UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE STILLING-WELL FOR THE BLOW-OFF STRUCTURE, SOAP LAKE (INVERTED) SIPHON - COLUMBIA BASIN PROJECT

Hydraulic Laboratory Report No. Hyd.-277

RESEARCH AND GEOLOGY DIVISION

BRANCH OF DESIGN AND CONSTRUCTION
DENVER, COLORADO

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CONTENTS

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Denver, Colorado
Date: April 28, 1950

Laboratory Report No. 277
Hydraulic Laboratory
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Subject: Hydraulic model studies of the stilling-well for the blow-off structure, Soap Lake (Inverted) Siphon—Columbia Basin Project.

PURPOSE

To develop a stilling-well which will dissipate the energy of the high-pressure flow from the blow-off line draining the inverted siphon at Soap Lake.

CONCLUSIONS

1. The most satisfactory stilling-well developed from these model studies is one with fillet corners (Figure 4H). There is a difference of 6 inches between the crest and trough of the waves measured on the 1-1/2:1 slope of the trapezoidal channel 15 feet downstream from the well when the blow-off is discharging 75 cfs.

2. An octagonal well with side wall projections (Figure 4G) is as satisfactory hydraulically as the well with fillet corners, but the latter is preferred because of its simplicity.

3. For best operation of the vertical-type well the discharge pipe should be placed vertically in the center of the well and extend to within 1-1/2- to 2-1/2-pipe diameters of the well floor.

4. The vertical-type stilling-well, being compact and simple, can be used economically for dissipating the energy of high-pressure flow from outlets where space is limited and tranquil flow is important.

5. The usefulness of the vertical-type stilling-well would be greatly increased by the development of a suitable cavitation-free regulating valve. (The gate valve in the blow-off structure at Soap Lake should be operated partially opened for a minimum time only.)

RECOMMENDATIONS

For the Soap Lake siphon blow-off, use a stilling-well 7-1/2 feet square, 11 feet deep, and with four corner fillets (Figure 4H). Place the 16-inch downspout vertically at the center of the well and terminate it 2-1/2 feet above the well floor.

INTRODUCTION

The West Canal is one of the prominent features of the Columbia Basin Project; it starts at the bifurcation works of the main canal just north of Adrian, Washington, and extends south and west for 80 miles into the Columbia Basin to furnish irrigation water for about 281,000 acres (Figure 1). Most of this acreage is now nonproductive land. The course of the canal crosses Soap Lake about 8 miles north of Ephrata, Washington. It was planned originally to place an inverted siphon under the lake, but undesirable foundation conditions rendered this infeasible, and the siphon was routed around the lake.

The siphon is 12,833 feet long, 22 feet 4 inches in diameter, and at its lowest point, elevation 1074.0, is 246 feet lower than the open canal. A blow-off is provided in an inverted siphon to drain it for inspection and maintenance, and in the usual case the waste water is released at the lowest point and allowed to flow into a watercourse nearby. At Soap Lake, however, the saline water is of commercial value and the dilution which would ensue if the siphon were drained into it was considered objectionable. Therefore, the main blow-off was placed at elevation 1107.5, 33.5 feet higher than the low point of the siphon, and a drainage channel constructed to Lake Lenore about 8,000 feet from Soap Lake. The water below elevation 1107.5 will be pumped to the main blow-off drainage channel.

The blow-off structure (Figure 2) consists of a 16-inch line directed downward into a stilling-well at the head of the drainage channel. This 16-inch line, located at Station 463+80 of the West Canal, is approximately 40 feet long with a gate valve near the downstream end. The stilling-well into which the line discharges was originally to be 6 feet square and 10 feet deep, while the channel downstream was trapezoidal with 1-1/2:1 side slopes and a 6-foot bottom.

The stilling-well was considered the most economical structure for dissipating the energy of the high-pressure flow, but there was little information as to the proper size and shape required for satisfactory operation; therefore studies were made with an hydraulic model. The results obtained can be used as a basis for further studies of a general nature to permit comparison of this type of well with other stilling structures.

The quantities and dimensions used in this report refer to the prototype unless otherwise indicated.

DESCRIPTION OF THE MODELS

1:4 Scale Model

A 1:4 scale model of the Soap Lake siphon blow-off structure was constructed to include a 4-inch line and gate valve, a stilling-well structure, and a portion of the trapezoidal drainage channel (Figure 3). The blow-off line approached the stilling-well horizontally and was turned downward into the well by a 90° elbow. This vertical section of pipe, with a 4-inch by 3-1/2-inch reducer on its open end, was so arranged that the distance from the reducer to the well bottom could be adjusted as desired. Water was supplied by a laboratory pump and the discharge measured with a venturi-orifice meter.

The model stilling-well, lined with sheet iron and containing an adjustable bottom, represented a well 6 feet square with a maximum depth of 21 feet. The trapezoidal channel at the headworks around the well and downstream for a distance of 20 feet prototype was constructed of concrete. Beyond this point, pea gravel was used to represent 60 feet of riprapped and natural channel. A tail gate was placed at the downstream end of the channel to regulate the water surface.

A point gage to measure the water surface in the channel, a scale to measure wave variations on the 1-1/2:1 slope, and the venturi-orifice meter mentioned above, were the only instruments used in the operation of the model. The tests for each change in design, size, or shape of the stilling-well consisted of regulating the discharge to the model, adjusting the water surface elevation in the channel, and observing the flow conditions above the well and in the channel.

1:5 Scale Model

Two conditions observed in the first model led to changing the model scale to 1:5. First, the capacity of the laboratory pump was too small to give the required discharge for a 1:4 scale and secondly, a larger well was thought to be a logical step toward securing tranquil flow. A change to the smaller scale overcame these two obstacles with the fewest changes to the model. A 1:5 scale permitted the pump to deliver 20 percent greater than the normal discharge; the actual size of the well in the model was not changed, making in effect a prototype well 7-1/2 feet square. The width of the channel bottom in the model was decreased to retain the 6-foot width of the prototype, but the model lengths of the concrete section and the gravel section were left unchanged.

In order to utilize the adjustable downspout and the 4-inch supply line, the entire section was raised until the adjusting mechanism was above the water surface, then a smaller pipe was attached to the sliding section to represent the 16-inch downspout (Figure 5). This change made the model differ from the prototype in that the horizontal section of the blow-off line, leading to the downspout, entered the well above instead of below the water surface.

THE INVESTIGATION

Initial Operation

With the 1:4 model operating at a discharge representing 60 cfs, there was a violent boiling above the corners of the well and considerable wave action downstream. The discharge from the blow-off pipe spread out radially on the well floor and concentrated in the corners after striking the walls of the well. It was noted that the waves produced by the boils were short and choppy, had no particular pattern, and were soon damped out in the trapezoidal channel.

To establish a criterion for the tranquility of flow, aside from observation of the scour of the gravel portion of the model channel, a measurement was made of the maximum high and low variation of the waves on the 1-1/2:1 concrete slope about 15 feet (prototype) from the downstream edge of the stilling-well. In the original design, with a discharge representing 60 cfs, this variation was the equivalent of about 4 feet. Since these conditions were unsatisfactory, and since a maximum prototype discharge of 75 cfs was desired, the model scale was changed to 1:5.

Downspout

Tests were conducted to study the shape of the discharge end of the downspout, the depth of the downspout end, and the depth of the stilling-well. Sizes and distances given in the text and on all drawings are for optimum flow conditions. A discharge of 75 cfs prototype was maintained unless otherwise indicated. The depth of the water in the drainage channel was maintained at 3 feet prototype.

A 16- by 14-inch reducer placed at the lower end of the downspout produced a wave variation on the 1-1/2:1 slope of 3-1/2 feet when the pipe end was 10 feet and the well floor 14 feet below the channel bottom.

A straight pipe end produced waves of 3-1/2 feet on the 1-1/2:1 slope when the pipe end was 8 feet and the well floor 10-1/2 feet below the channel bottom.

A 16- by 20-inch enlarging section 2 feet long produced 3-1/2-foot waves when the floor was 10 feet and the pipe end 7 feet below the channel bottom. Since a diverging section would cause a draft-tube action which might produce dangerously low pressures in the blow-off pipe, this design was not considered feasible. Because the straight pipe end required a smaller stilling-well floor depth than the converging nozzle, this design was considered to be the best. Figure 6 shows the water surface conditions for a discharge of 75 cfs and 90 cfs with the well floor 11 feet and a straight pipe end 8-1/2 feet below the channel bottom.

Baffle Wall

A model study of the Masonville turn-out, in which an oblong stilling-well with a submerged discharge pipe was used to dissipate the energy before the water entered a basin above a measuring weir (Hydraulic Laboratory Report 237), showed that a baffle wall between the stilling-well and the weir basin produced very good flow conditions. However, the vertical velocity in this stilling-well was somewhat less than that expected in the Soap Lake siphon blow-off structure.

Tests were made to explore the possibilities of the baffle wall in connection with the Soap Lake siphon blow-off structure. In these tests the stilling-well floor was maintained at 11 feet and the straight pipe end at 8-1/2 feet below the channel floor.

A baffle wall 1-foot thick was placed across the drainage channel at the downstream edge of the stilling-well. The first design had eight openings 18 inches square with 9-inch partitions between. The wall was symmetrical about the center line of the channel with the bottom of three of the openings on the channel floor and the other five 27 inches higher. The flow with this arrangement was unsatisfactory with a wave variation on the 1-1/2:1 slope of 3-1/2 feet. The upper holes were not submerged and very little damping action occurred.

The same wall with the upper five holes closed was next tested. The wave variation on the slope was about 3 feet. The water boiled up just downstream from the wall causing unsatisfactory flow conditions.

The three lower holes were increased in height and the top sloped to deflect the flow downward. This revision, making the holes 18 inches wide, 30 inches high on the upstream face and 24 inches high on the downstream face (Figure 4I) produced a flow with very little wave action; however, the flow was concentrated in the center of the channel and caused scour of the gravel channel bed.

It was apparent that a more complex baffle wall would be necessary to distribute the flow uniformly in the channel and since simplicity of design was considered to be of major importance, the tests on the baffle walls were not continued.

Floor Pedestals

In an effort to deflect and distribute the flow, a pedestal was placed on the stilling-well floor below the pipe. In these tests the three pipe-end shapes mentioned previously were used and the floor depth and pipe-end depth varied to find the optimum conditions.

The first pedestal tested was 32 inches in diameter and 16 inches high; the second was the same diameter and 8 inches high (Figure 4A). The pedestal was placed in the center of the well floor directly below the pipe. The flow was unsatisfactory under all conditions, the least objectionable occurring when the diverging pipe end section was used. The flow appeared to be similar to that without a pedestal.

The third pedestal, 2 feet 8 inches in diameter, had eight radial teeth equally spaced (Figure 4B). The surface boils with this design were somewhat smaller than those with the nontoothed pedestal. Minimum wave variation on the 1-1/2:1 slope was about 3 feet with the end of the straight pipe 8-1/2 feet and the well floor 11 feet below the channel bottom.

Although the toothed pedestal showed tendencies to produce better flow conditions on the surface, the danger of cavitation at the teeth with high velocity flow precluded further study along this line.

Circular Walls

To direct the flow off the well floor away from the walls and corners, vertical circular walls of various diameters and heights were placed on the well floor concentric with the outlet pipe. Walls with inside diameters of 4 feet, 5 feet, and 6 feet 8 inches, and heights ranging from 10 inches to 30 inches were tried, each producing unsatisfactory flow conditions. In all cases the surface boils appeared around the downspout.

The best of these designs was a wall 6 feet 8 inches inside diameter and 10 inches high (Figure 4J). The wave variation on the 1-1/2:1 slope in this case was about 3 feet 4 inches.

Corner Blocks on the Stilling-well Floor

Four blocks, 30 inches square and 18 inches high, were placed on the well floor, one in each corner (Figure 4D). The flow boiled up along the walls of the well causing a wave variation on the 1-1/2:1 slope of about 3 feet.

Another design consisted of blocks placed diagonally from the corners extending 2 feet 6 inches toward the center of the well. These blocks were 8 inches high and 18 inches wide (Figure 4F). The flow with the blocks alone was similar but far less violent than that produced by the unobstructed well. Boils occurred above the well corners causing a wave variation on the 1-1/2:1 slope of about 20 inches.

Corner fillets were used in conjunction with these floor blocks to divert the flow away from the corners of the well. The fillets were placed 30 inches above the floor blocks; they were triangular in plan with vertical faces 18 inches wide and 6 inches high, and the upper and lower faces of the fillets extended to the well corners on a 1:1 slope (Figure 4F). The flow with this design was reasonably tranquil with a maximum wave variation on the 1-1/2:1 slope of about

12 inches. This design satisfactorily dissipated the energy of the flow, but there was a danger that sediment might fill up the spaces around the blocks on the well floor causing the flow pattern to change thereby reducing the energy dissipating ability of the design.

Corner Shelves

A series of tests were made using triangular corner shelves, isoceles in plan. Six sizes ranging from 10 inches to ~~3 feet~~34 inches in leg lengths were tested at distances of 2 feet, 4 feet, and 6 feet above the well floor (Figure 4E). When the shelf measuring 10 inches on a side was used the water boiled up above the well corners as before, the 12-1/2-inch shelf produced a very turbulent surface with water boiling up intermittently over the entire surface above the well, and shelves larger than 12-1/2 inches caused the boils to appear above the center of the well around the downspout. The best flow conditions were achieved using a shelf 2 feet 6 inches on a side and set 4 feet above the well floor. This design produced a wave variation on the 1-1/2:1 slope of about 2-1/2 feet.

Shelves with circular openings were tested at heights of 12 inches, 3 feet, and 5 feet above the well floor. Two sizes, one 5 feet and the other 7 feet 3 inches in diameter were tested; the best results were obtained with the larger opening and the shelf set at 3 feet above the well floor (Figure 4C). The wave variation on the 1-1/2:1 slope in this case was about 3 feet 4 inches.

These tests indicated that neither the corner nor the circular shelf, when used alone, could satisfactorily dissipate the energy to be encountered in this particular stilling-well.

Octagonal-shaped Well

In the following tests the well floor was fixed at a depth of 11 feet below the channel bottom.

Several tests were made using an eight-sided well with various side widths. The eight-sided effect was achieved by placing vertical walls in each corner. Flow was best when the shape of well approached a true octagon in plan, with the vertical faces of the corner walls about 5 feet high. In the initial tests the tops of the corner walls were horizontal; after finding the optimum width and height of wall, the top was sloped up and back to the corner. It was found that the flow remained the same for slopes of the top flatter than 0.65:1. If the slope was steeper than that value, the upward flowing water clung to the sloping face and boiled up above the well corners.

A wave variation of about 20 inches on the 1-1/2:1 slope occurred when the corner walls were 5 feet high and formed a well octagonal in plan; the major disturbance was caused by a flow up along the side walls. Projections, 9 inches high and 3-3/4 inches thick, were placed horizontally on these side walls 2 feet above the well floor (Figure 4G). The wave variation on the 1-1/2:1 slope with this design was about 6 inches and there was no appreciable scour downstream. An objectionable feature of the design was the horizontal projection which would present some difficulty of construction.

Corner Fillets (Final Design)

Several shapes of deflectors, referred to as corner fillets, were mounted above the well floor, one in each of the vertical corners, to deflect and distribute the flow after it started upward. In the following tests the well floor remained square, free of any obstruction, and 11 feet below the drainage channel bottom. The pipe end was 2-1/2 feet above the well floor.

One fillet tested had a surface curved in the vertical plane as if a pipe were embedded in each vertical corner of the well, the axis of the pipe horizontal, making an angle of 45° with the walls of the well, and set in such a manner that the exposed fillet face was less than a half circle. One fillet of this type, having a face radius of 22 inches, a height of 3 feet 4 inches, and a maximum width of 2 feet 8 inches with the bottom point 15 inches above the well floor, was tested. The flow with this fillet was unsatisfactory. The waves on the 1-1/2:1 slope 15 feet downstream from the well had a maximum variation of about 2 feet. The surface boils occurred intermittently above the corners as before, but were somewhat less violent, indicating that some redistribution of the flow was being accomplished.

The fillet was revised by replacing the upper half with a rectangular plate 2 feet 8 inches wide and 20 inches high, mounted vertically and tangent to the fillet. This change aided in damping out the undesirable surface boils, and the waves on the 1-1/2:1 slope had a variation of about 20 inches.

Another corner fillet was made of flat surfaces, one face being rectangular and placed vertical, diagonally across the corner; another surface extended from the lower edge of the vertical face down and back to the corner of the well; the spaces behind the surfaces of the fillet were not filled. The flow with this design was surprisingly tranquil. Several sizes and variations of this type of fillet were tested.

The best results were obtained with a fillet 37-1/4 inches wide with the lower surface sloping back to the well corner on a 0.71:1 slope intersecting the corner 12 inches above the floor, the vertical face was 21-3/4 inches high and the upper surface sloped up and back to the well corner on the same slope as the lower surface (Figure 4H). The 0.71:1 slope of the lower face is critical; the upper face, however, was sloped for ease of field construction and can be equal to or flatter than the slope suggested here. The flow with this design produced water surface variations on the 1-1/2:1 slope of about 6 inches for a discharge of 75 cfs and about 9 inches for a discharge of 90 cfs (Figure 7). Because of the tranquil conditions obtained with this design it was recommended for the Soap Lake siphon blow-off drain.

FIGURE 1

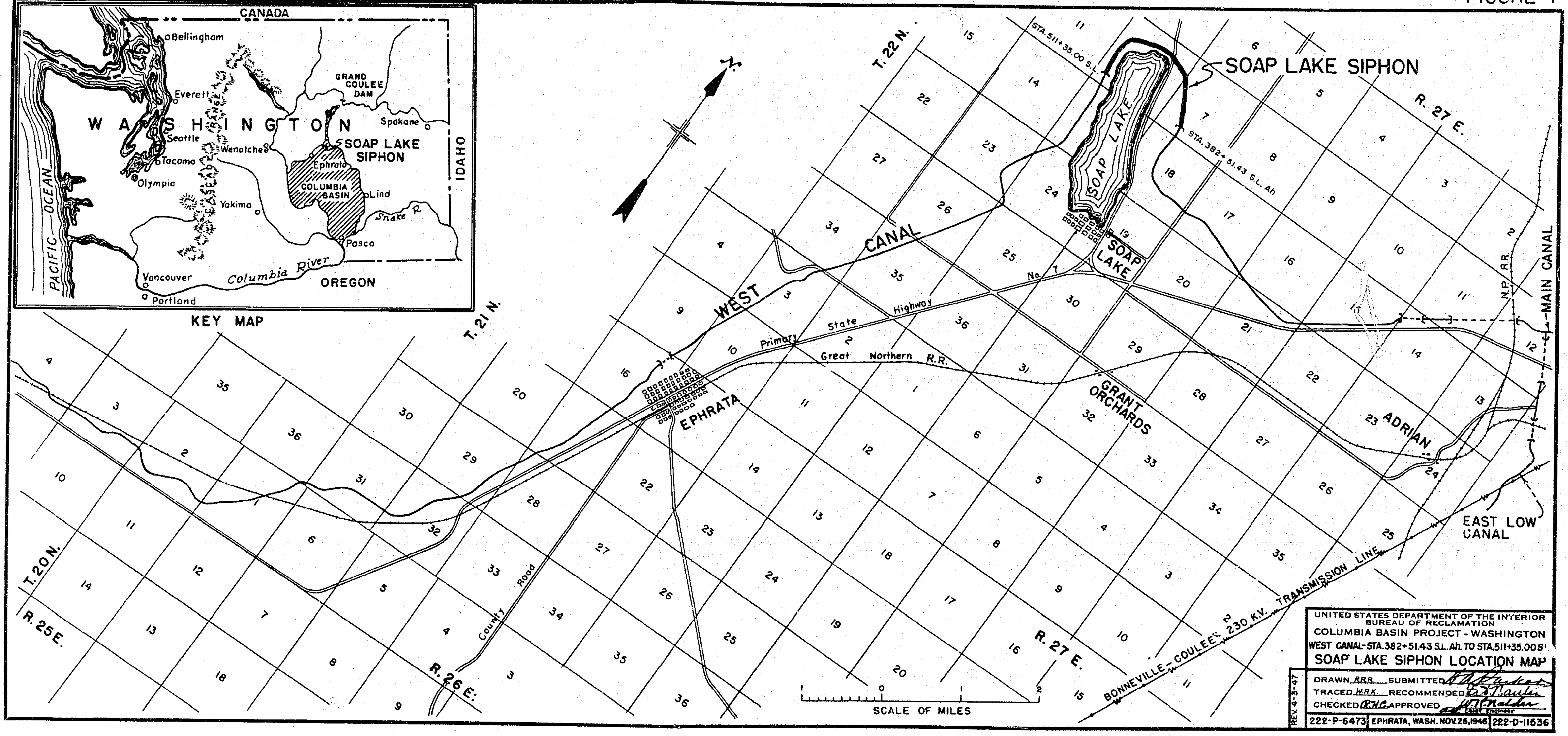
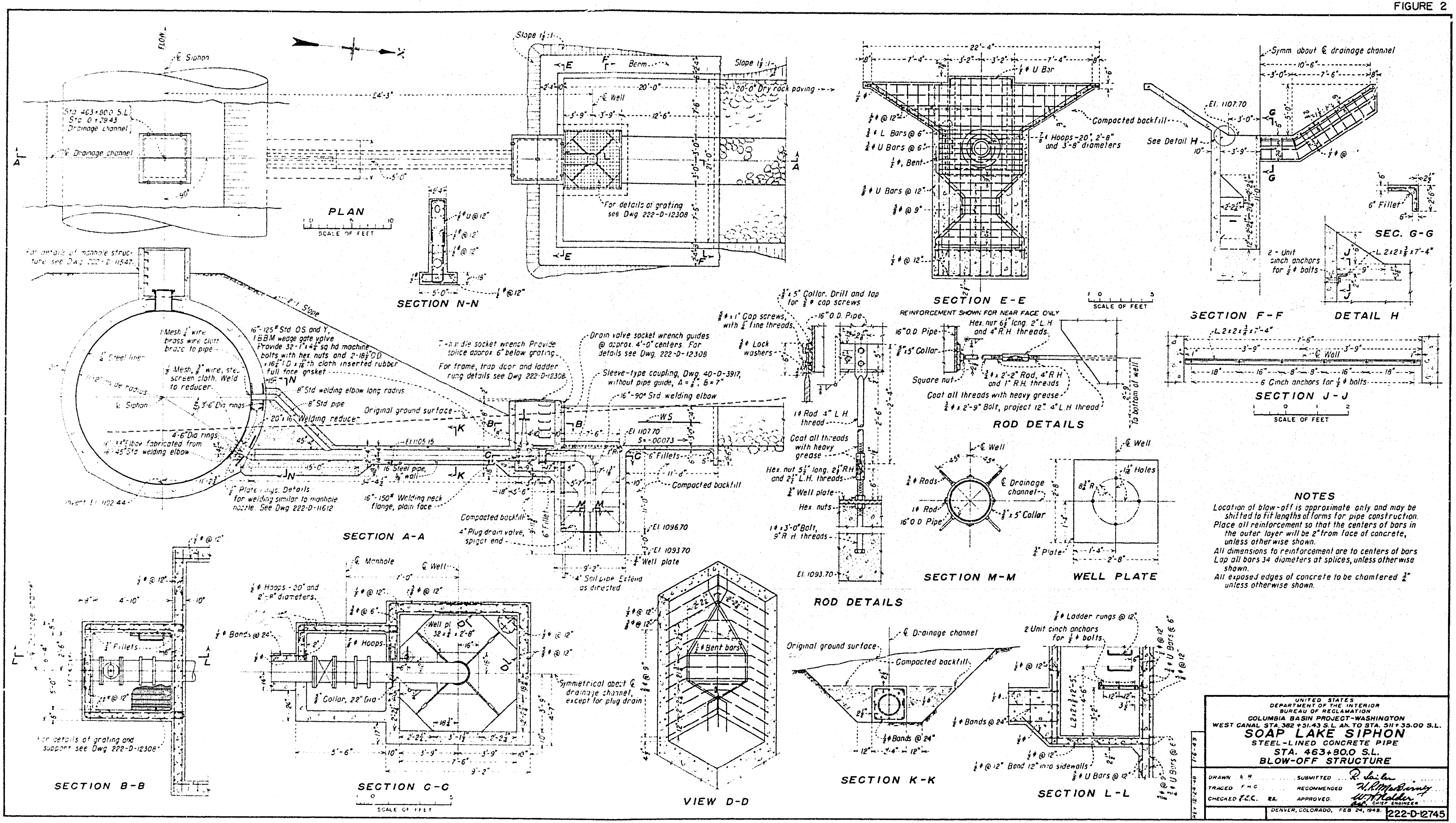

KEY MAP
CANADA
WASHINGTON
OREGON
IDAHO
PACIFIC OCEAN
Bellingham
Everett
Seattle
Tacoma
Olympia
Wenatchee
Yakima
Vancouver
Portland
GRAND COULEE DAM
Spokane
SOAP LAKE SIPHON
Ephrata
COLUMBIA BASIN
Lind
Pasco
Snake R.
Columbia River
CASCADE RANGE
SOAP LAKE SIPHON
STA. 511+35.00 S.L.
STA. 382+51.43 S.L. Ah
SOAP LAKE
WEST CANAL
T. 22 N.
T. 21 N.
T. 20 N.
R. 25 E.
R. 26 E.
R. 27 E.
No. 7 Primary State Highway
Great Northern R.R.
EPHRATA
GRANT ORCHARDS
ADRIAN
N.P. R.R.
MAIN CANAL
EAST LOW CANAL
County Road
BONNEVILLE - COULEE 230 K.V. TRANSMISSION LINE
SCALE OF MILES
0
1
2
UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT - WASHINGTON
WEST CANAL - STA. 382+51.43 S.L. Ah. TO STA. 511+35.00 S.L.
SOAP LAKE SIPHON LOCATION MAP
DRAWN R.R.R. SUBMITTED
TRACED W.R.K. RECOMMENDED
CHECKED R.H.C. APPROVED
REV. 4-3-47
222-P-6473
EPHRATA, WASH. NOV. 26, 1946
222-D-11536

FIGURE 2


PLAN
SECTION N-N
SECTION E-E
SECTION F-F
DETAIL H
SEC. G-G
SECTION J-J
ROD DETAILS
SECTION A-A
SECTION M-M
WELL PLATE
ROD DETAILS
SECTION B-B
SECTION C-C
VIEW D-D
SECTION K-K
SECTION L-L
NOTES
Location of blow-off is approximate only and may be shifted to fit lengths of forms for pipe construction.
Place all reinforcement so that the centers of bars in the outer layer will be 2" from face of concrete, unless otherwise shown.
All dimensions to reinforcement are to centers of bars
Lap all bars 34 diameters at splices, unless otherwise shown.
All exposed edges of concrete to be chamfered ¾" unless otherwise shown.
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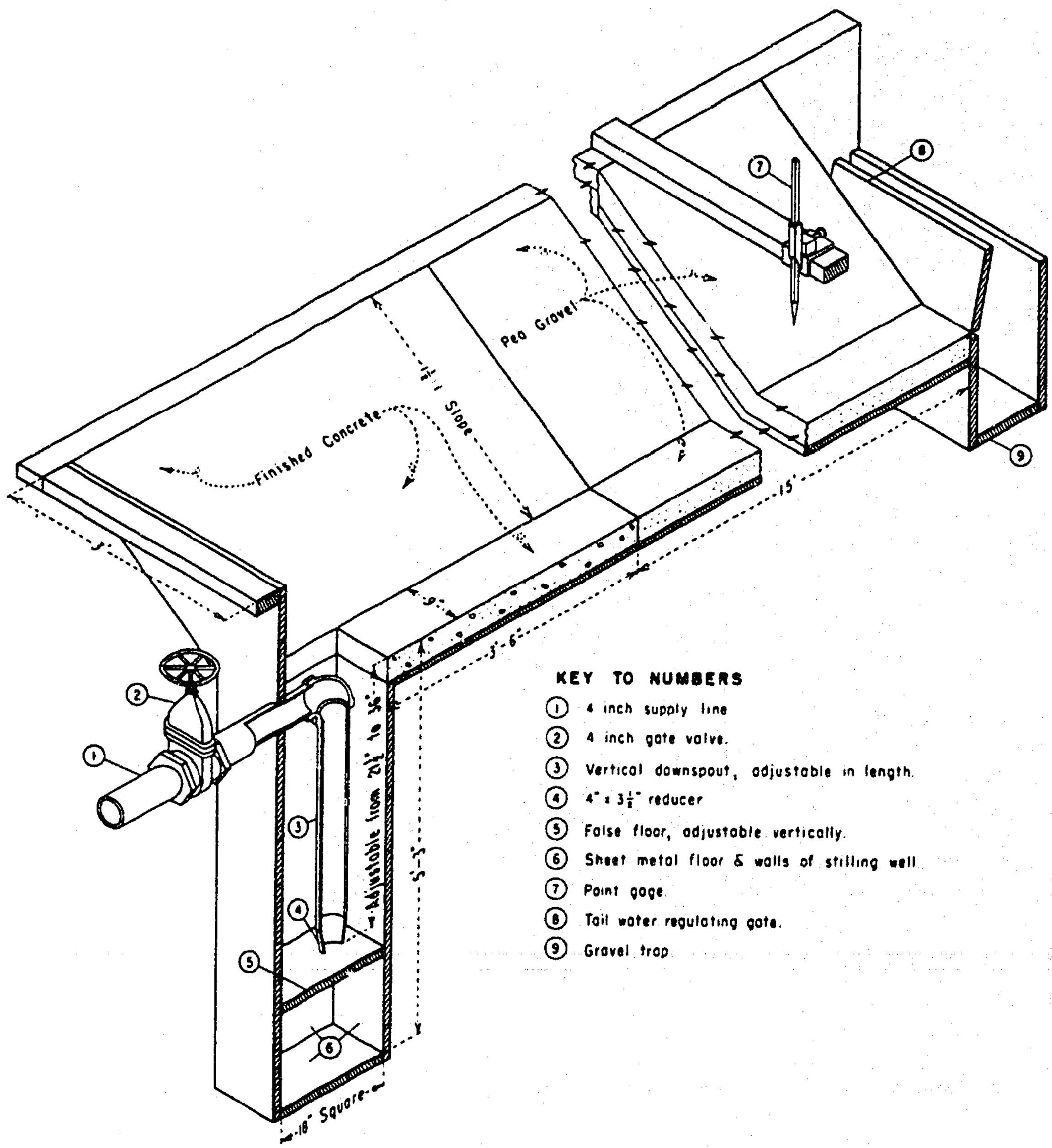
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
COLUMBIA BASIN PROJECT-WASHINGTON
WEST CANAL STA. 382+51.43 S.L. AH. TO STA. 511+35.00 S.L.
SOAP LAKE SIPHON
STEEL-LINED CONCRETE PIPE
STA. 463+80.0 S.L.
BLOW-OFF STRUCTURE
DENVER, COLORADO, FEB. 24, 1948.
222-D-12745



KEY TO NUMBERS

1. 4 inch supply line
2. 4 inch gate valve.
3. Vertical downspout, adjustable in length.
4. 4" x 3½" reducer
5. False floor, adjustable vertically.
6. Sheet metal floor & walls of stilling well
7. Point gage.
8. Tail water regulating gate.
9. Gravel trap

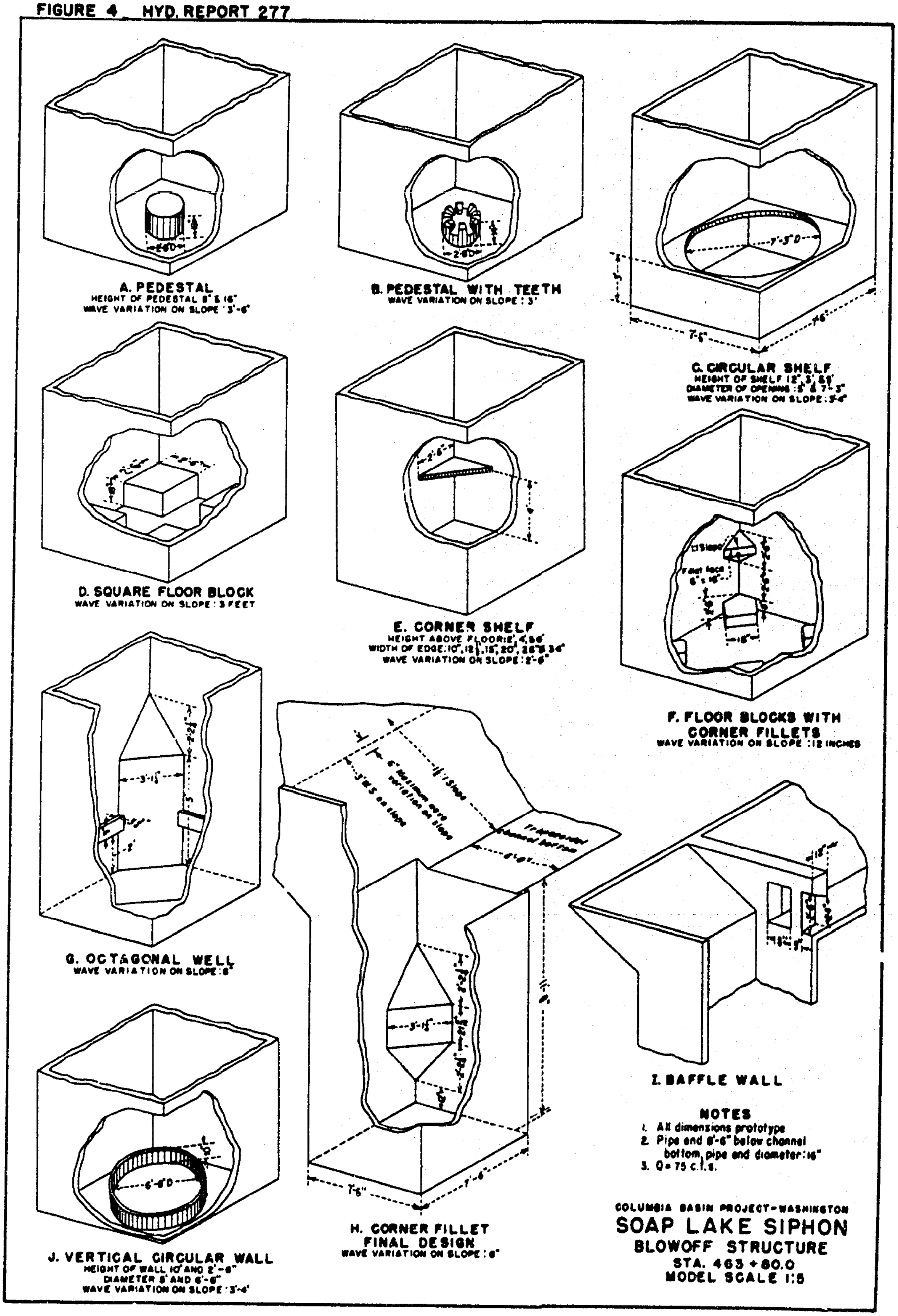
COLUMBIA BASIN PROJECT - WASHINGTON

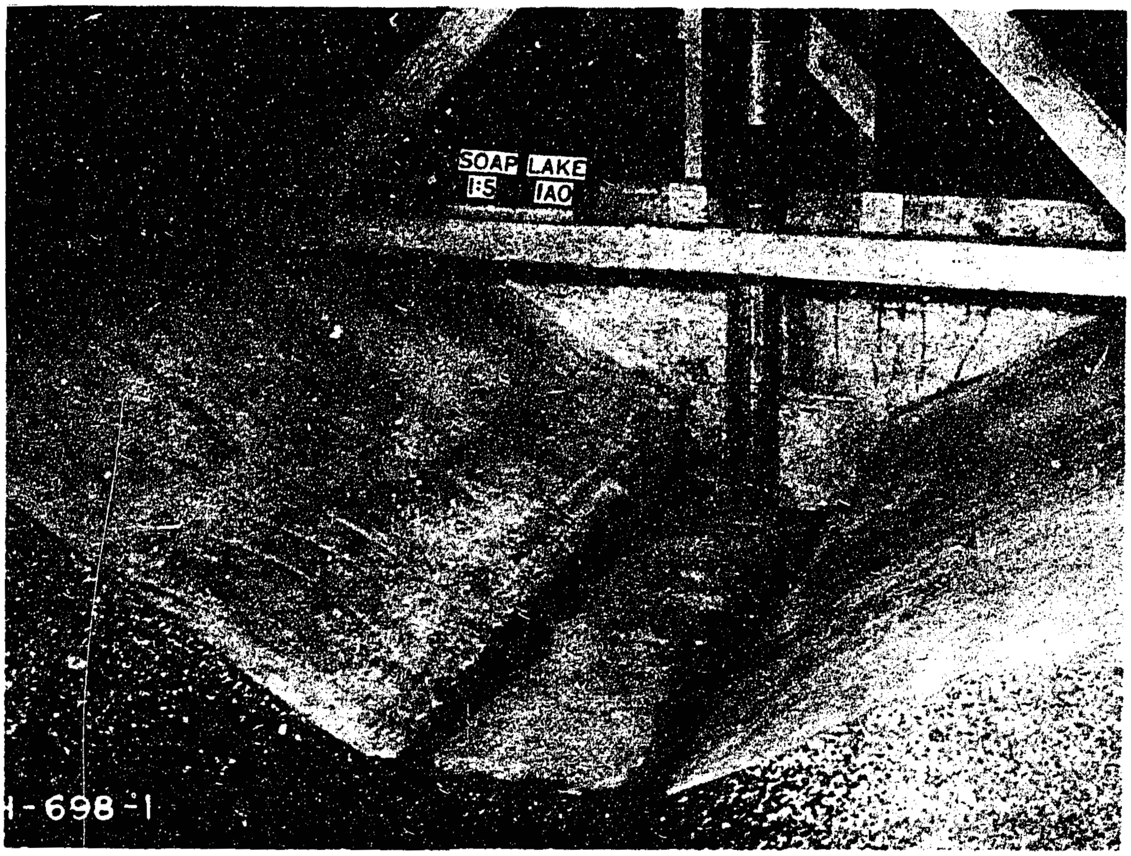
SOAP LAKE SIPHON

BLOWOFF STRUCTURE

ISOMETRIC SECTION THROUGH CENTER LINE
OF 1:4 MODEL REPRESENTING A
PROTOTYPE WELL 6 FEET SQUARE

FIGURE 4 HYD. REPORT 277



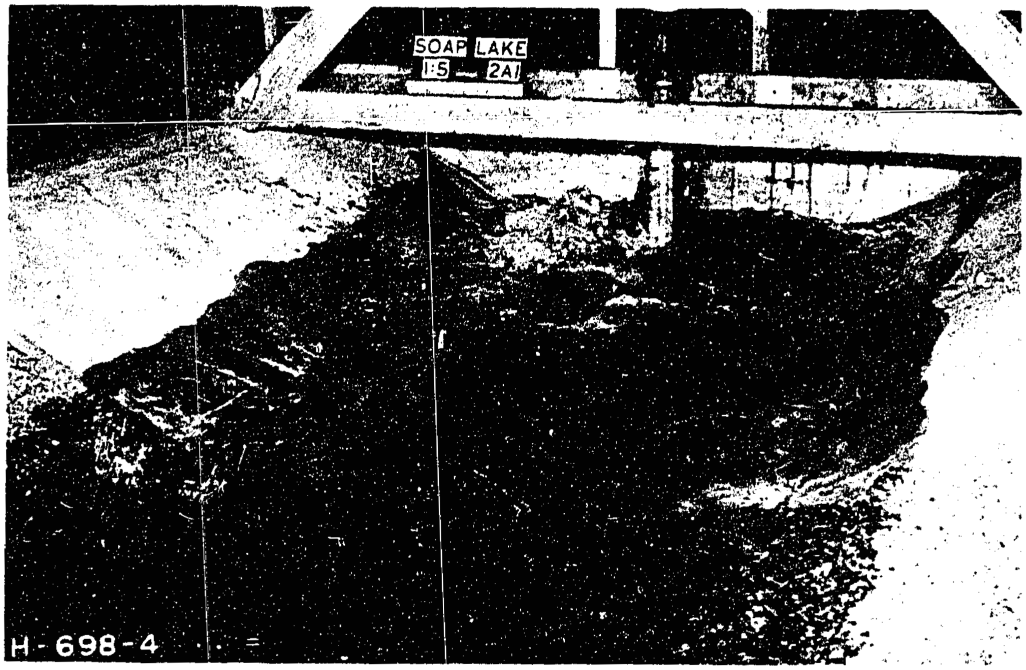


Model of the stilling well for the Soap Lake Siphon Blowoff Structure showing the trapezoidal drainage channel, upper portion of the stilling well, and the downspout.

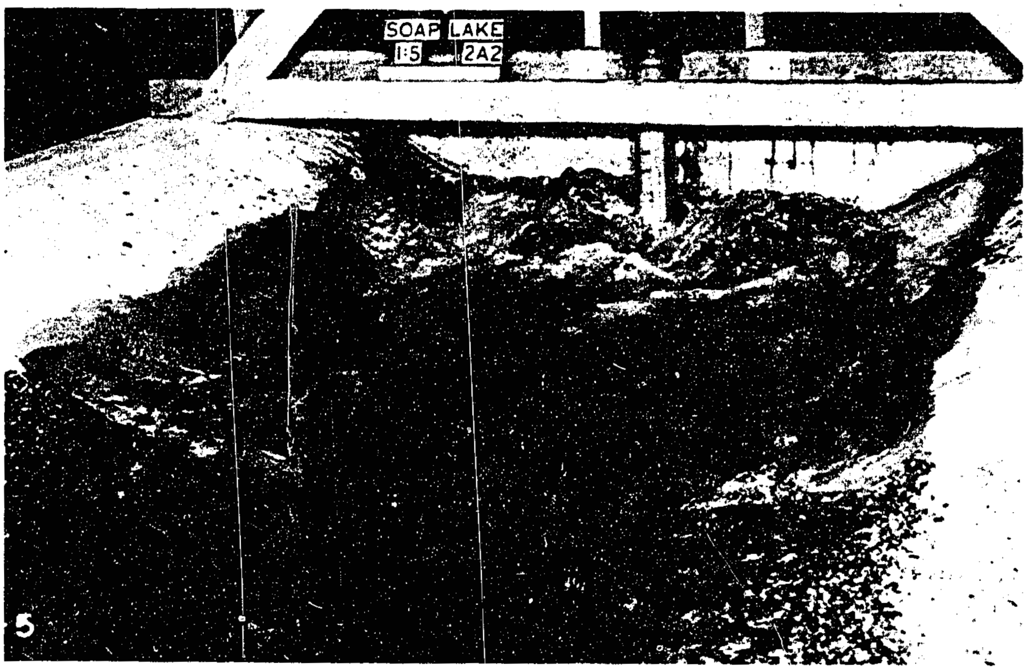
Dimensions Prototype:

Slope of channel sides - - - - - - - -	$1\frac{1}{2}$:1
Width of channel bottom- - - - - - -	6 ft.
Size of well - - - - - - - - - - - - - -	7.5 ft. square
Diameter of downspout- - - - - - - -	16 inches
Design depth of water in channel - -	3 ft.
Normal discharge - - - - - - - - - - -	75 cfs

Model Scale - 1:5



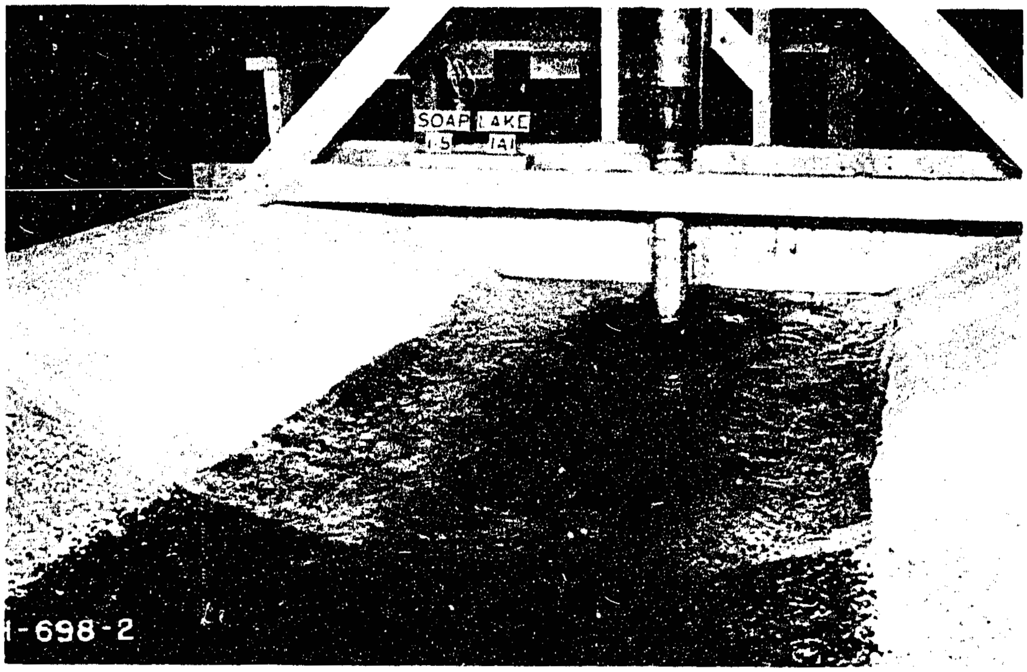
A. 75 cfs



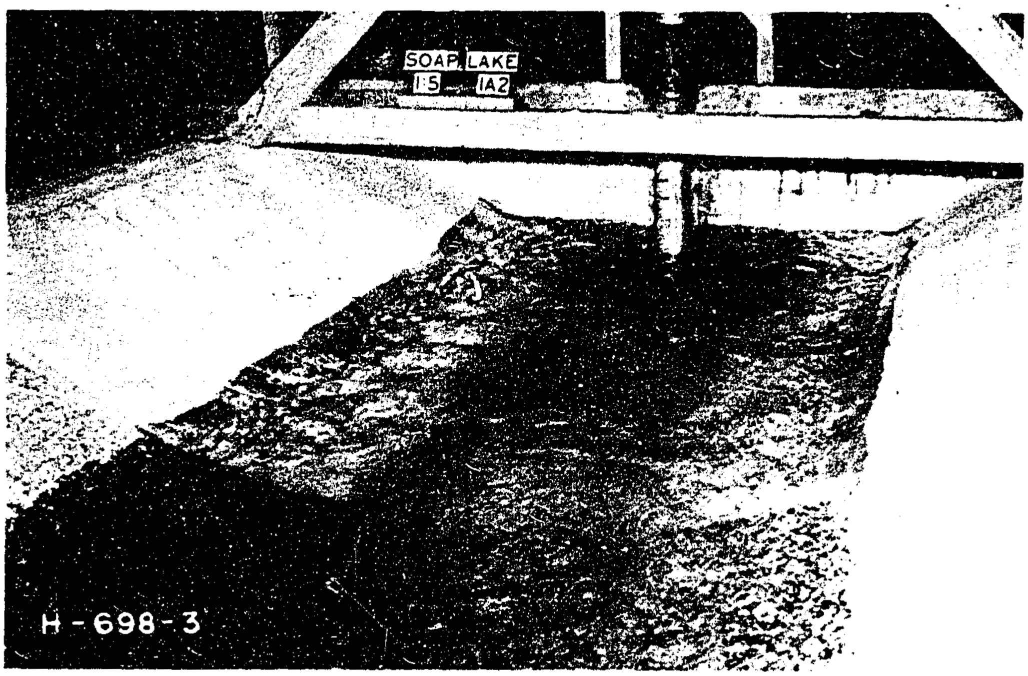
B. 90 cfs

Flow from the well as originally designed.

Model Scale - 1:5



A. 75 cfs



B. 90 cfs

Flow from the stilling well, final design

Model Scale - 1:5