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HYDRAULIC LABORATORY REPORT NO. 120

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HYDRAULIC MODEL STUDIES RELATING TO THE QUANTITY OF AIR REQUIRED AT THE OUTLET WORKS OF ANDERSON RANCH DAM

By

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Denver, Colorado,
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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
January 28, 1943

Laboratory Report No. 120
Hydraulic Laboratory
Compiled by: J. A. Lindsey

Subject: Hydraulic model studies relating to the quantity of air required at the outlet works of Anderson Ranch Dam.

INTRODUCTION

1. The prototype

The Anderson Ranch Dam is to be located on the South Fork of the Boise River, approximately 42 miles southeast of Boise, Idaho (figure 1). The project will consist of an earth dam across the river, an outlet works through the left abutment of the dam, and an open-channel spillway at the left abutment of the dam. The earth dam will be approximately 1,350 feet long and 330 feet above the river bed. The spillway discharge will be regulated by two 25- by 22-foot radial gates (figure 2). The outlet works will consist of a trashrack and inlet structure; a concrete-lined diversion tunnel 20 feet in diameter and approximately 1,500 feet long; and a plate-steel penstock and outlet pipe 15 feet in diameter, extending from a concrete plug in the tunnel to the powerhouse and outlet structure under the spillway channel and terminating in 96-inch ring-seal gates at the ends of the branch penstocks and in emergency gates and five 72-inch hollow-jet valves at the ends of the branch outlet pipes (figures 3 and 4).

2. Purpose of model studies

Each of the five 72-inch valves will discharge into a chamber underneath the spillway. It was anticipated that when the outlet jet impinged against the spillway jet, air would be partially exhausted from the outlet chamber, thus reducing the air pressure inside the chambers to considerably less than atmospheric. If this pressure were sufficiently low, there would be the danger of the walls of the chamber collapsing due to the atmospheric force on the outside; consequently, 12-foot diameter vent

holes were provided in the walls of each chamber to admit air to relieve this low-pressure condition. A model of one chamber was constructed for the purpose of obtaining the quantity of air required and the pressure differential under the worst possible conditions.

3. Summary of the investigation

The investigation of the quantity of air required to relieve the subatmospheric pressures inside the outlet chambers proved that the air demand is much smaller than anticipated. It was established that the air demand at a spillway discharge of 20,000 second-feet and outlet discharge of 10,000 second-feet was equal to 5,625 second-feet of air, or 56 percent of the outlet discharge. The pressure differential between the chamber and the atmosphere would not be over 30 pounds per square foot even if the size of the vents in each chamber were reduced from 12 feet to 6 feet in diameter. With 6-foot diameter vents the air velocity would be 166 feet per second, which is less than the allowable maximum.

4. The model

The model was built to a scale ratio of 1 to 12 and represented the center outlet chamber, or one-fifth of the prototype. The model was made of wood with a galvanized-iron-lined chamber (figure 5). The hollow-jet valve was a 6-inch valve used in previous investigations of the valve itself. The water was supplied to the model by the laboratory piping system and regulated by differential gages calibrated to give accurate discharge measurements. The tailwater elevation was adjusted by wood pickets placed at the end of the stilling pool channel. The air admitted was measured by placing an anamometer in a 4-inch pipe.

DISCUSSION

5. Preliminary tests

The model was tested to obtain the difference in pressure between the atmosphere and the inside of the outlet chamber. This differential was found to be equal to 0.02 foot of water on the model. From this it

was computed that the ratio of air discharge to outlet discharge was approximately 1/2 to 1. It was also found that the air demand increased slightly when the tailwater was lowered. To provide an added safety factor in the tests, the tailwater was partially controlled to correspond to the condition which would be present if the river bed should retrogress enough to prevent the formation of the hydraulic jump in the stilling pool.

These preliminary tests demonstrated that the 12-foot diameter vent holes, provided on the prototype, would be more than sufficient to relieve the subatmospheric pressures inside the outlet chambers.

6. Tests leading to recommended design

In the next tests the left vent was plugged and a 4-inch pipe connected to the right vent. Tests were then made with a constant outlet discharge and a varying spillway discharge for the purpose of determining the effect of the spillway discharge on the air demand (table 1 and figure 6). The spillway discharge was then held constant and the outlet discharge varied to determine the effect of the outlet discharge on the air demand (figure 6). The spillway discharge - air demand curve is nearly vertical. It would be more nearly vertical on the prototype as spillway velocity would vary due to the change in hydraulic radius, whereas, on the model the velocity changed due to the difference in pressure in the diffuser with an increase in the discharge. The outlet discharge - air demand curve is assumed to be a straight line which does not pass through the origin, as some air is required when the flow is passing over the spillway only.

The maximum air demand was obtained by extrapolation, as the maximum outlet discharge obtainable with the laboratory system when the higher discharges were required for the spillway was limited to 3.83 second-feet. By a special arrangement at a low spillway discharge, the outlet discharge was increased to 4.09 second-feet. When the outlet discharge - air demand curve was drawn, it was observed that the air

TABLE 1

ANDERSON RANCH DAM

BOISE PROJECT - IDAHO

HYDRAULIC MODEL STUDIES - 1:12 SCALE
Summary of Model Data

Run number	Spillway discharge Q_s	Outlet discharge Q_o	Air demand Q_a	Pressure differential p	Vent opening
A - 1	6.75	3.83	2.10	0.019	4-inch pipe
A - 2	6.29	3.82	2.09	0.021	4-inch pipe
A - 3	8.10	3.82	2.18	0.022	4-inch pipe
A - 4	1.50	3.83	1.96	0.015	4-inch pipe
A - 5	1.50	3.25	1.75	0.010	4-inch pipe
A - 6	1.50	2.50	1.20	0.003	4-inch pipe
A - 7 - a	1.50	3.83	1.98	0.012	4-inch pipe
A - 7 - b	1.50	3.83	1.37	0.014	3-inch orifice
A - 7 - c	1.50	3.83	0.32	0.018	1-1/2-inch orifice
A - 7 - d	1.50	3.83	0.06	0.018	1/2-inch orifice
A - 7 - e	1.50	3.83	0	0.020	No opening
A - 8	1.50	2.81	1.56	0.008	4-inch pipe
A - 9	1.50	3.61	1.93	0.012	4-inch pipe
A - 10	1.50	4.09	2.04	0.017	4-inch pipe

demand increased 0.07 second-foot when the outlet discharge was increased from 3.83 to 4.01 second-feet. It was then assumed that any curve of spillway discharge - air demand at a constant outlet discharge would be parallel to the straight-line curve previously obtained, when the outlet discharge was approximately 3.83 second-feet. Thus, the air demand at 4.01 second-foot outlet discharge and 8.02 second-foot spillway discharge would be 0.07 second-foot greater than at 3.83 second-foot outlet discharge and 8.02 second-foot spillway discharge or equal to a total of 2.25 second-feet of air. This air demand, equal to 56 percent of the outlet discharge, was far less than the anticipated 200 to 400 percent; consequently, the size of the vents could be reduced considerably.

The difference in pressure between the inside of the chamber and the atmosphere was measured on each test. This pressure differential was very small, and, as the data was not obtained with sufficiently precise instruments, it will not be used in computing the prototype pressures.

CONCLUSIONS

7. Results of the investigation

The tests demonstrated that hydraulic model studies of the air demand on structures to be built should be made when analogous data is unobtainable. With the limited knowledge now available on the subject it is generally impossible to ascertain beforehand any reliable estimate of the air demand when two jets of water impinge on one another.

Using the formula for flow through an orifice, $Q = CA\sqrt{2gh}$, one obtains $h = \frac{\left(\frac{Q}{CA}\right)^2}{2g}$. Then by substituting p for the head h and dividing by 1,000 feet, the height of an air column equivalent in weight to a 1-foot column of water, one obtains the relationship $p = \frac{\left(\frac{Q_a}{CA}\right)^2}{2{,}000\,g}$, where p equals the pressure differential in feet of water, Q_a equals

the air demand in cubic feet per second, C equals a coefficient of discharge assumed to equal 0.60, and A equals the area of the orifice opening in square feet, which will give a satisfactory estimate of the pressure differential. If 4-foot vents are provided through each chamber the air demand through the right chamber wall in the prototype would be equal to $\frac{10,000 \times 0.56}{2} = 2,800$ second-feet of air. Therefore

$$p = \frac{\left(\frac{2,800}{0.6 \times 12.57}\right)^2}{2,000 \times 32.2} = 2.14 \text{ feet of water or } 134 \text{ pounds per square foot.}$$

From the relationship $v = \frac{Q}{CA}$ the velocity of the air may be obtained. For the 4-foot vent, therefore, $v = \frac{2,800}{0.6 \times 12.57} = 371$ feet per second. Air traveling at this velocity is extremely noisy; therefore the vents should be made approximately 6 feet in diameter. The velocity would then be reduced to $v = \frac{2,800}{0.6 \times 28.27} = 165$ feet per second and the pressure differential to $p = \frac{\left(\frac{2,800}{0.6 \times 28.27}\right)^2}{2,000 \times 32.2} = 0.42$ foot of water or 26 pounds per square foot. These values appear reasonable and justify the recommendation that the size of the vents be reduced from 12-foot to 6-foot diameter holes in each chamber.

An attempt was made to resolve the data into nondimensional form, but the results were unsatisfactory, and the undertaking was abandoned after it was seen that no pertinent data was obtainable. The apparatus used in the study was not sufficiently precise to give results which would agree when analyzed nondimensionally.

A very worthy project for future study would be to determine nondimensional data on the effect to the air demand of varying the angle of impingement, and the relative velocities of the two jets of water. Such data would enable the designer to predict, with some degree of certainty, the air demand for structures similar to this one. The model data is summarized for use in future investigations (table 1).

8. Recommendations

On the basis of the model studies, it is recommended that

(a) The size of the vents be reduced from 12-foot to 6-foot diameter.

(b) The location of the vents is relatively immaterial as the drop in pressure between the chamber and the atmosphere is quite small.

(c) The thickness of the walls remain the same as originally provided, inasmuch as the pressure differential is not sufficient to collapse them.

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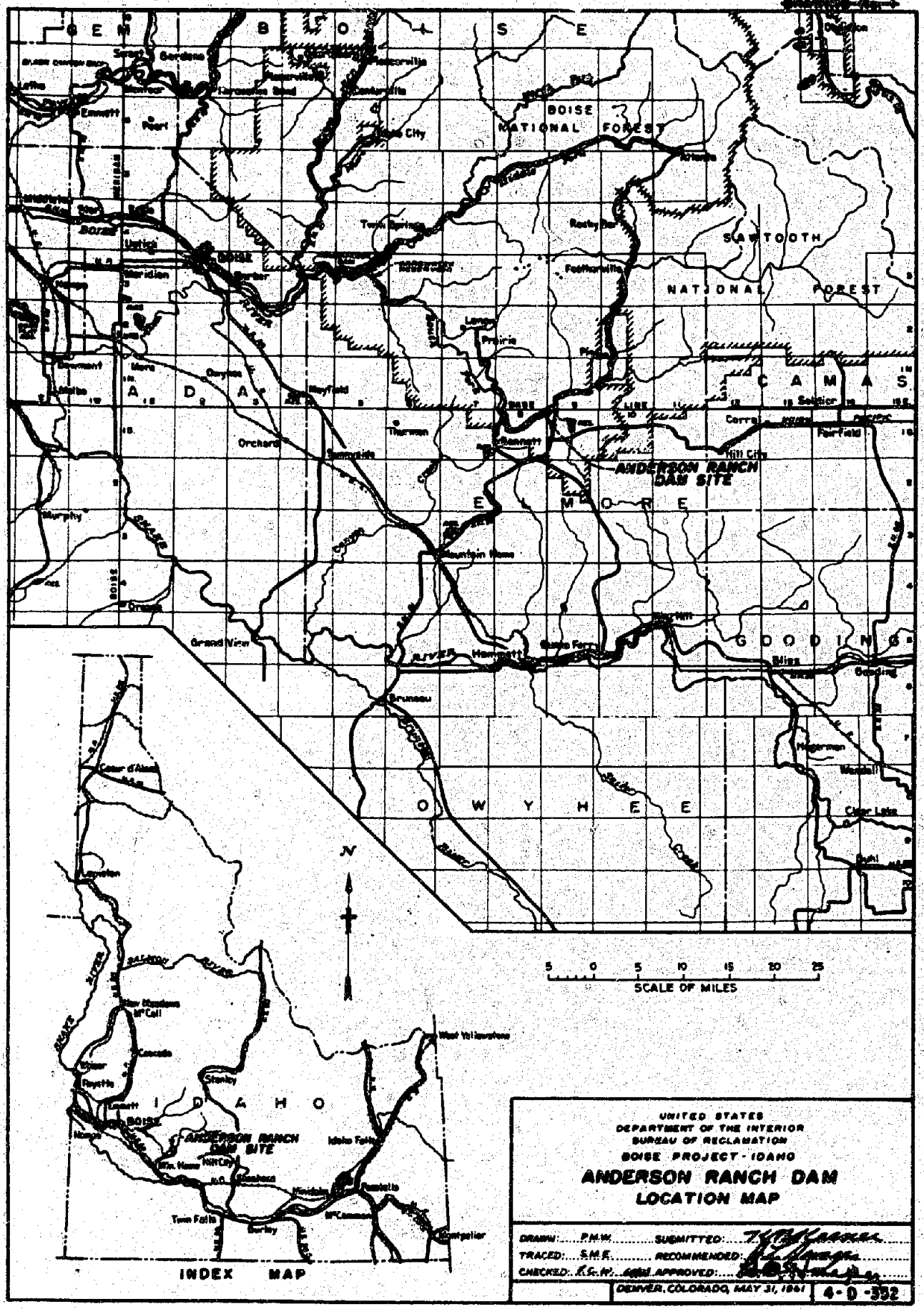
J. A. Lindsey

FIGURE 1


BOISE NATIONAL FOREST
SAWTOOTH NATIONAL FOREST
ADA
CAMAS
ELMORE
GOODING
OWYHEE
ANDERSON RANCH DAM SITE
Boise
Meridian
Nampa
Caldwell
Mountain Home
Hill City
Fairfield
Bennett
Hammett
Bliss
Gooding
Twin Falls
Burley
Rupert
Jerome
Shoshone
Hagerman
Malad
Clear Lake
Dubois
Salmon
Challis
Stanley
Ketchum
Sun Valley
Hailey
Idaho Falls
Pocatello
Montpelier
Lewiston
Coeur d'Alene
Grand View
Bruneau
Glenns Ferry
Mountain Home
Twin Springs
Featherville
Prairie
Atlanta
Rocky Bar
Arrowrock Dam
Lucky Peak Dam
Anderson Ranch Dam
Boise River
Snake River
Payette River
Salmon River
Big Lost River
Big Wood River
Malad River
Bruneau River
Owyhee River
Clearwater River
Weiser River
Pahsimeroi River
Lemhi River
Salmon River
Big Lost River
Big Wood River
Snake River
Boise River
Payette

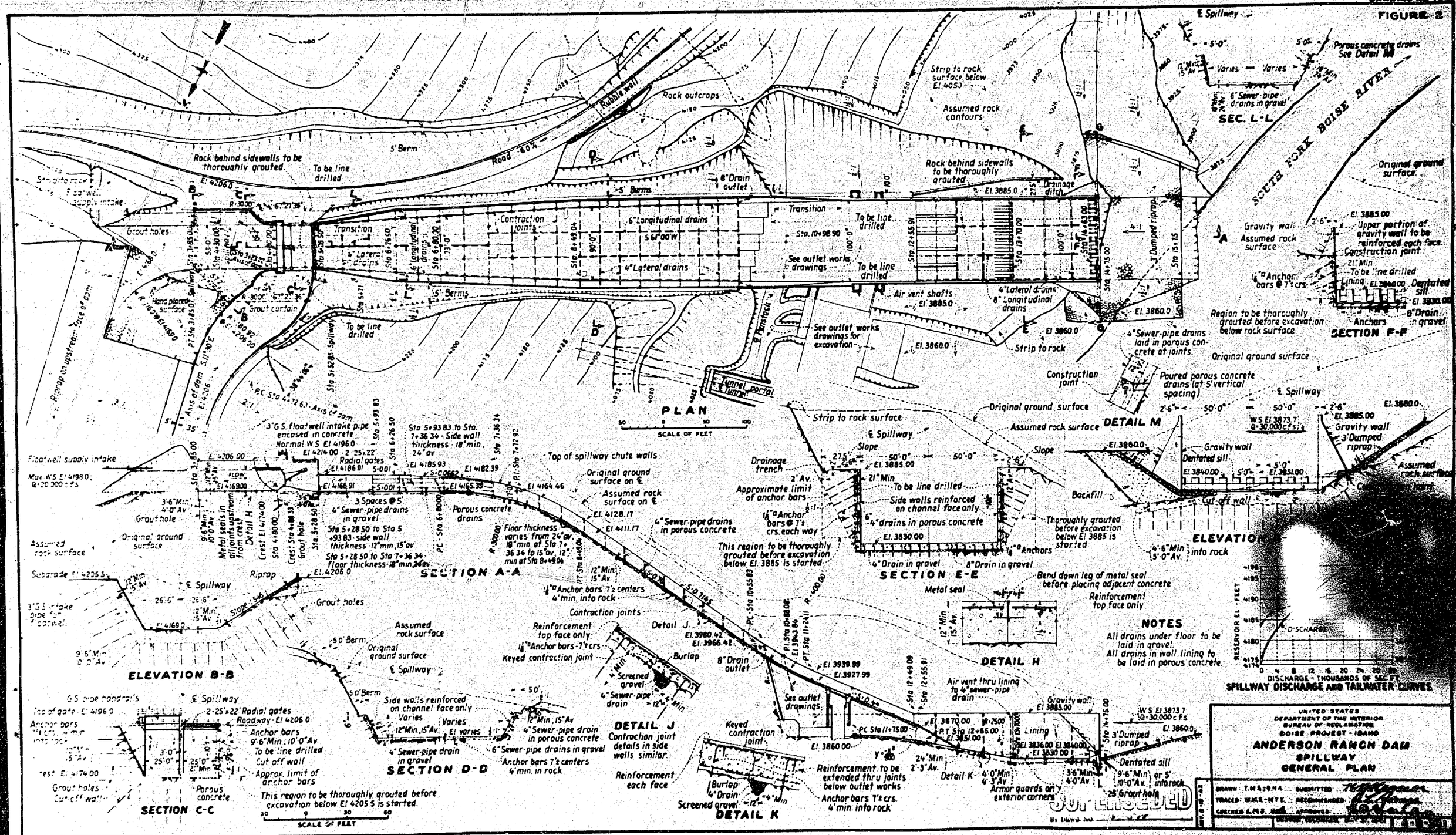
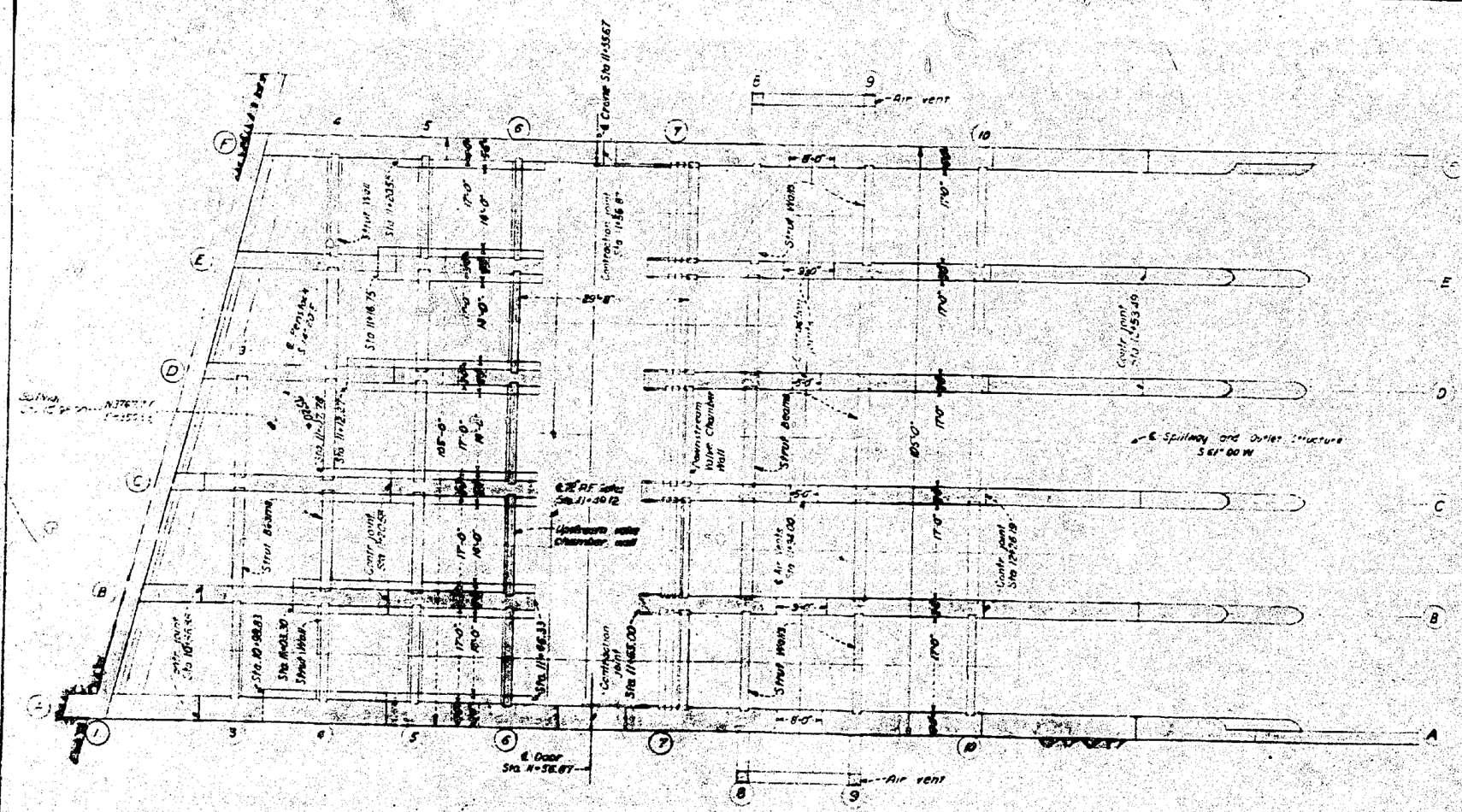


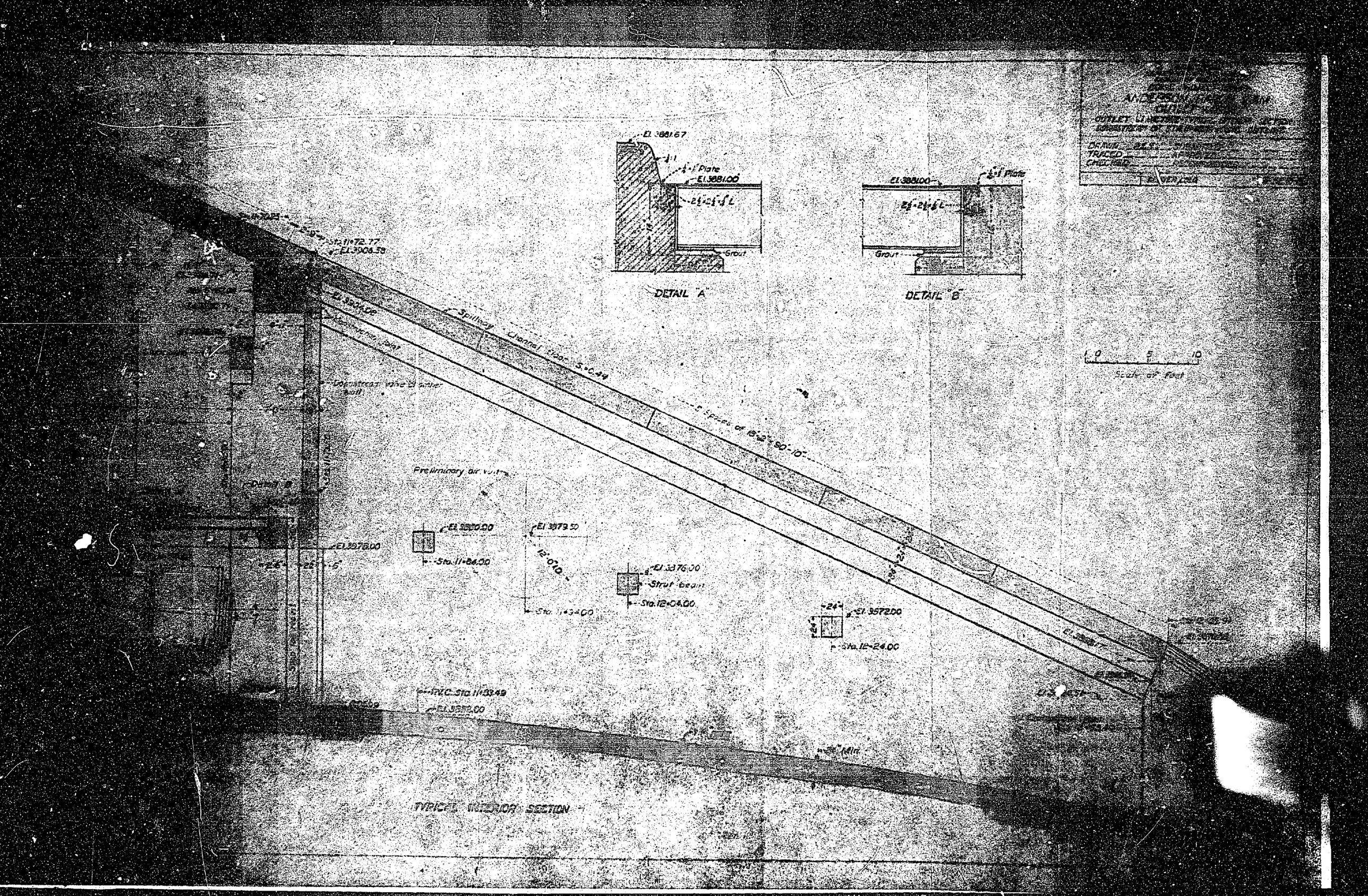
FIGURE 2
PLAN
SCALE OF FEET
SECTION A-A
SECTION C-C
SECTION D-D
SECTION E-E
SECTION F-F
SEC. L-L
DETAIL J
DETAIL K
DETAIL M
DETAIL H
ELEVATION B-B
ELEVATION
SOUTH FORK BOISE RIVER
NOTES
All drains under floor to be laid in gravel.
All drains in wall lining to be laid in porous concrete.
SPILLWAY DISCHARGE AND TAILWATER CURVES
DISCHARGE - THOUSANDS OF SEC FT
RESERVOIR EL - FEET
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
BOISE PROJECT - IDAHO
ANDERSON RANCH DAM
SPILLWAY
GENERAL PLAN
SUPERSEDED

FIGURE 3



BOISE PROJECT
ANDERSON RANCH DAM
OUTLET WORKS
OUTLET STRUCTURE
SECTIONAL PLAN

DRAWN P.E.S. SUBMITTED
TRACED APPROVED
CHECKED RECOMMENDED



DETAIL "A"
DETAIL "B"
Grout
Spillway Channel floor S=0.44
Preliminary air vent
Strut beam
Sta. 11+84.00
Sta. 12+04.00
Sta. 12+24.00
Scale of Feet
TYPICAL INTERIOR SECTION

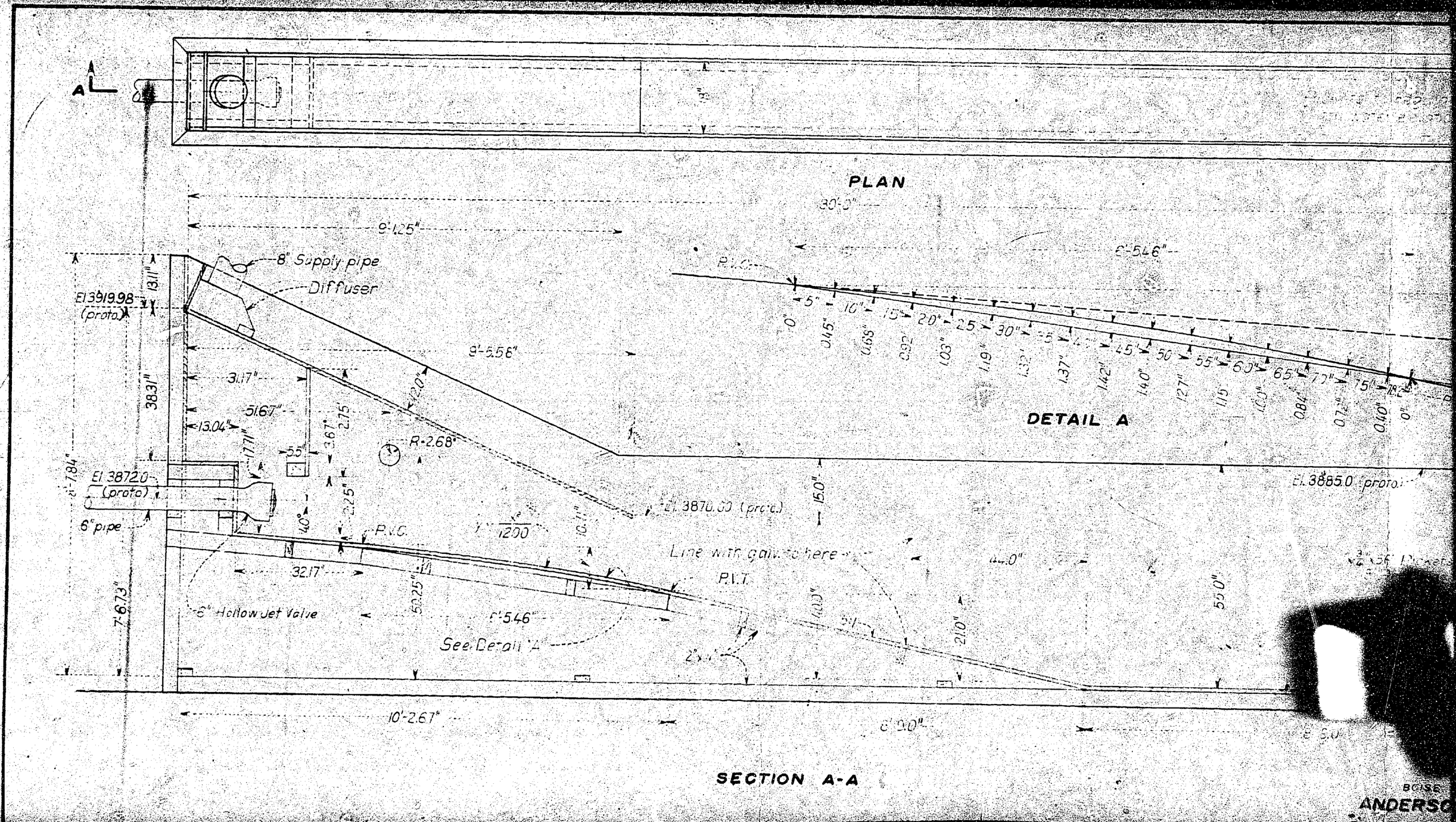
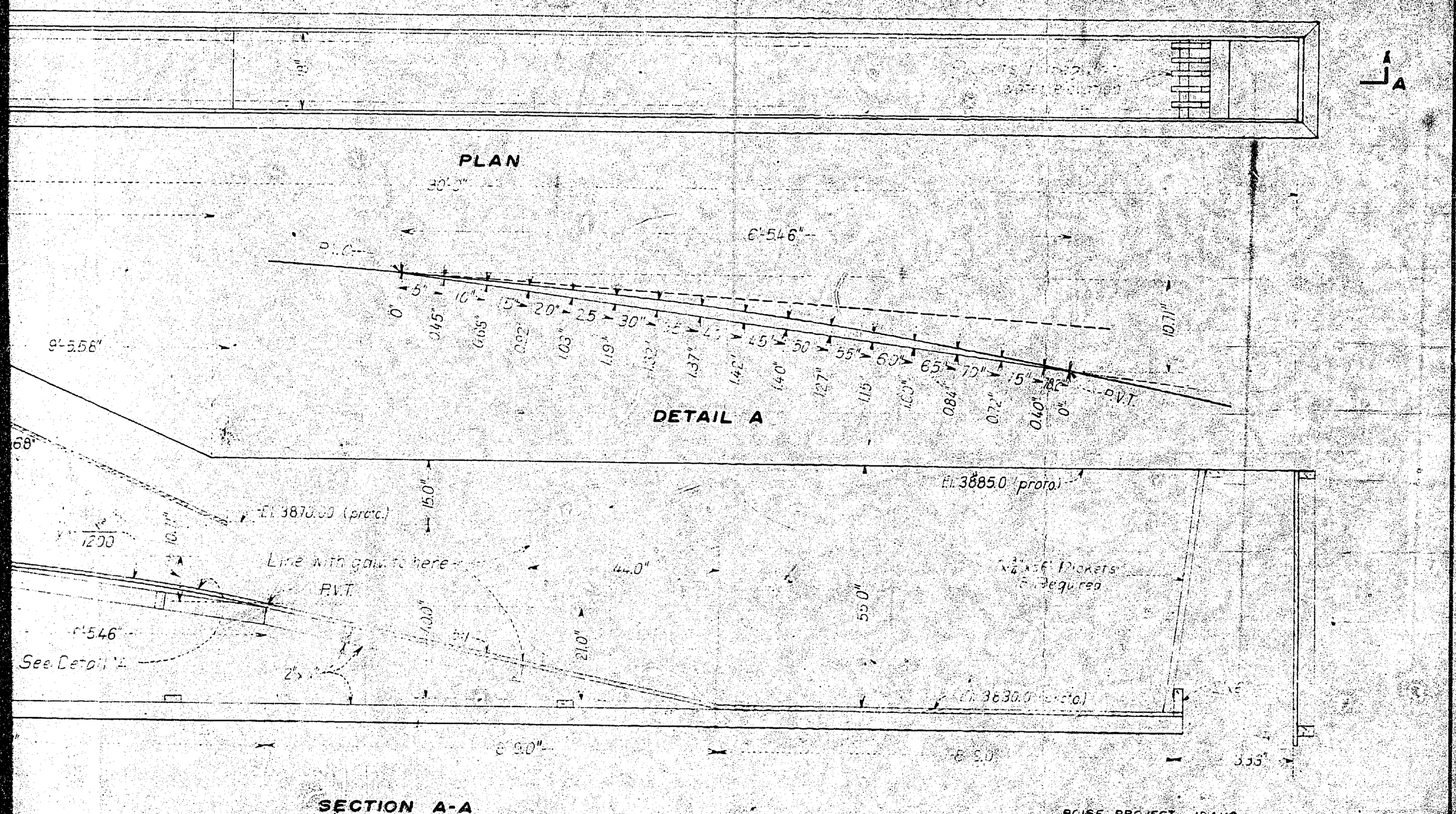

PLAN
DETAIL A
SECTION A-A
8" Supply pipe
Diffuser
El 3919.98 (proto)
El 3872.0 (proto)
6" pipe
6" Hollow Jet Valve
See Detail "A"
Line with galv. to here
P.V.C.
P.V.T.
R-2.68"
El 3870.00 (proto)
El 3885.0 (proto)
9'-1.25"
9'-5.56"
10'-2.67"
38.31"
7'-6.73"
BOISE
ANDERSO

FIGURE 5

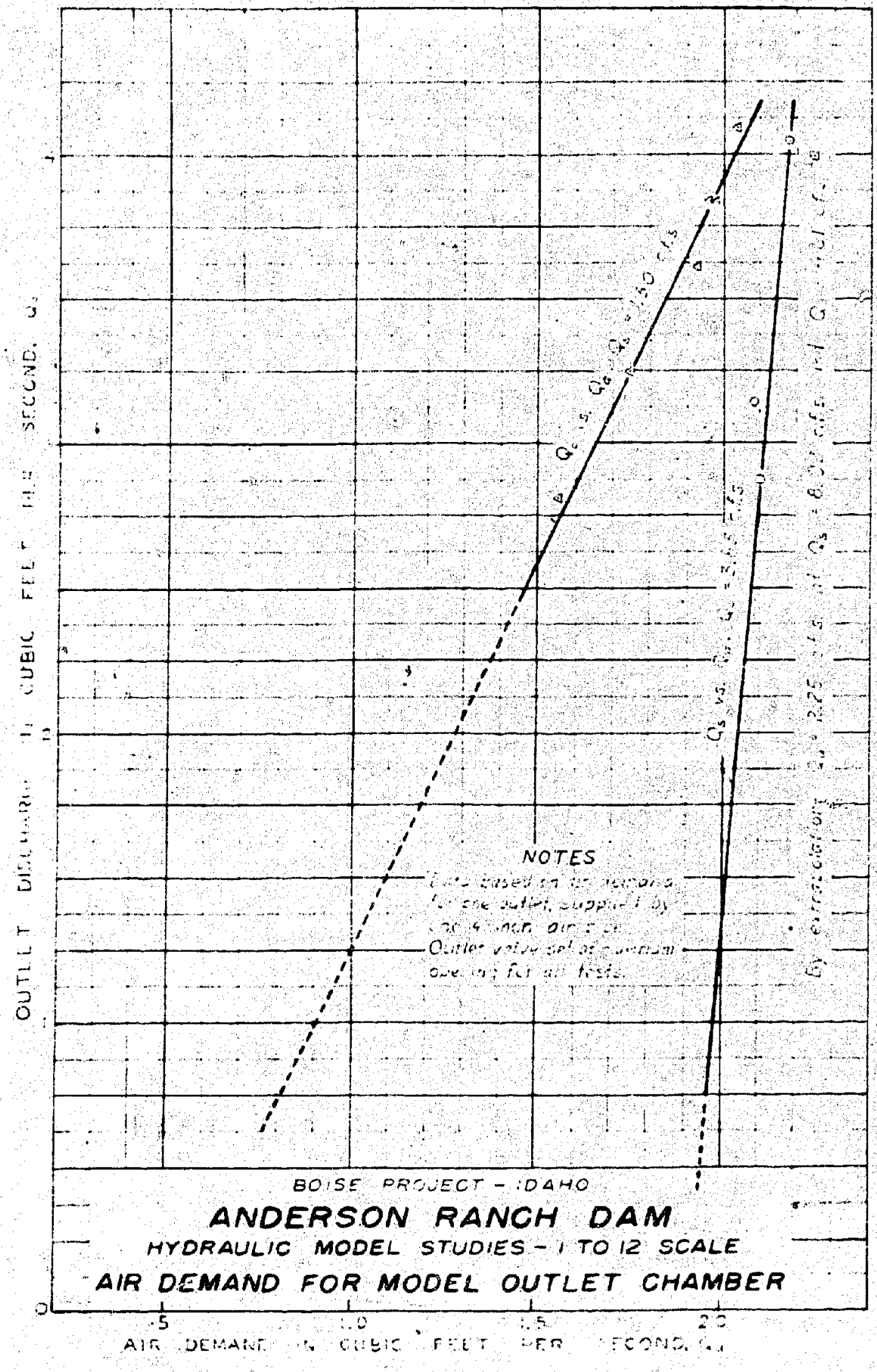


BOISE PROJECT - IDAHO

ANDERSON RANCH DAM

1:12 HYDRAULIC MODEL OF ONE OUTLET

FIGURE 6



BOISE PROJECT - IDAHO

ANDERSON RANCH DAM

HYDRAULIC MODEL STUDIES - 1 TO 12 SCALE

AIR DEMAND FOR MODEL OUTLET CHAMBER