UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

# HYDRAULIC MODEL STUDIES OF THE ENSIGN BALANCED VALVES--ARROWROCK DAM

Hydraulic Laboratory Report No. Hyd-258

RESEARCH AND GEOLOGY DIVISION

BRANCH OF DESIGN AND CONSTRUCTION
DENVER, COLORADO

APRIL 25, 1949

UNITED STATES
DEPARTMENT OF THE INTERIOR
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Branch of Design and Construction
Research and Geology Division
Denver, Colorado
Date: April 25, 1949

Laboratory Report No. 258
Compiled by: D. Colgate
Reviewed by: J. W. Ball

Subject: Hydraulic model studies of the Ensign balanced valves--Arrowrock Dam.

## PURPOSE OF STUDIES

When the Ensign valves at Arrowrock Dam are allowed to discharge under high heads, severe cavitation results which damages the outlet conduits by pitting. The proposed operating schedule for flood control requires that the valves be operated at heads up to double that now considered to be the allowable maximum. Hydraulic studies were made on a model of one of the lower irrigation outlets to determine the feasibility of making minor alterations to the valve seat rings to eliminate or materially reduce such cavitation so that flood control requirements might be met.

## CONCLUSIONS

Minor alteration (streamlining) of the valve seat rings would increase the outlet capacity, but would not improve the pressure conditions in the valve throats sufficiently to prevent damaging cavitation at high heads. Only by a major revision of the valves, or by restricting the flow areas downstream from the valves, would it be possible to prevent severe cavitation and damage to the conduit.

## RECOMMENDATIONS

In view of the results of the model investigation, it is recommended that no alteration be made to the valves, but that each of the seven 52-inch lower valve outlets and one 72-inch power conduit outlet at elevation 3018 be provided with some form of restriction, perhaps of the wedge-like shape used in the model study, to raise the pressure gradient within the conduit, thereby permitting safe operation under high heads. It is recommended also that the discharge ends of the 52-inch outlet and the 72-inch power conduit, which have steel pipe extensions leading to the sloped entrance of the diversion tunnel, be rearranged to allow the flow to discharge directly into the river channel, thereby eliminating any damage which would result from the turbulent flow if these outlets were allowed to discharge into the diversion tunnel when it is filled by backwater from Lucky Peak Reservoir.

## HISTORICAL BACKGROUND

With the development of water and power resources on the upper reaches of the Boise River, plans for routing floodwaters through the reservoir at Arrowrock Dam have become increasingly important. Early studies indicated that it would be necessary to provide a maximum capacity of 20,000 cubic feet per second with the Arrowrock Reservoir at elevation 3210. Such a discharge would require the use of 8 of the 10 elevation 3018 outlets and all of the elevation 3105 outlets, (Figure 1). The elevation 3018 outlets would have to be altered in some way, or perhaps completely revised, since the Ensign valves controlling the release from these outlets cannot be operated under high heads without causing severe cavitation erosion to the outlet tunnels.

Several alternate schemes for providing the required capacity, including proposed arrangements, discharge capacities, and cost estimates, were outlined in a memorandum from W. G. Weber to W. C. Beatty, dated May 27, 1946, (Appendix I), which was transmitted from the Denver office to the Region 1 office by a letter dated August 20, 1946. Cost estimates for model tests and other design work, required to determine the most economical and feasible plan, were requested by the Regional office in a letter dated October 4, 1946. Plans IA and IIA, listed in the memorandum mentioned above, were considered most likely to satisfy the capacity requirements at a reasonable cost and were submitted to the region by a letter dated December 24, 1946. Authorization to proceed with the studies needed to determine the feasibility of Plan IA, involving minor alterations to the valves in the proximity of the seat rings, was contained in a letter from the Regional Director to the Chief Engineer, dated April 19, 1948. A request for model studies relative to this plan was made by the Head of the Mechanical Division in a memorandum to the Chief Engineer, dated May 13, 1948, and approved on May 28. The model investigation was started shortly thereafter and the testing was completed in September 1948.

A teletype dated August 18, 1948, from the region to the Denver office revised the discharge capacity requirements for flood control. In the revised plans, it was desired that a capacity of 10,000 cubic feet per second be available when Arrowrock Reservoir was at elevation 3118 and Lucky Peak Reservoir at or below elevation 3020. Upon receipt of the above teletype, Mr. W. C. Beatty, Consulting Engineer, was requested by the Head of the Mechanical Division to Compile information relative to the Arrowrock problem. The information was presented in a memorandum dated September 17, 1948, from Mr. Beatty to the Chief Engineer. The memorandum is contained in this report as Appendix II.

## THE INVESTIGATION

Description of the model. The hydraulic model utilized in the study of the Arrowrock outlets consisted of a high-pressure steel tank, a 1:8-2/3 scale bronze model valve, and a section of brass pipe to represent the discharge conduit, (Figure 2). The model had been used previously for an investigation of conditions in the outlets at Shoshone Dam. Sections of the valve throat were removed as shown in Figure 3 to streamline the passage and make it conform with the alterations set forth under Proposal IA in W. G. Weber's memorandum to W. C. Beatty, (Appendix I). Nine piezometer openings were placed in the seat ring and throat of the model valve to enable a study of the pressure conditions at critical points. The shut-off plunger, arranged initially to be operated hydraulically, was locked in the fully open position for the tests, since it was planned that the prototype valve would not be operated at partial openings.

Effect of streamlining the valve seat ring. An increase of about 1-1/2 percent in the discharge capacity was realized with the minor throat alteration, (Figure 7). Severe negative pressures were measured on the seat ring and in the throat immediately downstream, when the model was operated at heads corresponding to from 100 to 200 feet prototype, indicating that cavitation, which limits the use of the present outlets, would be nearly as intense and extensive as if no change had been made, (Figure 4). It appeared that major revisions of the valves would be required to obtain satisfactory pressure conditions, but it was considered impracticable to make these revisions even though an increase in capacity would be realized.

Since the most severe subatmospheric pressure in the region of the valve seat was immediately downstream from the seal recess of the seat ring, it seemed possible that this condition might result from a separation of the flow from the boundary at the sharp downstream edge of the recess. To determine if such was the case the recess was filled with beeswax and formed to the contour of the valve throat. The pressure distribution in the vicinity of the seat ring and the discharge capacity remained unchanged; thus, it was concluded that the recess had no influence on the valve characteristics.

Effect of increasing needle-tip diameter. An attempt was made to raise the pressures in the throat by attaching a short piece of pipe to the needle tip as shown in Figure 3. It was believed undesirable to use pipe larger than 8 inches in diameter for the prototype, so the model was altered with this in mind. There was no improvement in the pressure conditions and further study of this treatment was not made.

Effect of tunnel restriction. It became evident that satisfactory operation of the outlets at Arrowrock Dam could not be obtained by making minor alterations to the valves. Restricting the flow area at the exits of the conduits was considered to be the next logical step to obtain satisfactory operation. The treatment was not new; it had been investigated previously in connection with the elimination of cavitation pressures on the walls of the Arrowrock power conduits and found most effective. It was realized that some reduction in discharge capacity would result from restricting the flow area, but whether this reduction would be sufficient to make the plan impracticable was not known. The model study, therefore, resolved into tests concerning pressure conditions within the outlet conduit and changes in discharge capacity resulting from different degrees of restriction.

The 1:8-2/3 scale-model valve was restored to its original contour, representing the prototype installation. Wedge-like restrictions of various sizes were placed in the conduit at its downstream end, (Figure 5), and pressure and discharge measurements made. Curves were prepared showing (1) the minimum pressure at the critical zone in the valve throat versus depth of the wedge restricting the end of the conduit, and (2) the discharge for various depths of the restricting wedge, (Figure 6). Assuming an allowable minimum pressure in the valve throat, the size of the restricting wedge necessary to give that pressure may be determined from Figure 6.

It was believed that there would be little danger of cavitation if the minimum throat pressure was limited to -15 feet of water when the outlets were operating at maximum head. The wedge thickness for this minimum value is 7.4 inches. The use of this wedge in the lower irrigation outlets would decrease the capacity by about 8 percent. If one of the power conduits were restricted to provide approximately the same discharge as an irrigation outlet, the total capacity of the 18 outlets would be about 10,200 cubic feet per second with the water surface in Arrowrock Reservoir at elevation 3118, (Figure 7).

Even with the tunnel restriction it is possible that cavitation will occur in small areas just downstream from the "V" guides when the outlets are operated at high heads. Such action would be concentrated on the metal parts of the throat liners where resistance to erosion would be a maximum and therefore could perhaps be tolerated for the short periods the valves would be in operation. Cavitation could be eliminated by providing larger tunnel restrictions, but the use of at least two power conduits would be required to realize the desired discharge. An investigation of the maximum pressures within the conduits should be made if larger restrictions are to be used. This pressure might be of such magnitude as to require lining of the conduits.

Cavitation begins in the present irrigation outlets when the head is approximately 75 feet; thus, some damage is to be expected in the upper tier outlets when they are operated for long periods at heads in excess of this figure.

# APPENDIX I

Denver 2, Colorado

May 27, 1946

Memorandum to Mr. W. C. Beatty
(W. G. Weber)

Subject: Alteration of outlets at Arrowrock Dam, Boise Project, Idaho.

1. There are at present the following openings through Arrowrock Dam:

a. Ten 52-inch diameter outlets at elevation 3105.00. Each outlet is approximately 70 feet long, with concrete walls except for about 28 feet of cast-iron lining at the upstream end. Each outlet is closed at its upstream end by a 58-inch Ensign-type balanced valve, with three of the ten valves equipped with positive controls for regulation.

b. Seven 52-inch diameter outlets at elevation 3018. Each outlet is approximately 128 feet long with walls, lining, and control valves (including three positive controls) as at elevation 3105.

c. Three 72-inch diameter outlets at elevation 3018, concrete-walled except for a 28-foot cast-iron-lined taper section at the upstream end of each outlet joined to a 58-inch Ensign-type balanced valve.

Two of the 72-inch diameter outlets and one 58-inch diameter outlet at elevation 3018 are connected through steel discharge pipes to the lower end of the construction diversion tunnel.

d. Five 60-inch diameter sluicing outlets 164 feet long at elevation 2967. A 6-foot by 5-foot high-pressure gate 28-1/2 feet from the face of the dam controls the flow in each outlet. Outlets are unlined except for a total of about 20 feet of cast-iron lining immediately upstream and downstream from each gate. These gates were designed for operation under heads of not more than 75 feet.

2. The present discharge capacity of the ten valves and outlets at elevation 3105 with the water surface at elevation 3210 (spillway crest) is approximately 10,000 cfs. Since none of the balanced valves, under present operating instructions, may be operated at more than about 100 feet of head, this 10,000 cfs discharge rate represents approximately the maximum present permissible discharge with the water surface at or lower than elevation 3210.

3. It is desired that a maximum flood control discharge rate of 20,000 cfs, with the reservoir water surface at elevation 3210, be made practicable, and that a discharge rate of 8,000 cfs for irrigation be available in season.

4. Various means of increasing the rate of discharge to the desired amount have been considered, and some of the more feasible proposals are outlined below. In all instances, the outlets at elevation 3105 are to be left unchanged, and no discharge from the sluice gates (elevation 2967) is included.

I-A. Leave all 58-inch balanced valves at elevation 3018 and the seven 52-inch diameter outlets unchanged except that the valves in the 52-inch outlets will have minor alterations made to seats. Under this proposal it is intended that all of the elevation 3018 balanced valves considered shall be used to discharge water when fully opened with heads up to 192 feet (W. S. 3210), leaving the positive control valves to discharge at partial openings when required at less than 100-foot heads as at present. The seat alterations, to be determined and checked by laboratory test using a model of the Shoshone balanced valve now on hand, are expected to eliminate cavitation to the extent that no more damage will be caused in the elevation 3018 valves and outlets under the higher heads than is now caused in the elevation 3105 installations. This damage, so far as is known to this office, is not serious. The 58-inch balanced valves at Shoshone Dam are similar in design to the Arrowrock valves, and have been operated at heads up to 215 feet without material damage to the valves. The Arrowrock elevation 3018 valves have also been operated at times at materially higher heads than the recommended 100 feet. (Ref. correspondence and "High-Pressure Reservoir Outlets" by Gaylord and Savage.) It is therefore proposed that, subject to favorable reports resulting from a thorough investigation of the present physical condition and operating characteristics of the elevation 3018 <u>balanced</u> valves, and of the present condition of the 52-inch diameter outlets through which they discharge, tests of a model-size valve of this type now available in the laboratory be made as suggested above, and, if tests are satisfactory, the seats of the seven valves in the 52-inch outlets be altered to correspond. This proposal provides a high discharge rate at the lowest cost of any considered. A section through the dam showing the outlets, and estimated costs and discharge curves are attached hereto under Proposal No. 1-A. Valve seat alterations, as now contemplated, could be made without dismantling of the valves but would require that the reservoir water level be dropped below elevation 3018 for a relatively short time.

I-B. Same as Proposal No. I-A but with all ten of the elevation 3018 valves altered and the three 72-inch outlets lined with 52-inch diameter concrete-backed steel pipe and discharging into the diversion tunnel. This proposal gives the highest discharge rate of any of the lower cost proposals considered. Estimated cost and discharge curves are shown under Proposal No. I-B.

II-A. In the event that either the results of laboratory model tests do not indicate that satisfactory discharge characteristics can be obtained by valve seal alterations, or field reports indicate that Proposals I-A and I-B are not feasible, it is proposed that all balanced valves at elevation 3018 be left unchanged, but that the 52-inch outlets be lined with 48-inch ID grout-encased steel pipe. It is expected that the decrease in the size of the outlets will create enough back pressure at the valve discharge orifices to virtually eliminate cavitation. Laboratory confirmation is available. Cost and discharge estimates are given under attached Proposal II-A. All work under Proposal II-A can be performed with balanced valves closed and reservoir water level at any elevation.

II-B. Same as II-A but with all ten elevation 3018 outlets lined with 48-inch steel pipe. Cost and discharge data II-B are attached. Obviously, if tests indicate that a compensating advantage will be gained, valve seat alterations, as under I, may also be made.

III-A. Line seven 52-inch outlets at elevation 3018 with 48-inch pipe as under II-A and install a 54-inch hollow-jet valve at the downstream end of each outlet. The present 58-inch balanced valves would be retained for emergency closure. Under this proposal, elimination of cavitation would be assured, and emergency closure of each of the seven outlets would be provided. Estimated cost and discharge curves are shown under Proposal No. III-A. Forty-eight-inch lining and 54-inch hollow-jet valves may be added for the three remaining outlets at elevation 3018, and discharge curves are shown for this condition, but the additional work is not included in the estimates.

III-B. Same as Proposal III-A except that the use of a modified hollow-jet valve is contemplated. It is believed that the modified hollow-jet tube valve can be manufactured at a lower cost than the present type of valve, and it is expected that laboratory tests will show a higher discharge coefficient. The valve is not yet out of the development stage, but estimated cost and discharge curves are given under III-B.

5. Other proposals have been considered, among them being Proposal IV, to enlarge the outlets to 72 inches, line them with 66-inch diameter steel pipe, and install 72-inch hollow-jet valves or 66-inch hollow-jet tube valves after removing the 58-inch balanced valves and providing bell-mouth inlets, a fixed-wheel gate, and a gantry crane; and Proposal V, to drive a new 16-foot diameter outlet under the left side of the dam, with steel lining, upstream stop logs, and six 78-inch hollow-jet valves or six 72-inch hollow-jet tube valves at the branched downstream end. All of these other proposals appeared too costly, impractical, or involving dangerously long periods of depleted reservoir storage.

6. A table showing the estimated cost and maximum discharge for each proposal is given below. Discharge from the ten outlets at elevation 3105 is included in each case.

| Proposal No. | Description | Estimated cost | Max. discharge cfs at res. El. 3210 |
|---|---|---|---|
| I-A | Modify seats on seven valves at El. 3018. | $9,800 | 18,400 |
| I-B | Modify seats on ten valves at El. 3018 and install 52-inch diameter steel lining in three power outlets. | 66,720 | 22,000 |
| II-A | Install 48-inch diameter steel pipe lining in seven outlets at El. 3018. | 64,620 | 17,600 |
| II-B | Install 48-inch diameter steel lining in seven irrigation and three power outlets at El. 3018. | 118,830 | 21,000 |
| III-A | Install 48-inch diameter steel pipe lining and 54-inch hollow-jet valves in seven outlets at El. 3018. | 249,724 | 16,800 |
| | Including 48-inch steel pipe lining in three power outlets at El. 3018. | 301,934 | 20,000 |
| III-B | Same as III-A except install hollow-jet tube valves. | 185,384 | 17,400 |
| | Including 48-inch steel pipe lining in three power outlets at El. 3018. | 237,594 | 20,400 |
| IV-A | Enlarge seven outlets at El. 3018 and install 66-inch diameter steel pipe lining and 72-inch hollow-jet valves. | 655,174 | 22,800 |
| IV-B | Same as IV-A except install seven 66-inch hollow-jet tube valves. | 519,910 | 22,800 |

| Proposal No. | Description | Estimated cost | Max. discharge cfs at res. El. |
|---|---|---|---|
| V-A | Install 16-foot diameter steel conduit at El. 3045, station 3+00 and install six 78-inch hollow-jet valves. | $758,100 | 21,200 |
| V-B | Same as V-A except install six 72-inch hollow-jet tube valves. | 517,800 | 21,200 |

7. The cost and discharge data have been prepared through Mr. B. H. Staats and Mr. J. W. Adolphson. A copy of a memorandum from Mr. D. J. Hebert is also attached.

CC-Byron H. Staats
John W. Adolphson
D. J. Hebert through J. E. Warnock

# APPENDIX II

Denver, Colorado

September 17, 1948

Memorandum

To: Chief Engineer
Through Chief, Mechanical Division

From: W. C. Beatty

Subject: Alterations to Arrowrock Dam to accommodate backwater from Lucky Peak Reservoir and provide 10,000 cfs discharge capacity from present valve installation at reservoir elevation of 3118 feet and above.

1. The purpose of this report is to list and discuss some of the main factors which should be considered in altering Arrowrock Dam to meet the flood-control requirements stated in a teletype from Regional Director, Region 1 to th› Denver office dated August 18, 1948. The data given herein should be supplemented as additional information is obtained. This report has been prepared at the request of the Chief of the Mechanical Division. J. W. Ball and D. Colgate collaborated in its preparation.

2. The three dams, Anderson Ranch, Arrowrock, and Lucky Peak, will be used to control floods in the Boise River. It is understood that the reservoirs above these dams will be filled in the order listed above and emptied in reverse order. For operation in this manner, the United States Engineers' Office has indicated that a minimum of 10,000 cfs outlet capacity will be required at Arrowrock for reservoir levels at and above elevation 3118.

3. The following data will be considered in discussing these factors:

Arrowrock Dam

Elevation 3105 Outlets--Ten 58-inch needle valves--52-inch conduits
Elevation 3018 Outlets--Seven 58-inch needle valves--52-inch conduits
Elevation 3018 Power outlets--Three 58-inch needle valves--72-inch conduits
Elevation 2967 Sluice outlets--Slide gates--60-inch diameter outlets
Elevation 3210--Spillway crest
Elevation 3216--Maximum water elevation
Maximmm heads on valves--Upper tier, 111-feet--Lower tier, 198 feet

Lucky Peak Dam

Elevation 3060--Maximum water surface
Elevation 3020--Discharge 10,000 cfs--Channel capacity

4. Since the outlets at Lucky Peak Dam are to be designed to handle the maximum capacity of the river channel downstream, 10,000 cfs, at reservoir elevation 3020, there seems to be no requirement for discharging this amount from Arrowrock when Arrowrock Reservoir is at elevation 3118 and Lucky Peak Reservoir is above elevation 3020. As Lucky Peak Reservoir is to be filled last and emptied first, this condition should seldom, if ever, exist. The discharge capacity for various degrees of submergence of the conduits can be determined from the attached graph.

5. The number of outlets required to release 10,000 cfs from Arrowrock Reservoir, with a water-surface elevation of 3118 and Lucky Peak Reservoir at or below elevation 3020, is as follows:

a. Assuming that 17 valve outlets and 1 power conduit will be used and that there will be no alteration to prevent cavitation at high heads except to the power outlet

| | |
|---|---|
| 7 lower outlets, 930 cfs each | 6,510 cfs |
| 1 power conduit (altered) | 855 |
| 10 upper outlets, 334 cfs each | 3,340 |
| Total outlet capacity | 10,705 cfs |

b. Assuming the same number of conduits will be used and that the seven lower valve outlets and one power conduit will be altered to prevent cavitation at high heads

| | |
|---|---|
| 7 lower outlets (altered) 855 cfs each | 5,985 cfs |
| 1 power conduit (altered) 855 cfs | 855 |
| 10 upper outlets (no alterations) 334 cfs each | 3,340 |
| Total outlet capacity | 10,180 cfs |

The above quantities are based on the discharge curves obtained from the model and contained on the attached graph. The submergence caused by Lucky Peak Reservoir being at elevation 3020 has not been considered in making the foregoing estimates; thus the actual capacity may be slightly less than indicated above.

6. It is not good engineering to assume that all 18 outlets are available for use 100 percent of the time. The decrease in capacity due to some of the valves being inoperative should not be critical however, since the capacity increases rapidly as the water surface in Arrowrock rises. For instance, if we assume that only 8 upper and 6 lower outlets (altered) can be used to release water from Arrowrock Reservoir, it would be possible to discharge 10,000 cfs with the water surface at approximately elevation 3140 and Lucky Peak Reservoir at or below elevation 3020.

7. No alteration to the upper-tier outlets is considered at this time since it is assumed that the cavitation which will occur in these conduits when the reservoir elevation is above 3180 will not be too destructive. A field inspection of the upper outlets would determine whether this assumption is correct.

8. Although the power conduits contain 58-inch Ensign valves, which are the same size as those in the outlets, the conduits expand to 72 inches in diameter immediately downstream. This expansion tends to increase the severity of cavitation to such an extent that restriction of the downstream ends is considered necessary to assure satisfactory performance at the operating heads.

9. It is understood that all of the outlet valves will be either wide open or closed. If such is the case, no consideration need be given to the fact that cavitation occurs on the needle tips at small openings.

10. Consideration should be given to the unlined portion of the lower outlets which will be subjected to pressures not contemplated in the original design. The pressure within a conduit might be as much as 40 psi, assuming operation of the outlet (altered) with full reservoirs at Arrowrock and Lucky Peak.

11. Since the 58-inch valves at Arrowrock are identical to those used at Shoshone Dam under 220 feet of head, they should prove as satisfactory mechanically under the lower head at Arrowrock.

12. Extensive repairs to the valves may be required before they can be used for flood control. An inspection of the valves would disclose what parts need to be replaced and purchase could be made so that the work could be scheduled to avoid loss of time. The expense of making the repairs can be kept to a minimum if the work can be performed when the Arrowrock Reservoir is at or below elevation 3011. By using stop logs and bulkheads, it would be possible to work on the valves with the reservoir at elevation 3028. Records in this office for the period between 1918 and 1935 show an average of 2 weeks per year in which the reservoir is below elevation 3011. With proper regulation of the discharge from Anderson Ranch Dam, it is probable that the reservoir could be kept at or below this elevation from 2 to 3 months each year.

13. Any additions or alterations necessary to accommodate the backwater from Lucky Peak Dam will be the same whether or not the valve outlets are altered to permit cavitation-free operation at high heads. Estimates and drawings have been prepared by the Dams Division for this work and transmitted to the Regional Director by letter of August 27, 1948.

14. An examination of pertinent drawings shows that steel-pipe extensions have been made to one 52-inch outlet and two 72-inch power

conduits in order to discharge their flow down the sloped entrance of the diversion tunnel. If the extensions are still in place, it will be relatively easy to rearrange them to discharge the flow from these conduits directly into the river channel, immediately downstream from the dam. The unlined rock walls of the diversion tunnel might be damaged if there is any tail water effect from Lucky Peak Dam and the flow from these pipes is allowed to discharge into the tunnel.

15. The proposed scheme of routing the flow through the three reservoirs to maintain maximum head and storage for generating power at Anderson Ranch Dam is very good. Better flood protection would be obtained by filling Lucky Peak and Arrowrock to elevations 3020 and 3118 respectively, before completing the filling of the reservoirs in the order mentioned.

16. The cost of placing a wedge or choke in the downstream end of each lower outlet and one power conduit, to prevent cavitation at high heads, would be relatively small.

17. Model tests of the Arrowrock outlets show that cavitation may be expected at heads in excess of 75 feet when no restriction of the conduit is made. This action may or may not be critical in the case of the upper outlets when operated under the maximum head of 111 feet. If prolonged operation under higher heads is necessary, as might be the case for the lower conduits, there is certain to be severe cavitation. The results of a thorough inspection of the valves and conduits as they exist at the present time should be used as a guide in determining the need for alteration. It is possible to eliminate cavitation in any outlet by placing sufficient restriction at its downstream end.

18. In view of the information set forth in the preceding paragraphs, it is recommended that:

a. Discharge curves for the Arrowrock outlets, with and without alteration of the conduits to permit cavitation-free operation at high heads, be furnished the project

b. A cost estimate be prepared and a working plan developed for repairing the valves, based on the results of a field inspection

c. The lower-tier outlets and one power conduit be provided with some type of restriction at their downstream ends to enable operation without serious damage from cavitation

Enclosure (1)

FIGURE I FOR APPENDIX II, HYD. 258

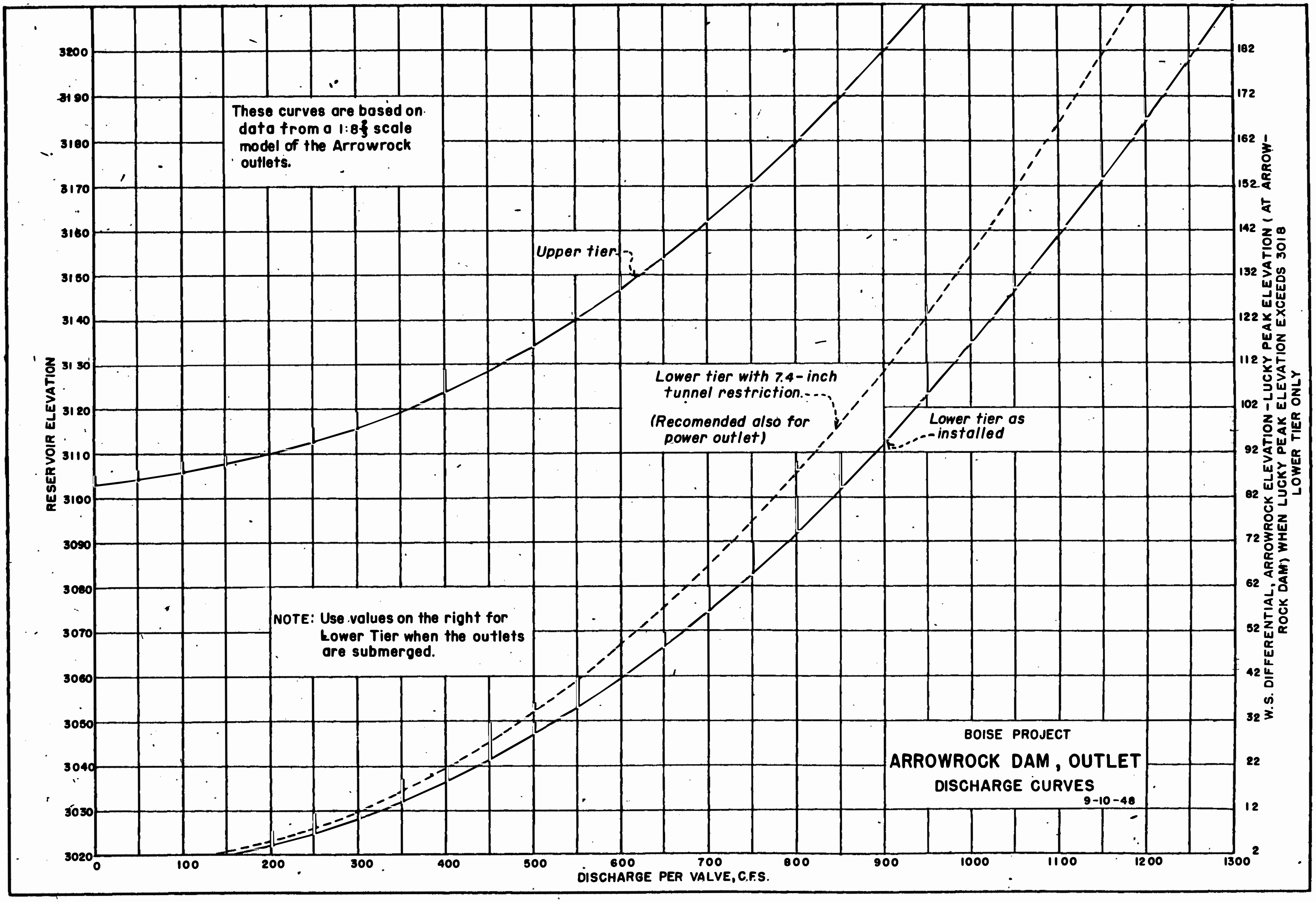
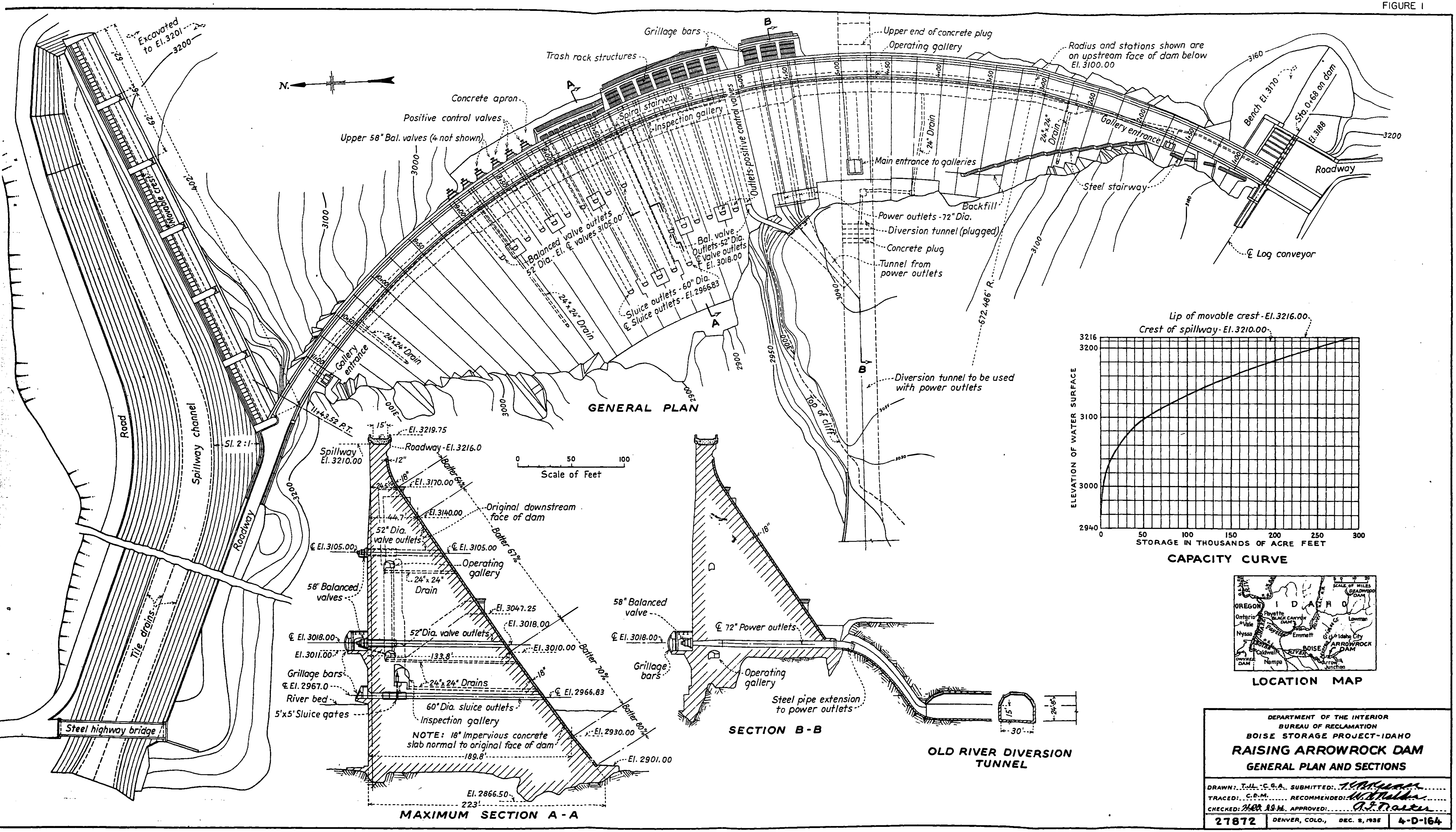
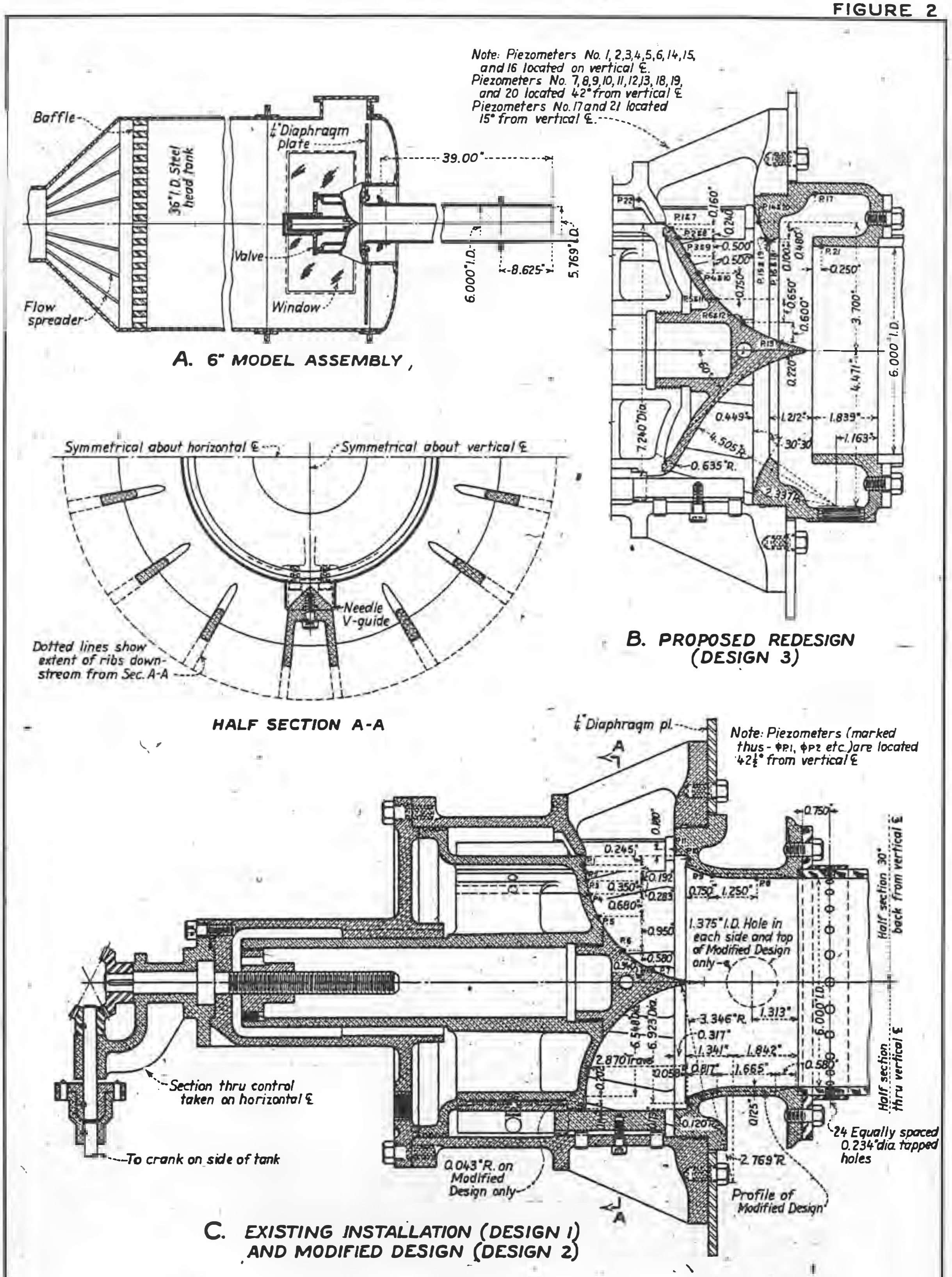


FIGURE 1



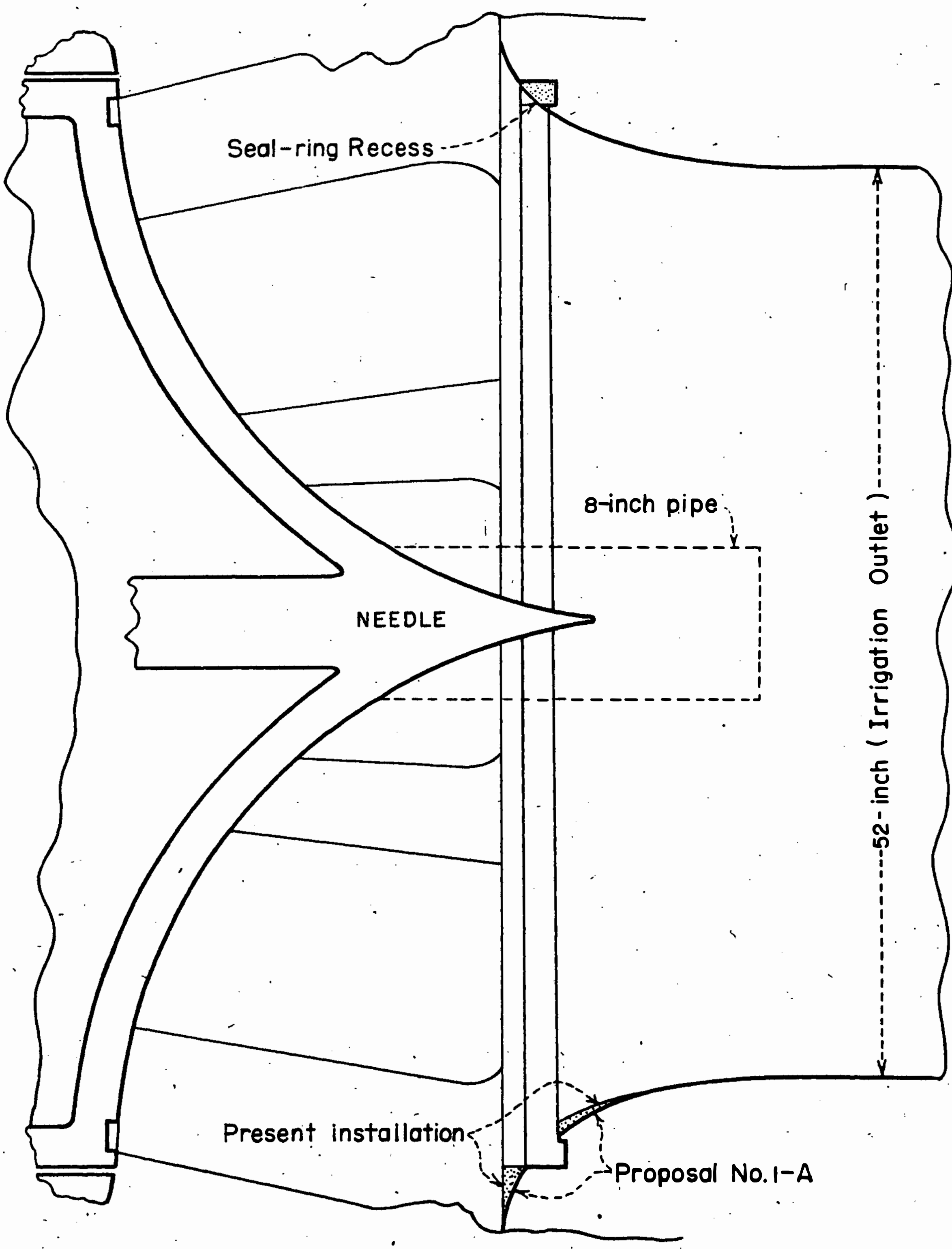
GENERAL PLAN
Excavated to El. 3201
Grillage bars
Trash rack structures
Upper end of concrete plug
Operating gallery
Radius and stations shown are on upstream face of dam below El. 3100.00
Concrete apron
Positive control valves
Upper 58" Bal. valves (4 not shown)
Spiral stairway
Inspection gallery
Movable crest
Outlets-positive control valves
24" Drain
24"x24" Drain
Gallery entrance
Bench El. 3170
Sta. 0+68 on dam
El. 3188
Roadway
Main entrance to galleries
Steel stairway
Backfill
Power outlets -72" Dia.
Diversion tunnel (plugged)
Concrete plug
Tunnel from power outlets
℄ Log conveyor
Balanced valve outlets 52" Dia. - El. ℄ valves 3105.00
Bal. valve Outlets-52" Dia. ℄ Valve outlets El. 3018.00
Sluice outlets - 60" Dia. ℄ Sluice outlets - El. 2966.83
672.486' R.
Diversion tunnel to be used with power outlets
Top of cliff
11+43.52 P.T.
Sl. 2:1
Road
Spillway channel
Tile drains
Steel highway bridge
MAXIMUM SECTION A-A
El. 3219.75
Roadway - El. 3216.0
Spillway El. 3210.00
Batter 67%
El. 3170.00
El. 3140.00
Original downstream face of dam
52" Dia. valve outlets
℄ El. 3105.00
Operating gallery
24"x24" Drain
58" Balanced valves
El. 3047.25
El. 3018.00
52" Dia. valve outlets
El. 3010.00
Batter 70%
℄ El. 3018.00
El. 3011.00
133.8'
Grillage bars
24"x24" Drains
℄ El. 2967.0
℄ El. 2966.83
River bed
60" Dia. sluice outlets
5'x5' Sluice gates
Inspection gallery
Batter 80%
El. 2930.00
NOTE: 18" Impervious concrete slab normal to original face of dam
189.8'
El. 2901.00
El. 2866.50
223'
Scale of Feet
SECTION B-B
58" Balanced valve
℄ 72" Power outlets
Grillage bars
Operating gallery
Steel pipe extension to power outlets
OLD RIVER DIVERSION TUNNEL
CAPACITY CURVE
Lip of movable crest - El. 3216.00
Crest of spillway - El. 3210.00
ELEVATION OF WATER SURFACE
STORAGE IN THOUSANDS OF ACRE FEET
LOCATION MAP
OREGON
IDAHO
BOISE
ARROWROCK DAM
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOISE STORAGE PROJECT-IDAHO
RAISING ARROWROCK DAM
GENERAL PLAN AND SECTIONS
DRAWN: T.J.L.-C.G.A.
TRACED: C.B.M.
SUBMITTED:
RECOMMENDED:
APPROVED:
27872
DENVER, COLO., DEC. 2, 1935
4-D-164

FIGURE 2




SHOSHONE DAM
58-INCH BALANCED VALVE
MODEL STUDIES - 1:8⅔ SCALE
ASSEMBLY AND DETAILS OF HYDRAULIC MODEL

FIGURE-3

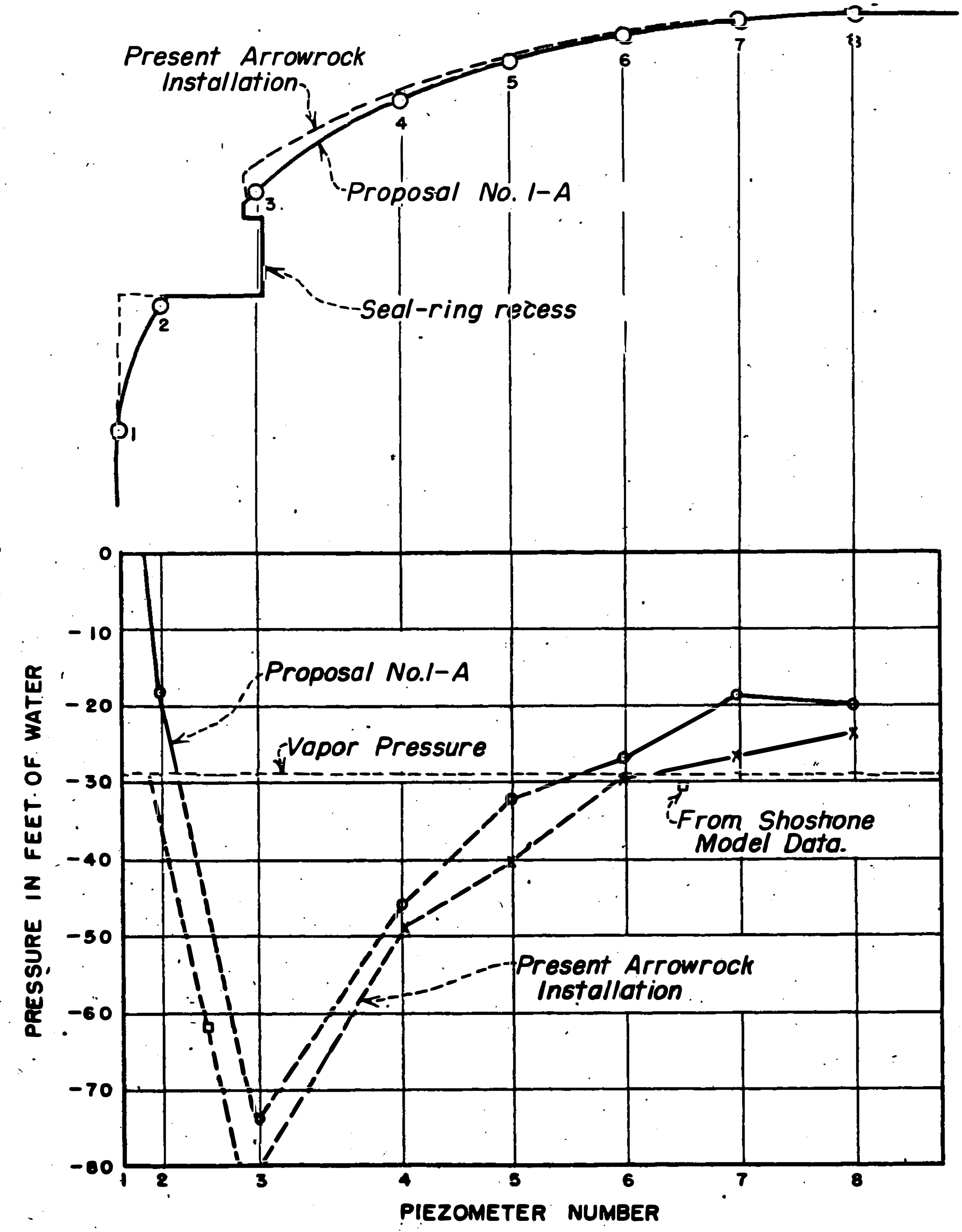



BOISE PROJECT

**ARROWROCK DAM, OUTLETS**

**ALTERATIONS TO THROAT AND NEEDLE OF ENSIGN VALVE**

1: $8\frac{2}{3}$ SCALE MODEL



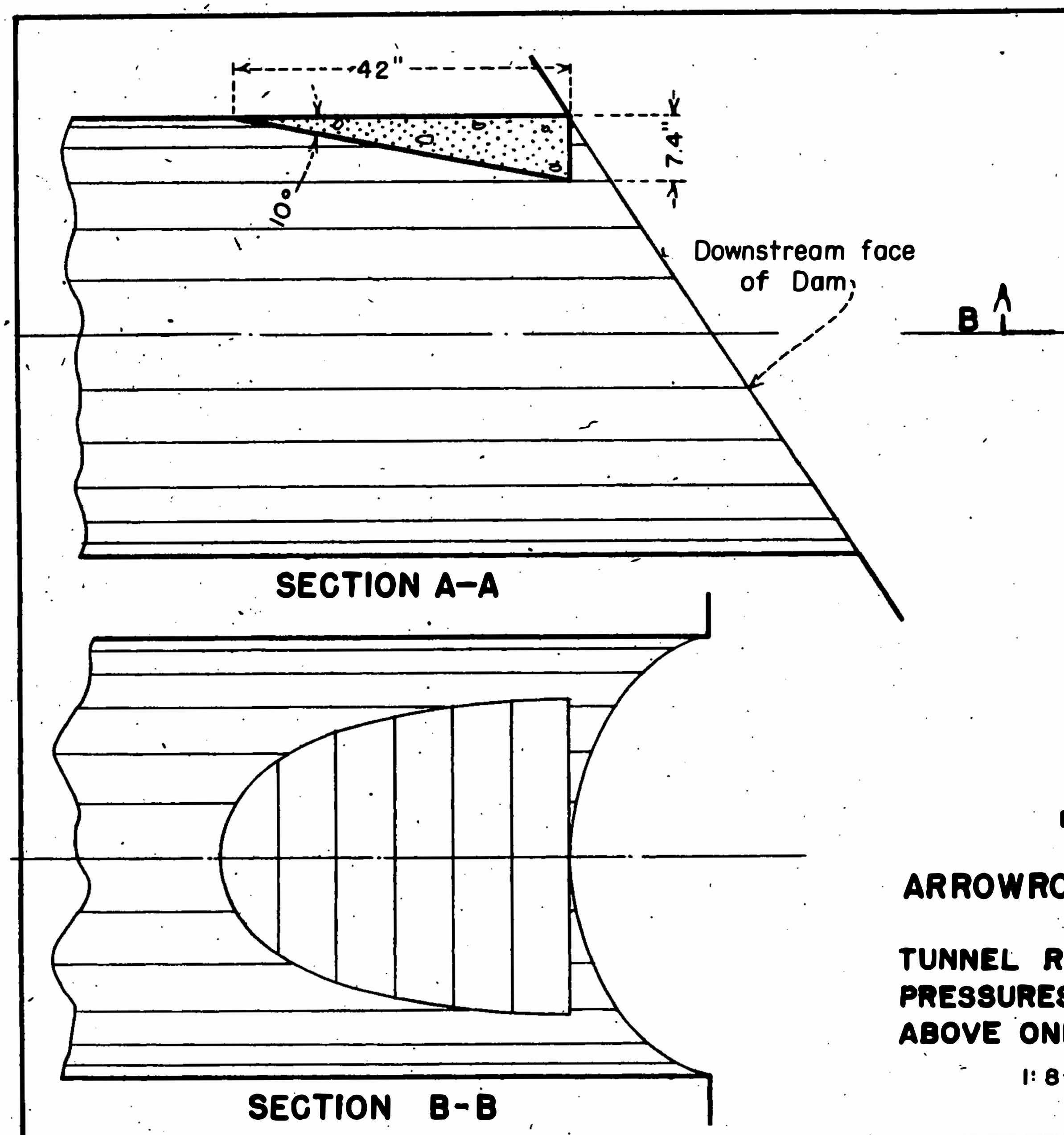

NOTE: Head on valve center-line = 192'

BOISE PROJECT

**ARROWROCK DAM, OUTLETS**

**PRESSURE DISTRIBUTION IN VALVE THROAT**

1: 8⅔ SCALE MODEL



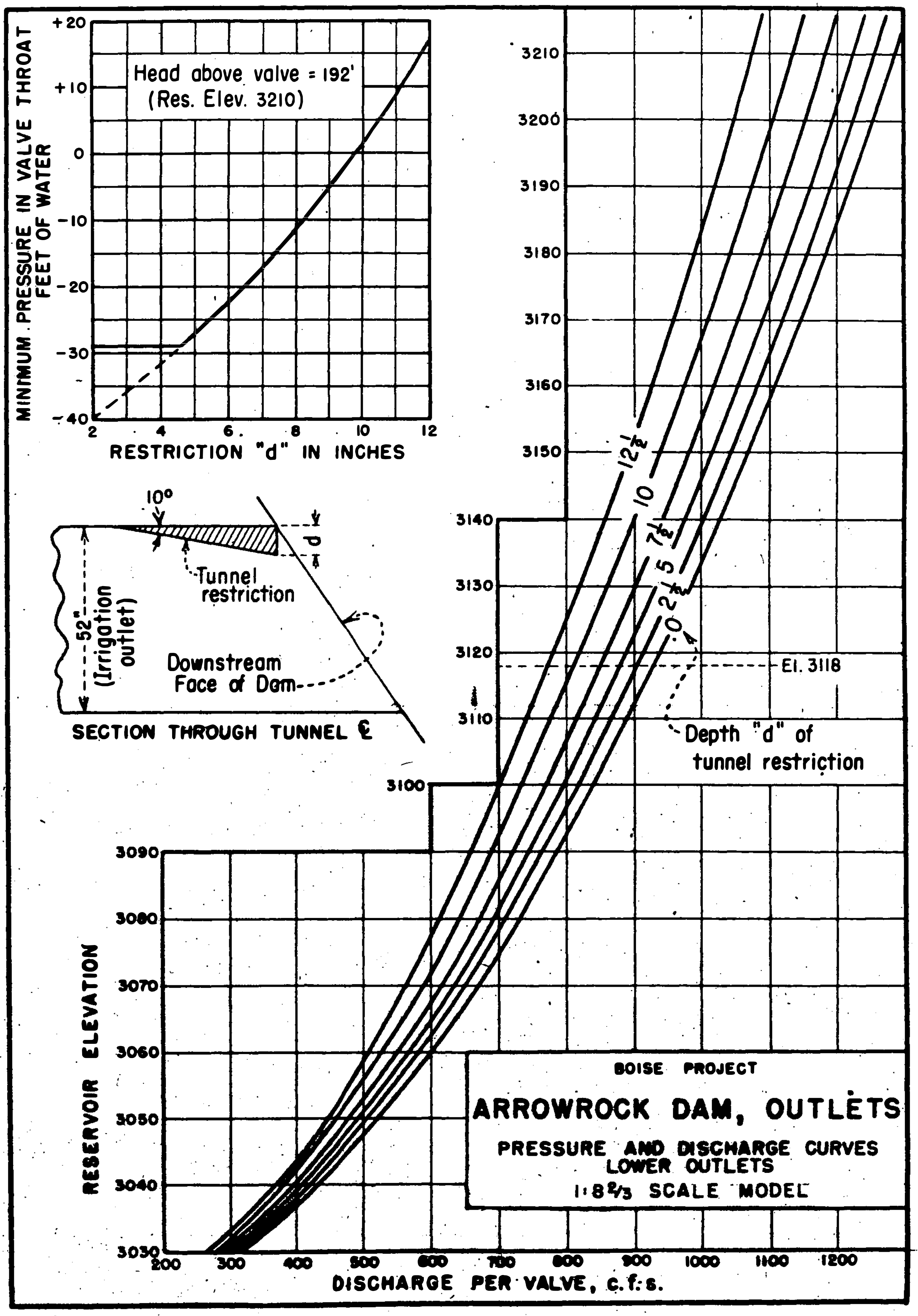

BOISE PROJECT

ARROWROCK DAM, OUTLETS

TUNNEL RESTRICTION TO KEEP PRESSURES IN THE VALVE THROAT ABOVE ONE-HALF ATMOSPHERE

1: 8$\frac{2}{3}$ SCALE MODEL

FIGURE 5

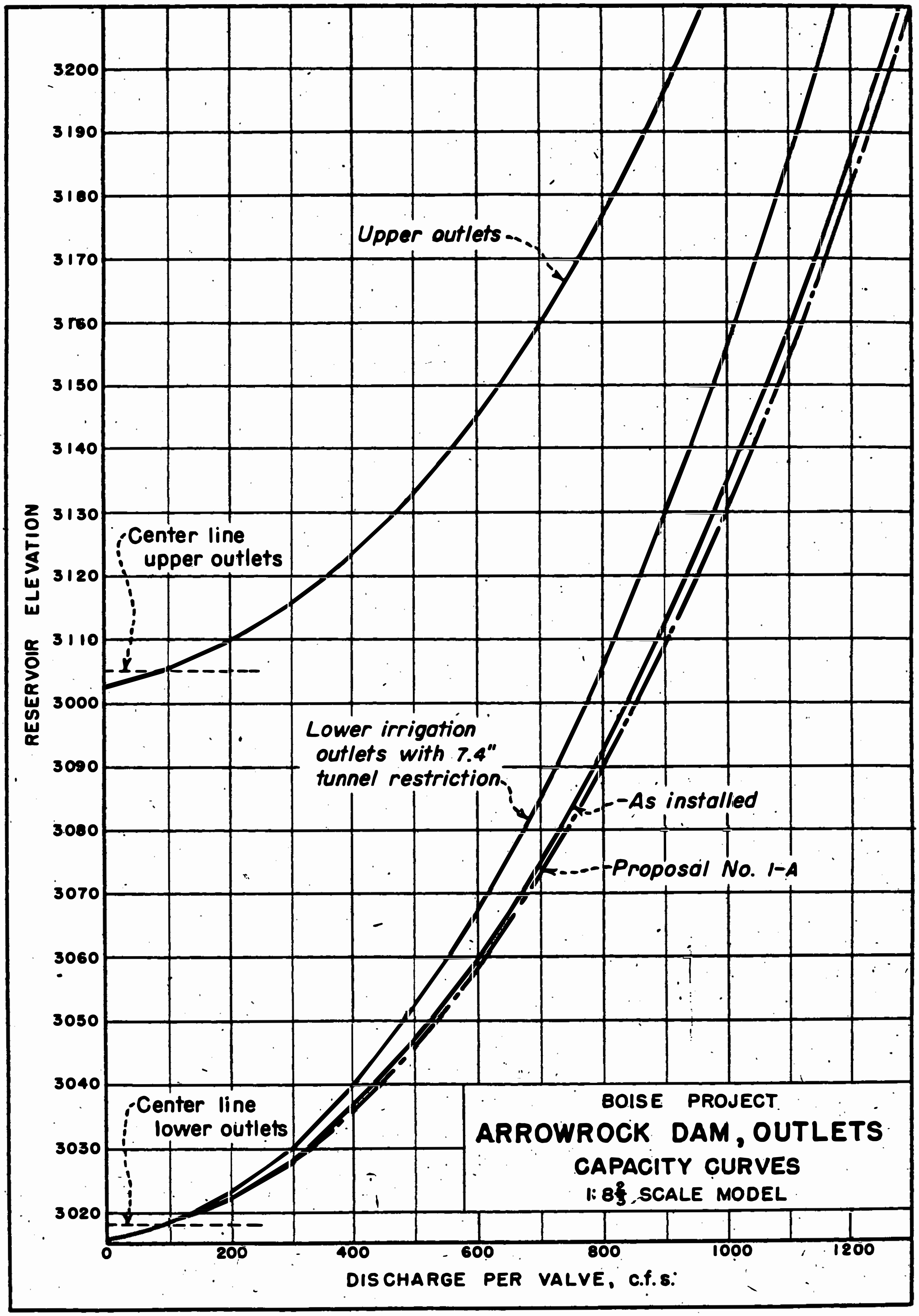



BOISE PROJECT

ARROWROCK DAM, OUTLETS

PRESSURE AND DISCHARGE CURVES
LOWER OUTLETS
1:8⅔ SCALE MODEL

FIGURE 7



3200
3190
3180
3170
3160
3150
3140
3130
3120
3110
3000
3090
3080
3070
3060
3050
3040
3030
3020
RESERVOIR ELEVATION
Upper outlets
Center line upper outlets
Lower irrigation outlets with 7.4" tunnel restriction
As installed
Proposal No. 1-A
Center line lower outlets
BOISE PROJECT
ARROWROCK DAM, OUTLETS
CAPACITY CURVES
1:8⅔ SCALE MODEL
0
200
400
600
800
1000
1200
DISCHARGE PER VALVE, c.f.s.