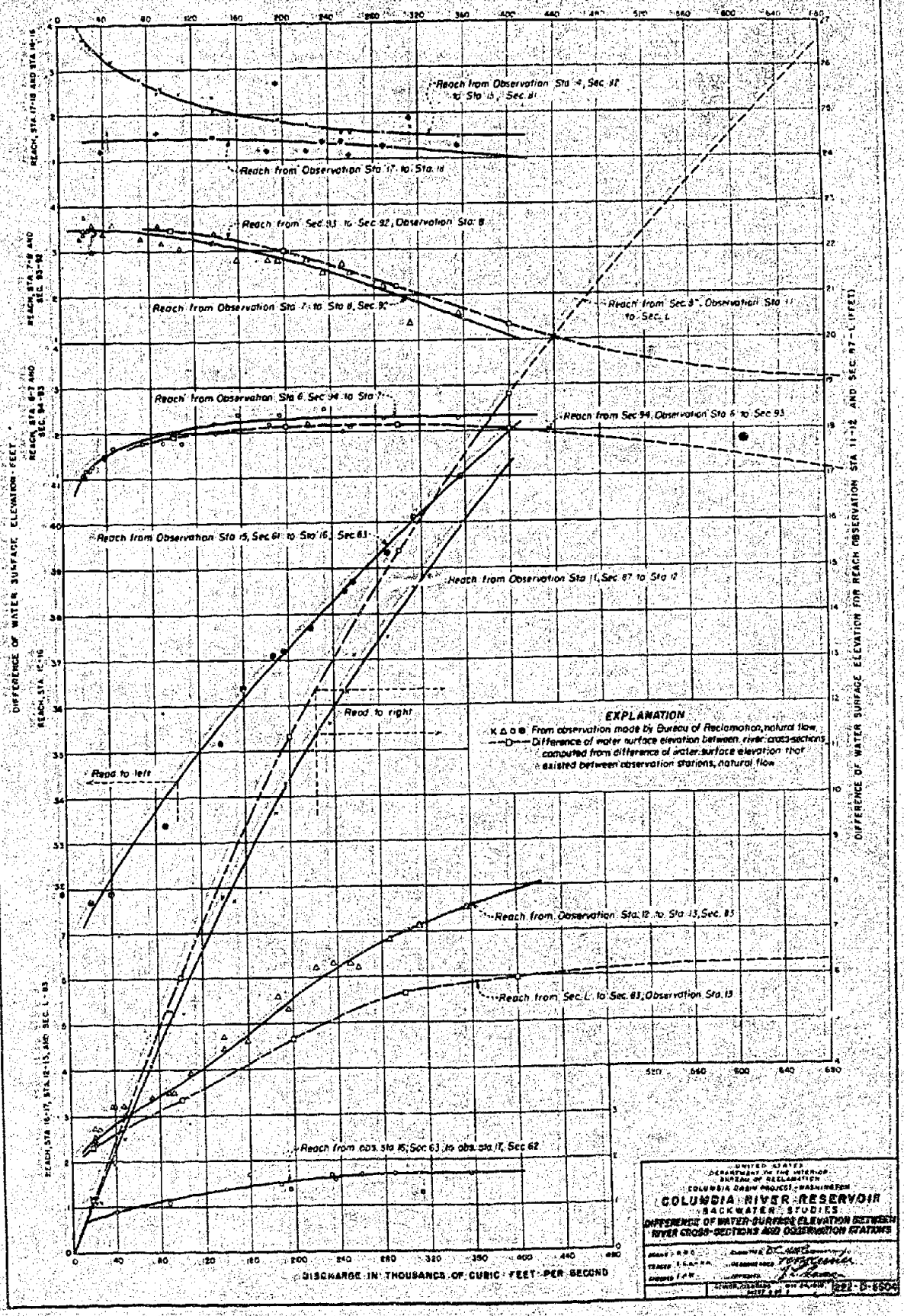
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
DIFFERENCE OF WATER-SURFACE ELEVATIONS BETWEEN RIVER CROSS-SECTIONS AND OBSERVATION STATIONS

FIGURE 8


Reach from Observation Sta 4, Sec 87 to Sta 15, Sec 81
Reach from Observation Sta 17 to Sta 18
Reach from Sec 93 to Sec 92, Observation Sta 8
Reach from Observation Sta 7 to Sta 8, Sec 92
Reach from Sec 8, Observation Sta 11 to Sec L
Reach from Observation Sta 6, Sec 94 to Sta 7
Reach from Sec 94, Observation Sta 6 to Sec 93
Reach from Observation Sta 15, Sec 61 to Sta 16, Sec 83
Reach from Observation Sta 11, Sec 87 to Sta 12
Read to right
Read to left
EXPLANATION
From observation made by Bureau of Reclamation, natural flow
Difference of water surface elevation between river cross-sections computed from difference of water surface elevation that existed between observation stations, natural flow
Reach from Observation Sta 12 to Sta 13, Sec 83
Reach from Sec L to Sec 83, Observation Sta 13
Reach from obs. sta 16, Sec 63 to obs. sta 17, Sec 62
DIFFERENCE OF WATER SURFACE ELEVATION - FEET
DIFFERENCE OF WATER SURFACE ELEVATION FOR REACH OBSERVATION STA 11-12 AND SEC. 87-L (FEET)
DISCHARGE IN THOUSANDS OF CUBIC FEET PER SECOND
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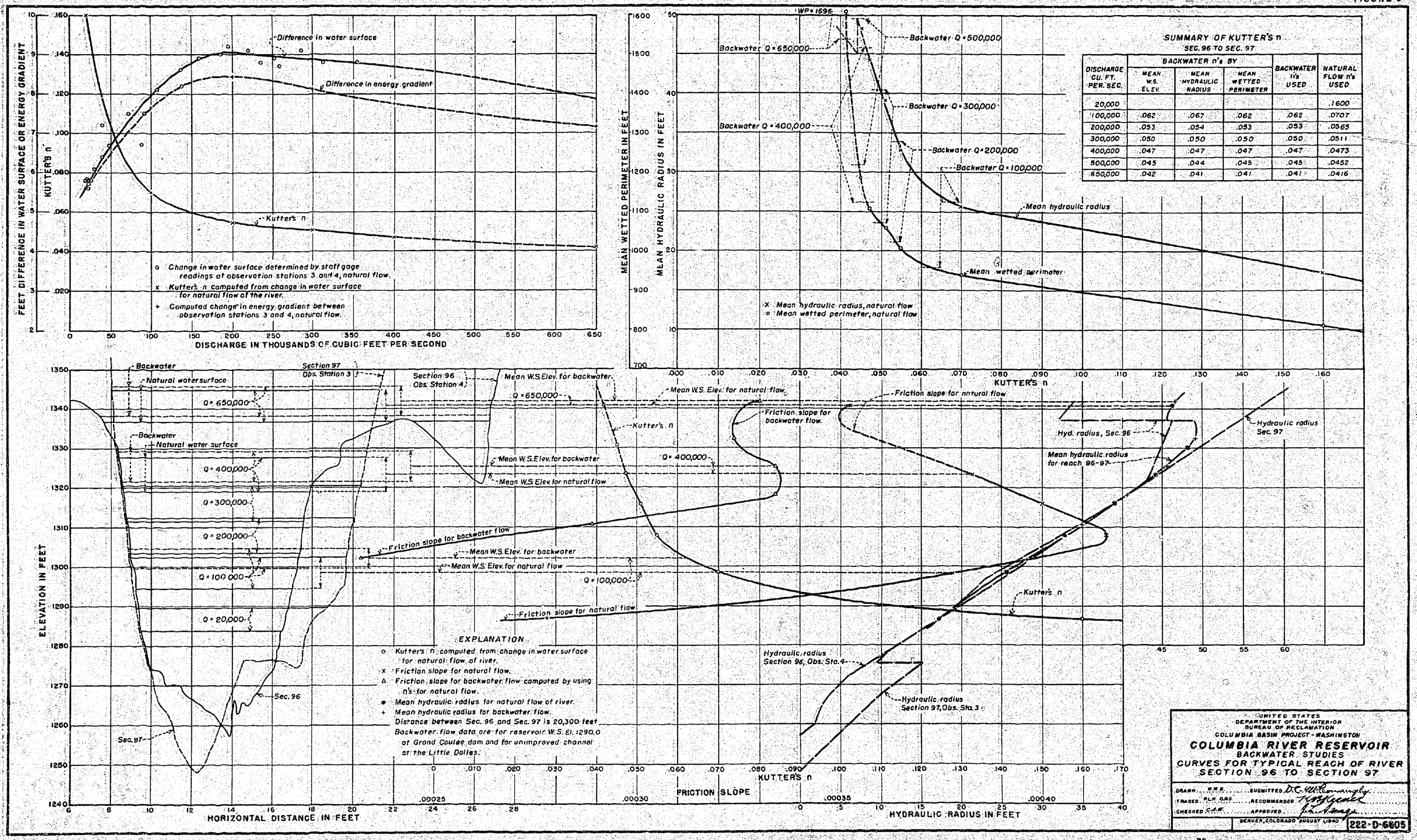
COLUMBIA BASIN PROJECT, WASHINGTON
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
DIFFERENCE OF WATER-SURFACE ELEVATION BETWEEN RIVER CROSS-SECTIONS AND OBSERVATION STATIONS

FIGURE 9



SUMMARY OF KUTTER'S n
SEC. 96 TO SEC. 97

DISCHARGE CU. FT. PER. SEC.	BACKWATER n's BY			BACKWATER n's USED	NATURAL FLOW n's USED
	MEAN W.S. ELEV.	MEAN HYDRAULIC RADIUS	MEAN WETTED PERIMETER		
20,000					.1600
100,000	.062	.067	.062	.062	.0707
200,000	.053	.054	.053	.053	.0565
300,000	.050	.050	.050	.050	.0511
400,000	.047	.047	.047	.047	.0473
500,000	.045	.044	.045	.045	.0452
650,000	.042	.041	.041	.041	.0416

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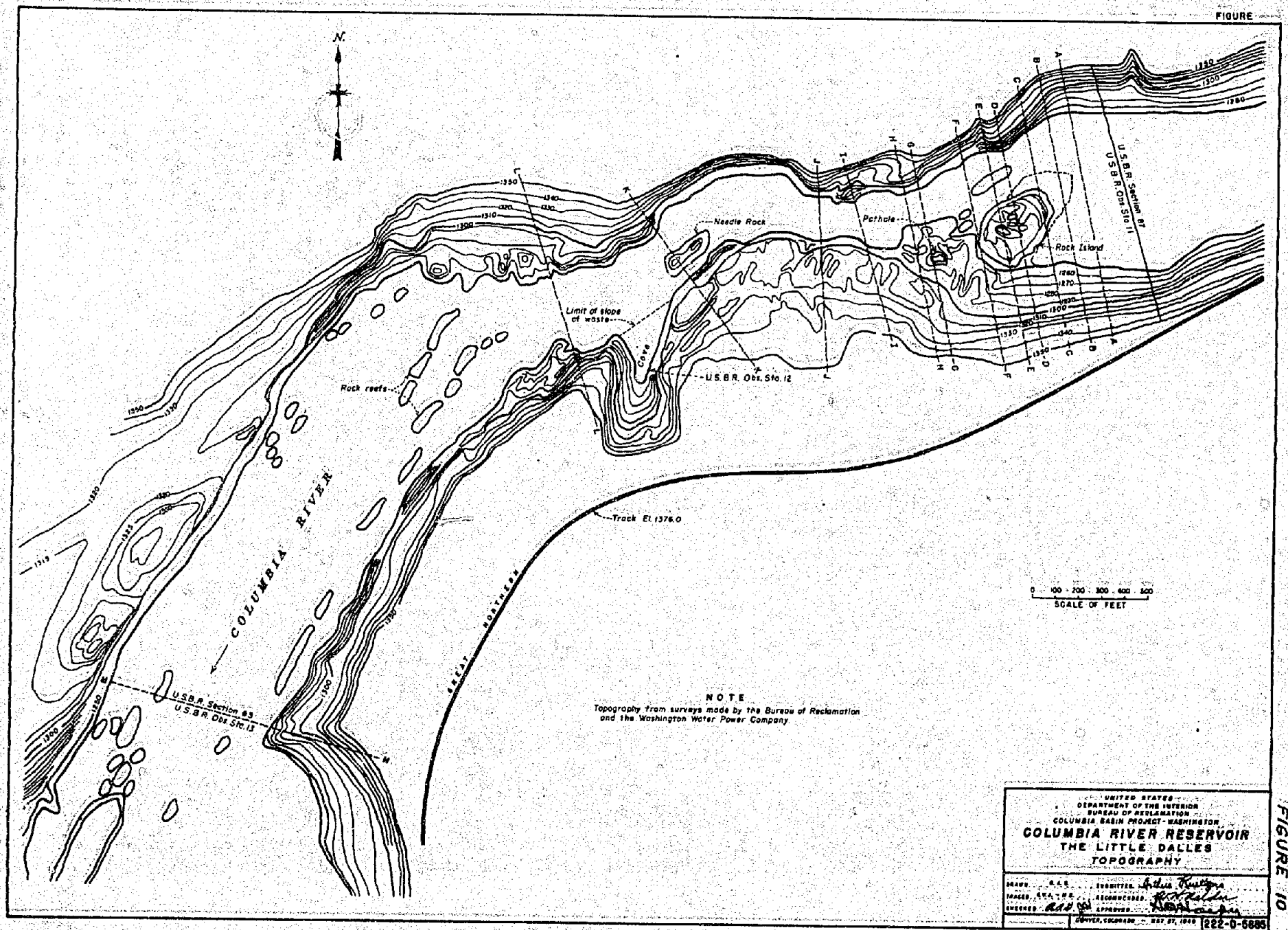
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
CURVES FOR TYPICAL REACH OF RIVER
SECTION 96 TO SECTION 97

DRAWN W.R.B. SUBMITTED D.C. McKinney
TRACED R.L.H. G.R.S. RECOMMENDED T.G. Peake
CHECKED C.A.W. APPROVED J.L. Savage
DENVER, COLORADO AUGUST 1940 222-D-6605

FIGURE



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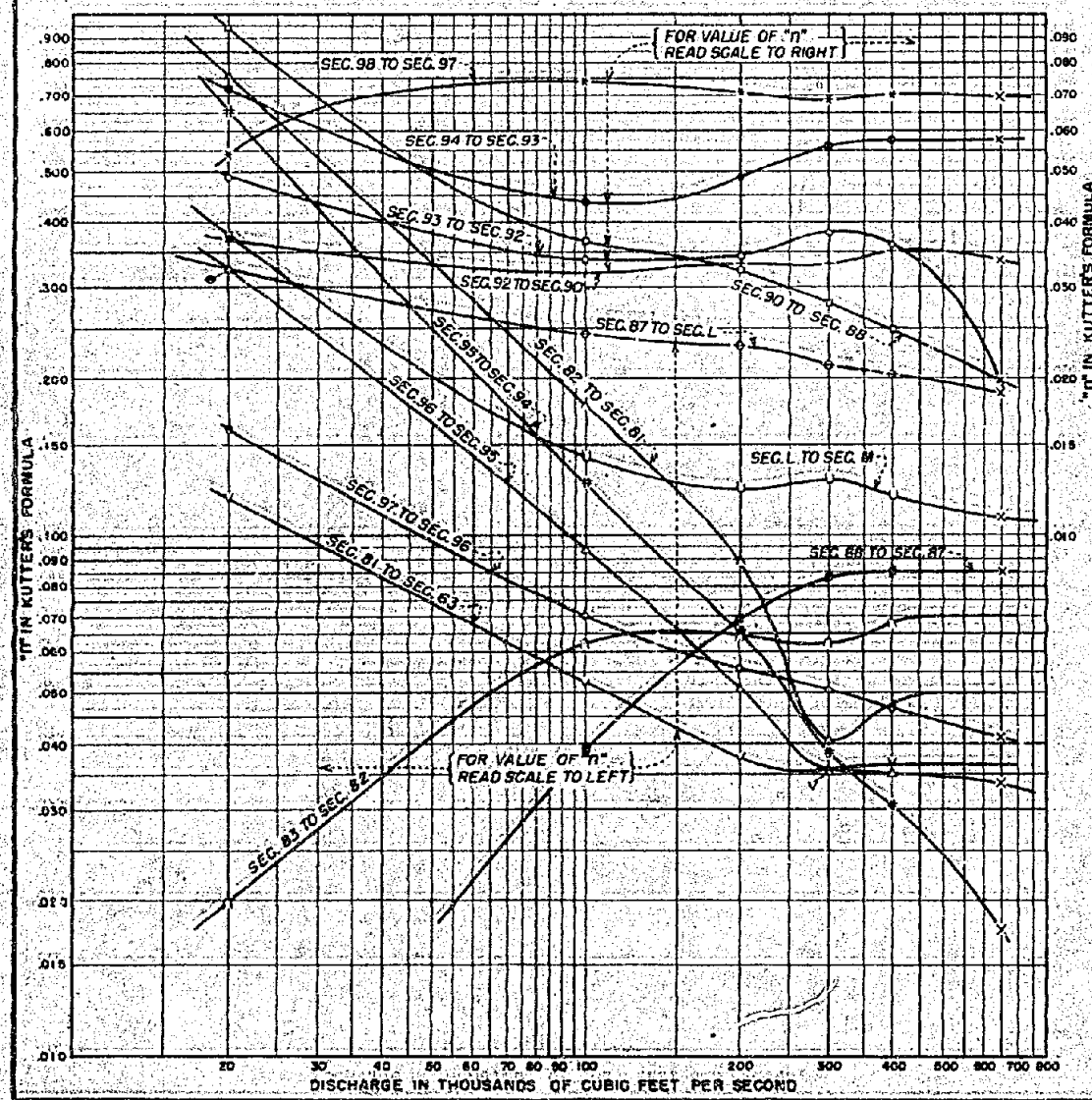
COLUMBIA BASIN PROJECT - WASHINGTON

COLUMBIA RIVER RESERVOIR
THE LITTLE DALLES
TOPOGRAPHY

DRAWN H.K.S. SUBMITTED Arthur Kuttger
TRACED E.K.T.R.E. RECOMMENDED
CHECKED RAP APPROVED
DENVER, COLORADO — OCT. 27, 1948 222-D-5885

FIGURE 10



EXPLANATION

x Indicates value of "n" used to compute water surface for natural flow of 650,000 sec. ft.

SYMBOL	REACH			
	OBSERVATION STATION		RIVER CROSS-SECTION	
	FROM	TO	FROM	TO
✱	2	3	98	97
○	3	4	97	96
△	4	5	96	95
✱	5	6	95	94
⊗	6	–	94	93
◇	–	8	93	92
+	8	9	92	90
□	9	–	90	88
Ø	–	11	88	87
⊖	11	–	87	L
∪	–	13	L	M-83
∩	13	14	83	82
∧	14	15	82	81
∨	15	16	81	63

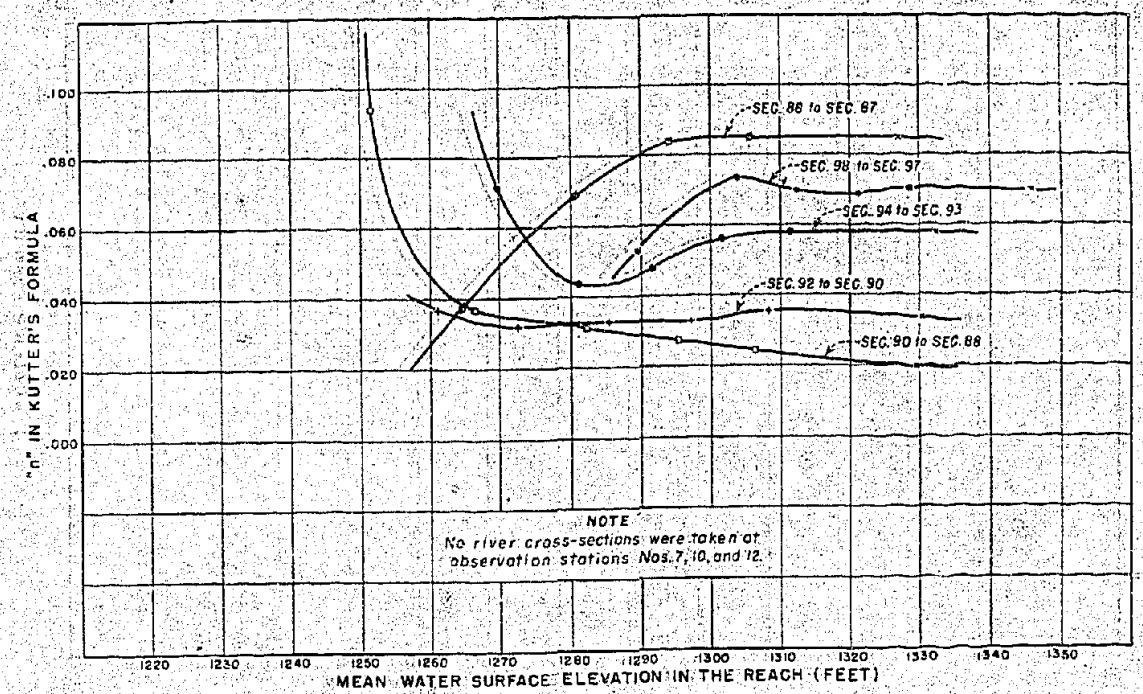
No river cross-sections were taken at observation stations Nos. 7, 10 and 12.

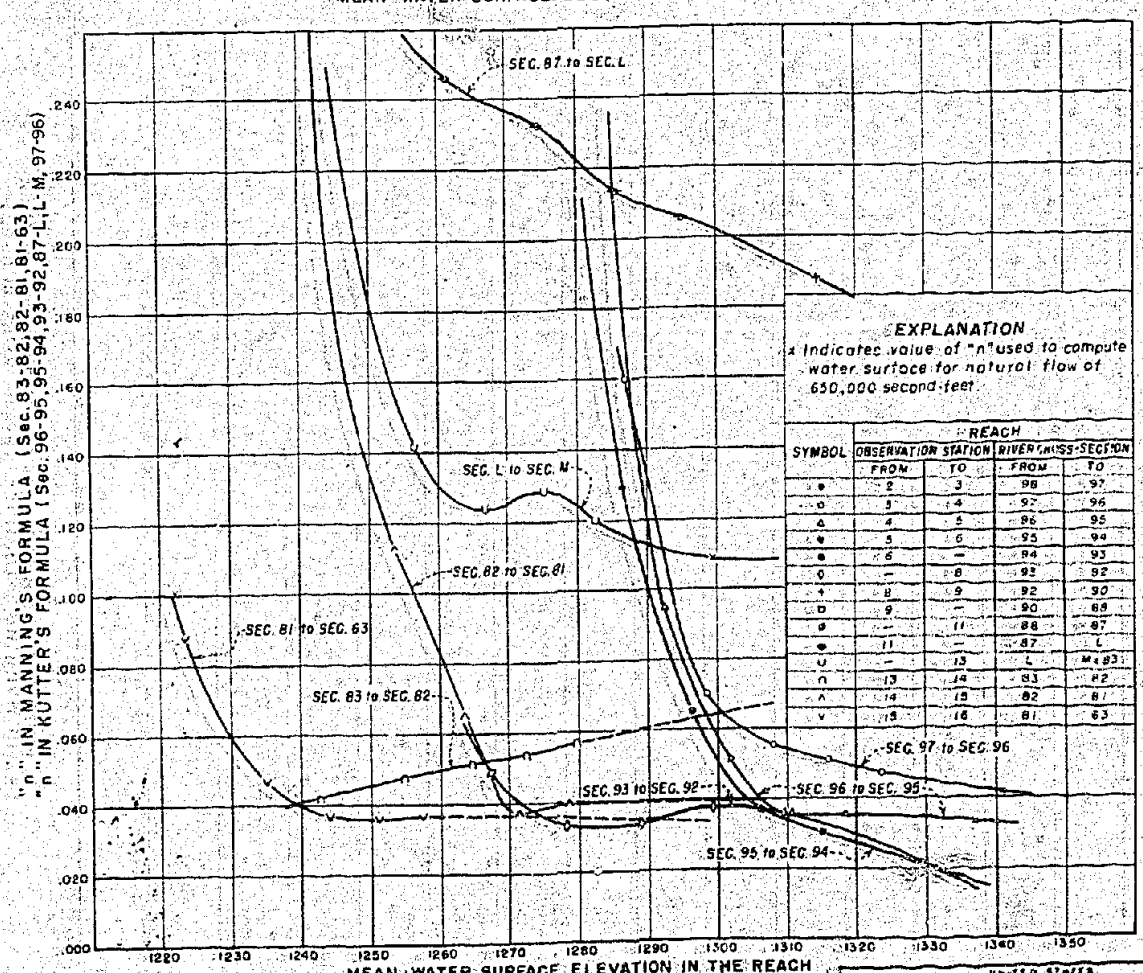
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
DISCHARGE - n CURVES
KETTLE FALLS TO INTERNATIONAL BOUNDARY
W.M.B. 3-9-40

222-D-6892

FIGURE 11

FIGURE 14





EXPLANATION

x Indicates value of "n" used to compute water surface for natural flow of 650,000 second-feet

SYMBOL	REACH: OBSERVATION STATION FROM	OBSERVATION STATION TO	RIVER CROSS-SECTION FROM	RIVER CROSS-SECTION TO
●	2	3	98	97
○	3	4	97	96
△	4	5	96	95
▲	5	6	95	94
■	6	—	94	93
◇	—	8	93	92
+	8	9	92	90
□	9	—	90	88
⊕	—	11	88	87
●	11	—	87	L
∪	—	13	L	M & 83
∩	13	14	83	82
∧	14	15	82	81
∨	15	16	81	63

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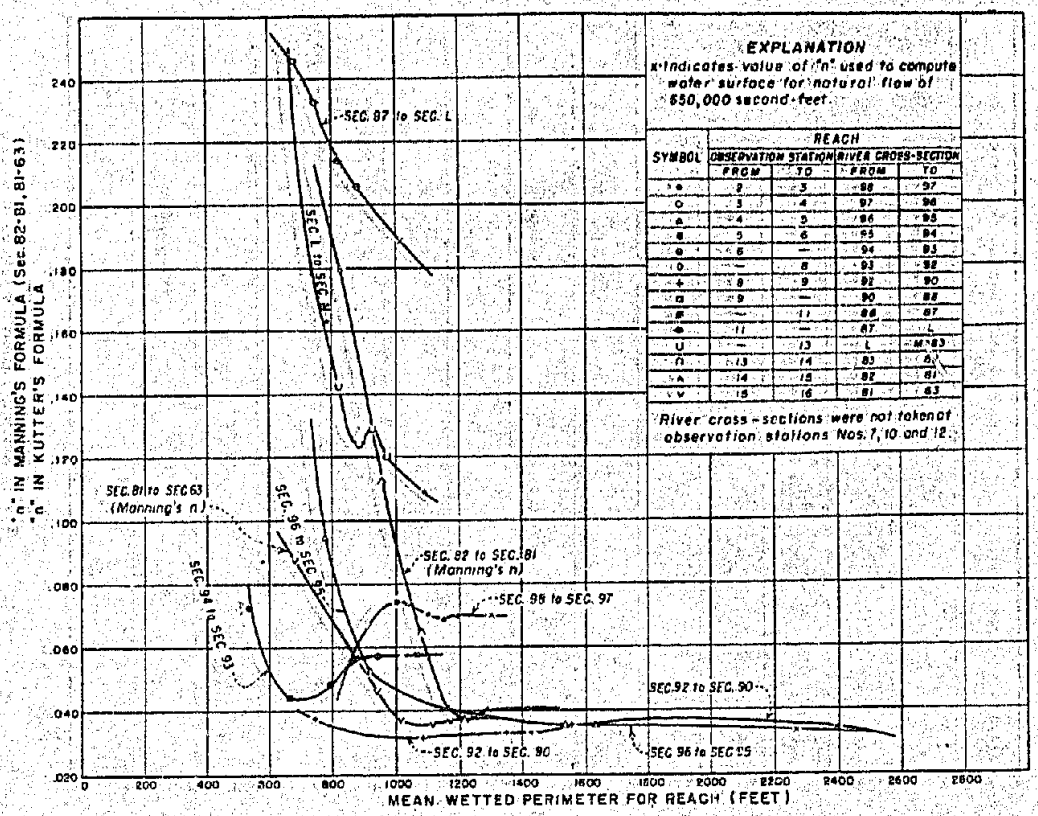
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
MEAN WATER SURFACE ELEVATION — "n" CURVES
KETTLE FALLS TO INTERNATIONAL BOUNDARY

DRAWN W.H.B. SUBMITTED D.C. McKenney
TRACED G.J.J. & W.A.S. RECOMMENDED T. Vanderpool
CHECKED G.A.W. APPROVED J. L. Savage
DENVER, COLORADO, OCT. 22, 1948
222-D-6305

FIGURE 15

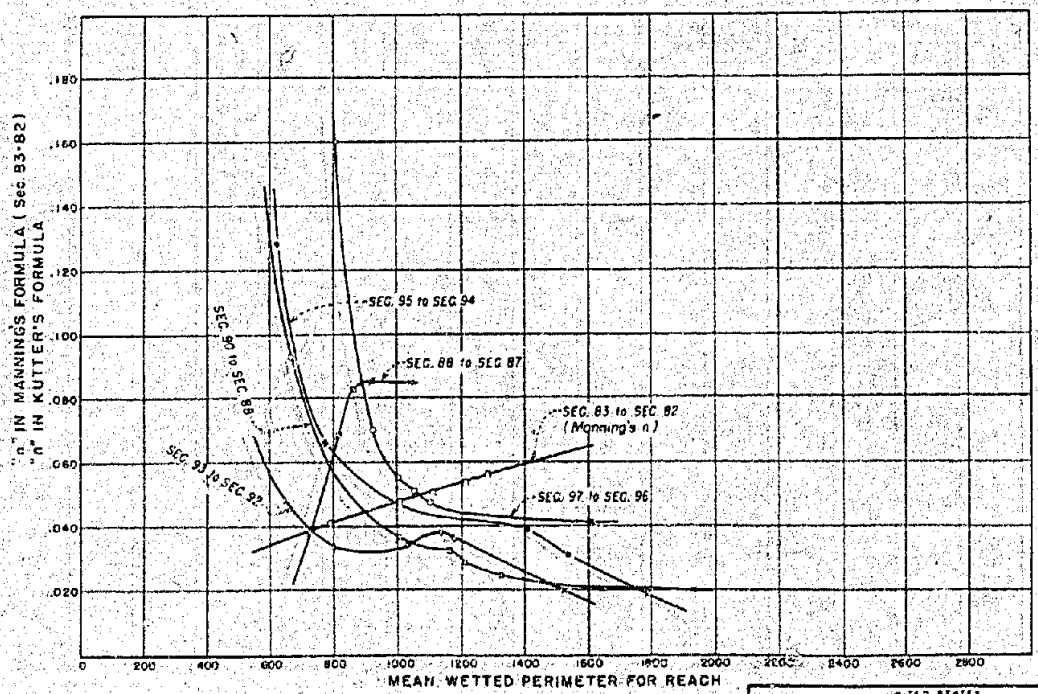


EXPLANATION

x indicates value of "n" used to compute water surface for natural flow of 650,000 second-feet

SYMBOL	REACH: OBSERVATION STATION FROM	TO	RIVER CROSS-SECTION FROM	TO
•	2	3	98	97
○	3	4	97	96
▲	4	5	96	95
■	5	6	95	94
●	6	—	94	93
◇	—	8	93	92
+	8	9	92	90
□	9	—	90	88
★	—	11	88	87
◆	11	—	87	L
U	—	13	L	M 83
⊓	13	14	83	82
△	14	15	82	81
▽	15	16	81	63

River cross-sections were not taken at observation stations Nos. 7, 10 and 12.



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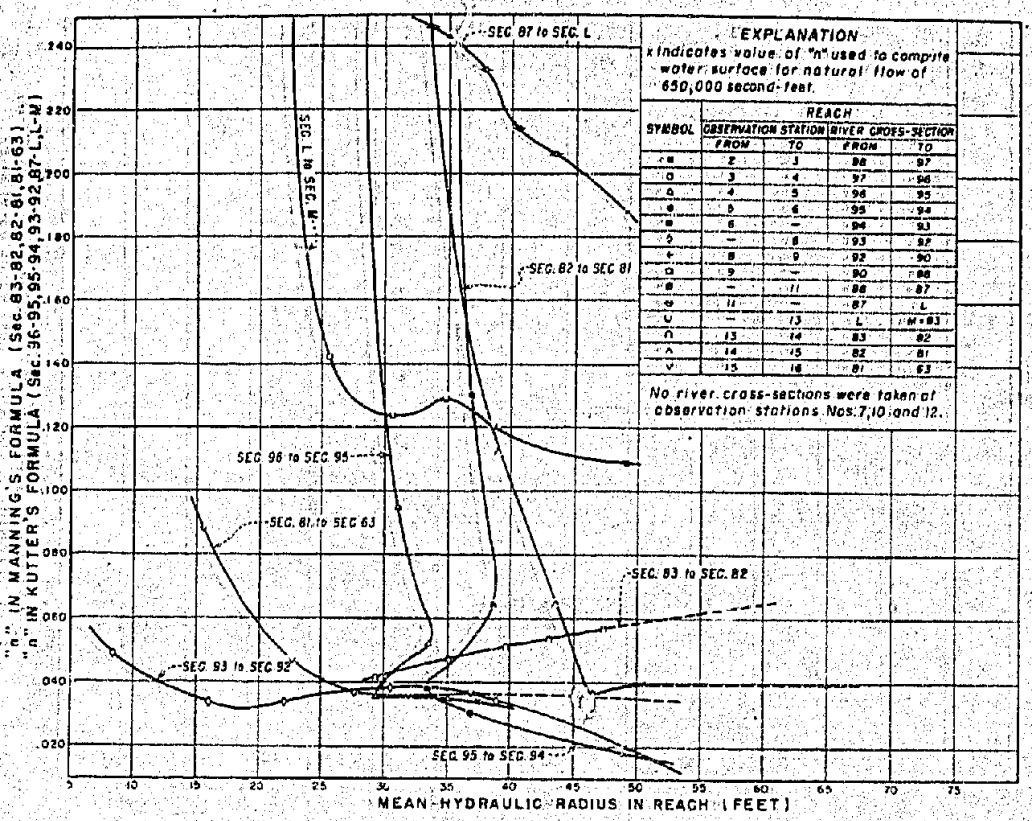
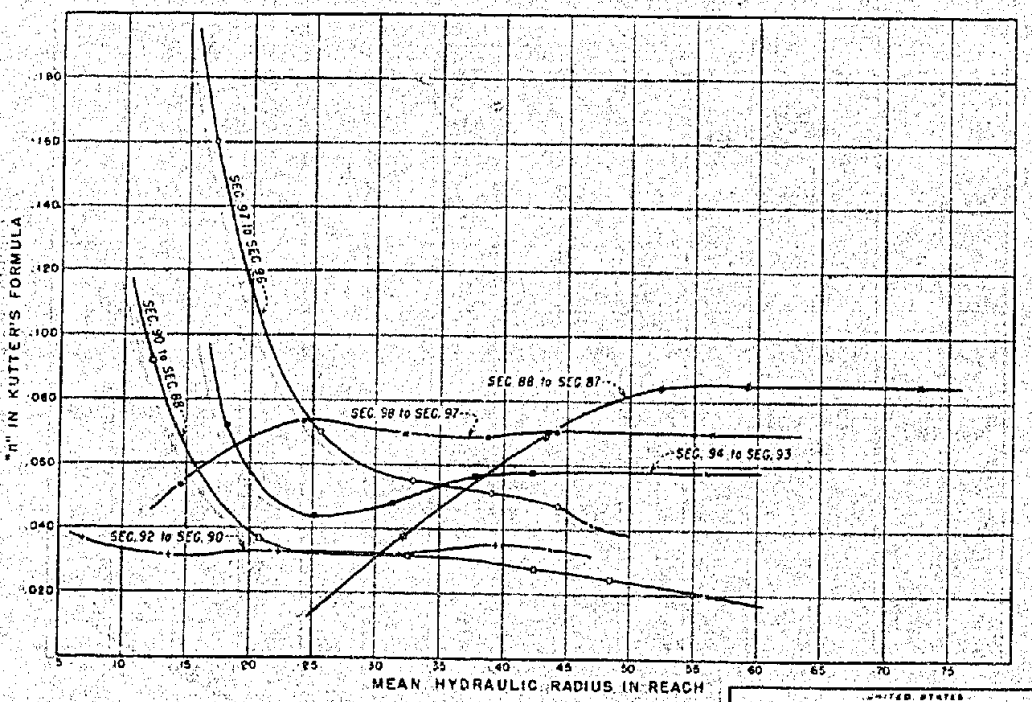
COLUMBIA BASIN PROJECT - WASHINGTON

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
MEAN WETTED PERIMETER — "n" CURVES
KETTLE FALLS TO INTERNATIONAL BOUNDARY

222-D-6807

FIGURE 14





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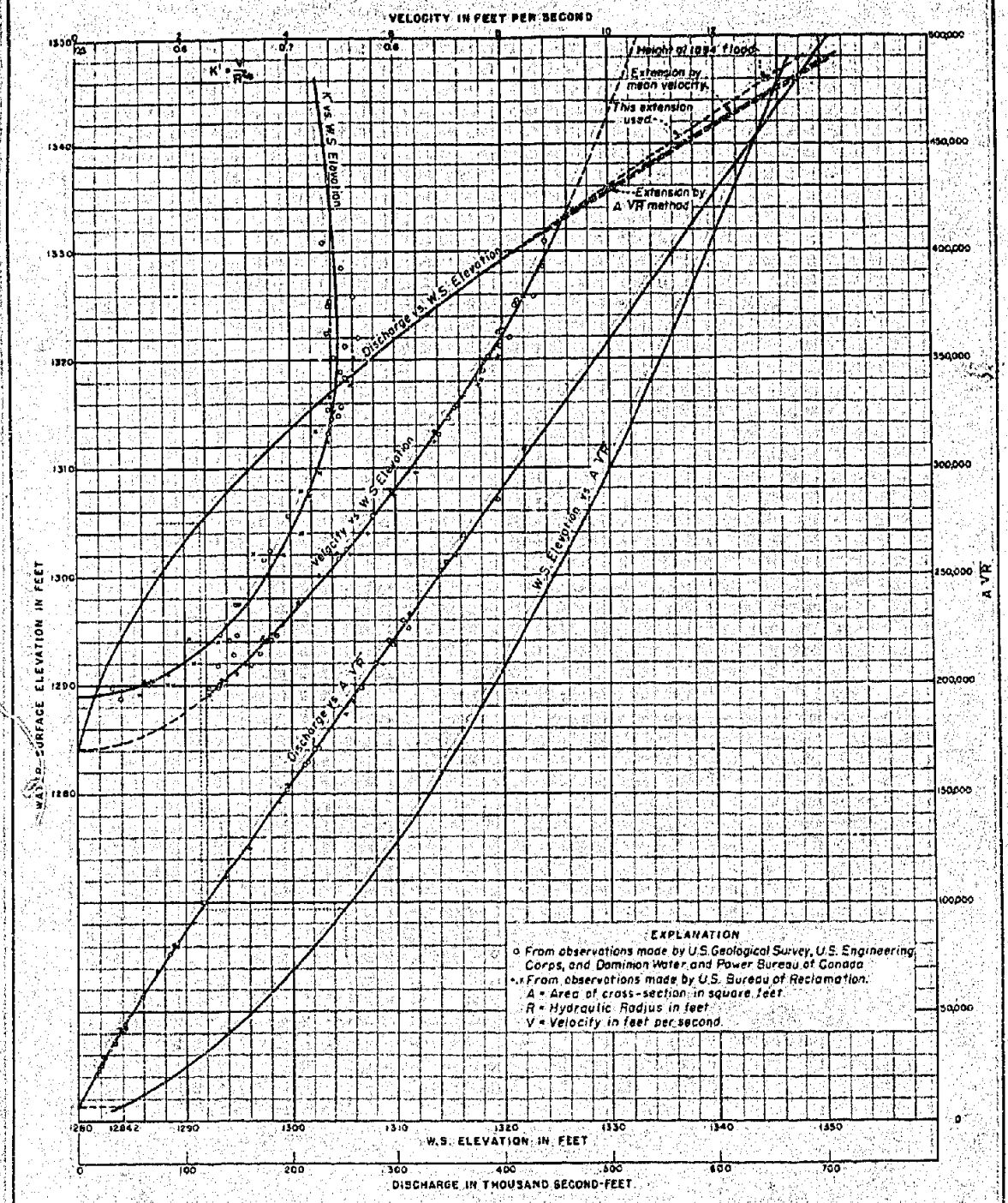
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
MEAN HYDRAULIC RADIUS — "n" CURVES
KETTLE FALLS TO INTERNATIONAL BOUNDARY

DRAWN W.R.R. SUBMITTED
TRACED R.F.J. - W.E.R. RECOMMENDED
CHECKED F.A.M. APPROVED

DENVER, COLORADO, MAY 15, 1950 | 222-D-6808

FIGURE 15



COLUMBIA RIVER RESERVOIR

BACKWATER STUDIES

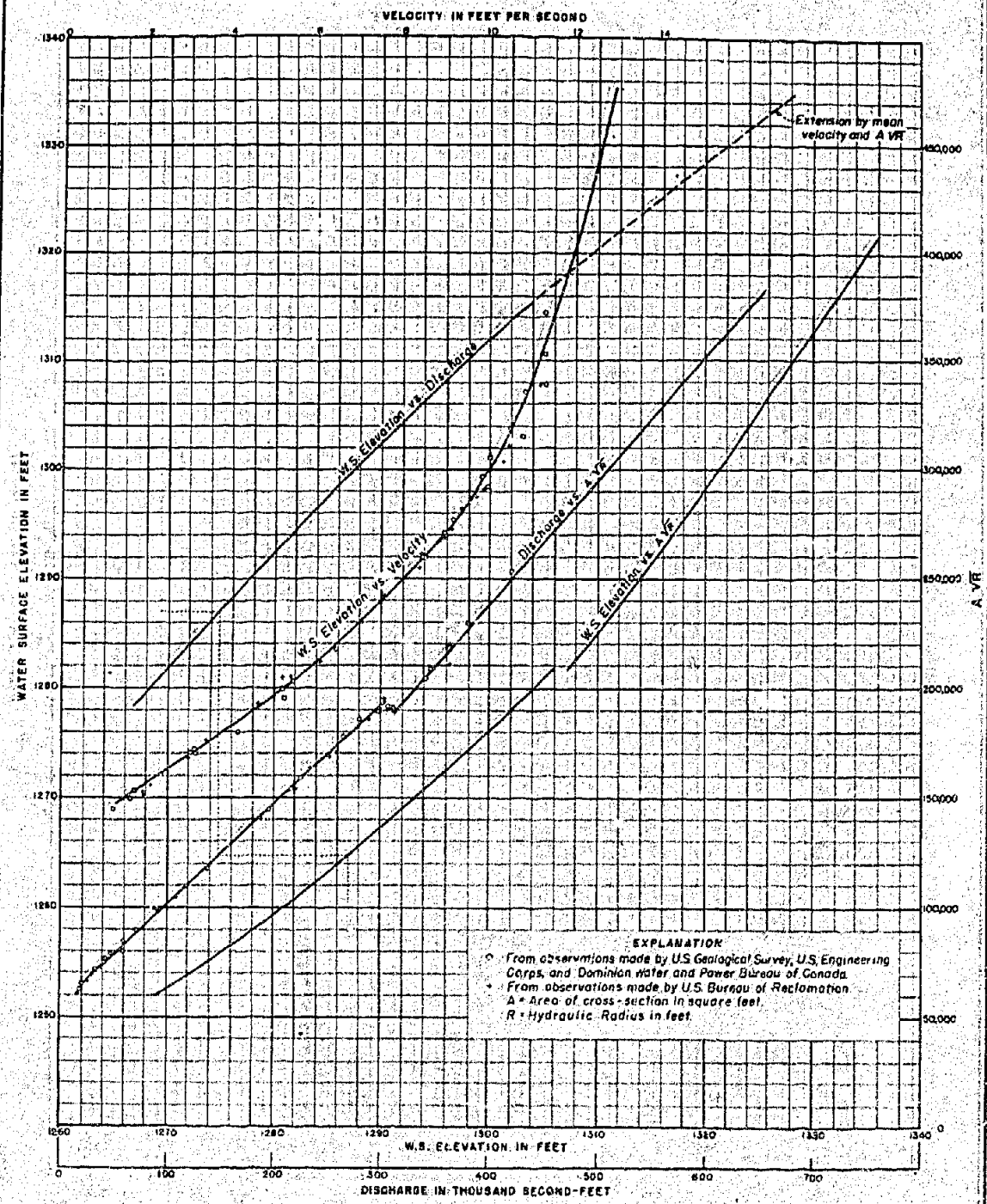
OBSERVATION STATION 2 - INTERNATIONAL BOUNDARY - SECTION 98

EXTENSION OF DISCHARGE CURVE

C.A.R. 5-15-40

222-D-5893

FIGURE 16



COLUMBIA RIVER RESERVOIR

BACKWATER STUDIES

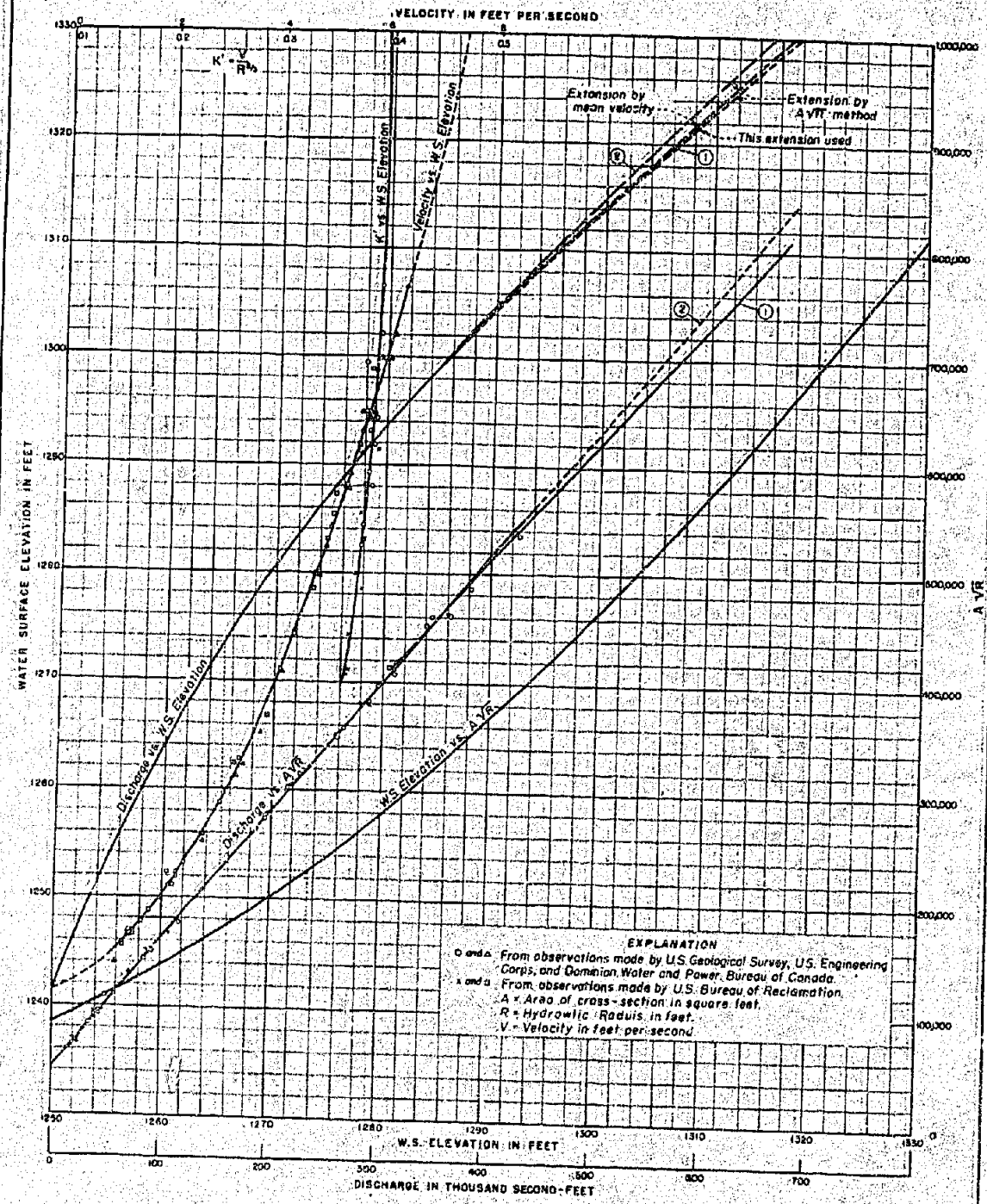
OBSERVATION STATION 6 - SHEEP CREEK BEND - SECTION 94

EXTENSION OF DISCHARGE CURVE

W.M.B. 9-21-40

222-D-6394

FIGURE 17



COLUMBIA RIVER RESERVOIR

BACKWATER STUDIES

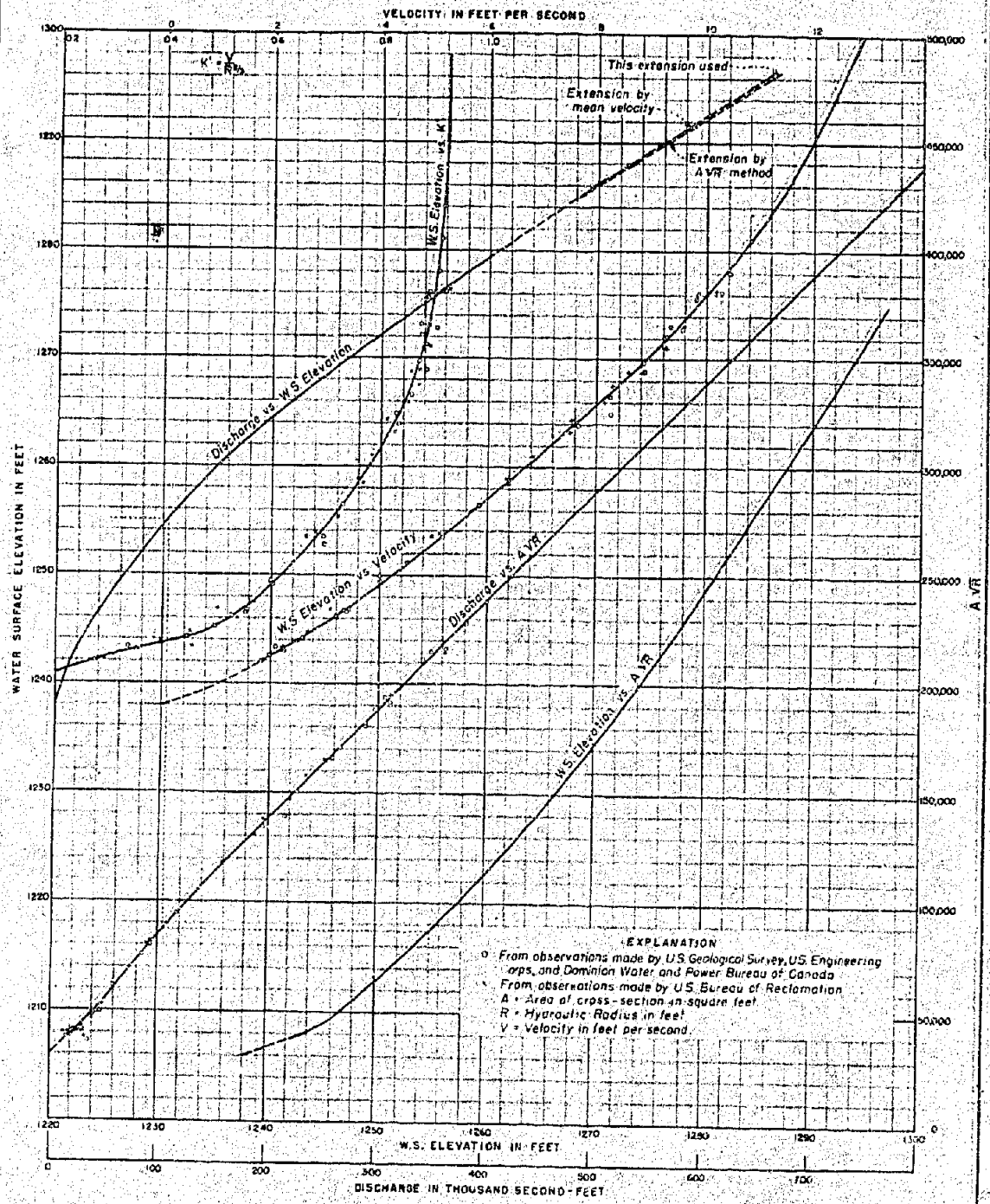
OBSERVATION STATION 11 - HEAD OF LITTLE DALLES - SECTION 87

EXTENSION OF DISCHARGE CURVE

W.M.B. 5-15-40

222-D-6895

FIGURE 18



COLUMBIA RIVER RESERVOIR

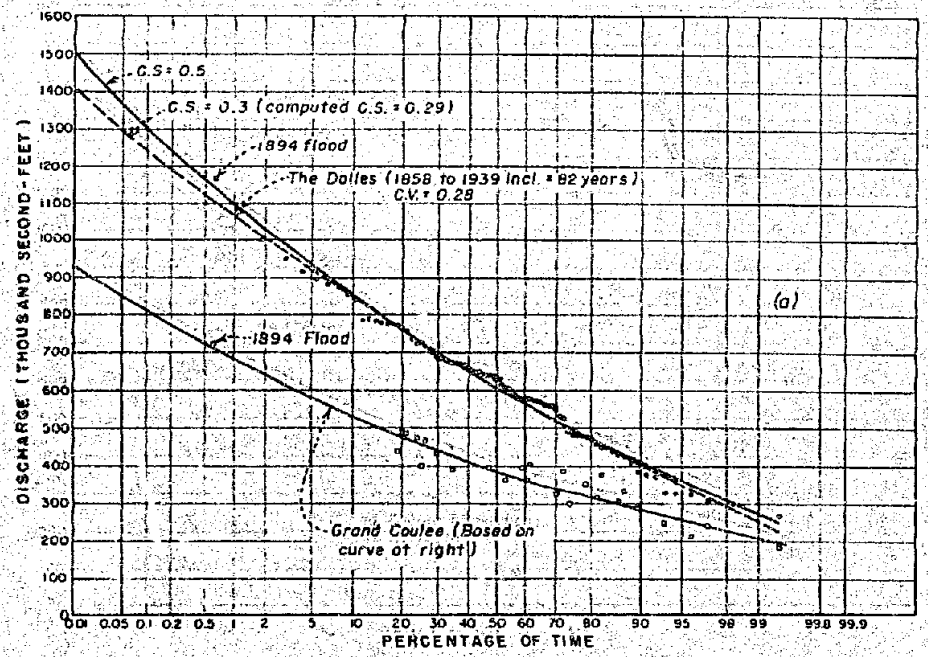
BACKWATER STUDIES

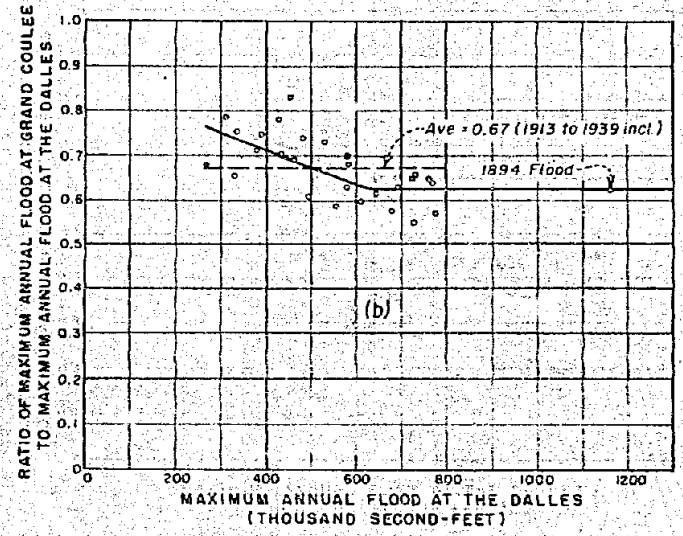
OBSERVATION STATION 13 - FOOT OF LITTLE DALLES - SECTION 83 - M

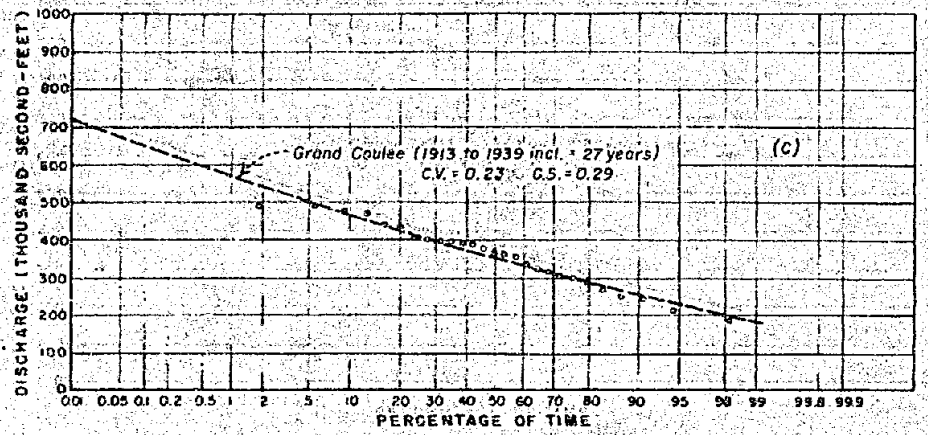
EXTENSION OF DISCHARGE CURVE

W.M.J. 6-10-40

222-0-6896







COLUMBIA RIVER RESERVIOR

BACKWATER STUDIES

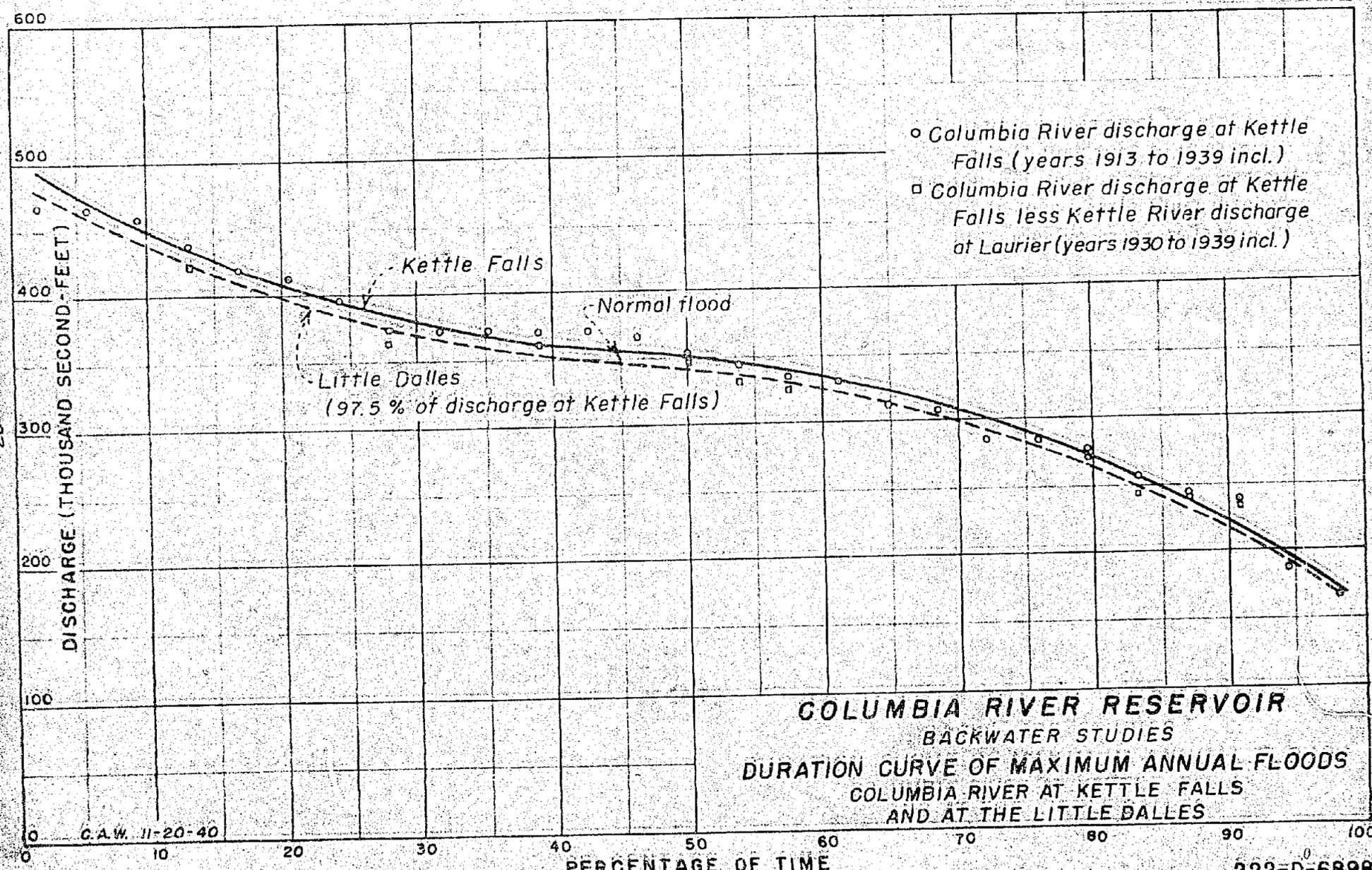
DURATION CURVE OF MAXIMUM ANNUAL FLOODS

COLUMBIA RIVER AT THE DALLES, OREGON AND AT GRAND COULEE DAM

FIGURE 19

C.A.H. 11-19-40

222-D-6897



COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
DURATION CURVE OF MAXIMUM ANNUAL FLOODS
COLUMBIA RIVER AT KETTLE FALLS
AND AT THE LITTLE DALLES

FIGURE 20

222-D-6898

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
DISCHARGE MEASUREMENTS OF COLUMBIA RIVER
AT INTERNATIONAL BOUNDARY

No.	Date	Water surface elevation	Discharge second-feet
1	August 15, 1939	1302.78	92,500
2	August 28, 1939	1301.09	77,300
3	December 9, 1939	1295.97	58,900
4	February 9, 1940	1291.99	29,900
5	February 23, 1940	1291.98	29,700
6	April 18, 1940	1299.60	70,100
7	May 11, 1940	1306.82	125,000
8	June 1, 1940	1317.69	255,000
9	June 19, 1940	1314.60	205,000

Note: Data furnished by U. S. Geological Survey.

COLUMBIA RIVER RESERVOIR

BACKWATER STUDIES

Change in Water Surface Elevation Between Major Observation Stations

Date	Discharge in thousands of cubic feet per second	Reach 2-6	Reach 6-11	Reach 11-13	
3-14-30	20.7	19.4	24.2	3.1	Observations by U.S. Geological Survey and U.S. Engineering Department
10-13-30	42.7	20.3	22.4	5.4	
1- 7-31	18.9	20.0	23.9	3.4	
5-31-32	266.0	19.6	10.0	19.6	
6- 6-32	284.0	19.3	9.1	20.6	
6-14-32	306.0	18.8	8.8	21.8	
6-18-32	341.1	17.9	8.3	23.2	
7- 6-32	297.1	19.1	9.1	20.9	
8-19-32	117.4	22.1	16.8	10.2	
11- 3-32	40.8	20.2	22.8	5.0	
11-22-32	43.0	20.3	22.4	5.2	
6-15-33	346.4	18.0	8.0	23.3	
6-21-33	420.2	16.6	7.8	25.5	
7- 4-33	385.9	17.9	8.5	24.1	
10-13-33	58.4	21.6	20.6	6.2	
12-4,5-35	25.8	19.9	23.6	3.8	
1-9,10-36	22.1			3.6	
2-14-36	17.8			3.3	
3-11-36	22.5	20.0	23.6	3.5	
4- 6-36	21.7	19.8	23.4	3.9	
4-17-36	39.4	20.5	21.6	5.4	
4-23-36	88.0	21.3	18.5	8.8	
4-29-36	138.2	21.9	14.9	12.2	
5- 9-36	195.2	21.2	12.2	15.6	
5-15-36	234.5	20.2	10.9	17.9	
5-23-36	258.6	20.0	9.9	19.3	
6- 1-36	312.0	20.4	7.4	21.7	
6- 4-36	361.5	17.9	8.0	23.5	
6-15-36	288.6	19.4	9.5	20.3	
6-20-36	251.6	20.0	10.2	18.6	
6-27-36	219.8	20.8	11.3	17.2	
7- 6-36	187.9	21.4	12.5	15.3	Observations by U.S. Bureau of Reclamation
7-15-36	158.9	21.3	14.0	13.3	
7-27-36	137.0	21.6	15.1	12.3	
8-10-36	107.5	21.6	17.2	9.8	
8-24-36	91.6	21.2	18.3	8.8	
9-10-36	72.4	21.5	19.7	7.5	
9-24-36	47.6	20.4	22.0	5.7	
10-12-36	39.1	20.3	22.6	5.1	
11- 3-36	29.8	19.9	23.2	4.2	
12- 1-36	22.0	19.9	23.7	3.8	

COLUMBIA RIVER RESERVOIR

BACKWATER STUDIES

Change in Water Surface Elevation
Between Major Observation Stations

Date	Discharge in thousands of cubic feet per second	Reach 2-6	Reach 6-11	Reach 11-13	
2-27-36	16.7		23.9	2.9	Observations by U. S. Geological Survey and Dominion Water & Power Bureau of Canada.
5-23-36	259.6	19.9	10.3	19.1	
6- 5-36	363.2	18.1	8.0	23.6	
8-24-36	92.2	21.9	18.3	8.7	
6- 7-37	215.8	20.6	11.6	17.9	
6-18-37	226.3	20.2	11.0	17.8	
11-11-37	59.3	20.9	20.9	6.5	
1-26-38	34.5	20.1	22.8	4.7	
4- 7-38	43.5	20.1		5.5	
6-17-38	311.3	19.0	8.7	21.5	
12-13-38	29.3	20.6	22.9	4.1	
4-26-39	84.7	21.8	18.5	8.5	
6-20-39	195.1	21.0	12.2	16.0	

COLUMBIA RIVER RESERVOIR

BACKWATER STUDIES

Change in Water Surface Elevation Between Observation Station
Measurements by U.S. Bureau of Reclamation

Date of observations	Discharge in thousands of cubic feet per second	Reach															
		Zone No. 4									Zone No. 3		Zone No. 2				
		2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18
12-4,5-35	25.8	0.3	5.8	3.6	10.2	1.2	3.5	9.2	9.7	0	1.1	2.7	0	3.6			
1-9,10-36	22.1	0.4	5.8				3.4	9.1	10.1	-0.1	1.2	2.4	0	3.7			
2-14-36	17.8	0.2	5.8				3.3	9.0	10.3	-0.1	1.2	2.1	-0.1	3.9			
3-11-36	22.5	0.4	5.7	3.5	10.4	1.2	3.7	8.7	10.1	-0.1	1.1	2.4	+0.1	3.7			
4- 6-36	21.7	0.2	5.8	3.4	10.4	1.1	3.5	9.5	10.0	-0.5	1.2	2.7	-0.2	3.7	31.7	2.5	0.3
4-17-36	39.4	0.5	6.4	3.8	9.8	1.5	3.0	10.2	7.2	-0.3	2.2	3.2	+0.1	3.4	31.9	0.9	1.2
4-23-36	88.0	1.5	6.7	5.3	7.8	2.0	3.6	10.9	1.9	+0.1	5.3	3.5	+0.2	2.5	33.4	1.1	1.6
4-29-36	138.2	1.6	8.2	3.9	8.2	2.0	3.4	6.3	2.6	0.6	7.8	4.4	+0.1	2.1	35.2	1.4	1.5
5- 9-36	195.2	1.3	9.2	3.1	7.6	2.4	2.8	4.3	1.7	1.0	10.3	5.3	0	1.9	37.2	1.4	2.7
5-16-36	234.5	1.5	8.8	3.0	6.9	2.5	2.5	3.1	1.9	0.9	11.6	6.3	+0.1	1.7	37.9	1.6	1.4
5-23-36	258.6	1.4	8.7	2.9	7.0	2.1	2.5	2.5		-	13.1	6.2	-0.1	1.6	38.7	1.7	1.1
6- 1-36	312.0	1.7	8.8	2.9	7.2	1.1	1.4	2.3	1.9	0.7	14.6	7.1	-0.2	1.7	40.1	1.3	1.9
6- 4-36	361.5	1.3	8.8	2.3	5.5	2.3	1.6	1.6	1.2	1.3	16.0	7.5	+0.1	1.5	41.0	1.7	1.3
6-13-36	288.6	1.4	9.1	2.4	6.5	2.3	2.2	2.1	1.5	1.4	13.5	6.8	-0.1	1.6	39.4	1.7	1.3
6-20-36	251.6	1.3	8.9	2.9	6.9	2.0	2.7	2.8	1.4	1.3	12.3	6.3	+0.3	1.6	38.5	1.7	1.4
6-27-36	210.8	1.3	9.1	2.9	7.5	2.2	2.8	3.5	2.0	0.8	11.0	6.2	0	1.8	37.7	1.6	1.2
7- 6-36	187.9	1.3	9.0	3.3	7.3	2.2	2.8	4.7	2.1	0.7	9.7	5.6	-0.1	1.9	37.1	1.5	1.2
7-15-36	158.9	1.0	8.9	3.2	8.2	2.4	2.8	5.9	2.2	0.7	8.7	4.6	+0.2	1.9	36.4	1.7	-
7-27-36	137.0	1.2	8.6	3.4	8.4	2.2	3.2	6.4	2.9	0.4	7.8	4.7	-0.3	2.4			
8-10-36	107.5	0.9	8.1	4.1	8.5	1.8	3.1	8.4	3.6	0.3	5.9	3.9	-0.1	2.5			
8-24-36	91.6	0.9	7.5	4.3	8.5	1.8	3.2	8.9	4.2	0.2	5.3	3.5	0	2.6			
9-10-36	72.4	1.2	7.5	4.3	8.5	1.8	3.3	9.5	5.1	0.2	4.1	3.4	0	2.8			
9-24-36	47.6	0.7	6.7	3.8	9.2	1.7	3.6	9.7	6.9	0.1	2.5	3.2	0	3.2			
10-12-36	39.1	0.6	7.2	2.8	9.7	1.5	3.4	9.8	7.8	+0.1	1.9	3.2	-0.1	3.5			
11- 3-36	29.8	0.4	6.1	3.5	9.9	1.3	3.6	9.4	9.2	-0.3							
12- 1-36	22.0	0.3	5.6	3.6	10.4	1.1	3.5	9.3	10.0	-0.2	1.1	2.5					

Table I

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

ROUGHNESS COEFFICIENTS FOR NATURAL FLOW IN ZONE 4
DISCHARGE = 400,000 SECOND-FEET

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
							Velocity					Friction								
Section	Obs. sta.	Length reach feet	Change W. S. feet	W. S. elev. feet	Hyd. Rad. R feet	Area A sq.ft.	V ft./sec.	h_v feet	ΔV	Enlargement loss $(\Delta V)^2/2g$	En. Gr. elev. feet	h_f feet	S_f	R_m	$\sqrt{R_m S_f}$	V_m	$C = \frac{V_m}{\sqrt{R_m S_f}}$	$R_m^{1/6}$	Futter's n	Manning's n
98	2			1339.10	40.50	45,800	8.73	1.185			50.285									
		3,150	1.40						2.050	0.065		1.826	.000580	44.10	.1600	7.785	48.25	1.880	.0709	.039
97	3			27.70	47.70	39,900	6.68	0.694			28.394									
		20,300	8.70									7.776	.000383	44.30	.1302	8.060	64.8	1.879	.0473	.042
96	4			19.00	40.90	39,200	10.20	1.618			20.618									
		9,050	2.04						4.180	0.272		2.823	.000312	34.95	.1044	8.11	77.7	1.809	.0357	.037
95	5			16.96	39.00	66,500	6.02	0.563			17.523									
		13,250	4.96									3.538	.000267	36.85	.0993	8.66	87.2	1.825	.0310	.032
94	6			1312.00	44.70	35,400	11.30	1.985			13.985									
		3,210	2.02						2.23	0.077		2.049	.000825	42.30	.1869	10.185	54.5	1.869	.0579	.048
93				09.98	39.90	44,100	9.07	1.279			11.259									
		4,590	1.33						0.61	0.006		1.510	.000329	38.90	.1132	8.765	77.5	1.841	.0363	.036
92	8			08.63	37.90	47,300	8.46	1.113			09.743									
		12,340	1.68						3.16	0.155		2.201	.0001784	39.55	.0842	6.68	61.8	1.843	.0355	.035
90	9			06.95	41.20	75,500	5.30	0.437			07.387									
		12,100	1.65									0.836	.0000732	48.30	.0595	7.015	117.4	1.91	.0250	.024
88				05.30	55.40	45,700	8.79	1.201			06.501									
		2,790	0.80						2.58	0.103		1.298	.000465	59.20	.1650	7.50	45.15	1.946	.0852	.0636
87	11			1304.50	63.00	64,400	6.21	0.600			05.100									
Check =			24.60	24.60				0.985		0.678	25.185	24.507								

Notes: Column 5 plus column 9 = column 12.

(Difference of values in column 12) minus column 11 = column 13.

In column 20, solve for Futter's n in $C = \dfrac{41.65 + \frac{0.00281}{S_f} + \frac{1.811}{n}}{1 + \frac{n}{\sqrt{R_m}}\left(41.65 + \frac{0.00281}{S_f}\right)}$. Convert equation into the form $an^2 + bn + c = 0$; then, $n = \dfrac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

In column 21, Manning's $n = \dfrac{1.486}{C} R_m^{1/6}$.

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
WATER SURFACE ELEVATIONS IN ZONE 2
BETWEEN OBS. STA. 15 AND OBS. STA. 16
(U.S.B.R. DATUM)

Cross section	Obs. sta.	Discharge second - feet	
		18,000	361,000
81	15	1238.7	1274.8
80		1237.5	1272.0
79		1236.5	1270.5
77		1235.0	1267.1
76		1234.0	1263.7
75		1230.3	1259.2
73		1227.2	1254.2
72		1225.9	1252.3
70		1223.4	1249.4
69		1218.9	1247.2
68		1215.0	1244.3
66		1211.6	1240.7
64		1209.0	1236.6
63	16	1207.4	1233.8

Notes: Above data taken from Bureau of Reclamation project drawing R_2-1999-6 (Denver file 22L-P-946z.) For continuation of profiles to International Boundary see data in Table (VI) opposite dates of Feb. 14, 1936 and June 4, 1936.

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

TRIAL COMPUTATION FOR KUTTER'S n IN ZONE 3 FOR NATURAL FLOW
DISCHARGE = 300,000 SECOND-FEET

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
							Velocity					Friction		$h_f = K \cdot L/2_m \cdot V_r^2/2g$						
Section	Obs. Sta.	Length Reach	Change W.S.	W.S. Elev.	Hydraulic Radius R	Cross-Sec. Area A	V	h_v	ΔV	Enlargement Loss $\Delta V^2/2g$	Em. Gr. Elev.	h_f	Slope	k_m	V_m	$V_m^2/2g$	$K=2_m/C^2$	h_f	Error in h_f	Kutter's n
57	11			1293.50	54.7	54,000	5.55	0.479			93.979									
									0.810	0.010		0.140	0.000814	59.05	5.145	0.412	0.116	0.139	-0.001	
A				1293.48	63.4	63,[illegible]00	4.74	0.349			93.829									
		100	0.36									0.104	0.00104	55.70	5.490	0.469	0.122	0.103	-0.001	
B				1293.12	48.0	48,100	6.24	0.605			93.725									
		100	0.61									0.240	0.00240	44.45	7.08	0.779	0.138	0.242	+0.002	
C				1292.51	40.9	37,900	7.92	0.975			93.485									
		118	1.22									0.640	0.00542	36.45	8.96	1.248	0.156	0.639	-0.001	
D				1291.29	32.0	30,000	10.00	1.555			92.845									
		70	0.35						0.550	0.005		0.512	0.00731	33.45	9.725	1.470	0.167	0.514	+0.002	
E				1290.94	34.9	31,750	9.45	1.388			92.328									
		108	0.11						1.81	0.051		0.539	0.00499	36.10	8.545	1.135	0.159	0.540	+0.001	Trial n = 0.217
F				1290.83	37.3	39,250	7.64	0.908			91.738									
		220	1.68									1.104	0.00497	36.90	8.705	1.178	0.157	1.103	-0.001	
G				1289.15	36.5	30,700	9.77	1.484			90.634									
		65	0.82									0.471	0.00725	36.50	24.315	1.655	0.159	0.469	-0.002	
H				1288.33	36.5	27,600	10.86	1.833			90.163									
		220	2.68									2.106	0.00957	36.70	11.905	2.204	0.159	2.102	-0.004	
I				1285.65	36.9	23,150	12.95	2.607			88.057									
		160	0.92						1.86	0.054		1.560	0.00975	36.65	12.02	2.246	0.159	1.560	nil	
J				1284.53	36.4	27,050	11.09	1.913			86.443									
		765	4.13						1.63	0.041		4.611	0.00602	40.60	10.275	1.642	0.140	4.610	-0.001	
K				1280.40	44.8	31,700	9.46	1.391			81.791									
	12	515	2.63	1279.41					0.09	nil		2.656	0.00516	39.975	9.445	1.378	0.150	2.660	+0.004	
L				1277.77	35.15	32,000	9.37	1.365			79.135									
	Check =		15.73				h_v=0.386			0.161	14.64	14.583						14.661		
L				1278.11	35.22	32,150	9.33	1.353			79.163									
		2,170	5.66						0.01	nil		5.662	0.00261	34.86	9.325	1.352				
83	13			1272.46	34.50	32,200	9.32	1.351			73.501									

Note: Water surface elevations for observation stations 11, 12, and 13 are from rating curves.
260= Distance from Obs. Sta. 12 to Sec. L
1.33 = 260/515 x 2.63 = ΔW.S. Elev. (Sec. L to obs. sta. 12)
14.40 = 15.73 - 1.33 = ΔW.S. Elev. (Sec. 87 to obs. sta. 12); n = 0.217
14.09 = 1293.50 - 1279.41 = ΔW.S. Elev. (Obs. sta. 11 to obs. sta. 12)
+0.31 = Error, 0.31/14.09 = +2.20% error

1.34 = 260/515 x 2.656 = h_f (Sec. L to obs. sta. 12)
13.34 = 14.68 - 1.34 = h_f (Sec. 87 to obs. sta. 12), n = 0.217
13.06 = 14.09 - 0.87 - 0.16 = h_f (obs. sta. 11 to obs. sta. 12)
+0.28 = Error, 0.28/13.06 = +2.15% error.

Adjusted n (Sec. 87 to Sec. L) = $0.214 = 0.217 \sqrt{\frac{14.40}{15.34}}$ since $\frac{h_{f_1}}{h_{f_2}} = \frac{(n_1)^2}{(n_2)^2}$ approx.
0.978 = 100.0% - 2.2%
15.39 = 15.73 x 0.978 = adjusted ΔW.S. Elev. (Sec. 87 to Sec. L)
1278.11 = 1293.50 - 15.39 = adjusted W.S. Elev. at Sec. L

Solving Kutter's formula, adjusted n (Sec. L to Sec. 83) = 0.129

Table XIII

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
PROPERTIES OF VARIOUS REACHES OF THE COLUMBIA RIVER

Reach		Discharge second-feet	NATURAL FLOW CONDITIONS				BACKWATER FLOW CONDITIONS #			
			Average value for reach			N.R.C. Kutter's "n"	Average value for reach			B.R.C. Kutter's "n"
River cross sections	Observation stations		Hydraulic radius	Wetted perimeter	W.S. elevation		Hydraulic radius	Wetted perimeter	W.S. elevation	
98-97	2-3	20,000	14.40	849	1289.69	0.0540				
		100,000	24.45	998	1302.93	.0745	24.40	1002	1302.95	0.074
		200,000	32.30	1087	1312.98	.0714	32.65	1096	1313.40	.070
		300,000	38.65	1143	1321.05	.0690	39.35	1150	1322.05	.069
		400,000	44.10	1193	1328.40	.0709	45.10	1200	1329.75	.070
		500,000	49.10	1242	1335.31	.0708	50.40	1254	1337.00	.070
		650,000	56.50	1302	1345.38	.0700	57.30	1307	1346.35	.070
97-96	3-4	20,000	17.25	809	1286.73	.1600				
		100,000	25.60	938	1298.38	.0707	26.25	954	1299.60	.062
		200,000	32.80	1005	1307.77	.0565	33.85	1018	1309.30	.053
		300,000	39.10	1058	1315.94	.0511	40.40	1070	1317.90	.050
		400,000	44.30	1107	1323.35	.0475	45.75	1122	1325.50	.047
		500,000	48.25	1185	1330.44	.0452	49.40	1218	1332.85	.045
		650,000	46.90	1608	1340.85	.0416	46.65	1696	1342.10	.041
96-95	4-5	20,000	26.90	647	1282.17	.3250				
		100,000	31.15	771	1292.40	.0955	31.50	833	1295.30	.069
		200,000	33.50	914	1301.66	.0518	31.35	1094	1304.85	.042
		300,000	29.30	1534	1310.21	.0360	31.45	1597	1313.50	.036
		400,000	34.95	1625	1317.98	.0357	37.10	1674	1321.10	.035
		500,000	39.05	1755	1325.39	.0359	40.75	1809	1328.50	.035
		650,000	37.75	2259	1336.17	.0340	37.45	2377	1337.80	.034
95-94	5-6	20,000	33.70	501	1275.25	.6550				
		100,000	36.85	625	1286.15	.1285	39.15	716	1293.90	.070
		200,000	39.65	779	1295.26	.0660	37.50	976	1302.15	.047
		300,000	33.50	1401	1305.71	.0388	34.05	1512	1310.50	.054
		400,000	36.85	1542	1314.48	.0310	39.30	1600	1318.55	.030
		500,000	41.65	1650	1322.52	.0260	43.95	1690	1326.15	.024
		650,000	48.55	1795	1334.88	.0180	49.45	1832	1335.70	.017
94-93	6-Obs. sta. 7 is downstream from sec. 93.	20,000	18.10	534	1269.51	.0720				
		100,000	25.10	667	1280.48	.0440	32.45	806	1292.80	.049
		200,000	31.25	798	1291.37	.0484	37.25	853	1299.95	.055
		300,000	37.90	865	1301.53	.0665	40.10	930	1307.70	.058
		400,000	42.30	948	1310.94	.0579	45.65	980	1316.00	.058
		500,000	48.05	1003	1319.67	.0581	50.65	1032	1323.95	.058
		650,000	55.55	1077	1331.78	.0580	56.85	1085	1333.80	.058

Table
Sheet 1 of 6

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
PROPERTIES OF VARIOUS REACHES OF THE COLUMBIA RIVER

Reach		Discharge second-feet	NATURAL FLOW CONDITIONS				BACKWATER FLOW CONDITIONS #			
			Average value for reach			N.R.C. Kutter's "n"	Average value for reach			B.R.C. Kutter's "n"
River cross sections	Observation stations		Hydraulic radius	Wetted perimeter	W.S. elevation		Hydraulic radius	Wetted perimeter	W.S. elevation	
93-92	-8 Obs. sta. 7 is down-stream from Sec. 93.	20,000	7.35	647	1267.23	0.049				
		100,000	16.00	796	1278.26	.034	25.00	1071	1292.50	0.035
		200,000	22.05	1054	1288.80	.0347	30.30	1133	1299.10	.037
		300,000	30.50	1133	1299.35	.0382	36.50	1166	1306.60	.037
		400,000	38.90	1176	1309.30	.0363	43.65	1200	1314.25	.037
		500,000	46.60	1211	1318.47	.0312	50.30	1252	1323.10	.029
		650,000	48.90	1533	1331.05	.0200	50.55	1544	1333.15	.020
92-90	8-9	20,000	6.70	747	1260.83	.037				
		100,000	13.60	1085	1272.30	.032	28.15	1380	1292.25	.033
		200,000	22.35	1341	1285.26	.0334	32.75	1446	1298.35	.033
		300,000	31.90	1426	1297.15	.0334	38.45	1502	1305.75	.034
		400,000	39.55	1540	1307.79	.0355	43.50	1631	1314.05	.037
		500,000	45.50	1707	1317.40	.0371	46.70	1954	1322.35	.035
		650,000	43.80	2397	1330.47	.0340	45.75	2410	1332.65	.034
90-88	9- Obs. Sta. 10 is up-stream from Sec. 88.	20,000	12.30	670	1251.15	.094				
		100,000	20.75	1006	1266.16	.037	39.95	1192	1292.05	.029
		200,000	32.50	1159	1282.15	.0325	43.85	1232	1297.80	.028
		300,000	42.40	1207	1295.18	.0280	48.15	1293	1305.05	.026
		400,000	48.30	1327	1306.12	.0250	51.20	1431	1313.10	.024
		500,000	52.15	1515	1315.88	.0225	52.75	1771	1321.10	.022
		650,000	56.30	1958	1329.07	.0200	58.10	1958	1331.55	.020
88-87	-11 Obs. Sta. 10 is up-stream from Sec. 88.	20,000	19.50	610	1246.16					
		100,000	32.15	725	1264.19	.038	51.15	860	1292.00	.082
		200,000	43.35	815	1280.71	.0686	54.65	884	1297.45	.084
		300,000	52.45	869	1293.90	.0840	56.95	919	1304.45	.085
		400,000	59.20	922	1304.90	.0852	63.40	961	1312.20	.085
		500,000	64.85	974	1314.70	.0814	68.15	1000	1320.10	.085
		650,000	72.90	1040	1327.85	.0850	74.45	1052	1330.50	.085
87-L	11- Obs. Sta. 12 is up-stream from Sec. L.	20,000	29.76	518	1245.69	.325			1290.07	
		100,000	33.70	680	1261.04	.246	41.68	843	1291.30	.210
		200,000	37.94	752	1274.93	.253	42.44	868	1294.95	.208
		300,000	40.35	820	1285.81	.214	43.98	897	1299.75	.204
		400,000	43.43	880	1295.25	.206	46.42	927	1305.25	.200
		500,000				.198	47.57	990	1311.30	.194
		650,000	46.85	1015	1314.63	.188	50.00	1045	1319.31	.187

Table XIV
Sheet 2 of 3

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
PROPERTIES OF VARIOUS REACHES OF THE COLUMBIA RIVER

Reach		Discharge	NATURAL FLOW CONDITIONS				BACKWATER FLOW CONDITIONS #			
			Average value for reach				Average value for reach			
River cross sections	Observation stations	second-feet	Hydraulic radius	Wetted perimeter	W.S. elevation	N.R.C. "n"*	Hydraulic radius	Wetted perimeter	W.S. elevation	B.R.C. "n"*
L-(M-83)	-13	20,000	21.15	664	1243.87	0.377	42.50	1010	1290.00	
	Obs. Sta.	100,000	25.50	827	1256.34	.142	42.67	1010	1290.67	0.114
	12 is up-	200,000	30.55	889	1266.93	.124	43.40	1026	1292.20	.113
	stream	300,000	34.86	924	1275.28	.129	44.32	1043	1294.60	.112
	from Sec.	400,000	38.52	966	1282.68	.120	45.45	1064	1297.50	.111
	L.	500,000					47.00	1085	1301.00	.110
		650,000	45.75	1071	1298.50	.109	49.67	1114	1306.22	.108
83-82	13-14	20,000	29.35	798	1242.72	.0416	53.15	1380	1290.00	.080
		100,000	35.00	1006	1254.65	.0472	53.35	1386	1290.50	.080
		200,000	39.70	1112	1264.59	.0512	54.10	1397	1291.80	.061
		300,000	43.00	1215	1272.45	.0535	55.10	1415	1293.85	.062
		400,000	47.30	1281	1279.52	.0568	56.55	1437	1295.40	.063
		500,000					58.25	1458	1299.30	.064
		650,000					61.05	1500	1304.08	.065
82-81	14-15	20,000	31.25	829	1240.71	.3965	57.30	1398	1290.00	.040
		100,000	39.00	961	1253.48	.1125	57.55	1403	1290.47	.040
		200,000	43.55	1088	1263.57	.0350	58.30	1414	1291.72	.040
		300,000	46.55	1216	1271.51	.0369	59.35	1430	1293.65	.040
		400,000	50.65	1291	1278.60	.0396	60.90	1447	1296.05	.040
		500,000					62.75	1463	1298.77	.040
		650,000					65.55	1497	1303.32	.040
81-63	15-16	20,000	15.54	690	1223.50	.088			1290.00	.034
		100,000	22.67	935	1235.05	.0468			1290.07	.034
		200,000	27.73	1003	1244.05	.0367			1290.36	.034
		300,000	31.86	1114	1250.90	.0355			1291.14	.034
		400,000	36.82	1165	1257.20	.0364			1292.46	.034
		500,00							1294.10	.034
		650,000							1297.14	.034

N.R.C. = Natural roughness coefficient. B.R.C. = Backwater roughness coefficient.
* Kutter's n, reach from Sec. L - 83. Manning's n, reaches from Sec. 83-82, 82-81, 81-63.
# Reservoir W.S. El. 1290.0 at Grand Coulee Dam and unimproved channel at the Little Dalles.

Table XIV
Sheet 3 of 3

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

DATA FOR EXTENSION OF RATING CURVE AT
OBSERVATION STATION 2 = SECTION 98 = INTERNATIONAL BOUNDARY

Discharge Sec.-Ft.	Water Surface Elevation Feet	Area of Cross Section A Sq. Ft.	Velocity V Ft./Sec.	Hydraulic Radius R Feet	$A\sqrt{R}$	$K = V/R^{2/3}$
20,700	1290.0	7,850	2.64	10.10	24,940	0.564
42,700	94.7	11,600	3.68	14.00	43,400	0.633
18,900	89.8	7,700	2.45	9.90	24,200	0.532
266,000	1318.9	34,800	7.64	32.60	198,700	0.748
280,000	20.3	36,200	7.74	33.60	209,900	0.742
306,000	22.5	38,600	7.93	35.40	229,700	0.735
341,100	25.0	41,400	8.24	37.30	252,800	0.737
297,100	21.3	37,300	7.97	34.40	218,800	0.753
117,400	05.6	21,100	5.57	22.50	100,100	0.698
40,800	1294.2	11,200	3.64	13.50	41,180	0.642
43,000	94.6	11,500	3.74	13.80	42,720	0.649
346,400	1325.4	41,800	8.29	37.60	256,200	0.739
420,200	30.9	47,700	8.81	41.80	308,500	0.732
395,400	28.5	45,100	8.77	40.00	285,200	0.750
58,400	1297.5	14,000	4.17	16.30	56,550	0.648
25,800	1291.1	8,700	2.97	10.90	28,710	0.604
22,100	90.5	8,200	2.69	10.50	29,330	0.562
17,800	89.2	7,200	2.47	9.30	21,950	0.558
22,500	90.5	8,200	2.74	10.50	26,570	0.571
21,700	90.1	7,900	2.75	10.10	25,100	0.589
39,400	94.4	11,400	3.46	13.70	42,180	0.604
88,000	1302.2	18,000	4.89	20.00	80,550	0.664
138,200	07.9	23,300	5.93	24.20	114,600	0.710
195,200	13.4	29,000	6.73	28.30	154,300	0.724
234,500	16.6	32,300	7.26	30.80	179,300	0.739
258,600	18.1	34,000	7.61	32.00	192,300	0.755
312,000	22.8	39,000	8.00	35.60	232,800	0.739
355,000	25.8	42,200	8.41	37.90	259,800	0.745
286,900	20.3	36,200	7.93	33.60	209,800	0.761
251,600	17.6	33,300	7.56	31.50	186,900	0.758
219,800	15.3	30,900	7.12	29.70	168,400	0.742
187,900	12.4	27,900	6.73	27.60	146,500	0.736
158,900	09.6	24,900	6.38	25.40	125,400	0.738
137,000	07.5	22,900	5.98	24.00	112,100	0.718
107,500	04.0	19,700	5.46	21.30	91,000	0.710
91,600	02.1	17,900	5.12	20.00	80,100	0.694

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

DATA FOR EXTENSION OF RATING CURVE AT
OBSERVATION STATION 2 - SECTION 98 - INTERNATIONAL BOUNDARY

Discharge Sec.-Ft.	Water Surface Elevation Feet	Area of Cross Section A Sq. Ft.	Velocity V Ft./Sec.	Hydraulic Radius R Feet	$A\sqrt{R}$	$K = V/R^{2/3}$
72,400	1300.1	16,000	4.53	18.50	68,850	0.647
47,600	1295.6	12,400	3.84	14.70	47,550	0.639
39,100	94.0	11,050	3.54	13.30	40,300	0.631
29,800	92.0	9,500	3.14	11.70	32,500	0.608
22,000	90.2	8,000	2.75	10.20	25,550	0.584
16,300	1288.8	7,000	2.33	9.0	21,000	0.540
259,600	1318.2	34,200	7.59	32.0	193,500	0.755
363,200	1325.9	42,200	8.61	38.0	259,000	0.761
92,200	1302.5	18,200	5.06	20.2	81,800	0.682
212,300	1314.6	30,300	7.00	29.1	163,500	0.740
215,800	1314.8	30,400	7.10	29.3	164,500	0.747
222,100	1315.5	31,100	7.11	30.0	170,500	0.737
226,300	1315.6	31,200	7.26	30.1	171,000	0.750
58,300	1297.4	14,000	4.16	16.2	56,400	0.650
59,300	1297.7	14,200	4.17	16.3	57,300	0.644
34,500	1292.9	10,100	3.42	12.2	35,300	0.646
34,600	1292.9	10,100	3.43	12.2	35,300	0.648
43,500	1294.2	11,300	3.85	13.7	41,800	0.672
311,300	1322.0	38,200	8.19	35.0	226,000	0.766
29,300	1291.8	9,000	3.25	11.7	30,700	0.631
84,700	1301.6	17,200	4.92	19.7	76,200	0.675
195,100	1313.1	28,600	6.82	28.2	152,000	0.736

COLUMBIA BASIN RESERVOIR
BACKWATER STUDIES

DATA FOR EXTENSION OF RATING CURVE AT
OBSERVATION STATION 6 = SECTION 94 = SHEEP CREEK BEND

Discharge Sec.-Ft.	Water Surface Elevation Feet	Area of Cross Section A Sq. Ft.	Velocity V Ft./Sec.	Hydraulic Radius R Feet	$A\sqrt{R}$	$K = \frac{V}{R^{2/3}}$
20,700	1270.6	12,000	1.72	29.3	65,000	0.181
42,700	1274.4	13,600	3.14	31.2	76,100	0.318
18,900	1269.8	11,600	1.63	29.0	62,400	0.173
265,400	1299.3	27,000	9.84	43.2	177,400	0.799
280,000	1301.0	28,000	10.00	43.8	185,200	0.804
306,000	1303.7	29,200	10.47	43.2	191,700	0.852
341,100	1307.1	31,500	10.82	42.1	204,500	0.894
297,100	1302.2	28,500	10.42	44.0	189,000	0.836
117,400	1283.5	18,300	6.42	35.5	109,000	0.595
40,800	1274.0	13,500	3.02	31.0	74,600	0.305
43,000	1274.3	13,600	3.16	31.1	75,800	0.320
346,400	1307.4	32,000	10.82	42.5	208,600	0.888
420,200	1314.3	37,300	11.27	46.2	253,100	0.876
390,200	1310.6	34,500	11.30	44.2	229,100	0.905
58,400	1275.9	14,100	4.14	31.9	79,600	0.412
26,000	1271.2	12,200	2.13	29.6	66,400	0.223
22,500	1270.5	12,000	1.87	29.3	64,900	0.197
21,700	1270.3	11,900	1.82	29.2	64,300	0.192
39,400	1273.9	13,500	2.92	30.8	75,000	0.297
88,000	1280.9	17,000	5.18	34.4	99,700	0.491
138,000	1286.0	19,600	7.04	36.5	118,300	0.637
195,000	1292.2	23,100	8.44	39.6	145,400	0.726
235,000	1296.4	25,200	9.33	41.6	162,500	0.777
258,600	1298.1	26,200	9.88	42.4	170,600	0.813
312,000	1302.2	28,400	10.98	44.0	188,200	0.882
361,500	1307.9	32,300	11.19	42.5	210,500	0.920
288,600	1300.9	28,000	10.31	44.0	185,600	0.827
251,600	1297.6	26,000	9.68	42.1	168,600	0.798
220,000	1294.5	24,200	9.10	40.6	154,000	0.769
188,000	1291.0	22,500	8.36	39.1	140,700	0.725
159,000	1288.3	21,000	7.57	37.7	128,800	0.674
137,000	1285.9	19,500	7.03	36.5	117,800	0.640
107,500	1282.4	17,700	6.08	35.0	104,700	0.568
91,500	1280.9	17,000	5.38	34.2	98,400	0.512
72,400	1278.6	15,600	4.64	33.0	89,600	0.450
47,600	1275.2	14,000	3.40	31.5	78,600	0.341

COLUMBIA BASIN RESERVOIR
BACKWATER STUDIES

DATA FOR EXTENSION OF RATING CURVE AT
OBSERVATION STATION 6 = SECTION 94 = SHEEP CREEK BEND

Discharge Sec.-Ft.	Water Surface Elevation Feet	Area of Cross Section A Sq. Ft.	Velocity V Ft./Sec.	Hydraulic Radius R Feet	$A\sqrt{R}$	$K = V/R^{2/3}$
39,100	1273.7	13,100	2.98	30.7	72,600	0.304
29,800	1272.1	12,600	2.37	30.0	69,000	0.245
22,000	1270.3	12,000	1.83	29.2	64,800	0.193
59,300	1276.8	14,800	4.05	32.4	84,400	0.398
34,500	1272.8	12,900	2.67	30.4	71,100	0.275
43,500	1274.1	13,500	3.22	31.0	75,200	0.325
311,300	1303.0	29,000	10.72	43.6	191,200	0.866
29,300	1271.2	12,200	2.42	29.6	66,400	0.253
84,700	1279.8	16,400	5.16	33.6	95,100	0.495
195,100	1292.1	23,000	8.49	39.5	144,500	0.733
16,700	1268.8	11,300	1.48	28.2	60,000	0.160
259,600	1298.3	26,200	9.92	42.6	170,800	0.814
363,200	1307.8	32,100	11.30	42.5	218,400	0.929
92,200	1280.6	17,000	5.42	34.2	99,400	0.514
215,800	1294.2	24,100	8.96	40.8	154,000	0.756
226,300	1295.4	24,700	9.16	41.2	158,400	0.768
59,300	1276.8	14,900	3.98	32.2	84,600	0.393
34,500	1272.8	13,000	2.65	30.4	71,600	0.272
43,500	1274.1	13,400	3.25	31.0	74,500	0.330
311,300	1303.0	29,000	10.73	43.3	191,000	0.870
29,300	1271.2	12,200	2.39	29.5	66,300	0.250
84,700	1279.8	16,200	5.22	33.7	94,000	0.504
195,100	1292.1	23,000	8.50	39.6	144,600	0.732

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

DATA FOR EXTENSION OF RATING CURVE AT
OBSERVATION STATION 11 - SECTION 87 - HEAD OF LITTLE DALLES

Discharge Sec.-Ft.	Water Surface Elevation Feet	Area of Cross Section A Sq. Ft.	Velocity V Ft./Sec.	Hydraulic Radius R Feet	$A\sqrt{R}$	$K = V/R^{2/3}$
21,100	1246.4	15,100	1.40	20.2	67,800	0.169
42,700	1252.0	19,000	2.25	24.6	94,200	0.263
18,900	1245.9	14,600	1.29	19.7	64,800	0.177
285,400	1289.3	50,000	5.32	51.5	357,000	0.384
288,000	1291.9	52,300	5.51	53.4	382,000	0.388
306,000	1294.9	55,300	5.54	55.7	413,000	0.380
341,100	1298.8	59,000	5.78	58.7	452,000	0.386
297,100	1293.1	53,600	5.54	54.5	396,000	0.385
116,700	1266.7	29,900	3.90	35.2	177,000	0.363
39,500	1251.2	18,500	2.13	23.9	90,000	0.257
43,000	1251.9	18,800	2.29	24.5	93,000	0.271
346,400	1299.4	59,500	5.78	59.1	457,000	0.381
422,500	1306.5	66,700	6.33	64.6	536,000	0.393
381,600	1302.1	62,200	6.13	61.2	486,000	0.394
57,700	1255.3	21,200	2.72	27.0	110,200	0.302
25,800	1247.6	15,800	1.63	21.0	72,400	0.214
22,100	1246.8	15,400	1.43	20.6	69,800	0.190
17,000	1245.5	14,300	1.24	19.3	62,800	0.172
22,500	1246.9	15,400	1.46	20.6	69,800	0.171
21,700	1246.9	15,400	1.41	20.6	69,800	0.188
39,400	1252.3	19,200	2.05	24.8	95,600	0.241
38,000	1262.4	26,800	3.26	32.3	152,000	0.323
138,200	1271.1	33,700	4.10	38.1	208,000	0.362
195,200	1280.0	41,500	4.70	44.6	277,000	0.373
234,500	1285.5	46,600	5.03	48.7	322,000	0.378
258,600	1288.2	49,100	5.27	51.0	351,000	0.382
312,000	1294.8	55,100	5.66	56.7	411,000	0.388
361,600	1299.9	60,100	6.02	59.4	463,000	0.396
288,600	1291.4	52,100	5.54	53.2	379,000	0.392
251,600	1287.4	48,500	5.19	50.1	342,000	0.382
219,800	1283.2	44,500	4.94	47.0	305,000	0.380
187,900	1278.5	40,100	4.69	43.5	264,000	0.378
158,900	1274.3	36,600	4.34	40.6	233,000	0.367
137,000	1270.8	33,300	4.12	38.0	205,000	0.364
107,600	1265.2	28,700	3.75	34.2	168,000	0.355
91,600	1262.6	27,000	3.39	32.5	154,000	0.332

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

DATA FOR EXTENSION OF RATING CURVE AT
OBSERVATION STATION 11 = SECTION 87 = HEAD OF LITTLE DALLES

Discharge Sec.-Ft.	Water Surface Elevation Feet	Area of Cross Section A Sq. Ft.	Velocity V Ft./Sec.	Hydraulic Radius R Feet	$A\sqrt{R}$	$K = V/R^{2/3}$
72,400	1258.7	24,000	3.03	29.9	131,000	0.314
47,600	1253.2	19,800	2.40	25.3	99,600	0.278
38,100	1251.1	18,300	2.14	23.9	89,400	0.258
29,800	1248.9	16,800	1.77	22.0	78,800	0.225
22,000	1246.6	15,200	1.45	20.3	68,500	0.195
16,700	1244.9	14,000	1.19	19.0	61,000	0.167
259,600	1288.0	49,000	5.30	50.7	348,700	0.387
363,200	1299.8	59,700	6.08	59.6	461,000	0.399
92,200	1262.3	26,500	3.48	32.2	150,400	0.344
215,800	1282.6	44,000	4.91	46.8	301,000	0.378
226,300	1284.4	45,500	4.98	48.0	315,000	0.378
59,300	1255.9	21,600	2.74	27.8	114,000	0.298
59,300	1256.0	21,700	2.73	27.8	114,400	0.297
34,500	1250.0	17,500	1.97	22.9	83,700	0.259
43,500	1252.3	19,200	2.26	24.9	95,800	0.265
311,300	1294.3	54,800	5.68	55.4	407,500	0.391
29,300	1248.3	16,500	1.77	21.6	76,600	0.228
84,700	1261.3	25,700	3.29	31.3	143,700	0.331
195,100	1279.9	41,300	4.73	44.5	275,200	0.377

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

DATA FOR EXTENSION OF RATING CURVE AT
OBSERVATION STATION 13 = SECTION 83 = FOOT OF LITTLE DALLES

Discharge Sec.-Ft.	Water Surface Elevation Feet	Area of Cross Section A Sq. Ft.	Velocity V Ft./Sec.	Hydraulic Radius R Feet	$A\sqrt{R}$	$K = V/R^{2/3}$
21,100	1243.3	10,100	2.09	15.9	40,300	0.331
42,700	1246.6	12,600	3.39	15.2	49,100	0.552
18,900	1242.5	9,500	1.99	16.6	38,700	0.306
265,400	1269.7	30,000	8.84	32.3	170,500	0.871
288,000	1271.3	31,300	9.20	33.6	18[illegible],500	0.882
306,000	1273.1	32,800	9.32	34.9	193,800	0.872
341,000	1275.6	34,800	9.80	36.8	211,100	0.884
297,000	1272.2	32,100	9.26	34.3	187,900	0.876
116,700	1256.5	20,000	5.83	22.5	94,900	0.731
39,500	1246.2	12,400	3.19	14.9	47,800	0.527
43,000	1246.7	12,600	3.41	15.2	49,100	0.556
346,000	1276.1	35,200	9.83	37.2	214,800	0.881
422,500	1281.0	39,100	10.81	40.9	250,000	0.910
381,600	1278.0	36,700	10.40	38.6	228,000	0.906
57,700	1249.1	14,500	3.98	17.1	60,000	0.600
25,800	1243.8	10,400	2.48	15.5	40,900	0.397
22,100	1243.2	10,000	2.21	16.0	40,000	0.348
17,800	1242.2	9,400	1.89	16.8	38,500	0.288
22,500	1243.4	10,200	2.21	16.7	40,400	0.353
21,700	1243.0	9,800	2.21	16.1	39,300	0.346
39,400	1246.9	12,800	3.08	15.3	50,000	0.500
88,000	1253.6	17,900	4.94	20.4	80,800	0.662
138,200	1258.9	21,800	6.34	24.3	107,500	0.756
195,200	1264.4	25,900	7.54	28.4	138,000	0.810
234,500	1267.6	28,400	8.26	30.8	157,700	0.870
258,600	1268.9	29,300	8.82	31.8	165,200	0.872
312,000	1273.1	32,900	9.48	34.9	194,400	0.887
361,500	1276.4	35,400	10.18	36.4	214,100	0.926
288,600	1271.1	31,200	9.25	33.4	180,300	0.890
251,600	1268.8	29,300	8.58	31.7	165,000	0.854
219,800	1266.0	27,000	8.13	29.6	147,000	0.850
187,900	1263.2	25,000	7.51	27.6	131,000	0.824
158,900	1261.0	23,3[illegible]0	6.82	25.8	118,300	0.782
137,000	1258.5	21,[illegible]00	6.37	24.0	105,300	0.766
107,500	1255.4	19,200	5.60	21.7	89,400	0.720
91,600	1253.8	18,000	5.09	20.5	81,400	0.680

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

DATA FOR EXTENSION OF RATING CURVE AT
OBSERVATION STATION 13 = SECTION 53 = FOOT OF LITTLE DALLES

Discharge Sec.-Ft.	Water Surface Elevation Feet	Area of Cross Section A Sq. Ft.	Velocity V Ft./Sec.	Hydraulic Radius R Feet	AVR	$K = \frac{V}{R^{2/3}}$
72,400	1251.2	16,100	4.50	18.7	69,800	0.640
47,600	1247.5	13,300	3.58	15.8	52,800	0.568
38,100	1246.0	12,100	3.23	14.7	46,400	0.538
29,800	1244.7	11,100	2.68	14.7	42,600	0.447
22,000	1243.0	9,800	2.25	16.1	39,300	0.353
16,700	1242.0	9,200	1.81	16.9	37,800	0.275
259,600	1268.9	29,400	8.83	31.6	165,300	0.883
363,200	1276.2	35,300	10.27	37.4	215,800	0.918
92,200	1253.6	17,800	5.16	20.4	80,400	0.693
215,800	1264.7	26,100	8.26	28.6	139,500	0.883
226,300	1266.6	27,500	8.23	30.0	150,500	0.852
59,300	1249.4	14,800	4.00	17.3	61,600	0.598
34,500	1245.3	11,700	2.94	14.4	44,400	0.497
43,500	1246.8	12,700	3.42	15.2	49,500	0.556
311,500	1272.8	32,500	9.58	34.6	191,500	0.902
29,300	1244.2	10,900	2.69	15.0	42,200	0.443
84,700	1252.8	17,100	4.95	19.7	75,800	0.679
195,100	1263.9	25,500	7.65	27.9	134,600	0.831

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

MAXIMUM DISCHARGES OF COLUMBIA RIVER (SECOND-FEET)

Year	The Dalles, Oregon	Kettle Falls, Wash.	Year	The Dalles, Oregon	Kettle Falls, Wash.
1858	563,000	326,000	1880	914,000	530,000
1859	874,000	507,000	1881	598,000	347,000
1860	668,000	387,000	1882	883,000	512,000
1861	618,000	358,000	1883	573,000	332,000
1862	948,000	550,000	1884	698,000	405,000
1863	777,000	450,000	1885	482,000	280,000
1864	654,000	379,000	1886	673,000	388,000
1865	714,000	414,000	1887	896,000	519,000
1866	832,000	486,000	1888	564,000	327,000
1867	671,000	388,000	1889	302,000	174,000
1868	438,000	254,000	1890	633,000	367,000
1869	328,000	189,000	1891	448,000	260,000
1870	777,000	450,000	1892	607,000	352,000
1871	856,000	496,000	1893	679,000	394,000
1872	737,000	427,000	1894	1,160,000	670,000
1873	638,000	370,000	1895	475,000	276,000
1874	582,000	338,000	1896	785,000	455,000
1875	684,000	396,000	1897	780,000	452,000
1876	1,000,000	580,000	1898	649,000	376,000
1877	486,000	282,000	1899	787,000	456,000
1878	485,000	282,000	1900	536,000	310,000
1879	643,000	373,000	1901	662,000	384,000

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

MAXIMUM DISCHARGES OF COLUMBIA RIVER (SECOND-FEET)

Year	The Dalles, Oregon	Kettle Falls, Wash.	Year	The Dalles, Oregon	Kettle Falls, Wash.
1902	644,000	373,000	1921	775,000	420,000
1903	787,000	456,000	1922	677,000	375,000
1904	629,000	364,000	1923	581,000	371,000
1905	412,000	238,000	1924	433,000	287,000
1906	374,000	217,000	1925	642,000	373,000
1907	587,000	341,000	1926	269,000	168,000
1908	653,000	379,000	1927	690,000	415,000
1909	675,000	391,000	1928	766,000	466,000
1910	566,000	328,000	1929	460,000	313,000
1911	574,000	333,000	1930	332,000	246,000
1912	568,000	329,000	1931	308,000	241,000
1913	759,000	468,000	1932	578,000	354,000
1914	493,000	286,000	1933	722,000	438,000
1915	328,000	189,000	1934	453,000	371,000
1916	727,000	458,000	1935	480,000	337,000
1917	727,000	367,000	1936	529,000	374,000
1918	578,000	396,000	1937	379,000	258,000
1919	553,000	309,000	1938	609,000	345,000
1920	428,000	332,000	1939	387,000	

From 1858 to 1912, incl., discharge at Kettle Falls estimated at 58% of that at The Dalles; from 1913 to 1938, incl., discharge at Kettle Falls obtained from Water-Supply Papers of U. S. Geological Survey.

From 1858 to 1894, incl., discharge at Kettle Falls equalled or exceeded discharge of 1928 nine times. From 1895 to 1939, incl., discharge at Kettle Falls equalled or exceeded discharge of 1928 two times. From 1858 to 1939, incl., discharge at Kettle Falls equalled or exceeded discharge of 1928 eleven times.

CHAPTER IV - BACKWATER COMPUTATIONS

38. Method used to compute backwater profiles. Many hydraulicians have spent considerable time and energy in developing formulas for computing the water-surface profile resulting from placing an obstruction or erecting a dam in a stream. The end sought is a mathematical formula which will give direct results; this is obtained by ignoring or neglecting one or more of the large number of variables usually present in a natural stream. The use of such formulas usually presents little advantage over the use of Bernoulli's theorem, from which all are derived, and the results obtained always are more or less uncertain when they are applied to a natural watercourse. On the other hand, the use of Bernoulli's theorem affords a method which is very flexible and in which any number of variables can be introduced, so that the solution is exact within the limits of the arithmetic integration necessary and to the extent to which the various factors entering the problem can be evaluated. This method was, therefore, used for the solution of the problem in hand, with a limited use of some of the other formulas where applicable; friction losses were estimated by use of either the Manning or the Kutter-Chezy formula, according to circumstances.

The friction formula and other factors for natural flow used in analyzing the water-surface profiles should be considered and used in computing the backwater profiles. In this way unsound formulas or faulty methods will result in less error than if a change in method or formula were made in computing the backwater curve. The only friction formulas used in analyzing the field data were the Manning and the Kutter-Chezy formulas. Since it was found that the roughness coefficient (n) used in both these formulas was not constant, methods used to compute the backwater curve should permit a variation in n, which can be done only by the use of the basic Bernoulli theorem. This theorem may be expressed as follows (J. C. Stevens (14)):

$$h_{1-2} = \frac{V_1^2}{2g} - \frac{V_2^2}{2g} + f\ (h_v) + K\ \frac{\ell}{R_m}\ \frac{V_m^2}{2g}$$

Here $f\ (h_v)$ is a function of change in velocity head in the reach and is used to take care of enlargement or contraction loss.

V_1 = mean velocity at the downstream end of the reach.
V_2 = mean velocity at the upstream end of the reach.

V_m = mean velocity throughout the reach = $\frac{V_1 + V_2}{2}$.
K = friction coefficient.
ℓ = length of reach.
R_m = mean hydraulic radius for the reach = $\frac{R_1 + R_2}{2}$.
h_{1-2} = difference in water-surface level between upstream and downstream end of the reach.

The last term of the equation gives the friction loss, where $K = \frac{2g}{C^2}$ and the value of C is determined by either the Manning or the Kutter formula. This expression for the difference of water-surface level requires a trial and error solution.

As is well known, for low velocities the Manning formula gives steeper slopes and consequently higher losses than the Kutter-Chezy formula. This tendency is shown by figure 21, where values of K computed by several well-known formulas are shown. To make the results conservative, where the energy gradient was excessively flat the Manning formula was used to compute the friction loss; where the slopes were steeper the Kutter formula was used.

A computation of the amount of backwater that would exist at the International Boundary with the reservoir water surface at elevation 1290.0 at the dam was made for zone 4 using the "unit fall" method (30). The results obtained checked those found by the method used in this report when using either natural or backwater roughness coefficients to within two-tenths of a foot for a discharge of 650,000 second-feet.

39. Variation in roughness coefficient with stage or discharge. In chapter III, it was shown that the analysis of the field data gave variable roughness coefficients. Moreover, it was impossible to determine how much of the variation in roughness coefficient was due to a change in discharge and how much was due to a change in stage. For natural flow, when a water-surface profile was computed above the range of field observations, n was considered to be dependent upon discharge, and the n-discharge curves were extended to obtain values of the roughness coefficient applicable to higher discharges. Here there is an increase in both stage and discharge, but the increase in stage is dependent upon natural controls and friction losses of the river channel and is fairly uniform throughout the length of the river. With an increase in discharge and stage, there is usually an increase in velocity. Under backwater conditions, the stage may be increased without a corresponding

increase in discharge, and the velocity will be decreased somewhat in proportion to the increase in stage. The important question is whether, under backwater condition, n should more properly vary with the stage or with the discharge. Actually, it probably varies with both, but it is impossible to take account of such variation with the field data available. Possible reasons for this variation have previously been given. They are: (a) faulty relationships in the friction formulas; (b) failure to make proper allowance for secondary loss such as enlargement, contraction, and bend losses, which are then included in the roughness coefficient; (c) difference in the roughness of the sides and bottom of the river channel; (d) change in ratio between size of protuberances of channel and cross section of water prism with variation in stage. It is impossible to say which of the above reasons accounts for the variation in roughness coefficient. If the variation is due to the change in roughness of the channel with stage, then, for backwater conditions, n should be a function of the stage. The variation may be due to failure to evaluate secondary losses properly; if these are taken too small, the tendency would be to show increased friction loss, or an increase in the value of n; if too large, a decrease in that value. The data do actually show such a decrease, and it might therefore be suspected that the variation of n with discharge, or velocity, is due to assuming too large values of secondary losses. However, computations made assuming no less except friction show the same tendency to decrease, so it was concluded that the value of n should be assumed to vary with stage (backwater n). Model tests confirmed this conclusion. Backwater curves were also computed assuming the value of n to vary with discharge (natural n).

When the roughness coefficient is considered as a function of the discharge, the backwater-surface profiles for any particular discharge are computed using the same roughness coefficients that were found to exist when that particular discharge was flowing under natural flow conditions. These roughness coefficients are designated as natural flow n's and are listed in table XIV for the various reaches.

If the roughness coefficient is considered to vary with the stage, curves of n plotted against river stage, or some function thereof, will define the relation. The curves of n plotted against mean water-surface elevation, wetted perimeter, and hydraulic radius, figures 12, 13, and 14, show this relation for each reach. For natural stages below the highest water-surface profile observed in the field, the value of n for any reach is the same when taken from any of these three curves; it is also the same for backwater stages at the elevation for a natural

flow of 650,000 second-feet. Where the values of n given by the curves differ, a mean of the three values was used for backwater computations. A list of these values of n for reservoir elevation 1290.0 at the dam may be found in table XIV. These roughness coefficients are designated as backwater n's since on the n curves, they correspond to a stage of the river caused by backwater conditions. The values of these backwater n's could not be determined until the approximate mean water-surface elevation was known for a given reach. The selection of the proper backwater n was combined with the trial-and-error process of computing the backwater profiles, and, since the values of n did not change materially with the small adjustments necessary, the computations were not appreciably complicated.

Backwater profiles were computed using values of n for both backwater and natural flow. For nearly all reaches, the value of n decreased with increases in either stage or discharge, and the stage of the river for backwater condition for a given discharge was, of course, higher than for natural flow; thus, for a given stage, the backwater n was usually smaller than the natural n. A typical relation, for the reach between section 96 and section 97, is shown on figure 9. Since the backwater n's were smaller, they gave less friction loss and lower water-surface profiles than the natural n's. It is considered that these profiles give the correct solution of the problem. Profiles obtained by using values of n for natural flow were also computed. In drawing conclusions, the lower profile has been used.

40. River flow condition brought about by backwater. With the construction of Grand Coulee Dam, the normal water surface will be raised from an elevation of 945.0 to 1290.0, or the depth of the river will be about 12 times what it was under natural flow conditions. With the reservoir full, the natural river channel near the dam forms only a small portion of the cross section and its properties and characteristics will have very little effect on the properties of the new channel. As one proceeds upstream from the dam, the natural river channel becomes a larger portion of the cross section until at the International Boundary they are nearly the same. For a complete profile of the reservoir and natural river, see figure 22. All rapids, waterfalls, and irregular cross sections in the lower portion of the reservoir will be submerged to great depths and will no longer offer a high resistance to the flow of water. The flow conditions in a large reservoir are not well understood. It is improbable that the whole mass of water moves forward at a very slow velocity; rather, only a small core of the mass moves forward at

a much higher velocity. The friction loss in the reservoir is computed as if the whole water mass moved slowly forward. If only a small portion moves forward, the velocity is much higher and the hydraulic radius is smaller, both factors tending to give a greater friction loss; but the roughness coefficient must be less where there is a wide zone of transition between the still water and the mass of moving water, and the smaller roughness coefficient may compensate for the higher velocity and smaller hydraulic radius. In any event, the friction loss in the deeper portion of the reservoir is only a small percentage of the total loss from the dam to the International Boundary.

In general, no exact division line can be drawn where the flow in a river channel becomes a current of water surrounded by the still water of a lake or where the properties of the river channel change to the properties of the reservoir. The change is gradual and is influenced a great deal by the amount of water discharged. For the Columbia River Reservoir, however, there is a rise of 36 feet in the river bed at Kettle Falls, which divides the reservoir from the river effectively. It was assumed that below this point the reservoir would act as a lake with nearly a level water surface while above this point the flow would approach that of a natural river. At normal discharge, the depth of the river just above Kettle Falls, with the reservoir water surface at elevation 1290.0 at the dam, will be about 4 times the depth for natural flow whereas at the dam the depth will be about 12 times the depth for natural flow. The friction loss in the reservoir is related to the ratio of the depth under backwater conditions to the depth under natural flow conditions. When the value of this ratio is high, the friction loss is nearly zero, and as it decreases the friction loss increases, becoming equal to that of the existing natural river when it reaches unity. A considerable change in water surface, located a great distance from some point on the river, will cause little or no change in the water surface at that point. This principle affects the accuracy required when computing backwater profiles along the reservoir, especially when it is realized that the portion of the reservoir with which this report is concerned is a stretch of river immediately adjacent to the International Boundary, 150 miles upstream from Grand Coulee Dam. As these two factors, the distance from the International Boundary and the ratio of depth for backwater to depth for natural flow, increase from the International Boundary toward the dam, the required degree of accuracy decreases. In each of the four zones into which the reservoir was divided, suitable requirements of accuracy were adhered to in computing the backwater profiles.

41. Backwater computations for zone 1. In zone 1, which extends from the dam to just above Kettle Falls, the water surface will be nearly level, there being a rise of only 0.7 foot in the water surface at the upper end of this long narrow lake for a flood of 400,000 second-feet. Since the friction slopes will be very flat, the Manning formula was used to compute the friction loss. Fifty-three river cross sections were used in the 111.0-mile length of reservoir included in zone 1. A roughness coefficient of $n = 0.035$ was used for each reach. As previously explained, the old river channel will have lost its identity in the newly formed reservoir, and the value of n applicable in this zone would have very little relation to that of the natural river channel. The value of $n = 0.035$ was selected partly as the result of measurements on the Columbia River above Marcus, where the natural river flows in a deep channel with very little disturbance, giving a value of n at high flows of 0.034. King's Handbook of Hydraulics (33) lists for a winding natural stream channel with some pools and shoals a value of n varying from 0.033 to 0.045. The velocities in the reservoir, when based on cross-sectional area of the reservoir, will be very small; even for the larger discharges, the velocities will nearly always be less than 1.0 foot per second. As the water entering the reservoir will never carry very much silt, the cross-sectional area will be sensibly unchanged for a long period of time; the effect of silting was therefore ignored. No attempt was made to compute the enlargement loss in any reach, and the velocity head was so small that the water surface was taken as the energy gradient.

It is not necessary to know the exact water-surface profile for zone 1 but only to know the water-surface elevation at the upper end of the zone so as to be able to start backwater computations for the next zone. The profile as determined at each river cross section was computed only for a discharge of 650,000 second-feet, with water-surface elevations 1290.0 and 1280.0 at the dam. The friction loss in this zone for a discharge of 650,000 second-feet, with the reservoir elevation 1290.0 at the dam, was only 1.71 feet. A method used by Harza (22) and also by Grimm (13) to compute the friction loss in a reach of river where the stage and friction loss are known for one discharge and where it is desired to find the friction loss for other discharges at approximately the same stage was used to determine water-surface elevations at the upper end of the zone for other discharges and elevations at the dam. The formula is $h_x = (\frac{Q_x}{Q})^2 h$, where h equals the known friction loss or, in this case, the change in water surface for the discharge Q, and h_x equals the desired change in water surface corresponding to a discharge Q_x. When the reservoir water-surface elevation is

1290.0 at the dam, the water-surface elevations at the upper end of zone 1 will be between 1290.0 and 1291.7 for all discharges. The above formula is applicable, and the change in water surface through zone 1 for any discharge is found from $h_x = 1.71 \left(\frac{Q_x}{650,000}\right)^2$. Similarly, when the reservoir is at elevation 1280.0 at the dam, the expression of the change of water surface at any discharge is $h_x = 5.02 \left(\frac{Q_x}{650,000}\right)^2$. Figure 23a is a graph plotted with water-surface elevation at the dam as the ordinate and change in water surface through zone 1, from the dam to observation station 17, as the abscissa, for discharges of 100,000, 200,000, 300,000, 400,000, 500,000, and 650,000 second-feet. The extension of the curves below elevation 1280.0 at the dam will be discussed under backwater computation for zone 2.

42. Backwater computations for zone 2. The backwater surface profiles in zone 2 were computed for discharges of 20,000, 100,000, 200,000, 300,000, 400,000, 500,000, and 650,000 second-feet, with water surfaces at elevations 1290.0 and 1280.0 at the dam, using backwater n. The change in water-surface elevation through zone 2 for a discharge of 650,000 second-feet was too great to permit computing the head loss for other discharges by the same method as was used for zone 1. A sample computation of the backwater surface profile will be discussed later for zone 4, table XXII. The change in velocity head between river cross sections and the enlargement loss through the reaches were taken into account in the backwater computation for this zone. A constant roughness coefficient (n = 0.037 for the Kutter formula and n = 0.034 for the Manning formula, as previously computed) was used for all reaches except reach 81-82 and reach 82-83, which comprise only a very small portion of the zone adjacent to the Little Dalles. Backwater n's only were used as the natural river channel does not form a large enough proportion of the reservoir cross-sectional area to warrant the use of natural-flow n's. At the upper end of zone 2, at the foot of the Little Dalles, for discharges up to 100,000 second-feet the ratio of depth for backwater to depth for natural flow is greater than 2, and at the lower end of the zone the ratio is greater than 4. At larger discharges there is very little difference in the values of natural and backwater roughness coefficients. The backwater profiles were computed by both the Manning and the Kutter-Chezy formulas, and the backwater rating curves at observation station 13, upper end of zone 2, are shown on figure 24. The Manning formula gave considerably more loss than the Kutter-Chezy formula because the friction slope was still fairly flat in this zone. The profiles and rating curve computed

by the Manning formula were believed to be more accurate; also, they were more conservative to use in establishing the maximum amount of backwater.

Water-surface elevations at each river cross section were computed for backwater conditions, thus defining the surface profile and obtaining the amount of backwater that will exist at any point within the zone for any particular discharge. The backwater profiles were of very little actual use in zones 1, 2, and 3 but were used in zone 4 to study the effect on the railroad. The water-surface elevation at the upstream end of each zone was needed in order to begin computation in the next zone. The reservoir elevation at the dam will not always be at 1290.0 but might be drawn down as low as 1208.0 during a dry season, and it is desirable to know the amount of backwater that will exist when the reservoir is lower than the maximum water-surface elevation. Since only the difference of water-surface elevation for various reservoir elevations was desired for zones 1, 2, and 3, a graph was devised to give this information (see figure 23b). To construct the graph for zone 2, the difference of water-surface elevation was obtained by computing the backwater profiles for the usual discharges with the reservoir elevation first at 1290.0 and then at 1280.0. The natural water-surface elevation was subtracted from the backwater surface elevation at the foot of the zone, for that particular discharge, giving the amount of backwater at the foot of the zone, which was plotted as the ordinate of the graph, while the difference of water-surface elevation that took place within the zone was plotted as the abscissa. With natural flow there was no backwater, so the difference of water-surface elevation in the zone for natural flow, or zero backwater, would be plotted on the axis of abscissas, the ordinate being zero. On this graph, lines with a slope of minus one may be drawn through the points of difference in water-surface elevation for natural flow. These lines are simply a convenient means of subtracting the amount of backwater at the lower end of the reach from the change, or difference, of elevation due to natural flow, so that the abscissa of any point on one of these lines represents the difference of elevation between the natural water surface at the upper end of the reach and the backwater surface at the lower end corresponding to the amount of backwater given by the ordinate of the point. So long, therefore, as the water surface at the upper end does not rise above the natural surface--that is, so long as there is no backwater there--the lines are the graphs obtained by plotting the amount of backwater at the lower end against difference of water surface through the reach and may be said to be lines of no backwater at the upper end.

With backwater at the upper end, however, it is evident that the water surface will be higher than for natural flow; consequently, the difference in elevation through the reach must be more than the difference of elevation between the backwater surface at the lower end and the natural surface at the upper end, which latter quantity is represented by the abscissas of points on the straight lines. If backwater exists at the upper end, therefore, the curves of backwater--that is, of difference of elevation versus amount of backwater at the lower end--must lie to the right of the straight lines.

When the backwater just reaches the elevation for natural flow at the upper end of the reach, the abscissa of the curve of backwater is the same as that of the line of no backwater. Evidently the two cannot cross above the axis of abscissas. The difference in abscissas of the line of no backwater, representing the difference in elevation between the backwater elevation at the lower end and the natural surface at the upper end, and the curve of backwater, representing the actual difference, is evidently the amount of backwater at the upper end.

Any point on the axis of ordinates represents a level water surface through the zone. As the depth of backwater at the lower end increases, the change in elevation through the reach will approach zero; therefore, the axis of ordinates will be an asymptote to the curve of backwater. This line of no backwater acts as a guide in drawing the curve of difference of water-surface elevation.

In zone 2, for each of the usual discharges the difference of water-surface levels was known from the computed profiles with the reservoir at elevations 1290.0 and 1280.0; this gave two points on the curve for each discharge (figure 23). The curves were drawn through these two points and tangent to the no-backwater-effect lines as it was improbable that they were entirely above these lines. This may appear to be very meager information upon which to base the curves of figure 23; however, a great many points were computed for similar curves in zones 3 and 4, so that more knowledge was obtained of the behavior of these curves. Also in zone 2, the highest accuracy was not required as an error of one-half foot at the upper end of the zone would result in only 0.05-foot error at the International Boundary. Curves similar to those prepared for zone 2 were constructed for zone 1 from the profile for a discharge of 650,000 second-feet, using the method of Grimm and Harza, previously discussed, and the no-backwater line.

By means of the curves on figure 23, it is possible to start at the dam with any reservoir elevation between 1260.0 and 1295.0

for one of the usual discharges used, determine the difference of water-surface elevation for zone 1, and add this to the reservoir elevation, obtaining the water-surface elevation at the upper end of zone 1, lower end of zone 2. The amount of backwater at the lower end of zone 2, observation station 17, is the difference between this elevation and that of the natural water surface as given in the table on figure 23. Using this computed backwater, the graph is entered and the change in water surface for zone 2 obtained, which is added to the backwater-surface elevation at the lower end of zone 2 to give the backwater-surface elevation at the upper end of zone 2 or the lower end of zone 3. Similar graphs have been prepared for zones 3 and 4, so that it is possible to continue in a manner similar to that used in zone 2 and finally to obtain the backwater surface elevation at the International Boundary. If the difference between this elevation and that of the natural water surface at this point is taken, the result is the amount of backwater at the International Boundary. Table XXI illustrates the method of making the computations, beginning with a reservoir elevation of 1288.0 at the dam for all the usual discharges. In this case, natural flow n's were used in zones 3 and 4; backwater n's were always used in zones 1 and 2. All data in the above-mentioned table are for unimproved river channel at the Little Dalles.

43. Backwater computations for zone 3. Zone 3 extends from the foot of the Little Dalles, observation station 13, to the head of the Little Dalles, observation station 11, a distance of 4,789 feet, or about 0.9 mile. The large rapids known as the Little Dalles has a change in water surface throughout its length varying from a few feet for low discharges to 32 feet for a discharge of 650,000 second-feet. These rapids will not be entirely submerged by backwater, and, while the change in water surface will be much less than for natural flow, it will still be large and will constitute a large portion of the total drop in water surface from the International Boundary to the dam. Figure 6 shows the change in water surface for this zone both for natural flow and backwater conditions when using natural n's. This zone was divided into 13 reaches, but the same value of the roughness coefficient had to be used for the upper 12 reaches between section L and section 87 because of insufficient field data. This coefficient is an average one for all of the 12 reaches and, when used for these reaches, is assumed to give the same over-all difference of water-surface levels as if the correct coefficients were used for each reach. The Kutter-Chezy formula was used to determine the friction loss; results from this formula differ little from those obtained by the Manning formula. Enlargement loss and change in velocity

head were considered in the backwater computations. The resulting backwater profiles are shown on figure 40, computed with both natural n's and backwater n's. The difference in these profiles, caused by using the two different types of roughness coefficient, is greatest for discharges of 200,000 to 400,000 second-feet. For lower discharges the mean velocity is so low that the friction loss is small, and, consequently, it does not make much difference which type of roughness coefficient is used. For the higher discharges (500,000 and 650,000 second-feet), the backwater stage and natural stage are so near the same elevation that there is not much reduction in the roughness coefficient due to increase in stage, so the backwater n's are nearly as large as the natural n's. The hydraulic model of the Little Dalles included all of zone 3, so that it was possible to compare the backwater surface profiles obtained from the model with the computed ones. After the model was properly roughened, it was set so as to reproduce the backwater rating curve at observation station 13. Thus, the computed and model profiles for any particular discharge have the same water-surface elevation at observation station 13, the foot of the Little Dalles. Through the Little Dalles the water-surface profiles for the model do not agree with those computed. This was to be expected since the roughness coefficients for the reaches between section L and section 87 would vary considerably from the average roughness coefficient as computed for the entire stretch. At observation station 11, head of the Little Dalles, the model and the computed profiles are in closer agreement. The model profile shows less change in water surface through zone 3 than either of the computed backwater surface profiles using natural n's or backwater n's, except for discharges of 200,000 and 300,000 second-feet, for which the change in water surface is practically the same as that computed with backwater n's.

The difference of water-surface elevation through zone 3 obtained from the computed backwater profiles was plotted against the amount of backwater at the lower end of zone 3 for the usual discharges, resulting in a graph (figure 25) similar to the one constructed for zone 2. For a discharge of 650,000 second-feet, a curve is shown for values of n which would have had to be used to give approximately the result obtained from the model. For other discharges such values can be estimated from the other curves shown. Backwater surface profiles, from which the difference of water-surface elevation through zone 3 was obtained, were computed using both natural and backwater roughness coefficients. The difference of water-surface-elevation curves must pass through the point on the axis of abscissas corresponding to the difference of water-surface elevation for natural flow. The variation between

the difference of water-surface-elevation curves computed with the two roughness coefficients is greatest for discharges from 200,000 to 400,000 second-feet. The reasons for this are those stated previously.

The hydraulic model provided a means of checking the computed change in water-surface curves through zone 3. For any discharge different amounts of backwater were set at observation station 13, foot of the Little Dalles, and the resulting water-surface elevation was read from a gage at observation station 11, head of the Little Dalles. The difference of water-surface elevation between the two observation stations was plotted against the backwater that existed at observation station 13. (See figure 25.) This was done for several discharges, and a curve was drawn which gives the relation of the amount of backwater at the lower end of zone 3 to the difference of water-surface elevation through zone 3. Since the natural-flow rating curve as found for the model at observation station 11 (figures 33 and 35) did not agree exactly with that determined from a consideration of the field data, the difference of water-surface-elevation curves for the model do not pass through the points on the axis of abscissas representing natural flow conditions for the prototype. This discrepancy is greatest for a discharge of 50,000 second-feet, where the model could not be made to simulate the prototype. The discrepancy at 650,000 second-feet may be accounted for by the uncertainty as to the extension of the rating curve at observation station 11, and it is not known whether the computed curve or the model curve more nearly represents the change in water surface through zone 3 that will occur in the prototype.

No backwater surface profiles for zone 3 were computed for any of the proposed channel improvement plans tested for the Little Dalles. Such computations would have required selection of a new set of roughness coefficients applicable to the improved channel, which would have been very difficult. The model results for the different plans of channel improvement were used to compute the amount of backwater that would exist under such conditions. Two graphs of difference of water-surface elevation through zone 3 (figures 26 and 27) were prepared from model studies in the same manner as was described for the model difference of water-surface-elevation curves for unimproved channel. One of these graphs (figure 26) gives the difference of water-surface elevation through zone 3 with only the large solid rock island in the entrance to the Little Dalles removed. The other graph (figure 27) gives the change in water surface through zone 3 for proposed channel improvement plan No. 5. Either of these graphs may be substituted for the one with unimproved channel

and used to obtain the amount of backwater or improvement that would exist at the International Boundary should such a plan of channel improvement be carried out.

These graphs of difference of water-surface elevation through zone 3 are similar to those for zone 2 and may be used in the same manner. Values taken from the graphs for the unimproved channel (figure 25) are used in making the computations shown in table XXI.

44. Backwater computations for zone 4. Zone 4 extends from the head of the Little Dalles, observation station 11, to the International Boundary, observation station 2. Calculations made in this zone will have more influence on the results at the International Boundary than those made in any other zone; for this reason more field data were taken. A different roughness coefficient was determined for each reach, necessitating the use of a different n for each reach in computing the backwater surface profiles. In this zone the ratio of depth for backwater flow to depth for natural flow is less than two, so the slope of the energy gradient for backwater conditions is not much less than that for natural flow. The friction slope for natural flow is nearly always smaller than 0.0009 and for backwater conditions is usually greater than 0.0001. With these backwater slopes the Kutter-Chezy formula gave results that were comparable with those given by the Manning formula; the Kutter-Chezy formula was used. Enlargement loss and change in velocity head were considered in computing the backwater surface profiles in this zone.

Table XXII is shown as a sample sheet of the computations made in determining the backwater profile through zone 4. Tables similar to this were used for zones 1, 2, and 3, so that with minor variations this table is typical of and illustrates the calculations made in all zones to determine the backwater profiles for various discharges.

Because of proposed channel improvement, it was necessary to compute water-surface profiles whose initial water-surface elevation at observation station 11 was below that for natural flow conditions. Several water-surface profiles for the same discharge with different amounts of backwater at observation station 11 were computed, and the resulting changes in water surface plotted on the graph (figure 28). It was then possible to draw curves which gave the difference of water-surface elevation through zone 4 in terms of backwater or improvement at observation station 11. The break in the curve for 650,000 second-feet is caused by a shelf on the river bank a few miles below the

International Boundary, at about elevation 1335.0. The lines of no-backwater at the upper end of zone 4 (International Boundary) are shown dotted with slope equal to minus one and drawn through the axis of abscissas at the point which gives the difference of water-surface elevation through zone 4 for natural flow conditions. As previously explained, the distance parallel to the axis of abscissas between the no-backwater-effect line at the International Boundary and the difference of water-surface-elevation curve for this zone gives the amount of backwater or improvement (if negative backwater) at the International Boundary. Backwater surface profiles were computed for all the usual discharges using natural n's; and backwater n's were also used for discharges of 20,000, 100,000, 200,000, 300,000, and 400,000 second-feet. At the larger flows of 500,000 and 650,000 second-feet, the stage for backwater conditions was not much different from the stage for natural flow, so that there was not enough difference between the values of natural n's and backwater n's to warrant computing another water-surface profile with backwater n's. On figure 28 note the decrease in the distance between the change of water-surface curves through zone 4 for natural n's and backwater n's as the discharge increases or, actually, as the ratio of the depth for backwater to the depth for natural flow approaches unity. For the lower discharges, a small amount of backwater at section 87 will cause no backwater effect at the boundary. That is, the backwater profiles, for all practical purposes, coincide with the natural water-surface profiles before they reach the boundary. The extent of the backwater curve is influenced considerably by the roughness coefficient used. For example, a discharge of 100,000 second-feet, using backwater n's results in the backwater profile becoming tangent to the natural profile before reaching the International Boundary even if the reservoir is held up to 1290.0 at the dam.

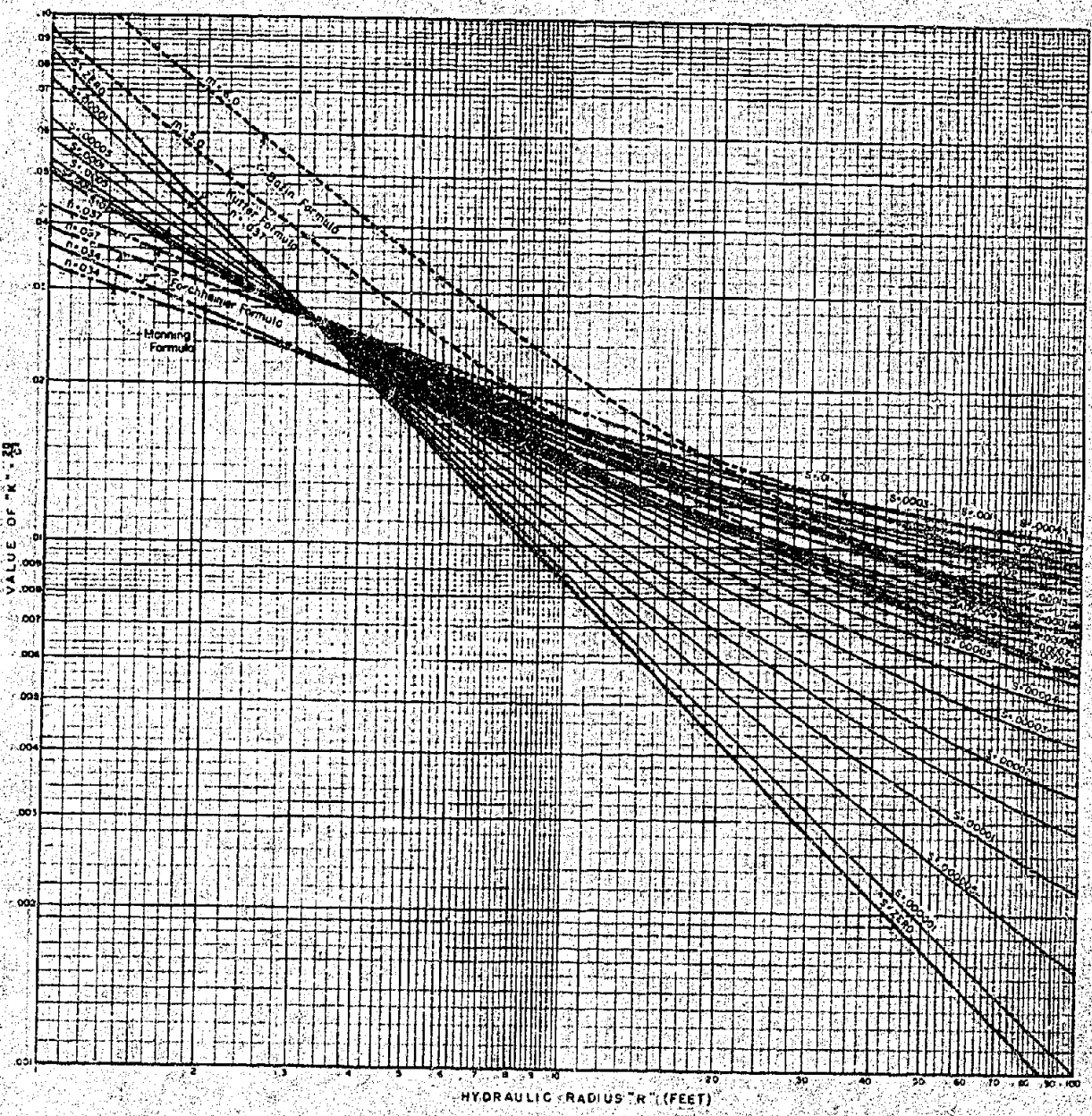
Computed water-surface profiles for unimproved channel with the reservoir at elevation 1290.0 at the dam are shown on figure 29. The natural water surface as observed in the field up to and including a discharge of 400,000 second-feet and the computed natural water surface for discharges of 500,000 and 650,000 second-feet are also shown. The Manning formula was used in zone 2 to compute the backwater profile shown as curve 1 while the Kutter-Chezy formula was used for curve 2. Figure 24 shows the difference in backwater rating curves at the foot of the Little Dalles, section 83, but, by the time the surface curves reached the International Boundary, this difference has been reduced to small proportions. On figure 29, for a discharge of 300,000 second-feet there was a difference of 1.7 feet between curve 1 and curve 2 at station 83, but the difference had reduced

to 0.13 foot at the boundary. The effect of using natural or backwater n's in zones 3 and 4 is shown by the difference between curve 2 and curve 4.

To aid in defining the limits of the amount of backwater at the International Boundary and to locate the terminal point of several different curves, a condition of zero discharge was considered. This condition will never occur. The rating curve for observation station 2, International Boundary, figure 15, was extended to zero discharge where it was determined that the water-surface elevation would be 1284.2. There is a hole at this point, and the lowest elevation of the bed is 1272.0. If it were possible to have zero discharge with the reservoir elevation 1288.0 at the dam, there would be 3.8 feet of backwater at the boundary; with reservoir elevation of 1290.0 at the dam, the minimum probable discharge at the boundary would be about 18,000 second-feet with about 2 feet of backwater.

Water-surface profiles for only a few water-surface elevations at the downstream end of zone 4, corresponding to different water-surface elevations of the reservoir, or different channel improvements, were computed, which defined the water-surface elevation at each of the river cross sections. It has been shown in this chapter how the losses or difference of water-surface elevation through the various zones were used to make up the graphs on figures 23, 25, and 28, which were relied upon to give the water surface at the upper end of the zones or at the boundary for all the varying reservoir elevations at the dam with various channel improvements at the Little Dalles and using either backwater n's or natural n's in zones 3 and 4. It was also possible to use the difference of water-surface elevation through zone 3 as determined from model experiments rather than the computed results for the unimproved channel and to ascertain the corresponding backwater at the International Boundary. If it were desired to calculate the water-surface elevation at the boundary with either the improved channel according to plan 5 or with the rock island at the entrance to the Little Dalles removed to elevation 1255.0, it would be necessary only to substitute either figure 26 or figure 27 for figure 25, which gives the computed difference of water-surface elevation through the Little Dalles with an unimproved channel.

FIGURE 21



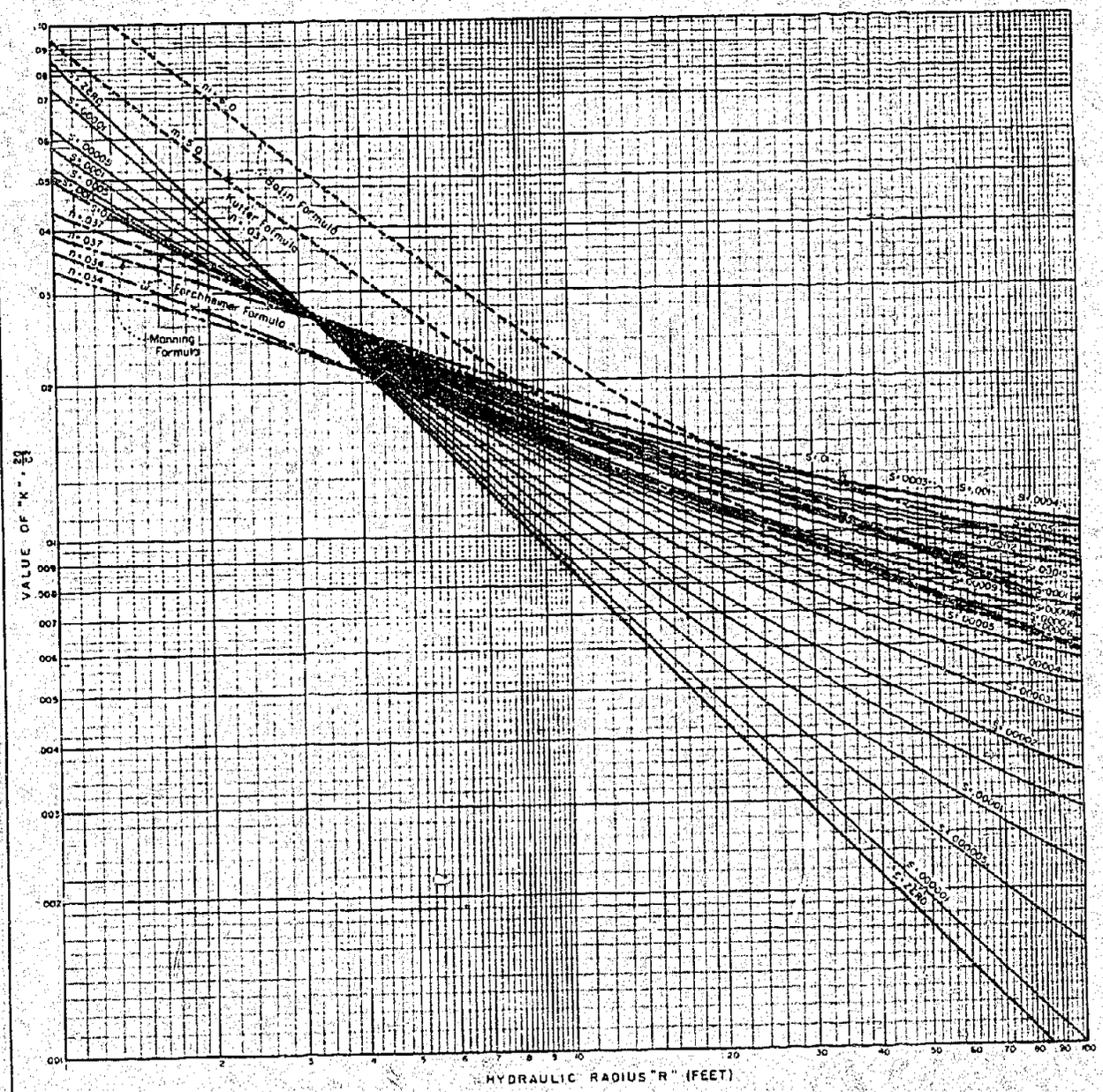
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

FRICTIONAL RESISTANCE – BY VARIOUS FORMULAE

VALUE OF K IN: $h_f = K \frac{1}{R} \frac{V^2}{2g}$

222-D-6892

FIGURE 21

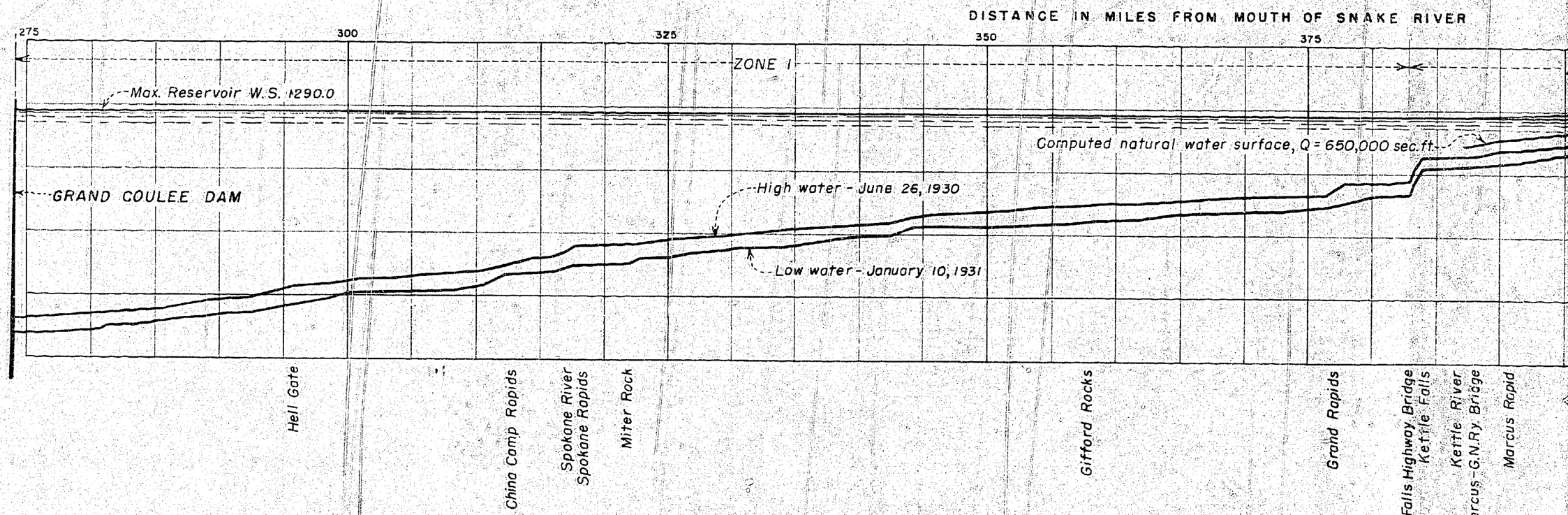


COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

FRICTIONAL RESISTANCE – BY VARIOUS FORMULAE

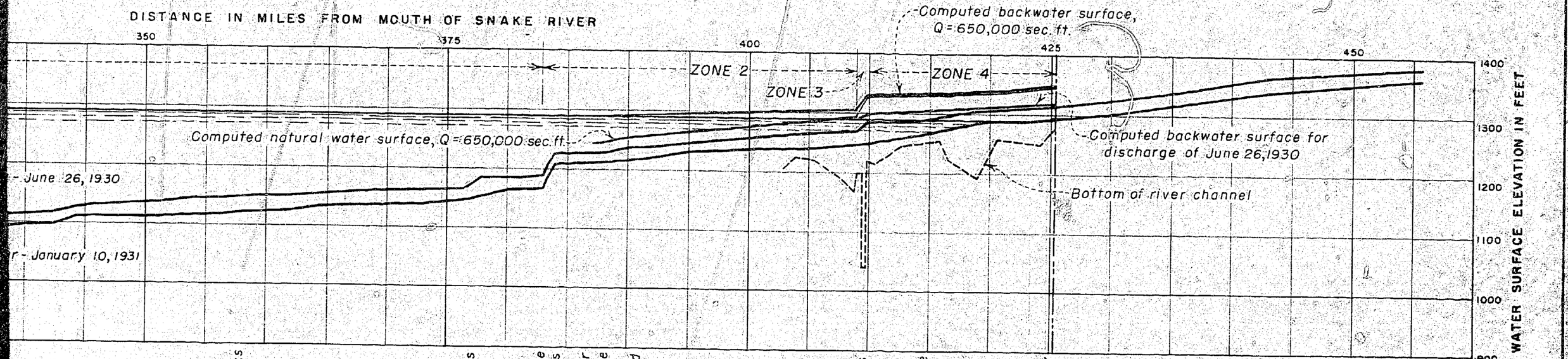
VALUE OF K IN $h_f = K \frac{L}{R} \frac{V_m^2}{2g}$

222-D-6899



NOTE
Data from U.S. Army Corp of Engineers, U.S. Geological Survey and Dominion Water and Power Bureau of Canada.

FIGURE 22

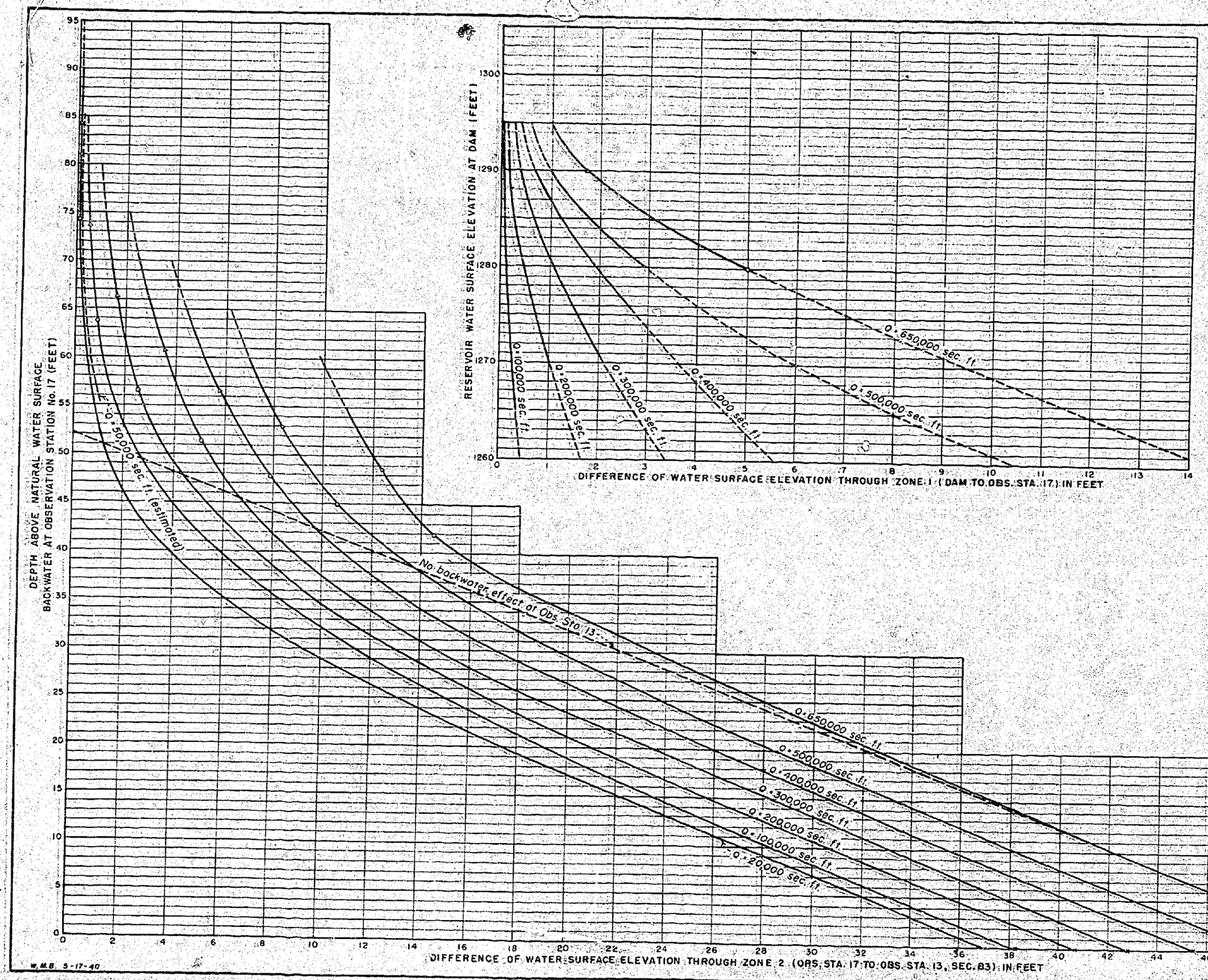


NOTE
S. Army Corp of Engineers,
cal Survey and Dominion Water
Bureau of Canada.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT-WASHINGTON
COLUMBIA RIVER RESERVOIR
WATER SURFACE PROFILES

DRAWN. C.A.W. SUBMITTED. F.B. Keenes
TRACED. E.E.J. H.S. RECOMMENDED. J. Walden
CHECKED. W.M.B. APPROVED.
DENVER, COLO. AUG. 20, 1940
222-D-6383
REV. 8-17-40

FIGURE 23



NOTES

To obtain water surface elevation at Sec. 83, Obs. Sta. 13, foot of Little Dalles.
Given the discharge at Little Dalles and the reservoir W.S. Elev. at the dam.

1. *From diagram obtain the rise in water surface through Zone 1.*
2. *To W.S. Elev at dam add rise in water surface through Zone 1 to obtain W.S. Elev. at Obs. Sta. 17.*
3. *From W.S. Elev at Obs. Sta. 17 subtract natural W.S. Elev. at Obs Sta. 17 to obtain backwater at Obs. Sta 17.*
4. *From diagram obtain rise in water surface through Zone 2.*
5. *To W.S. Elev. at Obs. Sta. 17 add rise in water surface through Zone 2 to obtain W.S. Elev. at Sec. 83, Obs. Sta. 13.*

EXPLANATION

× *Designates difference of water surface elevation, natural flow conditions.*
△ *Designates computed points by Manning's formula, W.S. at dam = El. 1290, backwater n's.*
○ *Designates computed points by Manning's formula, W.S. at dam = El. 1280, backwater n's.*

DISCHARGE AT LITTLE DALLES SEC.-FT.	NATURAL W.S. ELEV. AT OBS. STA. 17 FEET	NATURAL W.S. ELEV. AT OBS. STA. 13 FEET
0	1195.00	1238.00
20,000	1205.70	1242.72
50,000	1210.85	1248.00
100,000	1216.40	1254.65
200,000	1223.90	1264.59
300,000	1229.60	1272.45
400,000	1234.10	1279.52
500,000	1238.00	1286.05
650,000	1243.20	1295.37

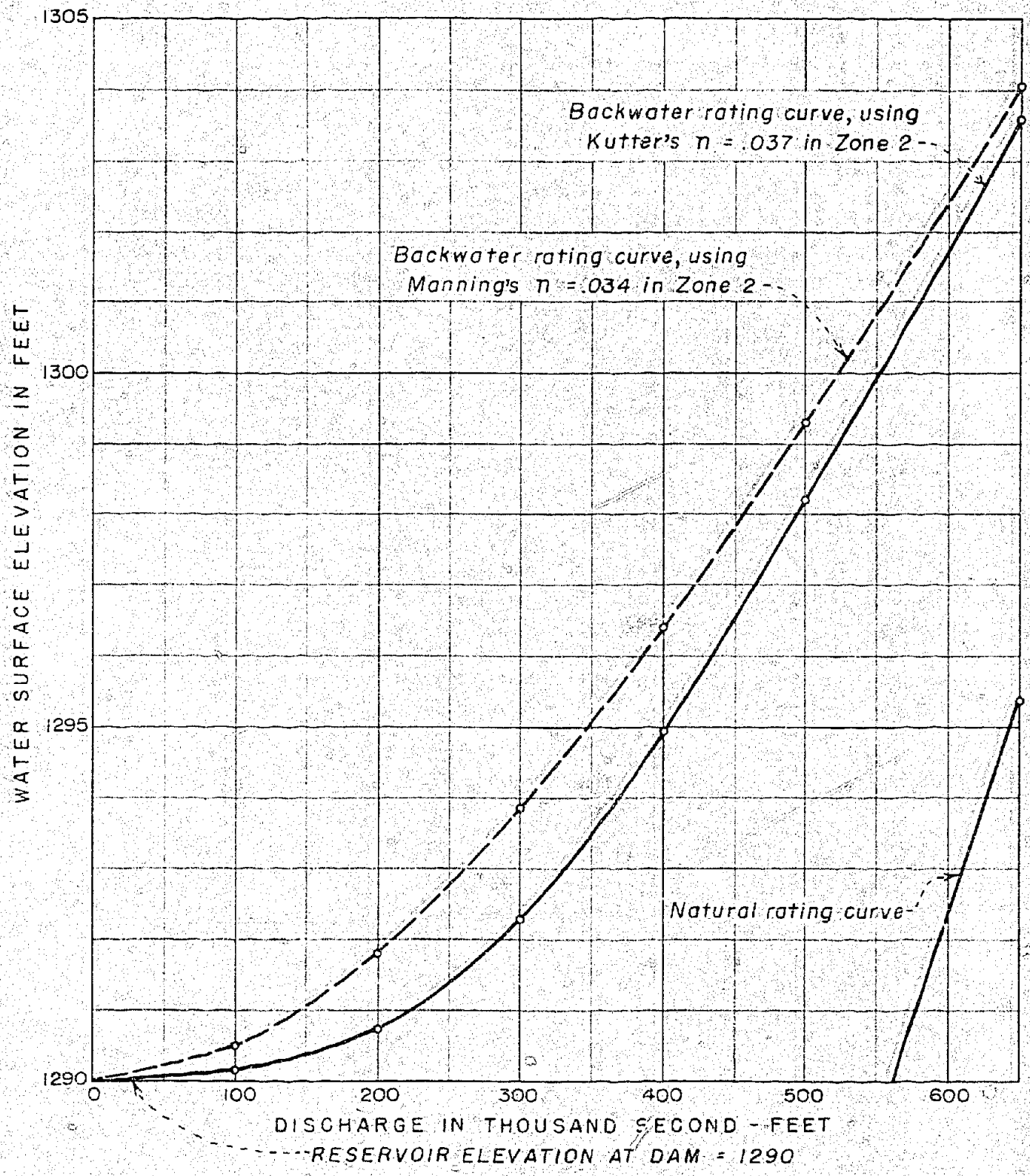
COLUMBIA RIVER RESERVOIR

BACKWATER STUDIES

DIFFERENCE OF WATER SURFACE ELEVATION THROUGH ZONES 1 AND 2
GRAND COULEE DAM TO SEC. 83, OBS. STA. 13, FOOT OF LITTLE DALLES

222-D-6900

FIGURE 24



COLUMBIA RIVER RESERVOIR

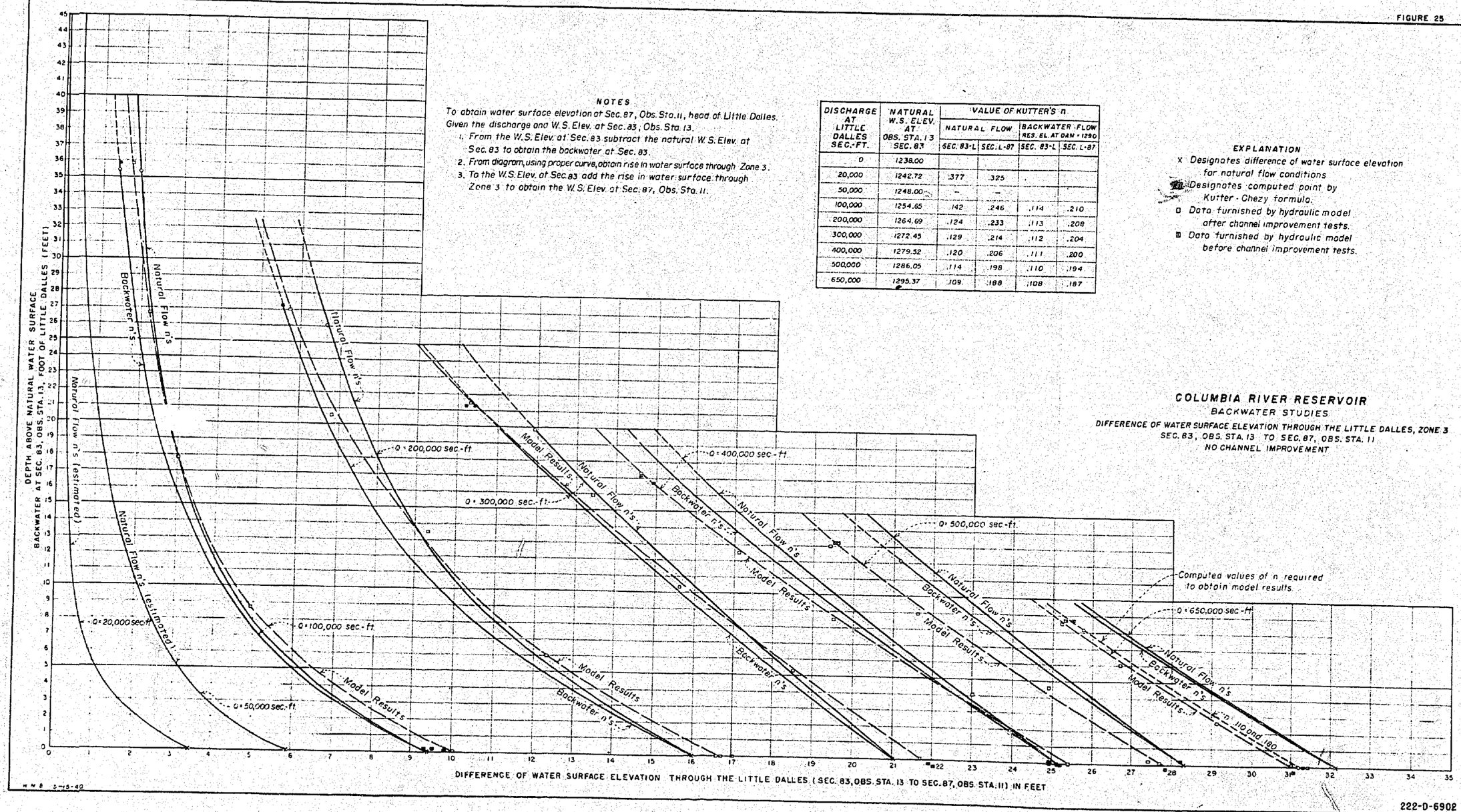
BACKWATER STUDIES

RATING CURVES FOR OBS. STA. 13, FOOT OF LITTLE DALLES

2-7-1940 C.A.W.

222-D-6901

FIGURE 25



222-D-6902

NOTES

To obtain water surface elevation at Sec. 87, Obs. Sta. 11, head of Little Dalles. Given the discharge and W.S. Elev. at Sec. 83, Obs. Sta. 13.

1. From the W.S. Elev. at Sec. 83 subtract the natural W.S. Elev. at Sec. 83 to obtain the backwater at Sec. 83.
2. From diagram, using proper curve, obtain rise in water surface through Zone 3.
3. To the W.S. Elev. at Sec. 83 add the rise in water surface through Zone 3 to obtain the W.S. Elev. at Sec. 87, Obs. Sta. 11.

DISCHARGE AT LITTLE DALLES SEC.-FT.	NATURAL W.S. ELEV. AT OBS. STA. 13 SEC. 83	VALUE OF KUTTER'S n			
		NATURAL FLOW		BACKWATER FLOW RES. EL. AT DAM = 1290	
		SEC. 83-L	SEC. L-87	SEC. 83-L	SEC. L-87
0	1238.00				
20,000	1242.72	.377	.325		
50,000	1248.00	—	—		
100,000	1254.65	.142	.246	.114	.210
200,000	1264.69	.124	.233	.113	.208
300,000	1272.45	.129	.214	.112	.204
400,000	1279.52	.120	.206	.111	.200
500,000	1286.05	.114	.198	.110	.194
650,000	1295.37	.109	.188	.108	.187

EXPLANATION

X Designates difference of water surface elevation for natural flow conditions

Designates computed point by Kutter - Chezy formula.

□ Data furnished by hydraulic model after channel improvement tests.

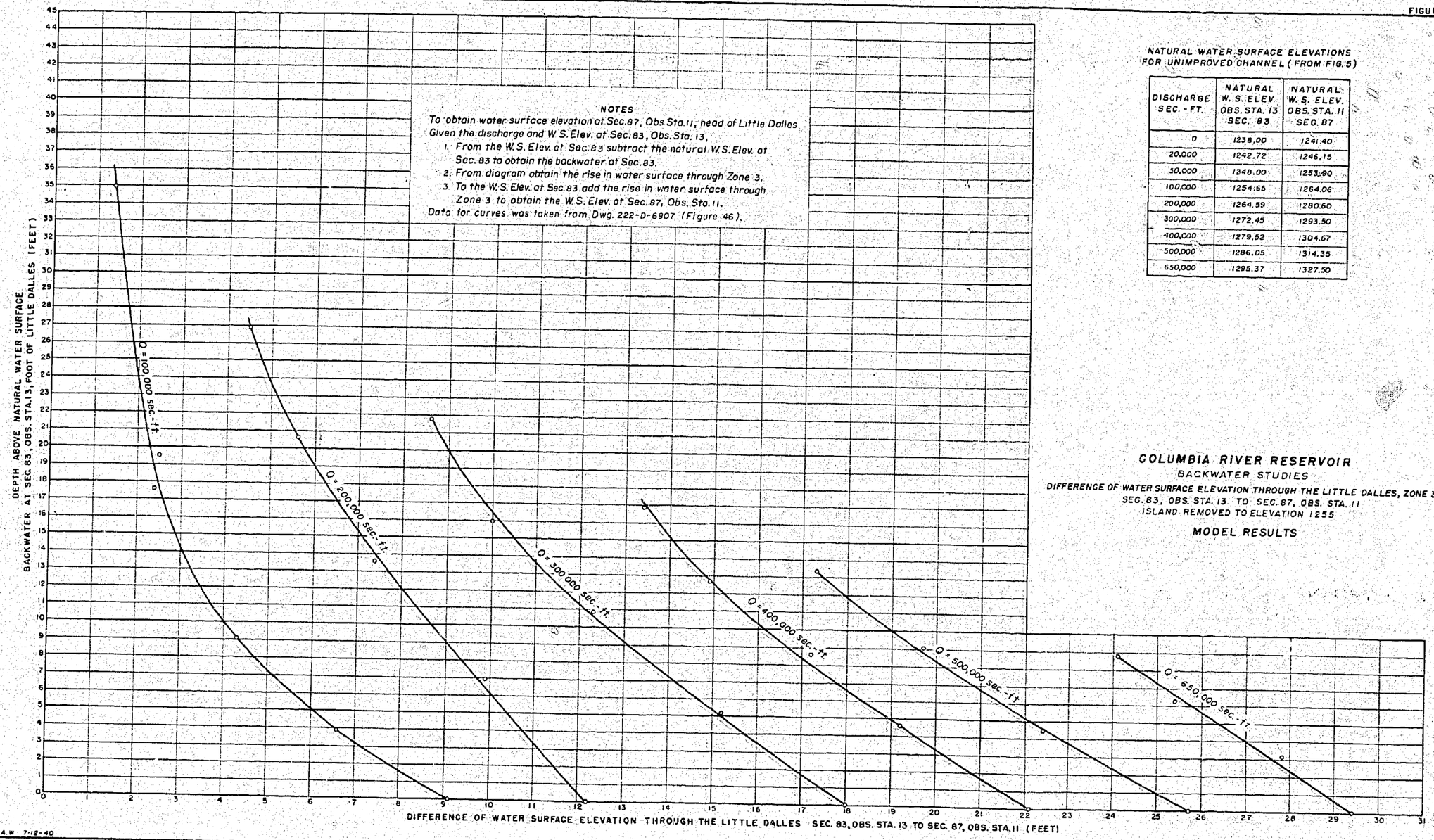
▨ Data furnished by hydraulic model before channel improvement tests.

COLUMBIA RIVER RESERVOIR

BACKWATER STUDIES

DIFFERENCE OF WATER SURFACE ELEVATION THROUGH THE LITTLE DALLES, ZONE 3
SEC. 83, OBS. STA. 13 TO SEC. 87, OBS. STA. 11
NO CHANNEL IMPROVEMENT

FIGURE 26



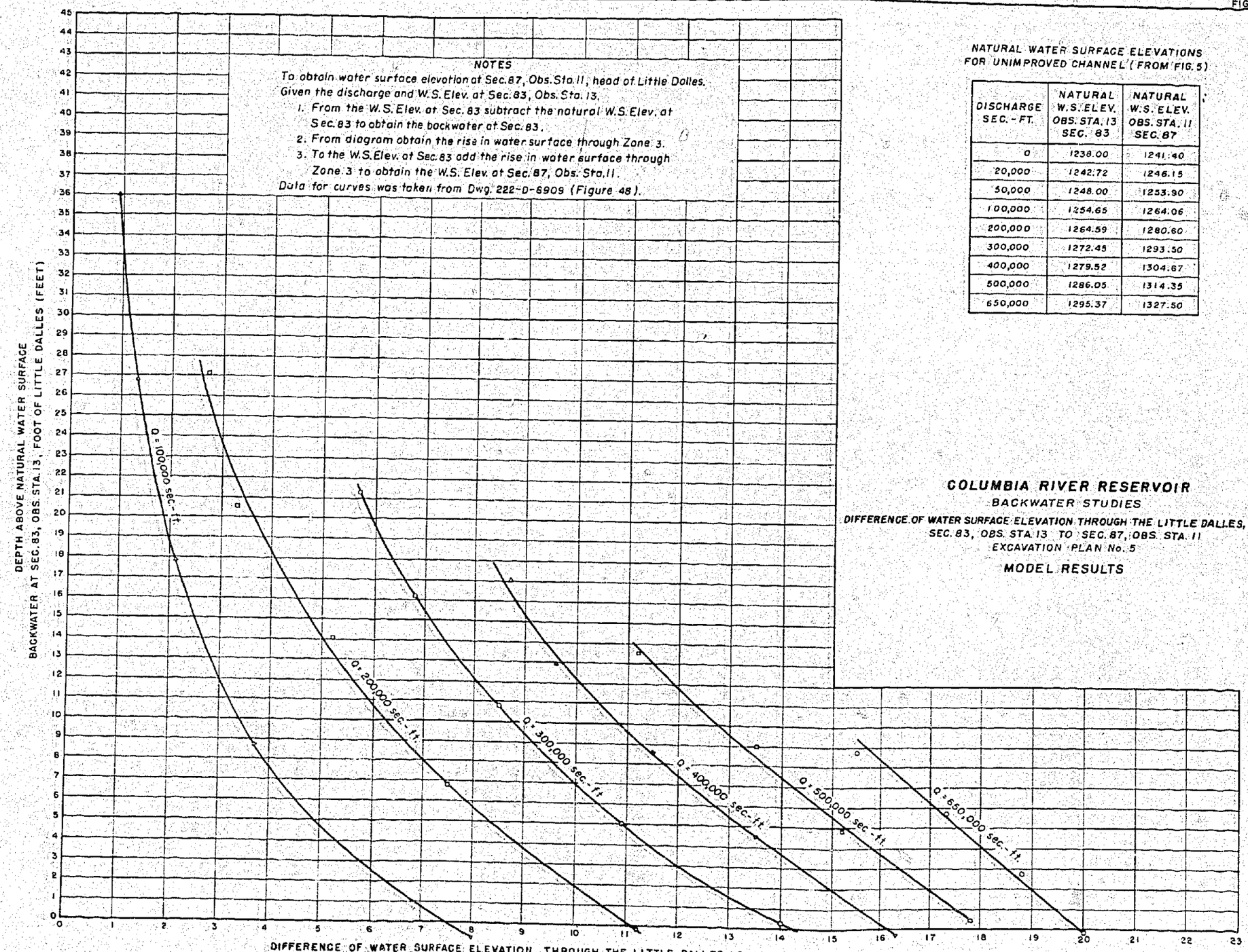
NATURAL WATER SURFACE ELEVATIONS FOR UNIMPROVED CHANNEL (FROM FIG. 5)

DISCHARGE SEC.-FT.	NATURAL W.S. ELEV. OBS. STA. 13 SEC. 83	NATURAL W.S. ELEV. OBS. STA. 11 SEC. 87
0	1238.00	1241.40
20,000	1242.72	1246.15
50,000	1248.00	1253.90
100,000	1254.65	1264.06
200,000	1264.59	1280.60
300,000	1272.45	1293.50
400,000	1279.52	1304.67
500,000	1286.05	1314.35
650,000	1295.37	1327.50

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
DIFFERENCE OF WATER SURFACE ELEVATION THROUGH THE LITTLE DALLES, ZONE 3
SEC. 83, OBS. STA. 13 TO SEC. 87, OBS. STA. 11
ISLAND REMOVED TO ELEVATION 1255
MODEL RESULTS

222-D-6903

FIGURE 27



NATURAL WATER SURFACE ELEVATIONS FOR UNIMPROVED CHANNEL (FROM FIG. 5)

DISCHARGE SEC.-FT.	NATURAL W.S. ELEV. OBS. STA. 13 SEC. 83	NATURAL W.S. ELEV. OBS. STA. 11 SEC. 87
0	1238.00	1241.40
20,000	1242.72	1246.15
50,000	1248.00	1253.90
100,000	1254.65	1264.06
200,000	1264.59	1280.60
300,000	1272.45	1293.50
400,000	1279.52	1304.67
500,000	1286.05	1314.35
650,000	1295.37	1327.50

COLUMBIA RIVER RESERVOIR

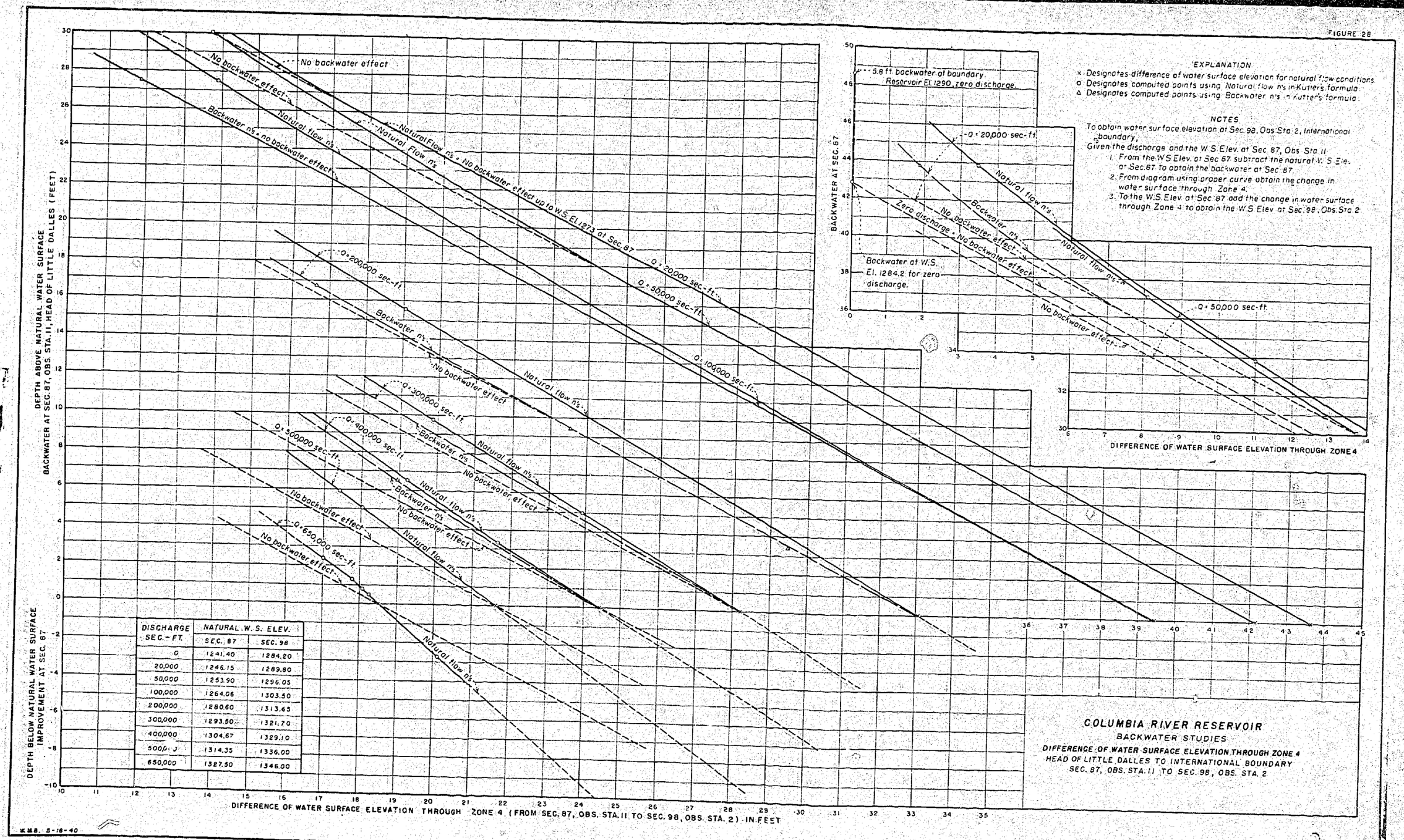
BACKWATER STUDIES

DIFFERENCE OF WATER SURFACE ELEVATION THROUGH THE LITTLE DALLES, ZONE 3
SEC. 83, OBS. STA. 13 TO SEC. 87, OBS. STA. 11
EXCAVATION PLAN No. 5

MODEL RESULTS

222-D-6904

FIGURE 28



DISCHARGE SEC.-FT.	NATURAL W.S. ELEV. SEC. 87	NATURAL W.S. ELEV. SEC. 98
0	1241.40	1284.20
20,000	1246.15	1289.80
50,000	1253.90	1296.05
100,000	1264.06	1303.50
200,000	1280.60	1313.65
300,000	1293.50	1321.70
400,000	1304.67	1329.10
500,000	1314.35	1336.00
650,000	1327.50	1346.00

222-D-6905

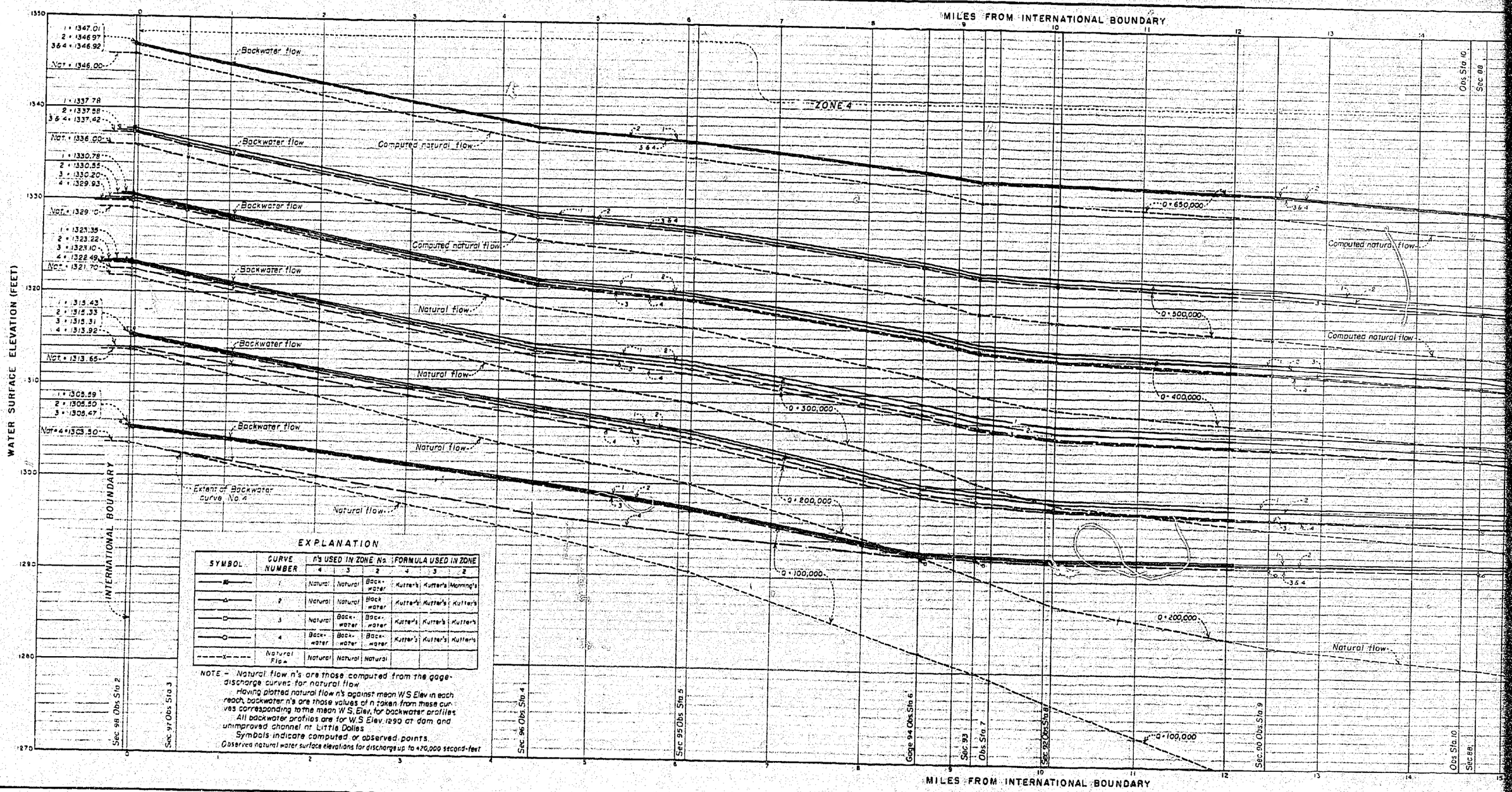
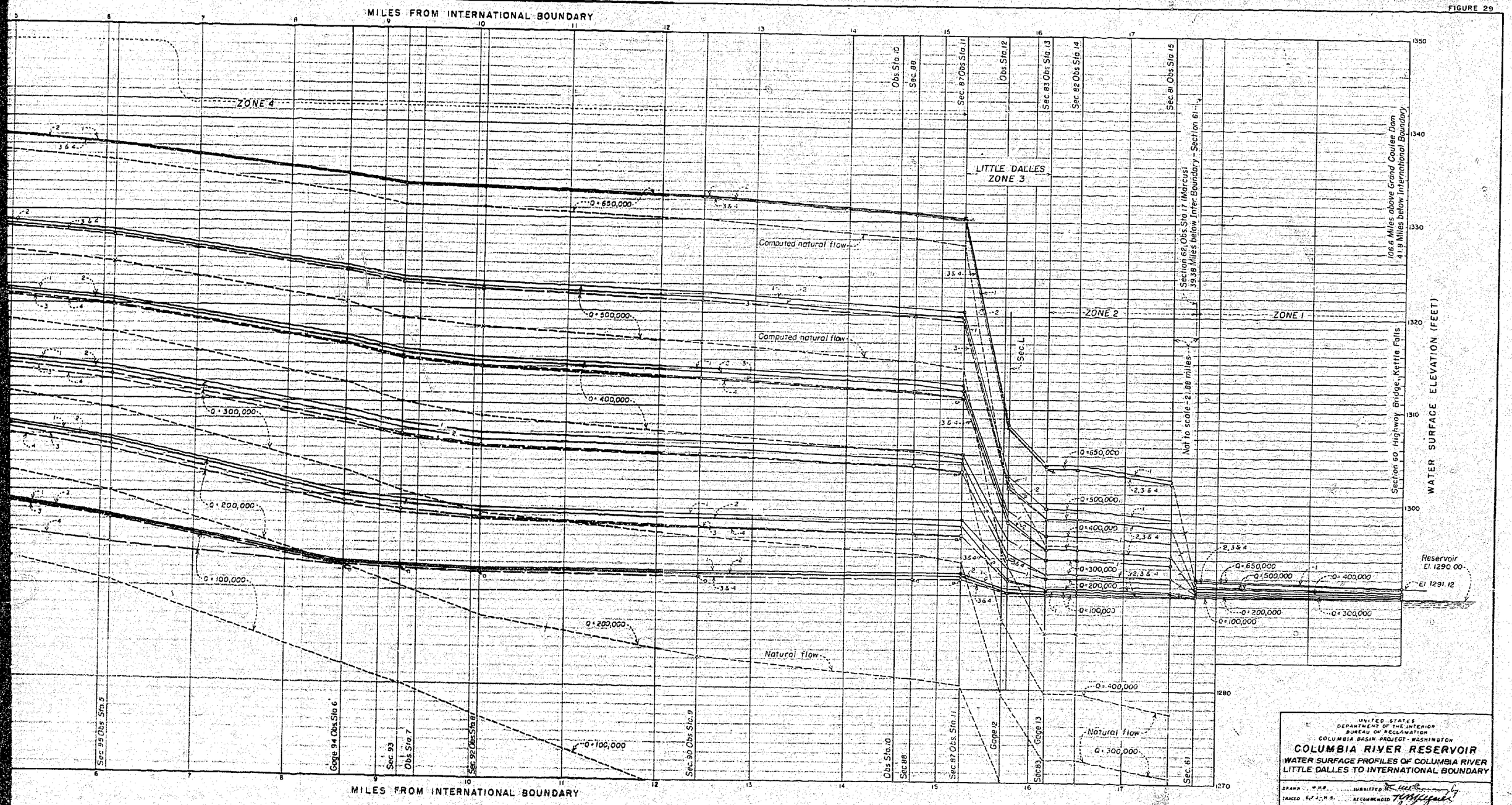

MILES FROM INTERNATIONAL BOUNDARY
WATER SURFACE ELEVATION (FEET)
INTERNATIONAL BOUNDARY
1 = 1347.01
2 = 1346.97
3 & 4 = 1346.92
Nat = 1346.00
1 = 1337.78
2 = 1337.58
3 & 4 = 1337.42
Nat = 1336.00
1 = 1330.79
2 = 1330.55
3 = 1330.20
4 = 1329.93
Nat = 1329.10
1 = 1323.35
2 = 1323.22
3 = 1323.10
4 = 1322.49
Nat = 1321.70
1 = 1315.43
2 = 1315.33
3 = 1315.31
4 = 1313.92
Nat = 1313.65
1 = 1305.59
2 = 1305.50
3 = 1305.47
Nat = 4 = 1303.50
Backwater flow
Computed natural flow
Natural flow
Extent of Backwater curve No. 4
ZONE 4
Q = 650,000
Q = 500,000
Q = 400,000
Q = 300,000
Q = 200,000
Q = 100,000
Sec. 98 Obs. Sta. 2
Sec. 97 Obs. Sta. 3
Sec. 96 Obs. Sta. 4
Sec. 95 Obs. Sta. 5
Gage 94 Obs. Sta. 6
Sec. 93
Obs. Sta. 7
Sec. 92 Obs. Sta. 8
Sec. 90 Obs. Sta. 9
Obs. Sta. 10
Sec. 88
EXPLANATION
SYMBOL
CURVE NUMBER
n's USED IN ZONE No.
FORMULA USED IN ZONE
1 Natural Natural Back-water Kutter's Kutter's Manning's
2 Natural Natural Back-water Kutter's Kutter's Kutter's
3 Natural Back-water Back-water Kutter's Kutter's Kutter's
4 Back-water Back-water Back-water Kutter's Kutter's Kutter's
Natural Flow Natural Natural Natural
NOTE – Natural flow n's are those computed from the gage-discharge curves for natural flow.
Having plotted natural flow n's against mean W.S. Elev. in each reach, backwater n's are those values of n taken from these curves corresponding to the mean W.S. Elev. for backwater profiles.
All backwater profiles are for W.S. Elev. 1290 at dam and unimproved channel at Little Dalles.
Symbols indicate computed or observed points.
Observed natural water surface elevations for discharges up to 420,000 second-feet

FIGURE 29



UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON

COLUMBIA RIVER RESERVOIR

WATER SURFACE PROFILES OF COLUMBIA RIVER
LITTLE DALLES TO INTERNATIONAL BOUNDARY

DRAWN W.H.B. SUBMITTED
TRACED E.F.J.-H.S. RECOMMENDED
CHECKED C.A.W. APPROVED
DENVER, COLORADO MAR. 18, 1940
222-D-6809

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

FLOOD DURATION AT GRAND COULEE DAM AND THE LITTLE DALLES

Probable occurrence of flood (Percentage of time)	Discharge (second-feet) equaled or exceeded			
	At Grand Coulee Dam estimated from records at		At the Little Dalles# estimated from records at	
	The Dalles Oregon*	Grand Coulee Washington**	The Dalles Oregon	Grand Coulee Washington
Once in 10,000 yrs.	930,000	725,000	875,000	680,000
Once in 1,000 yrs.	815,000	650,000	765,000	610,000
Once in 500 yrs.	775,000	625,000	730,000	590,000
Once in 100 yrs.	690,000	570,000	650,000	535,000
Once in 50 yrs.	645,000	545,000	605,000	515,000
Once in 10 yrs.	535,000	465,000	505,000	435,000
Once in 5 yrs.	480,000	425,000	450,000	400,000
Once in 3 yrs.	435,000	390,000	410,000	365,000

* Records available at The Dalles since 1858 (82 years).

** Records available at Grand Coulee since 1913 (27 years).

\# Flood discharge at the Little Dalles assumed 94.0% of that at Grand Coulee Dam.

Normal maximum annual flood at the Little Dalles or International Boundary equal to 345,000 second-feet based on record from 1913 to 1939 at Kettle Falls.

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES

FLOOD DURATION AT GRAND COULEE DAM AND THE LITTLE DALLES

Probable occurrence of flood (Percentage of time)	Discharge (second-feet) equaled or exceeded			
	At Grand Coulee Dam estimated from records at		At the Little Dalles# estimated from records at	
	The Dalles Oregon*	Grand Coulee Washington**	The Dalles Oregon	Grand Coulee Washington
Once in 10,000 yrs.	930,000	725,000	875,000	680,000
Once in 1,000 yrs.	815,000	650,000	765,000	610,000
Once in 500 yrs.	775,000	625,000	730,000	590,000
Once in 100 yrs.	690,000	570,000	650,000	535,000
Once in 50 yrs.	645,000	545,000	605,000	515,000
Once in 10 yrs.	535,000	465,000	505,000	435,000
Once in 5 yrs.	480,000	425,000	450,000	400,000
Once in 3 yrs.	435,000	390,000	410,000	365,000

* Records available at The Dalles since 1858 (82 years).

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\# Flood discharge at the Little Dalles assumed 94.0% of that at Grand Coulee Dam.

Normal maximum annual flood at the Little Dalles or International Boundary equal to 345,000 second-feet based on record from 1913 to 1939 at Kettle Falls.

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
BACKWATER COMPUTATIONS BY GRAPHS, USING NATURAL FLOW n's
GRAND COULEE DAM TO INTERNATIONAL BOUNDARY
UNIMPROVED CHANNEL

Description	Discharge in second-feet at Little Dalles							
	20,000	50,000	100,000	200,000	300,000	400,000	500,000	650,000
W.S. elev. at dam	1288.00	1288.00	1288.00	1288.00	1288.00	1288.00	1288.00	1288.00
ΔW.S. between dam - Obs. sta. 17	nil	0.02	0.06	0.20	0.47	0.87	1.26	2.24
W.S. elev. at obs. sta. 17	1288.00	1288.02	1288.06	1288.20	1288.47	1288.87	1289.26	1290.24
Natural W.S. elev. at obs. sta. 17	1205.70	1210.85	1216.40	1223.90	1229.60	1234.10	1238.00	1243.20
Backwater at obs. sta. 17	82.30	77.17	71.66	64.30	58.87	54.77	51.26	47.04
ΔW.S. between obs. stas. 17-13	0.08	0.18	0.54	1.78	3.80	6.16	8.74	12.75
W.S. elev. at obs. sta. 13	1288.08	1288.20	1288.60	1289.98	1292.27	1295.03	1298.00	1302.99
Natural W.S. elev. at obs. sta. 13	1242.72	1248.00	1254.65	1264.59	1272.45	1279.52	1286.05	1295.37
Backwater at obs. sta. 13	45.36	40.20	33.95	25.39	19.82	15.51	11.95	7.62
ΔW.S. between obs. stas. 13-11	0.05	0.43	1.96	6.74	11.94	16.82	21.76	27.05
W.S. elev. at obs. sta. 11	1288.13	1288.63	1290.56	1296.72	1304.21	1311.85	1319.76	1330.04
Natural W.S. elev. at obs. sta. 11	1246.15	1253.90	1264.06	1280.60	1293.50	1304.67	1314.35	1327.50
Backwater at obs. sta. 11	41.98	34.73	26.50	16.12	10.71	7.18	5.41	2.54
ΔW.S. between obs. stas. 11-2	4.73	9.95	14.75	18.55	19.02	18.71	17.77	16.84
W.S. elev. at obs. sta. 2	1292.86	1298.58	1305.31	1315.27	1323.23	1330.56	1337.53	1346.88
Natural W.S. elev. at obs. sta. 2	1289.80	1296.05	1303.50	1313.65	1321.70	1329.10	1336.00	1346.00
Backwater at obs. sta. 2	3.06	2.53	1.81	1.62	1.53	1.46	1.53	0.88

Table XXI

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
BACKWATER COMPUTATIONS, ZONE 4
DISCHARGE = 200,000 SECOND-FEET
UNIMPROVED CHANNEL
RESERVOIR WATER SURFACE ELEVATION 1290.00 AT GRAND COULEE DAM
BACKWATER ROUGHNESS COEFFICIENTS

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Cross section	Obs. station	Length of reach L feet	Change in W.S. elev. feet	Water surface elevation feet	Hyd. radius R feet	Area of cross section A sq. ft.	Velocity V = Q/A ft./sec.	Velocity head h_v feet	Change in velocity V ft./sec.	Enlargement loss $(\Delta V)^2/2g$ feet	Energy gradient elevation feet	Friction loss h_f feet	Friction slope $S_f = h_f/L$	Mean hyd. radius R_m feet	Mean velocity V_m ft./sec.	Velocity head $V_m^2/2g$ feet	Kutter's n	Friction factor $K = 2g/C^2$	Computed friction loss h_f feet	Error in h_f feet
87	11		[illegible]	1297.55	57.50	57,600	3.47	0.187			1297.537									
		2,790	0.20						1.55	0.037		0.368	0.000132	54.85	4.25	0.281	0.084	0.0260	0.373	+0.005
88				1297.55	51.80	39,800	5.02	0.392			1297.942									
		12,100	0.48									0.255	0.0000211	43.85	4.15	0.268	0.028	0.0035	0.259	+0.004
90	9			1298.03	35.90	60,900	3.28	0.167			1298.197									
		12,340	0.65						2.37	0.087		0.892	0.0000723	32.75	4.47	0.311	0.033	0.0076	0.891	-0.001
92	8			1298.68	29.60	35,400	5.65	0.496			1299.176									
		4,590	0.80						0.37	0.002		0.865	0.000188	30.30	5.84	0.530	0.037	0.0108	0.867	+0.002
93				1299.48	31.00	33,200	6.02	0.563			1300.045									
		3,210	0.93						1.23	0.023		1.161	0.000362	37.25	6.64	0.685	0.055	0.0197	1.163	+0.002
94	6			1300.41	43.50	27,600	7.25	0.817			1301.227									
		13,250	3.48									3.024	0.000228	37.50	6.04	0.567	0.047	0.01507	3.020	-0.004
95	5			1303.89	31.50	41,500	4.82	0.361			1304.251									
		9,050	1.89						2.54	0.100		2.271	0.000251	31.35	6.09	0.577	0.042	0.01362	2.268	-0.003
96	4			1305.78	31.20	27,200	7.36	0.842			1306.622									
		20,300	7.02									6.523	0.000321	33.85	6.04	0.567	0.053	0.01917	6.520	-0.003
97	3			1312.80	36.50	42,500	4.71	0.345			1313.145									
		3,150	1.18						2.05	0.065		1.481	0.000470	32.65	5.74	0.512	0.070	0.0299	1.477	-0.004
98	2			1313.98	28.80	29,600	6.78	0.711			1314.691									
Check =			16.63	16.63				0.524		0.314	17.154	16.840							16.838	-0.002

Note: In column 20, $h_f = K \cdot L/R_m \cdot V_m^2/2g$

In column 19, $C = \dfrac{41.65 + \dfrac{0.00281}{S} + \dfrac{1.811}{n}}{1 + \dfrac{n}{\sqrt{R}}\left(41.65 + \dfrac{0.00281}{S}\right)}$

Column 5 plus column 9 = column 12.
(Difference of values in column 12) minus column 11 = column 13.
Column 20 minus column 13 = column 21.

CHAPTER V - MODEL INVESTIGATIONS OF THE LITTLE DALLES

Introduction

45. Description of the Little Dalles. The Little Dalles is a reach of the Columbia River located about 16 miles downstream from the International Boundary, where the river, normally about 1,000 feet wide, is constricted to a narrow, deep channel about 300 feet wide and 200 feet deep for a distance of 2,500 feet. These rapids are in a hard, dolomitic limestone formation; the banks are free of overburden. The river under natural conditions expends a great deal of energy in passing through this rough reach. At the entrance to the Little Dalles, a large rock island obstructs the flow, deflecting the greater portion of the water toward the right bank. Downstream from the island, the right bank rises abruptly to form the side of a mountain while the left bank levels off on a broad shelf. At flood stages the island and a portion of the left bank are submerged. Photographs of the Little Dalles at discharges of 50,000 and 330,000 second-feet are shown on figures 30 and 31. A topographic survey of the Little Dalles was made by sounding the river at the various sections indicated on figure 32.

Two observation stations are located at the Little Dalles, one near the upstream end at section 87, and another nine-tenths of a mile downstream at section 83 (figure 32). Observation station 12 was also located at the Little Dalles but was of less use than stations 11 and 13 because of its poor location and lack of river cross section. The observations made at these stations and the resulting rating curves, together with their extensions to include higher flood flows, are discussed in chapters II and III of this report. The rating curves are shown on figures 33 and 35. and 44.

46. Reasons for the model. Calculations of the backwater effects from the Grand Coulee Dam indicate that raising the reservoir to elevation 1290.0 will produce backwater along the Great Northern Railroad's trackage above the Little Dalles and at the International Boundary. It was considered that a satisfactory solution of the backwater problem for the normal reaches of the river could be obtained by computation, but it was desired to have a check for the rough, turbulent sections of the Little Dalles; it was also desired to ascertain the results to be expected from various schemes for channel improvement to reduce the amount of backwater. Accordingly, it was decided to construct an hydraulic model.

47. Description of the model. The scale of the model, 1 to 120, was determined by the available laboratory space. The model was constructed in a metal-lined tank; metal templates of the shape obtained by soundings on the prototype were cut and fastened to the floor, the spaces between filled with sand, and a concrete crust placed over the sand to complete the rough topography shape. The channel between sections was built with the aid of contour maps drawn from the soundings and from a careful study of prototype pictures. Portions of the channel were further improved during the preliminary model tests by a study of prototype flow pictures. The island and a portion of the left bank near the channel were built with a horizontal joint at elevation 1255.0 to permit any proposed excavation to be easily duplicated on the model (figure 32).

Level tracks were installed on each side of the upstream portion of the model and used to support a point gage bar mounted on trucks. This arrangement permitted water-surface elevations to be measured at any point between sections 87 and L. A permanent point gage was installed at section 83, representing gage 13. A control gate downstream provided a means for regulating the water level at section 83.

48. Model adjustments. Preliminary tests were made to determine how much the model should be roughened to obtain a reasonable agreement between model and prototype rating curves at gages 11 and 12 when the water level at gage 13 was held at the proper elevation for natural flow. Ten trials, together with several observation tests, were required before a satisfactory fit was obtained between the model and prototype. Photographs of typical discharges for the original model are shown on figure 34. Rating curves for the original model and the first five trials are shown on figure 33. After each trial the model was roughened by adding lumps of concrete to the sides and bottom of the channel. Somewhat larger pieces of material in the shape of needles were placed in the bottom of the channel since the cross sections indicated that such formations were present. These needles produced little effect at low discharges but materially increased the losses with the higher velocities accompanying the medium and high flows.

Trial 5 produced a reasonable agreement at observation station 12 for all discharges and at observation station 11 for discharges up to 350,000 second-feet (figure 33). This suggested that the roughness was not correctly distributed between section 87 and the cove. Accordingly, an approximate rating curve was obtained from the field for water-surface elevations on the left bank at section I and checked against the

model. The result indicated that not enough roughness was present downstream from section I and too much upstream. It was found necessary to fill the channel partially between sections J and K and to remove some of the needles near the island. Five additional trials were made before a satisfactory agreement was obtained between model and prototype observations. After the final model adjustments were completed, it was found that the mathematical extensions of the prototype rating curves agreed reasonably well with the curves obtained from the model (figure 35). Photographs of the final model are shown on figure 36.

Natural Channel

49. Natural flow conditions. In addition to the rating curves, shown on figure 35, profiles for natural flow were obtained from the model at discharges approximating 100,000, 200,000, 300,000, 400,000, 500,000, and 650,000 second-feet. These profiles, together with the calculated profiles, are shown on figure 37. The calculated profiles were obtained by assuming a constant roughness factor through the Little Dalles and that the water-surface elevation in the channel near the cove was the same as given by gage 12. Accordingly, complete agreement could not be expected.

50. Backwater effects. The head loss between gages 11 and 13 was next obtained for various discharges and backwater stages. These data are shown on figures 38 and 39. Profiles taken at various discharges assuming the Grand Coulee Reservoir at elevation 1290.0 are shown, together with the calculated profiles, on figure 40. The model results indicate that the calculated backwater elevations at section 87 for natural n's are about a foot too high. The rating curve used at observation station 13 to reproduce the water surface for reservoir at elevation 1290.0 is shown on figure 41, together with the resulting rating curve obtained at observation station 11. With unimproved channel, about three feet of backwater would exist at a discharge of 650,000 second-feet.

Channel Improvement Studies

51. Introduction. Channel improvement studies were made to determine the excavation necessary in the Little Dalles to produce no backwater at section 87 for a discharge of 400,000 second-feet. This would lower the water surface below natural conditions for higher discharges while backwater would exist

at lower discharges. Rating curves at observation station 11 were obtained for various amounts of excavation and compared with the corresponding rating curve for natural flow (figure 41).

A rating curve obtained with the island removed to elevation 1255.0 lowered the water surface about 1.5 feet at discharges above 200,000 second-feet (figure 41). Removing the island to elevation 1250.0 did not produce any additional improvement.

52. Excavation plan No. 1. With the island at elevation 1250.0, a portion of the left bank downstream from the island was removed to elevation 1255.0 (figure 42). The rating curve shows that natural conditions were restored for a discharge of 550,000 second-feet (figure 41).

53. Excavation plan No. 2. The entrance was next improved and the excavation along the left bank extended downstream to the needle (figure 42). The cove was filled, resulting in less turbulence and smoother flow conditions between sections K and L. Removing the needle did not result in any additional improvement and it was accordingly replaced. This plan restored natural conditions above the Little Dalles for 433,000 second-feet while at 650,000 second-feet the water surface at observation station 11 was lowered 5.2 feet below the natural surface (figure 41).

54. Excavation plan No. 3. Plan No. 3 was obtained by an extension of the excavation along the left bank and a smoother entrance (figure 42). Studies of this arrangement with the island excavated both to elevations 1250.0 and 1255.0 produced practically the same rating curves, indicating that the island need not be removed below elevation 1255.0. When the left bank near the entrance was smoothed up by spreading gravel over the surface, a slight improvement was noted at high discharges, indicating that spoil could be dumped in this region if orderly placed. This plan restored natural flow conditions at a discharge of 406,000 second-feet and at a discharge of 650,000 second-feet lowered the water surface at observation station 11 by 6.4 feet (figure 41).

55. Excavation plan No. 4. Excavation plan No. 4 was identical with plan No. 3, except that 8,190 cubic yards were excavated on the right bank opposite the needle. This arrangement gave no improvement over the preceding one. However, when the needle was removed to elevation 1255.0, natural conditions were restored at 400,000 second-feet and the natural water surface lowered seven feet at 650,000 second-feet (figure 41).

56. Excavation plan No. 5. The flow characteristics obtained from plan No. 4 were considered satisfactory. However, observations made on the model indicated that no spoil should be dumped into the main channel, and, on account of the difficulty of otherwise disposing of the spoil and also of the comparative inaccessibility of the right bank, it was considered more economical to do more excavating on the left bank where the spoil could be easily removed. The cut on the right bank was therefore filled and the excavation on the left bank increased, resulting in plan No. 5 (figure 42). This arrangement gave satisfactory results with somewhat better characteristics at discharges above 400,000 second-feet than plan No. 4 (figure 41). Figures 57 and 58 show the model with channel improvement plan No. 5, reservoir elevation of 1290.0 at the dam, and discharges of 50,000, 200,000, 400,000, and 650,000 second-feet flowing in the river.

57. Analysis of excavation studies. After a satisfactory excavation plan had been evolved, in an effort to determine whether or not additional excavation would be justified, table XXIII was prepared, showing yards of excavation and discharge (Q), at which natural flow conditions were restored upstream from the Little Dalles for the various arrangements studied.

TABLE XXIII

EXCAVATION STUDIES FOR CHANNEL IMPROVEMENT
AT THE LITTLE DALLES

	Cubic yards	Q	Q - 297,000
Island removed	41,620	790,000	493,000
Plan No. 1	77,200	553,000	256,000
Plan No. 2	200,410	433,000	136,000
Plan No. 3	232,780	406,000	109,000
Plan No. 4	240,970	406,000	109,000
Plan No. 4 with needle removed	245,790	400,000	103,000
Plan No. 5	267,220	398,000	101,000

This table shows cubic yards of excavation above elevation 1255.0. The discharge at which natural conditions were restored with the island removed was approximated by extrapolation of the rating curves. Discharge was next plotted against yardage and some means sought to extend the curve. Figure 41 shows that an infinite amount of excavation at the Little Dalles could not restore natural conditions below a discharge

of 297,000 second-feet. When this value was subtracted from the discharges given in the table and plotted against yardage on logarithmic paper, the result was a straight line. This plot furnished a reasonable extension for the improvement curve (figure 43). This curve indicates that plan No. 5 represents about the limit of economical excavation and that approximately 270,000 cubic yards of additional excavation would be required to reproduce natural conditions at a discharge of 350,000 second-feet.

Supplementary Studies

58. Natural channel. After a satisfactory excavation plan had been developed, the natural channel was replaced in the model and readjusted until natural flow conditions obtained (figure 44). The adjustments were necessary since it was impossible to replace the topography in its exact original condition. Engineers from the Dominion Water and Power Bureau of Canada and engineers of the Bureau's staff from Grand Coulee inspected the model during this period. In addition, some model results were compared with corresponding field data. During the 1939 spring flood, profiles were obtained along the left bank at discharges approximating 95,000, 206,000, and 240,000 second-feet. These and the corresponding model profiles show a remarkable agreement between model and prototype (figure 45). Such discrepancies as exist may easily be due to differences in local conditions at the point of measurement.

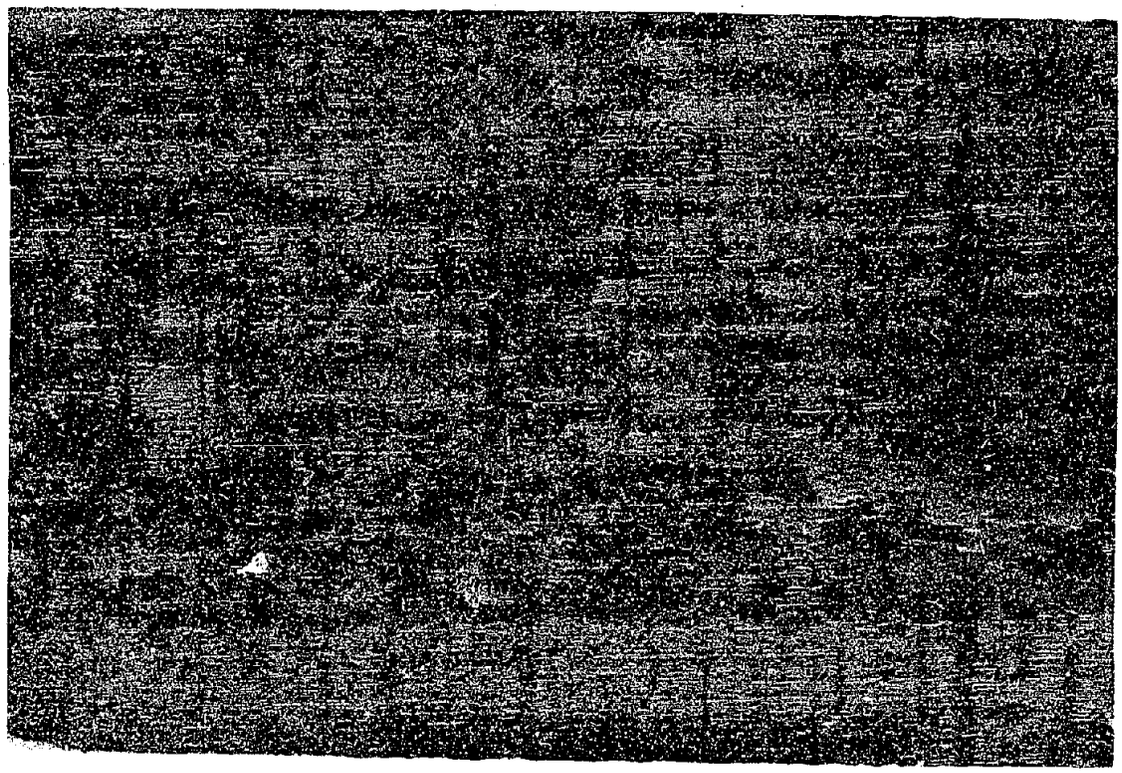
59. Island at elevation 1255.0. The island at the entrance to the Little Dalles was next removed to elevation 1255.0 and the losses through the rapids obtained for various discharges and backwater stages. These data are shown on figures 46 and 47.

60. Excavation plan No. 5. Plan No. 5 was next replaced on the model and the losses through the Little Dalles determined for various discharges and backwater stages (figures 48 and 49). With the model representing conditions for the reservoir at elevation 1290.0, water-surface profiles were obtained through the Little Dalles for discharges approximating 100,000, 200,000, 300,000, 400,000, 500,000, and 650,000 second-feet (figure 50). During these tests, velocities were also obtained at sections A, F, I, K, and L as shown on figures 51 to 56. These velocity studies were made so that data would be available on the possibilities of navigating the upper reaches of the Columbia River Reservoir after completion of the Grand Coulee Dam. Typical flow characteristics with backwater are shown on figures 57

and 58. Navigation through the Little Dalles has been impossible at high discharges because of the high velocities and large eddies in the narrow section and at low discharges because of numerous reefs in the lower section of the Little Dalles. The tops of these reefs are at about elevation 1260.0 so that for low discharges the reservoir should not be lower than 1270.0 at the dam for the safe passage of boats over the reefs. It is estimated that the reservoir water surface, with full development, will be above elevation 1270.0 for 85.5 percent of the time. The average discharge of the Columbia River is about 100,000 second-feet. With the proposed channel improvement and reservoir at 1290.0 at the dam, the mean velocity at this discharge at the narrowest section, I, of the Little Dalles will be 3.58 feet per second. Figure 51 shows the maximum velocity to be 4.87 feet per second. For every 10 feet the reservoir water surface is lowered until it reaches elevation 1270.0, the mean velocity will be increased about 14 percent and, presumably, the maximum velocity will likewise be increased. This rate of increase in mean velocity will be approximately applicable for other discharges.

61. Conclusions. While excavation plan No. 5 produced a satisfactory channel, means were considered for further reducing the backwater above the Little Dalles. When plan No. 5 was excavated to elevation 1250.0, no noticeable improvement was obtained, indicating that elevation 1255.0 was the limit of economical excavation. When material was broken off the left side of the deep channel below elevation 1255.0 and allowed to fall to the bottom of the channel, the losses through the Little Dalles increased, demonstrating that care should be exercised that only a minimum amount of excavated rock be allowed to fall into the river.

FIGURE 30

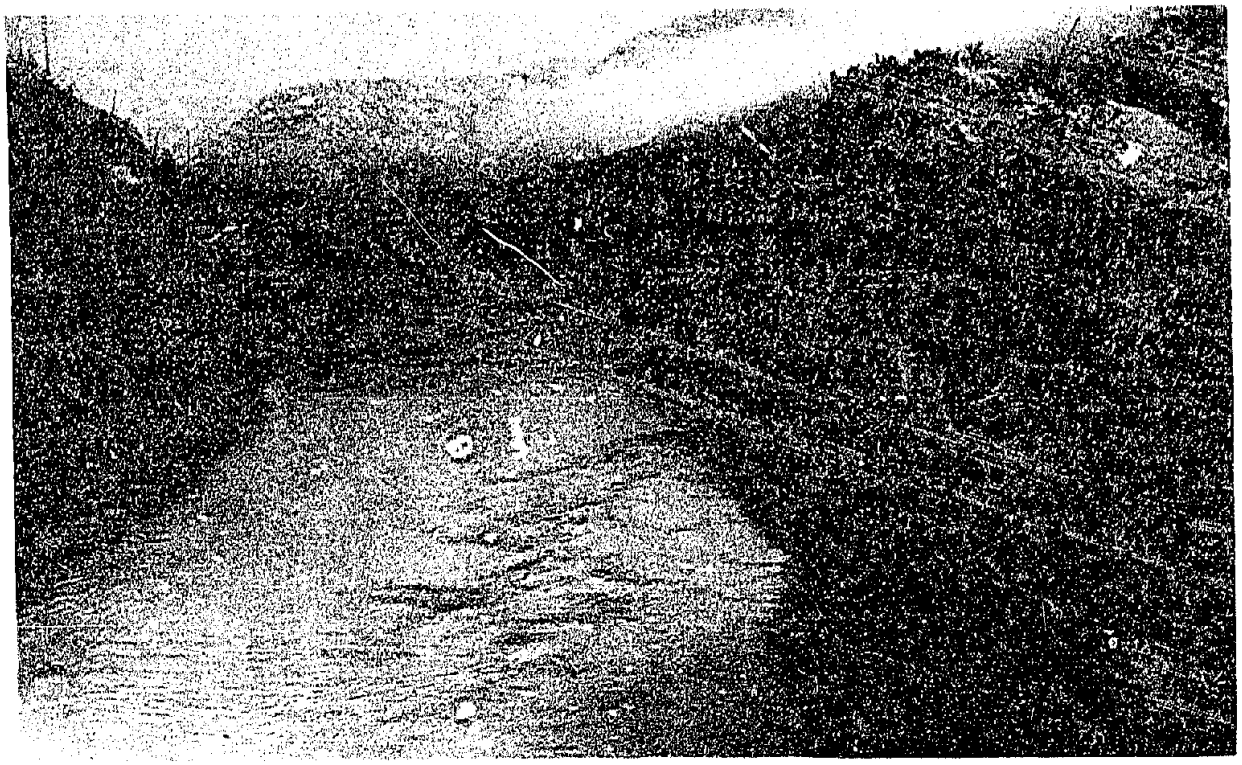


GENERAL VIEW

ENTRANCE

DISCHARGE 330,000 SECOND-FEET

THE LITTLE DALLES



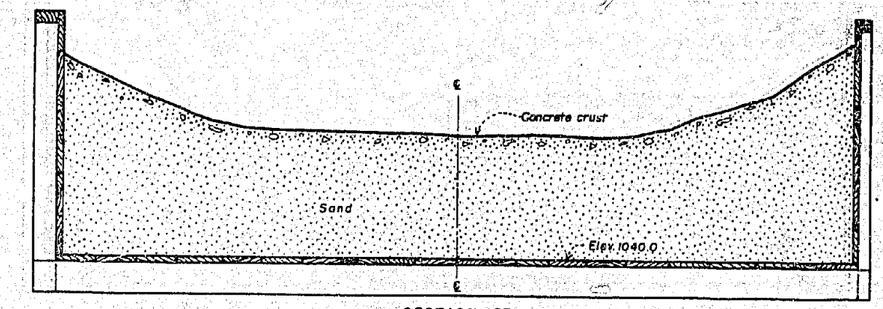
LOOKING UPSTREAM

LOOKING DOWNSTREAM

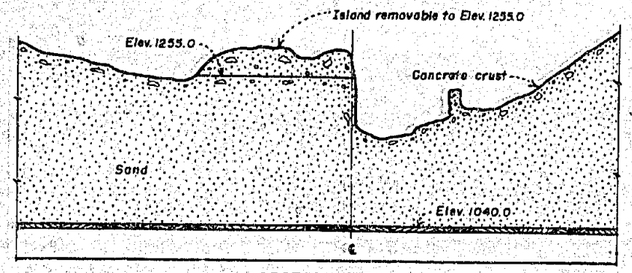
DISCHARGE 50,000 SECOND-FEET

THE LITTLE DALLES

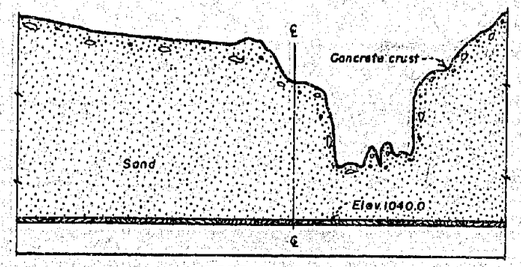
FIGURE 32



SECTION 87



SECTION E-E



SECTION I-I

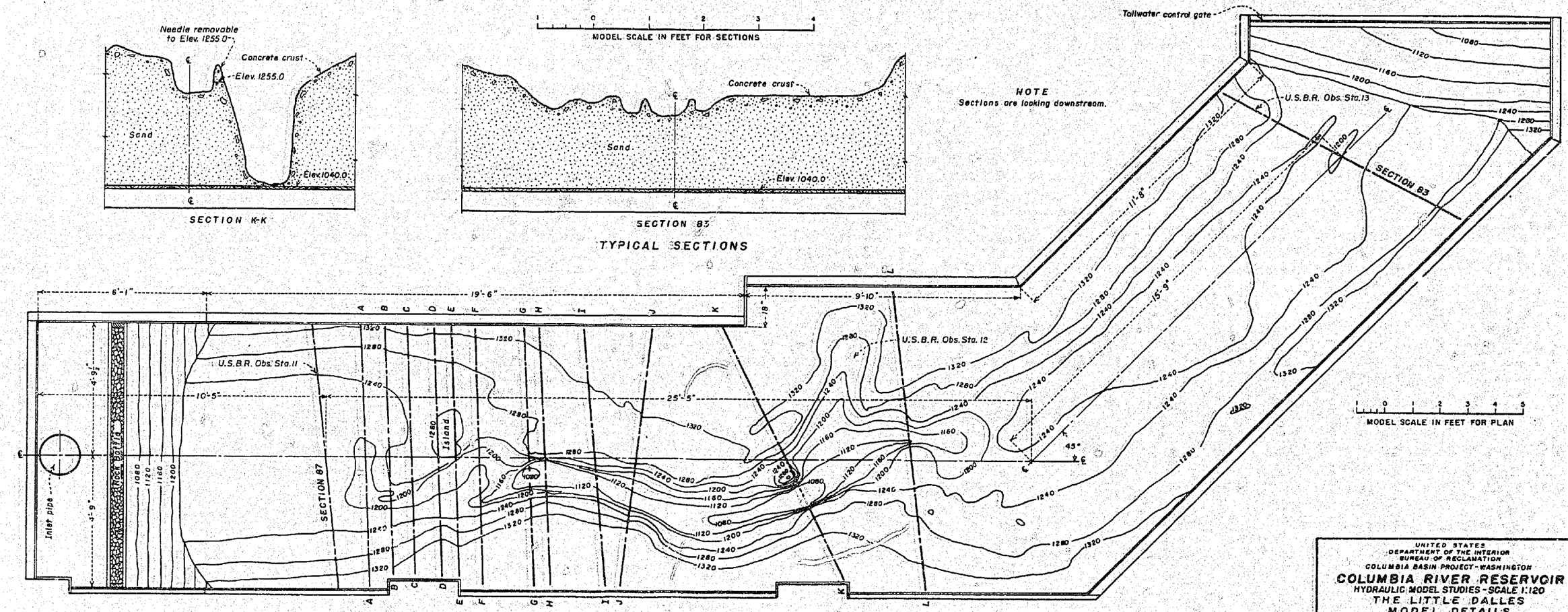
SECTION K-K

MODEL SCALE IN FEET FOR SECTIONS

SECTION 83

TYPICAL SECTIONS

NOTE
Sections are looking downstream.



PLAN

UNITED STATES
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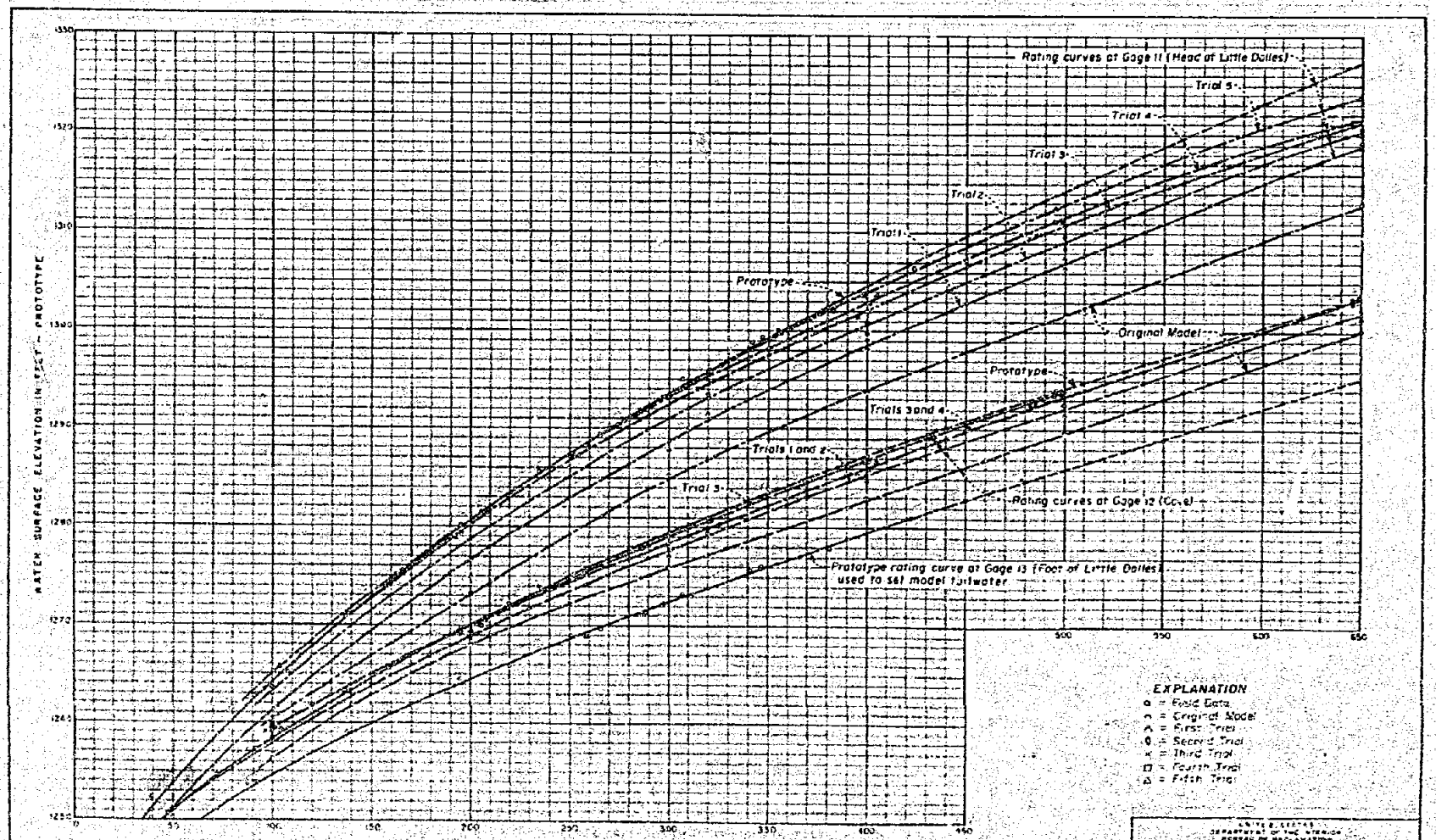
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON

COLUMBIA RIVER RESERVOIR
HYDRAULIC MODEL STUDIES - SCALE 1:120
THE LITTLE DALLES
MODEL DETAILS

DRAWN R.A.S. SUBMITTED
TRACED E.F.J. R.S. RECOMMENDED
CHECKED APPROVED
DENVER, COLORADO - MAR. 22, 1940 222-D-5886



NOTE

Model was roughened between each trial.

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COLUMBIA RIVER RESERVOIR

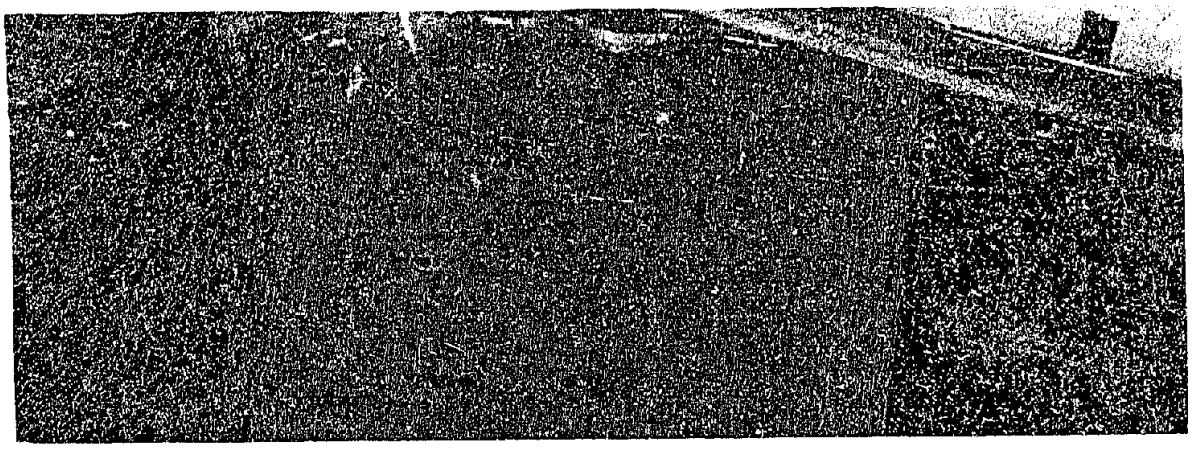
HYDRAULIC MODEL STUDIES - SCALE 1:120

THE LITTLE DALLES

TYPICAL RATING CURVES DURING MODEL ADJUSTMENT

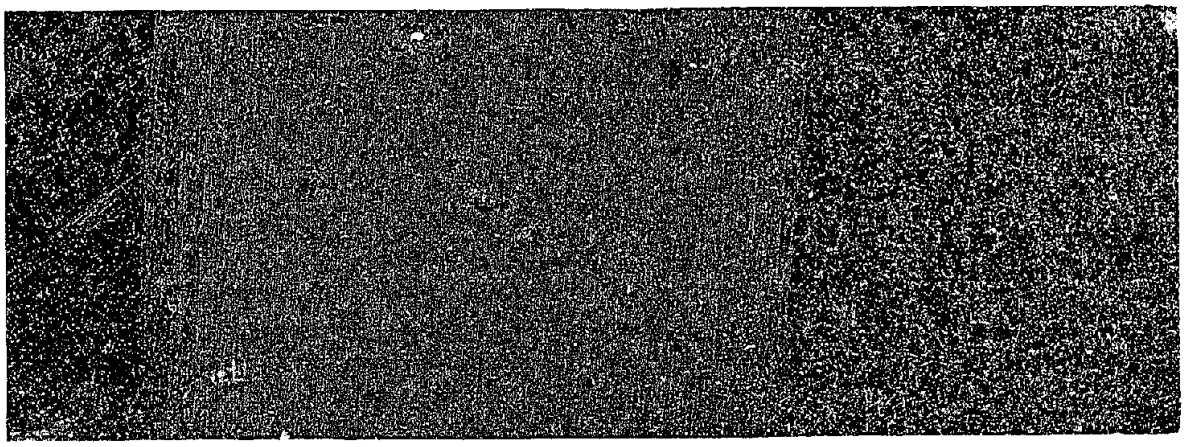
222-D-5887

FIGURE 33



DISCHARGE 50,000 SECOND-FEET

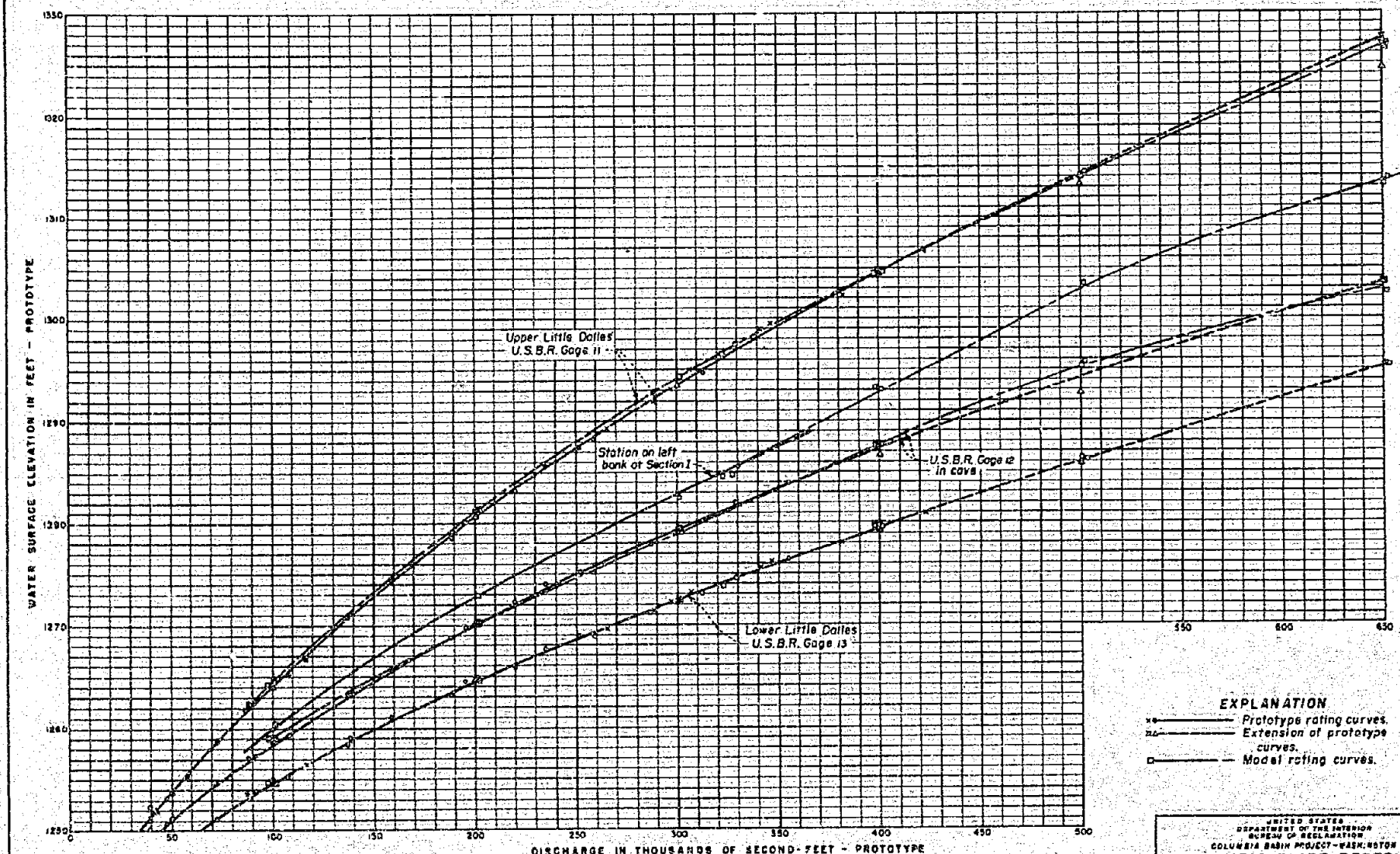
DISCHARGE 320,000 SECOND-FEET



DISCHARGE 400,000 SECOND-FEET

ORIGINAL MODEL

LITTLE DALLES MODEL STUDIES



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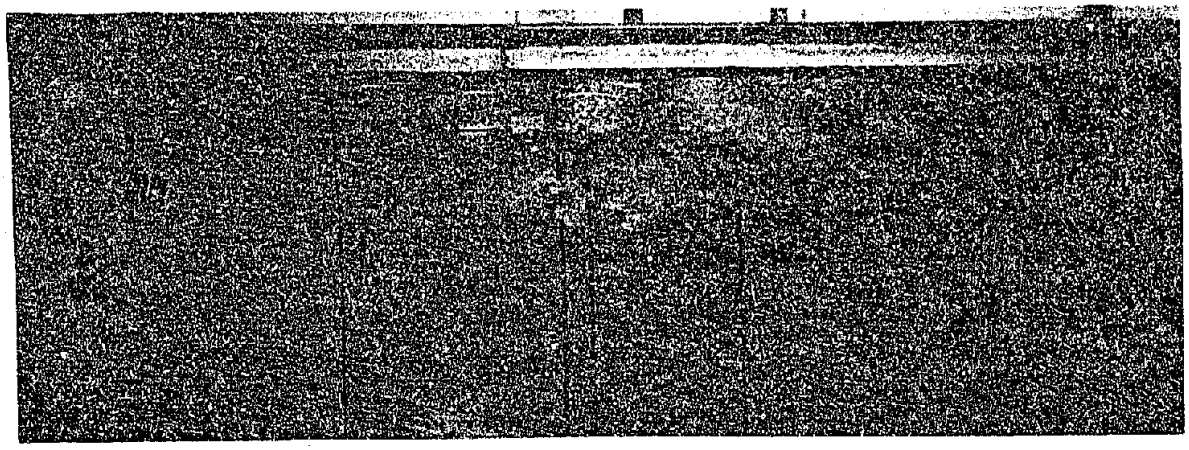
COLUMBIA BASIN PROJECT - WASHINGTON

COLUMBIA RIVER RESERVOIR
HYDRAULIC MODEL STUDIES - SCALE 1:120
THE LITTLE DALLES
NATURAL FLOW RATING CURVES

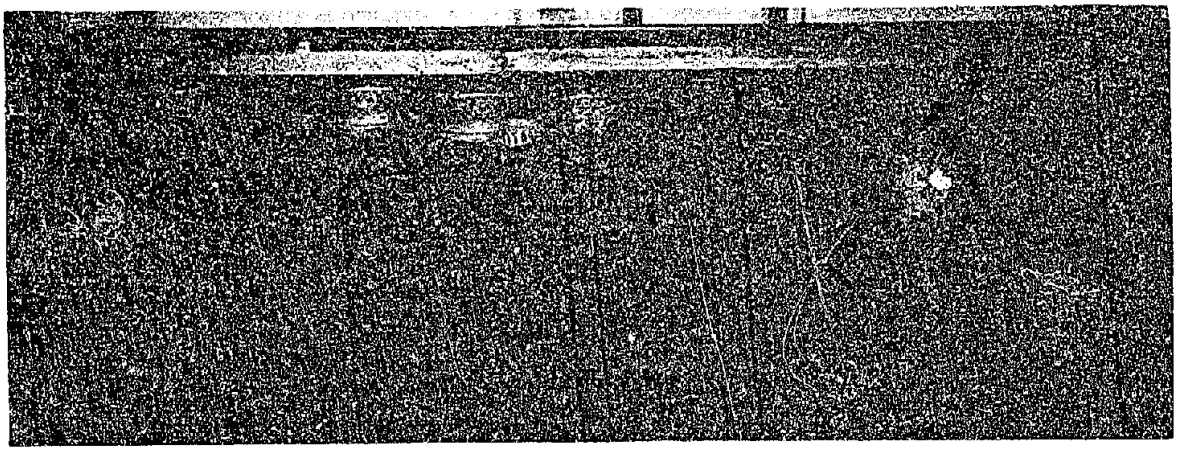
DRAWN: E.A.W. - P.A.A. SUBMITTED: Robert Rankin
TRACED: E.C.J. - H.A. RECOMMENDED: [illegible]
CHECKED: [illegible] APPROVED: [illegible]
SERVICE, COLORADO - APR. 8, 1941

222-D-3260

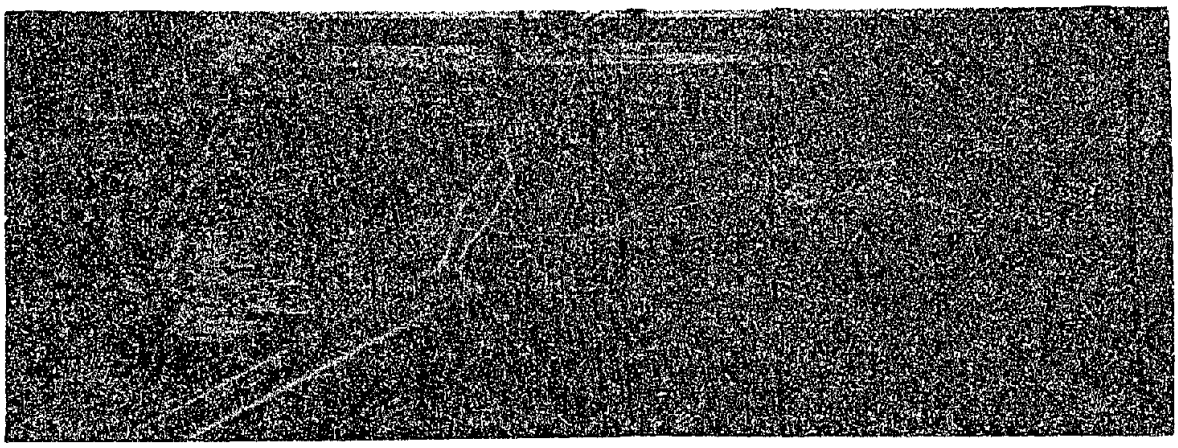
FIGURE 35



DISCHARGE 100,000 SECOND-FEET



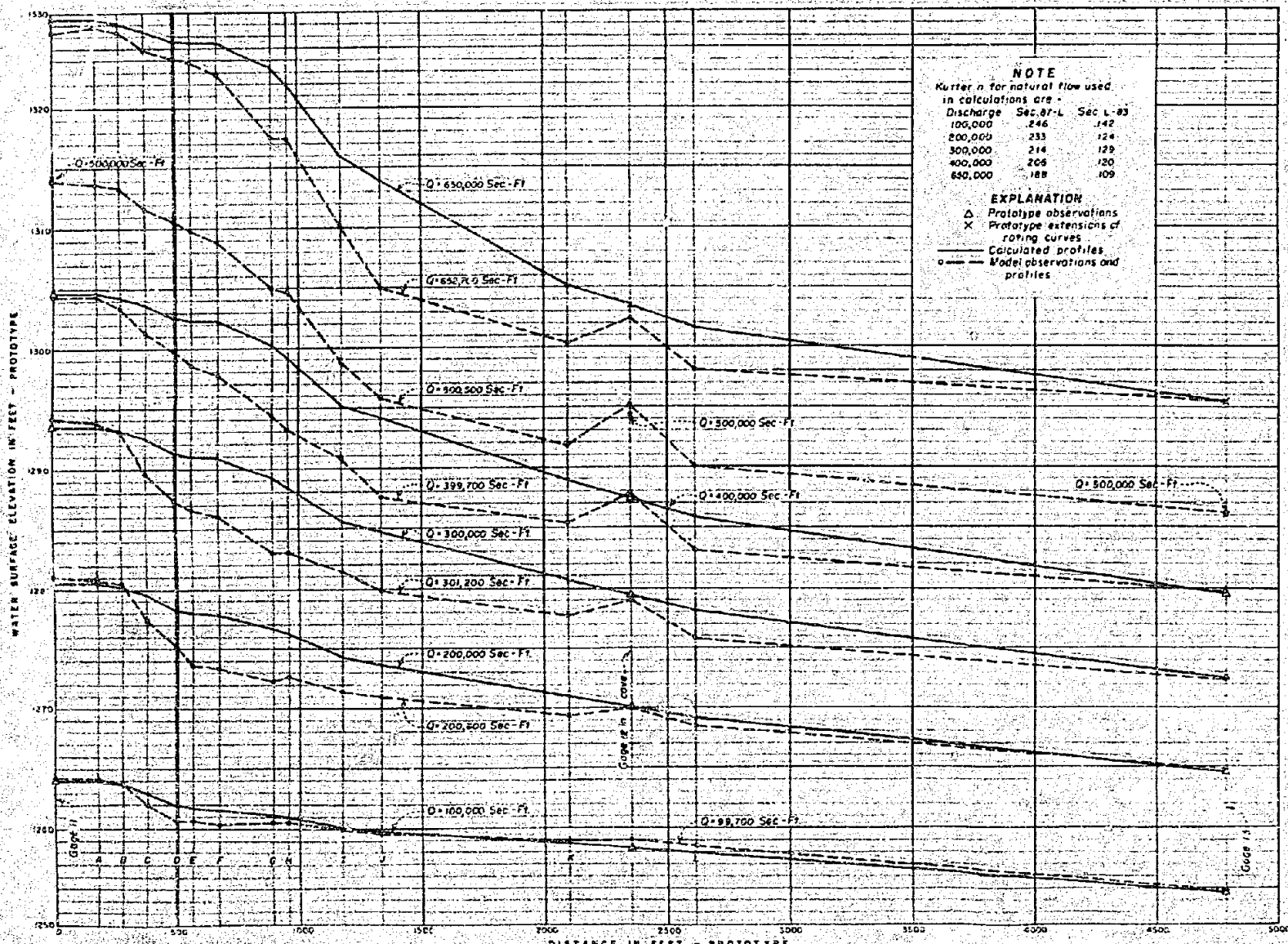
DISCHARGE 300,000 SECOND-FEET



DISCHARGE 500,000 SECOND-FEET

MODEL ADJUSTED TO NATURAL FLOW

LITTLE DALLES MODEL STUDIES



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COLUMBIA RIVER RESERVOIR

HYDRAULIC MODEL STUDIES - SCALE 1:120

WATER SURFACE PROFILES THROUGH THE LITTLE DALLES FOR NATURAL FLOW

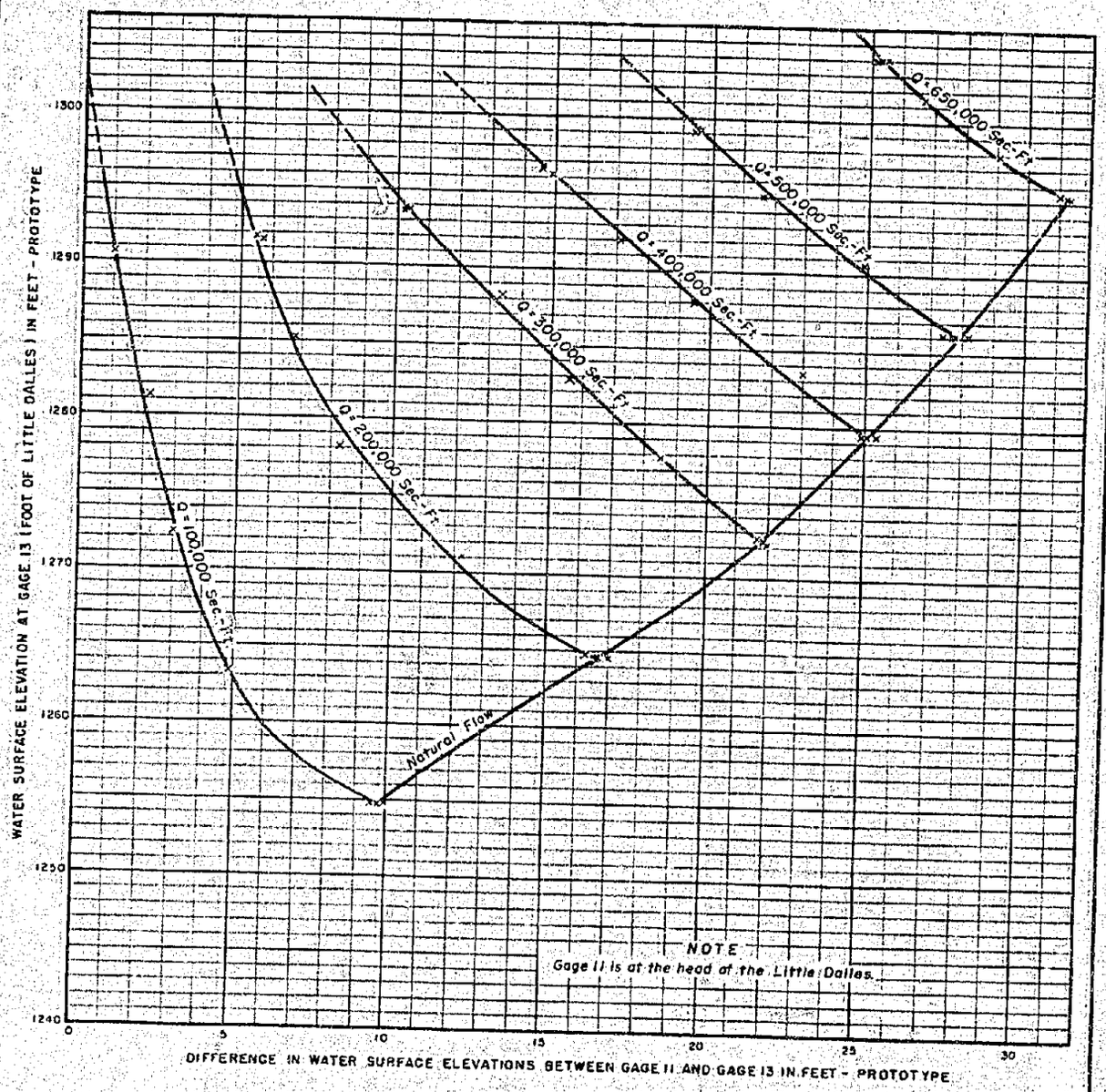
NATURAL CHANNEL

CAW-RAG 4-2-49

222-D-5889

FIGURE 37

FIGURE 38



BUREAU OF RECLAMATION

COLUMBIA RIVER RESERVOIR

HYDRAULIC MODEL STUDIES - SCALE 1:120

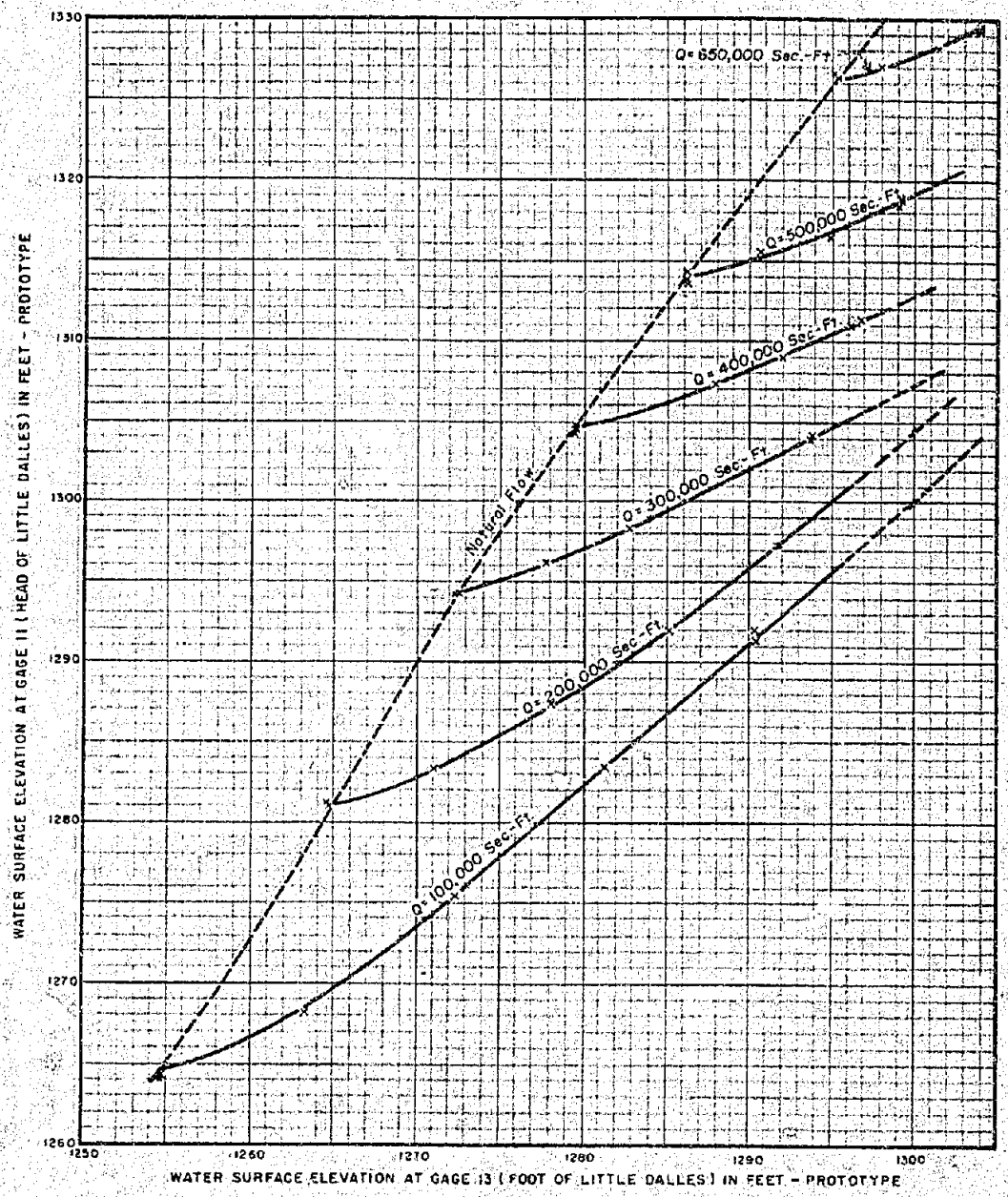
HEAD LOSS THROUGH THE LITTLE DALLES FOR VARIOUS BACKWATER STAGES

NATURAL CHANNEL

R.A.G. 5-4-40

222-D-5890

FIGURE 39



BUREAU OF RECLAMATION

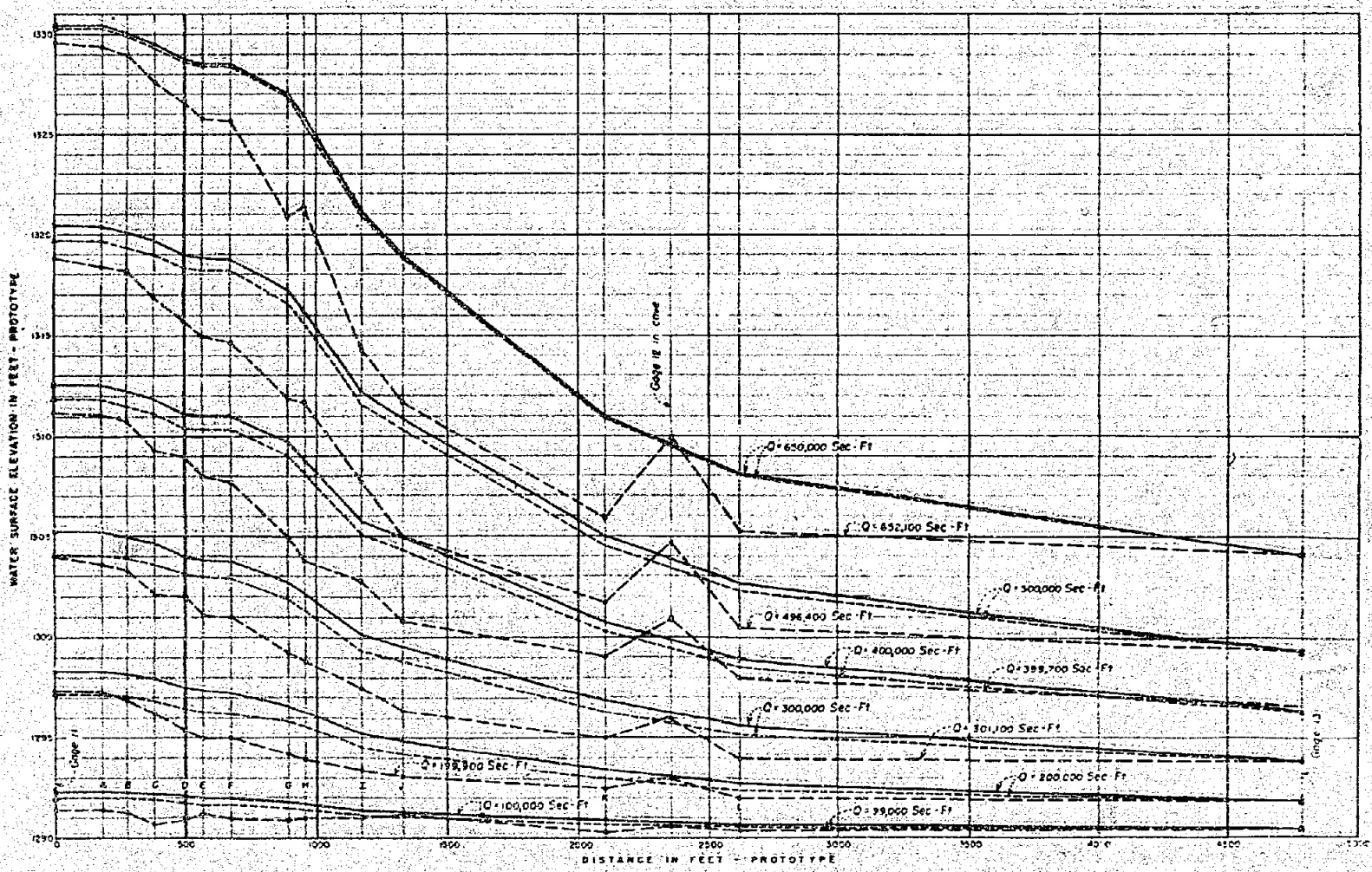
COLUMBIA RIVER RESERVOIR

HYDRAULIC MODEL STUDIES - SCALE 1:120

WATER SURFACE ELEVATIONS AT HEAD OF THE LITTLE DALLES
FOR VARIOUS BACKWATER STAGES
NATURAL CHANNEL

R.A.G. 5-4-40

222-D-5891



NOTES

Profiles are for natural channel with reservoir elevation 1290.0 at Grand Coulee Dam.

BUREAU OF RECLAMATION

COLUMBIA RIVER RESERVOIR

HYDRAULIC MODEL STUDIES - SCALE 1:120

WATER SURFACE PROFILES THROUGH THE LITTLE DALLES WITH BACKWATER
NATURAL CHANNEL

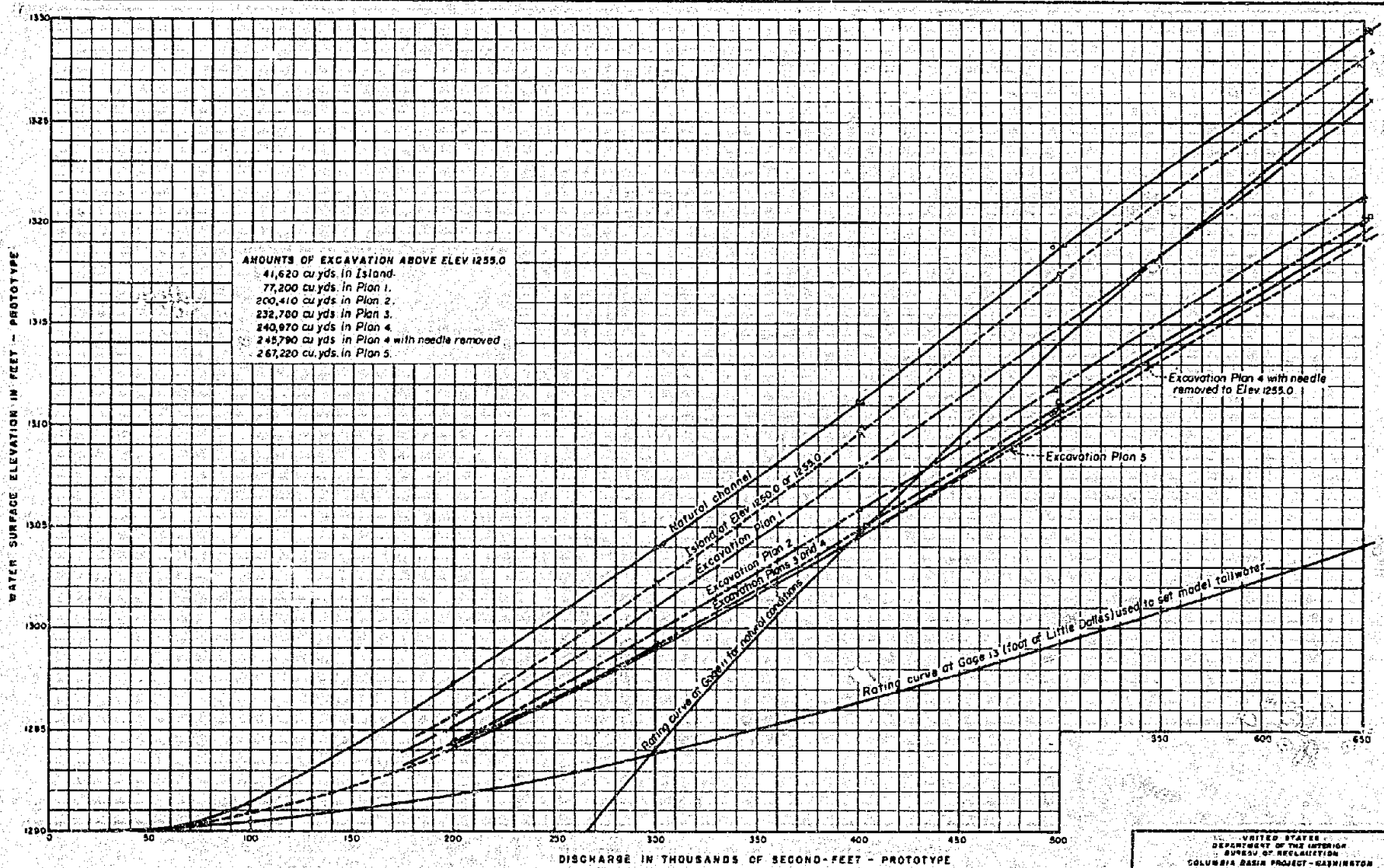
EXPLANATION

- Observed model profiles
- Calculated profiles using Kutter's n for natural flow
- Calculated profiles using Kutter's n for backwater flow

A.R.C. 4-2-40

222-D-5892

FIGURE 40



NOTE

All rating curves based on reservoir elevation 1290.0 at Grand Coulee Dam except natural rating curve at Gage 11. Gage 11 is at the head of the Little Dalles.

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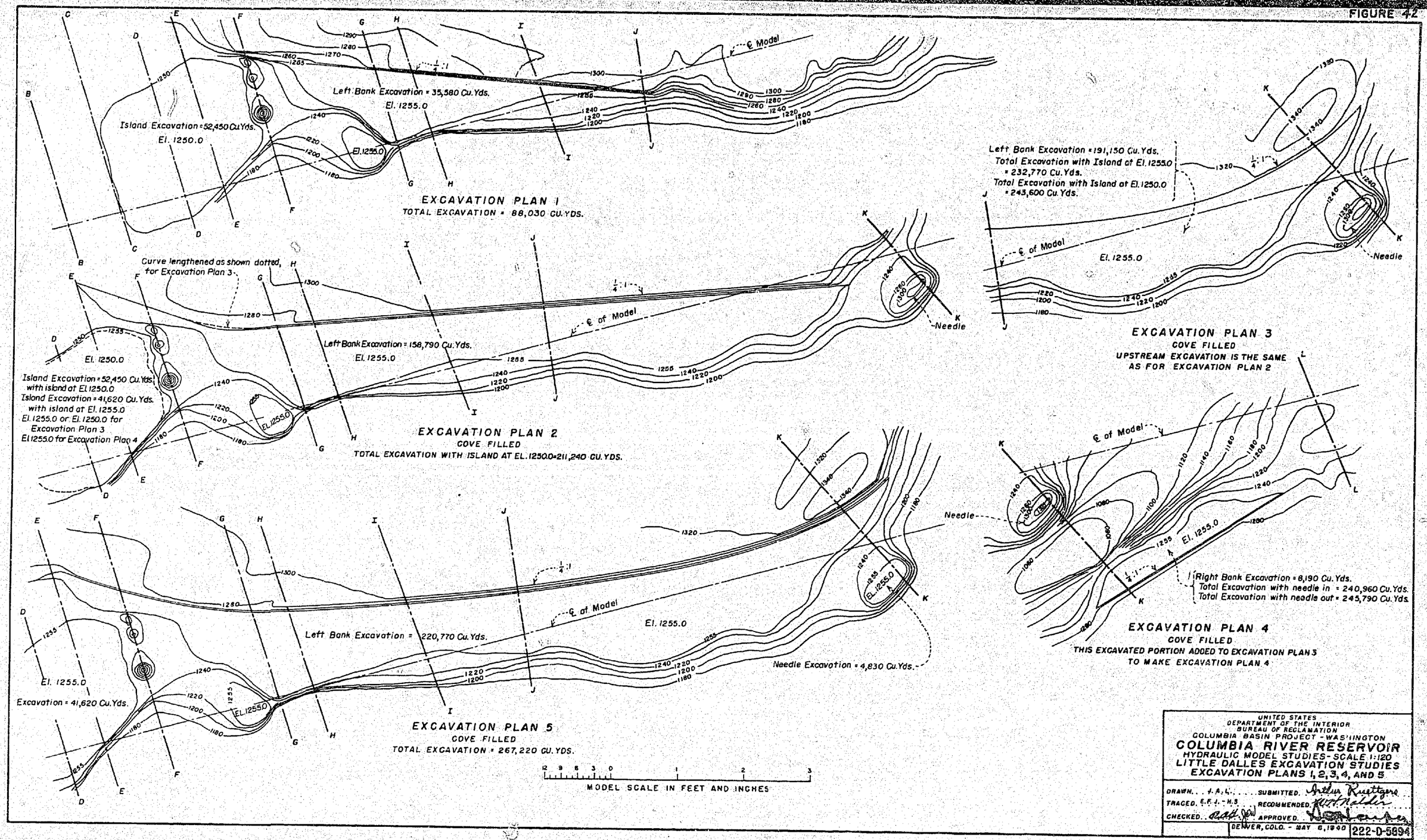
COLUMBIA RIVER RESERVOIR
HYDRAULIC MODEL STUDIES - SCALE 1:120
LITTLE DALLES EXCAVATION STUDIES
RATING CURVES FOR GAGE 11

DRAWN R.A.P. SUBMITTED Arthur Kartman
TRACED F.A.H.R. RECOMMENDED
CHECKED APPROVED
DENVER, COLORADO - DECEMBER 1950
E&R-D-5893

FIGURE 4

FIGURE 4-2


Left Bank Excavation = 35,580 Cu. Yds.
El. 1255.0
Island Excavation = 52,450 Cu. Yds.
El. 1250.0
℄ Model
EXCAVATION PLAN 1
TOTAL EXCAVATION = 88,030 CU. YDS.
Curve lengthened as shown dotted, for Excavation Plan 3.
Left Bank Excavation = 158,790 Cu. Yds.
El. 1255.0
El. 1250.0
Island Excavation = 52,450 Cu. Yds. with island at El. 1250.0
Island Excavation = 41,620 Cu. Yds. with island at El. 1255.0
El. 1255.0 or El. 1250.0 for Excavation Plan 3
El. 1255.0 for Excavation Plan 4
℄ of Model
Needle
EXCAVATION PLAN 2
COVE FILLED
TOTAL EXCAVATION WITH ISLAND AT EL. 1250.0 = 211,240 CU. YDS.
Left Bank Excavation = 191,150 Cu. Yds.
Total Excavation with Island at El. 1255.0 = 232,770 Cu. Yds.
Total Excavation with Island at El. 1250.0 = 243,600 Cu. Yds.
EXCAVATION PLAN 3
COVE FILLED
UPSTREAM EXCAVATION IS THE SAME AS FOR EXCAVATION PLAN 2
Left Bank Excavation = 220,770 Cu. Yds.
Needle Excavation = 4,830 Cu. Yds.
Excavation = 41,620 Cu. Yds.
EXCAVATION PLAN 5
COVE FILLED
TOTAL EXCAVATION = 267,220 CU. YDS.
Right Bank Excavation = 8,190 Cu. Yds.
Total Excavation with needle in = 240,960 Cu. Yds.
Total Excavation with needle out = 245,790 Cu. Yds.
EXCAVATION PLAN 4
COVE FILLED
THIS EXCAVATED PORTION ADDED TO EXCAVATION PLAN 3 TO MAKE EXCAVATION PLAN 4
MODEL SCALE IN FEET AND INCHES
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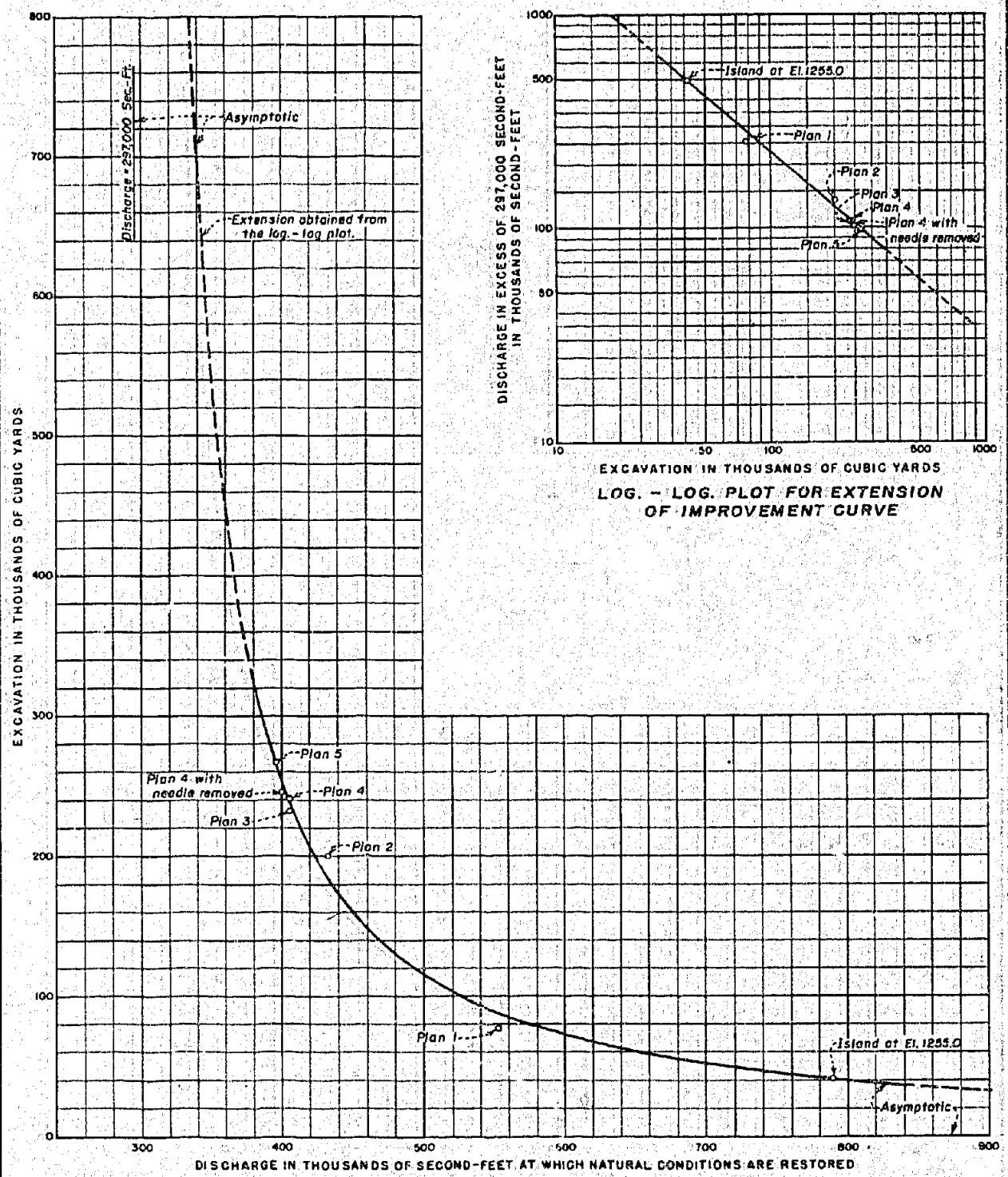
COLUMBIA RIVER RESERVOIR
HYDRAULIC MODEL STUDIES - SCALE 1:120
LITTLE DALLES EXCAVATION STUDIES
EXCAVATION PLANS 1, 2, 3, 4, AND 5
DRAWN. . . J.A.L. . . . . SUBMITTED.
TRACED. E.F.J. - H.S. . . RECOMMENDED.
CHECKED. . . . APPROVED.
DENVER, COLO. - MAY 6, 1940
222-D-5894



LOG. - LOG. PLOT FOR EXTENSION OF IMPROVEMENT CURVE

NOTE
Reservoir elevation 1290.0 at Grand Coulee Dam.

BUREAU OF RECLAMATION

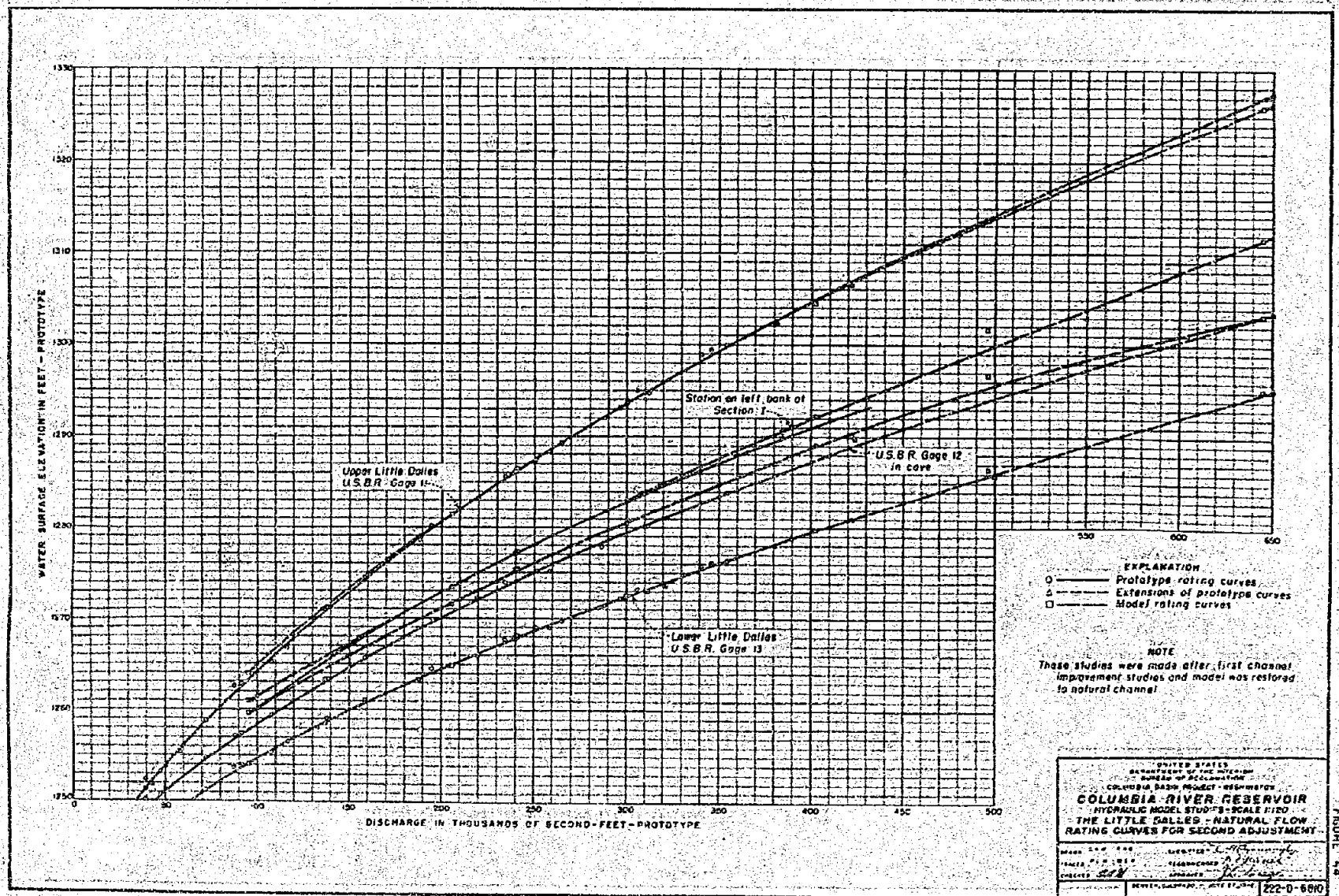
COLUMBIA RIVER RESERVOIR

HYDRAULIC MODEL STUDIES - SCALE 1:120

COMPARISON OF IMPROVEMENT AND EXCAVATION AT THE LITTLE DALLES BACKWATER CONDITIONS

R.A.G. 5-6-40

222-D-5895


WATER SURFACE ELEVATION IN FEET - PROTOTYPE
1330
1320
1310
1300
1290
1280
1270
1260
1250
0
50
100
150
200
250
300
350
400
450
500
DISCHARGE IN THOUSANDS OF SECOND-FEET-PROTOTYPE
Upper Little Dalles
U.S.B.R. Gage 11
Station on left bank of
Section 1
U.S.B.R. Gage 12
in core
Lower Little Dalles
U.S.B.R. Gage 13
550
600
650
EXPLANATION
Prototype rating curves
Extensions of prototype curves
Model rating curves
NOTE
These studies were made after first channel improvement studies and model was restored to natural channel
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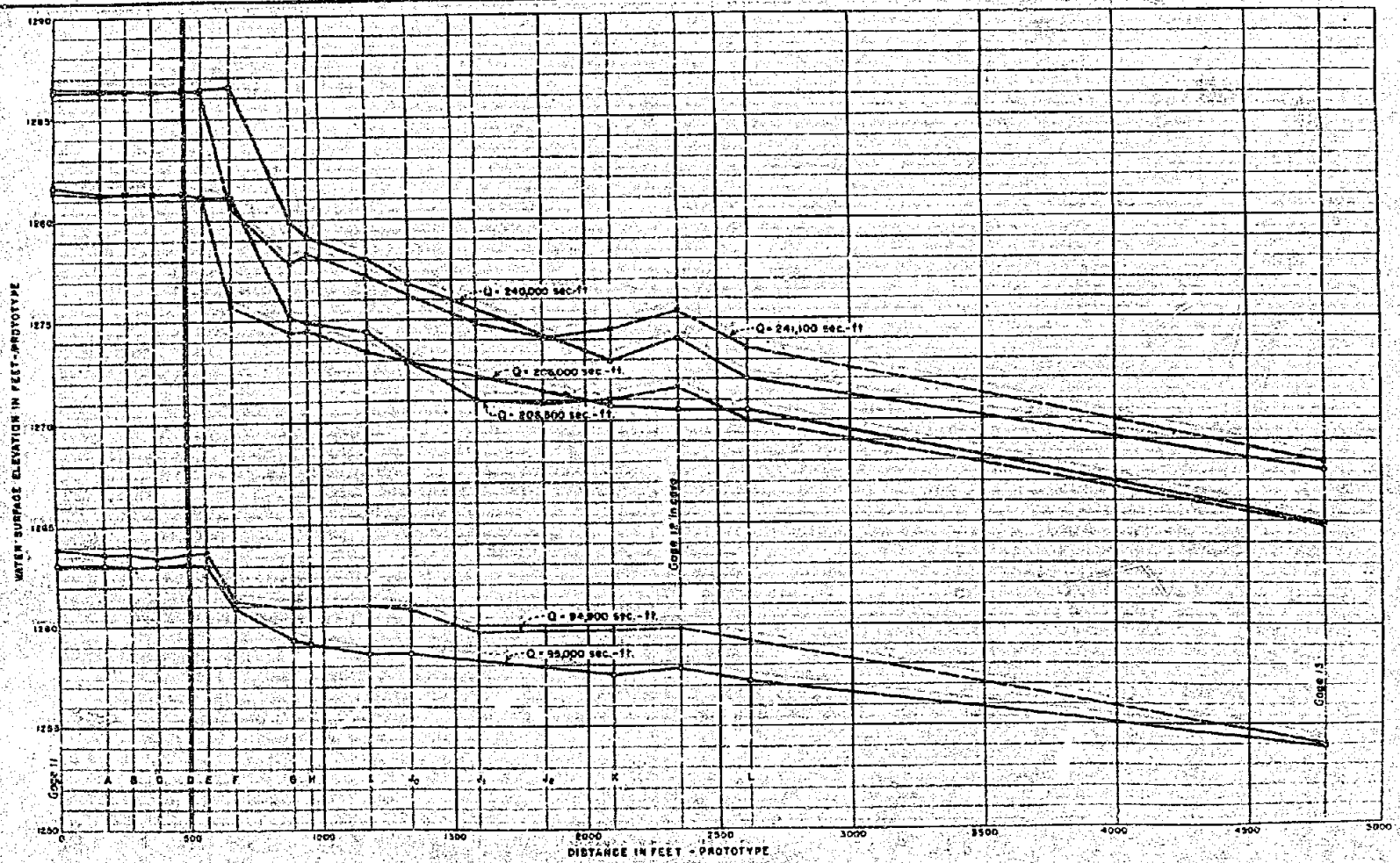
COLUMBIA BASIN PROJECT - WASHINGTON
COLUMBIA RIVER RESERVOIR
HYDRAULIC MODEL STUDIES - SCALE 1:120
THE LITTLE DALLES - NATURAL FLOW
RATING CURVES FOR SECOND ADJUSTMENT
222-D-6810

FIGURE 44



EXPLANATION

Prototype profiles.
Model profiles.

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COLUMBIA RIVER RESERVOIR

HYDRAULIC MODEL STUDIES

WATER SURFACE PROFILES ALONG THE LEFT BANK OF THE LITTLE DALLES

NATURAL CHANNEL - NATURAL FLOW

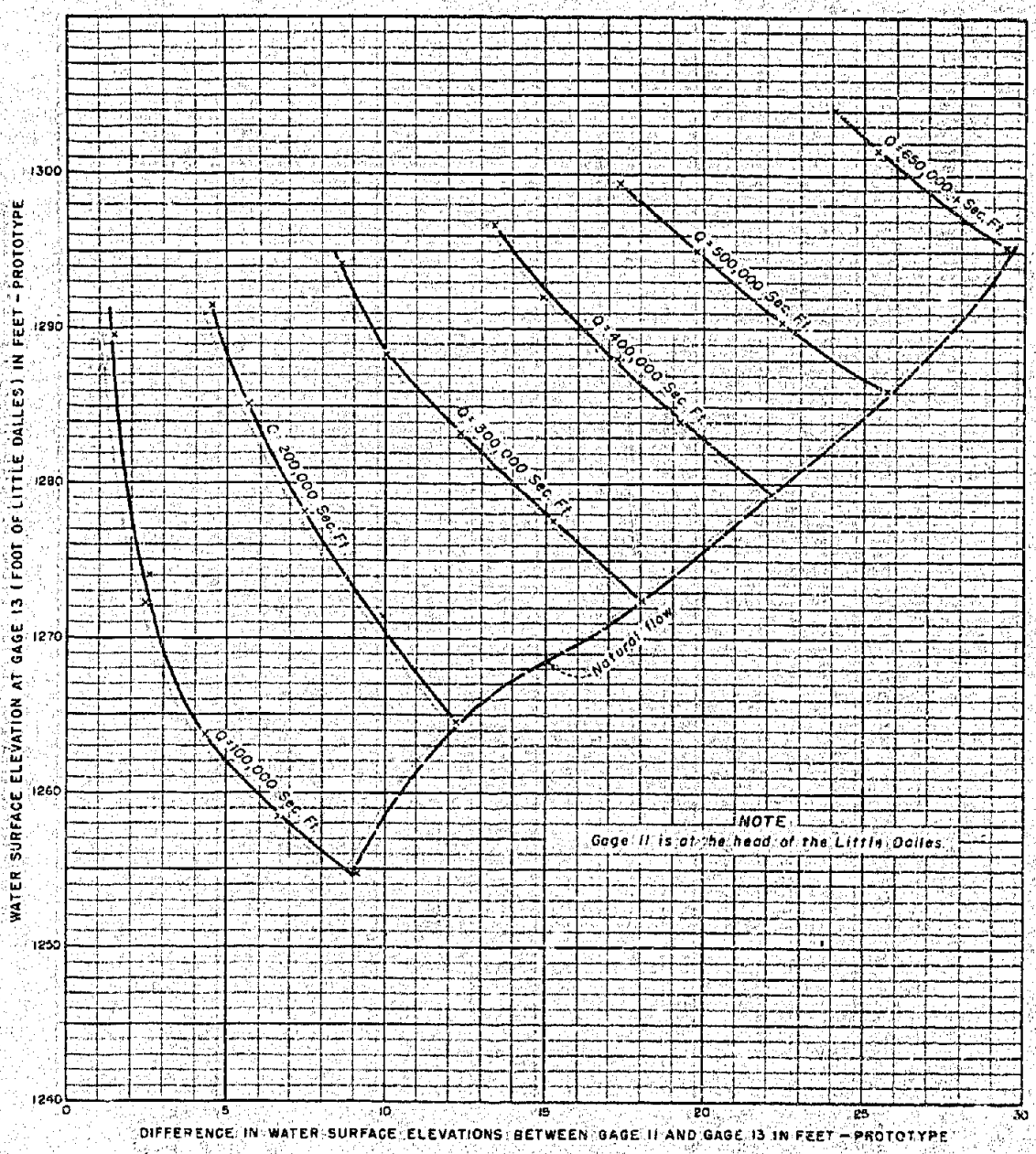
NOTE

The discharge for the higher prototype profile varied from 242,000 to 250,000 second-feet

222-D-6506

FIGURE 143

FIGURE 46



BUREAU OF RECLAMATION

COLUMBIA RIVER RESERVOIR

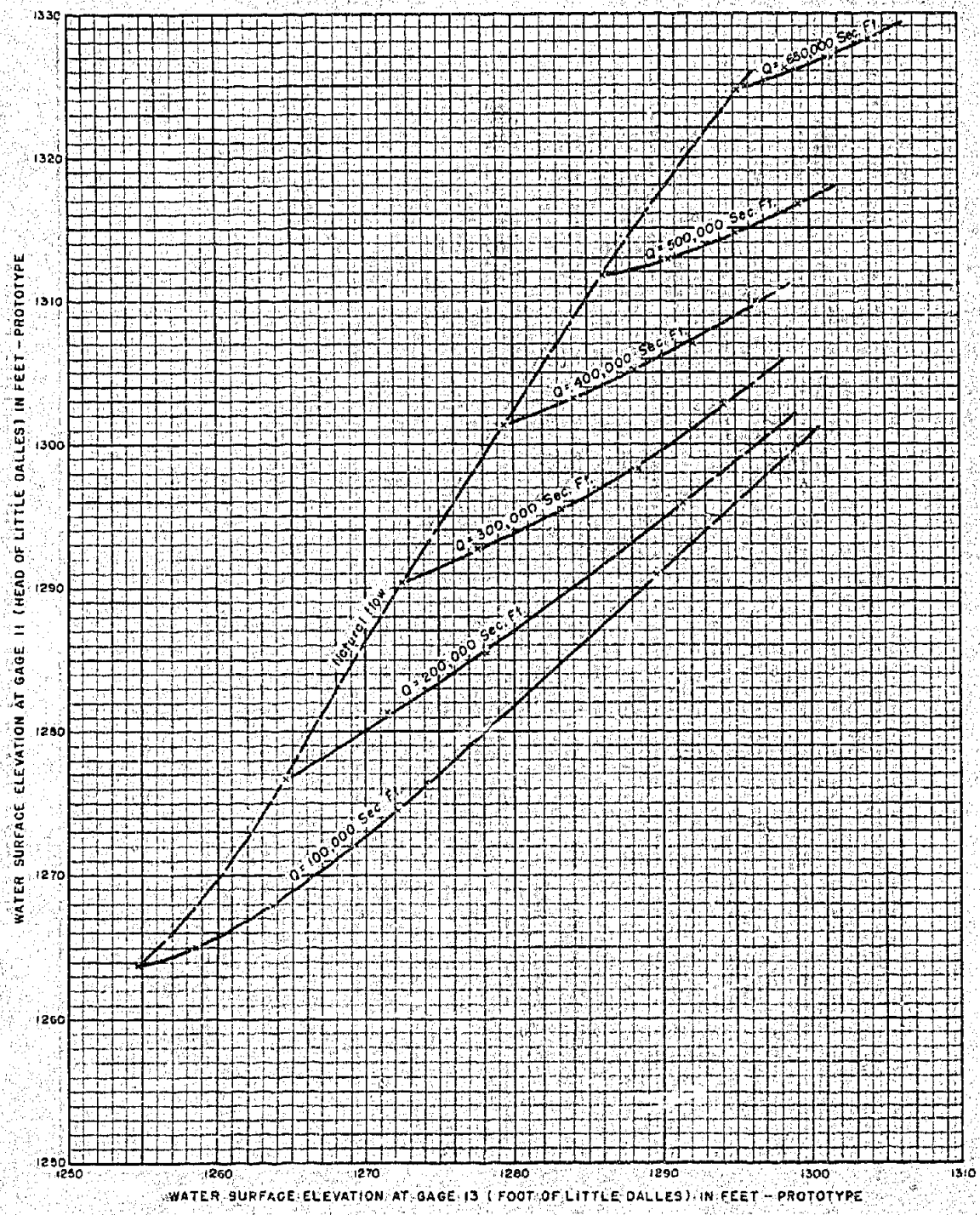
HYDRAULIC MODEL STUDIES - SCALE 1:120

HEAD LOSS THROUGH THE LITTLE DALLES FOR VARIOUS BACKWATER STAGES
ISLAND REMOVED TO ELEVATION 1255.0

R.A.G. 7-8-40

222-D-6907

FIGURE 47



BUREAU OF RECLAMATION

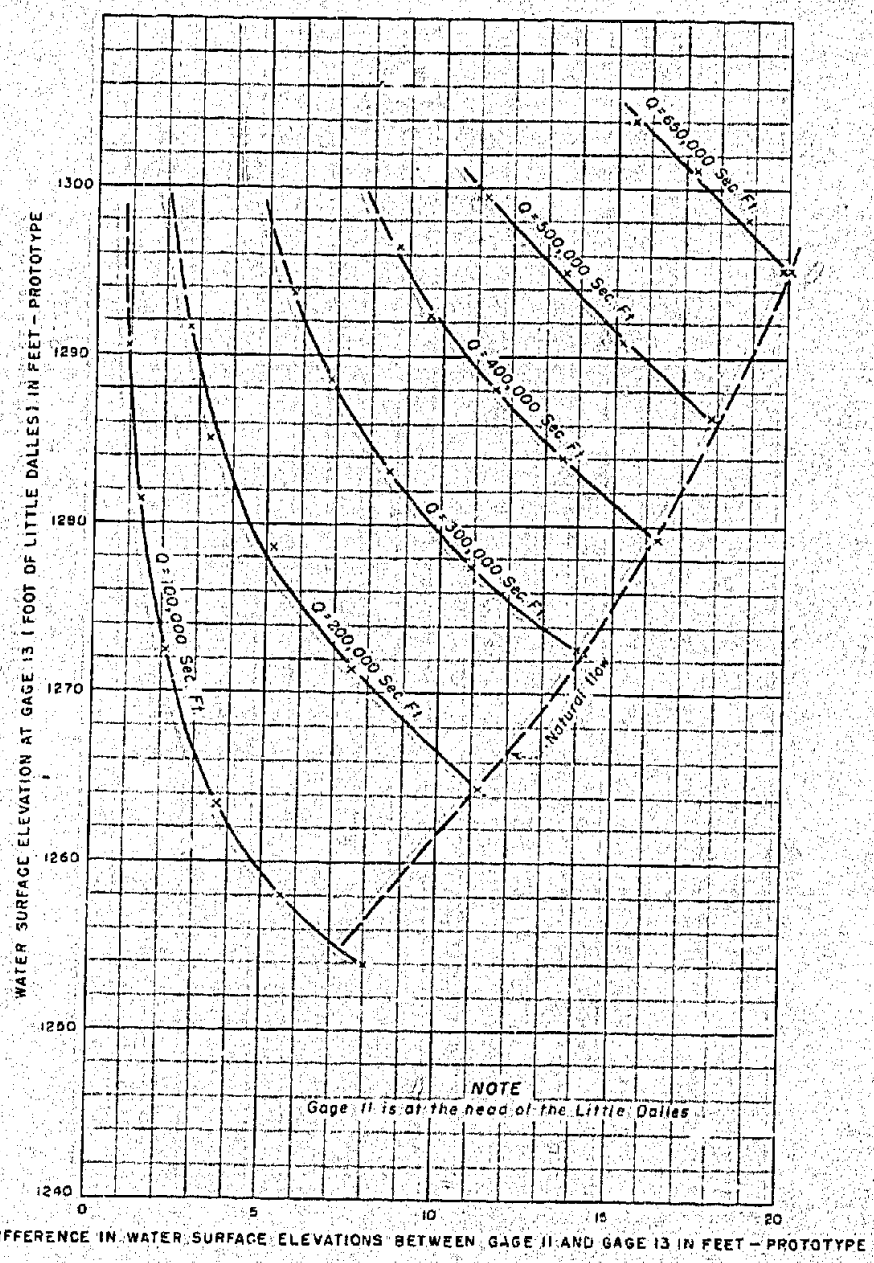
COLUMBIA RIVER RESERVOIR

HYDRAULIC MODEL STUDIES - SCALE 1:120

WATER SURFACE ELEVATIONS AT HEAD OF LITTLE DALLES FOR VARIOUS BACKWATER STAGES
ISLAND REMOVED TO ELEVATION 1255.0

R.A.G. 7-2-40

222-D-5908



BUREAU OF RECLAMATION

COLUMBIA RIVER RESERVOIR

HYDRAULIC MODEL STUDIES - SCALE 1:120

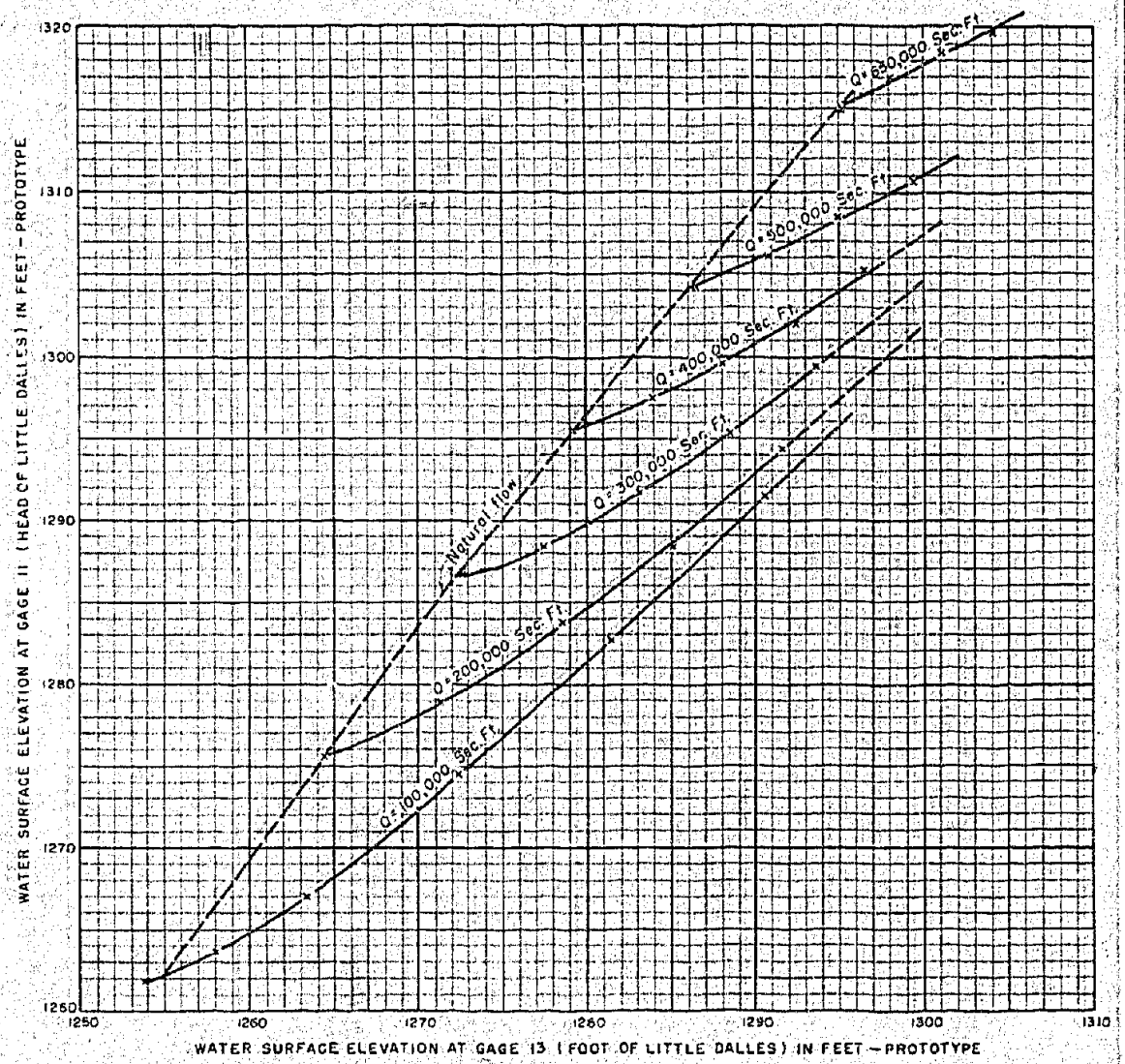
HEAD LOSS THROUGH THE LITTLE DALLES FOR VARIOUS BACKWATER STAGES

EXCAVATION PLAN 5

R.A.G. 7-17-40

222-D-6909

FIGURE 49



BUREAU OF RECLAMATION

COLUMBIA RIVER RESERVOIR

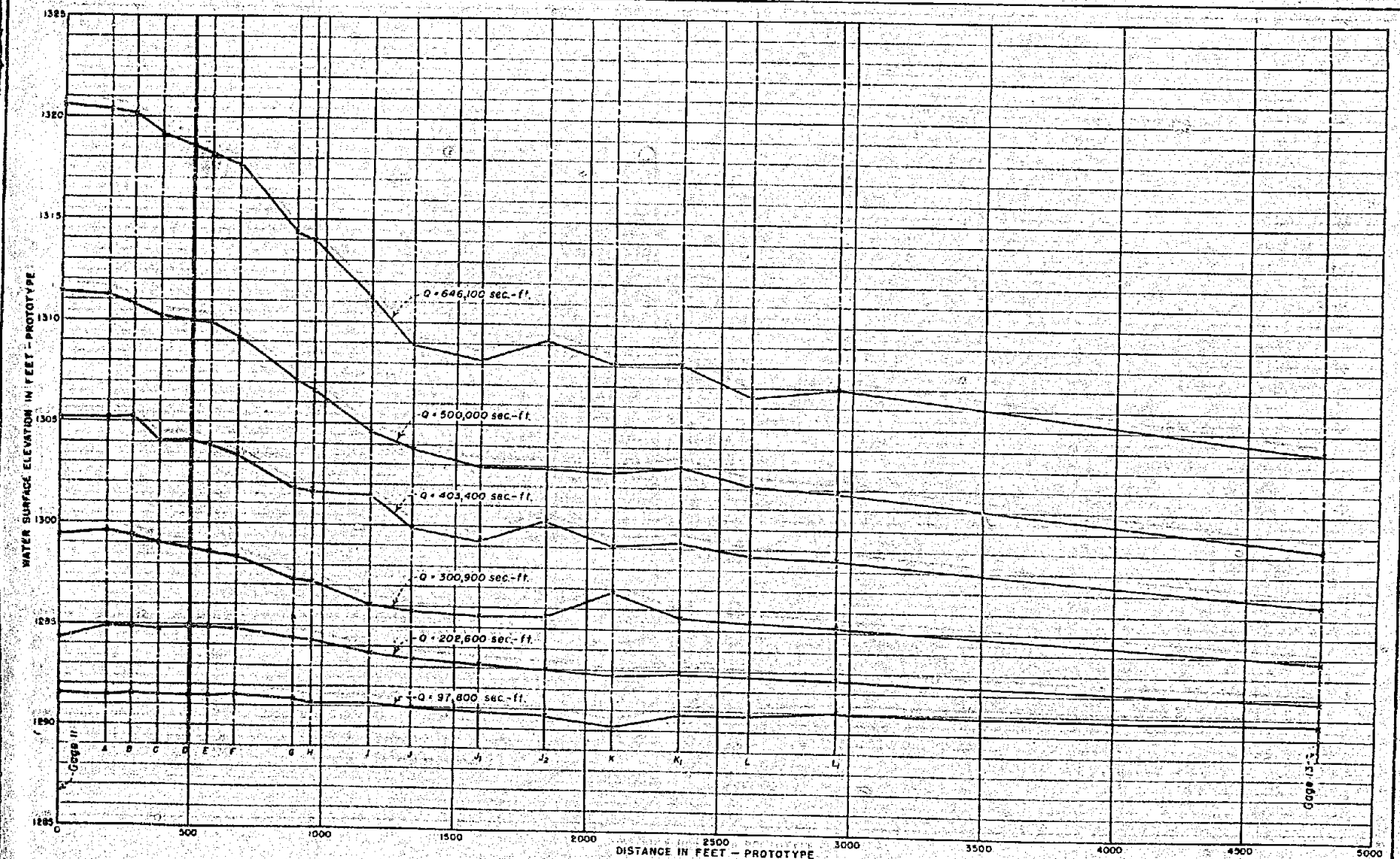
HYDRAULIC MODEL STUDIES - SCALE 1:120

WATER SURFACE ELEVATIONS AT HEAD OF THE LITTLE DALLES FOR VARIOUS BACKWATER STAGES

EXCAVATION PLAN 5

R.A.G. 7-17-40

222-D-6910



COLUMBIA RIVER RESERVOIR

HYDRAULIC MODEL STUDIES – SCALE 1:120

WATER SURFACE PROFILES THROUGH THE LITTLE DALLES WITH BACKWATER

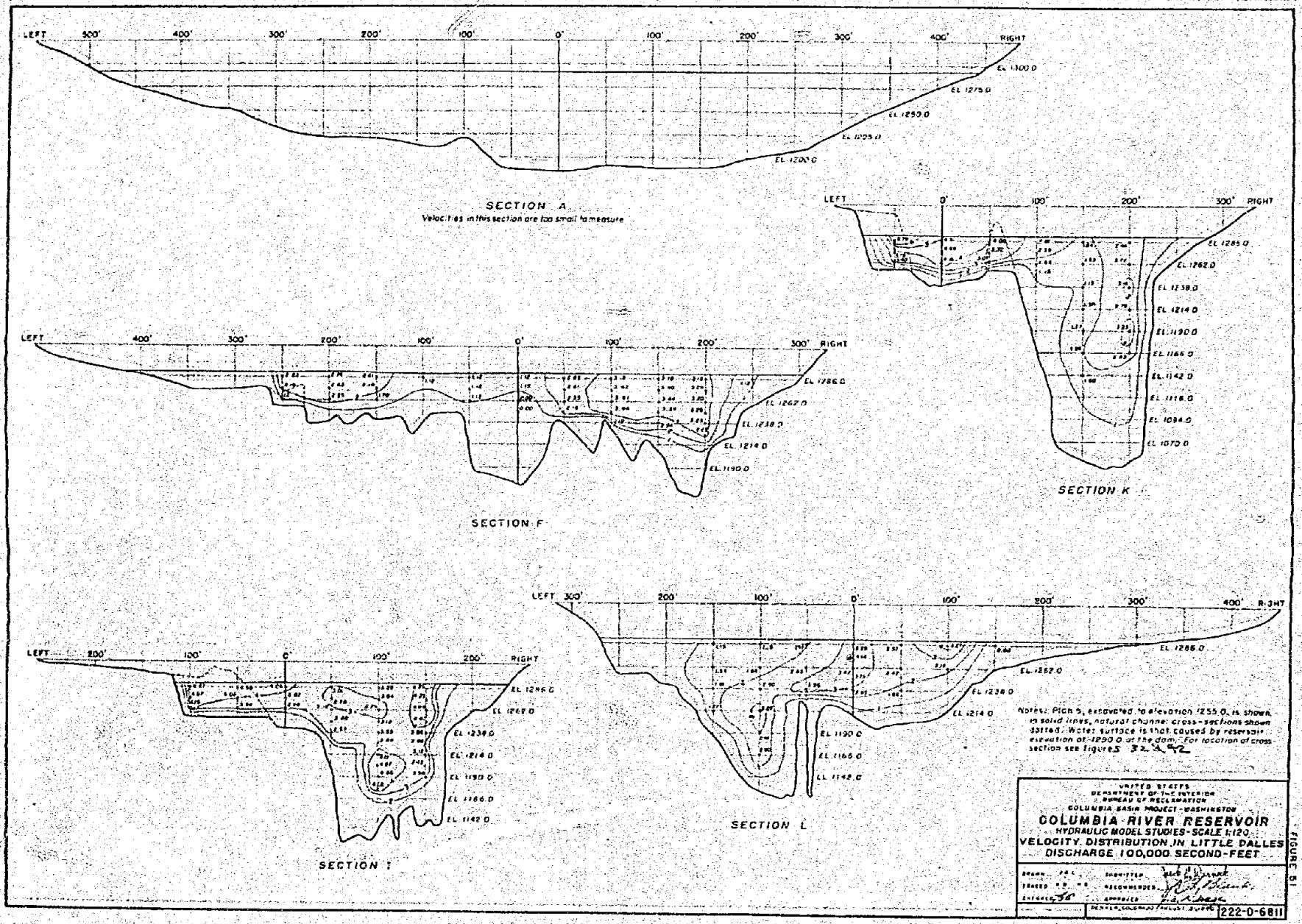
EXCAVATION PLAN 5

NOTE.
Reservoir elevation 1290.0 at Grand Coulee Dam.

FIGURE 50

222-D-6911

R 1 6 7-23-40


LEFT
RIGHT
EL 1300.0
EL 1275.0
EL 1250.0
EL 1225.0
EL 1200.0
SECTION A
Velocities in this section are too small to measure
EL 1286.0
EL 1262.0
EL 1238.0
EL 1214.0
EL 1190.0
EL 1166.0
EL 1142.0
EL 1118.0
EL 1094.5
EL 1070.0
SECTION K
EL 1286.0
EL 1262.0
EL 1238.0
EL 1214.0
EL 1190.0
SECTION F
EL 1286.0
EL 1262.0
EL 1238.0
EL 1214.0
EL 1190.0
EL 1166.0
EL 1142.0
SECTION I
EL 1286.0
EL 1262.0
EL 1238.0
EL 1214.0
EL 1190.0
EL 1166.0
EL 1142.0
SECTION L
Notes: Pitch 5, excavated to elevation 1255.0, is shown in solid lines, natural channel cross-sections shown dotted. Water surface is that caused by reservoir elevation of 1290.0 at the dam. For location of cross section see figures 32 & 42
UNITED STATES
DEPARTMENT OF THE INTERIOR
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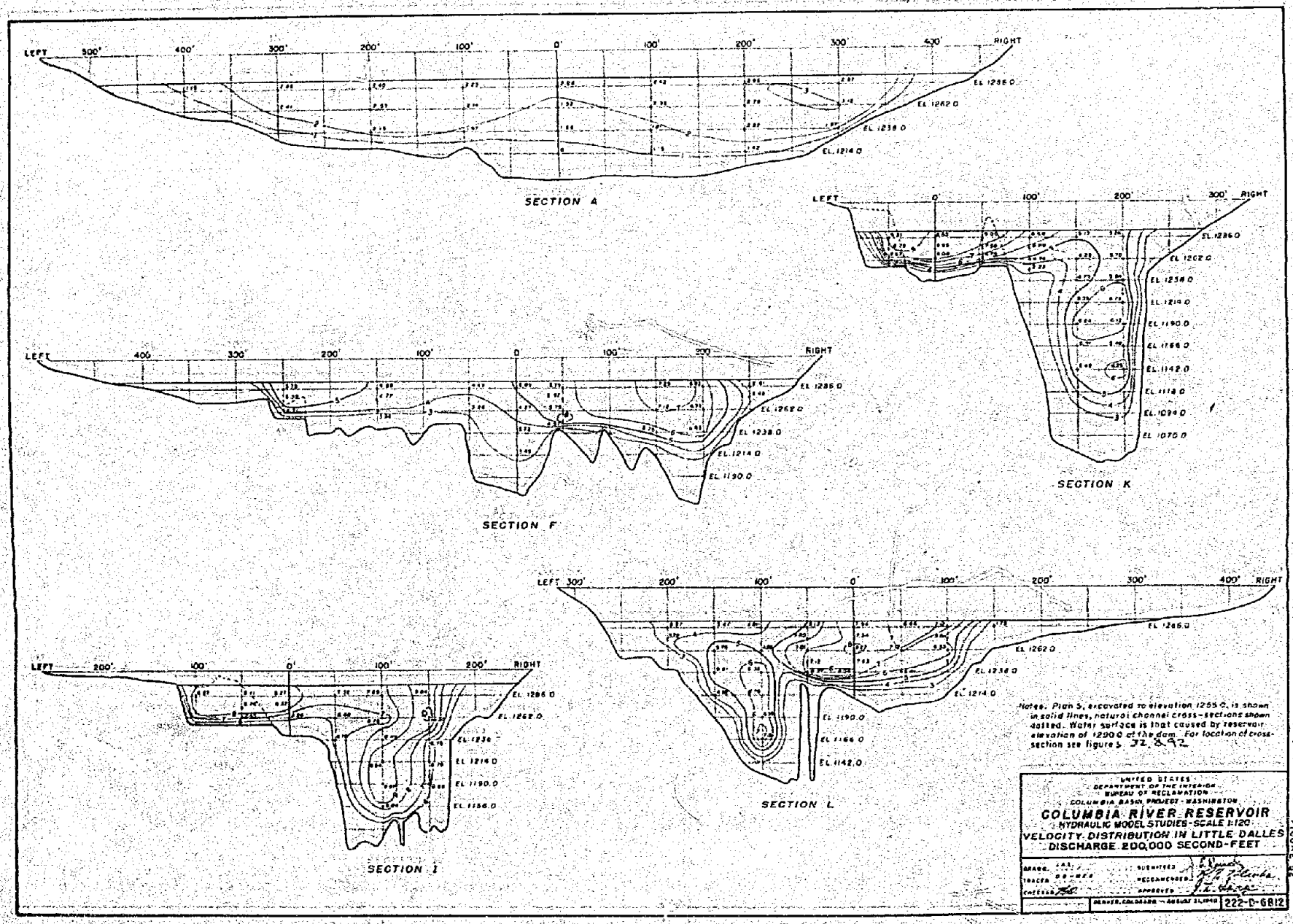
COLUMBIA BASIN PROJECT - WASHINGTON
COLUMBIA RIVER RESERVOIR
HYDRAULIC MODEL STUDIES - SCALE 1:120
VELOCITY DISTRIBUTION IN LITTLE DALLES
DISCHARGE 100,000 SECOND-FEET
222-D-6811

FIGURE 13



Notes: Plan 5, excavated to elevation 1255.0, is shown in solid lines, natural channel cross-sections shown dotted. Water surface is that caused by reservoir elevation of 1290.0 at the dam. For location of cross-section see figures 32, 33, 92

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COLUMBIA RIVER RESERVOIR

HYDRAULIC MODEL STUDIES - SCALE 1:120

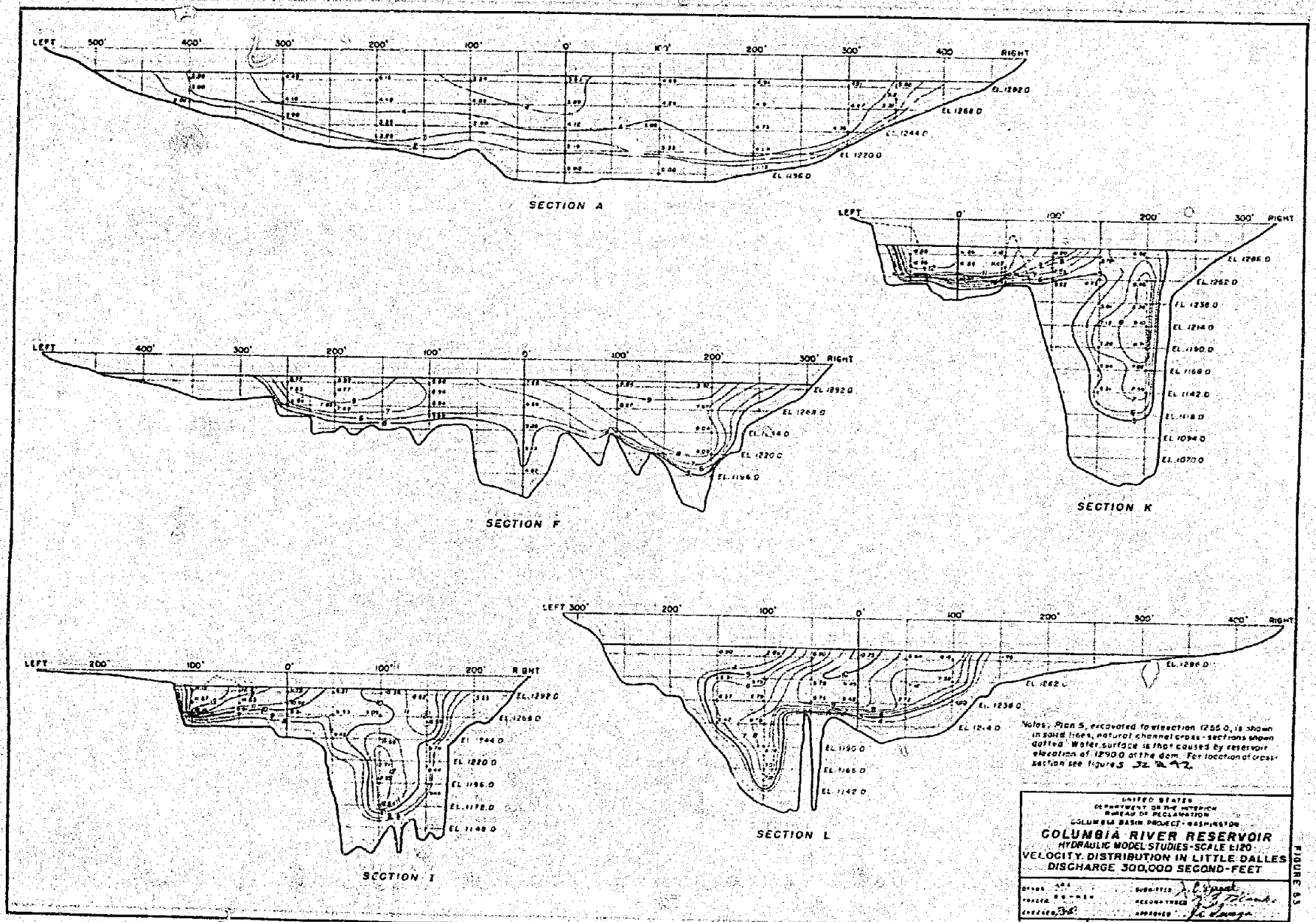
VELOCITY DISTRIBUTION IN LITTLE DALLES

DISCHARGE 200,000 SECOND-FEET

DRAWN J.A.L. SUBMITTED
TRACED D.R.M.E. RECOMMENDED
CHECKED APPROVED

DENVER, COLORADO — ABERDEEN, IDAHO 222-D-6812

FIGURE 92



Notes: Plan 5, excavated to elevation 1255.0, is shown in solid lines, natural channel cross-sections shown dotted. Water surface is that caused by reservoir elevation of 1290.0 at the dam. For location of cross-section see figures 32 & 42.

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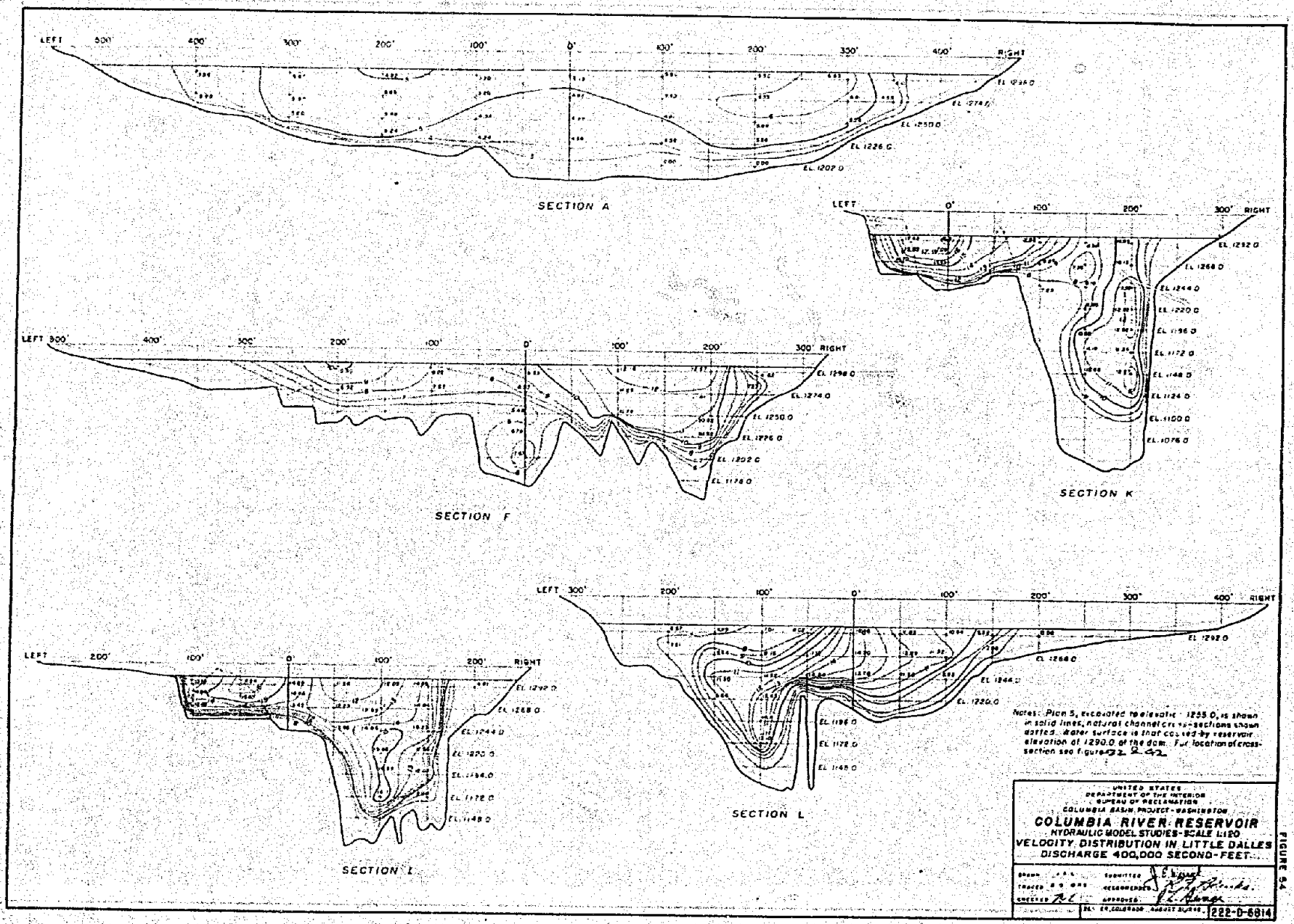
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON

COLUMBIA RIVER RESERVOIR
HYDRAULIC MODEL STUDIES-SCALE 1:120
VELOCITY DISTRIBUTION IN LITTLE DALLES
DISCHARGE 300,000 SECOND-FEET

DRAWN: [illegible] SUBMITTED: [illegible]
TRACED: [illegible] RECOMMENDED: [illegible]
CHECKED: [illegible] APPROVED: [illegible]

DENVER, COLORADO — AUGUST 21, 1950 222-D-6813

FIGURE 63



Notes: Plan 5, excavated to elevation 1255.0, is shown in solid lines, natural channel cross-sections shown dotted. Water surface is that caused by reservoir elevation of 1290.0 at the dam. For location of cross-section see figures 32 & 42

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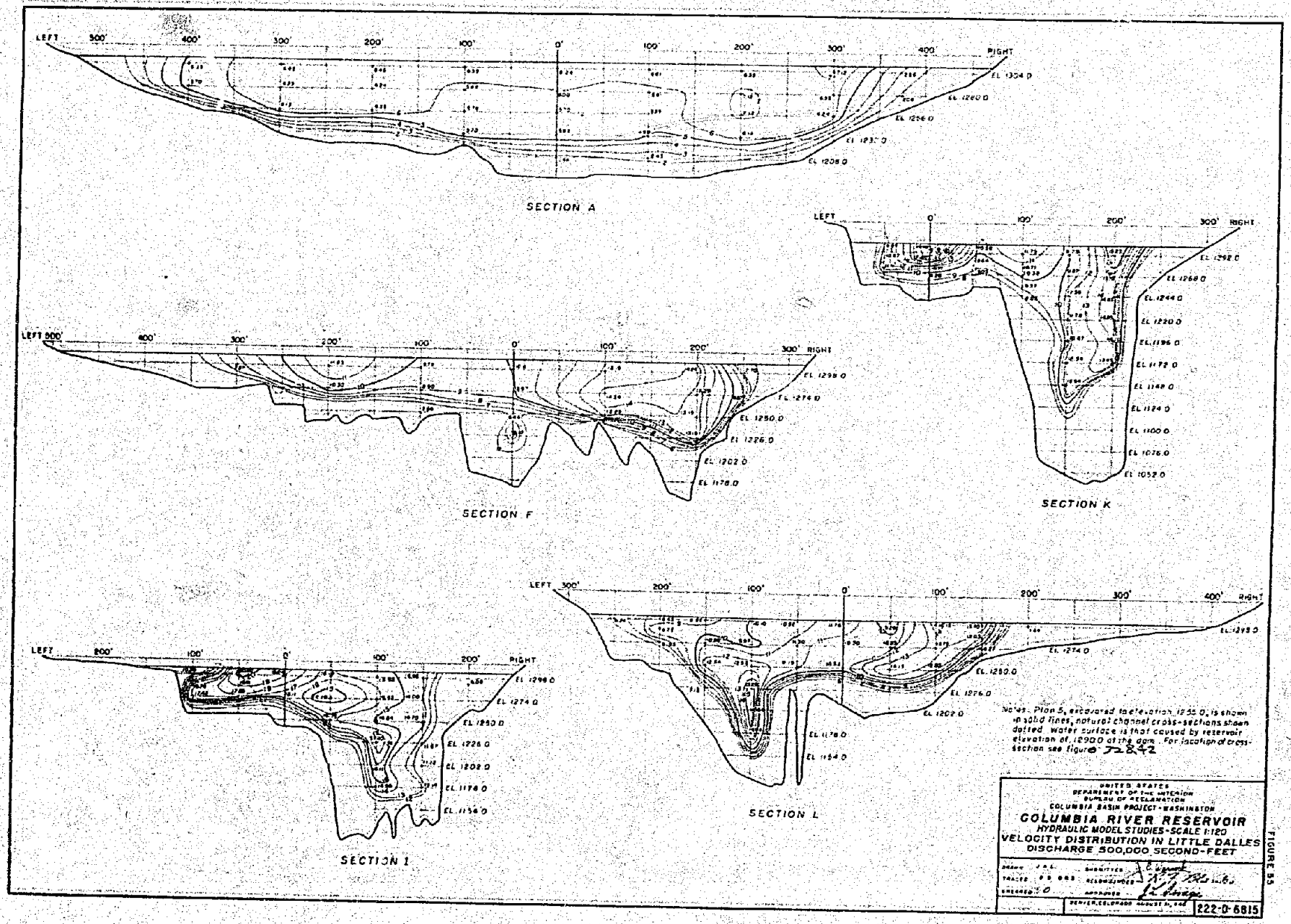
COLUMBIA BASIN PROJECT - WASHINGTON

COLUMBIA RIVER RESERVOIR
HYDRAULIC MODEL STUDIES - SCALE 1:120
VELOCITY DISTRIBUTION IN LITTLE DALLES
DISCHARGE 400,000 SECOND-FEET

DRAWN J.P.S. SUBMITTED
TRACED R.D.W. RECOMMENDED
CHECKED RL APPROVED

DENVER, COLORADO AUGUST 1949 222-D-6814

FIGURE 54



Notes - Plan 5, excavated to elevation 1255.0, is shown in solid lines, natural channel cross-sections shown dotted. Water surface is that caused by reservoir elevation of 1290.0 at the dam. For location of cross-section see figure 72842

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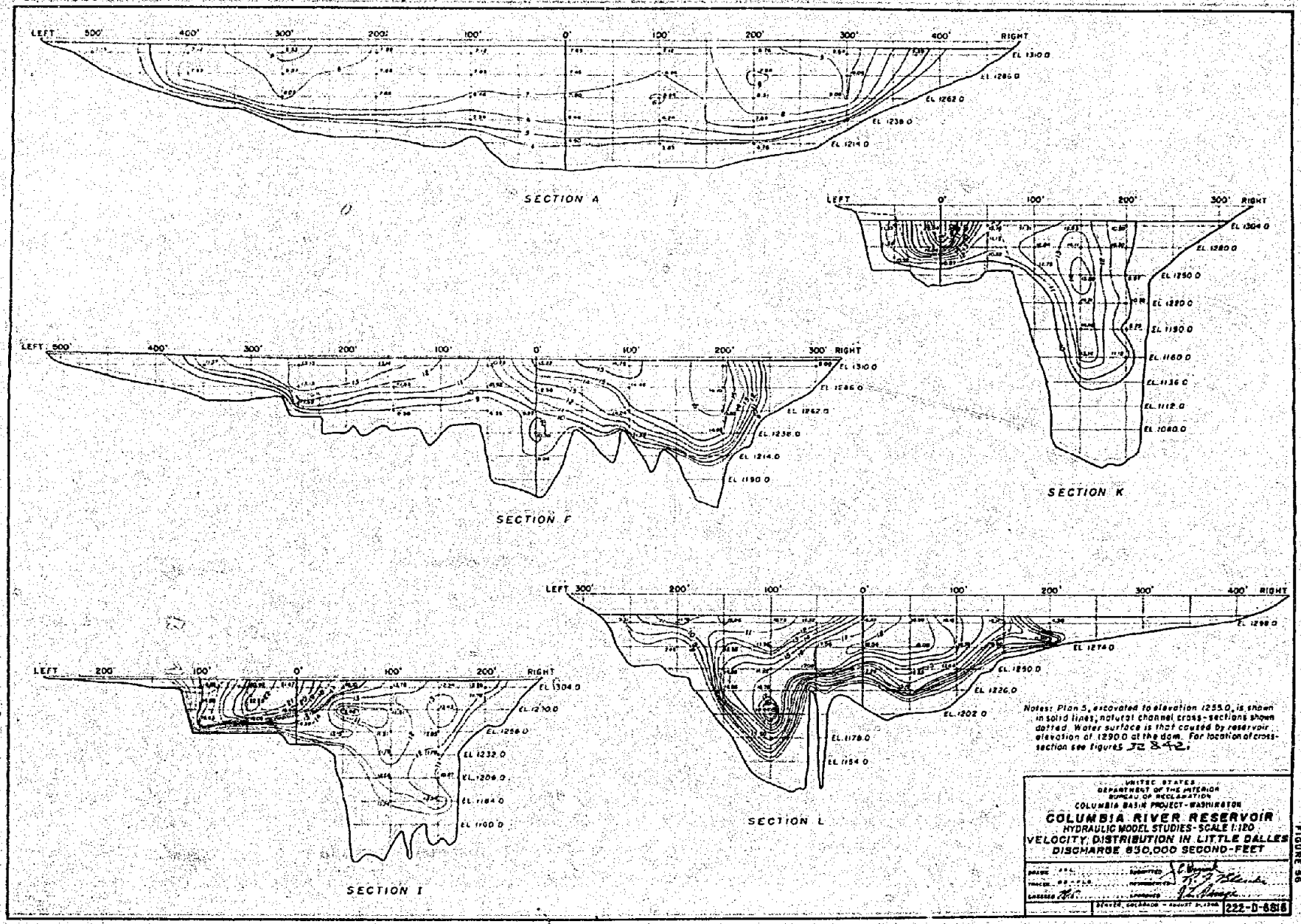
COLUMBIA RIVER RESERVOIR
HYDRAULIC MODEL STUDIES - SCALE 1:120
VELOCITY DISTRIBUTION IN LITTLE DALLES
DISCHARGE 500,000 SECOND-FEET

DRAWN J.A.L. SUBMITTED
TRACED R.B.G.B. RECOMMENDED
CHECKED J.O. APPROVED

DENVER, COLORADO AUGUST 14, 1948

222-D-6815

FIGURE 55



Notes: Plan 5, excavated to elevation 1255.0, is shown in solid lines; natural channel cross-sections shown dotted. Water surface is that caused by reservoir elevation of 1290.0 at the dam. For location of cross-section see figures 32 & 42.

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DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON

COLUMBIA RIVER RESERVOIR

HYDRAULIC MODEL STUDIES - SCALE 1:120

VELOCITY DISTRIBUTION IN LITTLE DALLES

DISCHARGE 850,000 SECOND-FEET

222-D-6818

FIGURE 56

DISCHARGE 50,000 SECOND-FEET

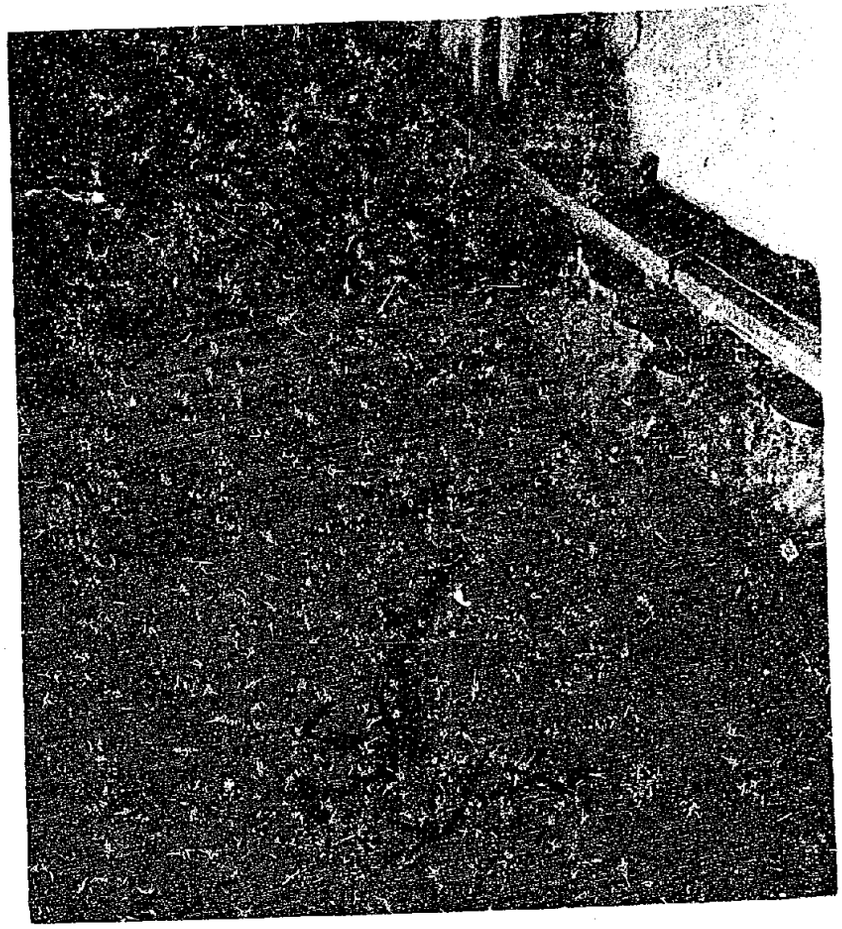
DISCHARGE 200,000 SECOND-FEET

PLAN 5 - EXCAVATED TO ELEVATION 1255.0 - RESERVOIR ELEVATION 1290.0

LITTLE DALLES MODEL STUDIES

FIGURE 57

DISCHARGE 400,000 SECOND-FEET



DISCHARGE 650,000 SECOND-FEET

PLAN 5 - EXCAVATED TO ELEVATION 1255.0 - RESERVOIR ELEVATION 1290.0

LITTLE DALLES MODEL STUDIES

FIGURE 58

CHAPTER VI - EFFECT OF BACKWATER ON CANADIAN PROPERTY AND GREAT NORTHERN RAILROAD

62. Introduction. The report of Corps of Engineers, U. S. Army, on "The Columbia River and Minor Tributaries," published as House Document No. 103, volume 3, 73d Congress, First Session, states on plate No. 147, "Upper Columbia River, Comprehensive Plan - Profile," that "Grand Coulee high dam would not cause backwater in Canada at any river stage." The reservoir water surface at the dam was shown at elevation 1287.6 on this same drawing. This is 2.4 feet lower than the maximum water-surface elevation adopted in Reclamation Bureau specifications No. 757, which give the maximum water-surface elevation at the dam as 1290.0. The backwater studies discussed in chapter IV show that for discharges of about 18,000 second-feet this 2.4-foot change in water-surface level at the dam would result in 1.0-foot change in water surface at the International Boundary, based on either backwater n's or natural flow n's, but for a flood discharge of 400,000 second-feet, the change in water surface at the International Boundary would be only 0.10 foot for backwater n's and 0.25 foot for natural n's.

This increase in reservoir level has a small effect on the computed amount of backwater at the International Boundary but not nearly as much as the error in levels connecting the dam and the boundary bench marks, which was discovered by the Bureau of Reclamation in making field surveys to establish the right-of-way line of the reservoir at elevation 1310.0. The elevations of bench marks at the International Boundary are 1.7 feet lower with respect to the elevations at the dam than had previously been assumed. This error in levels decreased the natural water-surface elevation at the International Boundary by the same amount and consequently increased the amount of backwater by this amount. The increase in reservoir water surface of 2.4 feet at the dam combined with the error in levels of 1.7 feet had the effect of increasing the backwater surface elevation at the International Boundary 2.7 feet for a discharge of 18,000 second-feet and, for a discharge of 400,000 second-feet, of producing 1.25 feet of backwater at the boundary and moving the upper end of the backwater surface from the United States into Canada. As the amount of backwater computed with backwater n's is only 2.8 feet for 18,000 second-feet and 1.25 feet for 400,000 second-feet, most of the backwater at the International Boundary is accounted for by these two factors, of which the error in levels contributed by far the largest part.

In the absence of a satisfactory analytical treatment, water-surface profiles must be computed by means of empirical formulas. Existing formulas have been derived from data on channels that are small compared with that of the Columbia River. There is some question as to whether these formulas are applicable to this large river channel; however, by analyzing the observed natural flow data with the same formulas and methods that are used to compute the backwater surface profiles, any errors that might result from the use of faulty formulas should be minimized. Because of insufficient field data and theoretical weaknesses in open channel flow formulas, it is impossible to obtain an exact solution of the backwater problem, but it is desirable to establish both the most probable water-surface profile and also the highest that can reasonably be expected to occur under backwater conditions. By using the coefficients of roughness that exist for natural flow (natural n's), a higher backwater surface profile is obtained than will probably result from the operation of Grand Coulee Dam. Computations of backwater profiles using roughness coefficients that correspond to the increased stage of the river (backwater n's) give rational profiles that are most likely to result from the operation of Grand Coulee Dam.

The water-surface profiles were computed for discharges of 20,000, 50,000, 100,000, 200,000, 300,000, 400,000, 500,000, and 650,000 second-feet, with reservoir elevation 1290.0 at the dam. The backwater profiles did not show much difference of water-surface elevation between the dam and the foot of the Little Dalles (14 feet for 650,000 second-feet) and were important only in that they established the water-surface elevation from which to start backwater computations in zones 3 and 4. The backwater profiles above the Little Dalles (figures 59 and 60) were computed using both backwater and natural roughness coefficients. The former are considered as most likely to be correct; the latter to give too large a friction loss between river cross sections and thus to give an upper limit for the backwater surface profile. For lower reservoir elevations than the maximum of 1290.0 at the dam, the water-surface elevations at the major observation stations may be found from graphs giving difference of water-surface elevation through the zones as a function of backwater at the downstream end of the zone. Figures 23, 25, and 28 for the unimproved or natural river channel are computed using backwater n's; figures 25 and 28 are computed using natural n's; and figures 26 and 27 for the improved channel at the Little Dalles are based on model results.

The backwater surface elevations for various discharges are completely defined throughout zone 4, where the Great

Northern Railroad parallels the river. The amount of backwater that will occur at the International Boundary with any possible reservoir elevation at the dam and for any discharge in the Columbia River is presented in the form of curves (figures 70, 77, and 79 computed with backwater n's and figures 71, 78, and 80 computed with natural n's) for the unimproved or natural river channel and for channel improvement at the Little Dalles with excavation plan No. 5 or with the island choking the entrance removed to elevation 1255.0.

63. General backwater conditions. The land that will be under the high-water line of the Columbia River Reservoir is largely unimproved. Of the 80,000 acres that will be submerged, less than one-half is of any appreciable value. This part is comprised of wheat land, small irrigated tracts, timberland, and a few small settled communities. The towns of Marcus and Kettle Falls, with a total population of 1,000, have been abandoned, and all buildings have been removed. The reservoir area downstream from the foot of the Little Dalles is being cleared of timber, and all buildings and improvements below elevation 1310.0 will be removed. For any point below the Little Dalles, the reservoir water surface and the effect of wave action will not exceed this elevation since the maximum computed water-surface elevation in this section is 1304.0 at the foot of the Little Dalles for a discharge of 650,000 second-feet. It has been necessary to relocate some 84 miles of state highway and 43 miles of county highway. The Great Northern Railroad has a branch line that runs northward from Spokane to Kettle Falls, shown on figure 1; here the road branches and one fork follows the Kettle River into Canada, while the other fork follows the Columbia River and, farther north in Canada, the Kootenay River to Nelson, British Columbia. A total of 28 miles of track has been relocated below the Little Dalles. Fifteen miles were relocated along the Columbia River between Kettle Falls and China Bend. The remaining thirteen miles were relocated between Kettle Falls and the town of Boyds; this section of railroad required a new bridge across the Columbia River below Kettle Falls, at the present site of the highway bridge, thus abandoning the old bridge at Marcus. It was also necessary to construct a new railroad bridge at Kettle River Gorge and relocate one just below Boyds. New highway bridges had to be built just below Kettle Falls and at Kettle River Gorge.

64. Effect of backwater on the railroad above the Little Dalles. Below the Little Dalles, steps have been taken to protect the Great Northern Railroad from backwater and wave action by relocation or otherwise. Above the Little Dalles, the relation between the backwater and the railroad was not self-evident.

The Columbia River from the head of the Little Dalles to the International Boundary flows in a shallow canyon with very little room between the river and the canyon sides. The Great Northern Railroad track follows the river canyon, being placed along its left, or east, side. The minimum elevation of the track coincides approximately with the natural water-surface profile for a discharge of about 450,000 second-feet. (See figure 60.) Where small creeks empty into the Columbia River, the road is carried on wooden trestles, and, in order not to have them too long or too high, the grade of the railroad was kept as low as was possible without danger of being damaged by large floods. During the flood of 1928, it is said that the water surface of the river was close enough to the track grade to cause damage for a considerable length of track at two locations upstream from the Little Dalles. The 1928 flood had a maximum discharge of 466,000 second-feet at Kettle Falls and was estimated to have had a peak discharge of 450,000 second-feet at the Little Dalles. On the basis of probability studies of stream-flow records at Kettle Falls since 1913, such a flood or larger will likely occur on an average of once in every 14 years. The 1894 flood, estimated to have had a peak discharge of 650,000 second-feet at the Little Dalles, inundated parts of the town of Northport, and the Great Northern Railroad tracks were covered to such a depth that trains were not permitted to operate. The water-surface profile for 650,000 second-feet, shown on figure 60, would indicate that the 1894 flood covered the tracks for about half the distance between the Little Dalles and the International Boundary. The 1928 flood probably submerged only a short stretch of track in the vicinity of Onion Creek just above the Little Dalles, but about 300 feet of railroad track located 1.5 miles above the mouth of Onion Creek and about 7,000 feet of track in the vicinity of Deep Creek were said to have been damaged as a result of water being held along the roadbed. It is reported that the railroad management has endeavored to protect its trackage against floods like that of 1928.

Figure 61 based on backwater n's and figure 62 based on natural n's show the depth of water over the Great Northern Railroad tracks at a point 2.2 miles above the head of the Little Dalles for an unimproved channel. This is the lowest point along the railroad with reference to the water surface. Figure 61 shows that, with the reservoir at elevation 1290.0 at the dam, a flood peak of 360,000 second-feet will just reach the track level. The probability studies indicate that such a flood peak is likely to be reached or exceeded, on the average, about once in every two to four years. Figures 61 and 62 show that the water-surface elevation at this point for the peak of the

usual flood of 300,000 to 400,000 second-feet is increased between 7 and 10 feet above natural stage when the reservoir is held at elevation 1290.0 at the dam.

65. Backwater at the International Boundary for unimproved channel. Figure 63 shows the amount of backwater at the International Boundary for various discharges and assumptions. Curve 1, as previously explained, is considered to be the upper limit of the backwater; curve 7 of figure 63 shows the amount of backwater believed most likely to occur. The amount of backwater at the International Boundary is small, varying from less than four feet for extremely small discharges to one foot for the maximum known flood peak of 650,000 second-feet.

An analysis of the available stream-flow data at Kettle Falls for the last 27 years by the use of a duration curve, figure 20, shows that the normal maximum annual discharge is 345,000 second-feet at the boundary. This flow corresponds to an elevation of 1325.0, which may be taken as the ordinary high-water mark at that point. Any water-surface elevation, even if caused by backwater, that does not exceed the ordinary high-water mark should not have any detrimental effect on agriculture nor should it endanger any settlements, highways, or other improvements since this is the elevation that in the past was most likely to be reached or exceeded each year by the peak of the annual flood. With the water-surface elevation of 1290.0 at the dam and unimproved channel, the discharge would have to be greater than 325,000 second-feet before the water surface at the boundary would exceed the ordinary high-water mark. For a peak discharge of 450,000 second-feet, equal to that of the 1928 flood, the amount of backwater at the boundary with a full reservoir would be only 1.45 feet, so that a flood peak of 433,000 second-feet at the Little Dalles with a full reservoir would produce the same water level at the boundary as the flood of 1928.

The town of Trail, located 10.5 miles above the boundary, has a concrete wall along the Columbia River opposite the large plant of the Consolidated Smelter Company. This wall is said to have been overtopped by high water on several occasions; however, it is understood that, since the last time this occurred, the wall has been heightened. The elevation of the top of this wall is unknown.

The exact extent of the backwater surface curve beyond the International Boundary has not been computed because of a lack of field data and of difficulty that would be experienced in making calculations at the junction of the Pend d'Oreille

and Columbia Rivers. The natural water-surface elevations are known for a number of locations, but no soundings have been made in the river to determine the river cross sections at these observation stations. The Pend d'Oreille River contributes from one-fourth to one-third the discharge of the Columbia River. When a flood peak comes down the Pend d'Oreille, it backs water up the Columbia to the town of Trail. This condition was so pronounced that the gaging station had to be moved from Trail to Birchbank. Water levels on the Columbia River above the Pend d'Oreille depend upon the relative discharges of the Pend d'Oreille and the main stem of the Columbia, and the effect of backwater at the junction on the water level above would be most difficult to compute. However, it has been estimated that there will be no backwater at Trail for all discharges of 300,000 second-feet or less and that there will be from one-tenth to two-tenths of a foot of backwater for all discharges between 300,000 and 500,000 second-feet, with possibly one-half foot for a discharge of 650,000 second-feet.

There are no hydropower plants on the Columbia River located between the International Boundary and the mouth of the Kootenay River, which is 30 miles above the boundary. The Clark Fork or Pend d'Oreille River empties into the Columbia River about one-quarter mile above the International Boundary. For 14 miles above its mouth, this river flows in Canada, dropping about 350 feet in elevation; then the river swings south, crossing the boundary line into the state of Washington. There is a power site on the Pend d'Oreille River about one-quarter mile from its junction with the Columbia. On account of the rapids at the mouth of the Pend d'Oreille River and the normal range of 45 feet between low and high water, it is questionable whether full advantage can be taken by any power project of the low water levels in the Columbia. At large discharges in the Pend d'Oreille, these rapids would be submerged but there would then be plenty of water for the production of power and the decrease in head caused by one or two feet of backwater will be relatively small considering the 350 feet of head available at this site. During years with a shortage of water, the Columbia River Reservoir will be drawn-down (see figures 73, 74, and 75), and such draw-down accompanied by low discharge will result in no backwater at the boundary. So as to conserve water in a dry season, it is important to produce power with the maximum possible head. During a dry season on the Pend d'Oreille, there will be no backwater to decrease the available head.

66. The discharge capacity of Grand Coulee Dam. There are four ways by which water may be withdrawn from Columbia River Reservoir. They are:

(a) By being spilled over the spillway section of the dam.
(b) By being released through the sluices or outlets that pass through the dam.
(c) By being passed through the hydraulic turbines, thereby producing power.
(d) By being withdrawn by the pumps and discharged into Grand Coulee regulatory reservoir.

The spillway section of the dam has a net length of 1,485 feet and is controlled by 11 drum gates which may be raised 28 feet. The fixed crest is at elevation 1260.0 so the drum gates control the reservoir water surface to elevation 1288.0. The maximum reservoir elevation has been fixed at 1290.0 so that when the gates are open the depth above the spillway crest is 30 feet, equivalent to a discharge of 885,000 second-feet. The springing line of the arch bridge over the spillway section of the dam is at elevation 1290.0, and the crown of the arch is at elevation 1307.25. In case of a superflood, the head on the spillway could probably be increased to 37 feet, reservoir elevation 1297.0, without encroaching on the bridge since the draw-down would reduce the head in the plane of the crest. Under these conditions the spillway discharge would be 1,240,000 second-feet. The capacity of the spillway with the gates open under ordinary conditions and also the discharge over the top of the drum gates for partial openings of the gates with the reservoir at either 1290.0 or 1288.0 are shown on figure 64. These discharge curves were obtained from extensive tests of large hydraulic models.

The sluices through the dam are constructed on three levels, with twenty 8.5-foot diameter outlet conduits grouped in pairs on each level. Large trashracks in front of the inlets rise 250 feet, or nearly the full height of the upstream face of the dam, so that each trashrack serves three pairs of outlets at three different levels. Precautions have been taken to keep these trashracks free from ice in the winter. The exposed area of each trashrack is nearly 15,000 square feet and is so great that clogging with trash is nearly impossible. The lower sluices at elevation 935.76 cannot be operated when the reservoir is above elevation 1180.0 because of the excessive head. The intermediate sluices at elevation 1036.67 and the upper sluices at elevation 1136.67 can be operated when water is passing over the spillway, so that their capacity may be added to that of the spillway. On figure 64 is shown the capacity of the upper and intermediate sluices separately and combined. There is also shown the combined capacity of the upper and intermediate sluices and the spillway. In case of the superflood mentioned above, the combined discharge capacity would be

1,440,000 second-feet with the reservoir at elevation 1297.0 while, with the reservoir at 1290.0, the maximum reservoir water surface used for design, the combined capacity of outlets and spillway is 1,070,000 second-feet. According to the probability studies, a flood peak of this magnitude might be expected on an average of once in a little over ten thousand years. The discharge-capacity curves of the sluices are based on extensive tests of hydraulic models.

Under the normal operating head of 335 feet, each of the main turbines will discharge 4,500 second-feet. At present only three of these units are being installed. The combined discharge capacity of the 18 main turbines ultimately proposed will be 81,000 second-feet, but it will be several years before they are all installed.

The normal capacity of the pumping plant will be 16,000 second-feet; however, it will be some time before its full capacity is required. The discharge capacity of the dam is considered to consist of the combined capacity of the outlets and spillway without regard to the capacity of the pumps and turbines. For the first few years, their discharge will not exceed 15,000 second-feet, which is relatively insignificant compared to the discharge of 175,000 second-feet which can be released by the sluices before the spillway is brought into action. The curve on figure 64 marked "Spillway and outlets combined" is used in all the following studies as the discharge capacity of Grand Coulee Dam. These data are also shown in tabular form on figures 70, 71, 77, 78, 79, and 80. The minimum possible water-surface elevation required for a given discharge below which it is impossible to draw the reservoir down is listed in the tables of the above-mentioned figures or may be obtained from the curve marked "Spillway and outlets combined," figure 64. This minimum water-surface elevation is of utmost importance in connection with studies that are to follow.

67. Means of reducing backwater. In the previous paragraphs, discussing backwater, it has been considered that the reservoir would be filled at all times to elevation 1290.0 at the dam and that the river channel would be unaltered, or in its natural state.

It has been mentioned that some damage is said to have been done to the railroad by a discharge of 450,000 second-feet above the Little Dalles. If, with the Columbia River Reservoir elevation 1290.0 at the dam, natural flow conditions could be restored at the head of the Little Dalles for all

discharges above 400,000 second-feet, the situation would remain unchanged for floods of that or greater magnitude. This would also be true as regards the town of Northport and the highway bridge that crosses the river at that point. This bridge does not have a great amount of clearance above high water; the elevations of its lower cord and its floor are shown on figure 60 in relation to the various water-surface profiles. If navigation is feasible above the Little Dalles after the filling of the reservoir, the clearance under this bridge is an important factor. The amount of backwater can be reduced by improvement of the river channel at the Little Dalles or by keeping the reservoir drawn down to a level that would cause no backwater above the Little Dalles.

Neither of these methods will eliminate backwater at all flows. The first method would accomplish the desired result for large rates of inflow, but there would always exist a small amount of backwater during periods of low flow. The last method would avoid backwater at low flows but for large flows it is impossible because the discharge capacity of the dam will not allow the reservoir to be held at low enough levels. Storage reservoirs could be used as an alternative but are hardly practicable and would not avoid backwater at low flows.

68. Reduction of backwater by channel improvement. The Little Dalles offers the only location where an excessive amount of excavation is not required to reduce effectively the losses of the natural river channel. Any channel improvement should be performed above low water since underwater excavation is difficult and expensive, model tests having shown that the excavated material must be entirely removed from the wetted section. Elevation 1255.0 was set as the bottom of any channel improvement; in order to have the water surface in the river at or below this elevation, the river discharge must not exceed 55,000 second-feet; for that discharge the reservoir must be held not higher than elevation 1240.0 at the dam in order to have no backwater that would flood the excavation. From figure 64 it will be noted that the reservoir cannot be held below this level after the inflow reaches 160,000 second-feet. If the reservoir is kept below elevation 1240.0, the natural flow in the Columbia River is the determining factor as to when channel improvement can be made. An inspection of the hydrographs shown on figure 4, accepting the flow at the Little Dalles as equal to 0.9 of the flow at Grand Coulee, indicates that any channel improvement will have to be carried out between the first of November and the first of April.

Channel improvement plan No. 5, requiring 270,000 cubic yards of excavation, is recommended as giving the greatest benefits per dollar expended. The contract for channel improvement at the Little Dalles according to this plan was awarded November 25, 1940. Figure 65 shows the widening of the river channel at the Little Dalles that is to be made under this contract. It was concluded (chapter V) from tests on an hydraulic model that it would be impracticable to eliminate backwater above the Little Dalles for discharges below 400,000 second-feet by means of channel improvement but that it would be feasible, with 400,000 second-feet flowing in the river, to lower the water level at the head of the Little Dalles, with reservoir elevation of 1290.0 at the dam, 6.5 feet below what it would be if the channel were left unimproved. This is precisely the amount of backwater that model results indicated a full reservoir would produce at this point with this discharge, so that natural flow conditions would be restored at this point for a flow of 400,000 second-feet. Figure 66 based on backwater n's and figure 67 based on natural n's show the backwater rating curve at the upper end of the Little Dalles for the unimproved channel. The distance it lies above the natural rating curve indicates the amount of backwater present at any discharge. The distance that the backwater rating curve, with channel improvement (plan No. 5), lies under the backwater rating curve for unimproved channel indicates the benefits of channel improvement. This curve lies above the natural rating curve for discharges of less than 400,000 second-feet, indicating backwater; for greater discharges the backwater rating curve, with channel improvement, lies below the natural rating curve, indicating an actual improvement or a lower river stage than exists under natural conditions, amounting to as much as eight feet for a discharge of 650,000 second-feet. Also shown on figures 66 and 67 are the rating curves at the International Boundary. The reduction in water-surface levels is much less than it is just upstream from the improved channel. The amount of improvement over natural river stage is now only three feet instead of eight feet found at the head of the Little Dalles for a discharge of 650,000 second-feet. It will be noted that channel improvement at the boundary or head of the Little Dalles is most effective at high discharges and that for discharges of 50,000 second-feet or less the benefits have disappeared.

The backwater surface profile with reservoir elevation of 1290.0 at the dam and channel improvement according to plan No. 5 is shown on figures 59 and 60. Figures 68 and 69 show the relation between water surface and railroad track grade at the critical point between the Little Dalles and the International Boundary. The water surface with a full reservoir will reach the

track at a flow of 460,000 second-feet whereas for natural flow conditions it reaches the track at a discharge of 435,000 second-feet. With a full reservoir excavation plan No. 5 will eliminate any backwater above the Little Dalles which might submerge the railroad and will reduce backwater at the International Boundary for inflow rates less than 400,000 second-feet; for greater discharges it will improve present natural flow conditions both along the railroad and at the boundary.

A second plan of channel improvement requiring only 45,000 cubic yards of excavation might have been adopted. This plan would have removed only the rock island choking the entrance to the Little Dalles to elevation 1255.0. Hydraulic model tests were made, and the effect on the water-surface elevation at the critical point along the railroad is shown on figures 68 and 69. This plan does not accomplish the desired result of eliminating backwater above the Little Dalles unless the reservoir is drawn-down to the minimum possible elevation for high rates of inflow. The disadvantage of this plan was the loss of power and storage resulting from operating with the reservoir as much as 28 feet below its contemplated normal operating elevation. Also, operating the turbine at lower heads would require the installation of new power units before they would be needed if the reservoir were operated at its maximum elevation. Under this second plan further channel improvement could have been completed at some future date when additional head for power, additional storage, or a decrease in pumping head to obtain an increase in pumping capacity had been found necessary. This would have required drawing the reservoir down to elevation 1240.0 during the time required for the excavation.

Channel improvement as contemplated by plan No. 5 will eliminate not only all backwater at the International Boundary when the reservoir is full and the river discharge is greater than 400,000 second-feet, but, at extremely high river stages, there will be a lower water level than exists under natural flow conditions (figure 63). This improvement will grow less as one proceeds upstream from the boundary; however, it amounts to three feet at the International Boundary for a discharge of 650,000 second-feet based on computations using either type of roughness coefficient. Under these conditions any overtopping of the sea wall at Trail which might occur could never be attributed to the effect of backwater from Grand Coulee Dam. Channel improvement at the Little Dalles will reduce backwater at the International Boundary for all discharges above 50,000 second-feet; yet it will not affect the amount of backwater at extremely low flows. However, the backwater that occurs with inflow discharges less than 335,000 second-feet will be below

the ordinary high-water mark based on computations using either type of roughness coefficient. The minimum flow of the Columbia River recorded at Kettle Falls gaging station since 1913 is 13,000 second-feet. This corresponds to a water-surface elevation of 1288.0 at the International Boundary. To spill this amount over the top of the spillway gates, at elevation 1288.0, requires a water-surface elevation of 1289.8 at the dam, which, even neglecting friction losses in the reservoir and the river channel, would produce 1.8 feet of backwater at the boundary; therefore, no amount of channel improvement at any location either above or below low water can reduce this amount of backwater. At the head of the Little Dalles with a reservoir elevation of 1290.0 at the dam, it was found to be impossible to restore natural flow conditions for discharges less than 297,000 second-feet because the stage corresponding to these conditions at observation station 13 would require a level water surface or no energy loss through the Little Dalles (figure 41). Figure 43 indicates that channel improvement, according to plan No. 5, would lower the water surface at the head of the Little Dalles as much as is economically feasible. The only way to accomplish a further reduction in backwater at the International Boundary at low discharges is by drawing down the reservoir water surface at the dam.

69. Reduction of backwater by drawing down the reservoir. The operation of Columbia River Reservoir at as high an elevation as possible has a decided advantage for the following reasons:

(a) It makes possible a higher head on the turbines, thus producing more power for the same turbine installation.

(b) It results in less head to pump against in lifting the water to the regulatory reservoir in Grand Coulee, thus saving power.

(c) The reservoir has more storage capacity and is thus more effective in regulating stream flow, thereby producing more firm power at Grand Coulee and aiding in producing firm power at plants downstream.

For the reasons listed above, the drawing down of Columbia River Reservoir, for no other reason than the elimination or reduction of backwater, is to be discouraged; however, the reservoir will be drawn down for other reasons and the lower reservoir elevations will affect the amount of backwater above the Little Dalles. Figure 70 based on backwater n's and figure 71 based on natural n's show the amount of backwater without the channel improvement that would exist at the International Boundary with various reservoir elevations at the dam. It will be noted that it is impossible to lower the reservoir elevation

so that there is no backwater at the boundary when the inflow is greater than 280,000 second-feet for backwater n's or 150,000 second-feet for natural n's because the discharge capacity of Grand Coulee Dam will not permit low enough reservoir elevations. The tables on these figures give the discharge capacity of spillway and sluices for various reservoir elevations. The discharge at the Little Dalles is taken as about 90 percent of that at Grand Coulee, being based on records of annual run-off. Lowering the reservoir water surface from 1290.0 to 1284.2 would just eliminate the backwater at the boundary for zero flow but as the flow increases drawing the reservoir down 5.8 feet would be less and less effective in reducing the amount of backwater. When the inflow is greater than 150,000 second-feet, a 10-foot draw-down at the dam would result in reducing the backwater at the boundary less than one foot when using either type of roughness coefficient. There is some water-surface elevation at the dam for each discharge and for given conditions which will just back the water up to the International Boundary. Since the backwater-surface curve approaches the natural water-surface curve as an asymptote, the question of what amount of backwater will be considered as no backwater must be decided. Anything less than one-tenth of a foot will be considered as no backwater, or, in other words, when the backwater-surface curve comes within less than one-tenth of a foot of the natural surface curve, the backwater curve is said to have stopped or reached its extent. By assuming various reservoir elevations for the usual discharges and computing the amount of backwater at the end of each zone by use of figures 23, 25, and 28, it is possible to construct a curve which shows the maximum reservoir elevation at the dam which will cause no backwater at the International Boundary, figure 72. This curve is fairly accurate for low discharges but is not so precise at large discharges because, for low reservoir, 10 feet variation in reservoir elevation at the dam will change the water-surface elevation at the boundary by only a few hundredths of a foot. The upper part of the curve is therefore shown dotted. Also drawn on this figure (72) is the discharge capacity curve for Grand Coulee Dam, adjusted to discharge at the Little Dalles or the International Boundary. Since it is impossible to draw the reservoir down below this capacity curve, whenever the curve of maximum water surface at the dam for no backwater at the boundary falls below the capacity curve it is impossible to prevent backwater at the boundary. Two curves of maximum water-surface elevation at the dam for no backwater at the boundary have been computed and are shown on figure 72 using either backwater n's or natural n's. Considerable difference in the curves is produced by the use of these two types of roughness coefficients. Figure 61, based on backwater

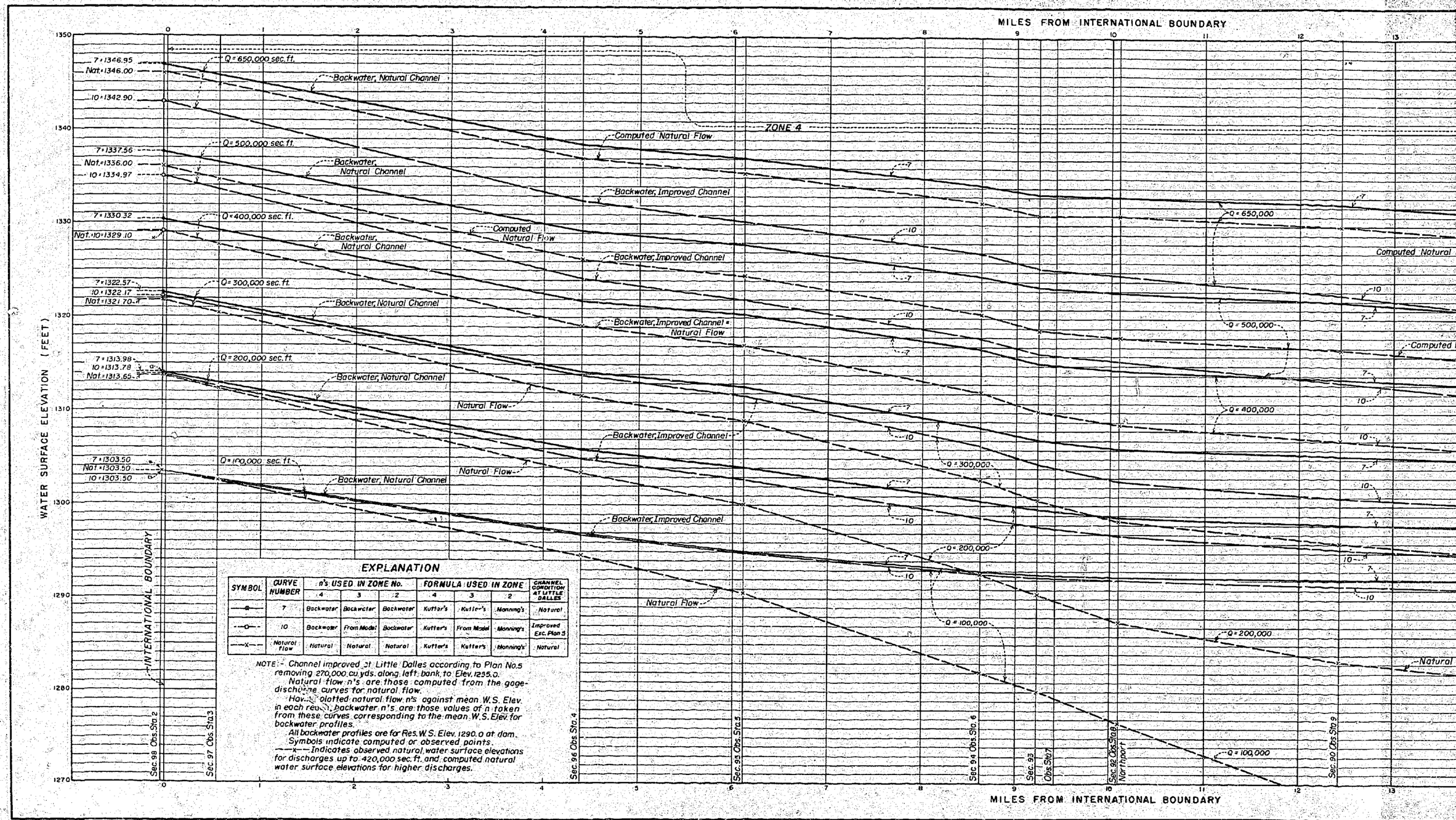
n's, shows the depth of water over the critical point on the railroad track and indicates that even by drawing the reservoir down to the minimum possible elevation the natural water surface will be raised by about two feet because of backwater.

The program for operating the Columbia River Reservoir has not been definitely determined, but it is usually assumed that it will be operated when the project is ultimately developed to produce the maximum amount of power and to supply the completely developed irrigated land with all the water needed, holding the reservoir elevation as high as possible. The curves figure 74, and 75 have been prepared to show how the reservoir elevation would behave if such a plan of operation, adopting a maximum water surface at elevation 1288.0, had been followed for the years from 1913 to 1937. There is also shown on these figures the amount of backwater, based on computations using either backwater n's or natural flow n's, that would have existed at the International Boundary for either unimproved channel or channel improvement according to plan No. 5 at the Little Dalles. During the low-flow periods of about one-half of the years, or 35.8 percent of the total time, there would have been no backwater at the boundary with unimproved channel, and this figure would be increased to 42.6 with channel improvement plan No. 5. These figures are based on computations using backwater n's; with natural n's, unimproved channel, there would be no backwater at the boundary for 17.75 percent of the time, and with plan No. 5 this figure would be increased to 19.25 percent. Six times during this period of 25 years, the flood discharge was greater than 400,000 second-feet, so that there would have been some benefit from the channel improvement. The water year 1929-1930 had the lowest yearly run-off of any year since 1913; operating conditions for this year are shown in detail on figure 76. Plotted on this figure are curves which give the elevation at which the reservoir would have to be held in order not to cause any backwater at the boundary for improved channel, based on either type of roughness coefficient. It will be noted that for unimproved channel there is a period from the middle of May to the end of July when it is impossible to keep the reservoir drawn down low enough to eliminate backwater at the boundary using natural n's. Using backwater n's, if the discharge had become greater than 280,000 second-feet, it would have been impossible to prevent backwater by drawing the reservoir down. Channel improvement is necessary if it is desired to eliminate backwater above the Little Dalles during high flood peaks.

70. <u>Reduction in backwater due to combination of channel improvement and draw-down of reservoir.</u> Figures 77 and 78 show

the amount of backwater at the boundary for various reservoir elevations with channel improved according to plan No. 5; it will be noted that with this channel improvement it is possible to keep the reservoir drawn down so as not to cause any backwater at the International Boundary. It is also possible to eliminate the backwater at the boundary by removing the rock island that chokes the entrance to the Little Dalles and keeping the reservoir drawn down nearly to its minimum possible elevation after the inflow discharge reaches 280,000 second-feet based on backwater n's, figure 79, or 150,000 second-feet based on natural n's, figure 80. The curve of maximum water surface at the dam that will produce no backwater at the boundary when the Little Dalles is improved, according to plan No. 5, is shown on figure 81. This curve lies above the discharge capacity curve for the dam, indicating that it is possible to keep the reservoir drawn down to such an elevation as to prevent any backwater at the boundary. According to the graph showing the reservoir operation applied to the water year 1929-1930 (figure 76), to prevent backwater with improved channel on the basis of backwater n's, it would be necessary during such a year to sacrifice an average of 4.4 feet of power head for 137 days of the year. Since normal operating head is 355 feet, this would reduce the power output 1.24 percent. When the ultimate capacities of the power plant and pumping station are reached, each foot the reservoir is lowered below 1288.0 at Grand Coulee Dam will decrease firm power output by 50,000,000 kilowatt-hours per year, which, at two mills, amounts to $100,000 per year, and increase power used for pumping by 7,000,000 kilowatt-hours per year, which, at one-half mill, amounts to $3,500 per year. The above estimated loss of revenue caused by drawing the reservoir down one foot for a year is $103,500, or, for this water year 1929-1930, prevention of backwater at the boundary by this method of drawing the reservoir down would cause a loss of $171,000. Computations based on natural n's with channel improvement plan No. 5 indicate that an average power head of 16.0 feet would have to be sacrificed for 219 days during such a year as 1929-1930 in order to prevent backwater at the International Boundary. This reduces the normal operating head by six percent and would result in an estimated loss of revenue of $994,000. Further, since this year requires the reservoir to be drawn down for a longer period than any other year on record, because of water shortage, the loss of revenue would always be greater than estimated above.

Channel improvement according to plan No. 5 will make possible the proposed operation of the reservoir, holding its water surface at the maximum elevation whenever possible, resulting in only a small amount of backwater at the International Boundary for small flows and with actually a decrease in the amount the railroad tracks might be submerged during large floods.



EXPLANATION

SYMBOL	CURVE NUMBER	n's USED IN ZONE No. 4	3	2	FORMULA USED IN ZONE 4	3	2	CHANNEL CONDITION AT LITTLE DALLES
—●—	7	Backwater	Backwater	Backwater	Kutter's	Kutter's	Manning's	Natural
—○—	10	Backwater	From Model	Backwater	Kutter's	From Model	Manning's	Improved Exc. Plan 5
—X—	Natural flow	Natural	Natural	Natural	Kutter's	Kutter's	Manning's	Natural

NOTE:- Channel improved at Little Dalles according to Plan No.5 removing 270,000 cu.yds. along left bank to Elev. 1235.0.

Natural flow n's are those computed from the gage-discharge curves for natural flow.

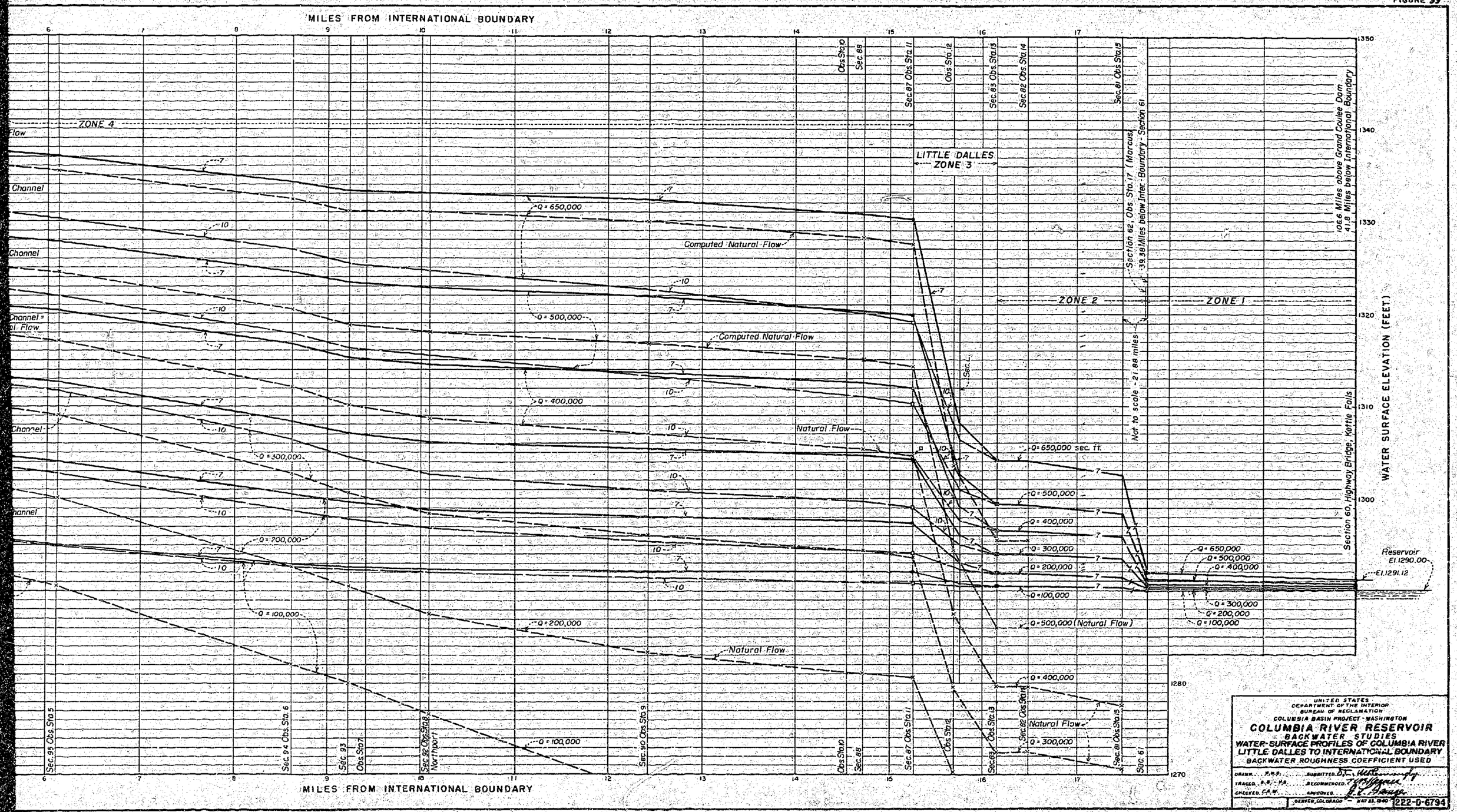
Have plotted natural flow n's against mean W.S. Elev. in each reach; backwater n's are those values of n taken from these curves corresponding to the mean W.S. Elev. for backwater profiles.

All backwater profiles are for Res. W.S. Elev. 1290.0 at dam.

Symbols indicate computed or observed points.

—x— Indicates observed natural water surface elevations for discharges up to 420,000 sec.ft. and computed natural water surface elevations for higher discharges.

FIGURE 59



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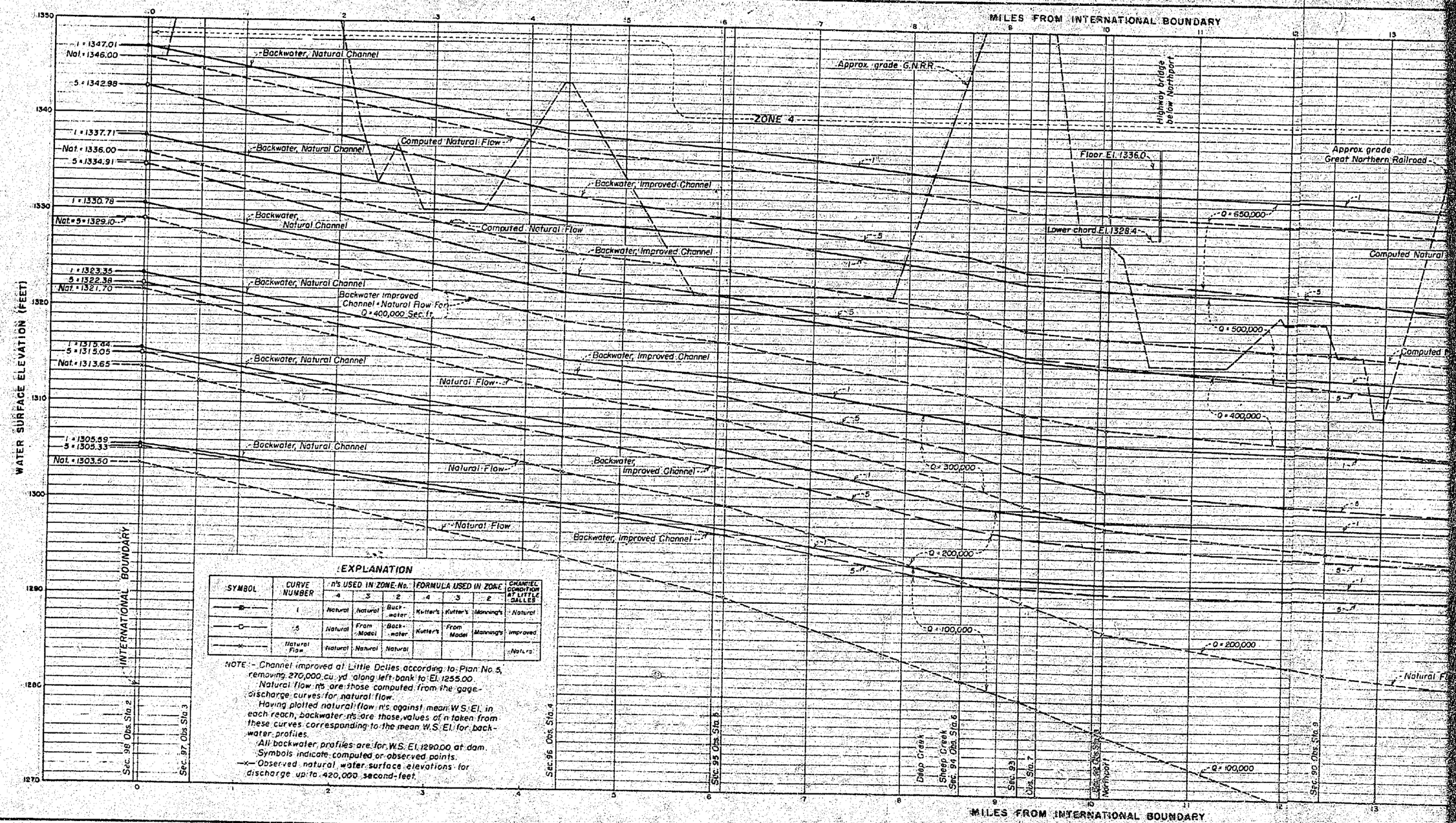
COLUMBIA BASIN PROJECT - WASHINGTON

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
WATER-SURFACE PROFILES OF COLUMBIA RIVER
LITTLE DALLES TO INTERNATIONAL BOUNDARY
BACKWATER ROUGHNESS COEFFICIENT USED

DRAWN H.R.P. SUBMITTED D.T. Mitchell
TRACED R.E.-H.R. RECOMMENDED T. Higgins
CHECKED C.A.W. APPROVED J.L. Savage
DENVER, COLORADO MAY 23, 1940 222-D-6794


MILES FROM INTERNATIONAL BOUNDARY
WATER SURFACE ELEVATION (FEET)
1350
1340
1330
1320
1310
1300
1290
1280
1270
I = 1347.01
Nat. = 1346.00
5 = 1342.98
I = 1337.71
Nat. = 1336.00
5 = 1334.91
I = 1330.78
Nat. = 5 = 1329.10
I = 1323.35
5 = 1322.38
Nat. = 1321.70
I = 1315.44
5 = 1315.05
Nat. = 1313.65
I = 1305.59
5 = 1305.33
Nat. = 1303.50
Backwater, Natural Channel
Computed Natural Flow
Backwater, Improved Channel
Backwater, Natural Channel
Computed Natural Flow
Backwater, Improved Channel
Backwater, Natural Channel
Backwater Improved Channel = Natural Flow For Q = 400,000 Sec. ft.
Backwater, Natural Channel
Backwater, Improved Channel
Natural Flow
Backwater, Natural Channel
Natural Flow
Backwater, Improved Channel
Natural Flow
Backwater, Improved Channel
ZONE 4
Approx. grade G.N.R.R.
Highway bridge below Northport
Floor El. 1336.0
Lower chord El. 1328.4
Approx grade Great Northern Railroad
Q = 650,000
Computed Natural
Q = 500,000
Computed
Q = 400,000
Q = 300,000
Q = 200,000
Q = 100,000
Q = 200,000
Natural Fl
Q = 100,000
INTERNATIONAL BOUNDARY
Sec. 98 Obs. Sta. 2
Sec. 97 Obs. Sta. 3
Sec. 96 Obs. Sta. 4
Sec. 95 Obs. Sta. 5
Deep Creek
Sheep Creek
Sec. 94 Obs. Sta. 6
Sec. 93
Obs. Sta. 7
Sec. 92 Obs. Sta. 8
Northport
Sec. 90 Obs. Sta. 9
EXPLANATION
SYMBOL
CURVE NUMBER
n's USED IN ZONE No.
FORMULA USED IN ZONE
CHANNEL CONDITION AT LITTLE DALLES
4 3 2 4 3 2
I Natural Natural Backwater Kutter's Kutter's Manning's Natural
5 Natural From Model Backwater Kutter's From Model Manning's Improved
Natural Flow Natural Natural Natural Natural
NOTE:- Channel improved at Little Dalles according to Plan No. 5, removing 270,000 cu. yd along left bank to El. 1255.00.
Natural flow n's are those computed from the gage-discharge curves for natural flow.
Having plotted natural flow n's against mean W.S. El. in each reach, backwater n's are those values of n taken from these curves corresponding to the mean W.S. El. for backwater profiles.
All backwater profiles are for W.S. El. 1290.00 at dam.
Symbols indicate computed or observed points.
—x— Observed natural water surface elevations for discharge up to 420,000 second-feet.

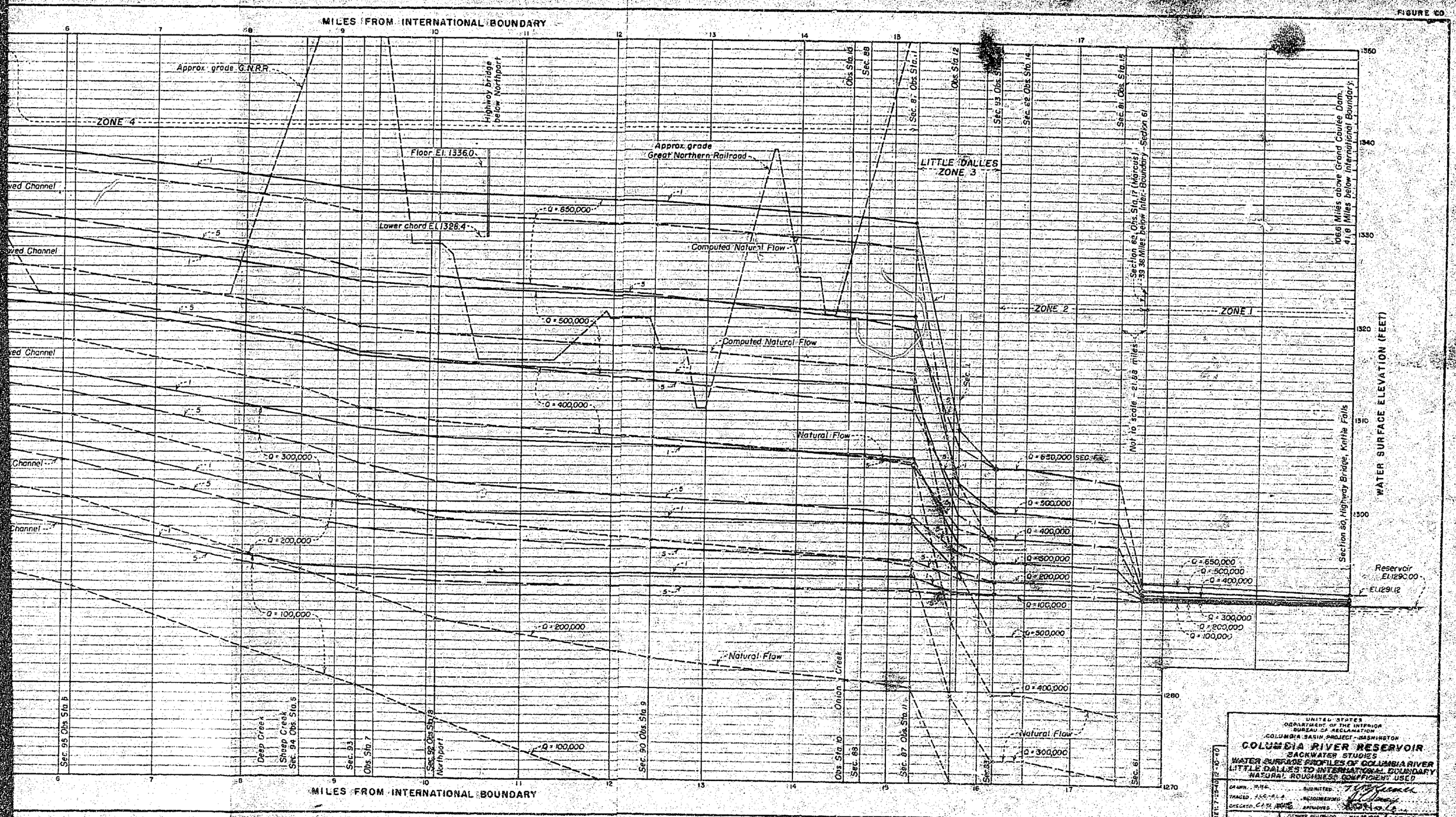


FIGURE 60
MILES FROM INTERNATIONAL BOUNDARY
WATER SURFACE ELEVATION (FEET)
Approx. grade G.N.R.R.
ZONE 4
Floor El. 1336.0
Highway bridge below Northport
Lower chord El. 1326.4
Approx. grade Great Northern Railroad
LITTLE DALLES ZONE 3
ZONE 2
ZONE 1
Computed Natural Flow
Natural Flow
Q = 650,000
Q = 500,000
Q = 400,000
Q = 300,000
Q = 200,000
Q = 100,000
Not to scale - 21.88 miles
Section 62, Obs. Sta. 17 (Marcus) - 39.38 Miles below Inter-Boundary - Section 61
106.6 Miles above Grand Coulee Dam
41.8 Miles below International Boundary
Section 80, Highway Bridge, Kettle Falls
Reservoir El. 1290.00
El. 1291.12
Sec. 96 Obs. Sta. 6
Deep Creek
Sheep Creek
Sec. 94 Obs. Sta. 5
Sec. 93
Obs. Sta. 7
Sec. 92 Obs. Sta. 8
Northport
Sec. 90 Obs. Sta. 9
Onion Creek
Obs. Sta. 10
Sec. 88
Sec. 87 Obs. Sta. 11
Sec. 83
Sec. 61
Obs. Sta. 12
Sec. 22 Obs. Sta. 14
Sec. 81 Obs. Sta. 15
1360
1340
1330
1320
1310
1300
1280
1270
UNITED STATES
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BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
WATER SURFACE PROFILES OF COLUMBIA RIVER
LITTLE DALLES TO INTERNATIONAL BOUNDARY
NATURAL ROUGHNESS COEFFICIENTS USED
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
OCTOBER, 1950
MAY 25, 1950
282-D-8612

FIGURE 61

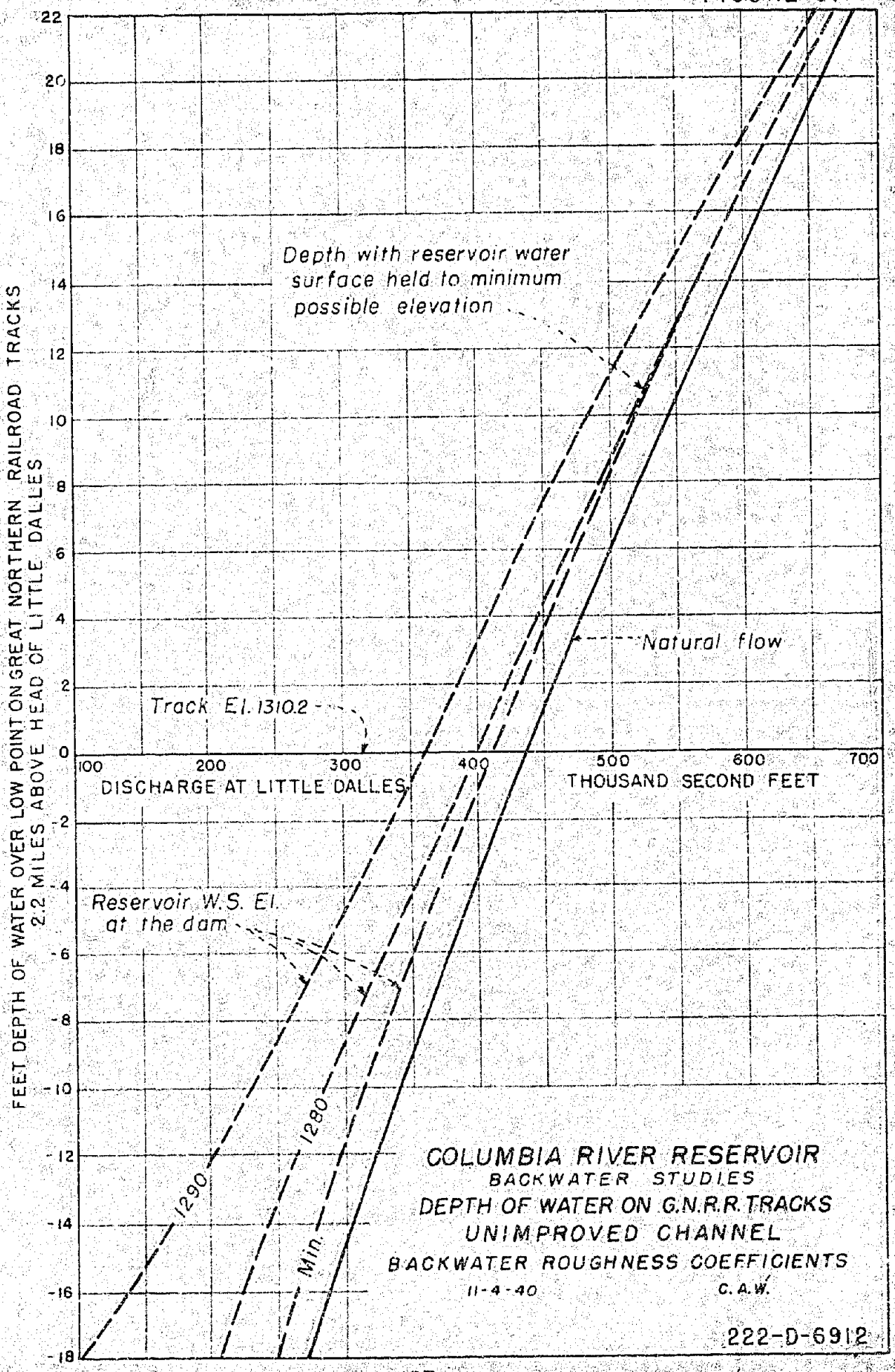
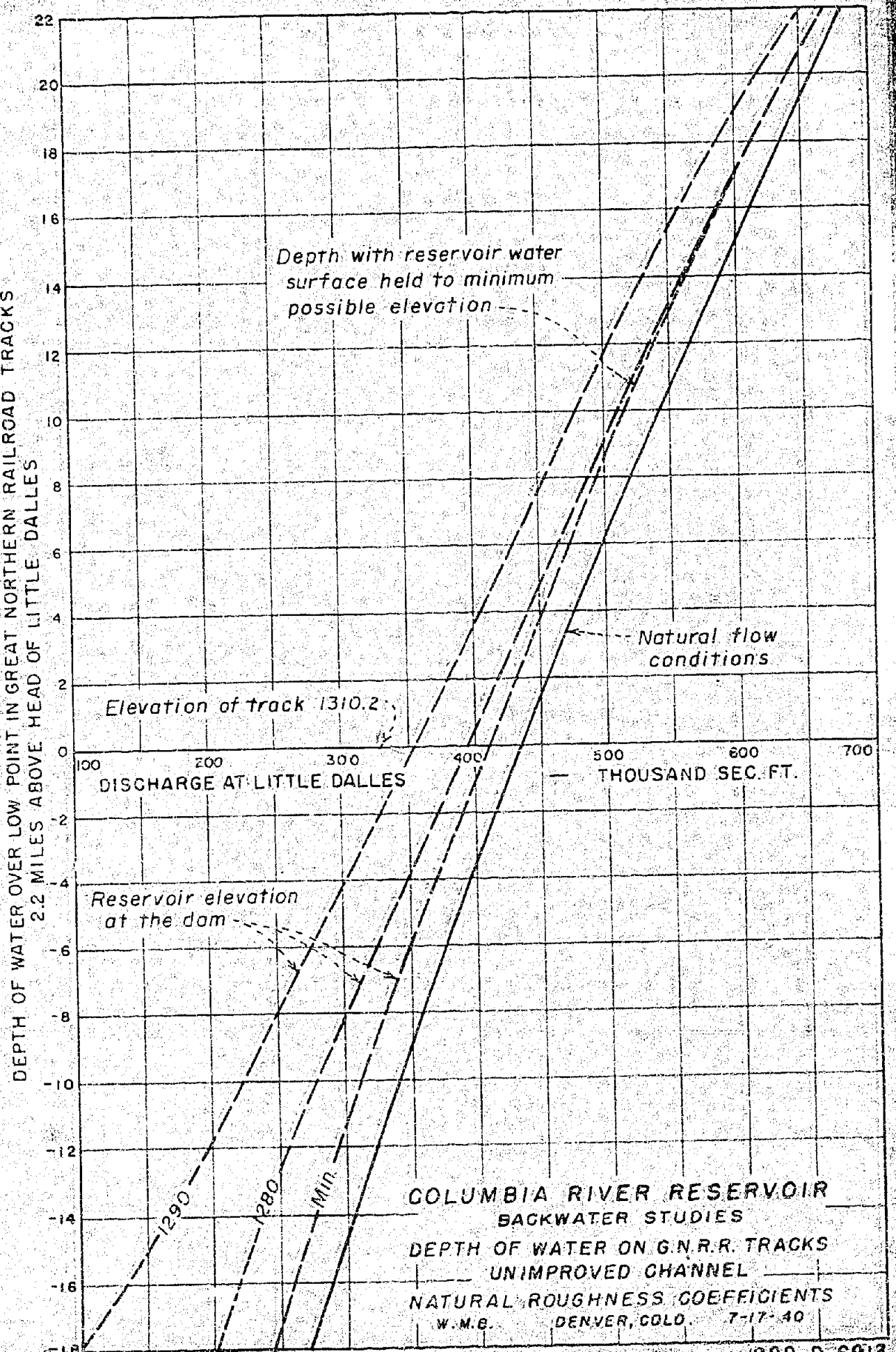
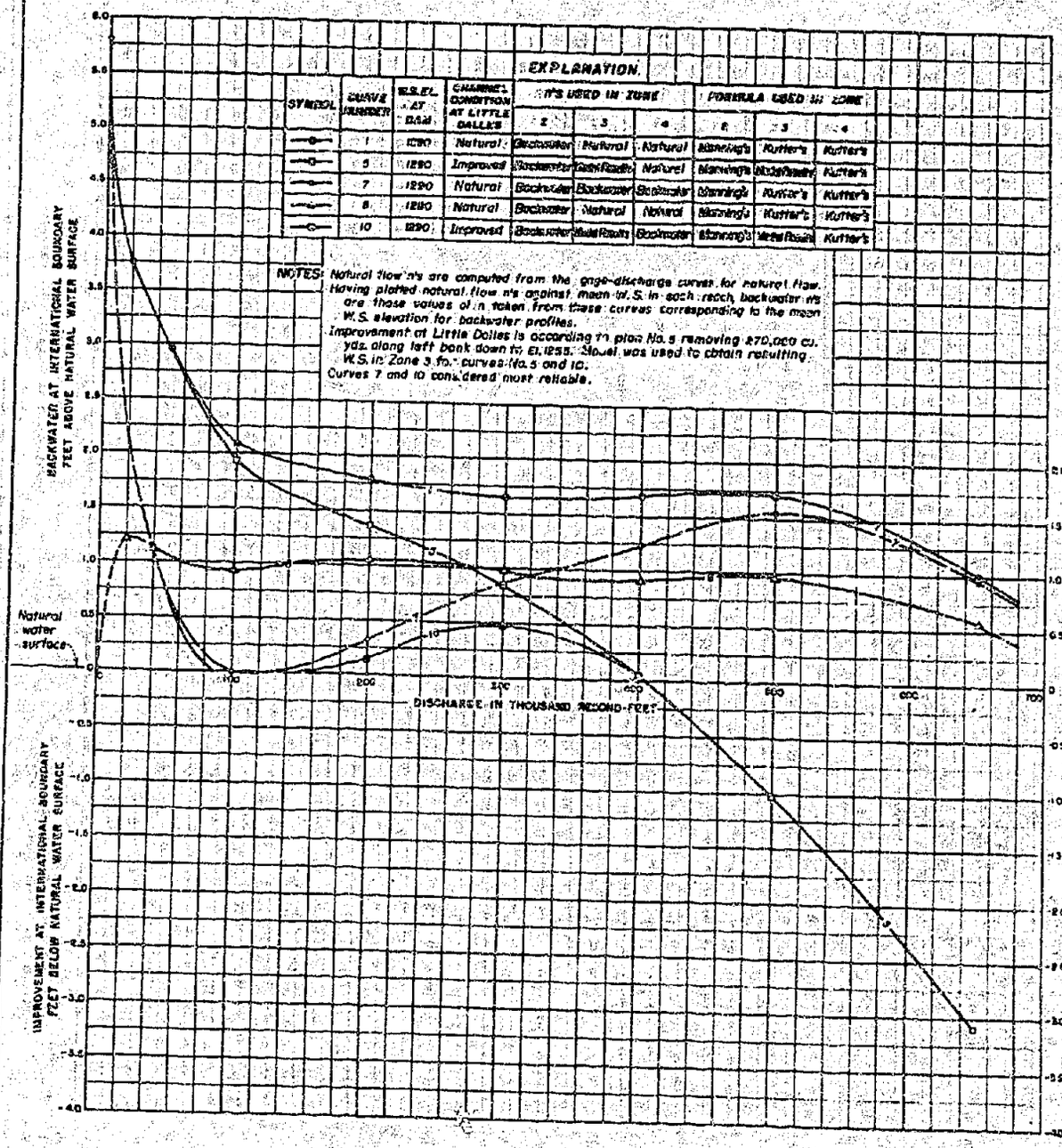

FEET DEPTH OF WATER OVER LOW POINT ON GREAT NORTHERN RAILROAD TRACKS
2.2 MILES ABOVE HEAD OF LITTLE DALLES
22
20
18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
100
200
300
400
500
600
700
DISCHARGE AT LITTLE DALLES
THOUSAND SECOND FEET
Depth with reservoir water surface held to minimum possible elevation
Natural flow
Track El. 1310.2
Reservoir W.S. El. at the dam
1290
1280
Min.
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
DEPTH OF WATER ON G.N.R.R. TRACKS
UNIMPROVED CHANNEL
BACKWATER ROUGHNESS COEFFICIENTS
11-4-40
C.A.W.
222-D-6912

FIGURE 62



222-D-6913

FIGURE 83



LOCATION OF ZONES

Zone No.1 - Grand Coulee Dam to Marcus.
Zone No.2 - Marcus to Foot of Little Dalles.
Zone No.3 - Little Dalles.
Zone No.4 - Head of Little Dalles to International Boundary.

UNITED STATES
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COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
BACKWATER AND IMPROVEMENT AT INTERNATIONAL BOUNDARY

222-D-5834

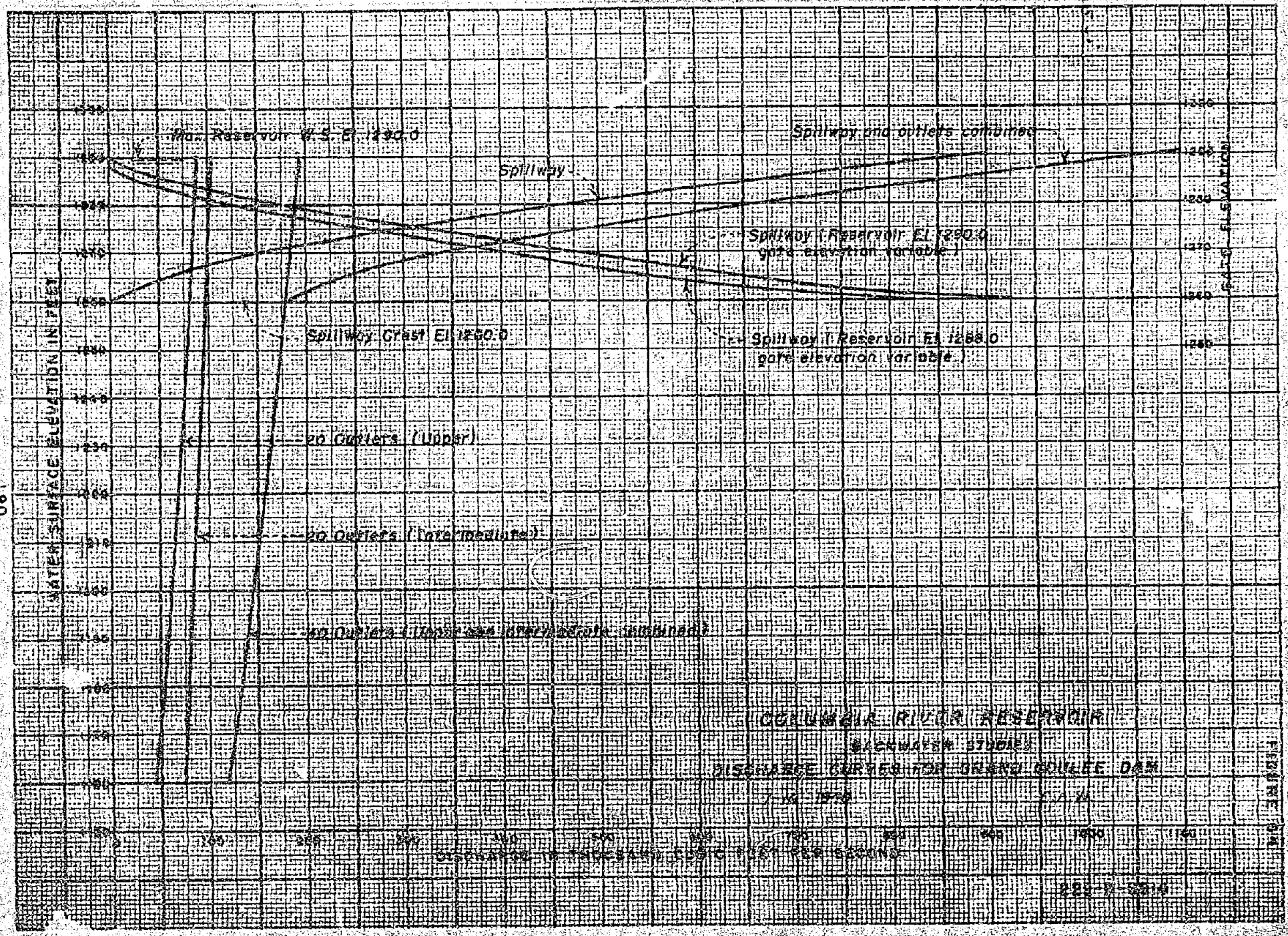

Max. Reservoir W.S. El. 1290.0
Spillway and outlets combined
Spillway
Spillway (Reservoir El. 1250.0 gate elevation variable)
Spillway Crest El. 1260.0
Spillway (Reservoir El. 1268.0 gate elevation variable)
20 Outlets (Upper)
20 Outlets (Intermediate)
20 Outlets (Lower after gate installed)
WATER SURFACE ELEVATION IN FEET
GATE ELEVATION
DISCHARGE IN THOUSAND CUBIC FEET PER SECOND
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
DISCHARGE CURVES FOR GRAND COULEE DAM
FIGURE 90

FIGURE 85

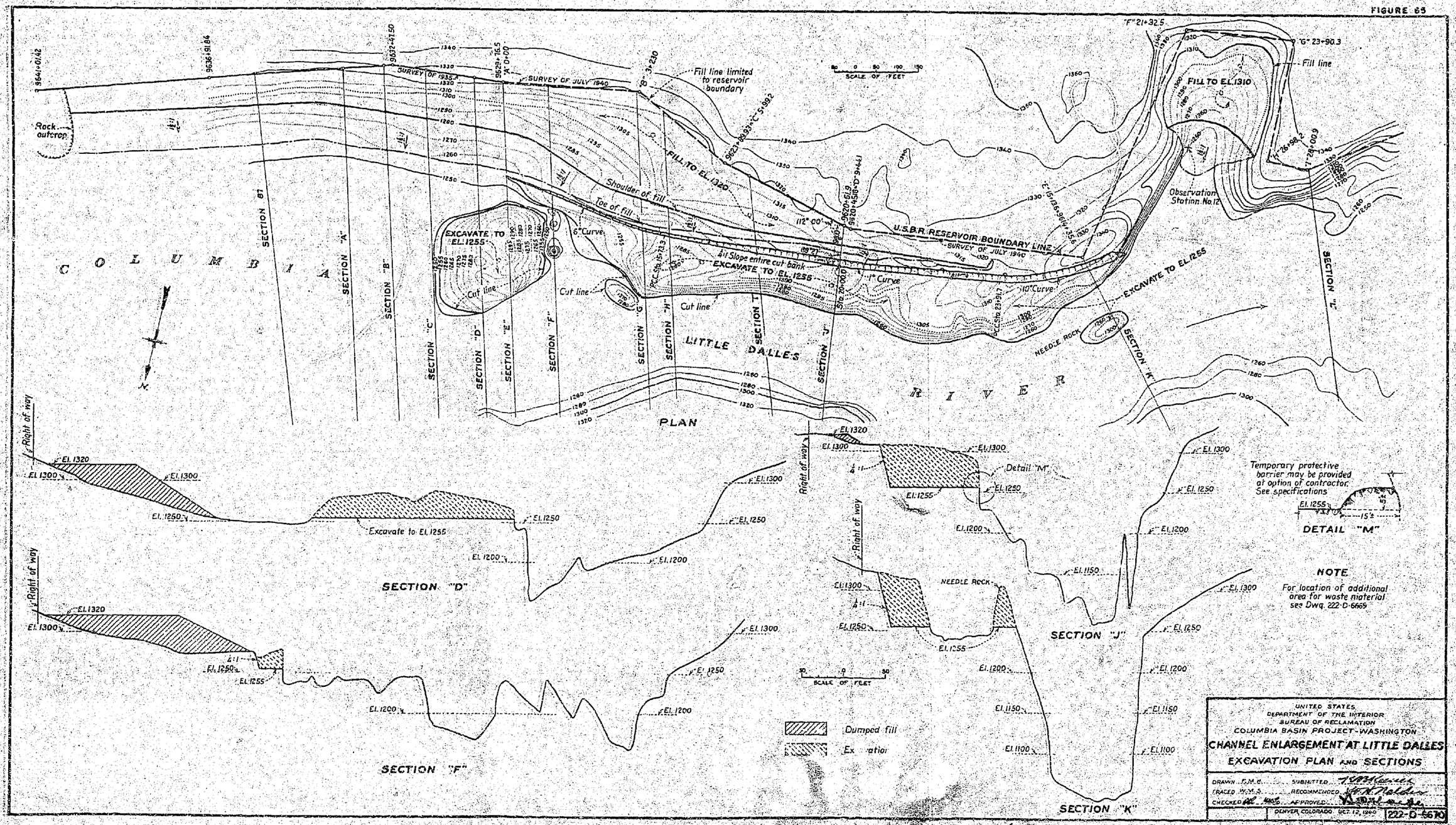
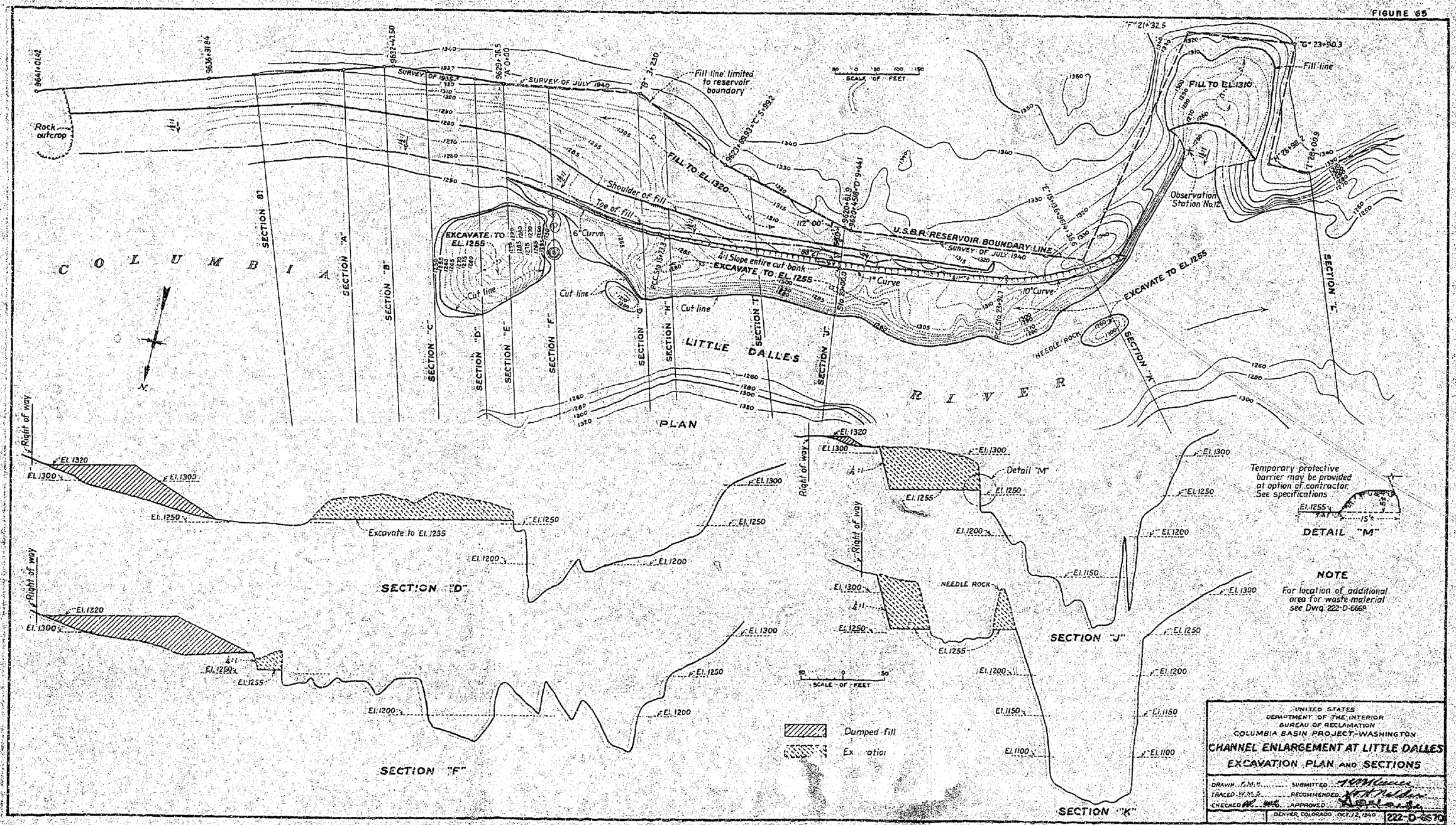
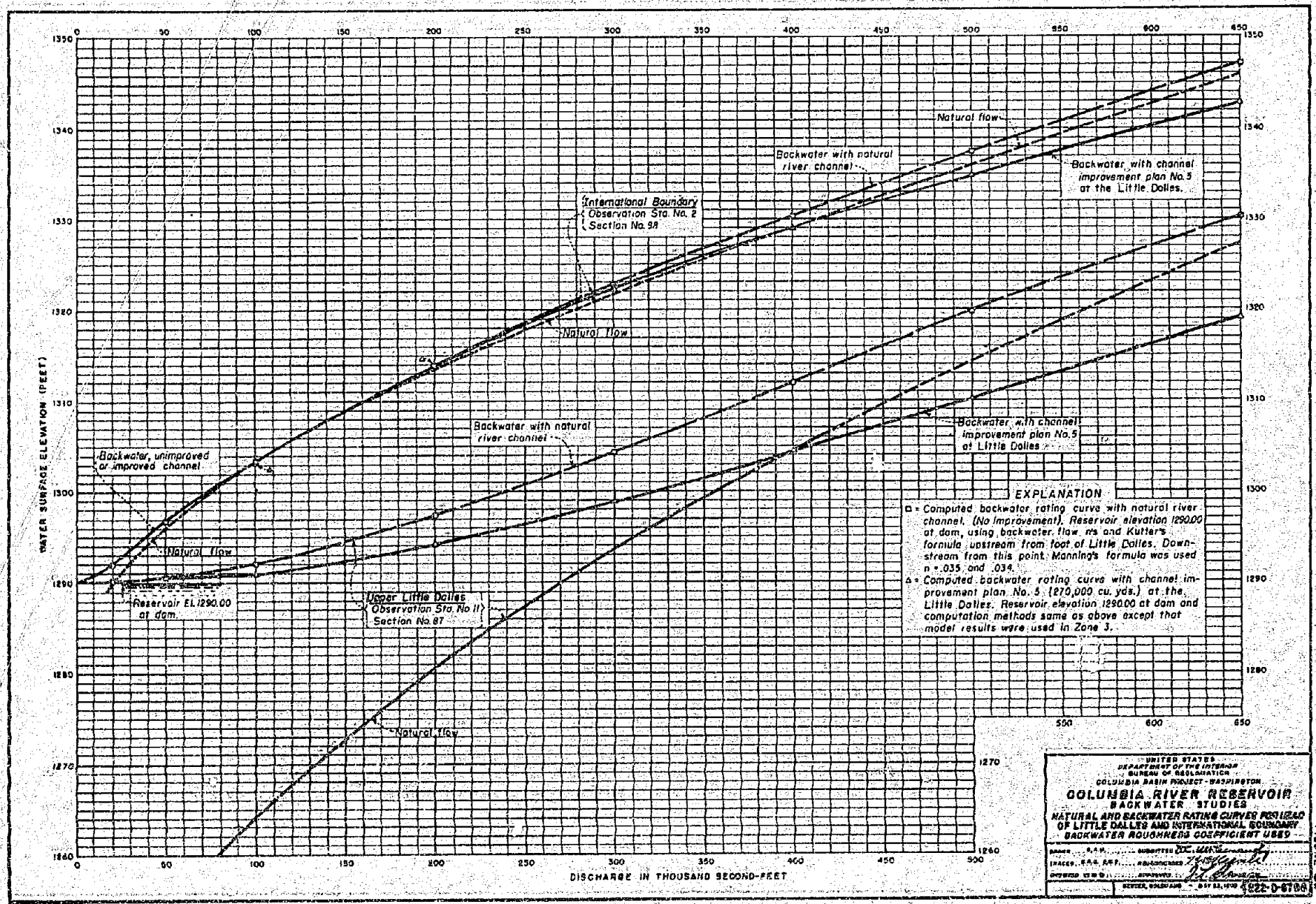

PLAN
COLUMBIA
RIVER
LITTLE DALLES
SECTION "A"
SECTION "B"
SECTION "C"
SECTION "D"
SECTION "E"
SECTION "F"
SECTION "G"
SECTION "H"
SECTION "I"
SECTION "J"
SECTION "K"
SECTION "L"
SURVEY OF 1935
SURVEY OF JULY 1940
Fill line limited to reservoir boundary
FILL TO EL. 1320
FILL TO EL. 1310
Fill line
Shoulder of fill
Toe of fill
EXCAVATE TO EL. 1255
4:1 Slope entire cut bank
EXCAVATE TO EL. 1255
U.S.B.R. RESERVOIR BOUNDARY LINE
SURVEY OF JULY 1940
Observation Station No. 12
Rock outcrop
Cut line
NEEDLE ROCK
SCALE OF FEET
Right of way
Excavate to El. 1255
SECTION "D"
SECTION "F"
Detail "M"
SECTION "J"
SECTION "K"
Temporary protective barrier may be provided at option of contractor. See specifications
DETAIL "M"
NOTE
For location of additional area for waste material see Dwg. 222-D-6669
Dumped fill
Excavation
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT-WASHINGTON
CHANNEL ENLARGEMENT AT LITTLE DALLES
EXCAVATION PLAN AND SECTIONS
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO OCT. 12, 1960
222-D-6670

FIGURE 65


PLAN
COLUMBIA
RIVER
LITTLE DALLES
SECTION 81
SECTION "A"
SECTION "B"
SECTION "C"
SECTION "D"
SECTION "E"
SECTION "F"
SECTION "G"
SECTION "H"
SECTION "I"
SECTION "J"
SECTION "K"
SECTION "L"
SURVEY OF 1935
SURVEY OF JULY 1940
Rock outcrop
Fill line limited to reservoir boundary
FILL TO EL. 1320
Shoulder of fill
Toe of fill
EXCAVATE TO EL. 1255
Cut line
6° Curve
4:1 Slope entire cut bank
1° Curve
10° Curve
U.S.B.R. RESERVOIR BOUNDARY LINE
SURVEY OF JULY 1940
FILL TO EL. 1310
Fill line
Observation Station No. 12
NEEDLE ROCK
Right of way
Excavate to El. 1255
Detail "M"
Temporary protective barrier may be provided at option of contractor. See specifications
DETAIL "M"
NOTE
For location of additional area for waste material see Dwg. 222-D-6668
Dumped fill
Excavation
SCALE OF FEET
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT-WASHINGTON
CHANNEL ENLARGEMENT AT LITTLE DALLES
EXCAVATION PLAN AND SECTIONS
DRAWN F.M.H.
TRACED W.M.S.
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO OCT. 12, 1940
222-D-6570


WATER SURFACE ELEVATION (FEET)
DISCHARGE IN THOUSAND SECOND-FEET
Natural flow
Backwater with natural river channel
Backwater with channel improvement plan No. 5 at the Little Dalles.
International Boundary Observation Sta. No. 2 Section No. 98
Natural flow
Backwater, unimproved or improved channel
Backwater with natural river channel
Backwater with channel improvement plan No. 5 at Little Dalles
Natural flow
Reservoir El. 1290.00 at dam
Upper Little Dalles Observation Sta. No. 11 Section No. 87
Natural flow
EXPLANATION
□ = Computed backwater rating curve with natural river channel. (No improvement). Reservoir elevation 1290.00 at dam, using backwater flow n's and Kutter's formula upstream from foot of Little Dalles. Downstream from this point Manning's formula was used n = .035 and .034.
△ = Computed backwater rating curve with channel improvement plan No. 5 (270,000 cu. yds.) at the Little Dalles. Reservoir elevation 1290.00 at dam and computation methods same as above except that model results were used in Zone 3.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT-WASHINGTON
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
NATURAL AND BACKWATER RATING CURVES REVISED OF LITTLE DALLES AND INTERNATIONAL BOUNDARY
BACKWATER ROUGHNESS COEFFICIENT USED
FIGURE 65
422-D-8786

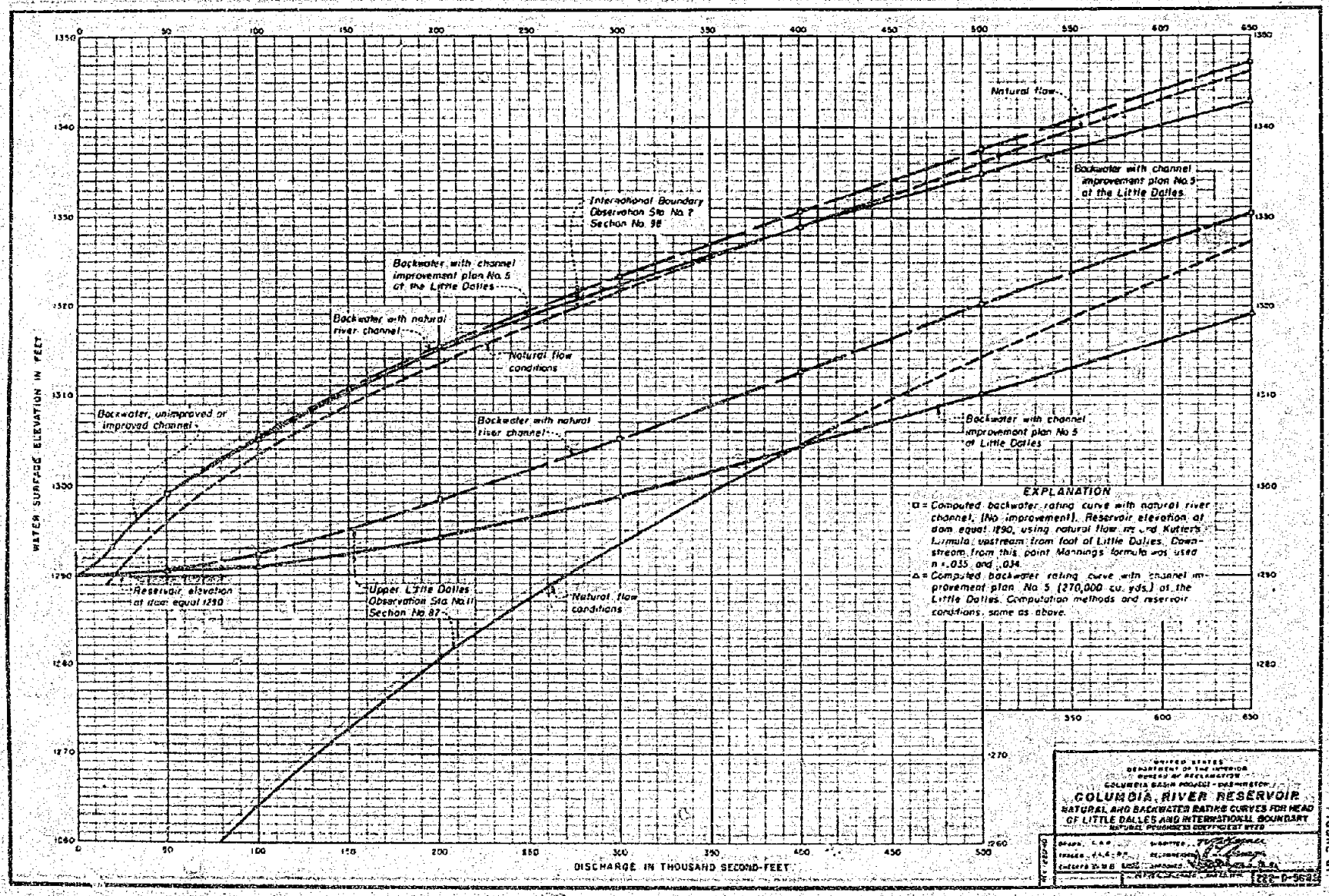
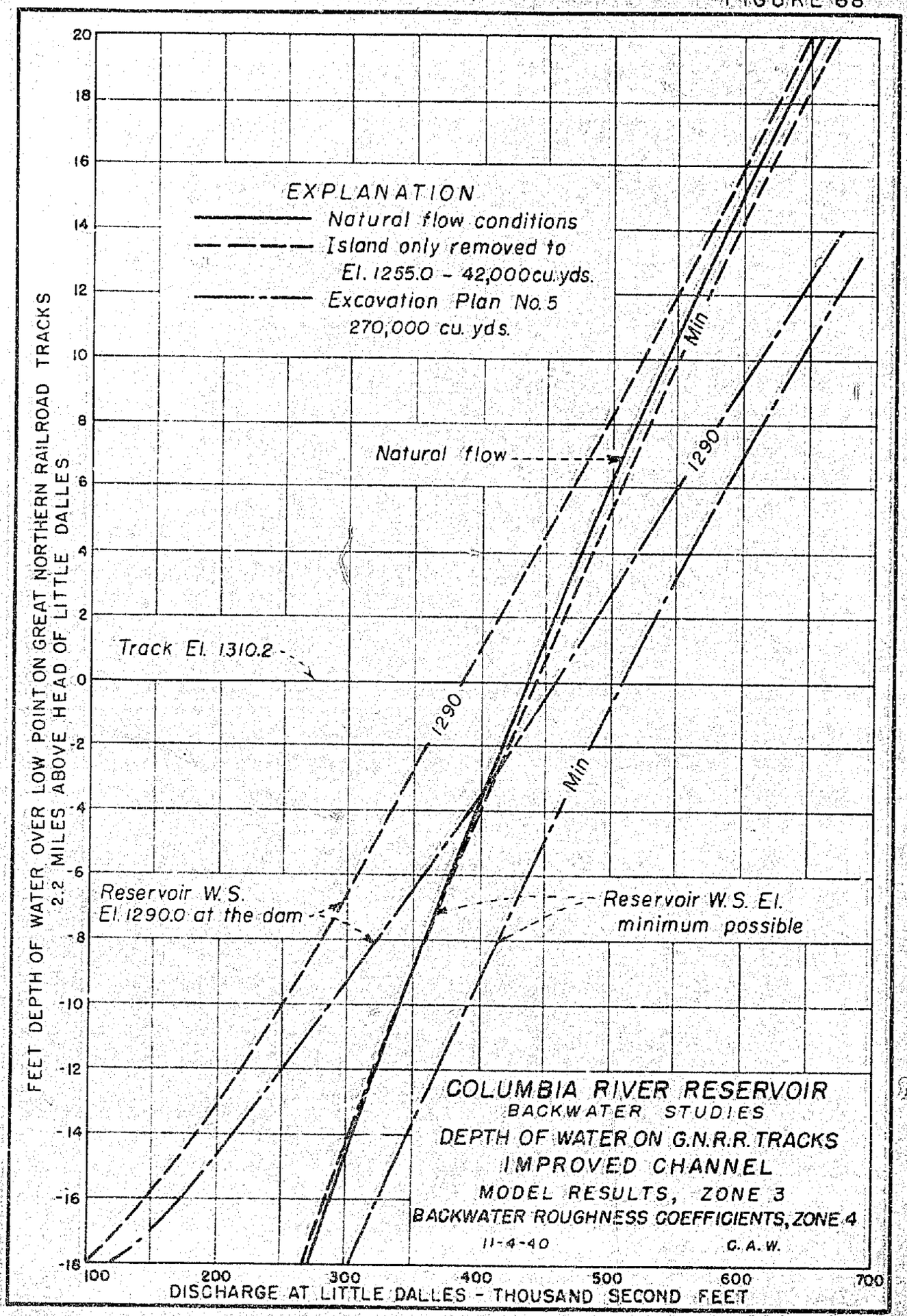

WATER SURFACE ELEVATION IN FEET
DISCHARGE IN THOUSAND SECOND-FEET
Natural flow
Backwater with channel improvement plan No. 5 at the Little Dalles
International Boundary Observation Sta. No. 7 Section No. 98
Backwater with channel improvement plan No. 5 at the Little Dalles
Backwater with natural river channel
Natural flow conditions
Backwater, unimproved or improved channel
Backwater with natural river channel
Backwater with channel improvement plan No. 5 at Little Dalles
Reservoir elevation at dam equal 1290
Upper Little Dalles Observation Sta. No. 11 Section No. 87
Natural flow conditions
EXPLANATION
□ = Computed backwater rating curve with natural river channel. (No improvement). Reservoir elevation at dam equal 1290, using natural flow in and Kutter's formula upstream from foot of Little Dalles. Downstream from this point Mannings formula was used n = .035 and .034.
△ = Computed backwater rating curve with channel improvement plan No. 5 (270,000 cu. yds.) at the Little Dalles. Computation methods and reservoir conditions, same as above.
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - DEE-WINATCHEE
COLUMBIA RIVER RESERVOIR
NATURAL AND BACKWATER RATING CURVES FOR HEAD OF LITTLE DALLES AND INTERNATIONAL BOUNDARY
NATURAL RESOURCES COMMITTEE 1939
222-D-562

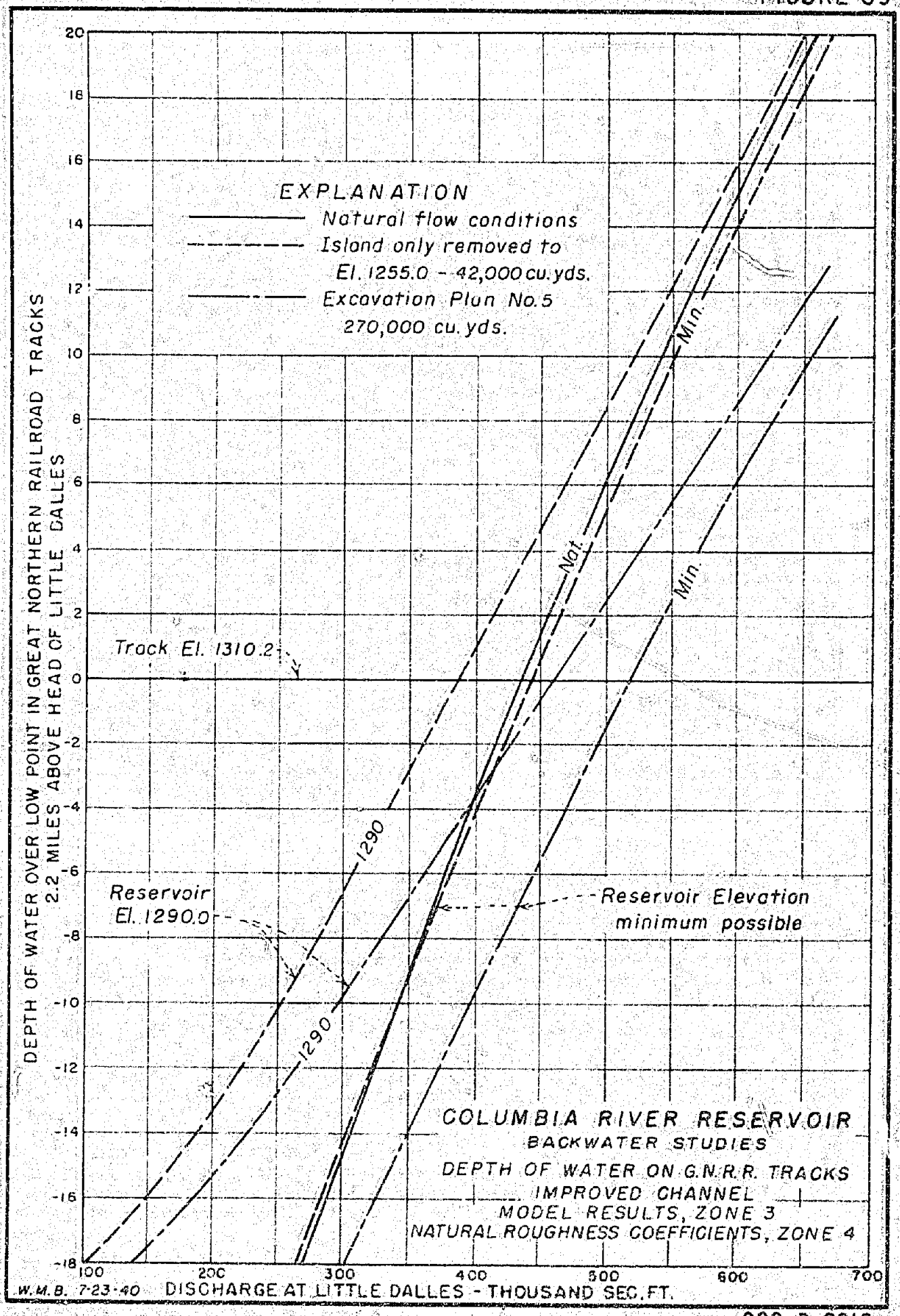
FIGURE 47

FIGURE 68



222-D-6915

FIGURE 69

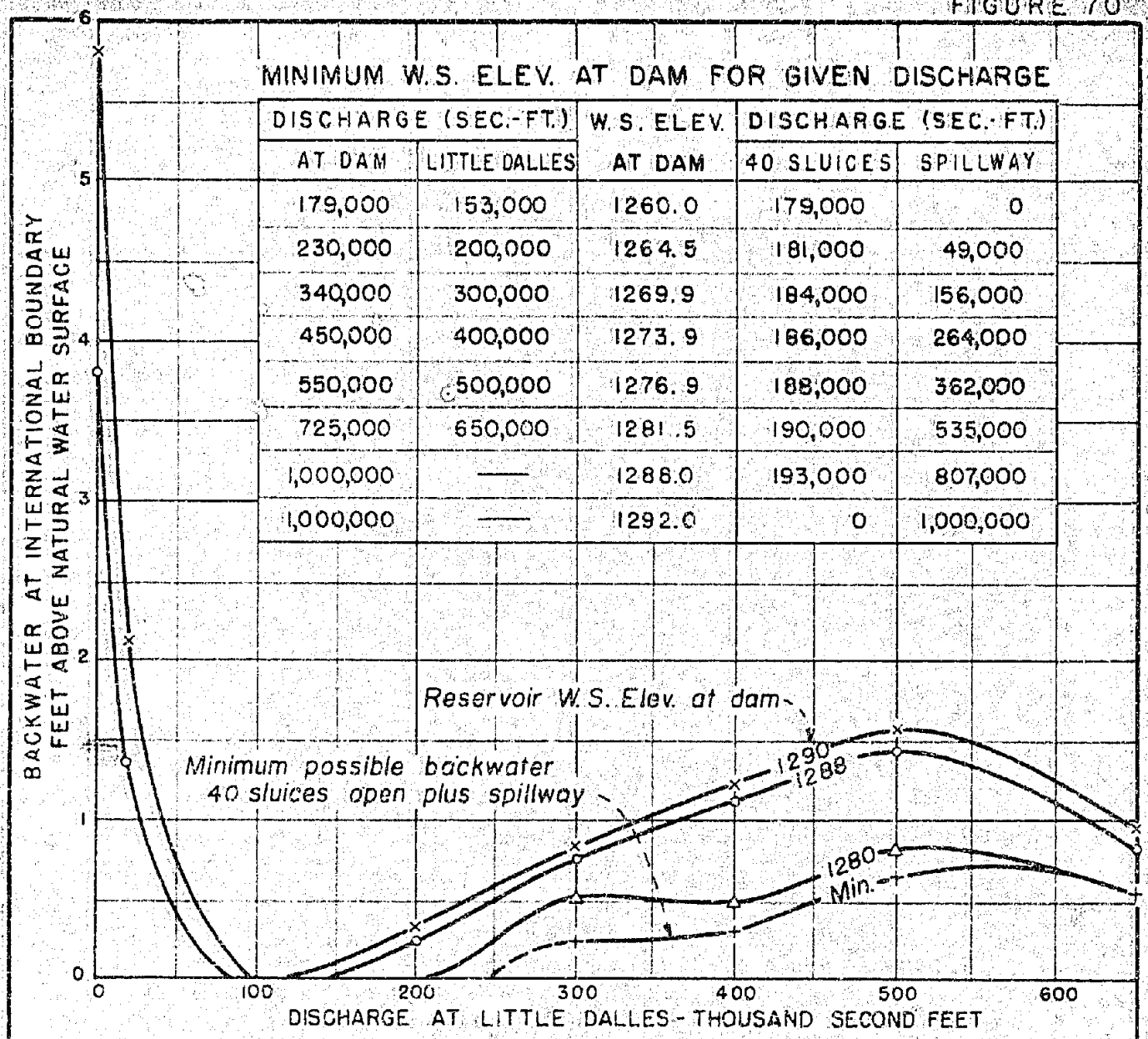


222-D-6916

FIGURE 70

MINIMUM W.S. ELEV. AT DAM FOR GIVEN DISCHARGE

DISCHARGE (SEC.-FT.)		W.S. ELEV.	DISCHARGE (SEC.-FT.)	
AT DAM	LITTLE DALLES	AT DAM	40 SLUICES	SPILLWAY
179,000	153,000	1260.0	179,000	0
230,000	200,000	1264.5	181,000	49,000
340,000	300,000	1269.9	184,000	156,000
450,000	400,000	1273.9	186,000	264,000
550,000	500,000	1276.9	188,000	362,000
725,000	650,000	1281.5	190,000	535,000
1,000,000	—	1288.0	193,000	807,000
1,000,000	—	1292.0	0	1,000,000

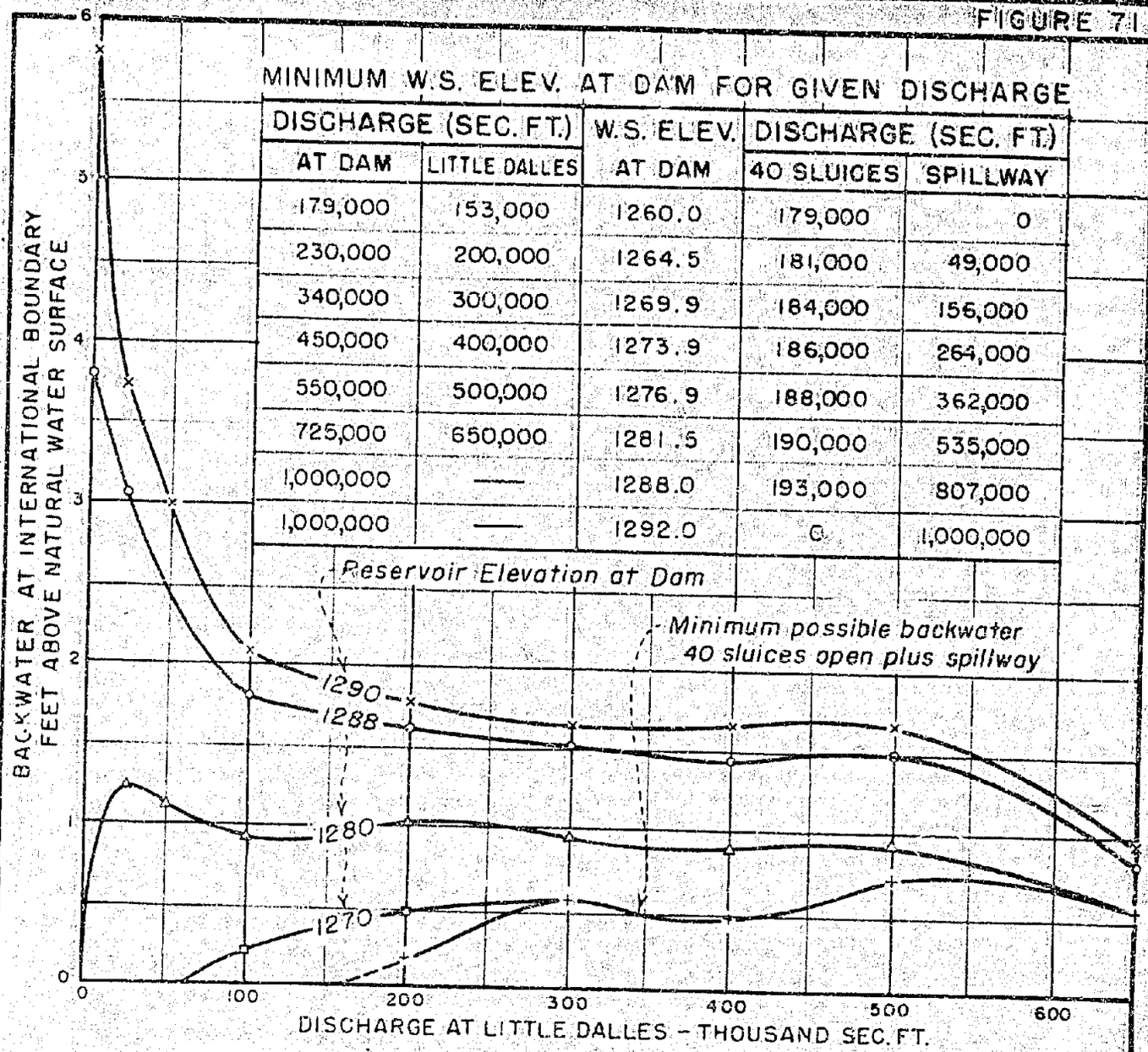


COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
BACKWATER AT INTERNATIONAL BOUNDARY
NO CHANNEL IMPROVEMENT
BACKWATER ROUGHNESS COEFFICIENTS

11-1-40 W. M. B.

222-D-6917

FIGURE 71



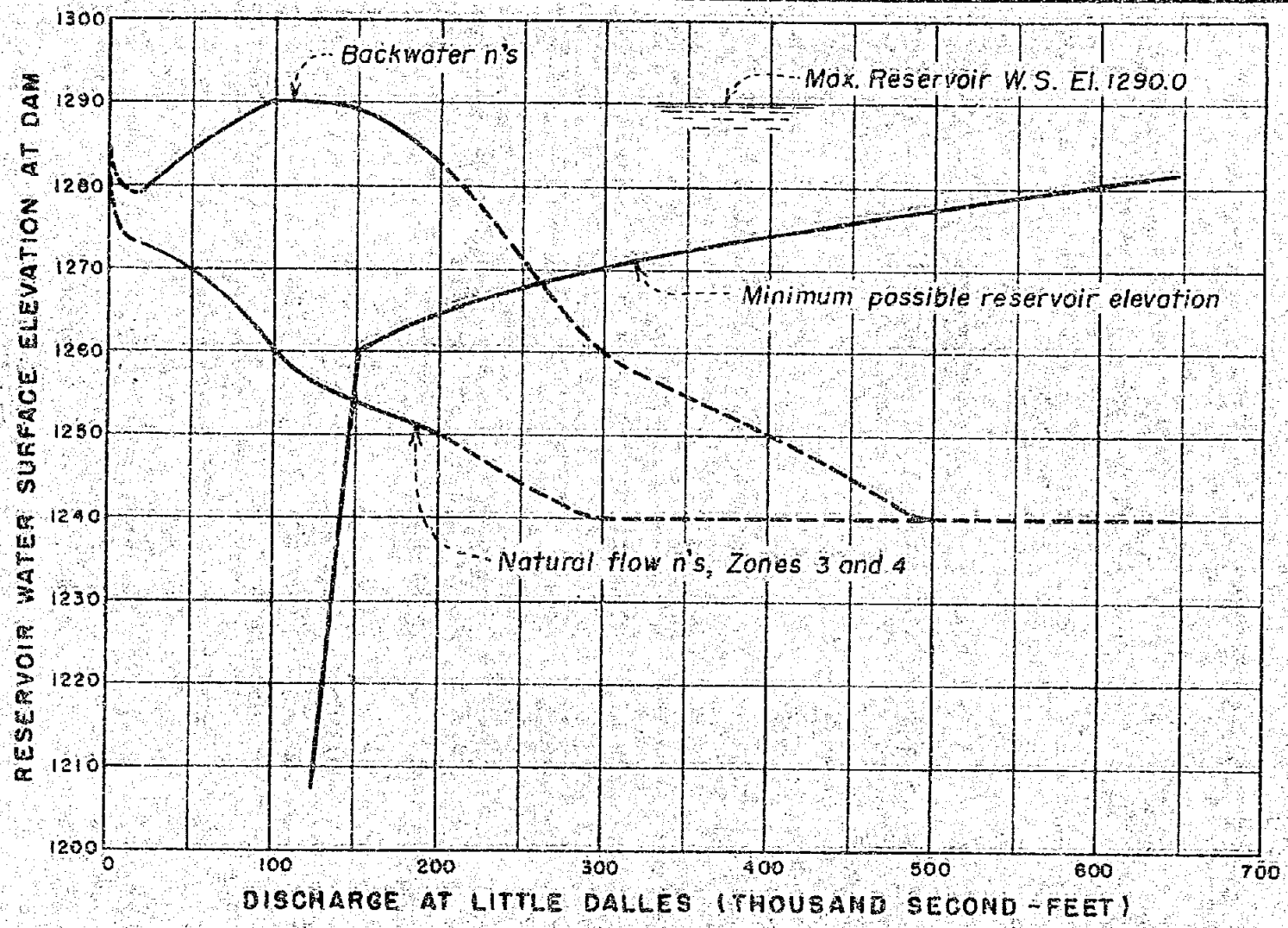
MINIMUM W.S. ELEV. AT DAM FOR GIVEN DISCHARGE

DISCHARGE (SEC. FT.)		W.S. ELEV.	DISCHARGE (SEC. FT.)	
AT DAM	LITTLE DALLES	AT DAM	40 SLUICES	SPILLWAY
179,000	153,000	1260.0	179,000	0
230,000	200,000	1264.5	181,000	49,000
340,000	300,000	1269.9	184,000	156,000
450,000	400,000	1273.9	186,000	264,000
550,000	500,000	1276.9	188,000	362,000
725,000	650,000	1281.5	190,000	535,000
1,000,000	—	1288.0	193,000	807,000
1,000,000	—	1292.0	0	1,000,000

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
BACKWATER AT INTERNATIONAL BOUNDARY
NO CHANNEL IMPROVEMENT
NATURAL ROUGHNESS COEFFICIENTS

W.M.B. 7-15-40

222-D-6918



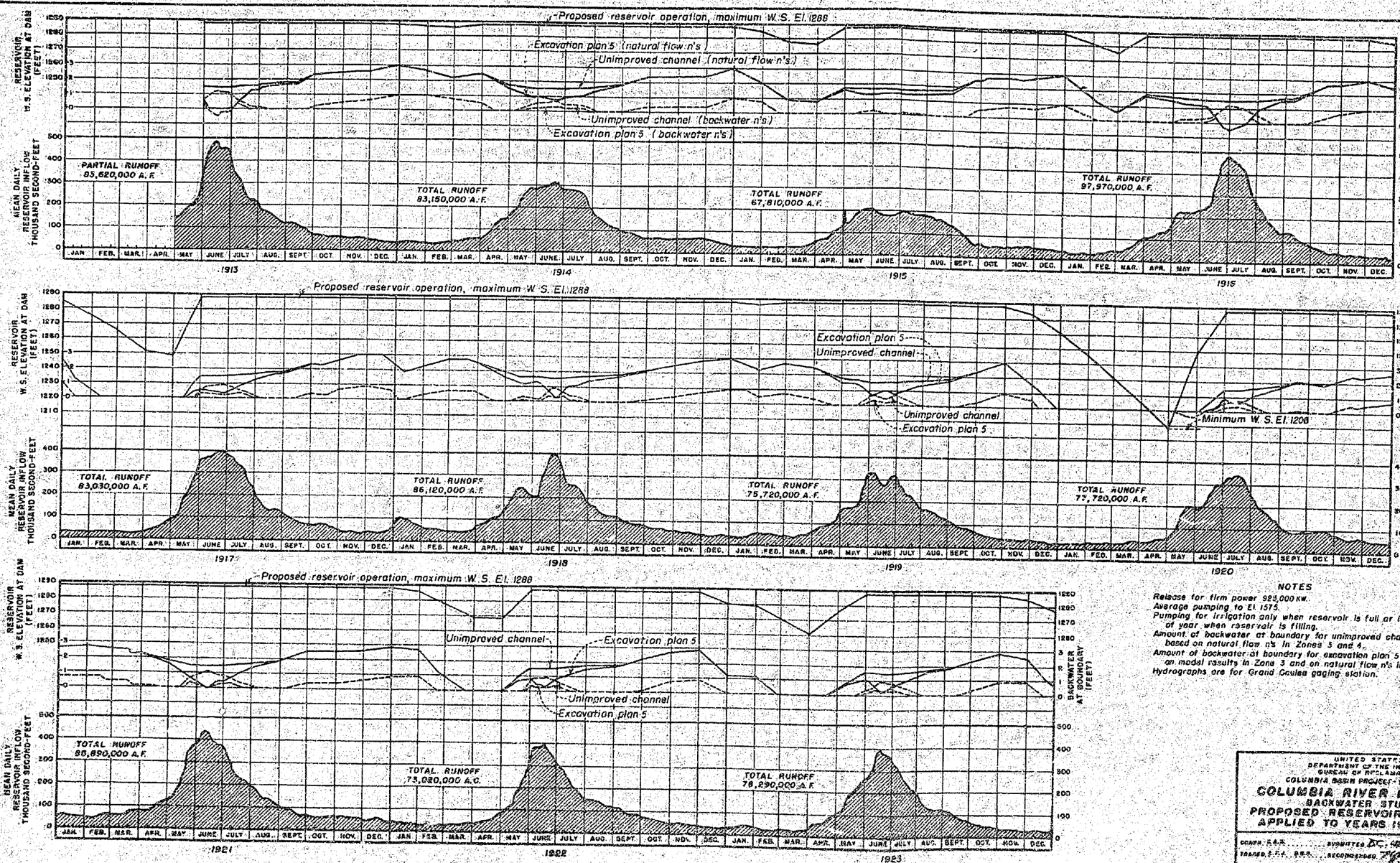
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
CURVES OF MAXIMUM WATER SURFACE ELEVATIONS AT DAM
THAT WILL CAUSE NO BACKWATER AT INTERNATIONAL BOUNDARY
NO CHANNEL IMPROVEMENT AT LITTLE DALLES

C.A.W. 9-6-40

222-D-6919

FIGURE 72

FIGURE 73



NOTES

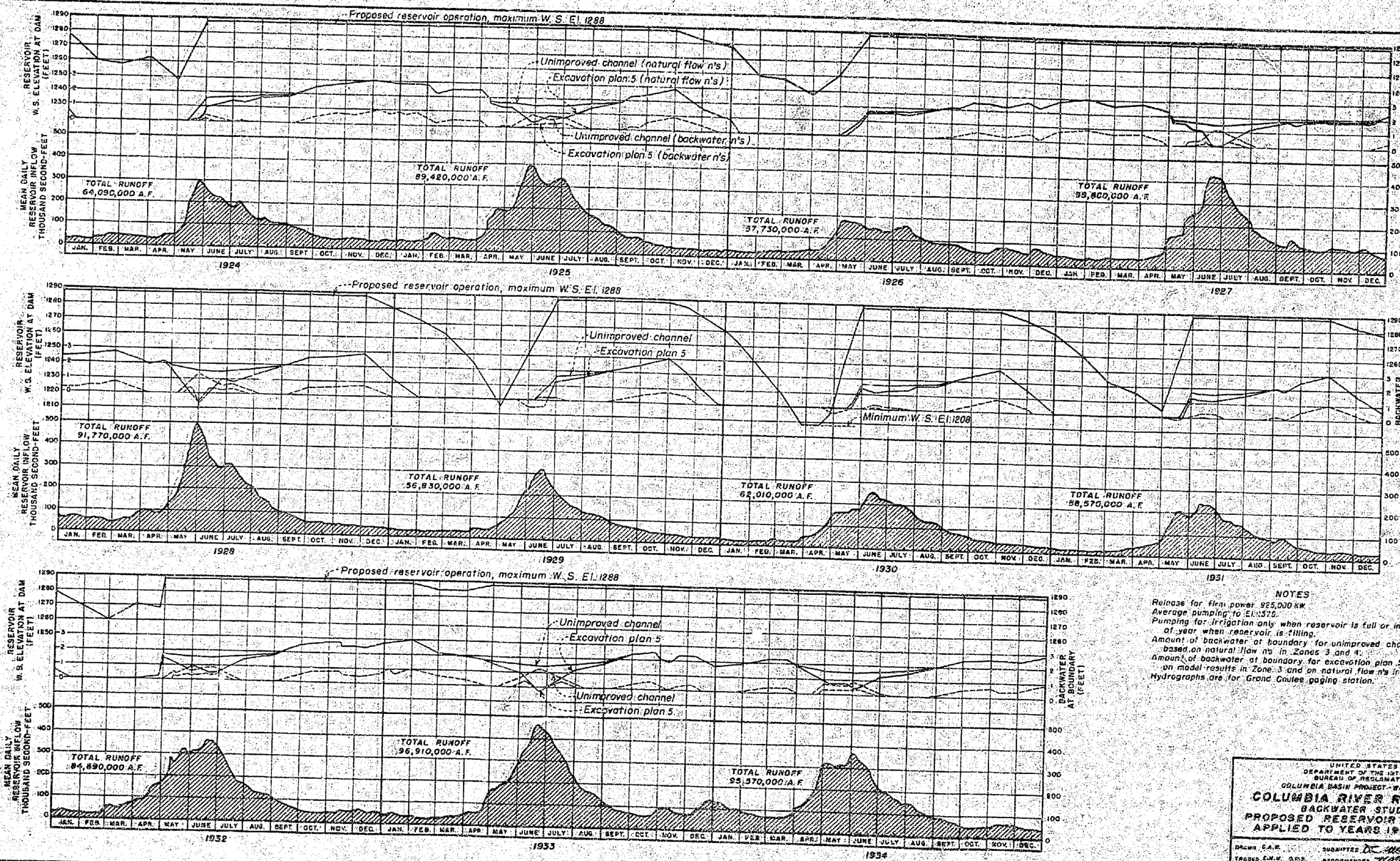
Release for firm power 983,000 KW.
Average pumping to El. 1575.
Pumping for irrigation only when reservoir is full or in spring of year when reservoir is filling.
Amount of backwater at boundary for unimproved channel is based on natural flow n's in Zones 3 and 4.
Amount of backwater at boundary for excavation plan 5 is based on model results in Zone 3 and on natural flow n's in Zone 4.
Hydrographs are for Grand Coulee gaging station.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
PROPOSED RESERVOIR OPERATION APPLIED TO YEARS 1913 TO 1923

DRAWN F.E.K. SUBMITTED D.C.
TRACED S.F.F. B.R.B. RECOMMENDED
CHECKED C.W.B. APPROVED
DENVER, COLORADO, OCT. 12, 1949
SEPT. 1949
SSB-B-6817

FIGURE 74



NOTES

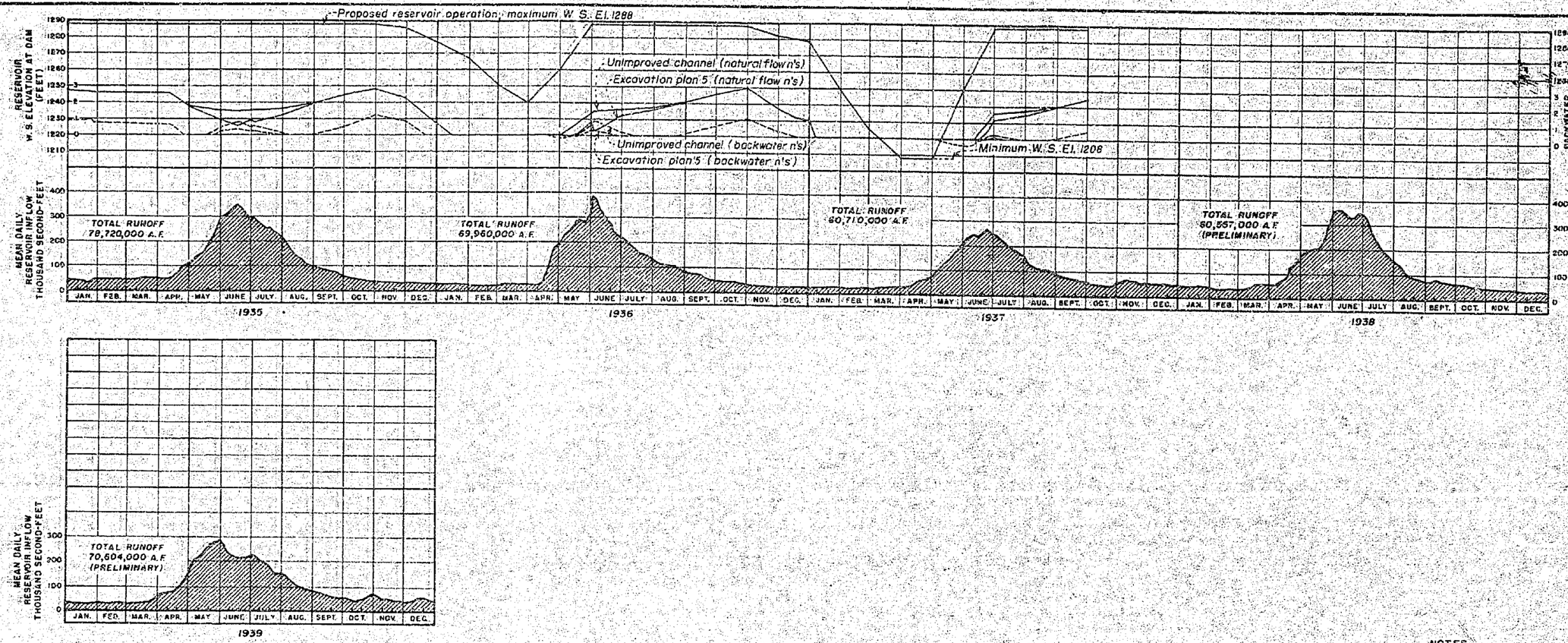
Release for firm power 925,000 kw.
Average pumping to El. 1575.
Pumping for irrigation only when reservoir is full or in spring of year when reservoir is filling.
Amount of backwater at boundary for unimproved channel is based on natural flow n's in Zones 3 and 4.
Amount of backwater at boundary for excavation plan 5 is based on model results in Zone 3 and on natural flow n's in Zone 4.
Hydrographs are for Grand Coulee gaging station.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
PROPOSED RESERVOIR OPERATION
APPLIED TO YEARS 1915 TO 1937.

DRAWN C.A.W. SUBMITTED
TRACED C.A.W. A.P.P. RECOMMENDED
CHECKED W.H.B. APPROVED
DENVER, COLORADO, OCT. 14, 1946
SHEET 2 of 3
NCI-D-3818

FIGURE 75



NOTES

Release for firm power 925,000 KW.
Average pumping to El. 1575.
Pumping for irrigation only when reservoir is full or in spring of year when reservoir is filling.
Amount of backwater at boundary for unimproved channel is based on natural flow n's in Zones 3 and 4.
Amount of backwater at boundary for excavation plan 5 is based on model results in Zone 3 and on natural flow n's in Zone 4.
Hydrographs are for Grand Coulee gaging station.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
PROPOSED RESERVOIR OPERATION
APPLIED TO YEARS 1935 TO 1939

DRAWN C.A.K. SUBMITTED
TRACED R.R.C. D.R.E. RECOMMENDED
CHECKED APPROVED
DENVER, COLORADO, OCT. 18, 1949
SCALE 1" = 50'
222-D-2819

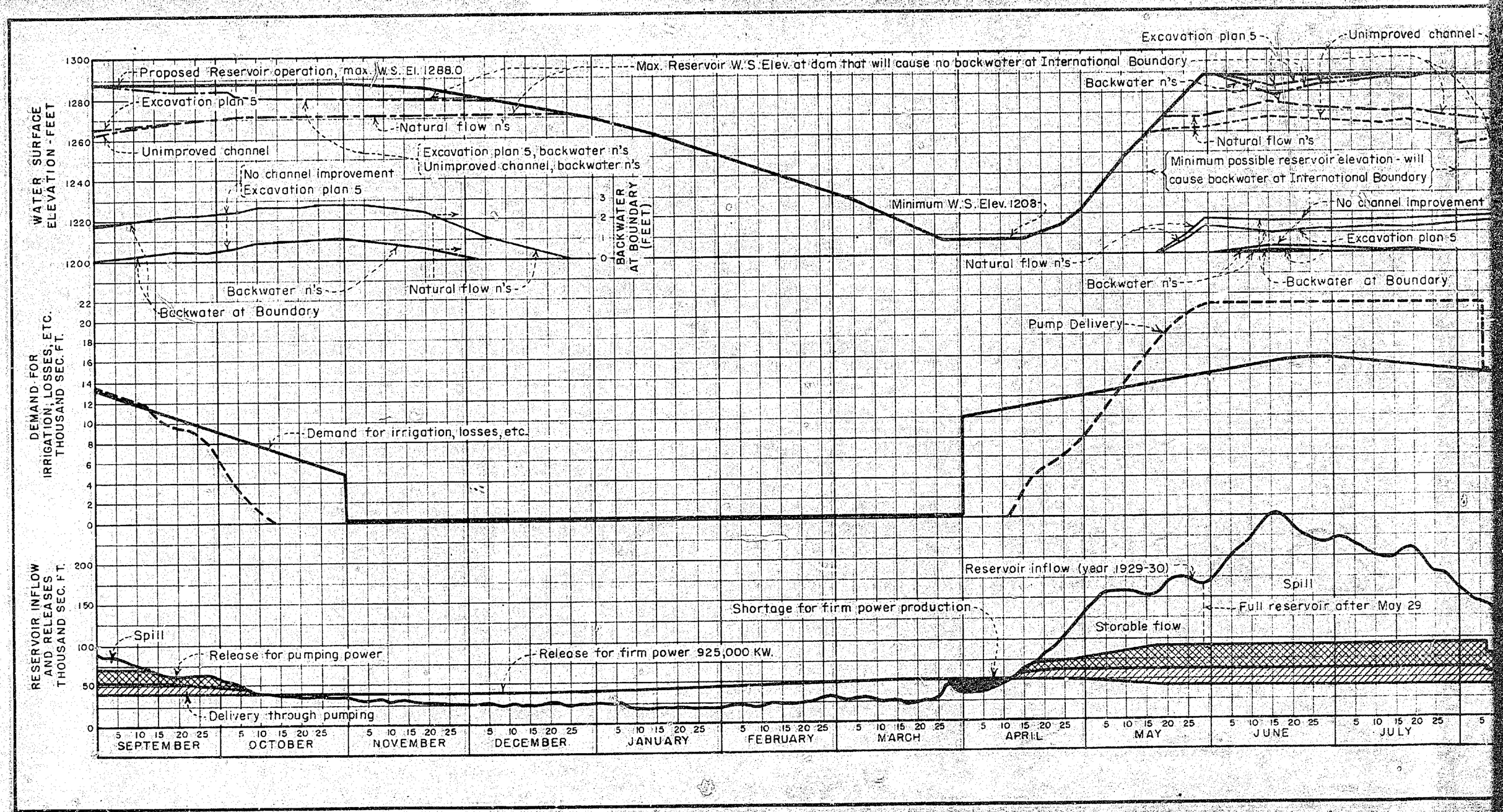
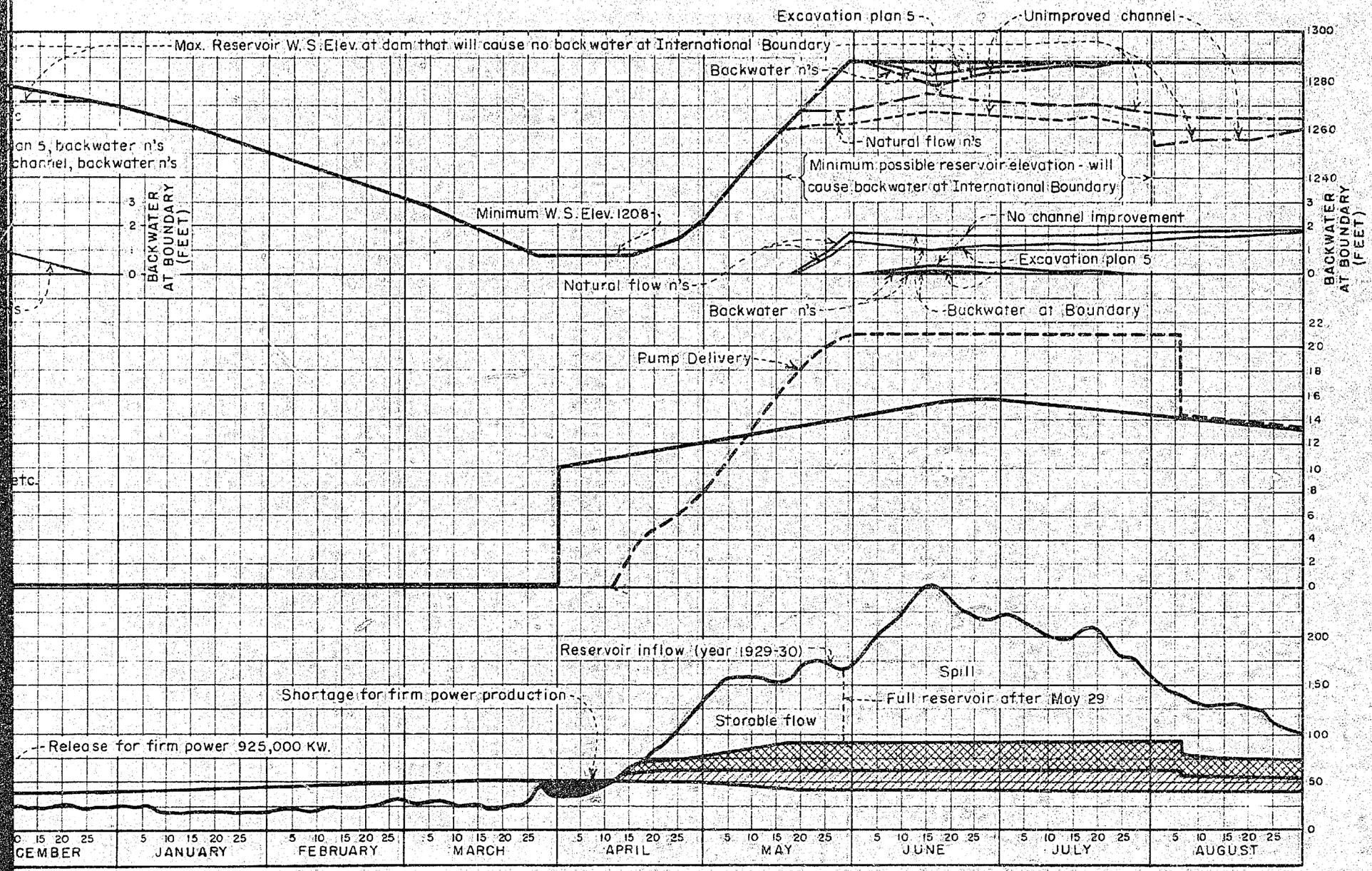

WATER SURFACE ELEVATION - FEET
1300
1280
1260
1240
1220
1200
Proposed Reservoir operation, max. W.S. El. 1288.0
Max. Reservoir W.S. Elev. at dam that will cause no backwater at International Boundary
Excavation plan 5
Natural flow n's
Unimproved channel
Excavation plan 5, backwater n's
Unimproved channel, backwater n's
No channel improvement
Excavation plan 5
Backwater n's
Natural flow n's
Backwater at Boundary
BACKWATER AT BOUNDARY (FEET)
3
2
1
0
Minimum W.S. Elev. 1208
Excavation plan 5
Unimproved channel
Backwater n's
Natural flow n's
Minimum possible reservoir elevation - will cause backwater at International Boundary
No channel improvement
Excavation plan 5
Natural flow n's
Backwater n's
Backwater at Boundary
DEMAND FOR IRRIGATION, LOSSES, ETC. THOUSAND SEC. FT.
22
20
18
16
14
12
10
8
6
4
2
0
Demand for irrigation, losses, etc.
Pump Delivery
RESERVOIR INFLOW AND RELEASES THOUSAND SEC. FT.
200
150
100
50
0
Spill
Release for pumping power
Delivery through pumping
Release for firm power 925,000 KW.
Shortage for firm power production
Reservoir inflow (year 1929-30)
Spill
Full reservoir after May 29
Storable flow
5 10 15 20 25
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
JANUARY
FEBRUARY
MARCH
APRIL
MAY
JUNE
JULY

FIGURE 76



NOTES

Average pumping to Elevation 1575.

The release for firm power, the delivery through pumping, the release for pumping power, and the reservoir inflow make up the curve for proposed reservoir operation.

The curves of maximum reservoir elevation at the dam that will cause no backwater at the Boundary are applicable only to the reservoir inflow.

Pumping for irrigation only when reservoir is full or in spring of year when it can be certain reservoir is going to fill.

Hydrograph is for Grand Coulee gaging station.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT-WASHINGTON

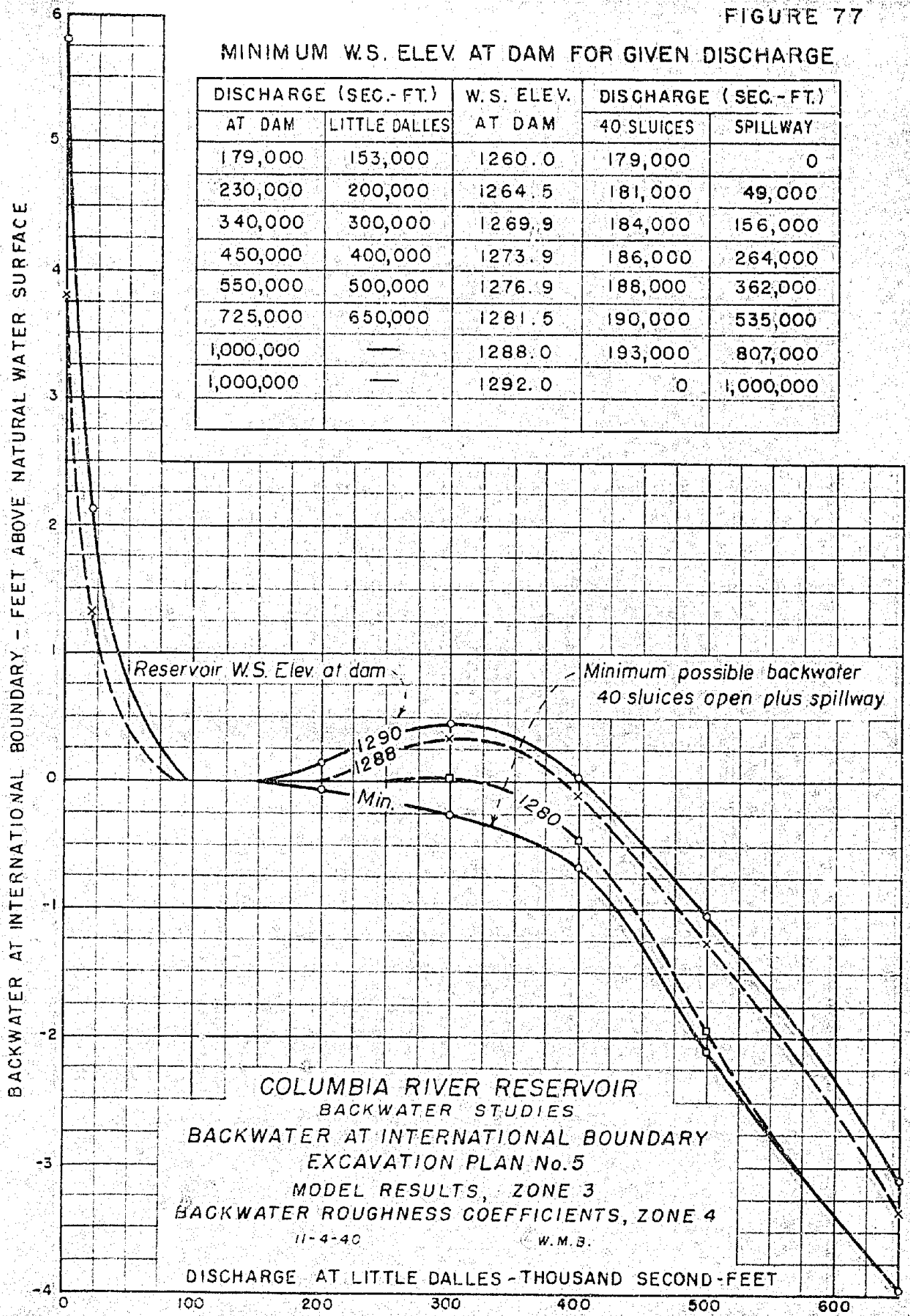
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
RESERVOIR OPERATION 1929-1930

DRAWN: E.R.-C.A.W. SUBMITTED: O. E. Meinzer
TRACED: J.L.C.-H.S. RECOMMENDED: J. L. Savage
CHECKED: W.M.B. APPROVED: Jas. Lawson
DENVER, COLO. SEPT. 6, 1940 222-D-929

FIGURE 77

MINIMUM W.S. ELEV. AT DAM FOR GIVEN DISCHARGE

DISCHARGE (SEC.-FT.)		W.S. ELEV.	DISCHARGE (SEC.-FT.)	
AT DAM	LITTLE DALLES	AT DAM	40 SLUICES	SPILLWAY
179,000	153,000	1260.0	179,000	0
230,000	200,000	1264.5	181,000	49,000
340,000	300,000	1269.9	184,000	156,000
450,000	400,000	1273.9	186,000	264,000
550,000	500,000	1276.9	188,000	362,000
725,000	650,000	1281.5	190,000	535,000
1,000,000	—	1288.0	193,000	807,000
1,000,000	—	1292.0	0	1,000,000



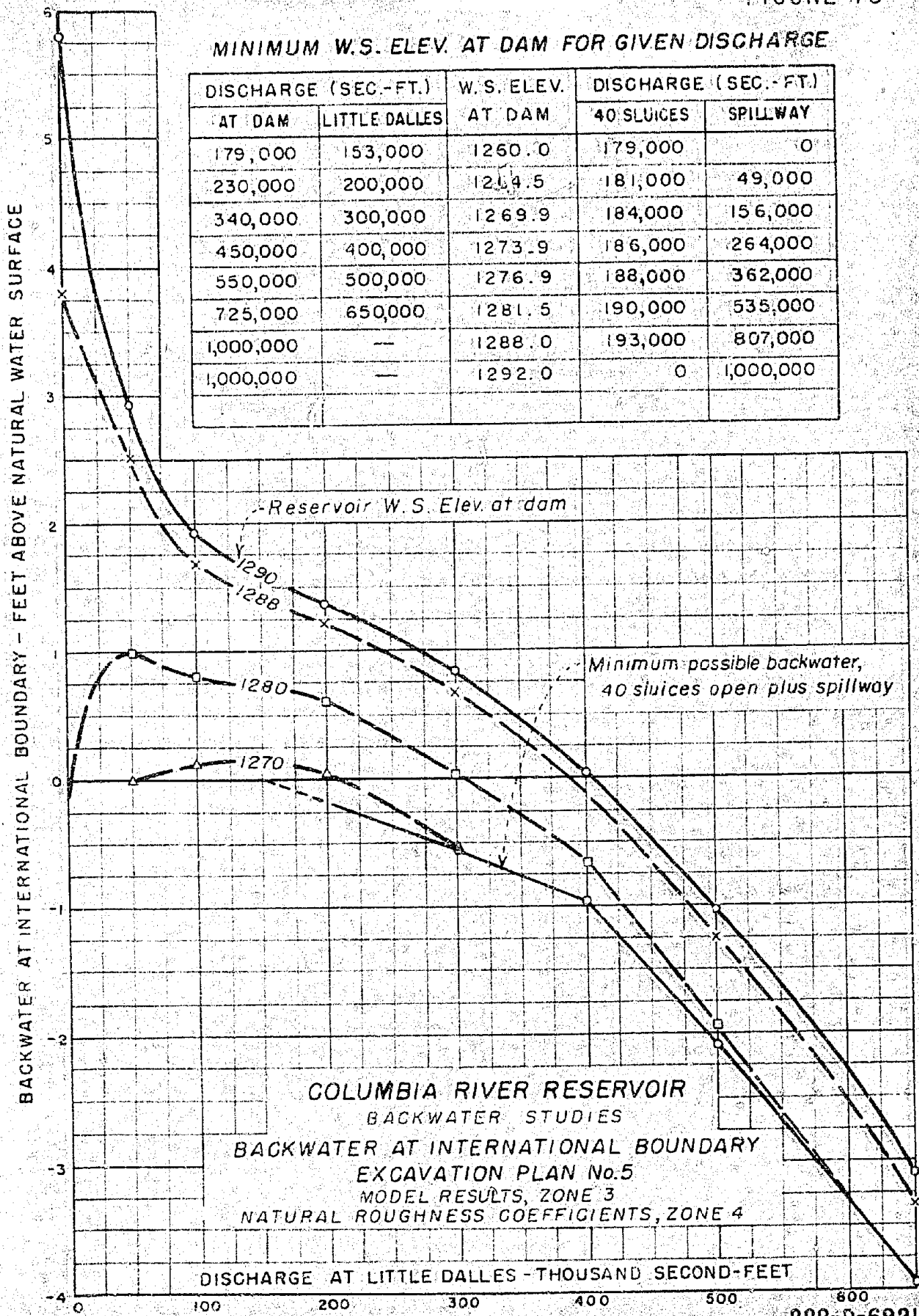
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
BACKWATER AT INTERNATIONAL BOUNDARY
EXCAVATION PLAN No. 5
MODEL RESULTS, ZONE 3
BACKWATER ROUGHNESS COEFFICIENTS, ZONE 4
11-4-40 W.M.B.

222-D-6920

FIGURE 78

MINIMUM W.S. ELEV. AT DAM FOR GIVEN DISCHARGE

DISCHARGE (SEC.-FT.)		W.S. ELEV.	DISCHARGE (SEC.-FT.)	
AT DAM	LITTLE DALLES	AT DAM	40 SLUICES	SPILLWAY
179,000	153,000	1260.0	179,000	0
230,000	200,000	1264.5	181,000	49,000
340,000	300,000	1269.9	184,000	156,000
450,000	400,000	1273.9	186,000	264,000
550,000	500,000	1276.9	188,000	362,000
725,000	650,000	1281.5	190,000	535,000
1,000,000	—	1288.0	193,000	807,000
1,000,000	—	1292.0	0	1,000,000

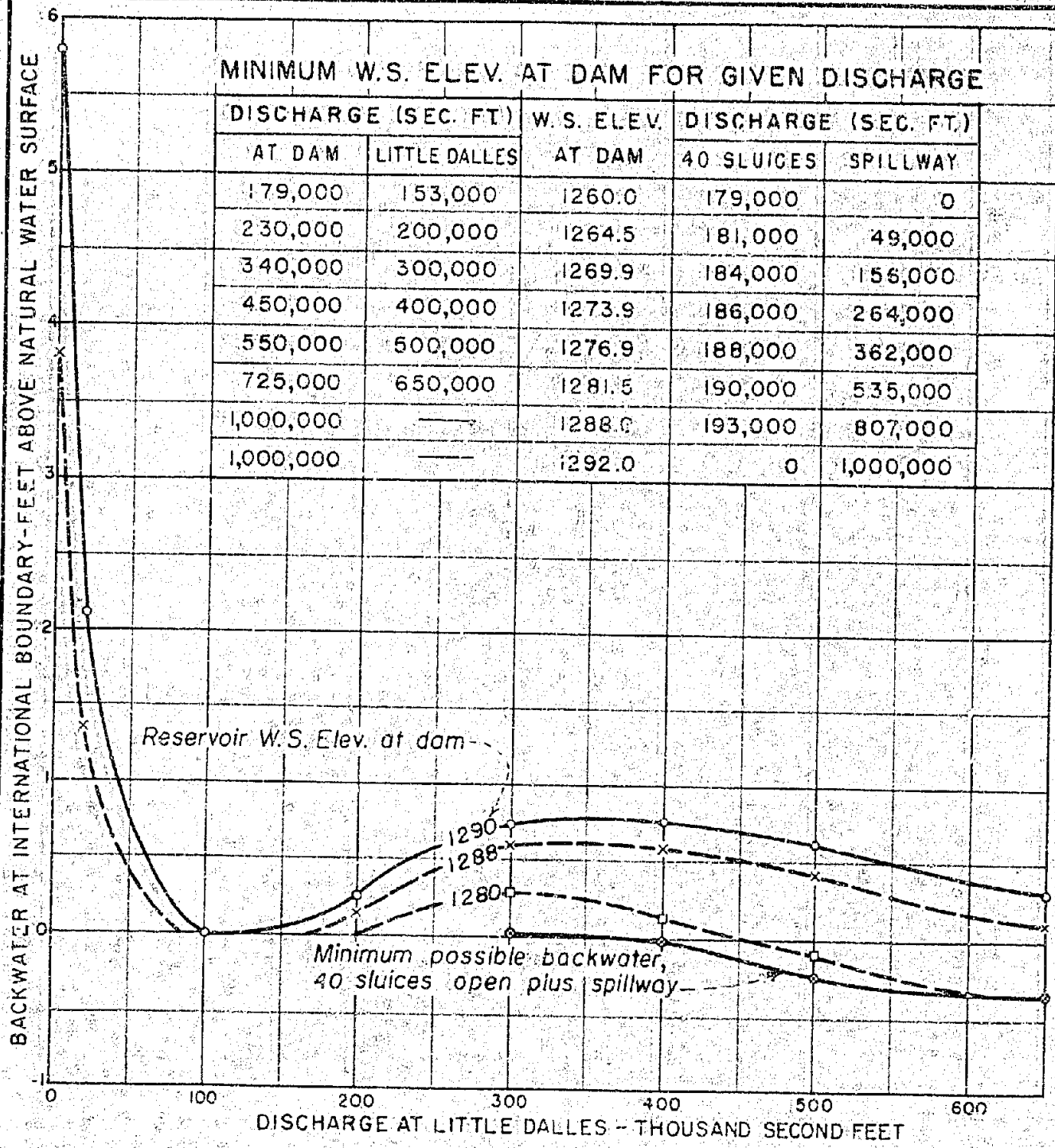


COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
BACKWATER AT INTERNATIONAL BOUNDARY
EXCAVATION PLAN No.5
MODEL RESULTS, ZONE 3
NATURAL ROUGHNESS COEFFICIENTS, ZONE 4

C.A.W. 7-23-40

222-D-6921

FIGURE 79



MINIMUM W.S. ELEV. AT DAM FOR GIVEN DISCHARGE

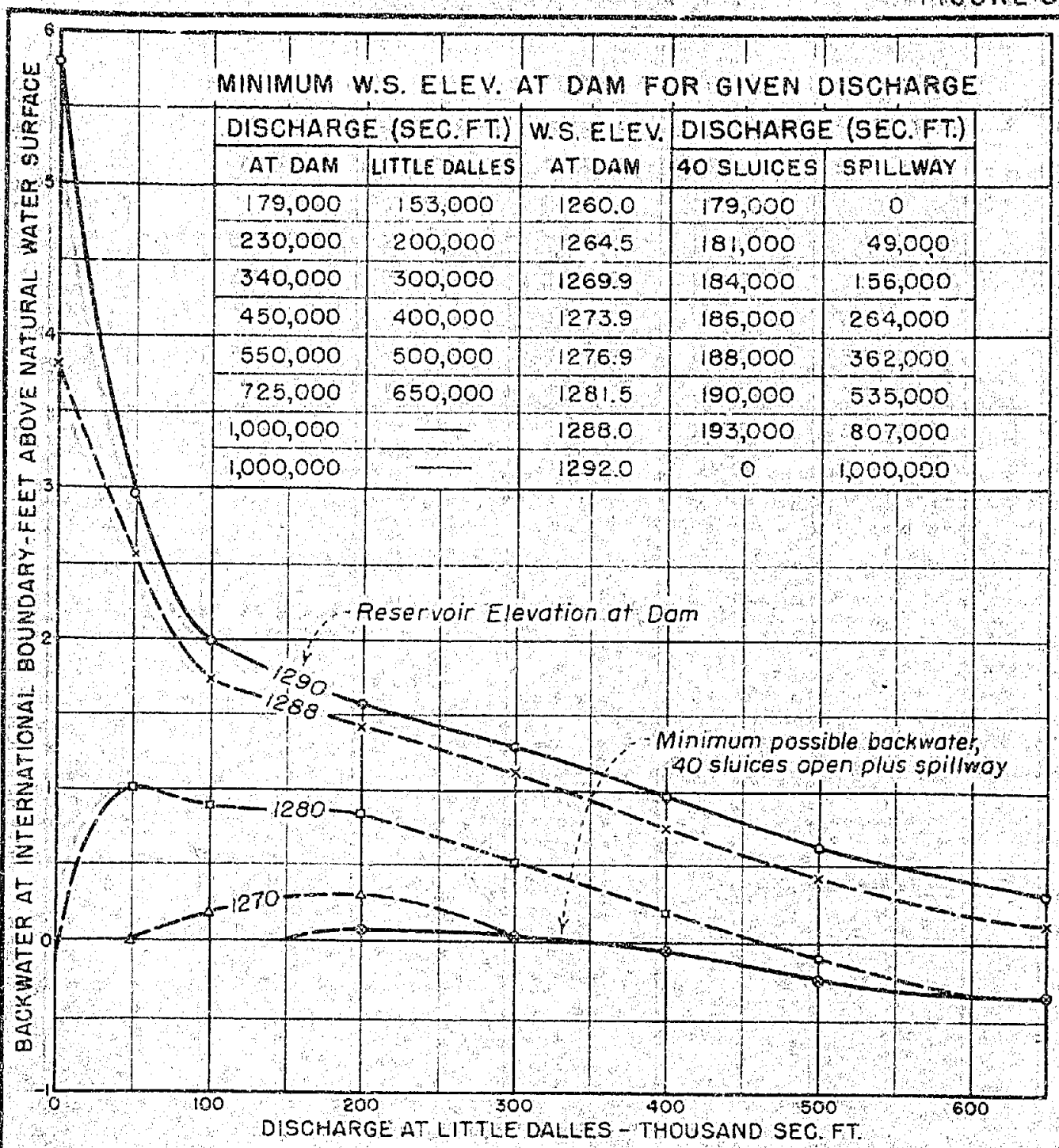
DISCHARGE (SEC. FT.)		W.S. ELEV.	DISCHARGE (SEC. FT.)	
AT DAM	LITTLE DALLES	AT DAM	40 SLUICES	SPILLWAY
179,000	153,000	1260.0	179,000	0
230,000	200,000	1264.5	181,000	49,000
340,000	300,000	1269.9	184,000	156,000
450,000	400,000	1273.9	186,000	264,000
550,000	500,000	1276.9	188,000	362,000
725,000	650,000	1281.5	190,000	535,000
1,000,000	——	1288.0	193,000	807,000
1,000,000	——	1292.0	0	1,000,000

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
BACKWATER AT INTERNATIONAL BOUNDARY
ISLAND REMOVED TO EL. 1255.0
MODEL RESULTS, ZONE 3
BACKWATER ROUGHNESS COEFFICIENTS, ZONE 4

11-5-40 W.M.B.

222-D-6922

FIGURE 80



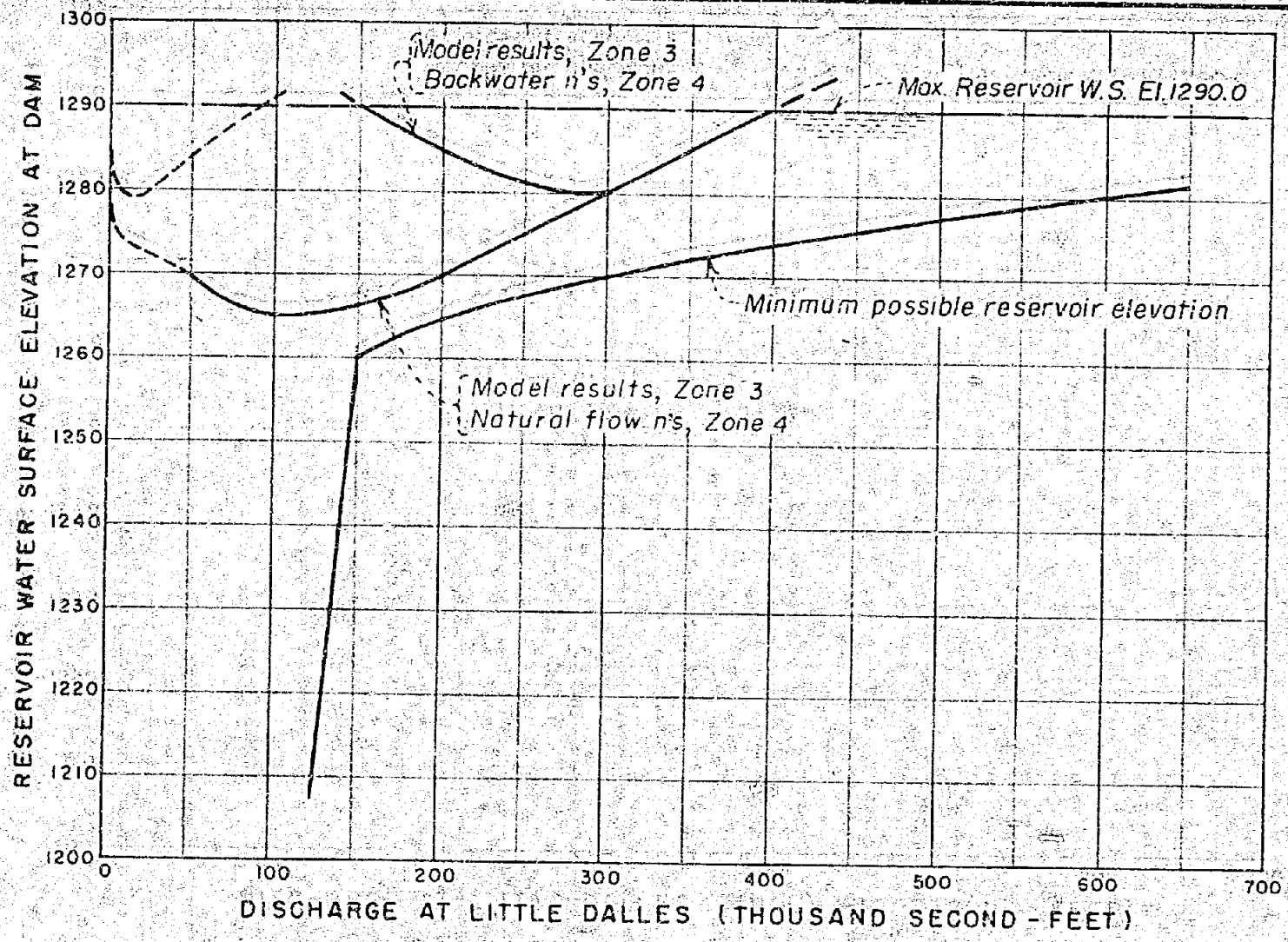
MINIMUM W.S. ELEV. AT DAM FOR GIVEN DISCHARGE

DISCHARGE (SEC. FT.)		W.S. ELEV.	DISCHARGE (SEC. FT.)	
AT DAM	LITTLE DALLES	AT DAM	40 SLUICES	SPILLWAY
179,000	153,000	1260.0	179,000	0
230,000	200,000	1264.5	181,000	49,000
340,000	300,000	1269.9	184,000	156,000
450,000	400,000	1273.9	186,000	264,000
550,000	500,000	1276.9	188,000	362,000
725,000	650,000	1281.5	190,000	535,000
1,000,000	——	1288.0	193,000	807,000
1,000,000	——	1292.0	0	1,000,000

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
BACKWATER AT INTERNATIONAL BOUNDARY
ISLAND REMOVED TO EL. 1255.0
MODEL RESULTS, ZONE 3
NATURAL ROUGHNESS COEFFICIENTS, ZONE 4

W.M.B. 7-17-40

222-D-6923



COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
CURVES OF MAXIMUM WATER SURFACE ELEVATIONS AT DAM
THAT WILL CAUSE NO BACKWATER AT INTERNATIONAL BOUNDARY
EXCAVATION PLAN 5 AT LITTLE DALLES

C.A.W. 9-6-40

222-D-6924

FIGURE 81

APPENDIX I

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APPENDIX II

List of Bibliography of Reports, Letters, and Memoranda

This Appendix has been omitted from most copies

A Report on Columbia Basin Irrigation Project, Washington, by Homer J. Gault, Engineer of U.S.B.R., with appendixes by A. T. Strshorn, Soil Scientist, Bureau of Soils by Kirk Bryan, Geologist, U. S. Geological Survey, and by G. L. Parker, Hydraulic Engineer, U. S. Geological Survey, published March 1924.

B 73rd Congress, 1st Session, House Document No. 103, Columbia River and Minor Tributaries, in two volumes, by U. S. Corps of Engineers, War Department.

C Water Elevations at Selected Points Along the Upper and Lower Arrow Lakes and Columbia River Between Revelstoke, B. C., and Little Dalles, Washington, 1930-1939, by C. E. Webb, Dominion Water and Power Bureau of Canada.

D Columbia River Between Birchbank, British Columbia, and the Little Dalles, Washington. Water Elevations at Selected Observation Points, 1930-1939, by Glenn L. Parker, District Engineer, U. S. Geological Survey.

E Columbia River Backwater Effect From Grand Coulee Dam, in two parts. Part I, Columbia River; Part II, Spokane River, by Assistant Engineer of U.S.B.R., J. C. Sharp.

F Letter of May 19, 1939, from Acting Construction Engineer, J. H. Miner, to Chief Engineer of U.S.B.R. Subject: Backwater from Grand Coulee Dam, Columbia Basin project.

G Memorandum to Chief Designing Engineer, U.S.B.R., Spillway Capacity, Grand Coulee Dam on Columbia River, by J. R. Riter, March 28, 1934.

H Memorandum to Chief Designing Engineer, U.S.B.R. Backwater Studies, Columbia River Above Grand Coulee Dam, Columbia Basin project, by D. C. McConaughy, Nov. 29, 1939.

I Memorandum to Mr. McConaughy, Inspection Trip to Coulee Dam Office and to Little Dalles. Backwater Studies of the Columbia River Reservoir, Columbia Basin project, Washington, by W. M. Borland, Jan. 27, 1940.

J Memorandum to the Chief Designing Engineer. Backwater in Columbia River from Grand Coulee Dam, Columbia Basin project, by D. C. McConaughy, May 6, 1940.

K Memorandum to Chief Designing Engineer, U.S.B.R. Backwater Investigations of the Columbia River Reservoir, by W. M. Borland and R. A. Goodpasture, May 27, 1940.

L Letter of July 21, 1939, from Chief Engineer, U.S.B.R., to the Commissioner. Subject: Backwater from Grand Coulee Dam, Columbia Basin project.

M Note from Canadian Legation No. 202, Aug. 1, 1939. Merchant Mahoney Charge d'Affaires to The Hornorable Cordell Hull, Secretary of State of the United States, Washington, D. C.

N Letter of Aug. 9, 1939, from John C. Sharp, Assistant Engineer, U.S.B.R., to Acting Supervising Engineer. Subject: Report of Methods of Backwater Study, by U. S. Engineers at Bonneville Dam and at Grand Coulee Dam.

O Letter of Aug. 10, 1939, from Acting Supervising Engineer, U.S.B.R., to Chief Engineer, U.S.B.R. Subject: Backwater Studies of the Columbia River Reservoir, Grand Coulee Dam, Columbia Basin project.

P Letter of July 5, 1940, to F. A. Banks, Construction Engineer, U.S.B.R., from F. M. Veatch, District Engineer, U. S. Geological Survey. Subject: Current Meter Measurements on Columbia River at International Boundary.

Q Letter of (about Aug. 7, 1940) from Acting Commissioner to Chief Engineer, U.S.B.R. Subject: Application to the International Joint Commission with Respect to the Higher Stage of the Columbia River Required by Operation of the Grand Coulee Dam and Reservoir.

R Letter of Sept. 4, 1940, from Supervising Engineer, Coulee Dam, to Chief Engineer, U.S.B.R. Subject: Water Levels at International Boundary, Columbia River, Columbia Basin project.

S United States Geological Survey Bulletin No. 674, p. 36, reference on level datum.

T Geodetic Survey of Canada Publication No. 24, "Precise Levelling in British Columbia," published in 1930. Contains elevation of bench marks in Canada used in connection with water surface observations.

U United States Geological Survey Water-Supply Papers Nos. 38, 51, 66, 75, 85, 100, 135, 178, 214, 252, 272, 292, 312, 332A, 362A, 392, 412, 442, 462, 482, 512, 532, 552, 572, 592, 612, 632, 652, 672, 692, 707, 722, 737, 752, 767, 792, 812, and 832.

APPENDIX III

List of Basic Data in Form of Drawing, Maps, Cross Sections, and Photographs

A Grand Coulee drawing No. $R_3$1078-3, "Map of Columbia River, Little Dalles to International Boundary." Scale: 1 inch = 1,000 feet, was taken from Washington Water Power Company's maps. Map is 24 inches wide and about 8 feet long. Gives topography along river.

B Grand Coulee drawing No. T2327, "R. S. Wells, Mine Property Survey T39N, R39E, W.M., Stevens county." Scale: 1 inch = 100 feet, shows topography at the upper end of the Little Dalles above low water. Contour interval 10 feet.

C Grand Coulee drawing No. R_2-1999-8, "Topography of Little Dalles." Scale: 1 inch = 50 feet. Contour interval 5 feet. This map was made up from field surveys and Washington Water Power Company's maps. Shows bed of river. Accuracy of map is only fair.

D Drawing No. 222-D-2668, "Hydrograph of Columbia River at Little Dalles," Oct. 1929 - Sept. 1939. Contained in Specifications No. 937, "River Channel Widening and Shore Protection."

E Grand Coulee drawing No. R_2-2737-1, "River Channel Cross Sections, Upper Little Dalles," shows cross section A to M at Little Dalles and ties in with traverse line.

F Photostats of Washington Water Power Company's maps. Scale: 1 inch = 500 feet. Contour interval 5 feet in flat country, 10 feet in steep country. Sheets 4A to 22A show river from Kettle Falls to International Boundary. One sheet of triangulation and levels. 27- by 36-inch sheets, white line on black. (Original tracing may be filed with Federal Power Commission.)

G Drawing No. 222-D-7001, sheets 1 to 41, inclusive. River cross sections between Kettle Falls highway bridge and International Boundary. 41 sheets, size 18 by 22 inches.

H U.S.B.R. drawing No. 222-D-7001, sheets 42 to 46, inclusive, revised U. S. Geological Survey maps, "Plan of Columbia River, International Boundary to Rock Island Rapids (Below Wenatchee) Washington," sheets A to E, inclusive, show topography along Columbia River to below Grand Coulee Dam on scale of 1 inch = 31,600 feet, contour interval 20 feet on land, 5 feet on river surface. Maps marked to show location of cross sections.

I "Aerial view of Columbia River, Little Dalles to International Boundary." Dated Jan. 24, 1940. Very good photograph showing nature of river in this region.

J Photographs of aerial views of Columbia River at International Boundary. Various views of Little Dalles both at low water and for Q = 330,000 second-feet. Bridge at Northport, bridge at Marcus, bridge over Clark Fork, mouth of Clark Fork, view of right bank of Columbia River at Trail. Photographs Nos. C41, C41D, 2768-2, 2756-2, 2762-2, 2767-2, 2751-2, 2761-2, 1560-3, 2765-2, 2753-2, 2754-2, 2752-2, 2757-2, 2766-2, 2758-2, 1566-3, 2755-2, 1561-3, 2764-2, 1243-2, 2763-2, 1249-2, 2579-2, 2567-2, 2577-2, and six unnumbered photographs.

K Drawing No. 222-D-1902. Hydrograph of Columbia River at Grand Coulee Dam, May 1913 to Dec. 1939. This is figure 4, p. 45 of this report.

L Photographs of Little Dalles taken to assist in building hydraulic model of same. Photographs Nos. 3622-2 to 3627-2 and unnumbered index photograph.