ADDRESS ALL COMMUNICATIONS TO
THE CHIEF ENGINEER

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CUSTOMHOUSE
OFFICE OF THE CHIEF ENGINEER
DENVER, COLORADO

March 6, 1940.

From Chief Engineer

To Construction Engineer, Boise, Idaho.

Subject: Report on condition of diversion pipes and connecting outlets - Arrowrock Dam - Boise Project.

1. Reference is made to your letter of July 3, 1937, discussing the severe vibration experienced in the operation of the two 72-inch power outlets and the 42-inch outlet at elevation 3018.00 which were connected to the diversion tunnel. In that report you described the bad erosion or cavitation in the No. 1 power outlet, the erosion extending all the way from the end of the steel liner near the upstream face of the dam to the connection with the diversion pipe at the downstream face of the dam. In paragraph 6 you requested the advice of a Denver engineer on the occasion of a field trip.

2. On October 27, 1938, Engineer R. J. Sier of this office discussed this problem with you in connection with changes which should be made on the outlet pipes to eliminate the roaring effect when water is discharged through the pipes. In a memorandum to the chief designing engineer on June 6, 1939, Mr. Sier requested a study of this problem in the hydraulic laboratory and suggested the use of a conical reducer at the end of the pipes similar to the scheme finally adopted for use on the river outlets for Grand Coulee and Parker dams. Mr. Sier discussed this same design with you and you considered it a possible solution.

3. A model of one of the 72-inch power outlets has been constructed to a scale of 1 to 24, and eight tests completed. It is considered advisable at this time to acquaint you with these results.

4. The model was operated under heads duplicating 50 to 200 feet on the field structure (prototype) and the pressure conditions within the conduit were measured for valve openings of 25, 50, 75, and 100 percent. In seven of the eight tests made, the pressure conditions were the most severe at 100 percent

valve opening, the exception occurring in test 8. For purposes of this letter, therefore, the discussion will be limited to that condition except in the case of test 8, where the most severe pressure conditions occurred at 25 percent valve opening.

5. The eight tests made are as follows:

(a) No cone at the downstream end of the conduit.
(b) Cone 1 - reducing from 3 to 2.5 inches, model (72 to 60 inches, prototype).
(c) Cone 2 - reducing from 3 to 2.05 inches, model (72 to 49.2 inches, prototype).
(d) Cone 3 - reducing from 3 to 1.5 inches, model (72 to 36 inches, prototype).
(e) Cone 4 - reducing from 3 to 1.65 inches, model (72 to 39.6 inches, prototype).
(f) Cone 2 - reducing from 3 to 2.05 inches (72 to 49.2 inches, prototype). Section of pipe below elbow removed to level which would correspond to elevation 3011.81 in prototype.
(g) Cone 5 - reducing from 3 to 1.8 inches (72 to 43.2 inches, prototype). Section of pipe below elbow removed.
(h) Cone 5 - reducing from 3 to 1.8 inches (72 to 43.2 inches, prototype) with mouth of valve rounded. Section of pipe below elbow removed.

6. The vibration and cavitation in the 72-inch power outlets are due to the excessively low pressures created by the outlet entrance. Recent laboratory studies on Grand Coulee, Shasta, and Friant Dam hydraulic passages show that the type of entrance used on the Arrowrock outlets is unsatisfactory. If it will be necessary to use these outlets for future release of water, certain remedial measures might be followed -

(a) Place a cone at the end of each conduit with sufficient reduction in area to raise the pressure in the conduit entrance above a point that will cause cavitation. The cone, however, will reduce the discharge capacity of the conduit as will be shown in the test results.

(b) Remove a section of the pipe below the bend, and use the condition in conjunction with a cone. The results of the tests show that this procedure obtains positive pressures at all points with a small reduction of area, and consequent larger discharge, than in first alternative where only the cone was used. The pipe was removed to a level in the model which would correspond to elevation 3011.81 in the prototype.

(c) Change the profile of the entrance to obtain a better flow distribution. The feasibility of this course is questionable because of the necessity of making the changes when the reservoir level is below these outlets. Will the reservoir in the future be drawn sufficiently low to provide access to the valves and seats? The results encountered in test 8 also indicate that this change of profile would have to be considerably more elaborate than that attempted for the test made.

(d) Addition of air vents?

7. The pressure diagrams on the accompanying photostats (4-2-3-JHH-1,5,9,10,11,12,13 and 20) show the low pressures at the entrance without any constriction at the lower end and also the effect of different size cones. The data on the head-discharge curve show the reduction of discharge due to the reduction of area at the lower end. For comparative purposes these data are summarized in the following table:

	PROTOTYPE HEAD			
	50 feet	100 feet	150 feet	200 feet
Discharge, second-feet Prototype				
Test 1 - No cone	1410	1835	2115	2430
" 2 - Cone 1	1070	1370	1625	1910
" 3 - Cone 2	845	1060	1255	1415
" 4 - Cone 3	430	555	665	740
" 5 - Cone 4	520	680	805	905
" 6 - Cone 2	730	975	1175	1355
" 7 - Cone 5	535	760	925	1070
" 8 - Cone 5	565	770	930	1070
Percent Discharge, without cone				
Test 1 - No cone	100.0	100.0	100.0	100.0
" 2 - Cone 1	75.9	74.7	76.8	78.6
" 3 - Cone 2	59.8	57.9	59.2	58.2
" 4 - Cone 3	30.5	30.2	31.4	30.5
" 5 - Cone 4	36.2	37.1	38.1	37.2
" 6 - Cone 2	51.8	53.1	55.6	55.8
" 7 - Cone 5	39.4	41.4	43.7	44.0
" 8 - Cone 5	40.0	42.0	44.0	44.0

	PROTOTYPE HEAD			
	50 feet	100 feet	150 feet	200 feet
Min. Model Pressure, feet of water				
Test 1 - No cone	-7.6	-11.0	-13.7	-17.0
" 2 - Cone 1	-2.9	- 4.1	- 5.0	- 6.3
" 3 - Cone 2	-1.6	- 1.8	- 2.1	- 2.4
" 4 - Cone 3	+1.1	+ 2.5	+ 4.0	+ 5.4
" 5 - Cone 4	+0.6	+ 1.7	+ 2.8	+ 3.8
" 6 - Cone 2	-0.6	- 0.9	- 1.2	- 1.6
" 7 - Cone 5	+0.5	+ 1.2	+ 1.8	+ 2.3
* " 8 - Cone 5	-1.5	- 1.4	- 1.7	- 2.4
*25% opening gave min. pressures in test 8 - All others 100%				
Min. Prototype Pressure, feet of water				
Test 1 - No cone	Absolute	Absolute	Absolute	Absolute
" 2 - Cone 1	Absolute	Absolute	Absolute	Absolute
" 3 - Cone 2	Absolute	Absolute	Absolute	Absolute
" 4 - Cone 3	+26.4	+60.0	+96.0	+129.6
" 5 - Cone 4	+14.4	+40.8	+67.2	+ 91.2
" 6 - Cone 2	-14.4	-21.6	-28.8	Absolute
" 7 - Cone 5	+12.0	+28.8	+43.2	+55.2
" 8 - Cone 5	Absolute	Absolute	Absolute	Absolute

8. An examination of the tables shows that, considering discharge, the best results were obtained in test 7, in which combination of reducing cone 5 was connected to the conduit at elevation 3011.81 to produce the desired positive pressures. This method reduces the discharge to approximately 42 percent of the discharge of the original design; but the minimum prototype pressure obtained was 12 feet of water, thus affording reasonable proof that only positive pressures would occur on the prototype.

9. It is not known in this office just how important the discharge is in this case; however, assuming that the reduction of the discharge by this amount is feasible, such a solution seems to be the most satisfactory. The other suggestions would involve either a complete redesign of the profile of the entrance or the construction of air vents.

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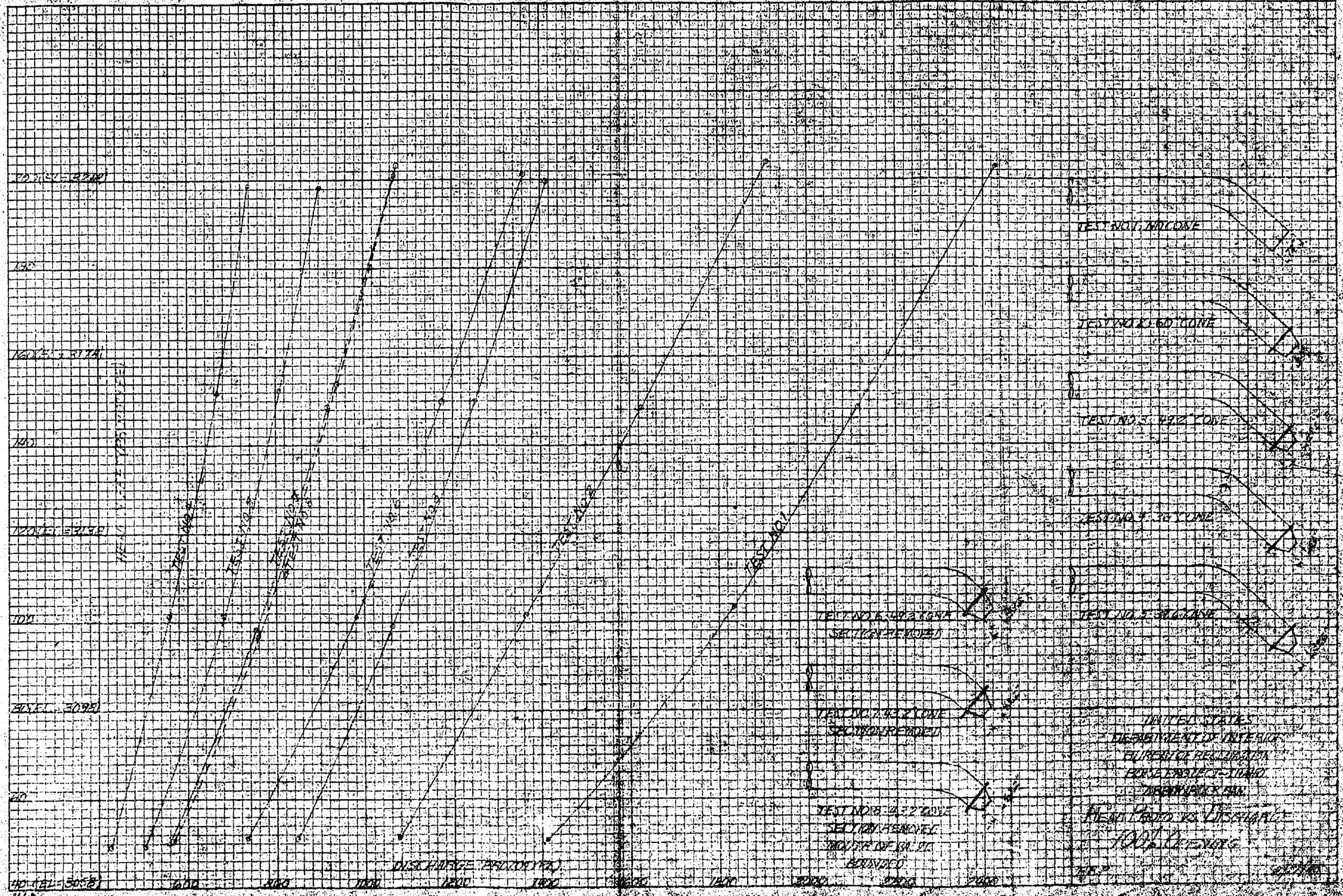
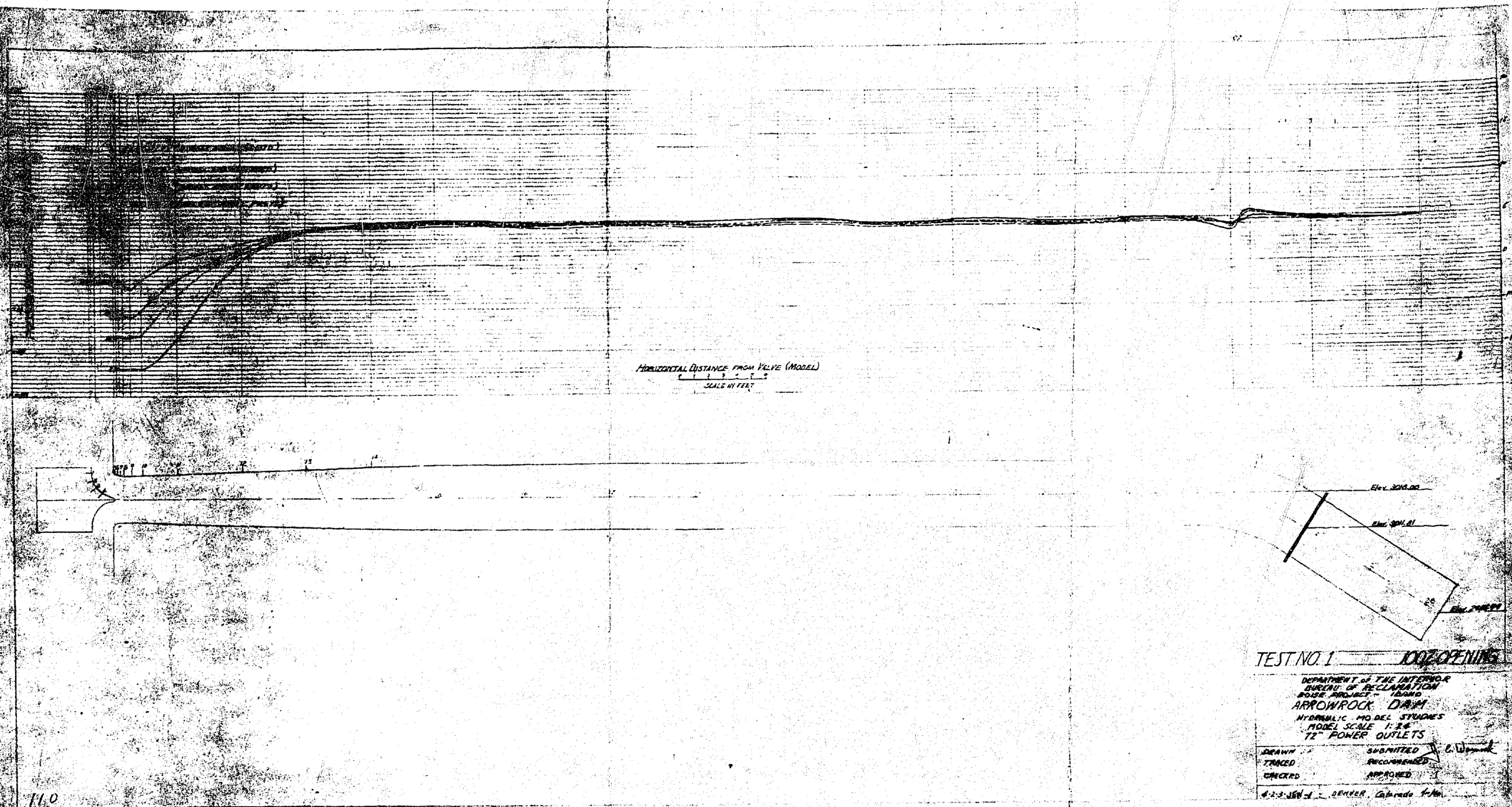
In dupl.



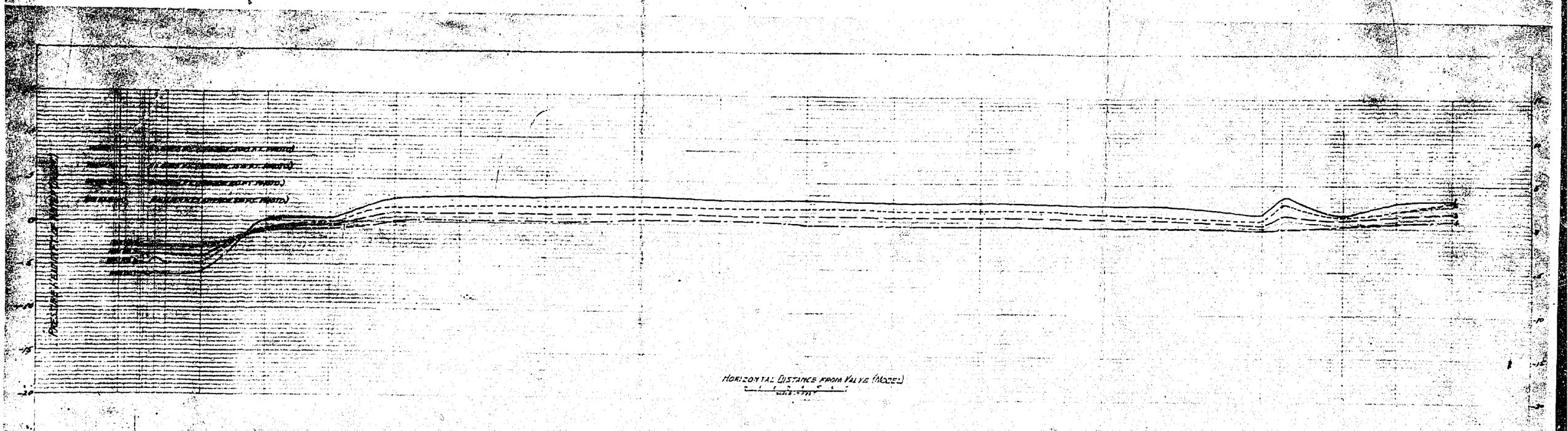


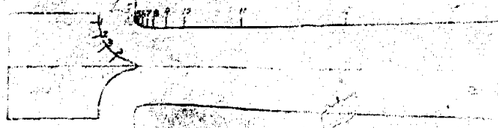
DEPARTMENT of THE INTERIOR
BUREAU OF RECLAMATION
BOISE PROJECT — IDAHO
ARROWROCK DAM
HYDRAULIC MODEL STUDIES
MODEL SCALE 1:24
72" POWER OUTLETS

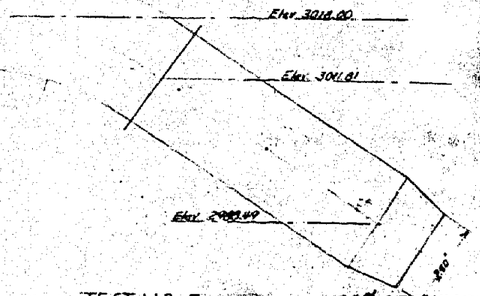
DRAWN	SUBMITTED	C. Warnick
TRACED	RECOMMENDED	
CHECKED	APPROVED	

4-2-3 JSW-d — DENVER, Colorado

Return to Warnick 4-8-...







TEST NO. 2 100% OPENING

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOISE PROJECT - IDAHO

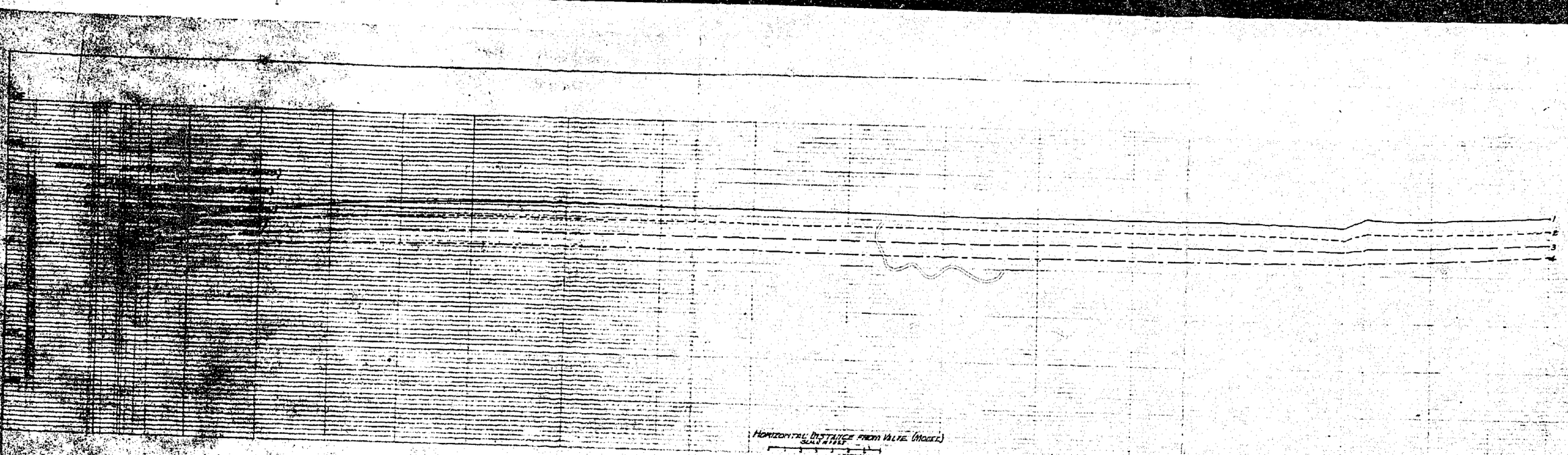
ARROWROCK DAM

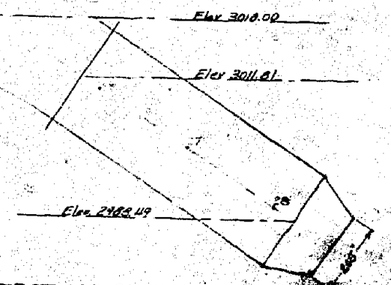
HYDRAULIC MODEL STUDIES
MODEL SCALE 1:24
72" POWER OUTLETS

DRAWN	SUBMITTED C. Wunsch
TRACED	RECOMMENDED
CHECKED	APPROVED

4-2-3-16W-5 DENVER, Colorado July

110





TEST NO. 3 100% OPENING

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOISE PROJECT - IDAHO

ARROWROCK DAM

HYDRAULIC MODEL STUDIES
MODEL SCALE 1:24
72" POWER OUTLETS

DRAWN
TRACED
CHECKED

SUBMITTED J. E. Warnock
RECOMMENDED
APPROVED

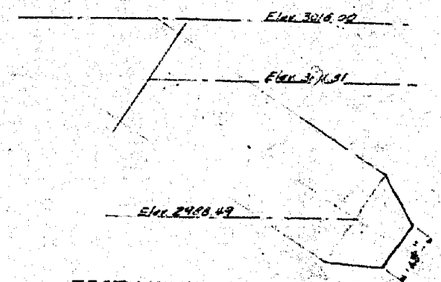
A-23-EM-9 DENVER, Colorado, 1/6/36

110

PRESSURE HEAD IN FEET (MODEL)

HORIZONTAL DISTANCE (MODEL)

SCALE IN INCHES



TEST NO 4 100% OPENING

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOISE PROJECT - IDAHO

ARROWROCK DAM

HYDRAULIC MODEL STUDIES
MODEL SCALE 1:24
12" POWER OUTLETS

DRAWN
TRACED
CHECKED
4-26-JSW-10

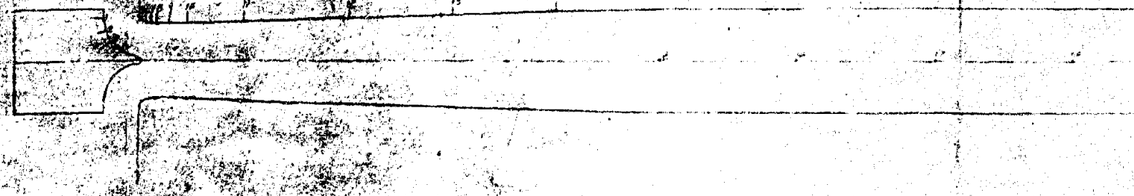
SUBMITTED
RECOMMENDED
APPROVED

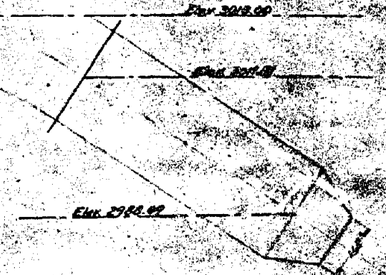
DENVER, COLORADO

HORIZONTAL DISTANCE FROM VALVE (MODEL)

0 1 2 3 4 5 6

SCALE IN INCHES



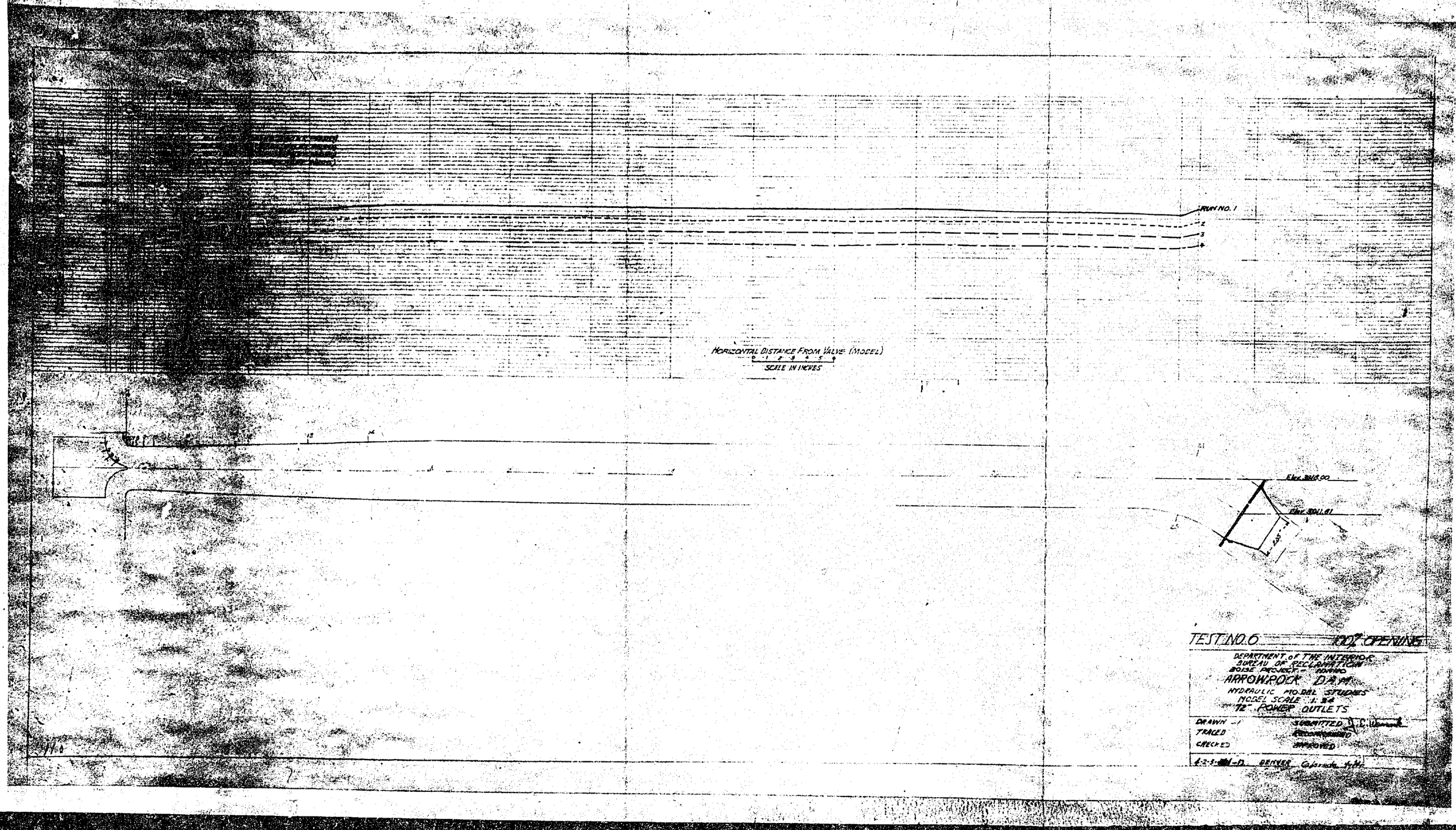


TEST NO. 5 OUTLET OPENING

DIVERSION DAM FOR IRRIGATION
BOISE PROJECT, IDAHO
ARROWROCK DAM
HYDRAULIC MODEL STUDIES
MODEL SCALE 1:24
72" POWER OUTLETS

DRAWN	SUBMITTED
TRACED	
CHECKED	

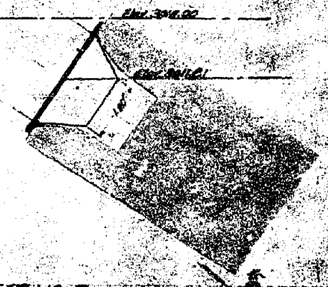
460-D-581-A1 DENVER, Colorado


RUN NO. 1
2
3
4
HORIZONTAL DISTANCE FROM VALVE (MODEL)
0 1 2 3 4 5
SCALE IN INCHES
Elev. 3049.00
Elev. 3041.81
TEST NO. 6 100% OPENING
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOISE PROJECT - IDAHO
ARROWROCK DAM
HYDRAULIC MODEL STUDIES
MODEL SCALE 1:24
72" POWER OUTLETS
DRAWN
TRACED
CHECKED
SUBMITTED C. Warnock
RECOMMENDED
APPROVED
4-2-5-M-D DENVER, Colorado, U.S.A.

RUN NO. 1

HORIZONTAL DISTANCE FROM VALVE (MODEL)

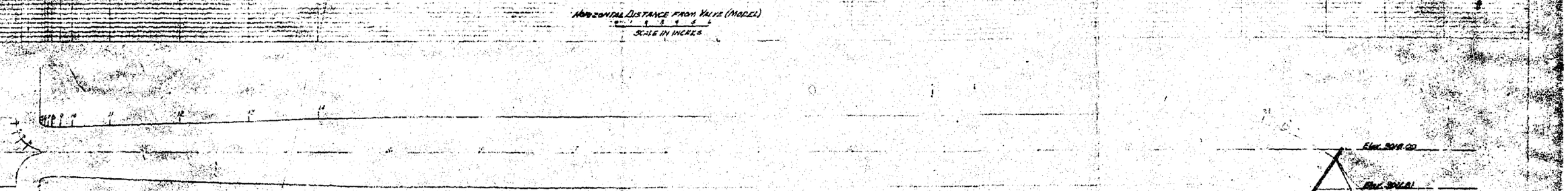
SCALE IN INCHES



TEST NO 7 — TOP OF OPENING

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOISE PROJECT - IDAHO
ARROWROCK DAM
HYDRAULIC MODEL STUDIES
MODEL SCALE 1:24
12" POWER OUTLETS

DRAWN — SUBMITTED
TRACED — RECOMMENDED
CHECKED — APPROVED
425-ED-D — DENVER, Colorado



TEST NO. 8 25% OPENING

DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
SNAKE PROJECT — IDAHO
ARROWROCK DAM
HYDRAULIC MODEL STUDIES
MODEL SCALE 6:1
72" POWER OUTLETS

DRAWN	SUBMITTED C.W. Wenzel
TRACED	RECOMMENDED
CHECKED	APPROVED

4-2-3-JAN-20 DENVER, Colorado, U.S.A.