HYDRAULIC LABORATORY
[redacted]

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

- - -

HYDRAULIC LABORATORY REPORT NO. 10

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LIMITS OF RIPRAP ON RIVER BANKS BELOW TAILRACES OF GRAND COULEE DAM COLUMBIA BASIN PROJECT

By

J. W. Ball
J. E. Warnock

- - -

Denver, Colorado

August 12, 1936

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

FORT COLLINS, COLORADO

August 10, 1936

MEMORANDUM TO CHIEF DESIGNING ENGINEER
(J. E. Warnock and J. W. Ball)

Subject: Limits of Riprap on River Banks below Tailraces of Grand Coulee Dam, Columbia Basin Project.

1. In compliance with your verbal instructions of June 5, in which you referred to item 8 of the report of the board of consulting engineers of April 6, 1936, the model of the ultimate development of the Grand Coulee Dam was reinstalled in the Fort Collins laboratory and actual testing was commenced on July 21.

2. The April 16 report of the board on this subject is as follows:

"Item 8 - Limits of Riprap on River Banks below Tailraces. In our study of this item, we have looked over, in such detail as time has permitted, the results of the Fort Collins model experiments bearing upon this problem. We have also inspected on the ground, the general condition of the banks between the dam and the highway bridge, especially on the west side of the river, taking note of the more recent fills along this bank, and their general condition as regards character of material and slope.

In the light of the results of these model experiments and in the exercise of our best judgment otherwise, we recommend as follows:

(1) On the west side of the river, riprap protection three feet in thickness, placed generally between the limits of elevation of 950 and 1000 and extending for a minimum distance of 1500 feet downstream from the end of the present tailrace riprap.

(2) As a protection to the bank near and just above the highway bridge piers on the east side of the river, and especially as a safeguard against any cutting which might en-

danger pier No. 1, we recommend the present placing on the east bank, of riprap of the same thickness and between the same limits of elevation, from the bridge pier for a distance of 100 feet both upstream and downstream.

(3) We recommend the setting up of a model similar to that with which the studies thus far have been made, but of such length as to indicate the character of the flow for a distance of some 2500 feet downstream from the present riprap limit; and the conduct of such experiments as shall serve to indicate the character of the flow over a river stretch of this length, or approximately between the dam and the highway bridge. We recommend further that consideration be given to such additional riprap protection on either or both sides of the river as the results of these tests may indicate to be needful.

In connection with this riprap protection, we may note that, with the large amount of scaling which has developed as necessary in the east cofferdam and abutment areas, and from other excavations yet to be made, there will be available an abundance of rock for such purpose and for the placing of which it appears probable that arrangements can be made with the contractor at a low cost."

3. The model of the ultimate development of the Grand Coulee Dam to a scale ratio of 1:120 had been originally constructed to assist in the development of the protection at the toe of the dam, but had been dismantled to provide space for the study of the diversion of the Columbia River through the west cofferdam area. In the new installation about 5,000 feet of river bed downstream from the dam has been represented with the topography up to elevation 1075. Highway bridge piers 2 and 3 (fig.1), constructed of sheet metal, were included in the first two tests. The topography (plates 1 and 8) was molded in fine sharp-grained sand of which 100 percent passed a ten-mesh screen. The topography was replaced at the beginning of each test by the use of the profilograph which was especially designed and built in the laboratory for that purpose. The riprap, when used, was a hard crushed shale, screened and mixed to conform as nearly as possible to the rock size specified in a letter from Construction Engineer Banks to the Chief Engineer, dated October 3, 1935, which says:

"In response to the request in your letter of September 20 on the above subject, we would advise that the gradation in size of the riprap actually being used for the protection of the downstream side of the tailrace from the west powerhouse, is estimated as follows. Two estimates are given, one for rock excavated from the west abutment, and the other of rock excavated from the floor of the west foundation. The rock from the west abutment is broken up to smaller sizes, possibly because the breaking up effect of blasting is supplemented by a similar effect due to falling from the steep and high abutment.

	Rock from West Abutment	Rock from floor of West Foundation
Dust to $\frac{1}{4}$"	5%	2%
$\frac{1}{4}$" to 1 cu.ft.	40%	20%
1 cu.ft. to 1 cu.yd.	50%	70%
Over 1 cu. yd.	5%	8%

"

The riprap material used in the model had a net density of 151 pounds per cubic foot, with an analysis as shown on figure 2. A concrete slab was placed immediately below the bucket extending 360 feet downstream to represent the rock at the damsite.

4. Preliminary tests on this model were witnessed at the time of its completion by Engineers Hammond and Hornsby of the Denver office. In these preliminary tests, no riprap was placed on the slopes of the tailraces. With a flow of 250,000 second-feet over the spillway there was no movement of the sand along the river banks other than a slight settling caused by wave action along the shore. As the flow was increased, a large, slow-moving surface eddy developed in each tailrace resulting from an "ejector action" produced by the high-velocity water at the downstream ends of the spillway training walls. The eddies were responsible for severe erosion of the tailrace slopes at or near the water surface. These could be partly eliminated by operating all turbines in the powerhouses, but, since this is not practical it was not considered a feasible solution.

5. Upon the completion of the preliminary tests, the topography of the river bed was restored to its initial shape (plate 1). The tailrace slopes were covered with riprap ten feet thick at the base and three feet thick at the top near the powerhouse roadway. This is according to the original recommendations of the Board. Riprap limits for test 1 are shown on figure 3 (the downstream limit in the west tailrace was that determined by tests on the 1:120 Grand Coulee diversion model). The tailwater-discharge relationship was maintained during any increase or decrease in discharge. The gates were operated to maintain an approximate reservoir elevation of 1288. The tailwater elevation, observed immediately upstream from the highway bridge, was regulated according

to the rating curve on figure 4, which was also used for previous tests on this same model. Each test was divided into four runs with discharges of 250,000, 500,000, 750,000 and 1,000,000 second-feet. The following table was adhered to in making the tests and the river bed was not disturbed between runs.

Discharge Sec. Ft.	Model time to attain Discharge *		Duration of Discharge				
			Model		Prototype		
	Hours	Minutes	Hours	Minutes	Days	Hours	Minutes
250,000	0	22	2	0	0	21	55
500,000	0	40	3	0	1	8	52
750,000	0	52	5	0	2	6	46
1,000,000	1	0	7	0	3	4	41

* The same times were used in reducing to zero discharge.

6 Cross-sections were taken at various points along the river for all runs except that with a flow of 250,000 second-feet. These sections are shown on figures 5 to 12 inclusive. Briefly, the results of test 1 are as follows:

(a) Flow - 250,000 second-feet (plate 7A). During a run of two hours on the model the riprap was not disturbed or the banks noticeably eroded. The usual rearranging of the river bed occurred exposing the rock surface at a point 180 feet downstream from the right end of the spillway. The top of the mound in this vicinity (figure 3) was moved a short distance downstream.

(b) Flow - 500,000 second feet. After a run of three hours the erosion increased downstream from the bucket. The wave action attacked the river banks but soon reached a stage of stability, ceasing to do further damage. The tailrace riprap was disturbed but was not carried away (plates 4B and 5B) and slight erosion occurred at the bridge piers (plate 6B).

(c) Flow - 750,000 second-feet. The wave action became more severe and considerable erosion occurred along the river banks, particularly where they were steep (plate 2). The continuity of the tailrace riprap was broken by the wave action and a return flow along the bank deposited very fine sand on the slopes in front of the powerhouses (plates 4C and 5C). A portion of the riprap at the foot of the tailrace slopes was disturbed and deposited immediately downstream from the lip of the bucket (plate 2). Erosion at the bridge increased exposing the top of the rectangular footing of pier 3 (plage 6C). The length of the run was five hours (model time).

(d) Flow - 1,000,000 second-feet. Very severe erosion occurred for this discharge. The run at this discharge was terminated after a seven-hour period, as movement of the bed material, except that caused by wave action (plate 7B) practically ceased. The tailrace slopes were seriously eroded and large piles of sand were deposited in front of the powerhouses, (plates 4D and 5D) but no sand was deposited in the draft tubes. Erosion of river banks near the highway bridge piers was severe but did not expose the tops of the two footings (plate 6D).

7. The thickness of tailrace riprap according to the present design is insufficient for floods greater than 500,000 second feet. To protect the river banks immediately below the tailraces for floods of this magnitude, it appears to be necessary to extend the riprap at least 500 feet downstream. Riprapping of the river bank behind highway bridge pier 2 is necessary for the protection of pier 1. After careful study of the results obtained from test 1, particularly those for the maximum discharge, Engineers Hammond and Hornsby recommended increasing the thickness of the riprap as well as an extension downstream. The riprapping of both tailraces (figure 3) was extended to the end of the $2\frac{1}{2}$:1 excavated slope and a uniform thickness of six feet was used between elevation 960 and the edge of the roadway and to a limit of elevation 1050 at the lower end. The other limits of this thickness were the point of curvature of the 3:1 slope and the end of the $2\frac{1}{2}$:1 excavated slope. From the point of curvature on the 3:1 slope, the space occupied by the added rock was triangular in shape reaching the original thickness of three feet near the abutment end of each tailrace as indicated on figure 3. The east powerhouse roadway was placed on a four percent grade to protect it from the wave action during large floods. The right bank at the highway bridge was riprapped between elevations 930 and 1050 for a distance of 100 feet upstream and downstream from the nose and tail of pier 2. When these changes were incorporated in the model (plate 8) the same procedure was followed as for test 1. The results of test 2 indicated that the riprap was still insufficient to withstand the wave action at the higher discharges. Better conditions were prevalent, however, for discharges up to and including 750,000 second-feet (plates 9 to 14, incl., and figures 13 to 20, incl.). It is believed that additional thickness along the upper limits of the tailrace slope and the extension of the riprap to a point farther downstream would aid in resisting this erosion, but would not completely eliminate it. The three feet of rock on the right bank near pier 2 is sufficient protection for discharges up

to 750,000 second feet. Indications were that with a flow of 1,000,000 second-feet, erosion would endanger the end bridge piers (plate 14). It is intended to verify this belief by tests using a complete set of bridge piers. Design details of the end piers were not available until after the completion of test 2 thus preventing the inclusion of that data in this memorandum.

8. As a protection against the severe scour conditions and the high wave action prevalent in the stilling pool at the higher discharges, as indicated by the model, the following suggestions are made:

(a) Place riprap protection approximately five feet in thickness on the west river bank, between elevations 975 and 1030, extending approximately 1500 feet downstream from the end of the $2\frac{1}{2}$:1 excavated slope.

(b) Increase the thickness of the riprap on the west tailrace slopes, used in test 2, from six to ten feet, between elevations 975 and 1030, extending from a point 300 feet upstream from the curve connecting the 3:1 and the $2\frac{1}{2}$:1 slopes to the downstream end of the latter slope. It is believed that riprap thus placed should be bonded by mortar or some asphalt compound to make it more resistant to the severe wave action.

(c) Place riprap protection five feet in thickness on the east river bank between elevations 975 and 1030, extending approximately 500 feet from the downstream end of the $2\frac{1}{2}$:1 excavated tailrace slope. A small amount of additional excavation would be necessary to properly place this riprap.

(d) Increase the thickness of the riprap on the east tailrace slopes, used in test 2, from 6 to 10 feet, between elevations 975 and 1030, extending from a point 300 feet upstream from the curve connecting the 3:1 and the $2\frac{1}{2}$:1 slopes to the downstream end of the latter slope. It is believed that this riprap should also be bonded.

(e) Place riprap protection five feet in thickness in the vicinity of bridge piers 2 and 3 between elevations 950 and 1030, extending 100 feet upstream and 100 feet downstream from the extreme limits of the pier base.

9. All the features in paragraph 8 are being incorporated in the model at the present time including a complete set of bridge piers. The results will be forwarded to you before the conclusion of the meeting of the Board.

10. It is deemed advisable that you, and if possible the members of the Board, visit the laboratory in the near future to inspect the model in operation.

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J. E. Warnock

J. W. Ball

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
August 12, 1936

Laboratory Report No. 10
Hydraulic Laboratory
Compiled by: J. W. Ball
Reviewed by: J. E. Warnock

Subject: Limits of riprap on river banks below tailraces of Grand Coulee Dam - Columbia Basin Project.

1. Test 3, containing the features noted under paragraph 8 in our memorandum dated August 10, 1936, has just been completed and part of the data is presented herewith as a supplement to the progress report contained in that memorandum. Data corresponding to that taken for previous tests was obtained. Time does not permit its entire completion so as to reach you before the end of the board meeting and thus a short discussion, with pictures, will be presented at this time. Cross-sections of the river bed will be available in the near future and if requested can be furnished each member of the board.

2. The features, except parts (b) and (d), outlined in paragraph 8 of our memorandum dated August 10, 1936, were followed explicitly (plate 15). In parts (b) and (d) the thickness of riprap between the points of curvature of the 3:1 slope and a point 300 feet upstream was made variable instead of a uniform 10-foot thickness, figure 21, plates 19 A and 20 A. As this difference occurred within the region of bonded riprap this change had no effect on the results. Furthermore, if bonding is used the 10-foot thickness of riprap will not be necessary.

3. The results of test 3 are contained in the following discussion:

(a) Flow 250,000 second-feet. No movement of material was noted other than the usual rearranging of the river bed just downstream from the bucket.

(b) Flow 500,000 second-feet. The erosion immediately downstream from the bucket was increased. Some erosion due to the wave action was noted on both banks and immediately downstream from the sections of bonded riprap (plates 16, 19 B and 20 B). In general the conditions were the same as in tests 1 and 2 (plate 16).

(c) Flow 750,000 second-feet. With this discharge the riprap along the lower limits of the $2\frac{1}{2}$:1 excavated tailrace slopes was disturbed such that the bonded sections were undermined (plates 19 C and 20 C), otherwise the conditions along the tailrace slopes were much improved (plate 17). Slight improvement was also noted along the banks below the tailraces and in the vicinity of the bridge piers. A small slide, which was probably due to the steep slope, was noted near pier 4 and the west approach to the bridge (plate 21 C). Extension of the area of bonded riprap on the tailrace slopes would serve to prevent undermining at the lower edge.

(d) Flow 1,000,000 second-feet. Continued undermining of the bonded riprap sections was noted (plates 19 D and 20 D). The erosion became more severe but did not reach proportions comparable with those of test 1 and 2, (plate 18). Some sand was deposited on the tailrace slopes immediately downstream from the spillway end of both powerhouses (plates 19 D and 20 D). The riprap on the banks of the river at the ends of the highway bridge was not washed away. That near pier 1 settled slightly but was not overtopped (plate 21 D). Near pier 4 and the approach considerable settling was noted. The riprap settled below the water surface, sand was washed away and the footing exposed. The top of the rectangular base on pier 3 was also exposed.

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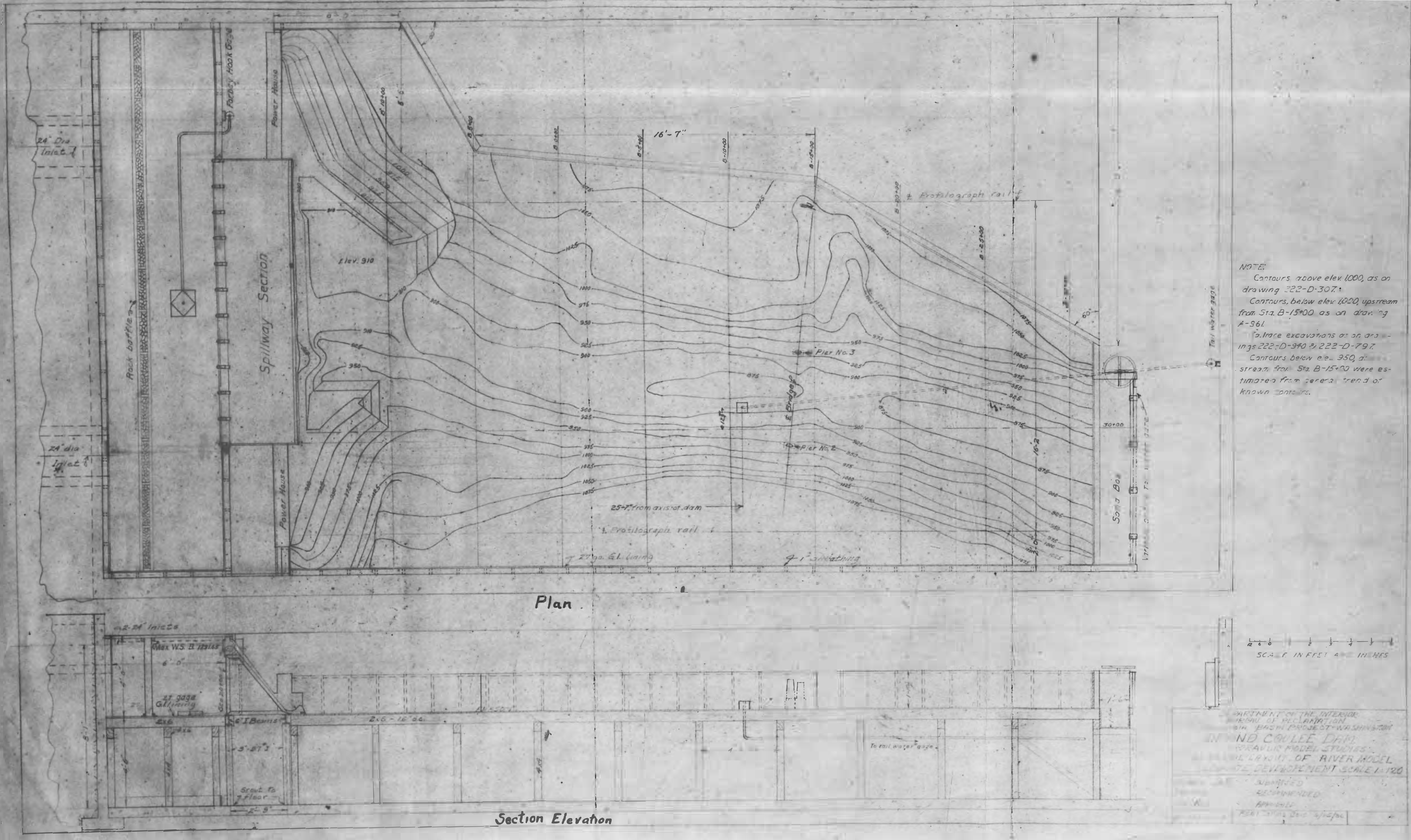
J. E. Warnock

J. W. Ball



24" Dia Inlet
24" dia Inlet
Rock baffles
Forbay Hook Gage
Power House
Spillway Section
Elev. 910
16'-7"
Pier No. 3
Pier No. 2
Bridge
Protilograph rail
25+7 from axis of dam
27 ga. G.I. lining
1" sheathing
Sand Box
Tail water gage
Plan
2-24" Inlets
Max W.S. El. 1231.65
6'-0"
27 gage G.I. lining
2x6
6" I Beams
2x6 - 16" oc.
To tail water gage
Grout to floor
Section Elevation
SCALE IN FEET AND INCHES
NOTE:
Contours above elev. 1,000, as on drawing 222-D-307.
Contours, below elev. 1,000, upstream from Sta. B-15+00 as on drawing A-961.
Contours below elev. 950, downstream from Sta. B-15+00 were estimated from general trend of known contours.
ND COULEE DAM
OF RIVER MODEL
SCALE 1:120
SUBMITTED
RECOMMENDED
APPROVED

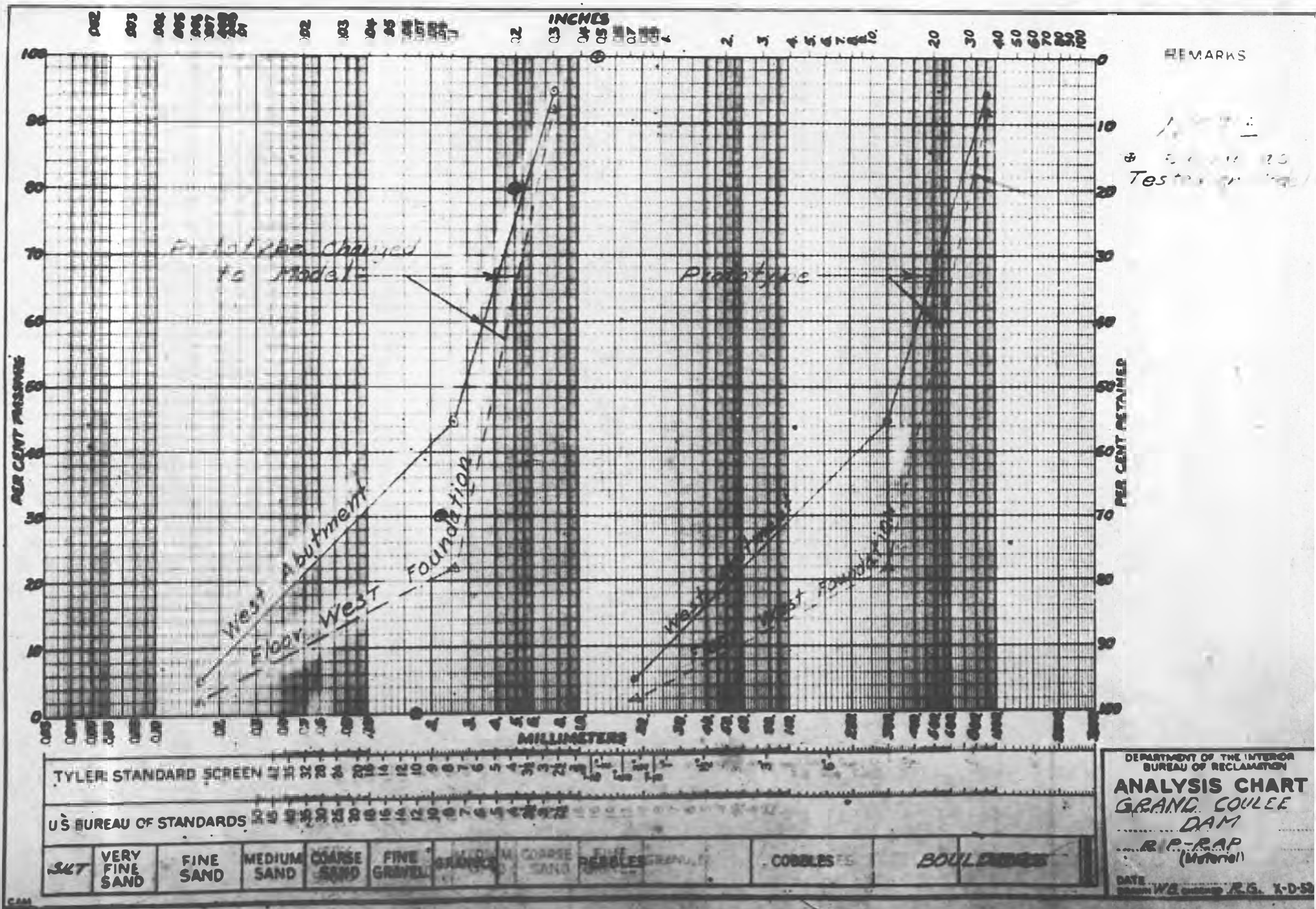

INCHES
MILLIMETERS
PER CENT PASSING
PER CENT RETAINED
REMARKS
Prototype changed to Model
Prototype
West Abutment
Floor West Foundation
West Foundation
TYLER STANDARD SCREEN
U.S. BUREAU OF STANDARDS
SILT
VERY FINE SAND
FINE SAND
MEDIUM SAND
COARSE SAND
FINE GRAVEL
COBBLES
BOULDERS
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
ANALYSIS CHART
GRAND COULEE DAM
RIP-RAP
(Material)
DATE
X-D-53

Fig. 3

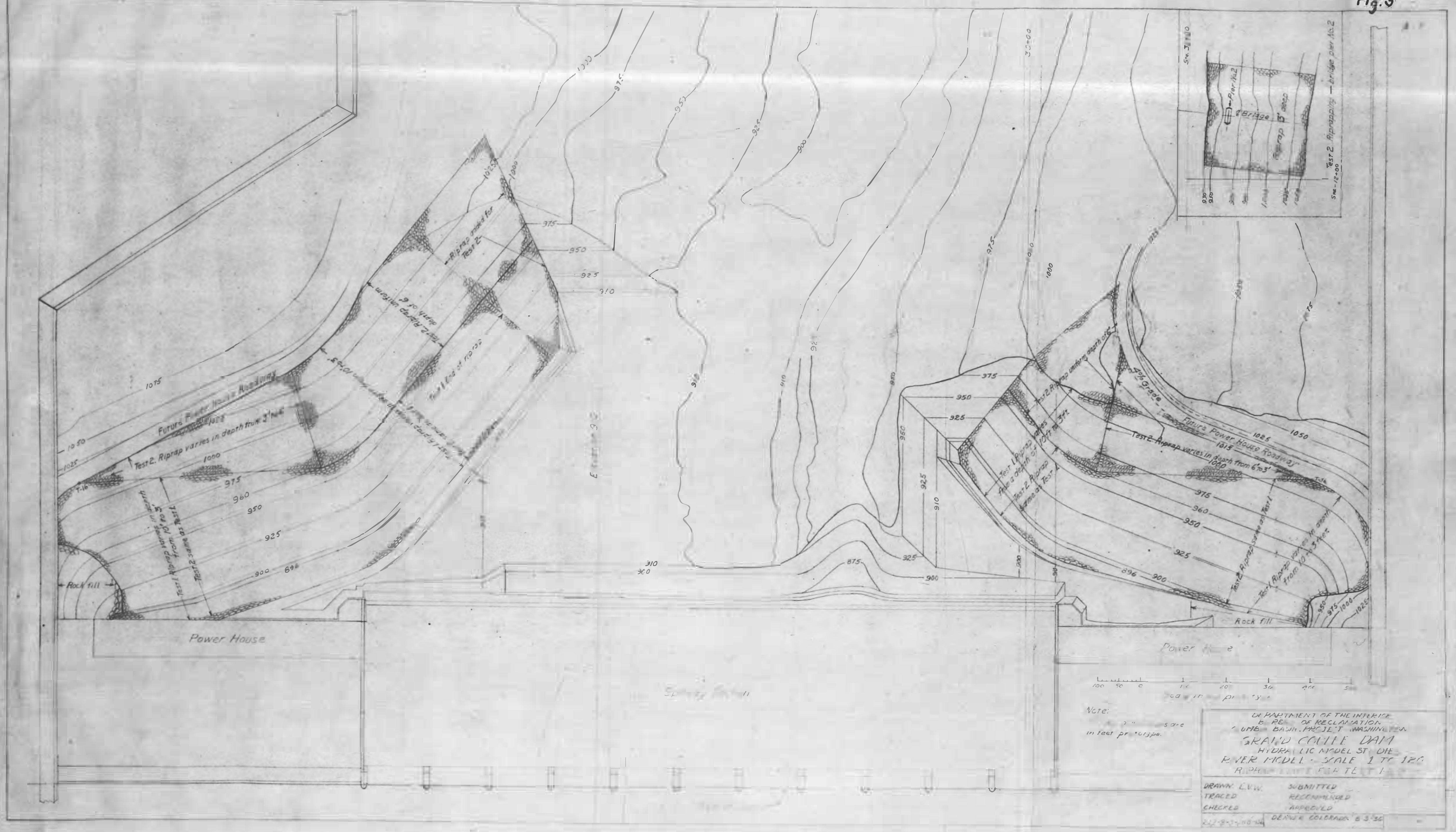

Test 2 Riprapping — bridge pier No. 2
Pier No. 2
Bridge
Riprap 5' deep
Riprap added for Test 2
Test 2, Riprap uniform depth of 6'
Future Power House Roadway
Test 2. Riprap varies in depth from 3' to 6'
Rock fill
Power House
Test 2. Riprap uniform depth of 6'
5% Grade
Test 2. Riprap varies in depth from 6' to 3'
Test 1 Riprap varies from a depth of 10 ft. to 3 ft.
Test 2 Riprap same as Test 1
Power House
Spillway Bucket
Note:
in feet prototype.
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT WASHINGTON
GRAND COULEE DAM
HYDRAULIC MODEL STUDIES
RIVER MODEL - SCALE 1 TO 120
DRAWN: E.V.W.
TRACED
CHECKED
SUBMITTED
RECOMMENDED
APPROVED
DENVER, COLORADO

FIG. 4

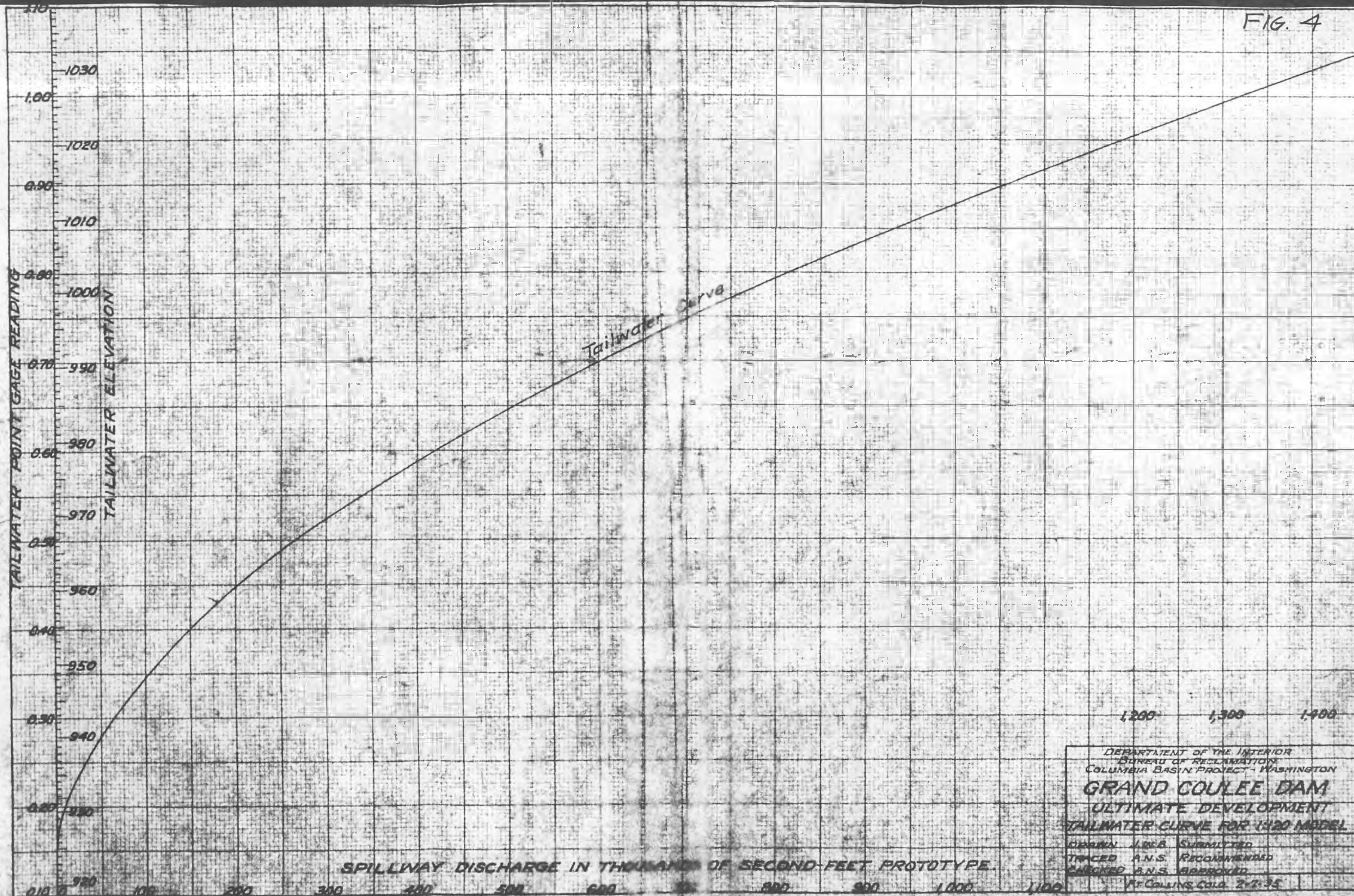
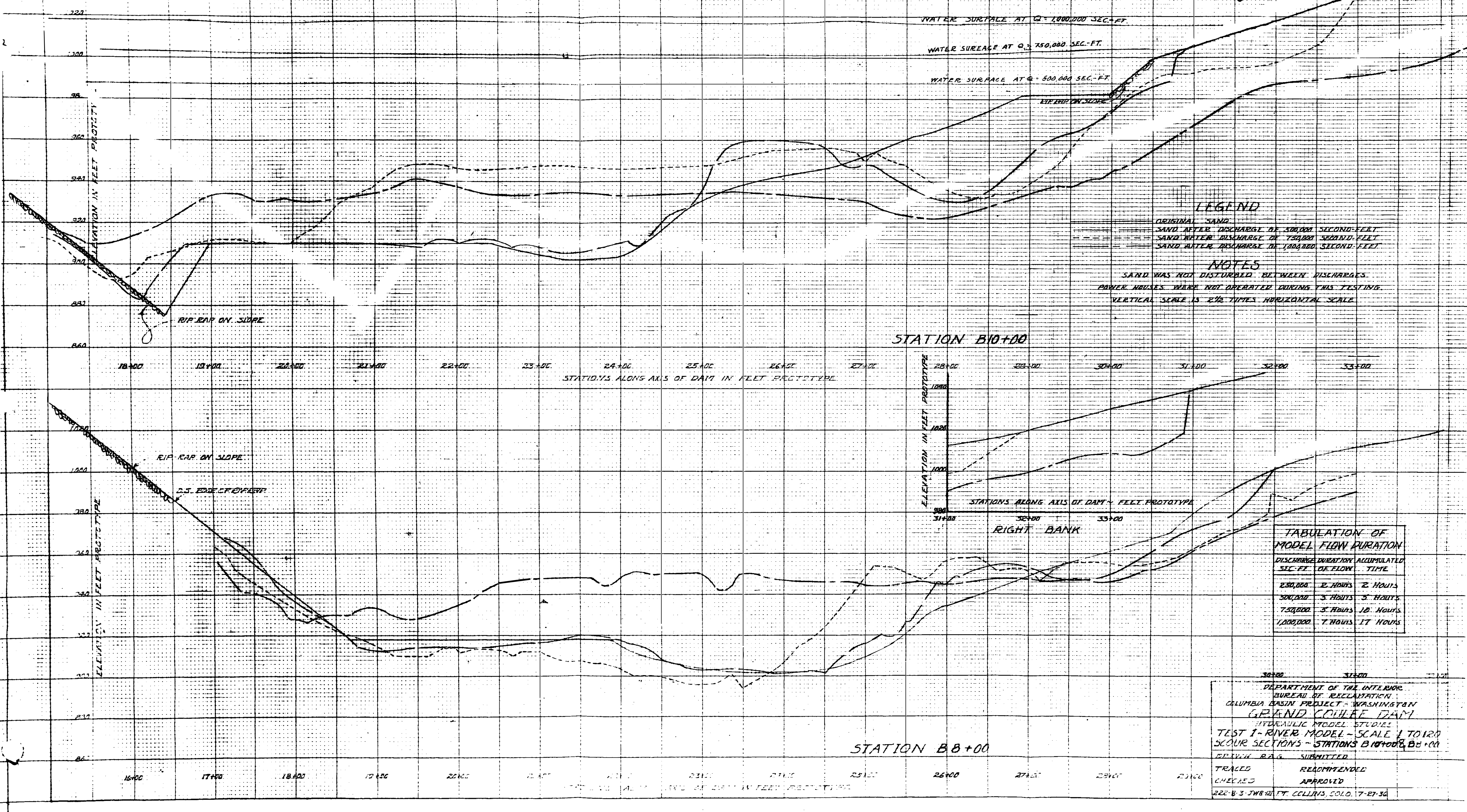
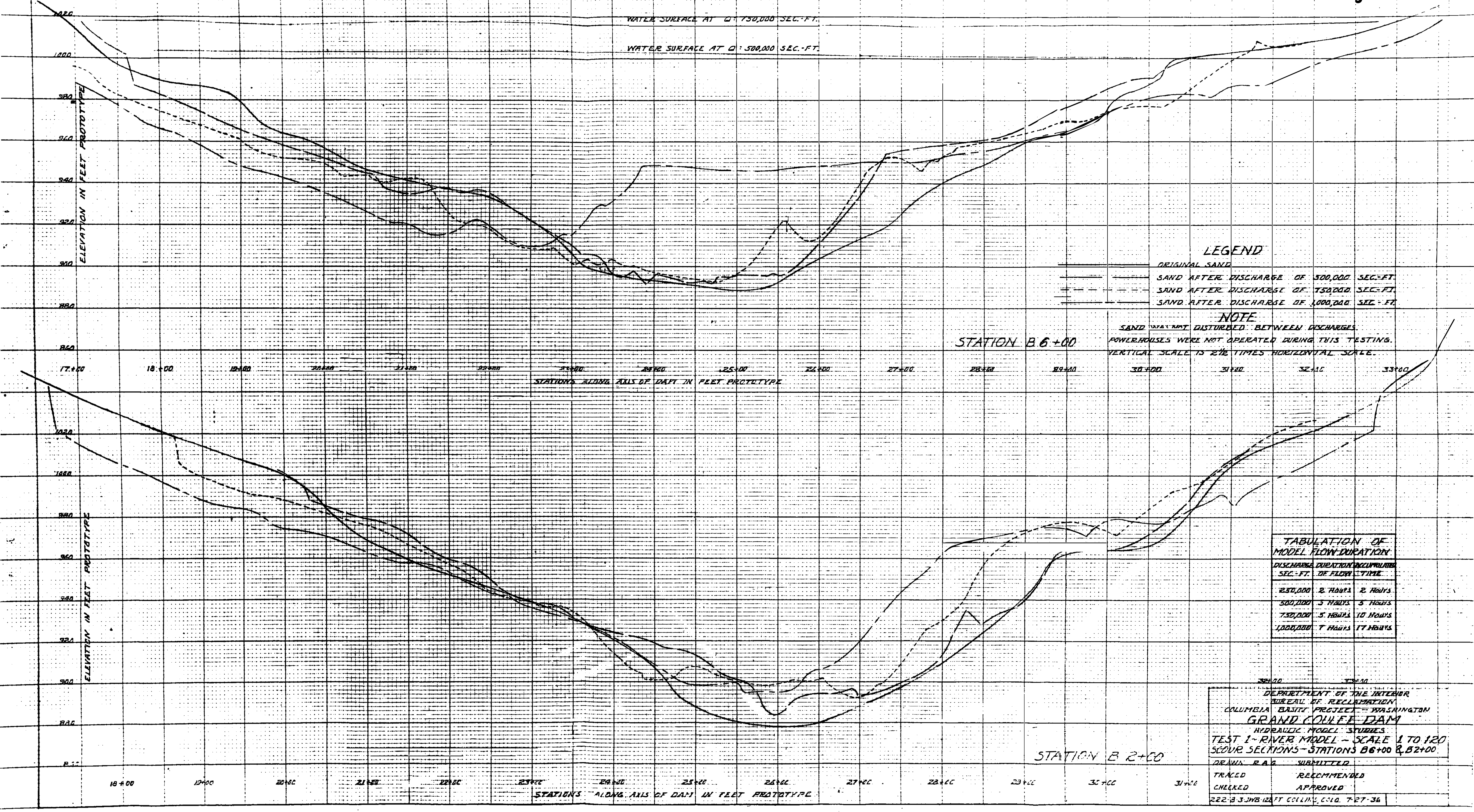

TAILWATER POINT GAGE READING
TAILWATER ELEVATION
Tailwater Curve
SPILLWAY DISCHARGE IN THOUSANDS OF SECOND-FEET PROTOTYPE
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON
GRAND COULEE DAM
ULTIMATE DEVELOPMENT
TAILWATER CURVE FOR 1:120 MODEL
DRAWN J.W.B. SUBMITTED
TRACED A.N.S. RECOMMENDED
CHECKED A.N.S. APPROVED
FT. COLLINS, COLO. 2-7-35

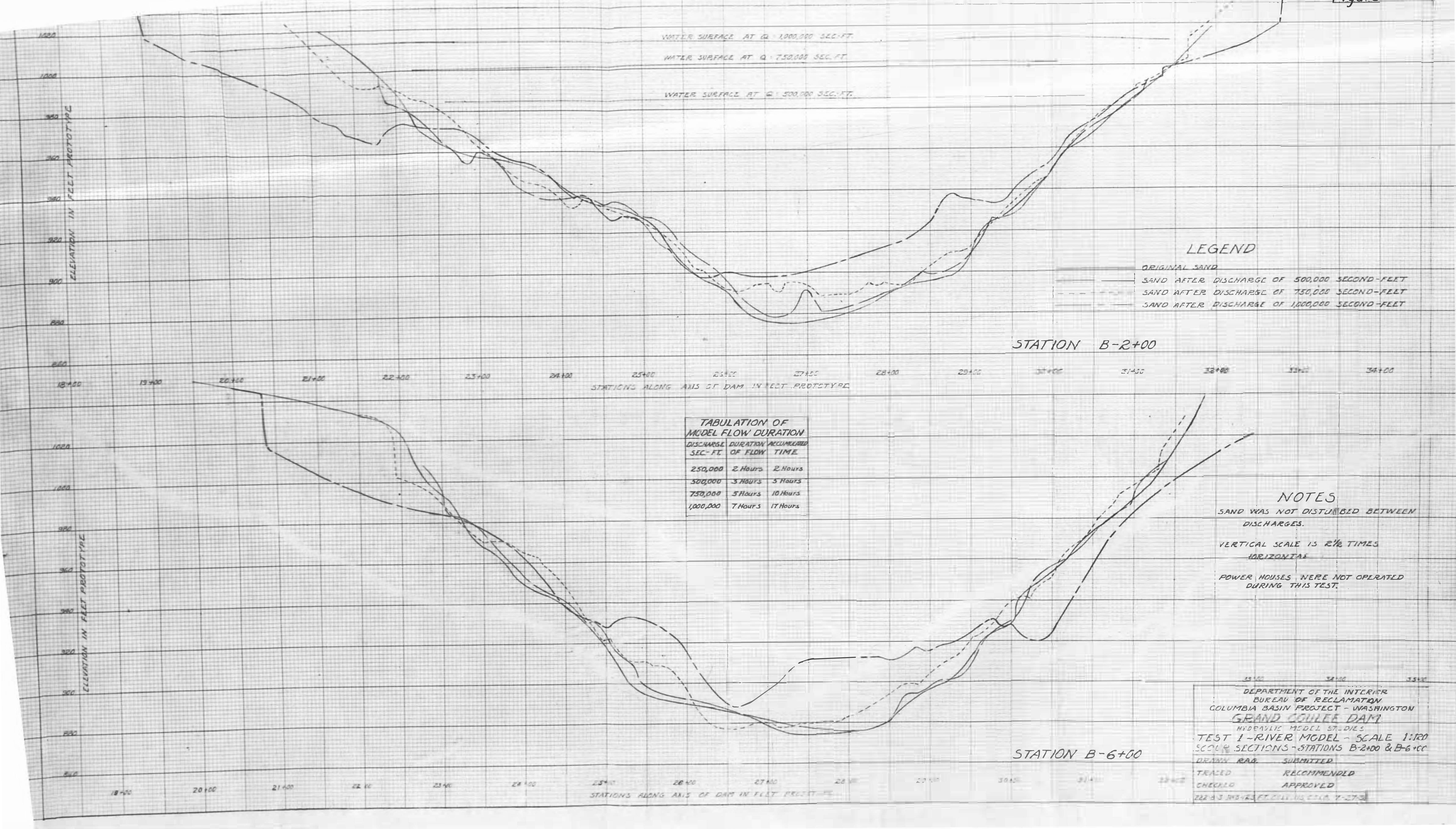
Figure 6



WATER SURFACE AT Q = 1,000,000 SEC.-FT.
WATER SURFACE AT Q = 750,000 SEC.-FT.
WATER SURFACE AT Q = 500,000 SEC.-FT.
RIPRAP ON SLOPE
ELEVATION IN FEET PROTOTYPE
RIP-RAP ON SLOPE
LEGEND
ORIGINAL SAND
SAND AFTER DISCHARGE OF 500,000 SECOND-FEET
SAND AFTER DISCHARGE OF 750,000 SECOND-FEET
SAND AFTER DISCHARGE OF 1,000,000 SECOND-FEET
NOTES
SAND WAS NOT DISTURBED BETWEEN DISCHARGES.
POWER HOUSES WERE NOT OPERATED DURING THIS TESTING.
VERTICAL SCALE IS 2½ TIMES HORIZONTAL SCALE
STATION B10+00
18+00
19+00
20+00
21+00
22+00
23+00
24+00
25+00
26+00
27+00
28+00
29+00
30+00
31+00
32+00
33+00
STATIONS ALONG AXIS OF DAM IN FEET PROTOTYPE
RIP-RAP ON SLOPE
D.S. EDGE OF RIPRAP
ELEVATION IN FEET PROTOTYPE
STATIONS ALONG AXIS OF DAM ~ FEET PROTOTYPE
31+00
32+00
33+00
RIGHT BANK
TABULATION OF MODEL FLOW DURATION
DISCHARGE SEC-FT. | DURATION OF FLOW | ACCUMULATED TIME
230,000 | 2 Hours | 2 Hours
500,000 | 3 Hours | 5 Hours
750,000 | 5 Hours | 10 Hours
1,000,000 | 7 Hours | 17 Hours
STATION B8+00
16+00
17+00
18+00
26+00
30+00
31+00
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON
GRAND COULEE DAM
HYDRAULIC MODEL STUDIES
TEST 1 - RIVER MODEL - SCALE 1 TO 120
SCOUR SECTIONS ~ STATIONS B10+00 & B8+00
DRAWN R.A.G.
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
222-B-3-JW8-12
FT. COLLINS, COLO.
7-27-36

Figure 7

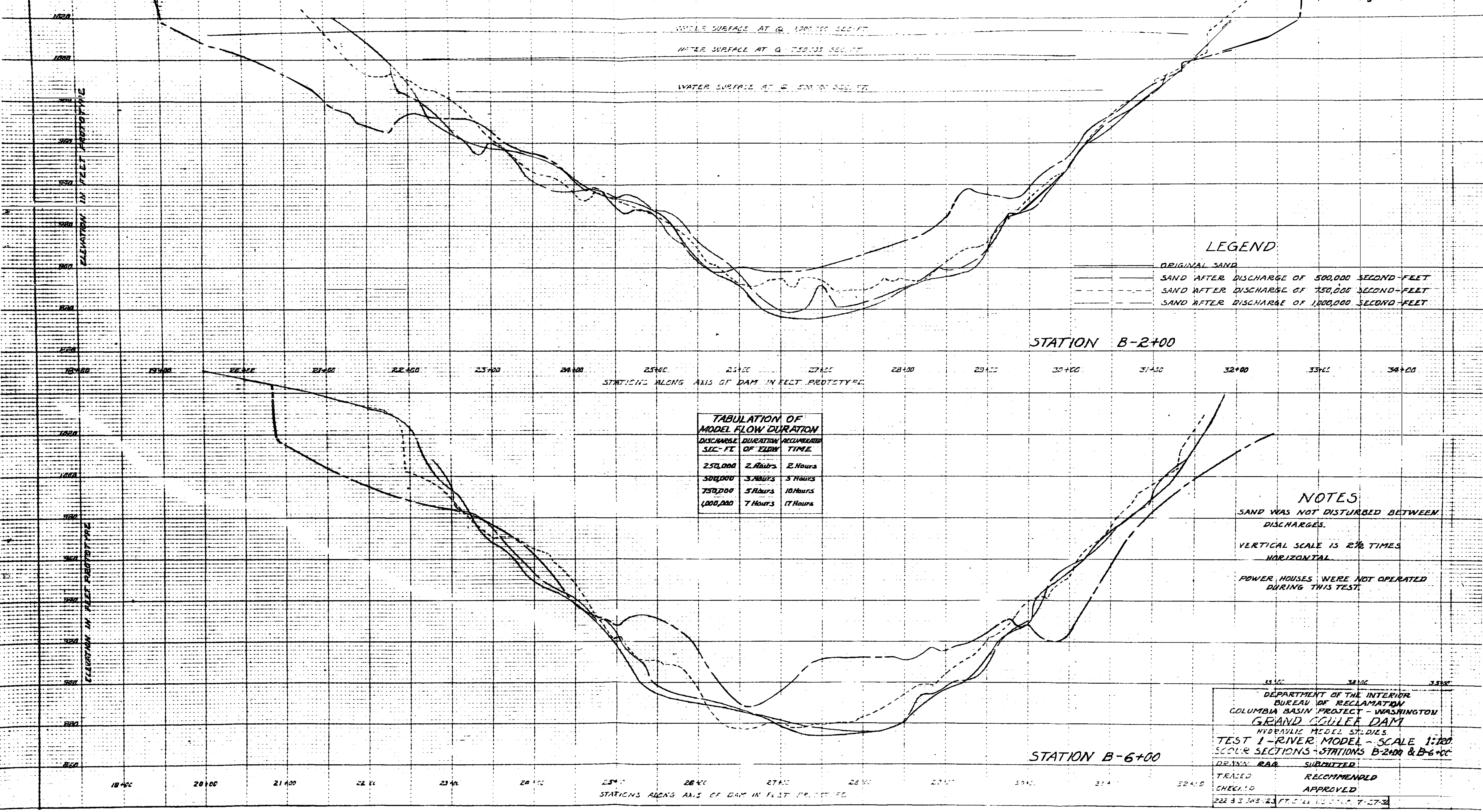

WATER SURFACE AT Q = 1,000,000 SEC.-FT.
WATER SURFACE AT Q = 750,000 SEC.-FT.
WATER SURFACE AT Q = 500,000 SEC.-FT.
ELEVATION IN FEET PROTOTYPE
STATIONS ALONG AXIS OF DAM IN FEET PROTOTYPE
LEGEND
ORIGINAL SAND
SAND AFTER DISCHARGE OF 500,000 SEC.-FT.
SAND AFTER DISCHARGE OF 750,000 SEC.-FT.
SAND AFTER DISCHARGE OF 1,000,000 SEC.-FT.
NOTE
SAND WAS NOT DISTURBED BETWEEN DISCHARGES.
POWERHOUSES WERE NOT OPERATED DURING THIS TESTING.
VERTICAL SCALE IS 2½ TIMES HORIZONTAL SCALE.
STATION B 6+00
STATION B 2+00
TABULATION OF MODEL FLOW DURATION
DISCHARGE SEC.-FT.
DURATION OF FLOW
ACCUMULATED TIME
250,000 2 Hours 2 Hours
500,000 3 Hours 5 Hours
750,000 5 Hours 10 Hours
1,000,000 7 Hours 17 Hours
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT – WASHINGTON
GRAND COULEE DAM
HYDRAULIC MODEL STUDIES
TEST 1 – RIVER MODEL – SCALE 1 TO 120
SCOUR SECTIONS – STATIONS B6+00 & B2+00
DRAWN R.A.G.
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
222-B-3 JWB-122 FT. COLLINS, COLO. 7-27-36



TABULATION OF MODEL FLOW DURATION

DISCHARGE SEC.-FT.	DURATION OF FLOW	ACCUMULATED TIME
250,000	2 Hours	2 Hours
500,000	3 Hours	5 Hours
750,000	5 Hours	10 Hours
1,000,000	7 Hours	17 Hours

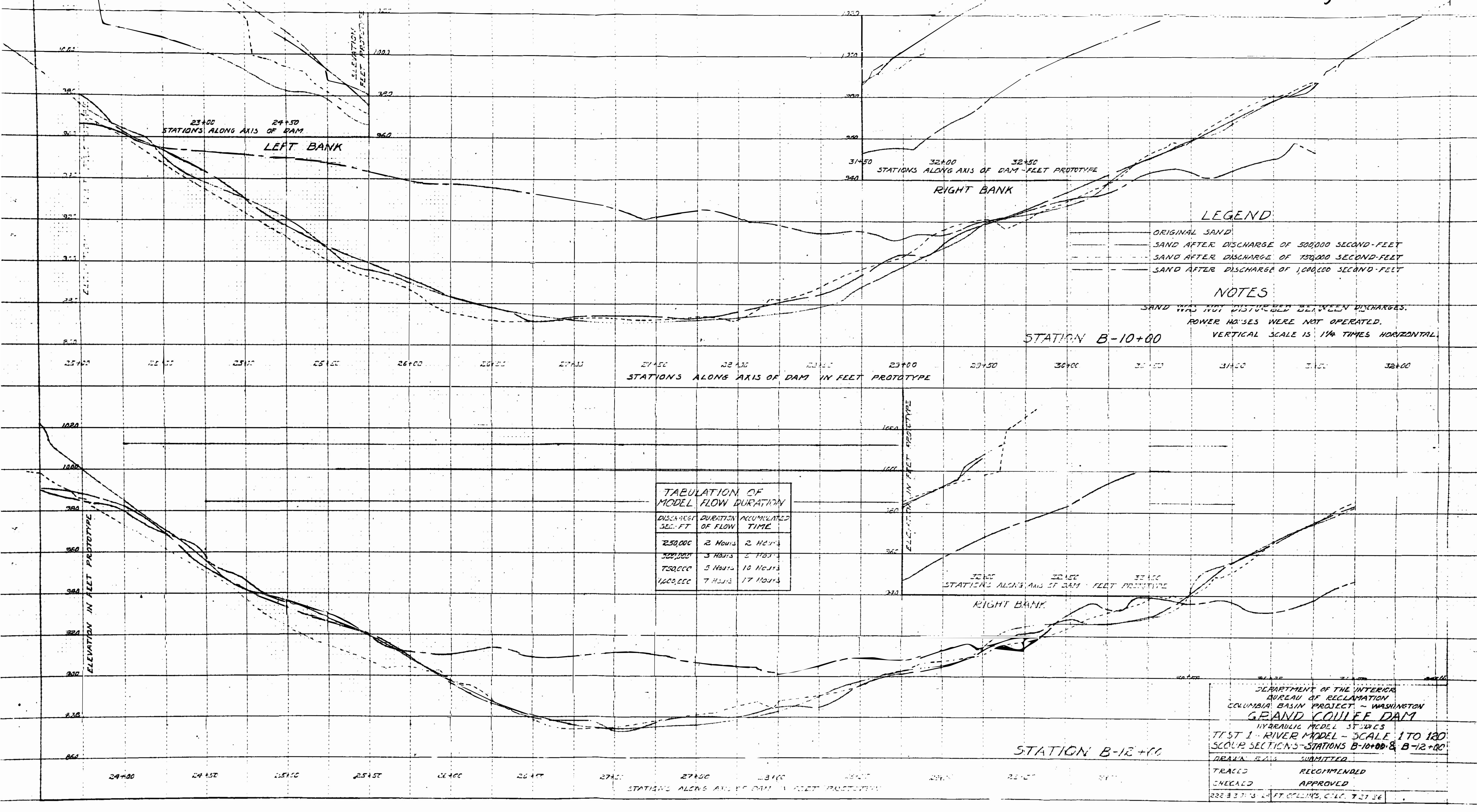
Figure 8



TABULATION OF MODEL FLOW DURATION

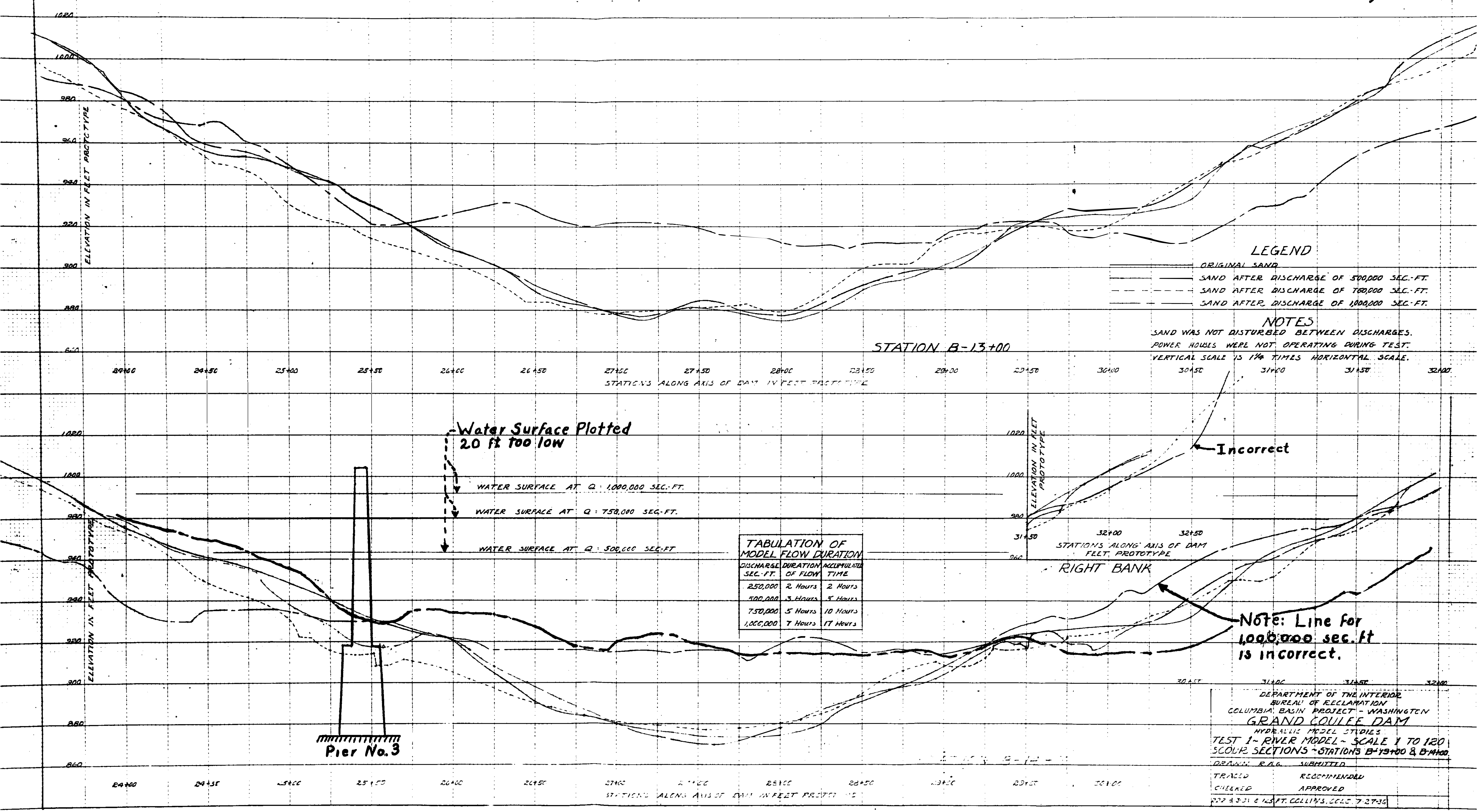
DISCHARGE SEC-FT.	DURATION OF FLOW	ACCUMULATED TIME
250,000	2 Hours	2 Hours
500,000	3 Hours	5 Hours
750,000	5 Hours	10 Hours
1,000,000	7 Hours	17 Hours

Figure 9



LEFT BANK
STATIONS ALONG AXIS OF DAM
RIGHT BANK
STATIONS ALONG AXIS OF DAM - FEET PROTOTYPE
LEGEND
ORIGINAL SAND
SAND AFTER DISCHARGE OF 500,000 SECOND-FEET
SAND AFTER DISCHARGE OF 750,000 SECOND-FEET
SAND AFTER DISCHARGE OF 1,000,000 SECOND-FEET
NOTES
SAND WAS NOT DISTURBED BETWEEN DISCHARGES.
POWER HOUSES WERE NOT OPERATED.
VERTICAL SCALE IS 1¼ TIMES HORIZONTAL.
STATION B-10+00
STATIONS ALONG AXIS OF DAM IN FEET PROTOTYPE
TABULATION OF MODEL FLOW DURATION
DISCHARGE SEC.-FT
DURATION OF FLOW
ACCUMULATED TIME
250,000 2 Hours 2 Hours
500,000 3 Hours 5 Hours
750,000 5 Hours 10 Hours
1,000,000 7 Hours 17 Hours
ELEVATION IN FEET PROTOTYPE
RIGHT BANK
STATION B-12+00
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON
GRAND COULEE DAM
HYDRAULIC MODEL STUDIES
TEST 1 - RIVER MODEL - SCALE 1 TO 120
SCOUR SECTIONS - STATIONS B-10+00 & B-12+00
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
FT. COLLINS, COLO.

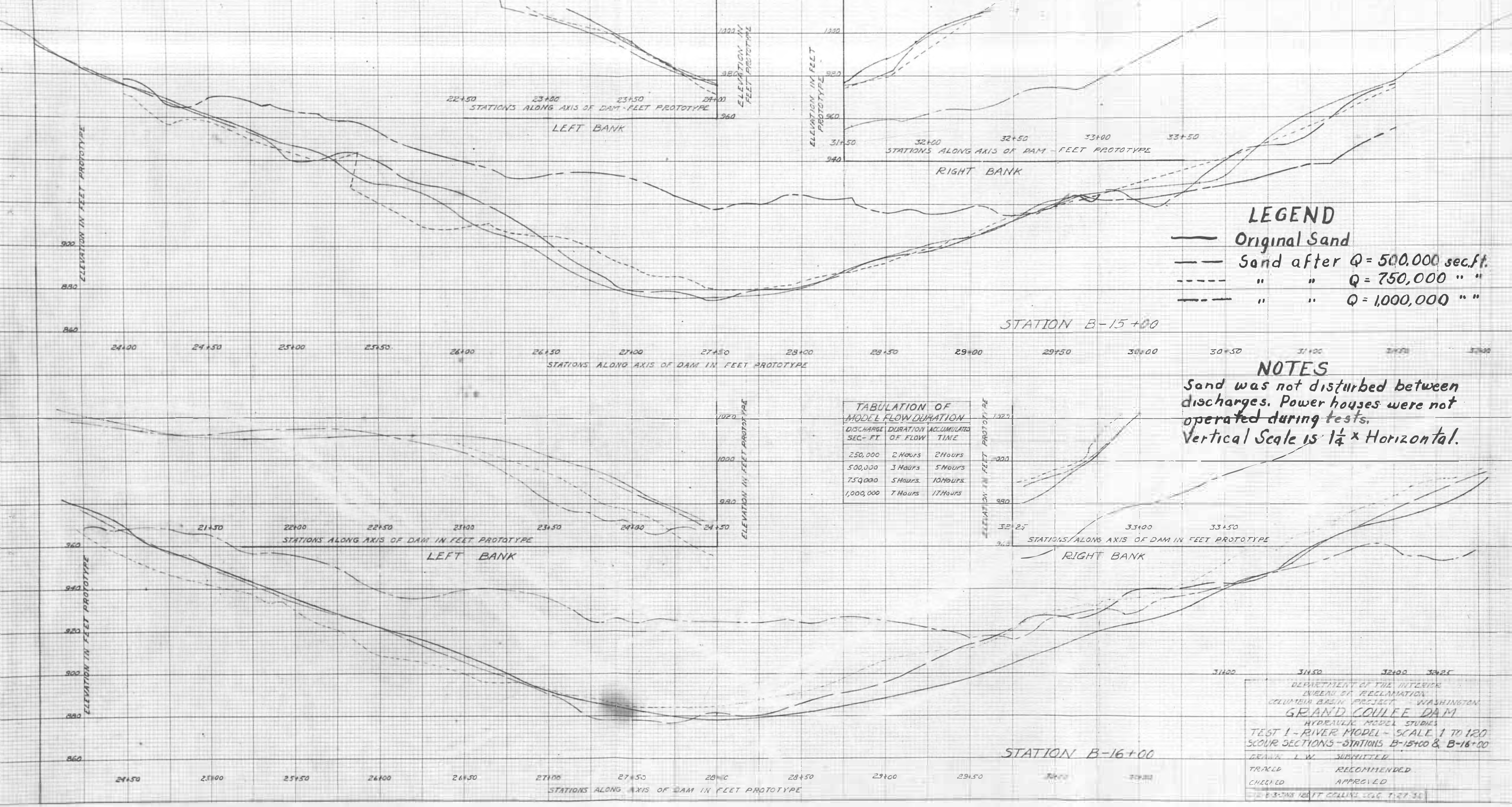
Figure 10

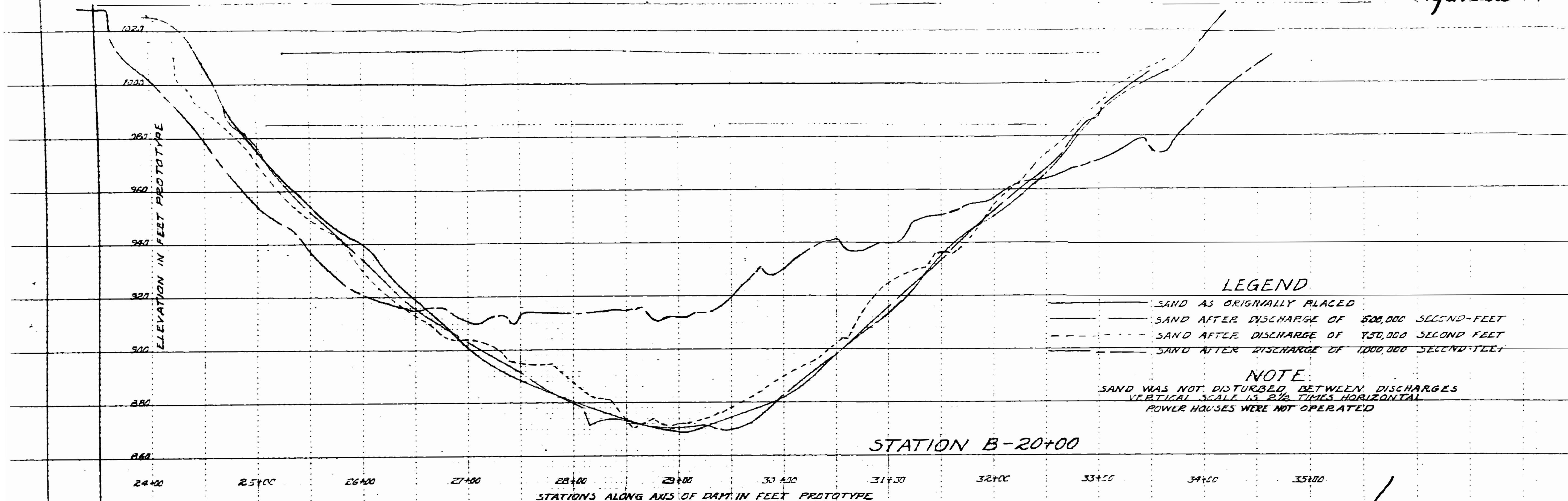


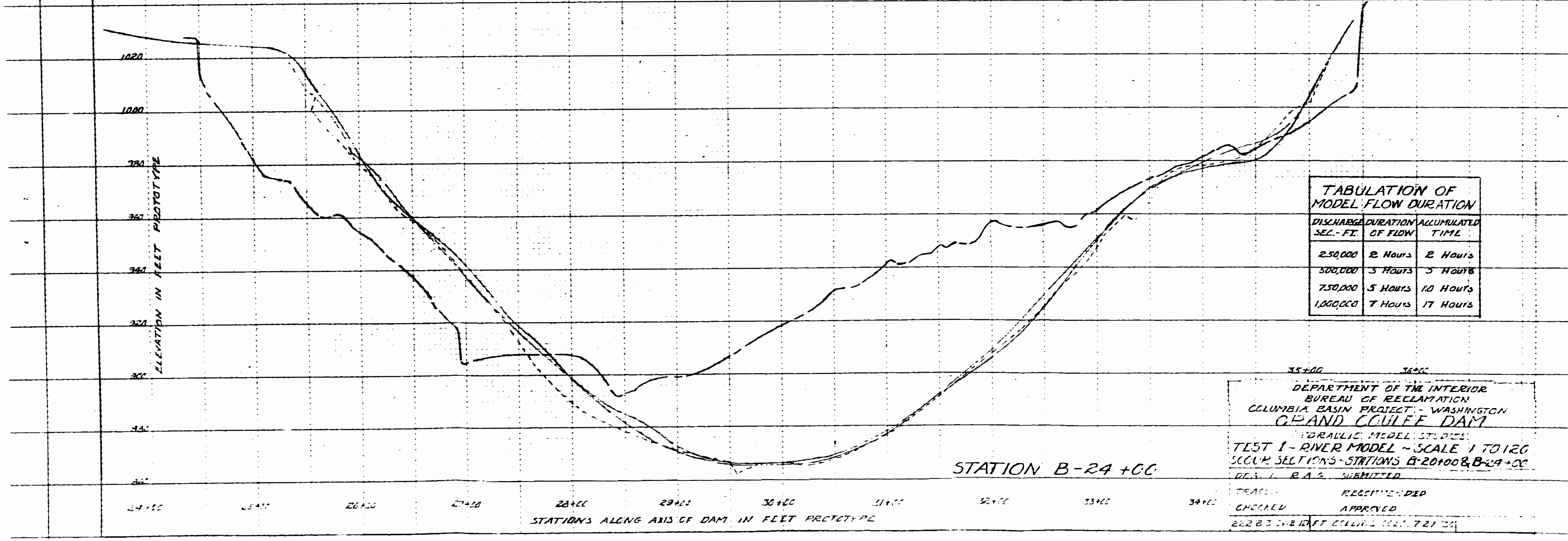
TABULATION OF MODEL FLOW DURATION

DISCHARGE SEC.-FT.	DURATION OF FLOW	ACCUMULATED TIME
250,000	2 Hours	2 Hours
500,000	3 Hours	5 Hours
750,000	5 Hours	10 Hours
1,000,000	7 Hours	17 Hours

Figure 11


LEFT BANK
STATIONS ALONG AXIS OF DAM - FEET PROTOTYPE
ELEVATION IN FEET PROTOTYPE
RIGHT BANK
STATIONS ALONG AXIS OF DAM - FEET PROTOTYPE
ELEVATION IN FEET PROTOTYPE
LEGEND
Original Sand
Sand after Q = 500,000 sec.ft.
" " Q = 750,000 " "
" " Q = 1,000,000 " "
STATION B-15+00
STATIONS ALONG AXIS OF DAM IN FEET PROTOTYPE
ELEVATION IN FEET PROTOTYPE
NOTES
Sand was not disturbed between discharges. Power houses were not operated during tests.
Vertical Scale is 1¼ x Horizontal.
TABULATION OF MODEL FLOW DURATION
DISCHARGE SEC-FT. | DURATION OF FLOW | ACCUMULATED TIME
250,000 | 2 Hours | 2 Hours
500,000 | 3 Hours | 5 Hours
750,000 | 5 Hours | 10 Hours
1,000,000 | 7 Hours | 17 Hours
LEFT BANK
STATIONS ALONG AXIS OF DAM IN FEET PROTOTYPE
RIGHT BANK
STATIONS ALONG AXIS OF DAM IN FEET PROTOTYPE
STATION B-16+00
STATIONS ALONG AXIS OF DAM IN FEET PROTOTYPE
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT WASHINGTON
GRAND COULEE DAM
HYDRAULIC MODEL STUDIES
TEST 1 - RIVER MODEL - SCALE 1 TO 120
SCOUR SECTIONS - STATIONS B-15+00 & B-16+00
DRAWN L.W. SUBMITTED
TRACED RECOMMENDED
CHECKED APPROVED



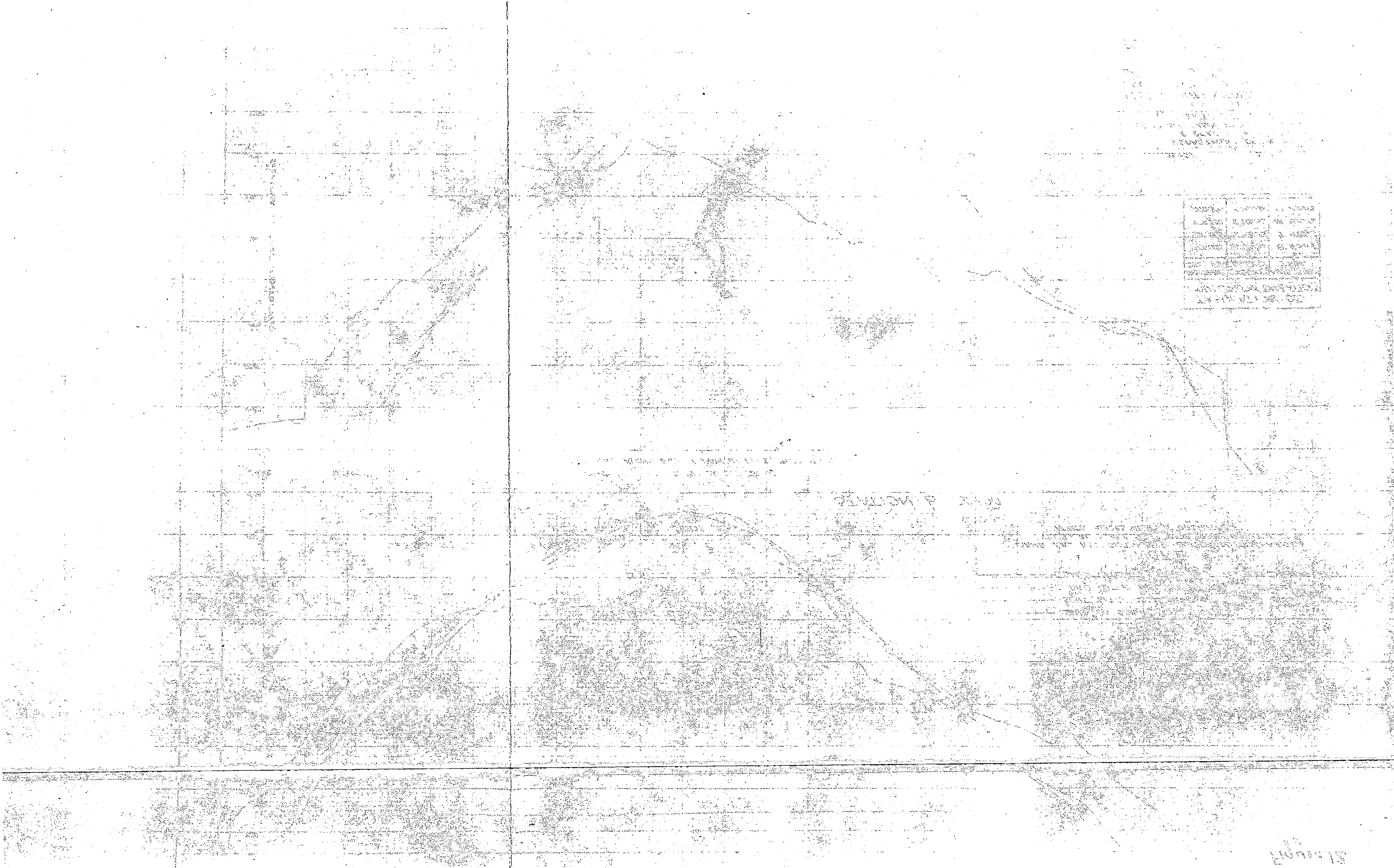


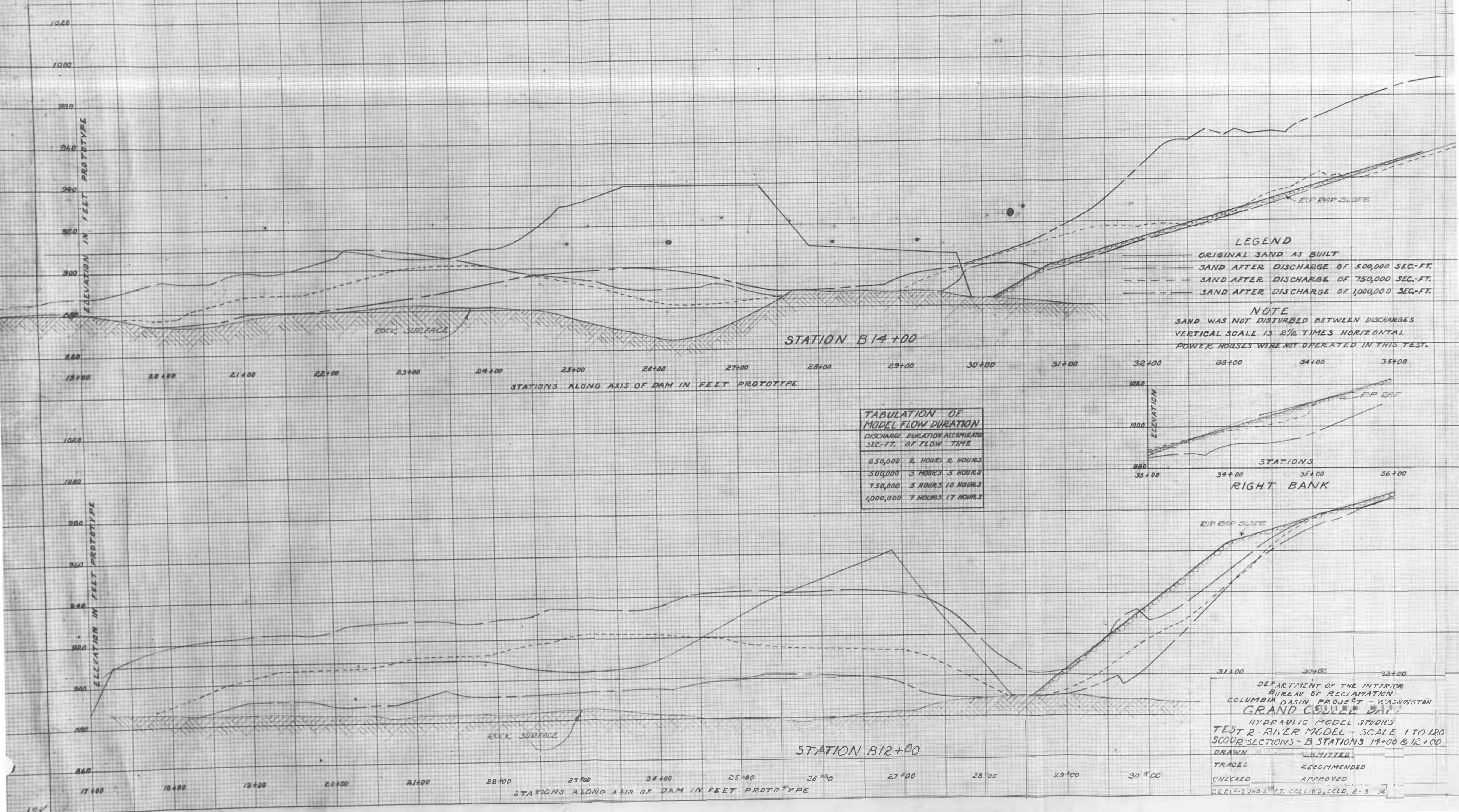
TABULATION OF MODEL FLOW DURATION

DISCHARGE SEC.-FT.	DURATION OF FLOW	ACCUMULATED TIME
250,000	2 Hours	2 Hours
500,000	3 Hours	5 Hours
750,000	5 Hours	10 Hours
1,000,000	7 Hours	17 Hours

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON
GRAND COULEE DAM
HYDRAULIC MODEL STUDIES
TEST I - RIVER MODEL - SCALE 1 TO 120
SCOUR SECTIONS - STATIONS B-20+00 & B-24+00

DES. RAS SUBMITTED
TRACED RECOMMENDED
CHECKED APPROVED
222 83 ... FT. COLLINS ... 7-21-36





TABULATION OF MODEL FLOW DURATION

DISCHARGE SEC.-FT.	DURATION OF FLOW	ACCUMULATED TIME
250,000	2 HOURS	2 HOURS
500,000	3 HOURS	5 HOURS
750,000	5 HOURS	10 HOURS
1,000,000	7 HOURS	17 HOURS

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT ~ WASHINGTON
GRAND COULEE DAM
HYDRAULIC MODEL STUDIES
TEST 2 - RIVER MODEL ~ SCALE 1 TO 120
SCOUR SECTIONS ~ B STATIONS 14+00 & 12+00

DRAWN SUBMITTED
TRACED RECOMMENDED
CHECKED APPROVED

FT. COLLINS, COLO. 8-3-36

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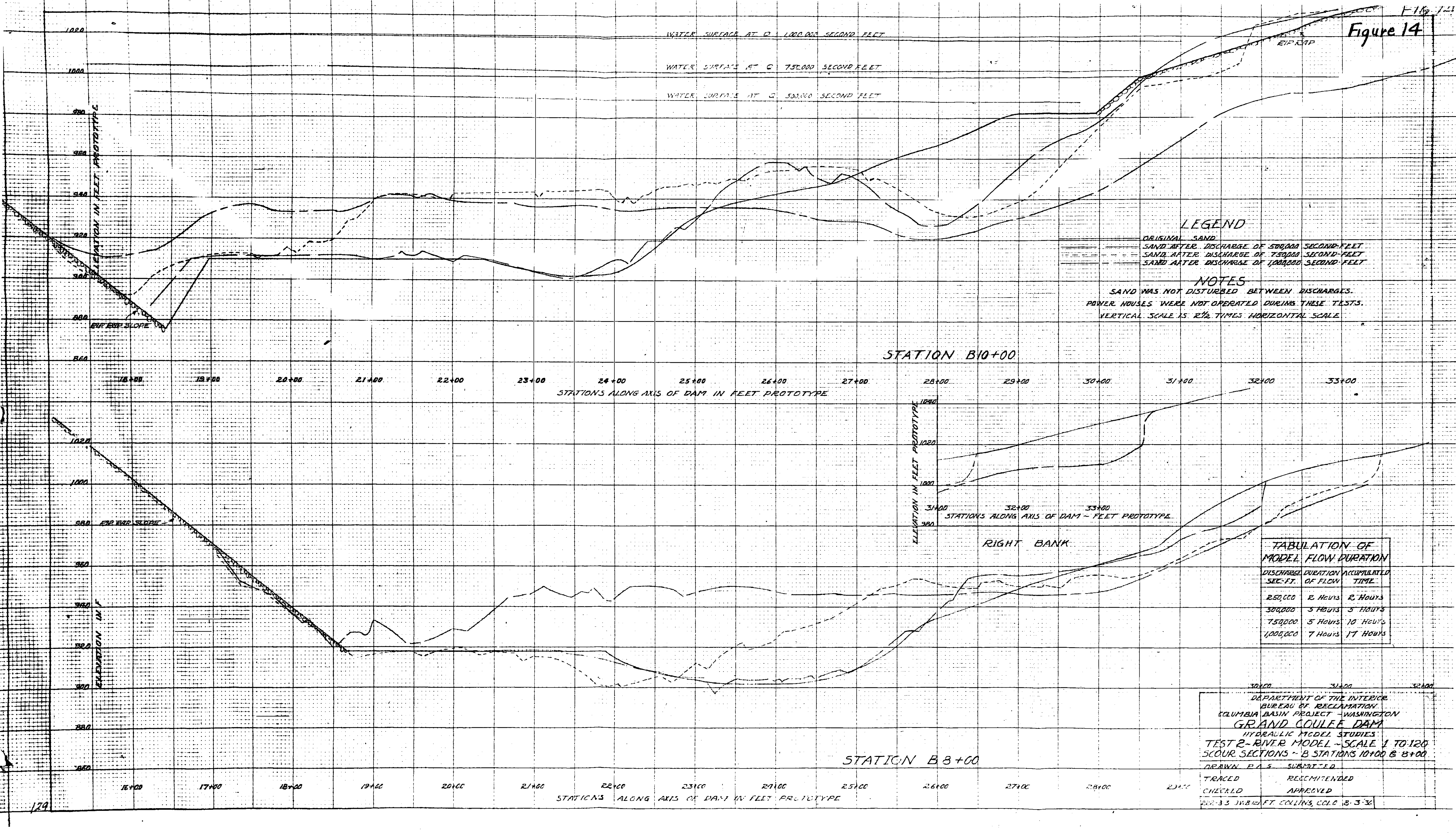
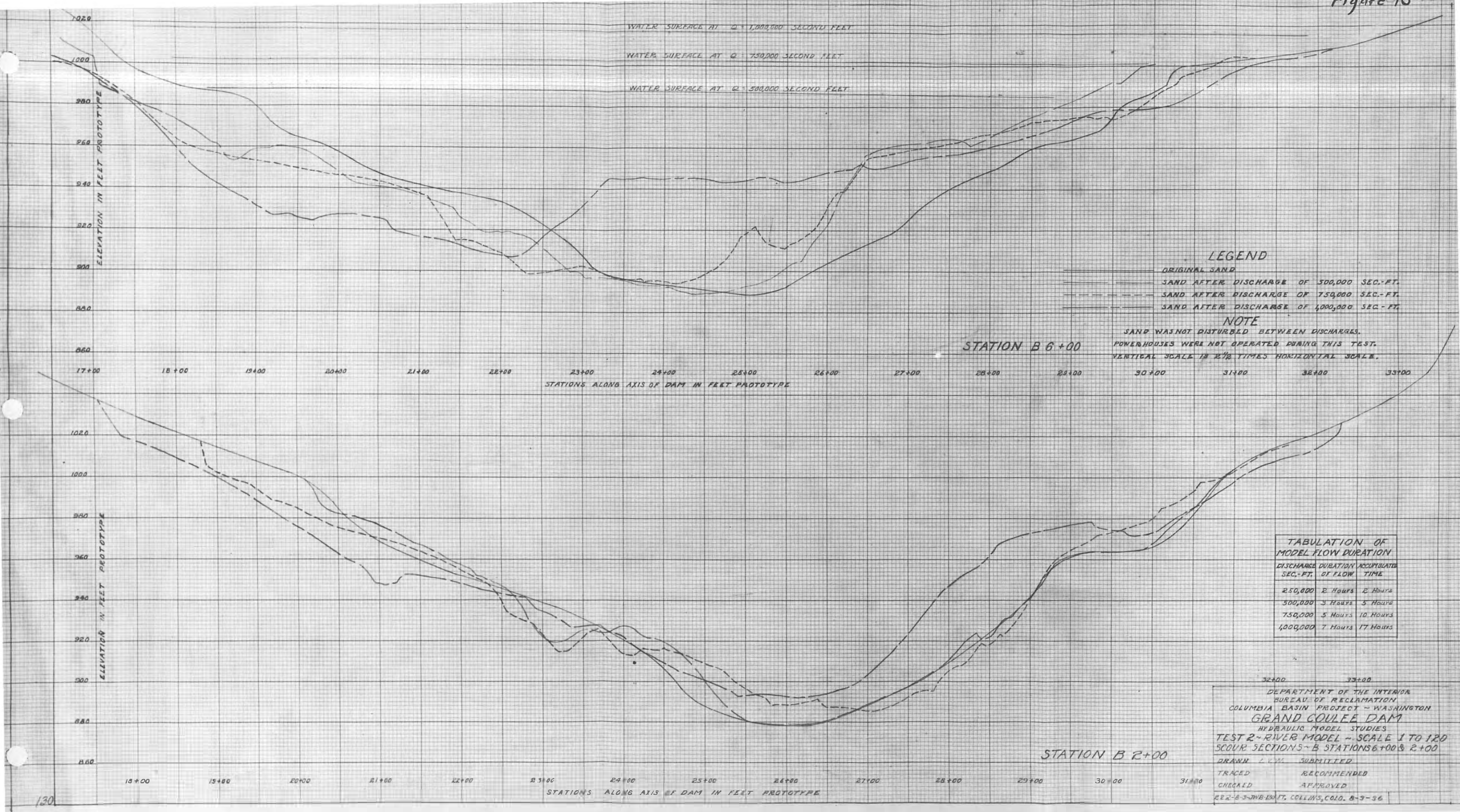


TABULATION OF MODEL FLOW DURATION

DISCHARGE SEC-FT.	DURATION OF FLOW	ACCUMULATED TIME
250,000	2 Hours	2 Hours
500,000	3 Hours	5 Hours
750,000	5 Hours	10 Hours
1,000,000	7 Hours	17 Hours

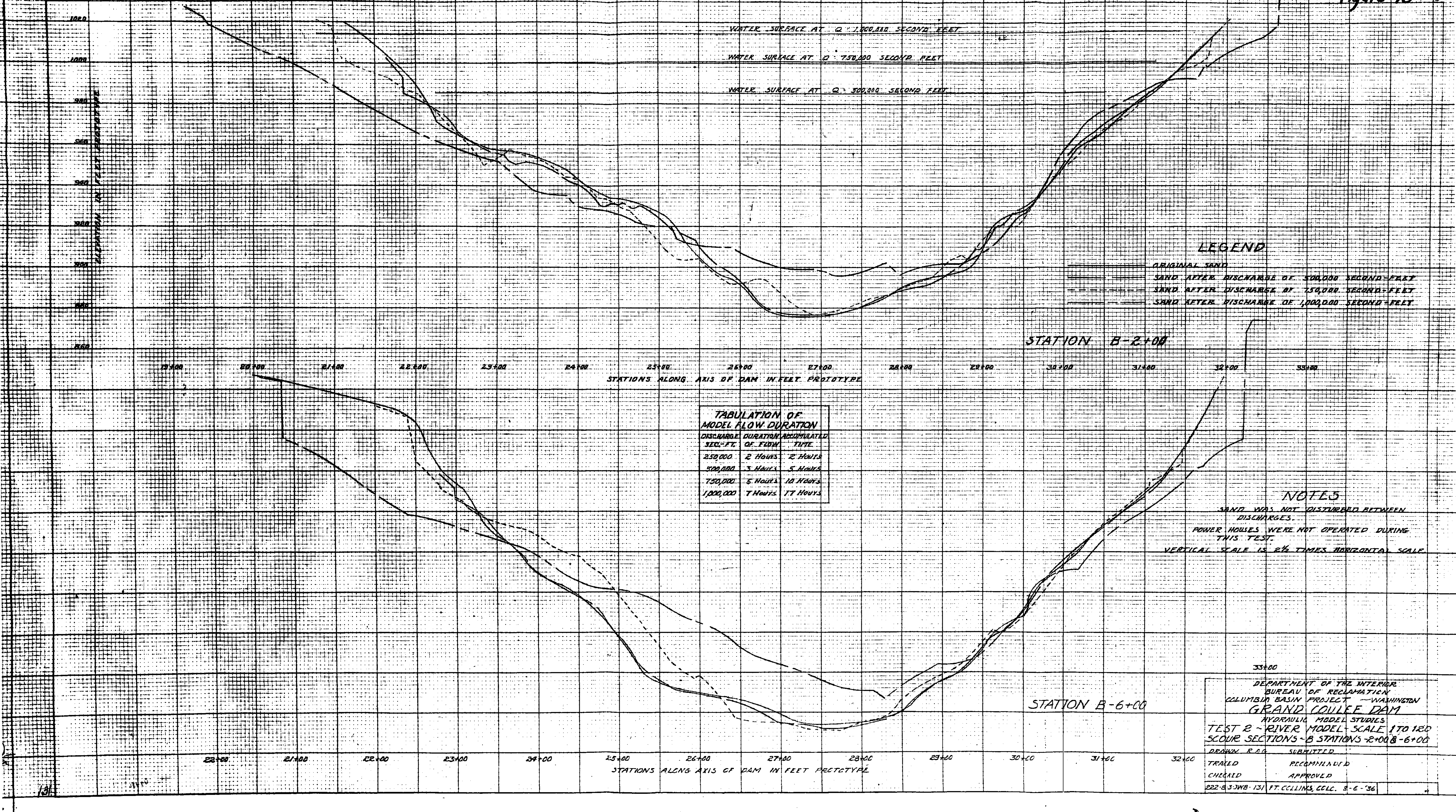
Figure 16



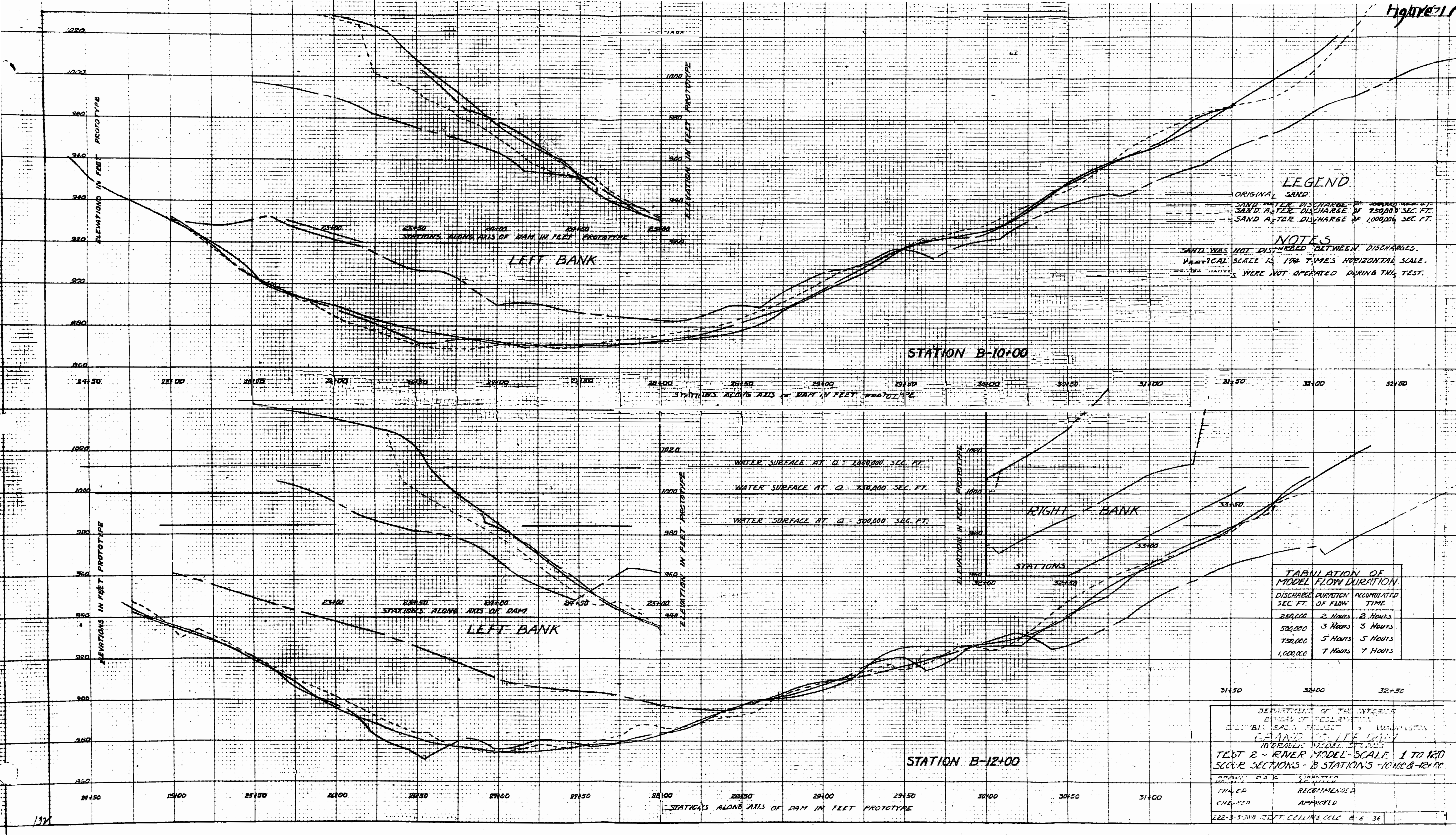
TABULATION OF MODEL FLOW DURATION

DISCHARGE SEC.-FT.	DURATION OF FLOW	ACCUMULATED TIME
250,000	2 Hours	2 Hours
500,000	3 Hours	5 Hours
750,000	5 Hours	10 Hours
1,000,000	7 Hours	17 Hours

Figure 16



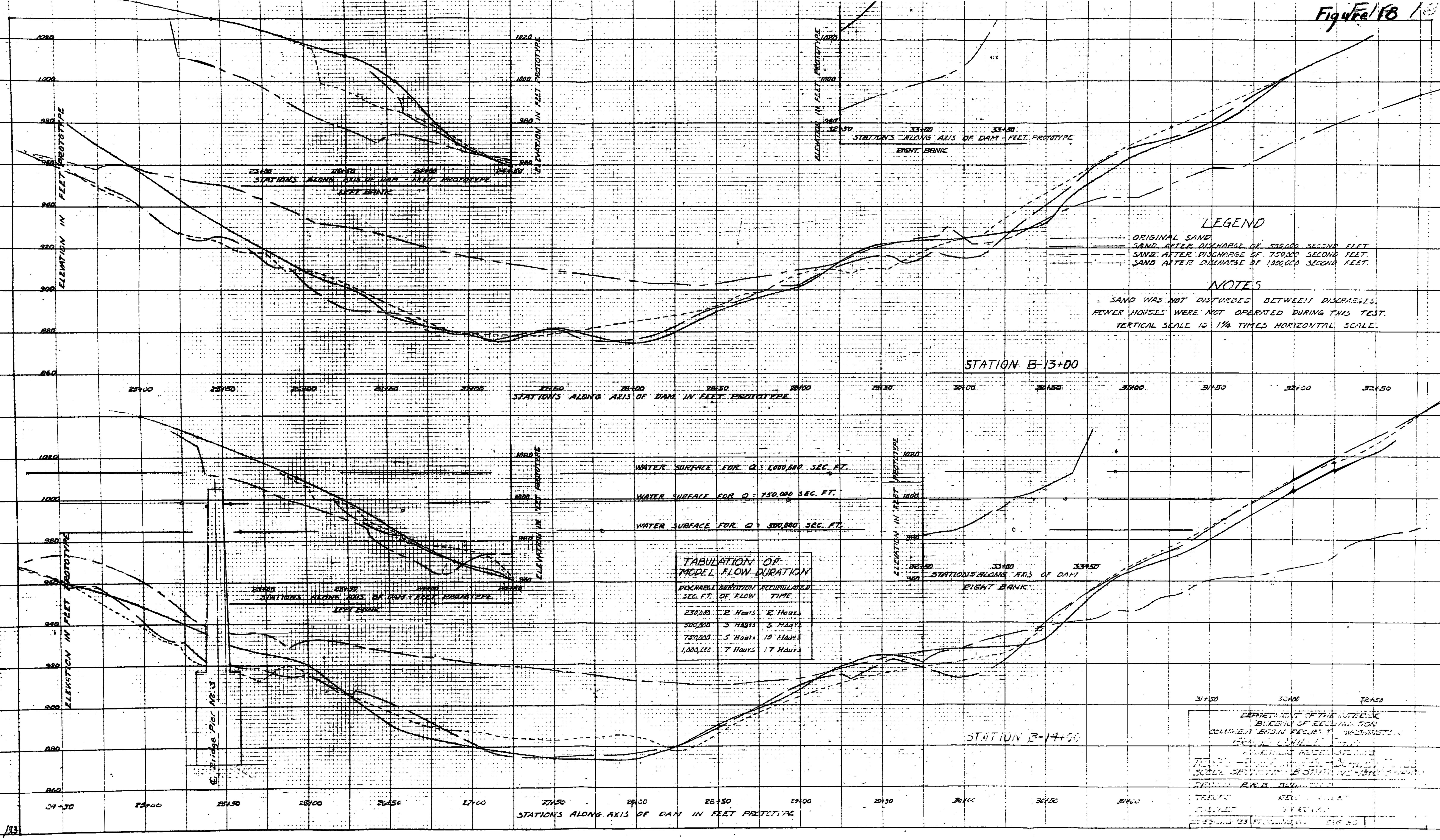
DISCHARGE SEC.-FT.	DURATION OF FLOW	ACCUMULATED TIME
250,000	2 Hours	2 Hours
500,000	3 Hours	5 Hours
750,000	5 Hours	10 Hours
1,000,000	7 Hours	17 Hours



TABULATION OF MODEL FLOW DURATION

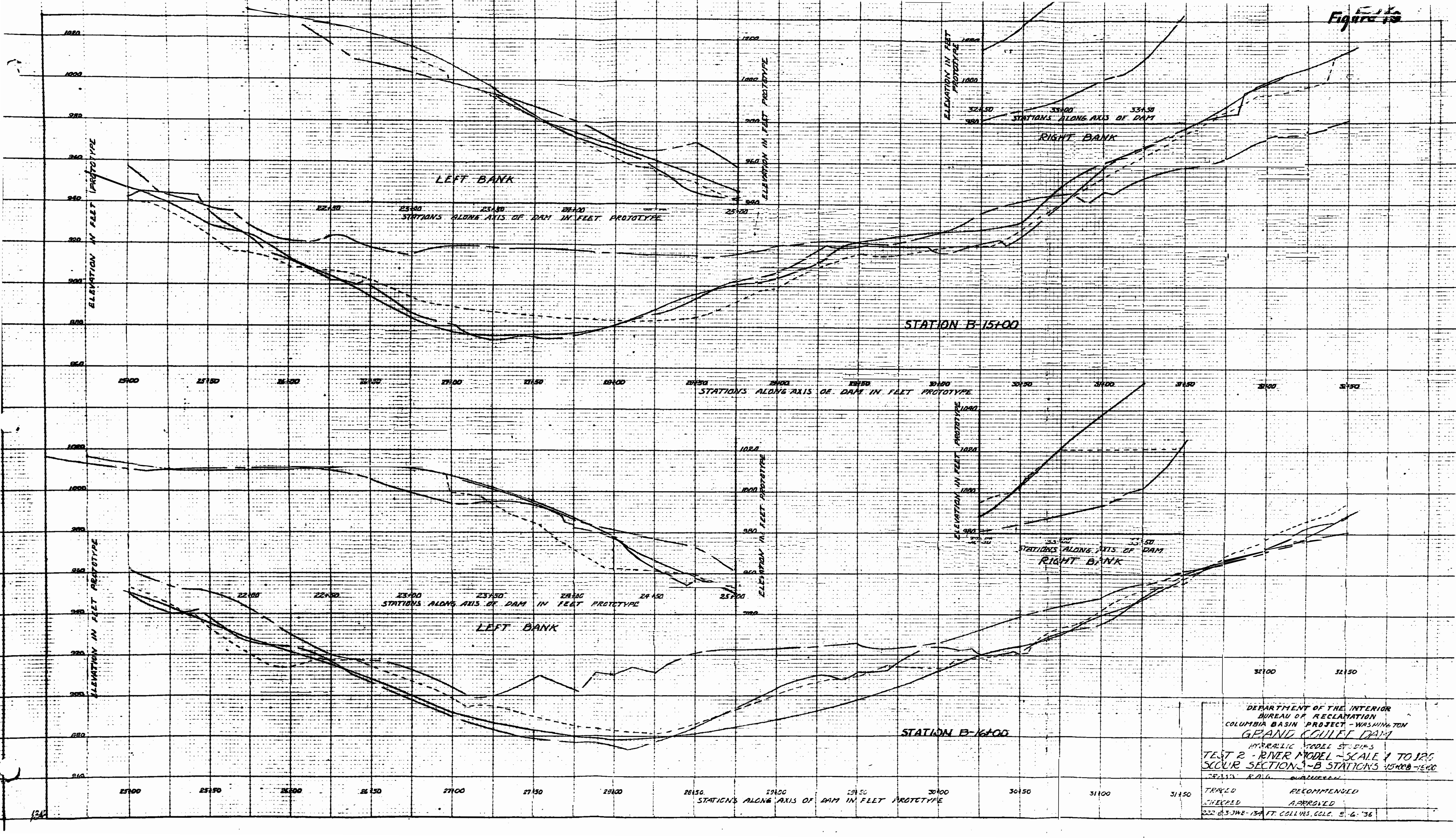
DISCHARGE SEC. FT.	DURATION OF FLOW	ACCUMULATED TIME
250,000	2 Hours	2 Hours
500,000	3 Hours	3 Hours
750,000	5 Hours	5 Hours
1,000,000	7 Hours	7 Hours

Figure 18



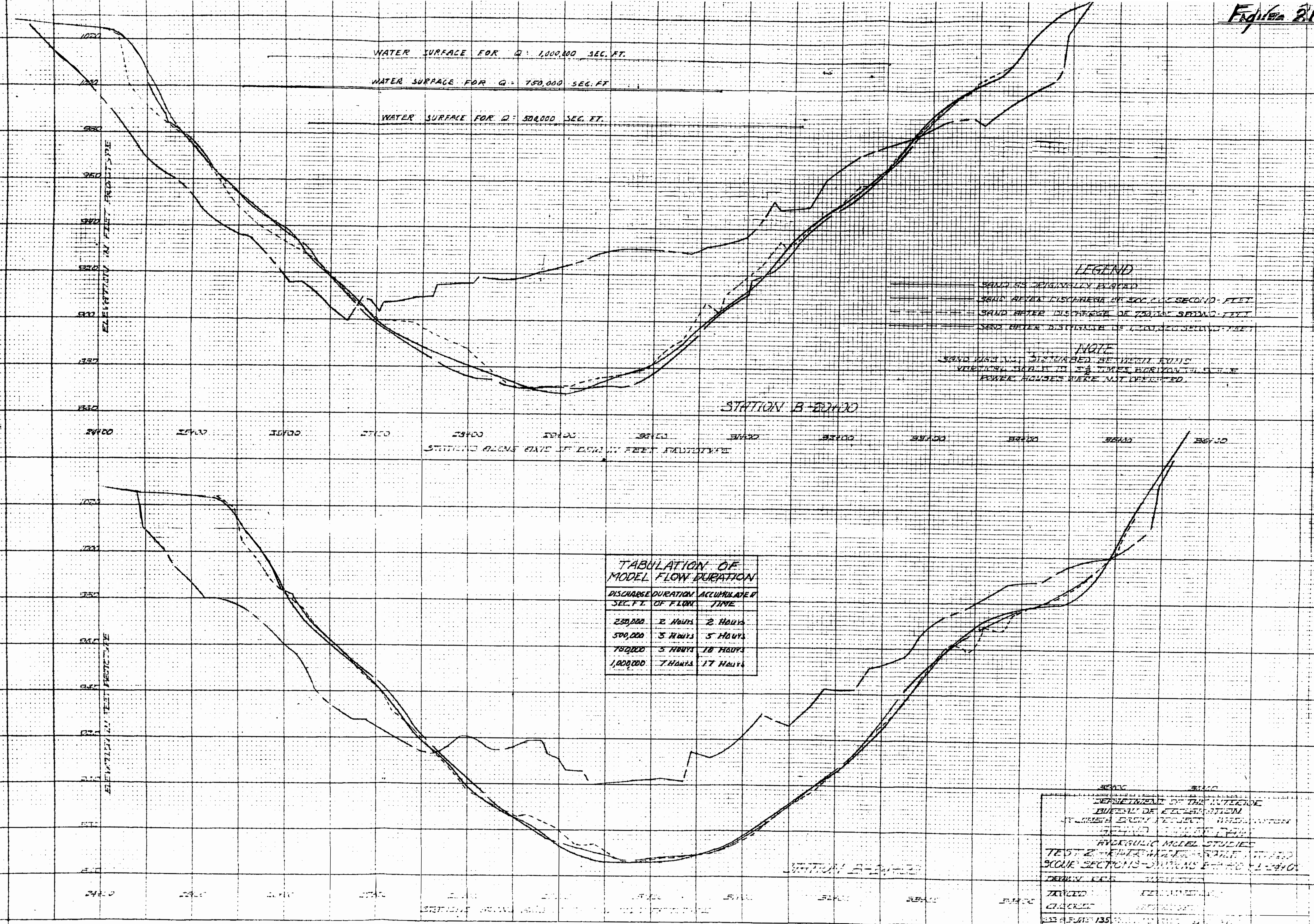
TABULATION OF MODEL FLOW DURATION

DISCHARGE SEC. FT.	DURATION OF FLOW	ACCUMULATED TIME
230,000	2 Hours	2 Hours
500,000	3 Hours	5 Hours
750,000	5 Hours	10 Hours
1,000,000	7 Hours	17 Hours

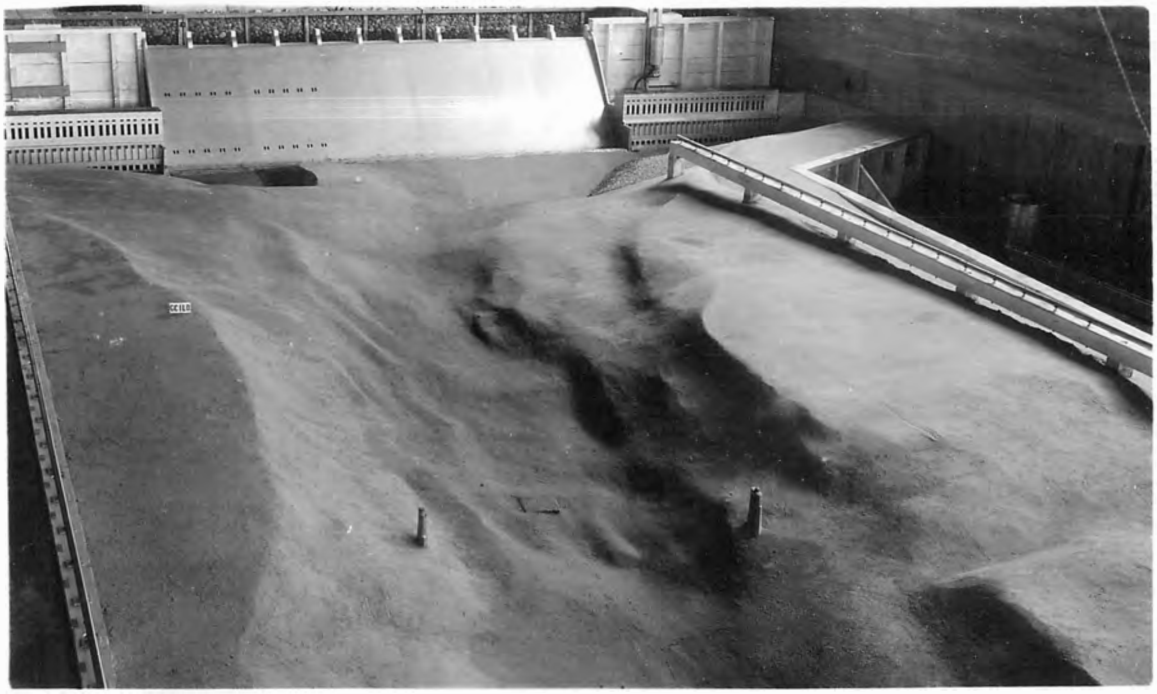


LEFT BANK
STATIONS ALONG AXIS OF DAM IN FEET PROTOTYPE
ELEVATION IN FEET PROTOTYPE
RIGHT BANK
STATIONS ALONG AXIS OF DAM
STATION B-15+00
STATIONS ALONG AXIS OF DAM IN FEET PROTOTYPE
LEFT BANK
RIGHT BANK
STATION B-16+00
STATIONS ALONG AXIS OF DAM IN FEET PROTOTYPE
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON
GRAND COULEE DAM
TEST 2 - RIVER MODEL ~ SCALE 1 TO 120
TRACED
RECOMMENDED
CHECKED
APPROVED
FT. COLLINS, COLO. 9-6-'36

Figure 20



TABULATION OF MODEL FLOW DURATION		
DISCHARGE SEC. FT.	DURATION OF FLOW	ACCUMULATED TIME
250,000	2 Hours	2 Hours
500,000	3 Hours	5 Hours
750,000	5 Hours	10 Hours
1,000,000	7 Hours	17 Hours



LOOKING UPSTREAM.

LOOKING DOWNSTREAM.

INITIAL RIVER BED FOR TEST 1.

LOOKING UPSTREAM.

LOOKING DOWNSTREAM.

TEST 1

RIVER BED AFTER A FLOW OF 750,000 SECOND-FEET.

LOOKING UPSTREAM.

LOOKING DOWNSTREAM.

TEST 1

RIVER BED AFTER A FLOW OF 1.000.000 SECOND-FEET.

BEFORE TEST.

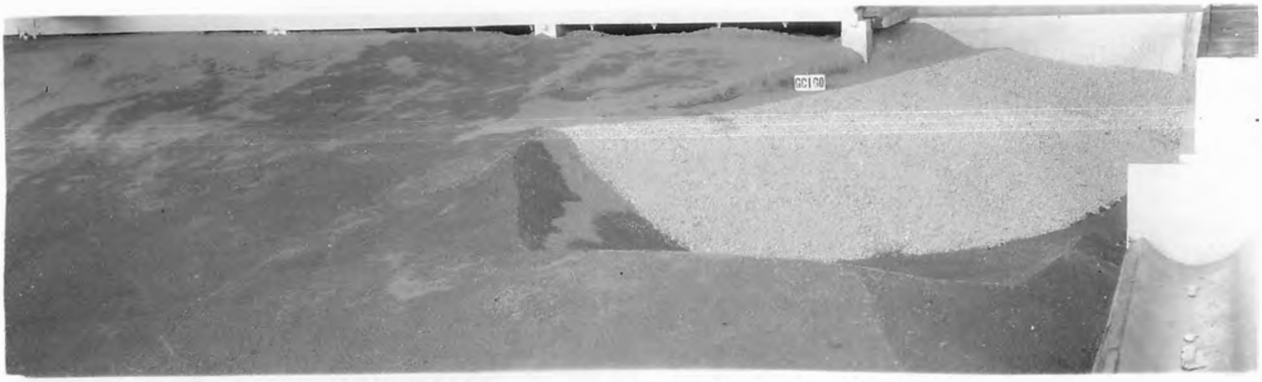
AFTER DISCHARGE OF 500,000 SECOND-FEET.

AFTER DISCHARGE OF 750,000 SECOND-FEET.

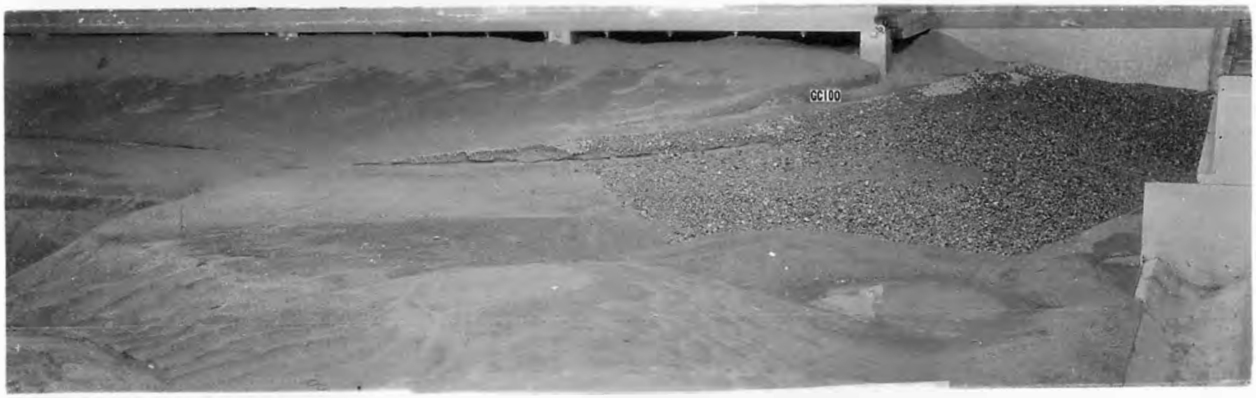
AFTER DISCHARGE OF 1,000,000 SECOND-FEET.

TEST 1

EROSION AT LEFT TAILRACE.



BEFORE TEST.



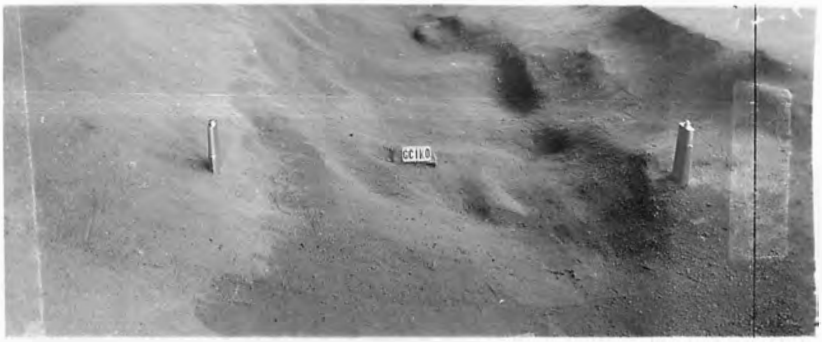
AFTER DISCHARGE OF 500,000 SECOND-FEET.

AFTER DISCHARGE OF 750,000 SECOND-FEET.

AFTER DISCHARGE OF 1,000,000 SECOND-FEET.

TEST 1

EROSION AT RIGHT TAILRACE.



BEFORE TEST.

AFTER DISCHARGE OF 500,000 SECOND-FEET.

AFTER DISCHARGE OF 750,000 SECOND-FEET.

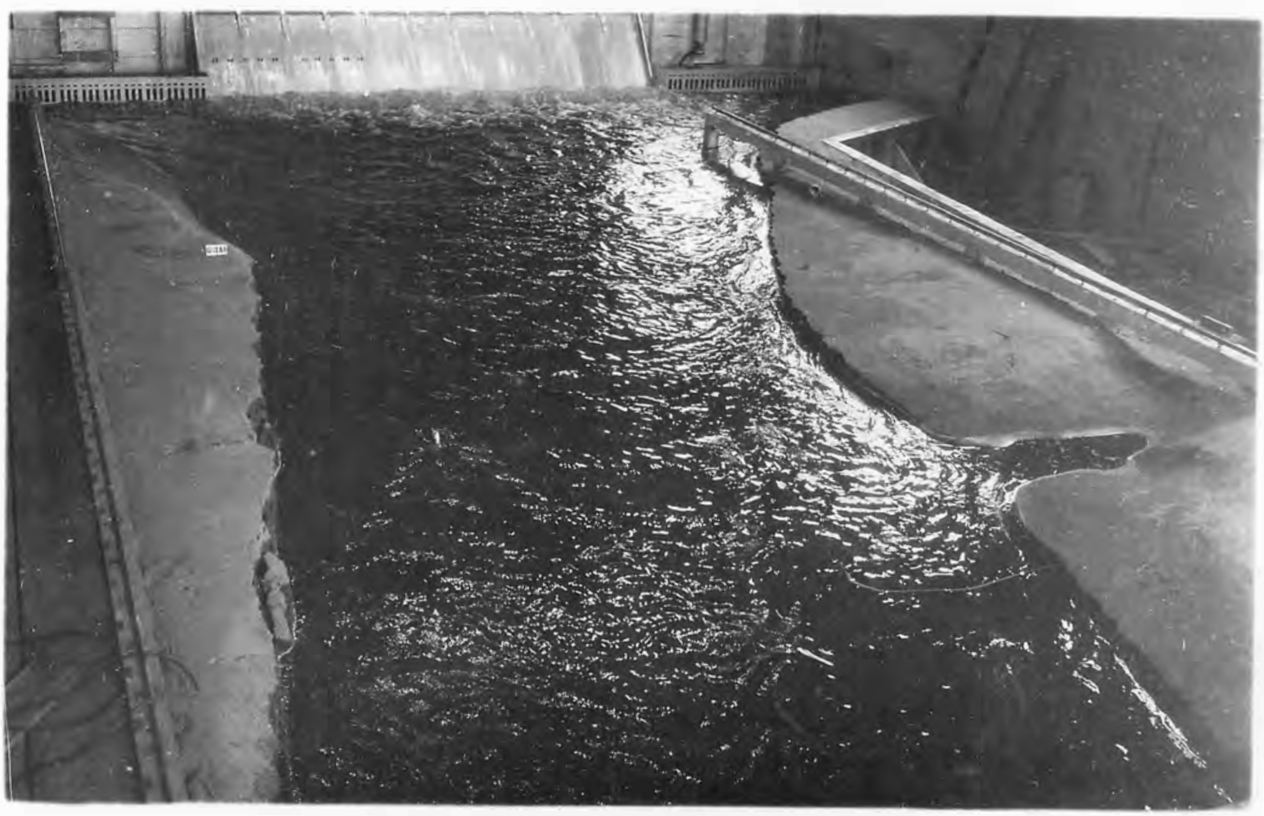
AFTER DISCHARGE OF 1,000,000 SECOND-FEET.

LOOKING UPSTREAM.

TEST 1

EFFECT OF FLOW ON RIVER BANKS NEAR HIGHWAY BRIDGE PIERS 2

DISCHARGE OF 250,000 SECOND-FEET.



DISCHARGE OF 1,000,000 SECOND-FEET.

TEST 1

FLOW CONDITIONS IN RIVER - LOOKING UPSTREAM.

LOOKING UPSTREAM.

LOOKING DOWNSTREAM.

INITIAL RIVER BED FOR TEST 2.

LOOKING UPSTREAM.

LOOKING DOWNSTREAM.

TEST 2

RIVER BED AFTER A FLOW OF 500,000 SECOND-FEET.

LOOKING UPSTREAM.

LOOKING DOWNSTREAM.

TEST 2

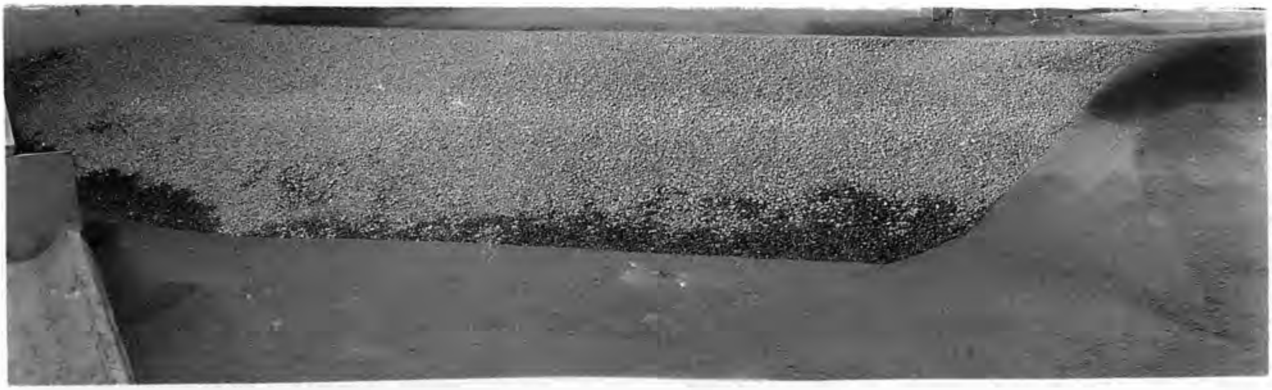
RIVER BED AFTER A FLOW OF 750,000 SECOND-FEET.

LOOKING UPSTREAM.

LOOKING DOWNSTREAM.

TEST 2

RIVER BED AFTER A FLOW OF 1,000,000 SECOND-FEET.



BEFORE TEST

AFTER A DISCHARGE OF 500,000 SECOND-FEET.

AFTER DISCHARGE OF 750,000 SECOND-FEET.

AFTER A DISCHARGE OF 1,000,000 SECOND-FEET.

TEST 2

EROSION AT LEFT TAILRACE.

BEFORE TEST.

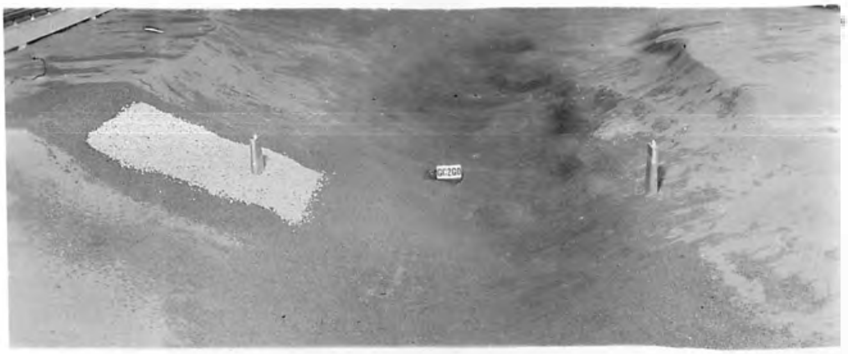
AFTER DISCHARGE OF 500,000 SECOND-FEET.

AFTER DISCHARGE OF 750,000 SECOND-FEET.

AFTER DISCHARGE OF 1,000,000 SECOND-FEET.

TEST 2

EROSION AT RIGHT TAILRACE.



BEFORE TEST.

AFTER DISCHARGE OF 500,000 SECOND-FEET

AFTER A DISCHARGE OF 750,000 SECOND-FEET

AFTER DISCHARGE OF 1,000,000 SECOND-FEET.

LOOKING UPSTREAM

TEST 2

EFFECT OF FLOW ON RIVER BANKS NEAR HIGHWAY BRIDGE PIERS 2 & 3.

Figure 21

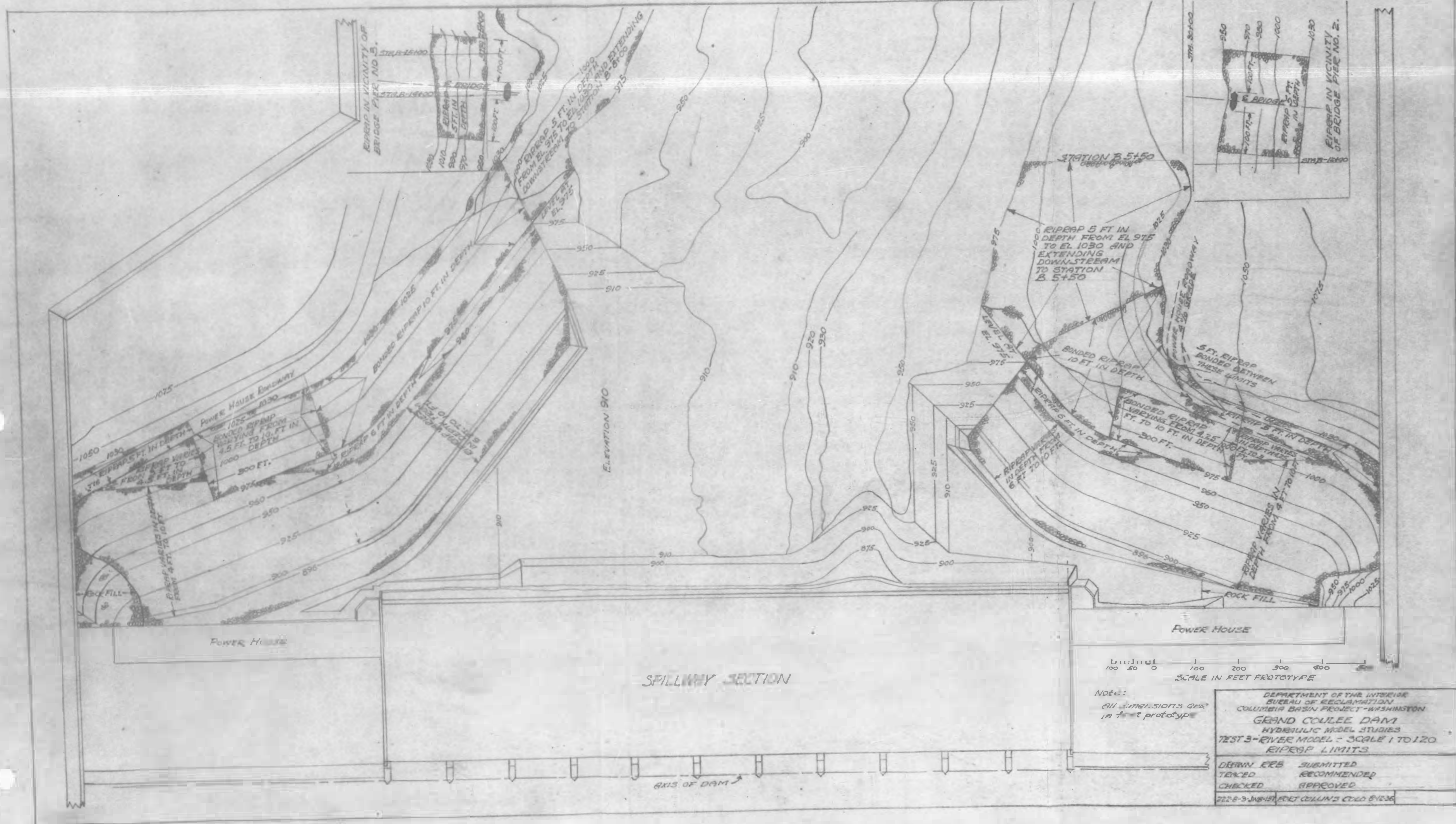
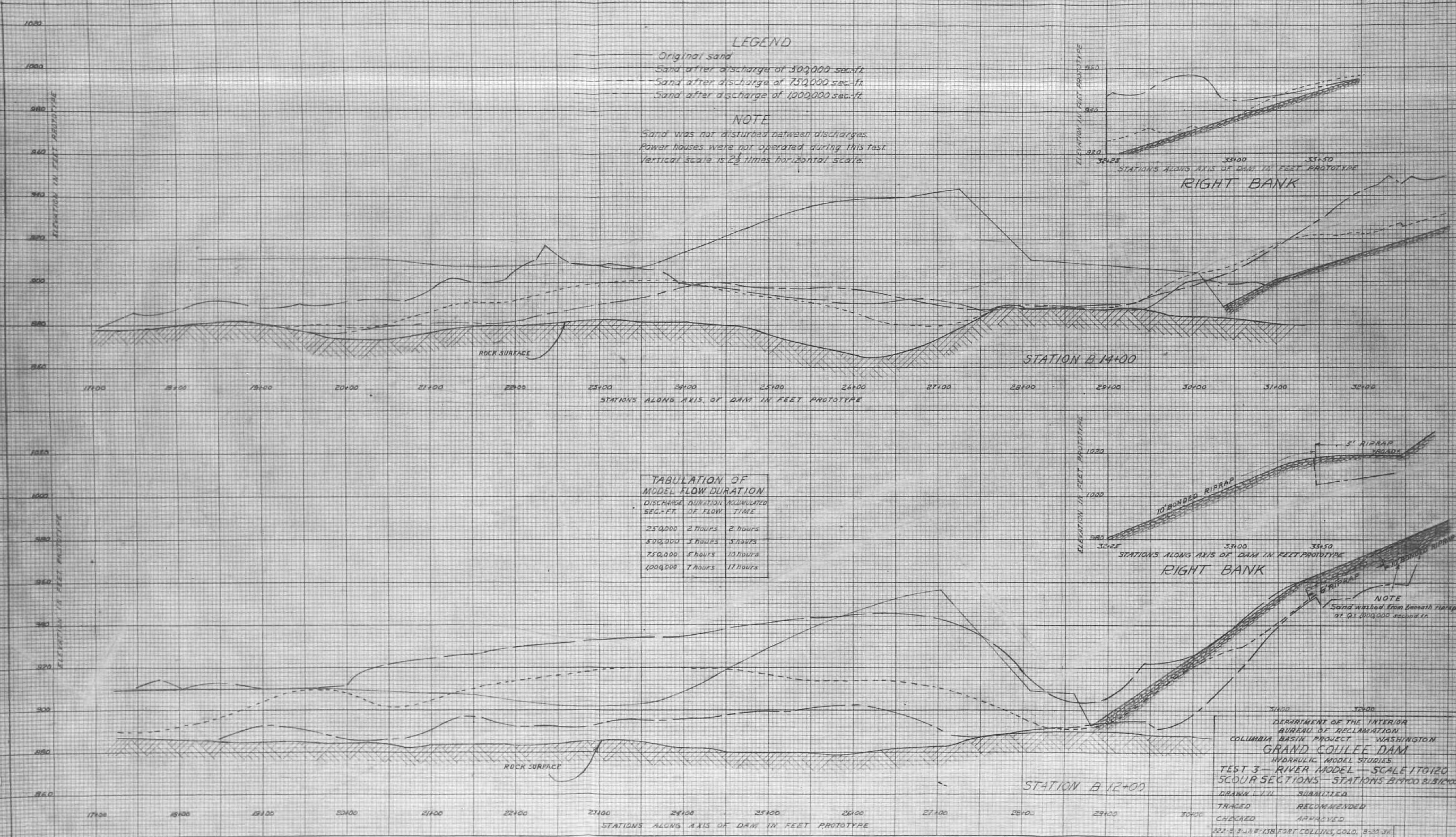
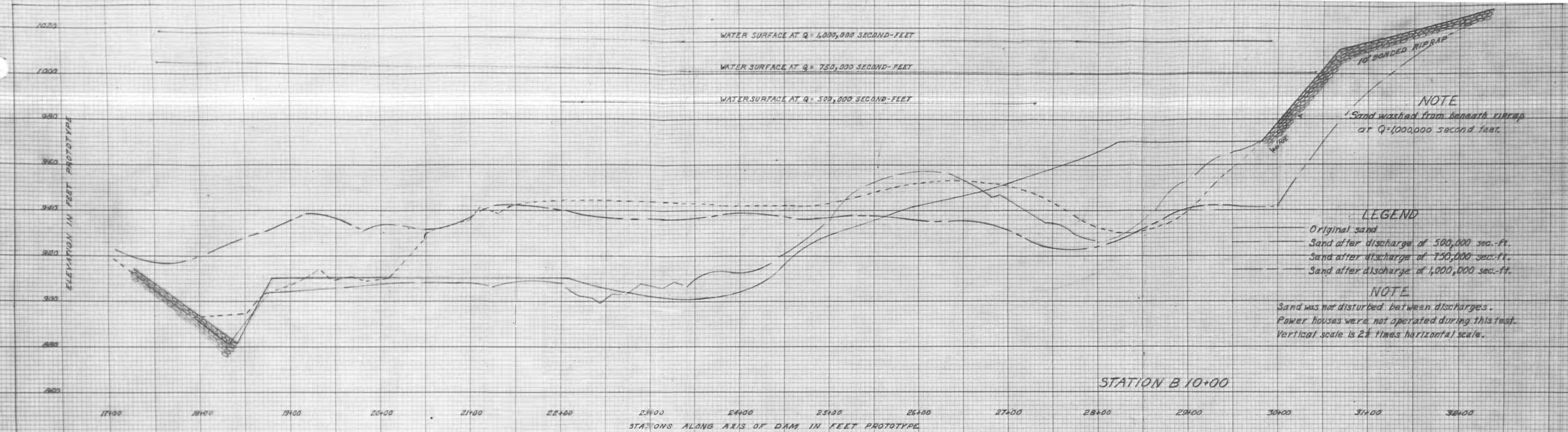

RIPRAP IN VICINITY OF BRIDGE PIER NO. 3.
RIPRAP 5 FT. IN DEPTH FROM EL. 975 TO EL. 1030 AND EXTENDING DOWNSTREAM TO STATION B-6+00
RIPRAP 5 FT. IN DEPTH
POWER HOUSE ROADWAY
BONDED RIPRAP VARYING FROM 4.5 FT. TO 10 FT. IN DEPTH
RIPRAP VARIES FROM 4.5 FT. TO 10 FT. IN DEPTH
BONDED RIPRAP 10 FT. IN DEPTH
RIPRAP 6 FT. IN DEPTH
RIPRAP VARIES IN DEPTH FROM 4 FT. TO 10 FT.
ROCK FILL
LEVEL AT EL. 975
ELEVATION 910
POWER HOUSE
SPILLWAY SECTION
AXIS OF DAM
STATION B. 5+50
RIPRAP 5 FT. IN DEPTH FROM EL. 975 TO EL. 1030 AND EXTENDING DOWNSTREAM TO STATION B. 5+50
RIPRAP IN VICINITY OF BRIDGE PIER NO. 2.
℄ BRIDGE
POWER HOUSE ROADWAY
5 FT. RIPRAP BONDED BETWEEN THESE LIMITS
BONDED RIPRAP 10 FT. IN DEPTH
BONDED RIPRAP VARYING FROM 4.25 FT. TO 10 FT. IN DEPTH
RIPRAP 6 FT. IN DEPTH
RIPRAP VARIES IN DEPTH FROM 6 FT. TO 10 FT.
RIPRAP VARIES IN DEPTH FROM 4 FT. TO 10 FT.
RIPRAP 5 FT. IN DEPTH
300 FT.
ROCK FILL
POWER HOUSE
100 50 0 100 200 300 400 500
SCALE IN FEET PROTOTYPE
Note:
All dimensions are in feet prototype
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON
GRAND COULEE DAM
HYDRAULIC MODEL STUDIES
TEST 3 - RIVER MODEL - SCALE 1 TO 120
RIPRAP LIMITS
DRAWN R.R.B. SUBMITTED
TRACED RECOMMENDED
CHECKED APPROVED
222-D-3-JAN-1937 FORT COLLINS COLO. 8-12-36

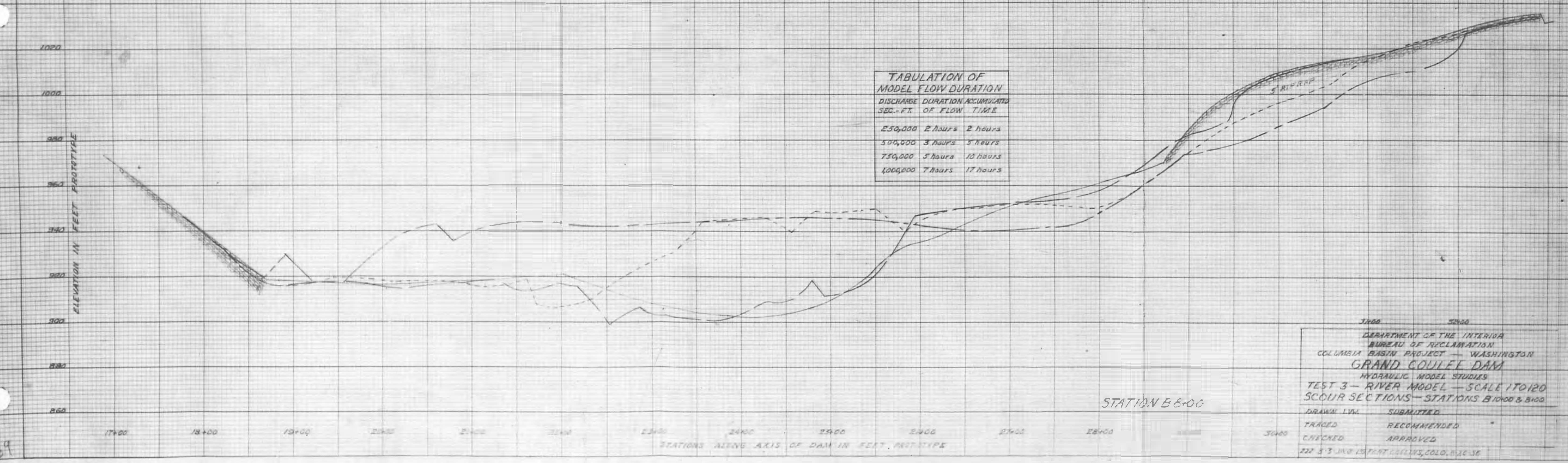
FIG 22



TABULATION OF MODEL FLOW DURATION

DISCHARGE SEC.-FT.	DURATION OF FLOW	ACCUMULATED TIME
250,000	2 hours	2 hours
500,000	3 hours	5 hours
750,000	5 hours	10 hours
1,000,000	7 hours	17 hours





TABULATION OF MODEL FLOW DURATION

DISCHARGE SEC.-FT.	DURATION OF FLOW	ACCUMULATED TIME
250,000	2 hours	2 hours
500,000	3 hours	5 hours
750,000	5 hours	10 hours
1,000,000	7 hours	17 hours

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

GRAND COULEE DAM

HYDRAULIC MODEL STUDIES

TEST 3 — RIVER MODEL — SCALE 1 TO 120
SCOUR SECTIONS — STATIONS B 10+00 & B 8+00

DRAWN L.V.W. SUBMITTED
TRACED RECOMMENDED
CHECKED APPROVED

222 3-3 JH 8-13 FORT COLLINS, COLO. 8-26-36

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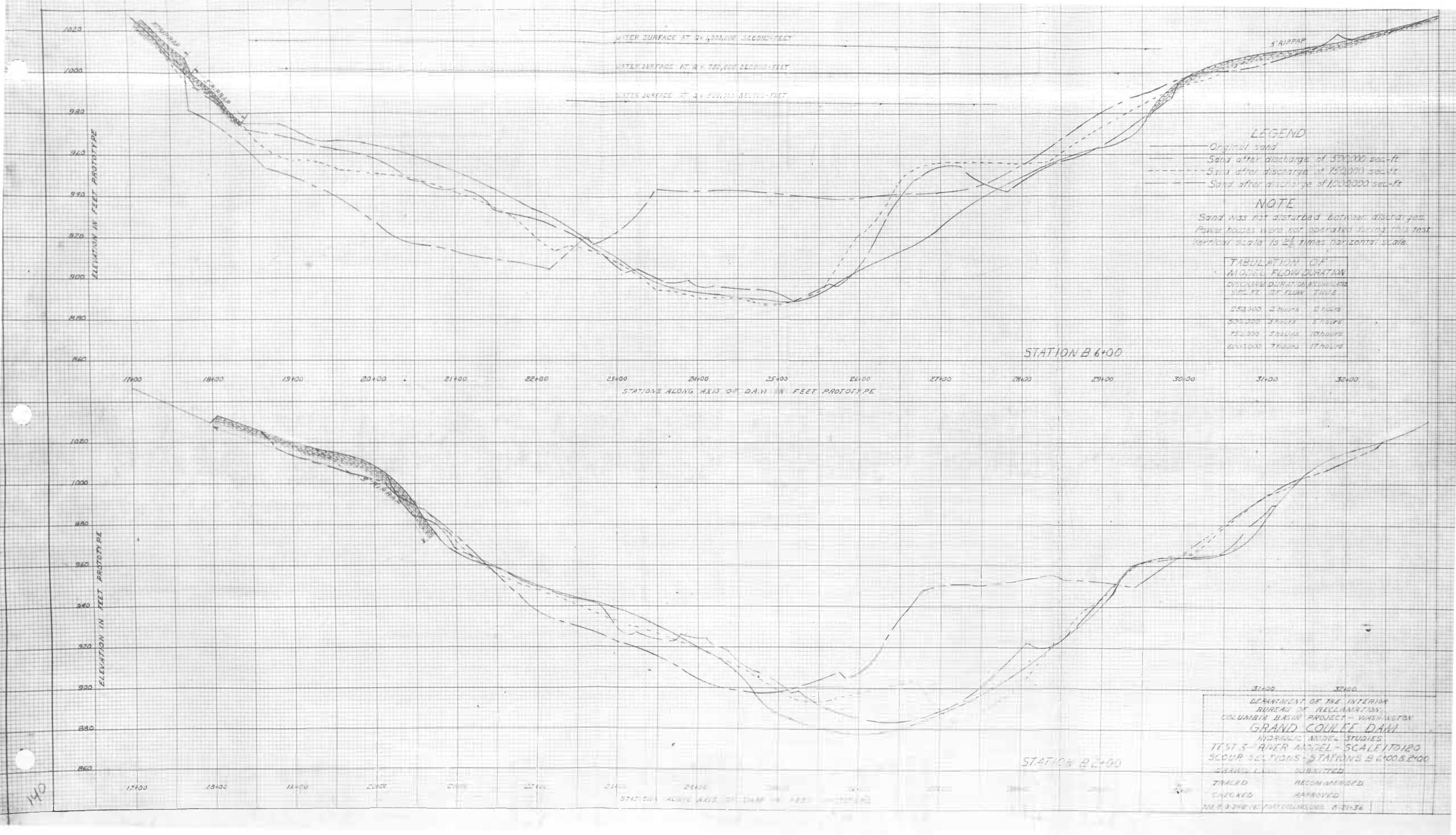
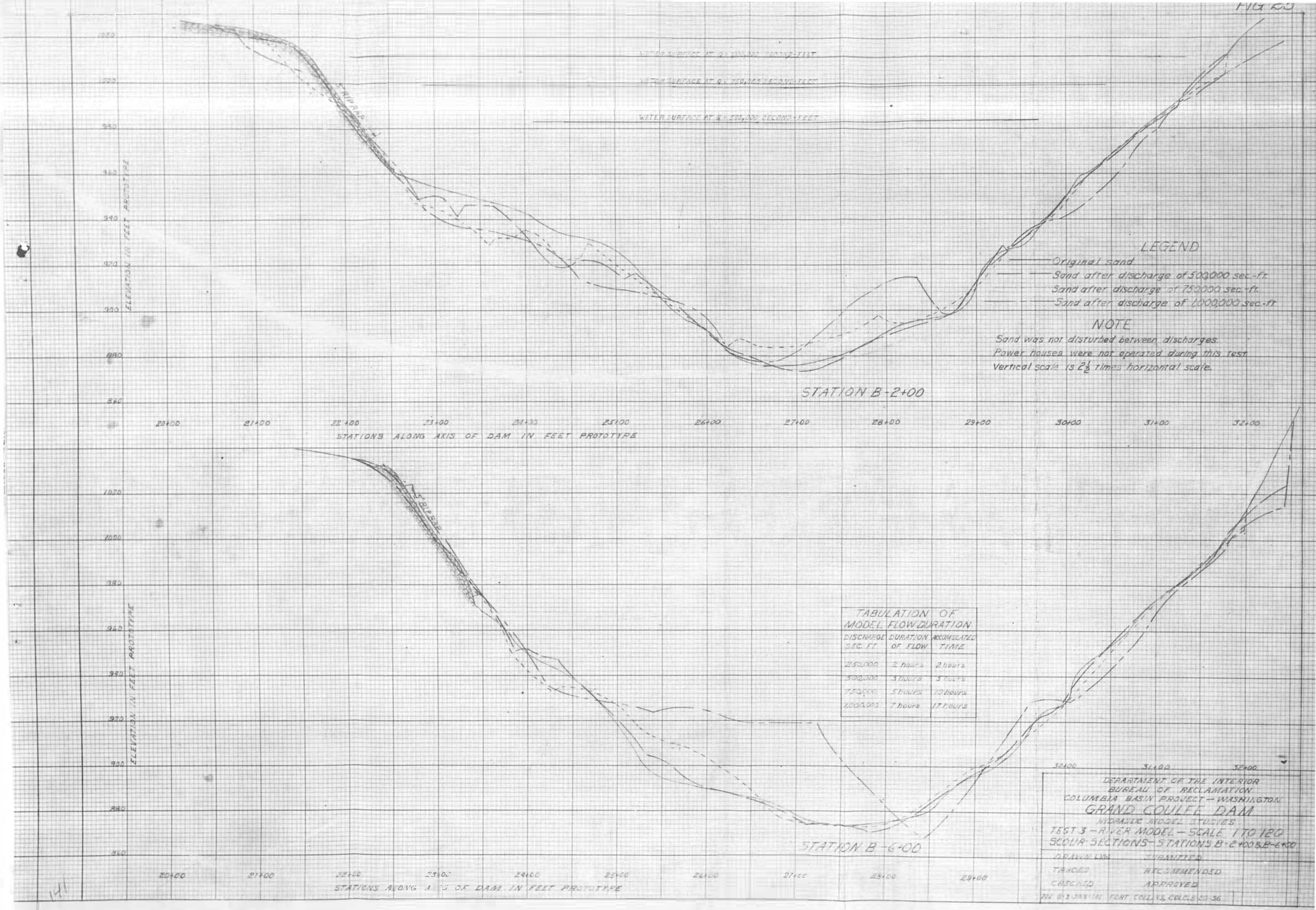
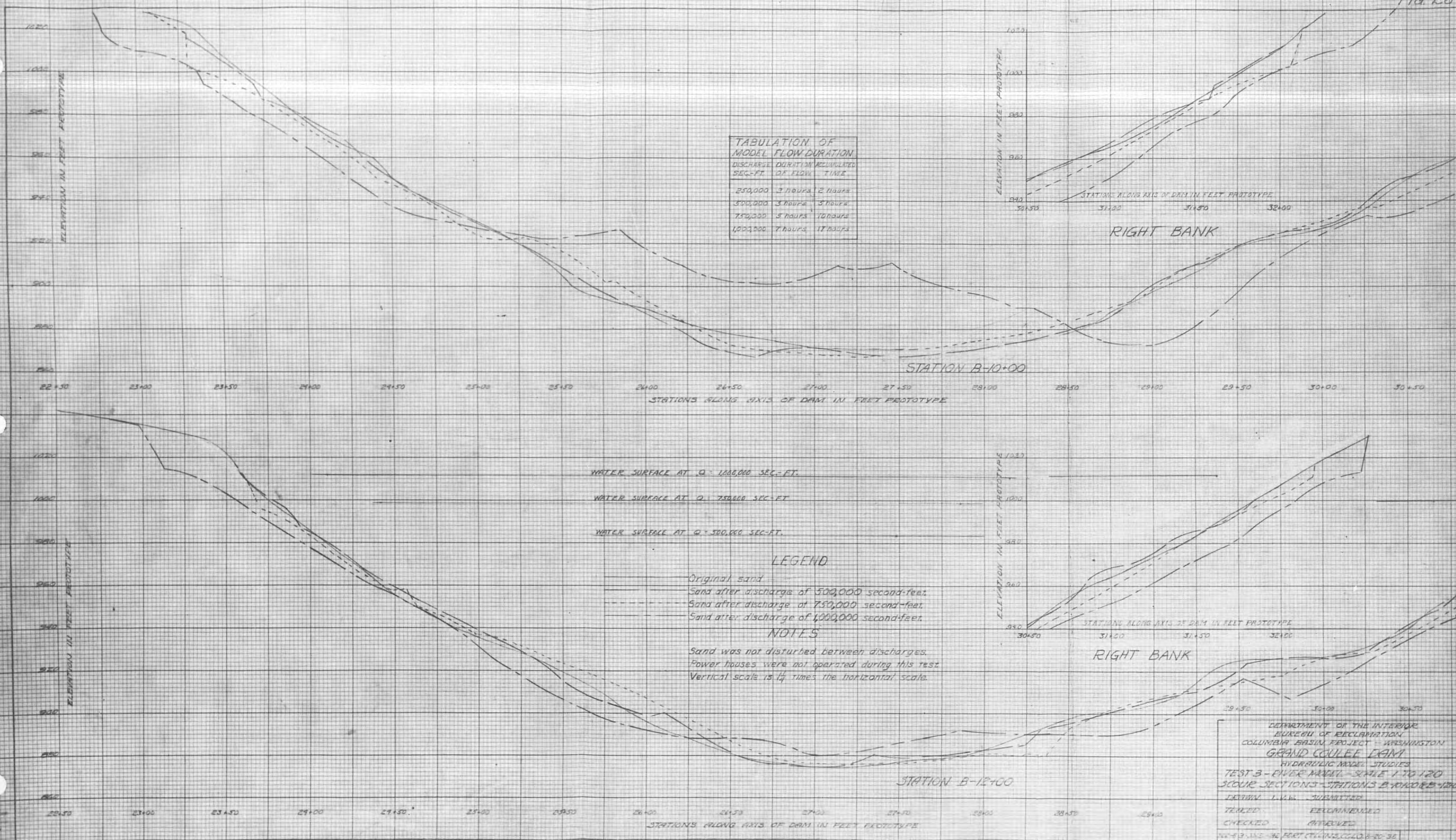

WATER SURFACE AT Q = 1,000,000 SECOND-FEET
WATER SURFACE AT Q = 750,000 SECOND-FEET
5" RIPRAP
ELEVATION IN FEET PROTOTYPE
LEGEND
Original sand
Sand after discharge of 500,000 sec-ft
Sand after discharge of 750,000 sec-ft
Sand after discharge of 1,000,000 sec-ft
NOTE
Sand was not disturbed between discharges.
Power houses were not operated during this test.
Vertical scale is 2½ times horizontal scale.
TABULATION OF MODEL FLOW DURATION
DISCHARGE SEC.-FT. | DURATION OF FLOW | ACCUMULATED TIME
250,000 | 2 hours | 2 hours
500,000 | 3 hours | 5 hours
750,000 | 5 hours | 10 hours
1,000,000 | 7 hours | 17 hours
STATION B 6+00
STATIONS ALONG AXIS OF DAM IN FEET PROTOTYPE
STATION B 2+00
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT – WASHINGTON
GRAND COULEE DAM
HYDRAULIC MODEL STUDIES
TEST 3 – RIVER MODEL – SCALE 1 TO 120
SCOUR SECTIONS – STATIONS B 6+00 & 2+00
DRAWN
SUBMITTED
TRACED
RECOMMENDED
CHECKED
APPROVED
222-D-3-ING-140 FORT COLLINS, COLO. 8-21-36
140



TABULATION OF MODEL FLOW DURATION

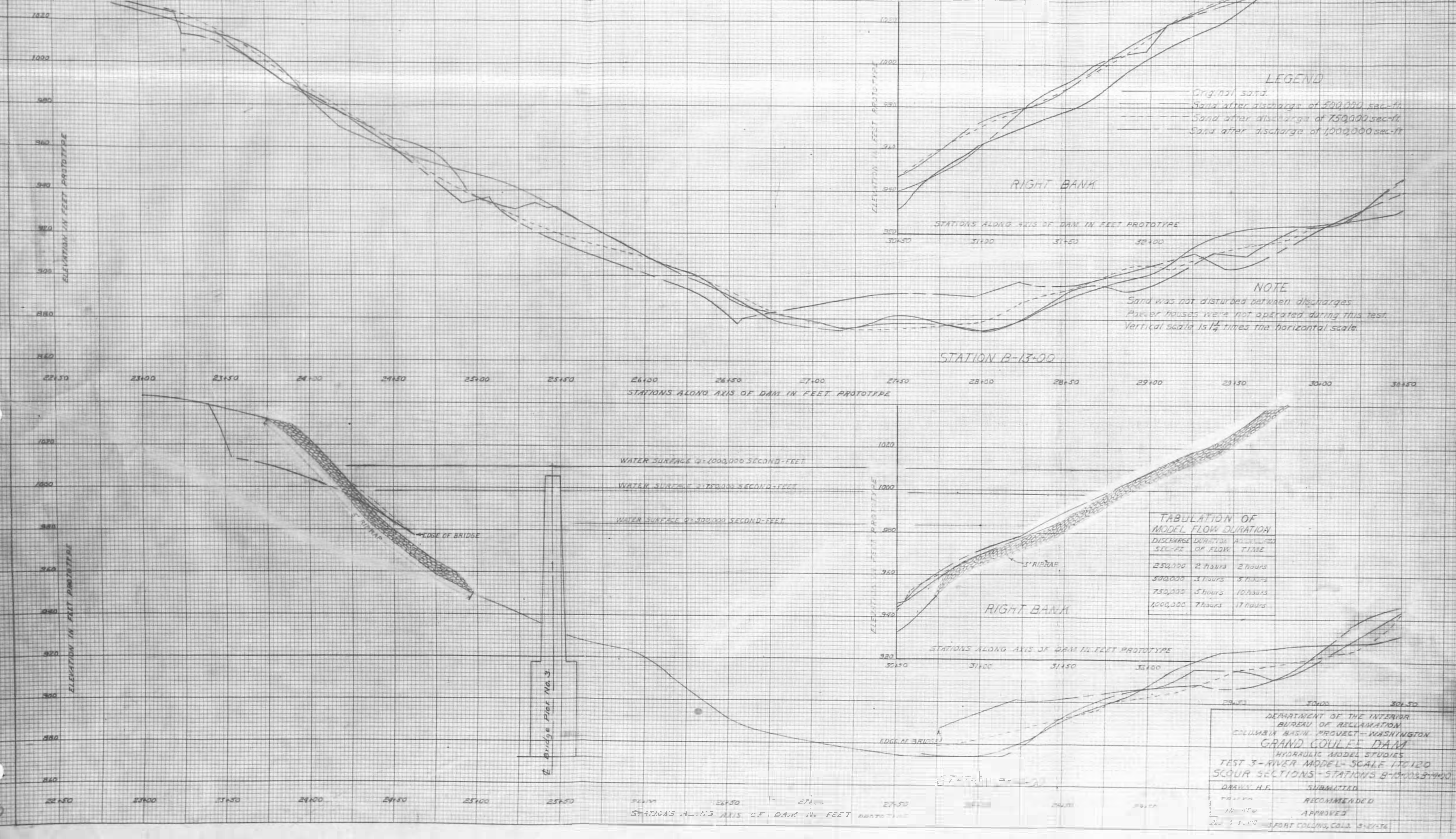
DISCHARGE SEC. FT.	DURATION OF FLOW	ACCUMULATED TIME
250,000	2 hours	2 hours
500,000	3 hours	5 hours
750,000	5 hours	10 hours
1,000,000	7 hours	17 hours



TABULATION OF MODEL FLOW DURATION

DISCHARGE SEC.-FT.	DURATION OF FLOW	ACCUMULATED TIME
250,000	2 hours	2 hours
500,000	3 hours	5 hours
750,000	5 hours	10 hours
1,000,000	7 hours	17 hours

FIG. 27


LEGEND
Original sand.
Sand after discharge of 500,000 sec-ft.
Sand after discharge of 750,000 sec-ft.
Sand after discharge of 1,000,000 sec-ft.
NOTE
Sand was not disturbed between discharges.
Power houses were not operated during this test.
Vertical scale is 1¼ times the horizontal scale.
ELEVATION IN FEET PROTOTYPE
RIGHT BANK
STATIONS ALONG AXIS OF DAM IN FEET PROTOTYPE
STATION B-13-00
WATER SURFACE Q=1,000,000 SECOND-FEET
WATER SURFACE Q=750,000 SECOND-FEET
WATER SURFACE Q=500,000 SECOND-FEET
EDGE OF BRIDGE
3' RIPRAP
℄ Bridge Pier No. 3
EDGE OF BRIDGE
TABULATION OF MODEL FLOW DURATION
DISCHARGE SEC-FT | DURATION OF FLOW | ACCUMULATED TIME
250,000 | 2 hours | 2 hours
500,000 | 3 hours | 5 hours
750,000 | 5 hours | 10 hours
1,000,000 | 7 hours | 17 hours
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT—WASHINGTON
GRAND COULEE DAM
HYDRAULIC MODEL STUDIES
TEST 3—RIVER MODEL—SCALE 1 TO 120
SCOUR SECTIONS—STATIONS B-13-00 & B-14-00
DRAWN H.F.
SUBMITTED
RECOMMENDED
APPROVED
FORT COLLINS, COLO. 5-27-36

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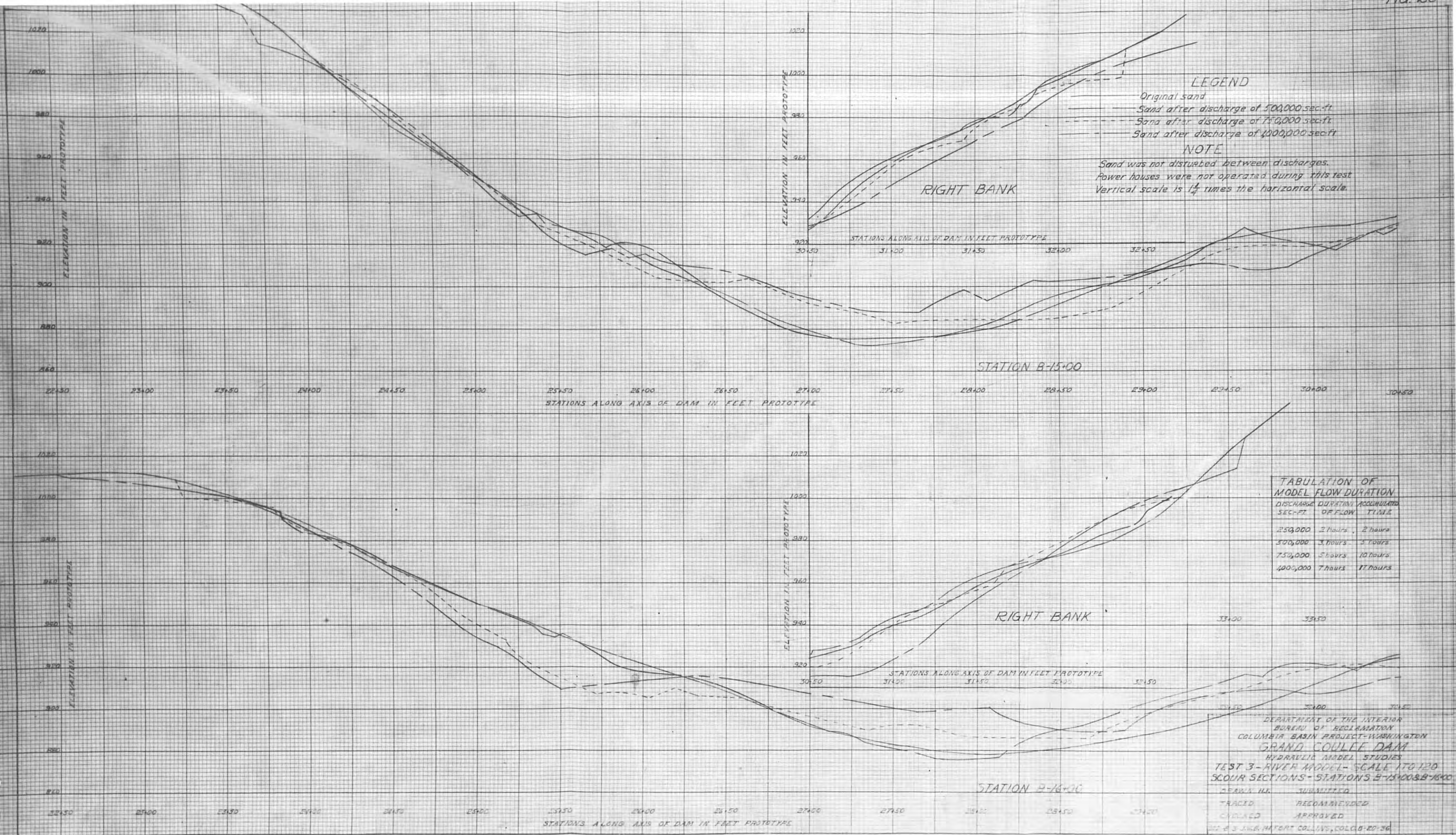
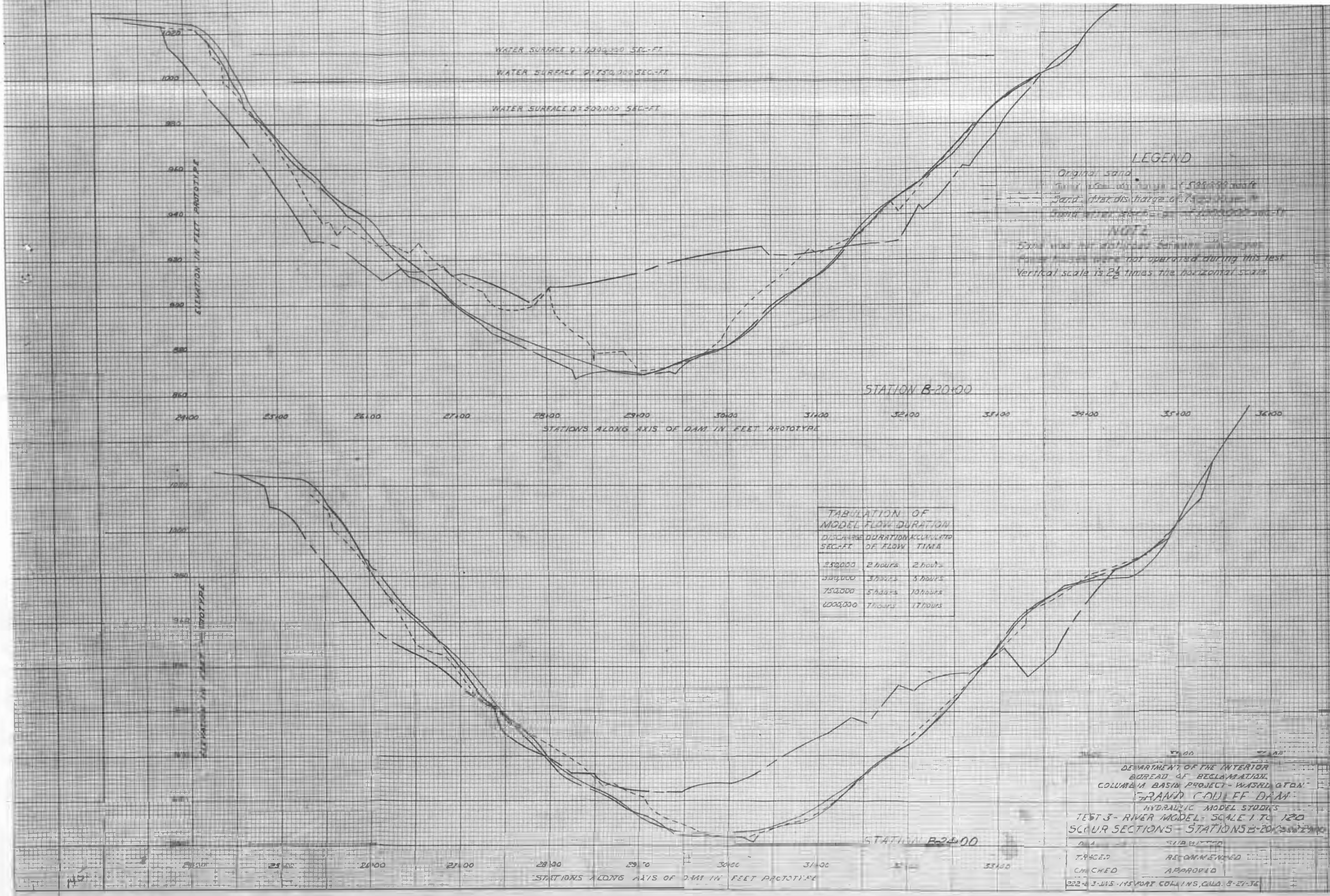
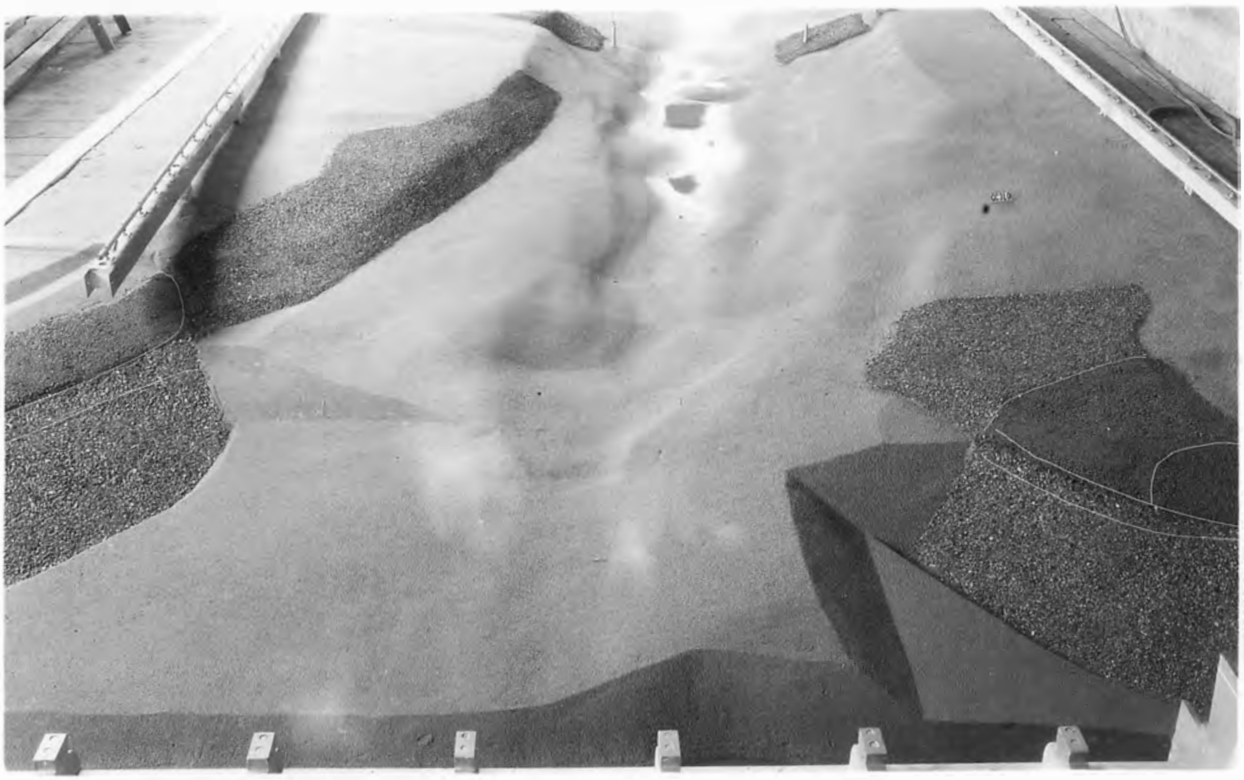


TABULATION OF MODEL FLOW DURATION

DISCHARGE SEC-FT.	DURATION OF FLOW	ACCUMULATED TIME
250,000	2 hours	2 hours
500,000	3 hours	5 hours
750,000	5 hours	10 hours
1,000,000	7 hours	17 hours


WATER SURFACE Q=1,000,000 SEC-FT.
WATER SURFACE Q=750,000 SEC-FT.
WATER SURFACE Q=500,000 SEC-FT.
ELEVATION IN FEET PROTOTYPE
LEGEND
Original sand
Vertical scale is 2½ times the horizontal scale.
STATION B-20+00
24+00
25+00
26+00
27+00
28+00
29+00
30+00
31+00
32+00
33+00
34+00
35+00
36+00
STATIONS ALONG AXIS OF DAM IN FEET PROTOTYPE
TABULATION OF MODEL FLOW DURATION
DISCHARGE SEC-FT.
DURATION OF FLOW
ACCUMULATED TIME
250,000
2 hours
2 hours
3 hours
5 hours
750,000
10 hours
17 hours
STATION B-24+00
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON
GRAND COULEE DAM
HYDRAULIC MODEL STUDIES
TEST 3 - RIVER MODEL - SCALE 1 TO 120
SCOUR SECTIONS - STATIONS B-20
TRACED
RECOMMENDED
CHECKED
APPROVED
FORT COLLINS, COLO. 8-21-36

LOOKING UPSTREAM.



LOOKING DOWNSTREAM.

INITIAL RIVER BED FOR TEST 3.

LOOKING UPSTREAM.

LOOKING DOWNSTREAM.

TEST 3 - RIVER BED AFTER A FLOW OF 500,000 SECOND-FEET.

LOOKING UPSTREAM.

LOOKING DOWNSTREAM.

TEST 3 - RIVER BED AFTER A FLOW OF 750,000 SECOND-FEET.

LOOKING UPSTREAM.

LOOKING DOWNSTREAM.

TEST 3 - RIVER BED AFTER A FLOW OF 1,000,000 SECOND-FEET.

BEFORE TEST.

AFTER DISCHARGE OF 500,000 SECOND-FEET.

AFTER DISCHARGE OF 750,000 SECOND-FEET.

AFTER DISCHARGE OF 1,000,000 SECOND-FEET.

TEST 3 - EROSION AT LEFT TAILRACE.

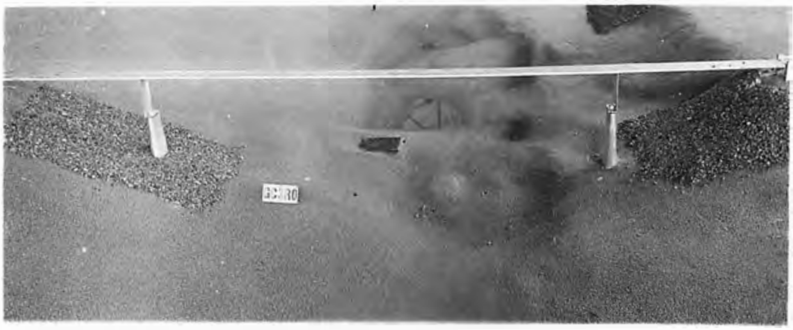
BEFORE TEST.

AFTER DISCHARGE OF 500,000 SECOND-FEET.

AFTER DISCHARGE OF 750,000 SECOND-FEET.

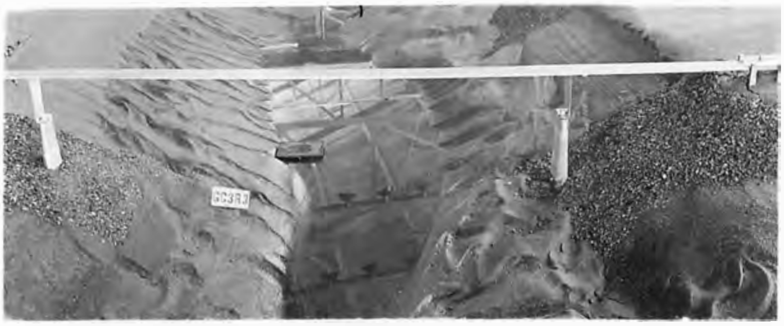
AFTER DISCHARGE OF 1,000,000 SECOND-FEET.

TEST 3 - EROSION AT RIGHT TAILRACE.



BEFORE TEST.

AFTER DISCHARGE OF 500.000 SECOND-FEET.



AFTER DISCHARGE OF 750,000 SECOND-FEET.

AFTER DISCHARGE OF 1,000,000 SECOND-FEET.

TEST 3 - LOOKING UPSTREAM - EROSION IN VICINITY OF BRIDGE PIERS.