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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Memorandum to Chief Designing Engineer

BACKWATER INVESTIGATIONS OF THE COLUMBIA RIVER RESERVOIR

BY

W. M. BORLAND, ASSOCIATE ENGINEER
AND
R. A GOODPASTURE, ASSISTANT ENGINEER

Denver, Colorado,
May 27, 1940.

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PREFACE

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. The backwater studies were made under the direction of D. C. McConaughy, Senior Engineer, by W. M. Borland, Associate 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.

These investigations were made under the general supervision of J. L. Savage, Chief Designing Engineer. All engineering work of the Bureau of Reclamation is under the direction of R. F. Walter, Chief Engineer, and all activities of the Bureau are under the direction of J. C. Page, Commissioner.

Denver, Colorado, May 24, 1940.

MEMORANDUM TO THE CHIEF DESIGNING ENGINEER
(W. M. Borland and R. A. Goodpasture)

Subject: Investigations of backwater of the Columbia River Reservoir.

1. Introduction. The Grand Coulee Dam located on the Columbia River about 150 miles downstream from the Canadian boundary will, when completed, form a vast 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 develop some plan of channel improvement to relieve the excessive backwater along the railroad and 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 Corp 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). Sounding 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. A total of 41 river cross sections are available along the upper end of the reservoir where they were most needed in the backwater computations.

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 mouth of 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, British Columbia, to the flow of the Clark Fork below Z Canyon.

3. Analysis of field data. 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. The rating curves at the major observation stations were accurately defined up to 420,000 second-feet. These curves were then extrapolated by various methods with the aid of meager field data to include the 1894 flood, estimated as 650,000 second-feet. The roughness coefficient was found to vary with the discharge and stage, so that for discharges greater than 400,000 second-feet, the roughness coefficient versus discharge curves could be extrapolated and so adjusted that they were in agreement with the extrapolated rating curves. The value of n was usually found to decrease with an increase in the discharge or stage of the river. With any backwater stage a new n for any reach is determined from the n versus average water surface elevation curve. This coefficient is designated as the backwater n while the coefficient obtained, assuming variation only with the discharge, was designated as the natural n.

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 3). However, the difference was considerable 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 logical that the correct backwater curve should lie between the extremes obtained with natural and backwater coefficients. In the interest of conservatism, the backwater curves for the upper end of the reservoir were computed by using natural coefficients, and are used as the basis for future comparisons.

Kutter's formula for computing the value of C in the Chezy formula has enjoyed wider use than Manning's and was used 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 were conservatively based on the backwater rating curve at the foot of the Little Dalles as given by the Manning formula. Upstream from this point, the slope of the energy gradient was steeper, and while the Kutter formula was used, it gave results comparable with the Manning formula.

5. The Little Dalles. The Great Northern Railroad parallels the Columbia River for 17 miles below the Canadian border (figure 1). Along this section, 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 probable damage to the railroad and the backwater that would exist at the boundary, a location was sought where channel improvement would improve backwater conditions at high discharges. 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, the railroad would not suffer additional flood damage and backwater would be eliminated 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 13.5 feet through these rapids (figure 3). Channel improvement at this location would be effective in reducing energy losses at both natural and backwater flow conditions. The Little Dalles is shown in figure 4.

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, a 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. A 1 to 120 hydraulic model was built to represent the river between the major observation stations at the Little Dalles (figure 5). The model was constructed from the field topography and a careful study of prototype pictures. The model was roughened by adding lumps of concrete on the bed and walls of the channel so that when natural-flow conditions were reproduced at the foot of the Little Dalles, the upstream rating curves agreed reasonably well with those obtained from the prototype (figure 6).

After the model had been calibrated to simulate natural-flow conditions, backwater conditions representing the reservoir at elevation 1290.0 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 7). The backwater computed through the Little Dalles , using backwater coefficients, was 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 the computed one. The discrepancy was always less than 1.00 foot, or never greater than 5 percent of the total energy loss in the Little Dalles 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 the material must be broken up and removed, it was hoped that the desired channel improvement might be accomplished above 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 8). A rating curve for gage 11 at the head of the Little Dalles was obtained for each excavation plan (figure 7). The first improvement study was made with the large rock island at the entrance to the Little Dalles removed to elevation 1255.0. Subsequent tests showed that no additional improvement was gained 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 8). 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 were removed above elevation 1255.0 (excavation plan 5, figure 8). This plan restored natural-flow conditions above the Little Dalles at a discharge of 397,000 second-feet for reservoir elevation 1290.0. Above a discharge of 400,000 second-feet, the water level was lower than with natural channel flow.

7. Analysis of excavation studies. After a satisfactory excavation plan had been evolved, it was natural to inquire whether additional excavation would be justified. Accordingly, the amount of excavation for each excavation plan was plotted against the corresponding discharge at which natural conditions were re-

stored upstream and an approximate extension obtained by logarithmic plotting (figure 9). The intersection of the natural rating curve at gage 11 with the backwater rating curve at gage 13 (figure 7) shows that no amount of excavation would restore natural conditions below a discharge of 297,000 second-feet. Accordingly, the improvement curve must be asymptotic to this discharge as shown on figure 9. 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.

8. Backwater with improved channel. Figure 7 shows that while the recommended channel improvement would restore natural-flow conditions at the head of the Little Dalles for a discharge of 400,000 second-feet, some additional improvement is obtained for all larger floods. This improvement would be greatest at the Little Dalles, but would still be noticeable at the boundary (figure 10). Profiles of the backwater for natural and improved channel are shown on figure 3. The amount of backwater at the International Boundary with channel improvement is shown as curve No. 5, figure 11. These computations were based on natural roughness coefficients, however, if backwater coefficients had been used this curve would always be below curve No. 7, giving practically no backwater for discharges greater than 80,000 second-feet. The following table gives the water surface elevations at the International Boundary for natural flows and backwater conditions for both natural and improved channels with the reservoir water surface at elevation 1290.0.

BACKWATER ELEVATIONS AT INTERNATIONAL BOUNDARY

Discharge	Natural flow conditions	Backwater conditions		
		Natural channel conditions		Improved channel
		Natural coefficinet n	Backwater coefficient n	Excavation plan No.5 nat. coefficient n
0	1,284.2	1,290.00 (+5.80)		1,290.00 (+5.80)
20,000	1,289.80	1,293.45 (+3.65)		1,293.45 (+3.65)
50,000	1,296.05	1,299.02 (+2.97)		1,299.02 (+2.97)
100,000	1,303.50	1,305.59 (+2.09)	1,303.50 (0)	1,305.33 (+1.83)
200,000	1,313.65	1,315.43 (+1.78)	1,313.98 (+0.33)	1,315.05 (+1.40)
300,000	1,321.70	1,323.35 (+1.65)	1,322.57 (+0.87)	1,322.38 (+0.68)
400,000	1,329.10	1,330.78 (+1.68)	1,330.32 (+1.22)	1,329.10 (0)
500,000	1,336.00	1,337.71 (+1.71)	1,337.56 (+1.56)	1,334.91 (-1.09)
650,000	1,346.00	1,347.01 (+1.01)	1,346.95 (+0.95)	1,342.98 (-3.02)

* Figure in parentheses indicates backwater if plus and improvement if minus.

An inspection of the table 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 as they are at the present time. Accordingly the damage to the railroad would be less than at present. The table and figures 3 and 11 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. A flood of 400,000-second-feet magnitude will occur once every 4 or 5 years. If the reservoir surface is lowered approximately 15 feet, there will be no backwater at the boundary for discharges up to 50,000 second-feet. The plan for reservoir operation is indefinite and is being studied at the present time. It has been estimated that for one-half of the periods of yearly minimum flow, the reservoir will be low enough to produce no backwater at the boundary. Draw-down would necessarily be made during the "lean" water years.

9. Conclusions. It is concluded:

(a) That without channel improvement there will exist at the International Boundary from about 3.5 feet of backwater at low flow to about 0.75 foot at extreme high flows with about 1.75 feet at ordinary flood stages.

(b) That without channel improvement backwater along the railroad will be from 2 to 8 feet higher than at present for discharges above 300,000 second-feet and that for discharges in the neighborhood of 400,000 second-feet , which have previously caused some damage, the backwater surface will be about at the same elevation as the natural surface for 100,000 second-feet less discharges.

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

(d) That by channel improvement at the Little Dalles requiring about 270,000 cubic yards of excavation, the backwater at the boundary can be reduced about 0.4 foot, or to 2.6 feet, at 100,000 second-feet; about 1.8 feet, or to nothing, at 400,000 second-feet; and about 4.2 feet, or to 3.5 feet lower than under present conditions at 680,000 second-feet.

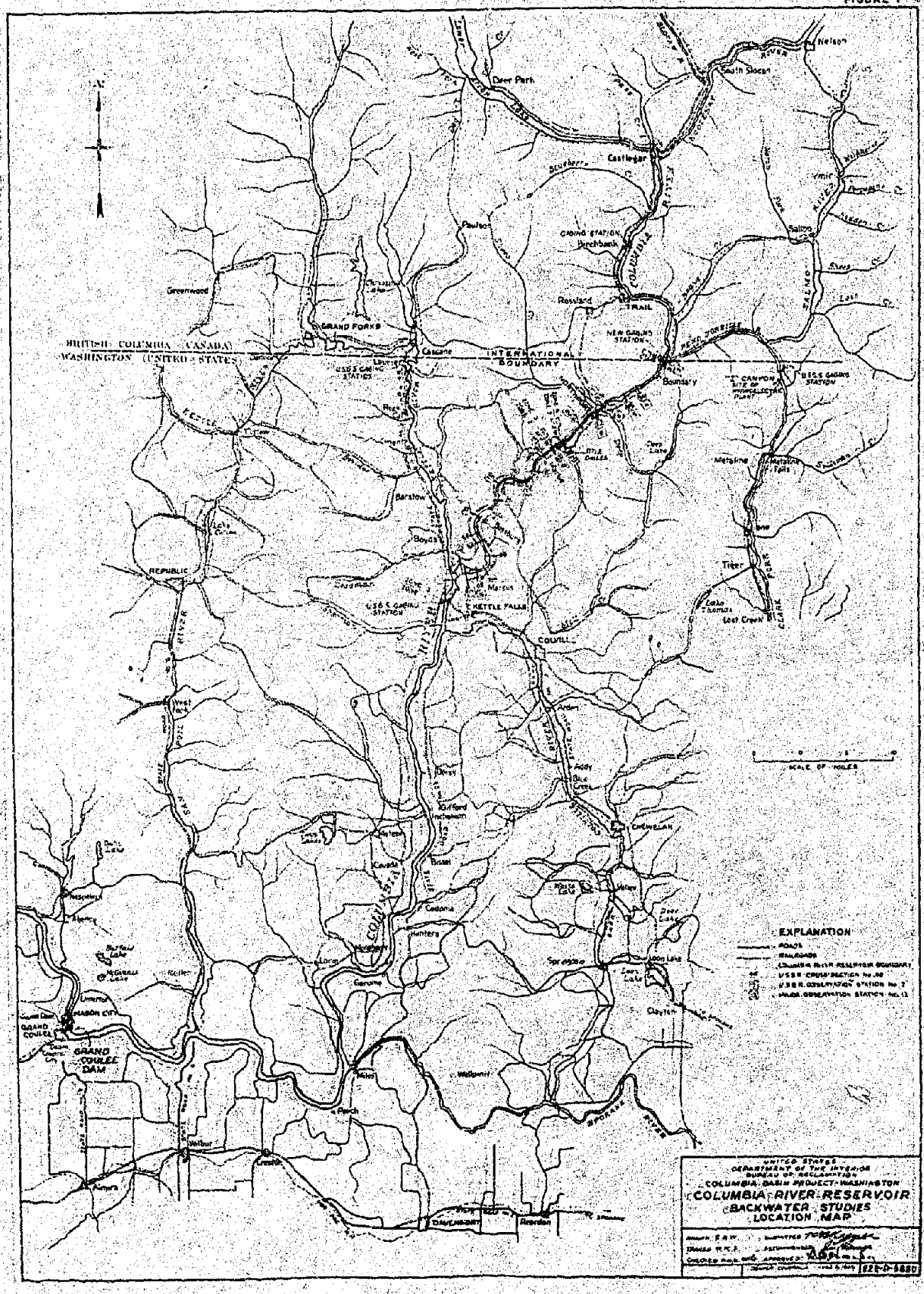
(e) That by this improvement the water surface along the railroad will be no higher than under present conditions for a discharge of 400,000 second-feet and will be lower than under present conditions for greater discharges by amounts up to about 11 feet.

(f) That the above figures are conservative and that actual benefits from the channel improvement may exceed those given above by an appreciable margin.

- - -

W. M. Borland and R. A. Goodpasture.

FIGURE 1



Nelson
South Slocan
Deer Park
Castlegar
Vmir
Salmo
Paulson
GAGING STATION
Birchbank
COLUMBIA RIVER
Rossland
TRAIL
Greenwood
GRAND FORKS
BRITISH COLUMBIA (CANADA)
WASHINGTON (UNITED STATES)
Cascade
INTERNATIONAL BOUNDARY
NEW GAGING STATION
Boundary
Metaline
Metaline Falls
Barstow
Boyds
REPUBLIC
KETTLE FALLS
Marcus
COLVILLE
Tiger
Lost Creek
CLARK FORK
Arden
Addy
Blue Creek
Gifford
Inchelium
CHEWELAN
Bossel
Cedonia
Hunters
Springdale
Loon Lake
Clayton
Keller
MASON CITY
GRAND COULEE
GRAND COULEE DAM
Miles
Wellpinit
Porch
Wilbur
Creston
Almira
Davenport
Reardan
SPOKANE RIVER
SCALE OF MILES
EXPLANATION
ROADS
RAILROADS
COLUMBIA RIVER RESERVOIR BOUNDARY
U.S.G.S. CROSS SECTION No. 40
U.S.G.S. OBSERVATION STATION No. 2
MAJOR OBSERVATION STATION No. 13
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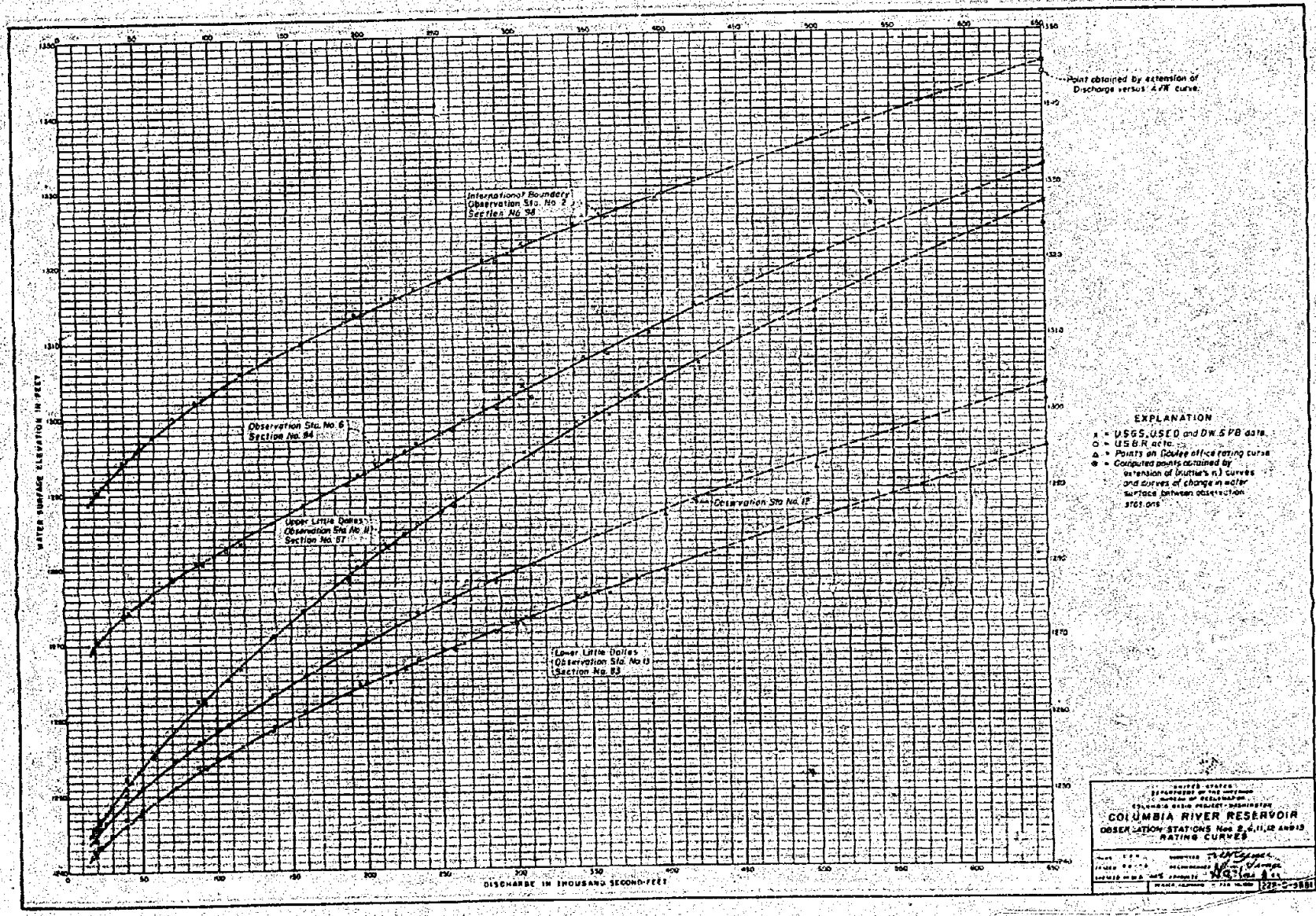
COLUMBIA BASIN PROJECT-WASHINGTON
COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
LOCATION MAP



Point obtained by extension of Discharge versus AVW 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
WATER SURFACE ELEVATION IN FEET
DISCHARGE IN THOUSAND SECOND-FEET
EXPLANATION
x = USGS, USED and DW.S.P.B. data.
o = USBR data.
Δ = Points on Goulee office rating curve
● = Computed points obtained by extension of (Mutter's n.) curves and curves of change in water surface between observation stations
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COLUMBIA BASIN PROJECT-WASHINGTON
COLUMBIA RIVER RESERVOIR
OBSERVATION STATIONS Nos 2, 6, 11, 12 AND 13
RATING CURVES

FIGURE 2

MILES FROM INTERNATIONAL BOUNDARY

WATER SURFACE ELEVATION

1350
1340
1330
1320
1310
1300
1290
1280
1270

0 1 2 3 4 5 6 7 8 9 10 11 12 13

ZONE 4

1 = 1347.01
Nat = 1346.00
5 = 1342.98
Backwater, Natural Channel

1 = 1337.71
Nat = 1336.00
5 = 1334.91
Backwater, Natural Channel
Computed Natural Flow
Backwater, Improved Channel

1 = 1330.78
Nat = 5 = 1329.10
Backwater, Natural Channel
Computed Natural Flow
Backwater, Improved Channel

1 = 1323.35
5 = 1322.38
Nat = 1321.70
Backwater, Natural Channel
Backwater Improved Channel = Natural Flow For Q = 400,000 Sec. ft.

1 = 1316.44
5 = 1315.05
Nat = 1313.65
Backwater, Natural Channel
Natural Flow
Backwater, Improved Channel

1 = 1305.59
5 = 1305.33
Nat = 1303.40
Backwater, Natural Channel
Natural Flow
Backwater, Improved Channel
Natural Flow

Q = 650,000
Computed Natural Flow
Q = 500,000
Computed Natural
Q = 400,000
Q = 300,000
Q = 200,000
Q = 100,000
Q = 200,000
Natural Flow
Q = 100,000

INTERNATIONAL BOUNDARY

Sec. 98 Gage 2
Sec. 97 Gage 3
Sec. 96 Gage 4
Sec. 95 Gage 5
Sec. 94 Gage 6
Sec. 93 Gage 7
Sec. 92 Gage 8
Sec. 90 Gage 9

EXPLANATION

SYMBOL	CURVE NUMBER	RATING CURVE USED a SEC. 83	n's USED IN ZONE No. 4	3	2	FORMULA USE IN ZONE 4	3	2	CHANNEL CONDITION AT LITTLE DALLES
—o—	1	Coulee Office	Natural	Natural	Back-water	Kutter's	Kutter's	Manning's	Natural
—□—	5	Coulee Office	Natural	From Model	Back-water	Kutter's	From Model	Manning's	Improved
—×—		Natural flow from field obs. to 420,000	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. yd. along left bank to El. 1255.00

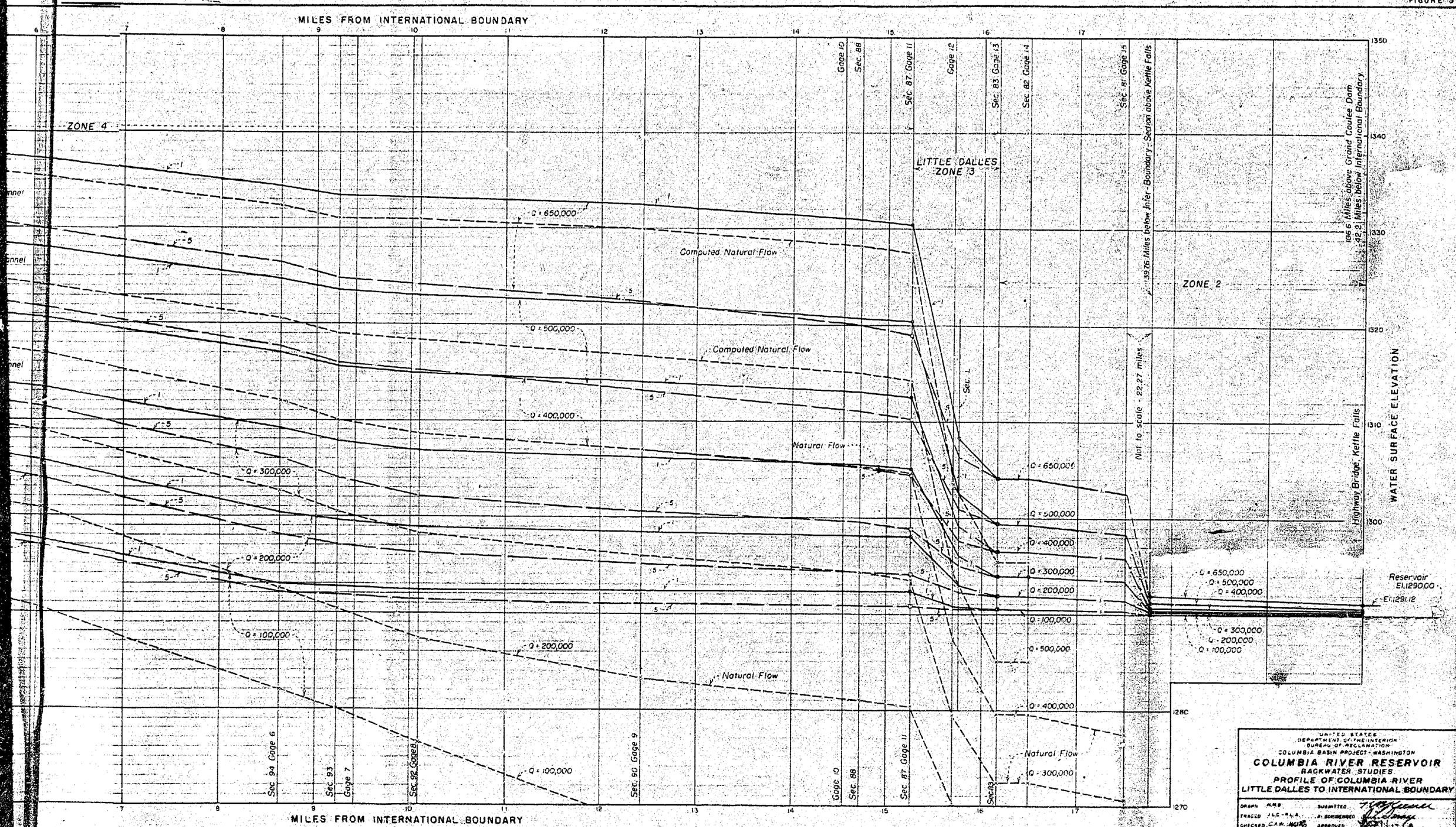
Natural flow n's are those computed from the gage-discharge curves for natural flow.

Having plotted natural flow n's against mean W.S. E'. in each reach, backwater n's are those values of n taken from these curves corresponding to the mean W.S. El. for backwater curves.

All backwater profiles are for W.S. El. 1290.00 at dam.

Symbols indicate computed or observed points.

FIGURE 3



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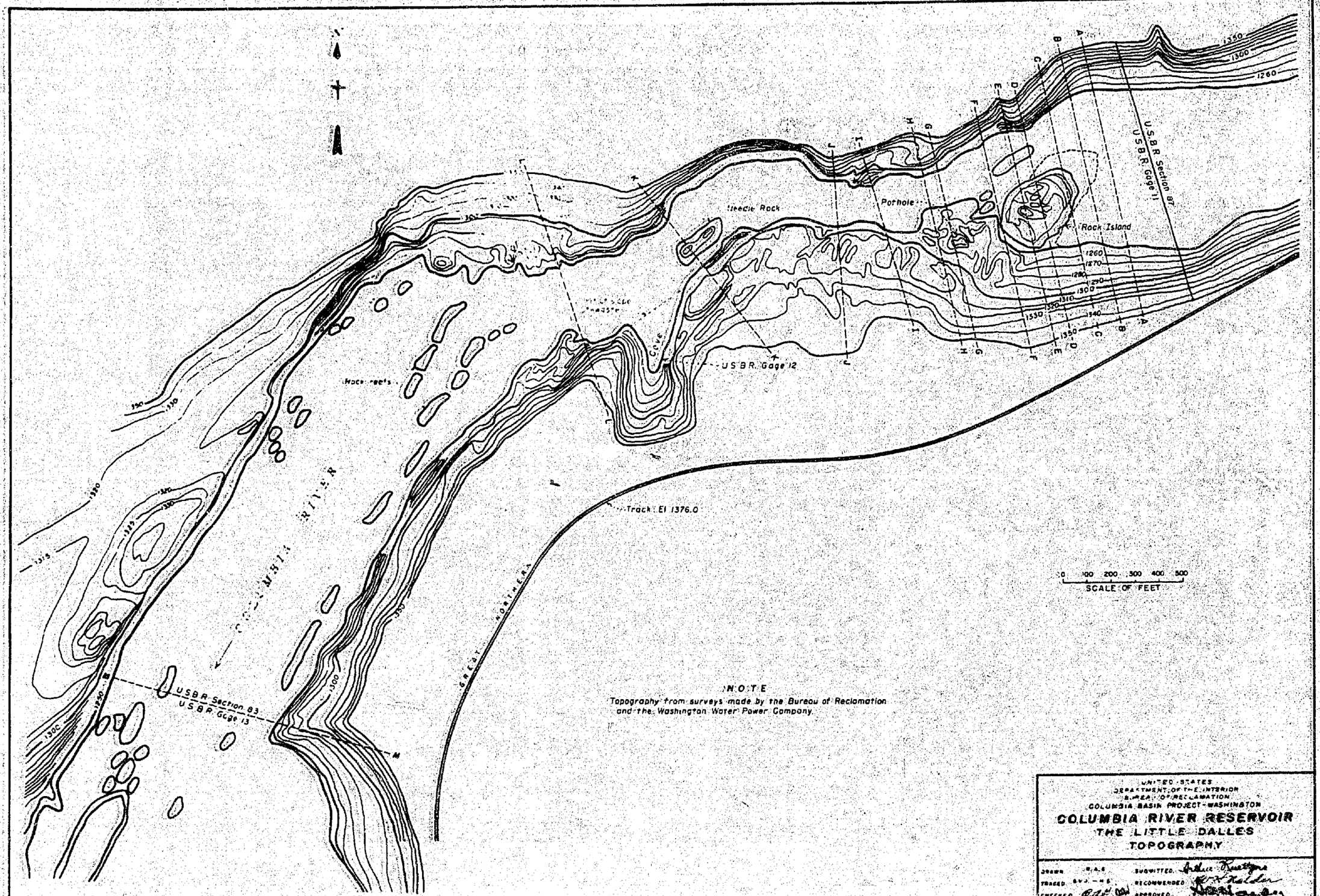
COLUMBIA BASIN PROJECT - WASHINGTON

COLUMBIA RIVER RESERVOIR
BACKWATER STUDIES
PROFILE OF COLUMBIA RIVER
LITTLE DALLES TO INTERNATIONAL BOUNDARY

DRAWN K.M.B. SUBMITTED
TRACED J.L.C.-R.L.A. RECOMMENDED
CHECKED C.A.W. APPROVED
DENVER, COLORADO MAY 23, 1940 222-D-5882

FIGURE 4



NOTE

Topography from surveys made by the Bureau of Reclamation and the Washington Water Power Company.

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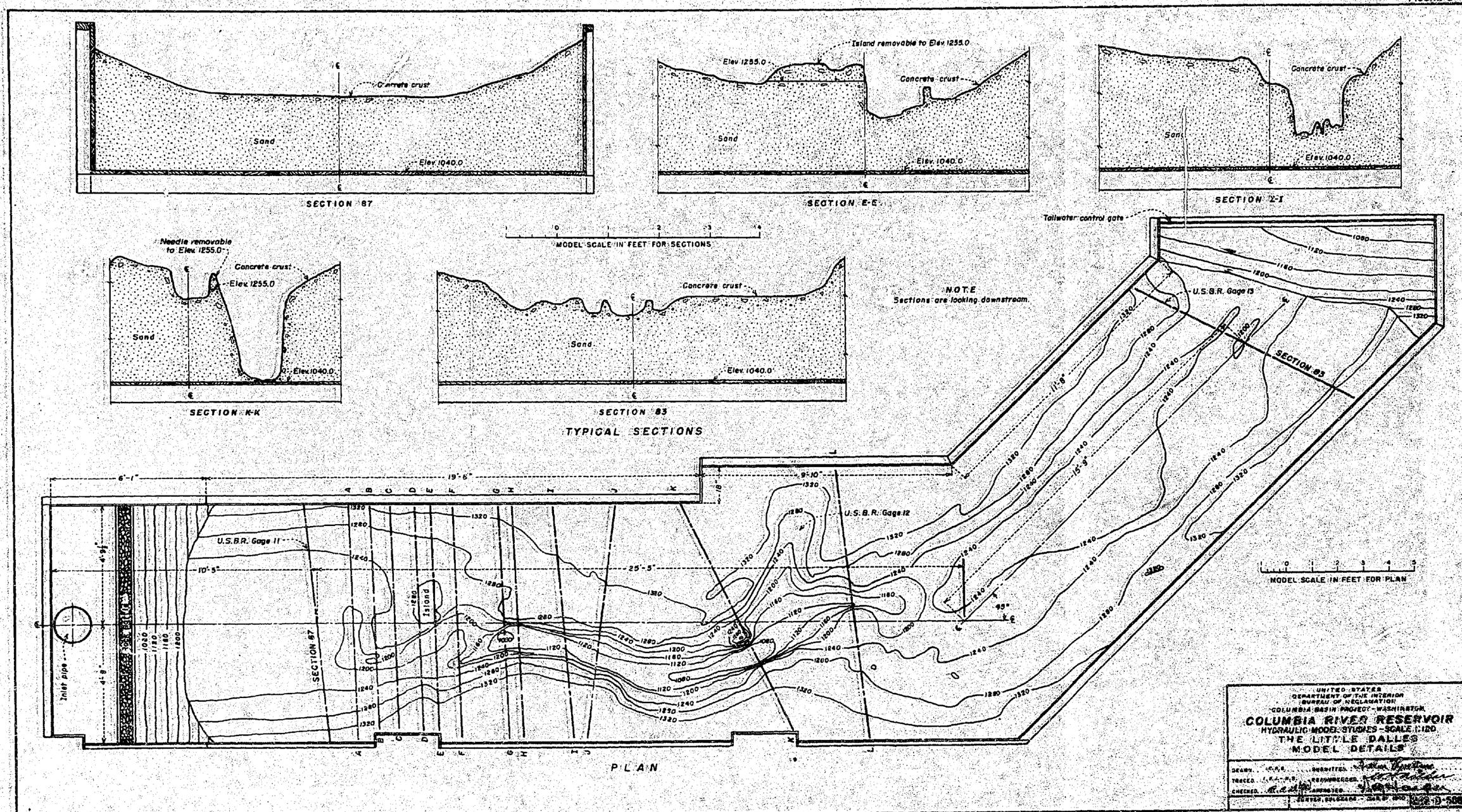
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON

COLUMBIA RIVER RESERVOIR
THE LITTLE DALLES
TOPOGRAPHY

DRAWN	R.A.S.	SUBMITTED	
TRACED	B.V.J. — H.E.	RECOMMENDED	
CHECKED		APPROVED	

DENVER, COLORADO — MAY 21, 1960 | 222-D-5685

FIGURE 5



SECTION 87
Concrete crust
Sand
Elev. 1040.0
SECTION E-E
Island removable to Elev. 1255.0
Elev. 1255.0
Concrete crust
Sand
Elev. 1040.0
SECTION Z-I
Concrete crust
Sand
Elev. 1040.0
MODEL SCALE IN FEET FOR SECTIONS
Needle removable to Elev. 1255.0
Concrete crust
Elev. 1255.0
Sand
Elev. 1040.0
SECTION K-K
Concrete crust
Sand
Elev. 1040.0
SECTION 83
TYPICAL SECTIONS
NOTE
Sections are looking downstream.
Tailwater control gate
U.S.B.R. Gage 13
SECTION 83
U.S.B.R. Gage 12
U.S.B.R. Gage 11
SECTION 87
Island
Inlet pipe
6'-1"
19'-6"
9'-10"
10'-5"
25'-5"
11'-8"
15'-9"
45°
MODEL SCALE IN FEET FOR PLAN
PLAN
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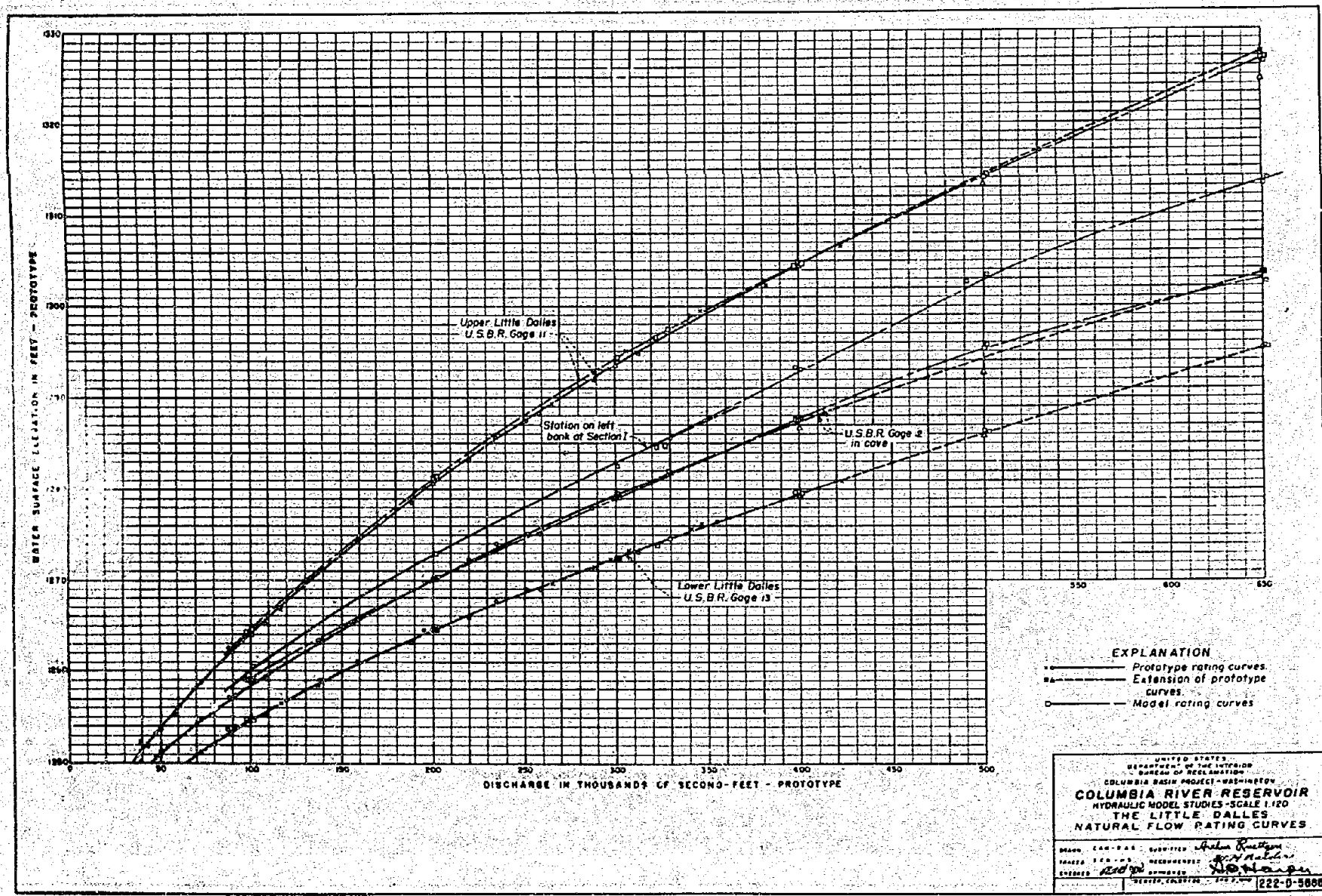
COLUMBIA BASIN PROJECT - WASHINGTON
COLUMBIA RIVER RESERVOIR
HYDRAULIC MODEL STUDIES - SCALE 1:120
THE LITTLE DALLES
MODEL DETAILS
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED



WATER SURFACE ELEVATION IN FEET - PROTOTYPE
DISCHARGE IN THOUSANDS OF SECOND-FEET - PROTOTYPE
Upper Little Dalles U.S.B.R. Gage 11
Station on left bank at Section I
U.S.B.R. Gage 2 in cove
Lower Little Dalles U.S.B.R. Gage 13
EXPLANATION
Prototype rating curves.
Extension of prototype curves.
Model rating curves
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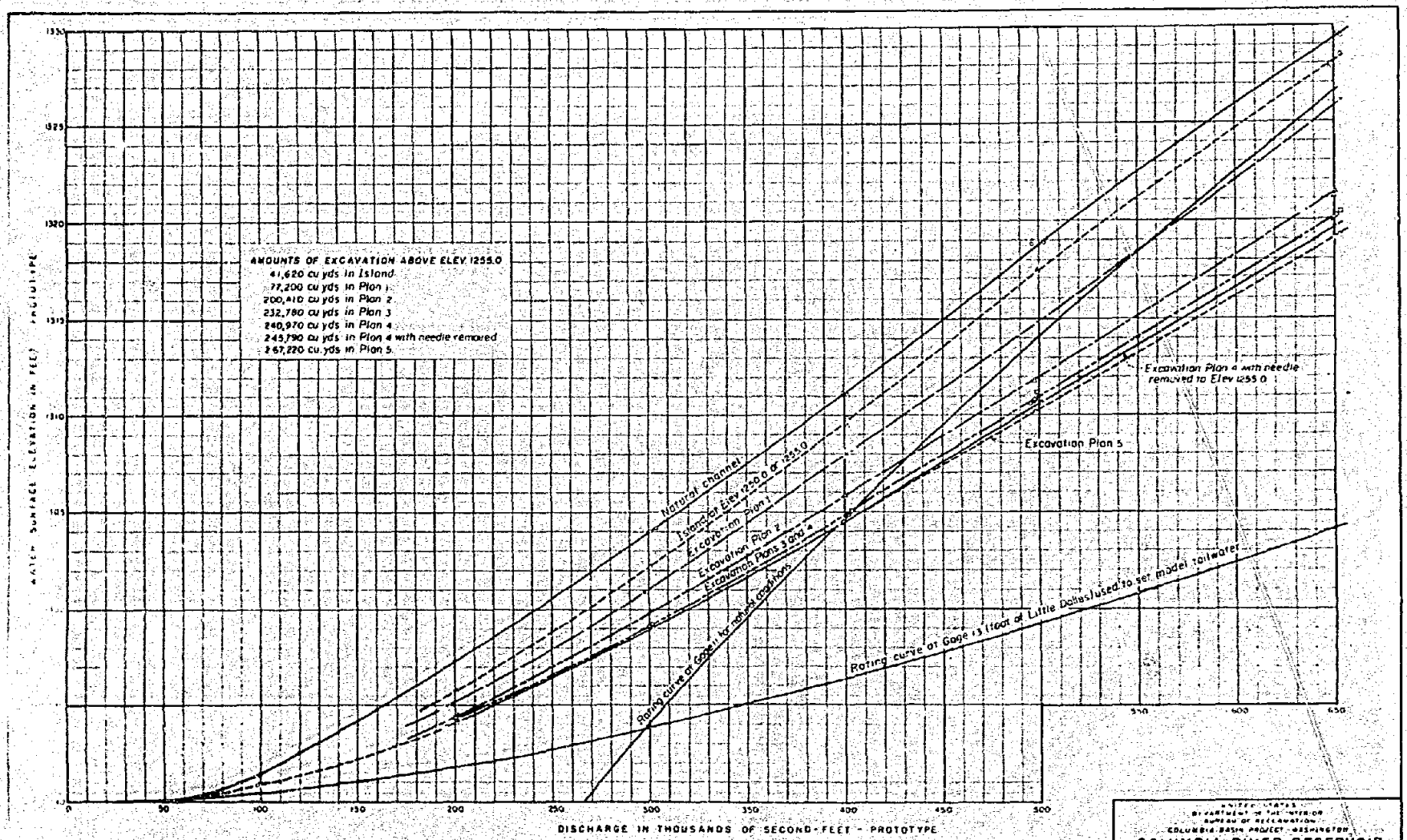
COLUMBIA BASIN PROJECT - WASHINGTON
COLUMBIA RIVER RESERVOIR
HYDRAULIC MODEL STUDIES - SCALE 1:120
THE LITTLE DALLES
NATURAL FLOW RATING CURVES
222-D-5666

FIGURE 6



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 BASIN PROJECT - WASHINGTON

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

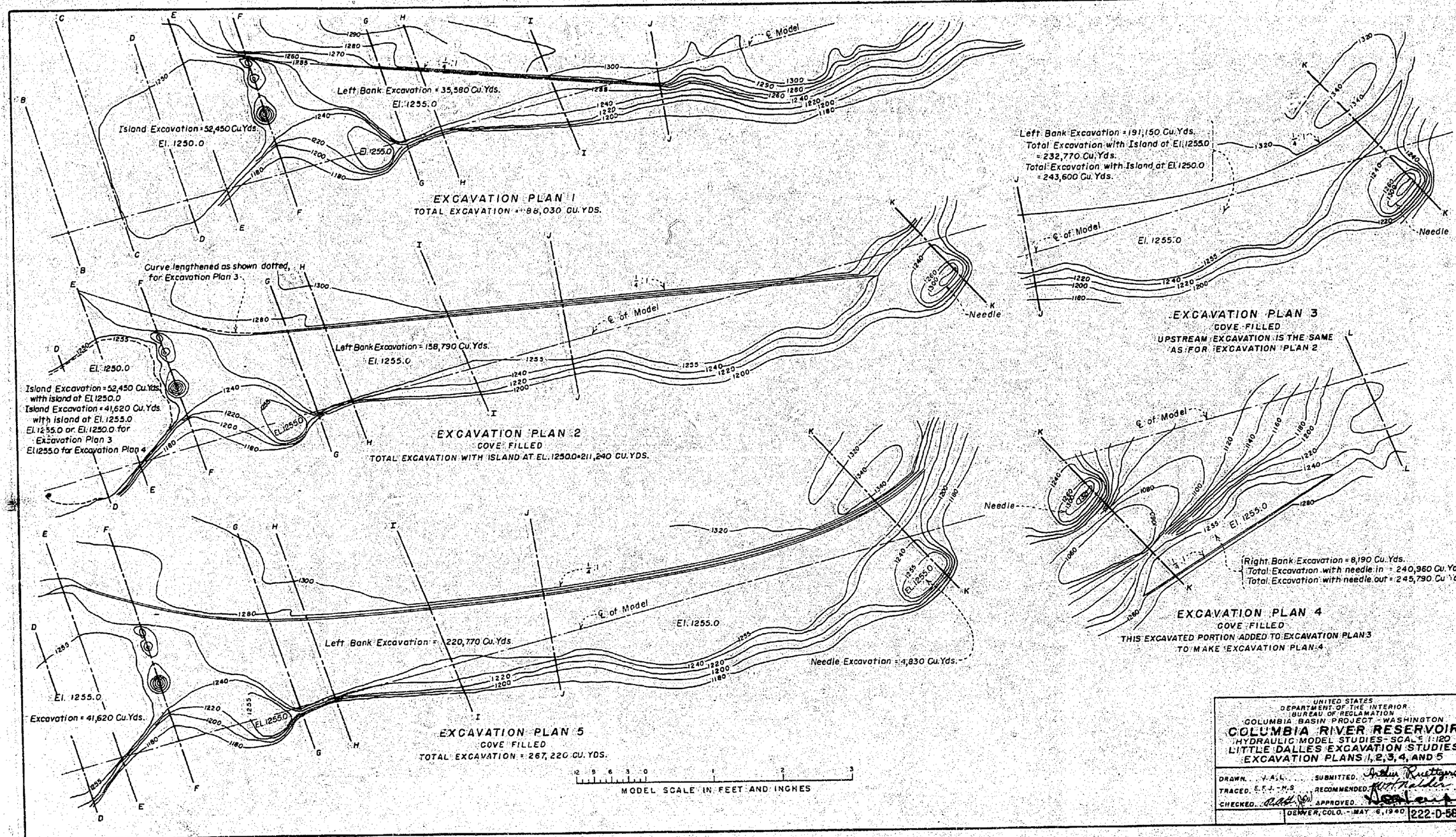
DRAWN
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED

DENVER, COLORADO

222-D-5893

FIGURE 7

FIGURE 8



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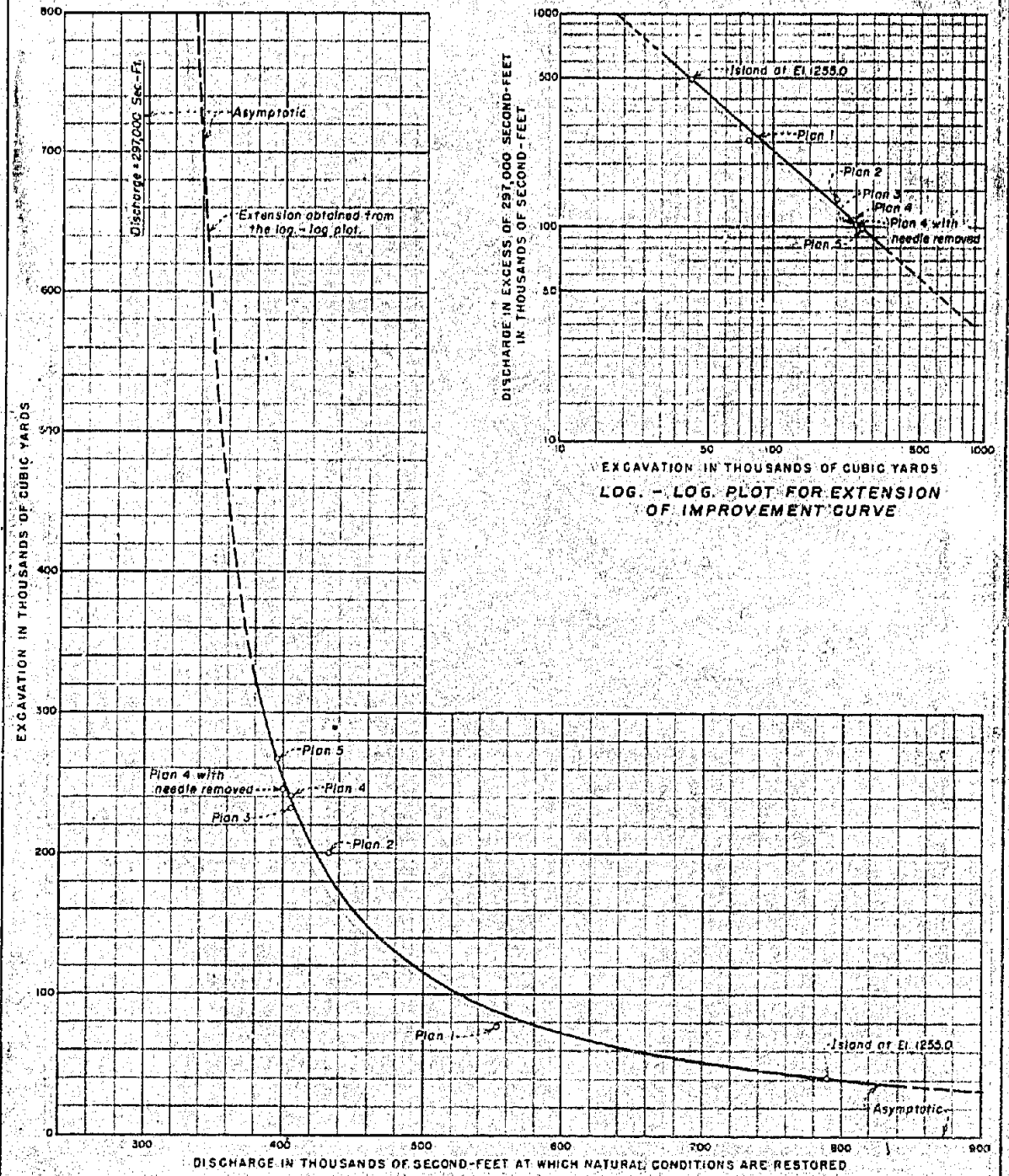
COLUMBIA BASIN PROJECT - WASHINGTON

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 Arthur Ruettgers
TRACED E.F.J.-H.S. RECOMMENDED W.H. Nalder
CHECKED R.A.H. APPROVED [signature]
DENVER, COLO. - MAY 6, 1940 222-D-5894

FIGURE 9



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

RAG 5-3-40

222-D-5895

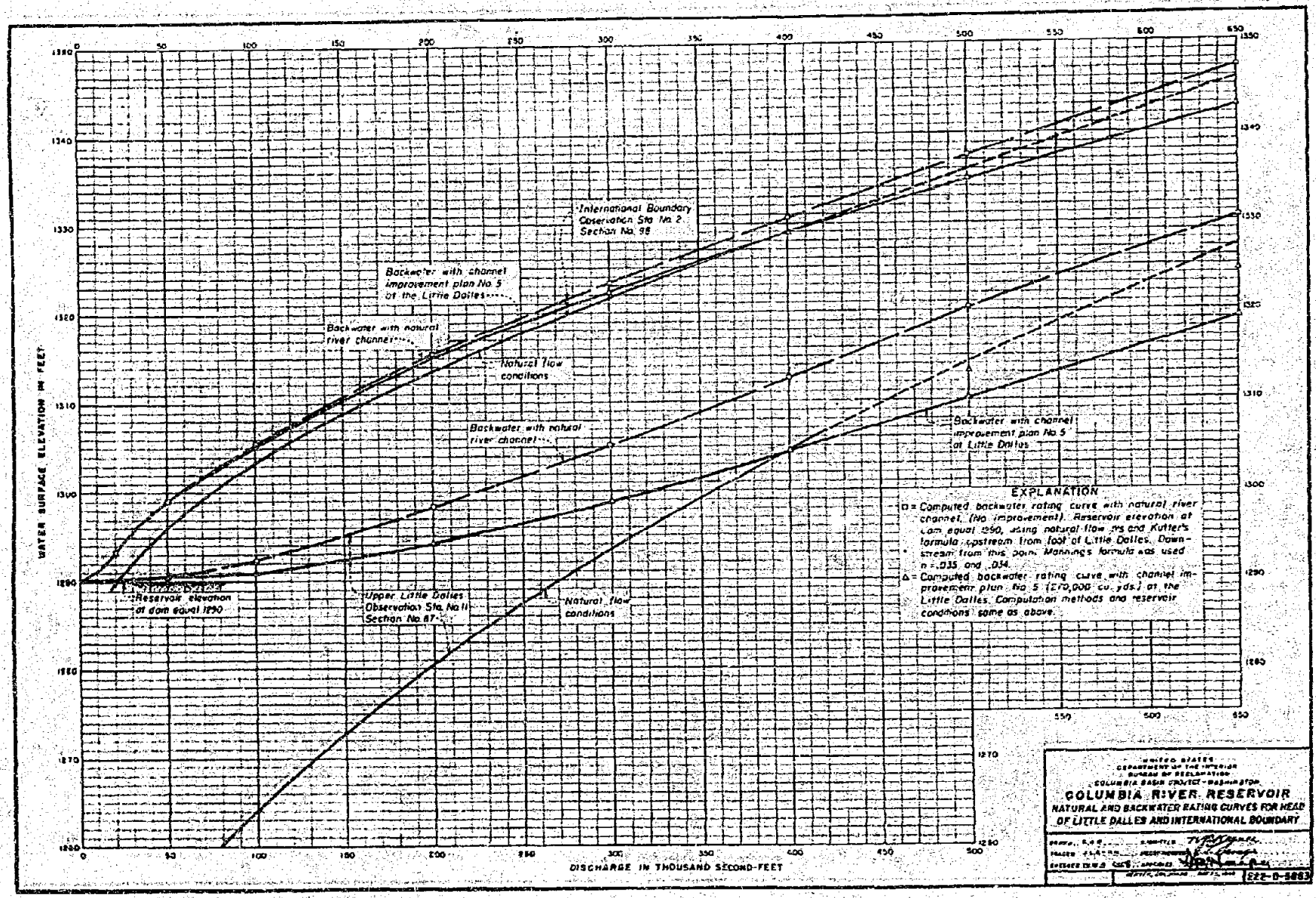
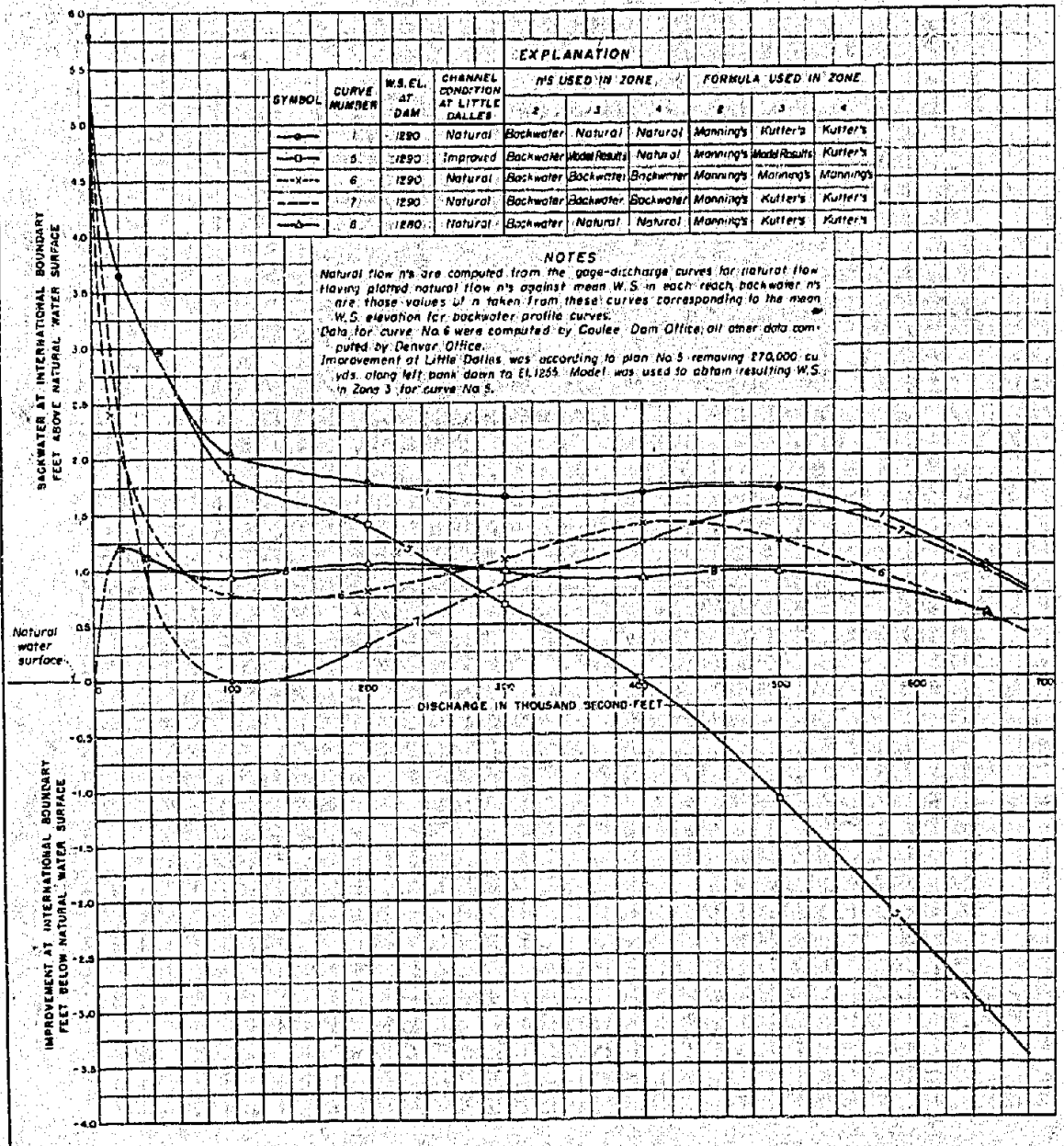

WATER SURFACE ELEVATION IN FEET
DISCHARGE IN THOUSAND SECOND-FEET
International Boundary
Observation Sta No 2
Section No 98
Backwater with channel improvement plan No 5 at the Little Dalles
Backwater with natural river channel
Natural flow conditions
Backwater with natural river channel
Backwater with 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 "n" and Kutter's formula upstream from foot of Little Dalles. Downstream from this point Manning's formula was used n = .035 and .034.
Δ = 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 - WASHINGTON
COLUMBIA RIVER RESERVOIR
NATURAL AND BACKWATER RATING CURVES FOR HEAD OF LITTLE DALLES AND INTERNATIONAL BOUNDARY
222-D-5883

FIGURE 10

FIGURE 11



EXPLANATION

SYMBOL	CURVE NUMBER	W.S. EL. AT DAM	CHANNEL CONDITION AT LITTLE DALLES	n's USED IN ZONE 2	n's USED IN ZONE 3	n's USED IN ZONE 4	FORMULA USED IN ZONE 2	FORMULA USED IN ZONE 3	FORMULA USED IN ZONE 4
—o—	1	1290	Natural	Backwater	Natural	Natural	Manning's	Kutter's	Kutter's
—□—	5	1290	Improved	Backwater	Model Results	Natural	Manning's	Model Results	Kutter's
—x—	6	1290	Natural	Backwater	Backwater	Backwater	Manning's	Manning's	Manning's
— —	7	1290	Natural	Backwater	Backwater	Backwater	Manning's	Kutter's	Kutter's
—△—	8	1280	Natural	Backwater	Natural	Natural	Manning's	Kutter's	Kutter's

NOTES

Natural flow n's are computed from the gage-discharge curves for natural flow. Having plotted natural flow n's against mean W.S. in each reach, backwater n's are those values of n taken from these curves corresponding to the mean W.S. elevation for backwater profile curves.

Data for curve No. 6 were computed by Coulee Dam Office; all other data computed by Denver Office.

Improvement at Little Dalles was according to plan No. 5 removing 270,000 cu. yds. along left bank down to El. 1255. Model was used to obtain resulting W.S. in Zone 3 for curve No. 5.

LOCATION OF ZONES

Zone No. 1 – Grand Coulee Dam to Kettle Falls Highway Bridge.
Zone No. 2 – Kettle Falls Highway Bridge to Foot of Little Dalles.
Zone No. 3 – Little Dalles.
Zone No. 4 – Head of Little Dalles to International Boundary.

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BACKWATER STUDIES
BACKWATER AND IMPROVEMENT AT INTERNATIONAL BOUNDARY

DENVER, COLORADO – MAY 30, 1952 — 1952-D-5864