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HYDRAULIC MODEL STUDIES OF THE CANAL STRUCTURES ADJACENT TO BACON SIPHON AND TUNNEL COLUMBIA BASIN PROJECT WASHINGTON

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Engineering and Research Center
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16. ABSTRACT

A 1:49.8 scale model was used to aid development of design modifications to increase the capacity of the Main Canal near Grand Coulee Dam in Washington. Portal-to-canal transitions with wave suppressors were developed for the tunnels from the 2 siphons. Flow characteristics in the canals upstream and downstream of the siphons and tunnels were studied to develop designs for the bifurcation and the canal junction, and to determine the proper cross-sectional size of the canals.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS--/ *siphons/ *canals/ tunnels/ *hydraulic models/ model tests/ Mannings Equation/ cross sections/ roughness coefficient/ waves/ standing waves/ velocity distribution/ water surface profiles/ transition flow/ outlets/ Washington/ *wave suppressors/ flow characteristics/ canal design/ bifurcations/ *hydraulic design

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July 1972

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PURPOSE

The purpose of the model study was to aid in the development of the design of the canals leading to and from the Bacon Siphon and tunnels.

CONCLUSIONS

1. The theoretical discharge through the proposed second unit was verified.

2. The proposed width of the canal upstream of the existing and proposed siphons was reduced from 108 feet (ft) (32.92 meters (m)) to 90 ft (27.43 m).

3. The design of the bifurcation upstream of the two siphons was found to provide good hydraulic flow conditions.

4. The entrance flow conditions to the existing siphon transition were improved by modification of one of the warped transition walls.

5. The floor width of the concrete-lined canal to be added downstream from the existing siphon was increased from 12 ft (3.66 m) to 20 ft (6.10 m) to improve the velocity distribution.

6. The hydraulic design of the tunnel exit portal and the canal outlet transition for the second unit was developed.

7. Wave suppressors were developed for the exit portal to canal transitions in the existing and proposed second siphon units.

8. The hydraulic design of the junction of the two canals downstream from the siphons was developed.

APPLICATIONS

The study was performed specifically for the canal structures leading to and from the Bacon Siphon and Tunnel units. However, the results should be of general interest to designers of canal transitions, canal junctions, and bifurcations.

INTRODUCTION

Bacon Siphon and Tunnel, existing structures in the Columbia Basin Project, Washington, are located on the Main Canal as shown on the location map (Figure 1). Because of the Bacon Tunnel the existing canal is limited in capacity to about 7,250 cubic feet per second (cfs) (205.3 cubic meters per second (cms)). The inlet and outlet transitions to the existing siphon and tunnel discharging 6,930 cfs (196.3 cms) are shown in Figure 2.

It is planned to increase the canal capacity to 19,300 cfs (546.5 cms) by widening the existing canal and branching to a second siphon and tunnel unit as shown in the preliminary design arrangement, Figure 3.

THE MODEL

Due to the shape of the space available in the laboratory the 1:49.8 scale model (Figure 4) was constructed as a mirror image of the proposed prototype plan (Figure 3). The model included the canal transition, proposed enlargement of the canal, and the bifurcation upstream of the siphons, the siphons, the tunnels, and the canals downstream of the siphons.

The discharge was controlled and measured using the permanent water supply system in the laboratory. The flow depth upstream of the siphon was not controlled, other than by the siphons themselves, while studying the flow characteristics in that portion of the system, Figure 5. While studying the flow characteristics downstream of the tunnels, the flow depth was controlled with an adjustable slot orifice at the downstream end of the model, using a water surface point gage to measure flow depth at Station 216+02, Figure 6.

The siphons were constructed of clear plastic, the tunnel sections of sheet metal, inlet and outlet transitions of concrete, and the canal sections of wood. A rock baffle in a small head box was used at the upstream end of the model to smooth the flow entering the canal section.

THE INVESTIGATION

The investigation was concerned with the development of the hydraulic design of the canals, the inlet and outlet transitions to the siphons and tunnels, the wave suppressors for the outlet transitions, and the canal junctions upstream of the siphons and downstream of the tunnels.

Upstream Canals

For this part of the investigation, the flow depth upstream of the siphons was dependent upon the flow through the siphons. The flow depth measured upstream of the bifurcation at Station 78+00 was slightly more than the computed depth, Figure 7, indicating that the head losses represented in the model siphons were higher than those anticipated in the prototype. At the maximum capacity of the siphons for which this study was primarily concerned the difference was insignificant. To determine the percentage of flow being carried by the new second unit, velocity meter measurements were made in each of the two canal branches upstream of the siphons and in the main canal upstream of the bifurcation at Station 78+50. The average velocity at each station was considered to be the numerical average of the velocities measured at the six locations in the section, as shown in Figure 8. The average velocity determined in this way multiplied by the cross-sectional area provided an approximate discharge in each of the two units. This method was not exact since the total discharge in the two branches determined by this method was approximately 8 percent higher than was measured at the meter. Nevertheless, the percent of flow carried by the second siphon unit could be determined reasonably well and was sufficiently close to the theoretical value (Figure 9) to provide a check on the computated discharge.

At the upstream end of the model, the 50-ft (15.24-m) wide prototype canal transitioned to a width of 120 ft (36.57 m) through a length of 250 ft (76.20 m), Figure 10. Some small eddies occurred along the left (prototype) bank of the transition but flow conditions were satisfactory.

This wider canal is to be concrete lined and is 6,900 ft (2,103.1 m) long to the bifurcation. Each branch is to be concrete lined to the siphon transitions. Operation of the preliminary design indicated that the canal was wider than required except at the bifurcation where it was important to maintain a relatively slow velocity of flow. Therefore, in the recommended design, the width of the enlarged canal was decreased from 120 to 90 ft (36.58 to 27.43 m) from Station 59+50 to Station 75+50, 300 ft (91.44 m) upstream of the bifurcation, Figure 10. Here a 250-ft (76.20-m) long transition from the 90-ft (27.43-m) width back to the original 120-ft (36.58-m) width at Station 78+00 was installed.

Attempts to simplify the design of the bifurcation by replacing the rounded nose of the bank between the two branches with the natural junction of the two straight slopes failed because of a slight water surface drawdown at the junction. Therefore, the rounded nose which provided good flow conditions was accepted for the recommended design.

The entrance to the existing siphon was not on the centerline of the inlet transition (Figure 10), because at the time it was designed and constructed, it was anticipated that the single canal and transition would eventually serve two siphons. Therefore, a pocket of dead water with eddies and a water surface drawdown condition existed at the headwall of the inlet transition, causing an additional head loss. (See the prototype operation in Photograph A of Figure 2.) Therefore, a warped transition shape was installed on the dead water pocket side (Figure 10), which provided better flow conditions at the inlet of the existing siphon unit. Flow conditions in the inlet transition to the second siphon unit were satisfactory.

With these recommendations installed, flow conditions in the recommended canals upstream of the siphons were observed using confetti on the water surface. Figures 11 and 12 are for flows of 19,300 cfs (546.5 cms) and 12,000 cfs (339.8 cms), respectively. Dye injected below the surface, and velocity measurements at several critical cross sections, Figure 13, were used to further verify the satisfactory flow characteristics.

Siphons and Tunnels

Operation of the existing siphon and tunnel in the model disclosed no hydraulic problems; however, operation of the second siphon produced an asymmetrical flow distribution in the canal downstream because of the nonlinear plan view alinement of the siphon, Figure 14. No change was recommended in the design of the existing siphon and tunnel or the second siphon and tunnel except at the outlet portal. This is discussed further in the following section.

Downstream Canals

Second Unit.—Flow from the second unit through the preliminary design outlet transition, Figure 15, produced a relatively rough water surface with standing waves that fluctuated in magnitude and location. A flow velocity concentration occurred to the left of the model centerline (to the right of centerline in the prototype). The asymmetrical distribution of flow resulted from the angular path that the flow follows in plan view through the siphon. Further, because the full length of the tunnel between the siphon and portal was not represented in the model, the asymmetrical flow through the outlet transition might be reversed again in the prototype or damped out to some degree. However, model tests were continued in an effort to provide better flow conditions into the canal.

This asymmetrical distribution of flow across the canal produced some eddies in the transition, as evidenced by velocity contour measurements at the downstream end of the transition. Wave heights of 4 ft (1.2 m) from maximum peak to minimum trough were measured at the downstream end of the transition when the flow depth in the canal was set for a Manning roughness coefficient of n = 0.025. Waves were 1 ft (0.3 m) high for n = 0.030.

As a result of these observations, the transition was lengthened from 120 to 200 ft (36.58 to 60.96 m) and designed with an accelerating rate of warping instead of a constant rate. This transition was no better than that of the preliminary design for controlling wave heights in the downstream canal. The Froude number of the flow in the tunnel was computed to be approximately 0.91, which probably accounted for the standing wave condition.

To suppress the waves and perhaps improve the flow distribution from the outlet transition, a wave suppressor in the form of a flat roof-type cover, 60 ft (18.29 m) long, was placed in the flow either at the downstream end of the transition or immediately downstream from the end of the transition. It was placed low enough to intercept the water surface for a total canal flow in both units of 16,000 cfs (453.1 cms).

The suppressor reduced the 4-ft (1.2-m) wave heights to about 1 ft (0.3 m), but increased the depth of flow at the tunnel portal. The portal nearly filled for the design flow using a depth setting for a Manning roughness coefficient of n = 0.030. This was an undesirable operating condition; therefore, other types of wave suppressors were tested, such as floating rafts made up of timbers spaced far apart at right angles to the flow and anchored to the portal by means of a rope. For the design flow these floating rafts were not as effective as the fixed roof in reducing wave heights. Some of their effectiveness was lost because of the requirement to construct the rafts narrow enought that they would not become lodged on the warped walls of the transition at the lower water levels.

The recommended modification to the outlet, Figure 16, was to steepen the invert of the transition for 120 ft (36.58 m) downstream of the portal. The invert of the transition was thus lowered 9.58 ft (2.92 m). (Following completion of the model test, the roof over this portion of the transition was removed in the recommended design.) This was followed by an open rectangular section expanding to a width of 40 ft (12.19 m) in a distance of 60 ft (18.29 m) and, thence, 40 ft (12.19 m) wide for an additional 60 ft (18.29 m) to the beginning of the outlet transition.

Tests showed that there was still a need for the wave suppressor. Therefore, a fixed-box-type roof wave suppressor, 60 ft (18.29 m) long was installed over a part of the basin just upstream from a 160-ft (48.77-m) long canal transition section, Figure 16. The suppressor was installed low enough to intercept the water surface for a total canal flow of 12,000 cfs (339.8 cms), assuming a canal roughness coefficient of n = 0.025.

The increase in depth of flow at the end of the covered transition was negligible and the improvement in water surface smoothness was as good or better than any other arrangement tested. Tests made without the wave suppressor showed the wave suppressor to be beneficial in reducing the wave heights in the outlet transition and canal downstream, Figure 16, and was effective for flows as low as 12,000 cfs (339.8 cms) (both units). Wave height fluctuations in the water surface were reduced from 4 ft (1.2 m) to approximately 0.8 ft (0.2 m) at the design flow.

A proposed center wall under the suppressor for structural support was extended upstream and tested in the model. No significant improvement in the hydraulic performance was detected; therefore, its use for support of the suppressor was abandoned in the recommended design.

An upward slope of 3 ft (0.91 m) in the downstream 15 ft (4.57 m) of the suppressor roof provided no significant improvement in wave reduction; and is, therefore, not recommended for the prototype.

Although the water surface immediately adjacent to the upstream side of the wave suppressor averaged 1.50 ft (0.5 m) or more higher than the downstream canal water surface, the average water surface elevation between the portal and the suppressor was not noticeably higher than that downstream from the suppressor. This verified the design computations using Monograph No. 25,[1] that the head loss through the suppressor was only a small fraction of a foot.

Dye added to the flow showed improvement in flow distribution and water surface smoothness when the wave suppressor was used, Figure 17. Velocity contours showed an improvement in the flow

[1] Engineering Monograph No. 25, "Hydraulic Design of Stilling Basins and Energy Dissipators" U.S. Department of the Interior—Bureau of Reclamation.

distribution across the width of the canal, but also indicated that there was still a higher velocity flow concentration to the left of the canal centerline in the model (to the right in the prototype), Figure 18. These velocity measurements aided the designers in determining the need for reinforcement in the canal lining or the need for increasing the cross-sectional area of the canal.

Existing Unit.—Following the development of the outlet transition for the second unit design, modification for the outlet in the existing unit was developed. The outlet transition in the existing tunnel unit discharges into an earthen channel, Figure 2B, which is to be replaced with a concrete lined canal, Figure 15.

Flow from the existing unit was symmetrical through the outlet transition section, because of the straight-line configuration of the canal, siphon, and tunnel upstream. At design flow of 19,300 cfs (546.5 cms) (both units), the wave heights from maximum peak to minimum trough at the downstream end of the outlet transition were 3 ft (0.9 m) when the flow depth was set for a roughness coefficient of n = 0.025. Maximum wave heights were 4 ft (1.2 m) in the second unit. Setting the flow depth for a roughness coefficient n = 0.030 reduced the wave heights to approximately 1 ft (0.3 m).

A fixed-roof-type wave suppressor, 20 ft (6.10 m) long, similar to the one developed for the second unit, was tested. It was first installed immediately downstream from the transition. The suppressor was placed low enough to intercept the water surface when the total flow in both units was 16,000 cfs (453.1 cms) or more while assuming a roughness coefficient in the canal of n = 0.025. This suppressor performed quite well in reducing downstream wave heights. Upstream the flow depth was increased slightly in the transition, but not enough to cause even momentary filling of the tunnel at the portal.

The velocity distribution diagrams recorded at the beginning of the bend downstream from the siphon and 100 ft (30.48 m) farther into the bend indicated that the canal should be widened to reduce a maximum velocity concentration along the outside bank. The canal bottom was, therefore, widened from 12 to 20 ft (3.66 to 6.10 m) with a fixed-roof type wave suppressor again installed downstream from the transition.

At this location, the suppressor was placed low enough to intercept the water surface for flows as low as 12,000 cfs (339.8 cms) (both units) when assuming a roughness coefficient of n = 0.025. Operation of the model while assuming a flow depth for a roughness coefficient of n = 0.030 was also satisfactory but showed that the suppressor could not be lowered further without possibly submerging the tunnel portal.

Water surface elevations recorded upstream and downstream of the suppressor, Figure 19, were averaged to determine the head loss through the suppressor for the design flow of 19,300 cfs (546.5 cms) (both units). The model confirmed a computed loss of approximately 1.0 ft (0.3 m) through the suppressor. The suppressor reduced the water surface fluctuation in the canal from 3 ft (0.9 m) to 0.85 ft (0.3 m).

Other locations of the suppressor closer to the portal were tested, primarily in an attempt to reduce the magnitude of two side eddies in the transition between the portal and suppressor. With the suppressor installed in the existing transition, the magnitude of the eddies was reduced. However, the effectiveness of the suppressor in the reduction of waves and redistribution of velocity appeared to be less than when the suppressor was located farther downstream.

For the recommended design, a compromise location was selected which placed the suppressor immediately downstream from the existing transition, but in the extended portion of the transition, Figure 20. It was further tested and recommended that the downstream end be extended 15 ft (4.57 m) into the regular canal section with the underside sloping upward 3 ft (0.91 m) as recommended in EM25.[1] The underside of the suppressor was placed at the same elevation as before to intercept the water surface for a total canal flow in both units of 12,000 cfs (339.8 cms) or more, for a canal roughness coefficient of n = 0.025.

Operation of the recommended design with dye injected in the flow showed that the wave suppressor smoothed the water surface and better distributed the flow across the channel width, Figure 21. Water surface elevations upstream and downstream of the suppressor were similar to those recorded in Figure 20 with the wave suppressor at the same height, but farther downstream.

Velocity distribution diagrams were again recorded at two sections downstream from the suppressor location, with and without the wave suppressor, Figure 22. These provided further proof that the wave suppressor improved the flow distribution downstream.

Canal Junction.—The preliminary canal junction downstream from the tunnel portals, Figure 15, performed satisfactorily; however, to simplify the design, the rounded corner junction of the two inside banks was replaced with the normal planar junction of the two side slopes, Figure 23. Water surface elevations upstream and downstream of the junction, Figure 23, were measured to verify the head loss computations.

The hydraulic performance of this junction, Figure 24, appeared to be even better than that of the preliminary design. The joining of the two flows occurred very smoothly, whereas, in the preliminary design small eddies formed in the dead water area between the two joining flows. Dye injected into the flow from the existing unit showed visually how the two flows from the two units merge, Figure 24.

Velocity distribution diagrams, Figure 25, recorded upstream and downstream of the junction aided the designers in determining the need for reinforcing steel in the canal lining, or for possible modifications to provide better flow distribution. No further modifications were recommended.

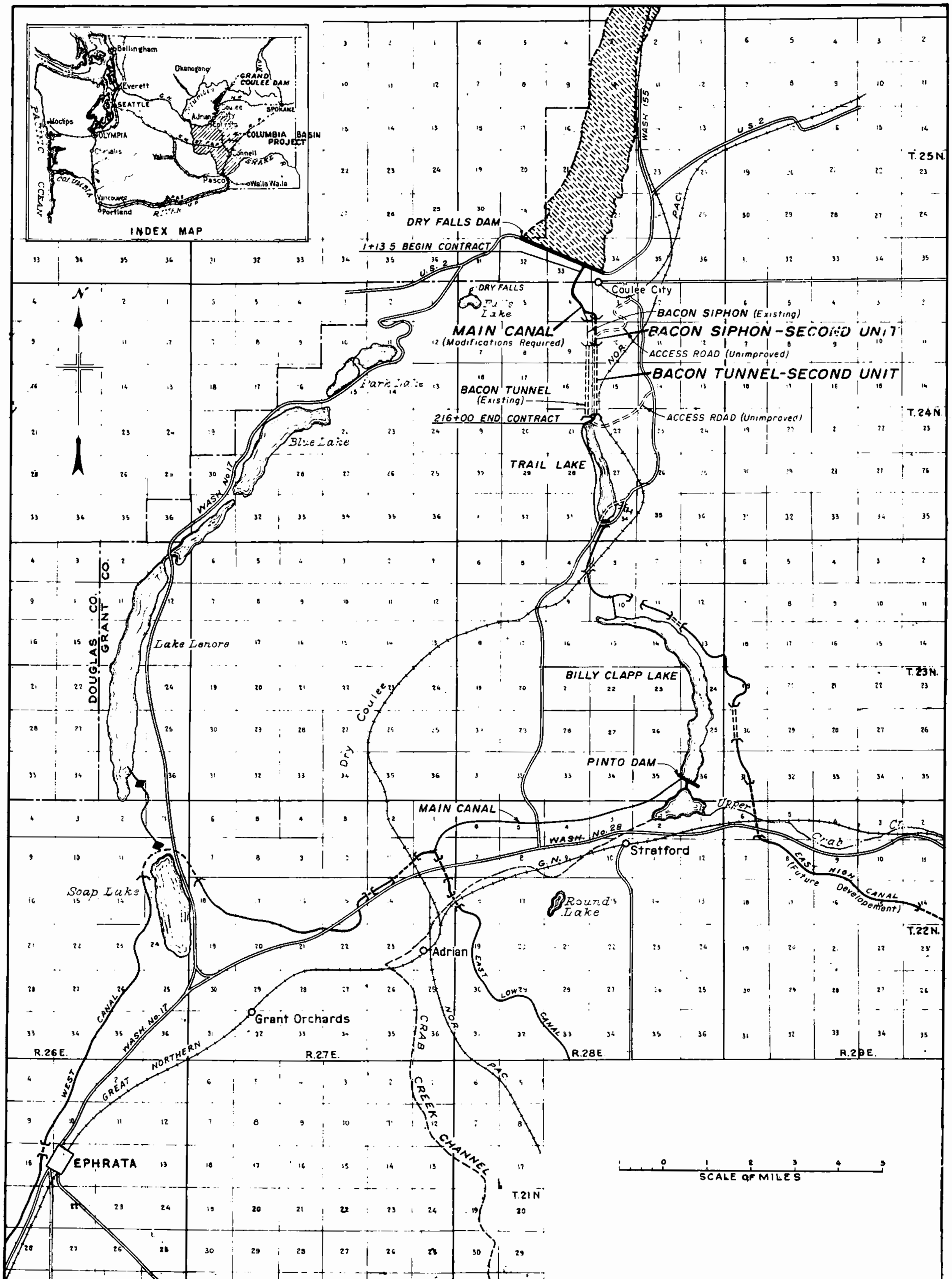
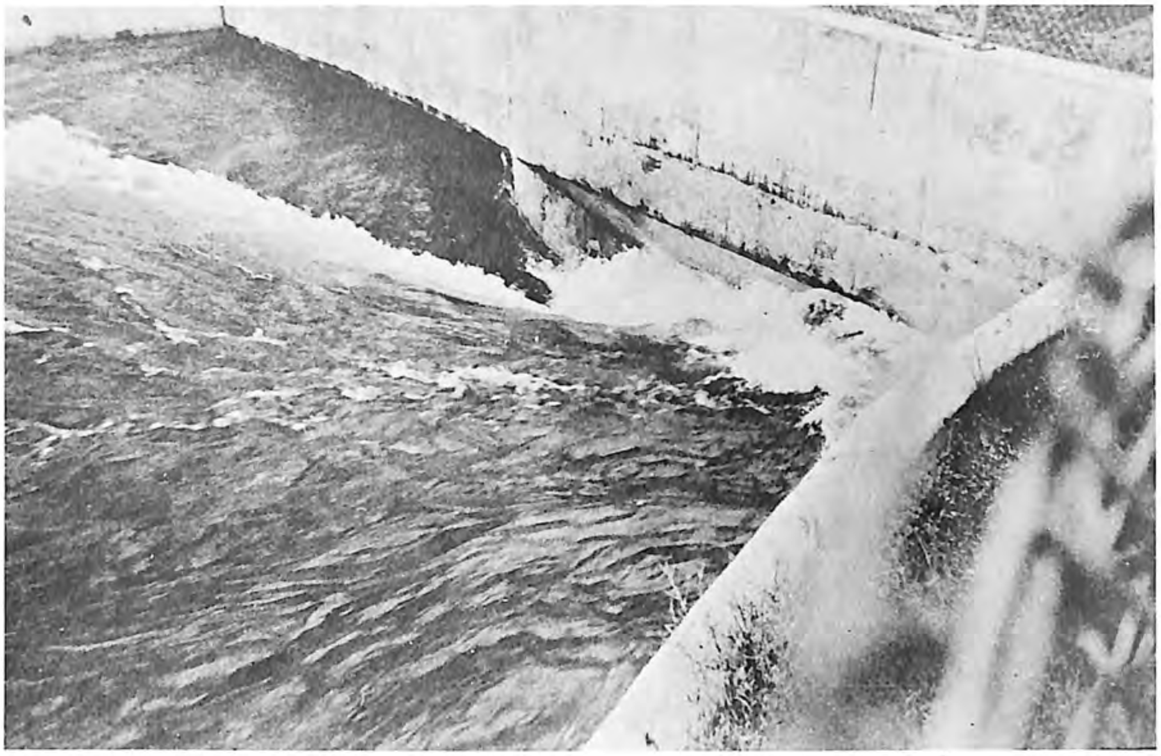
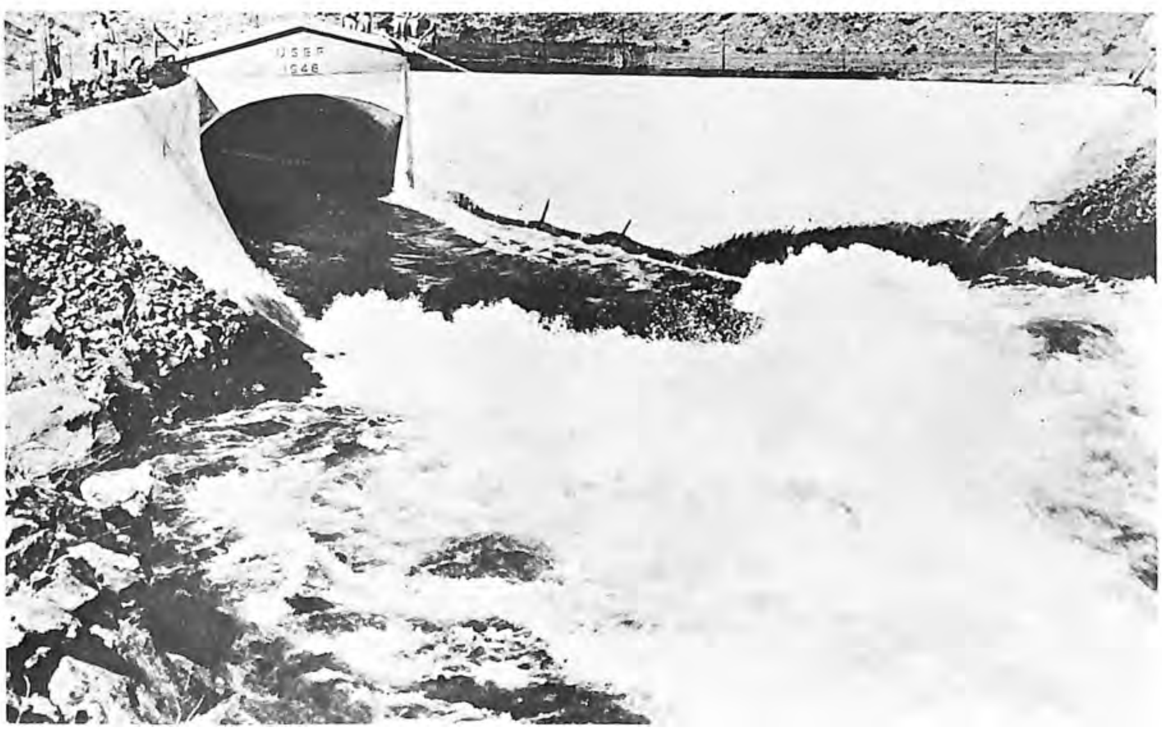


Figure 1. Location map.

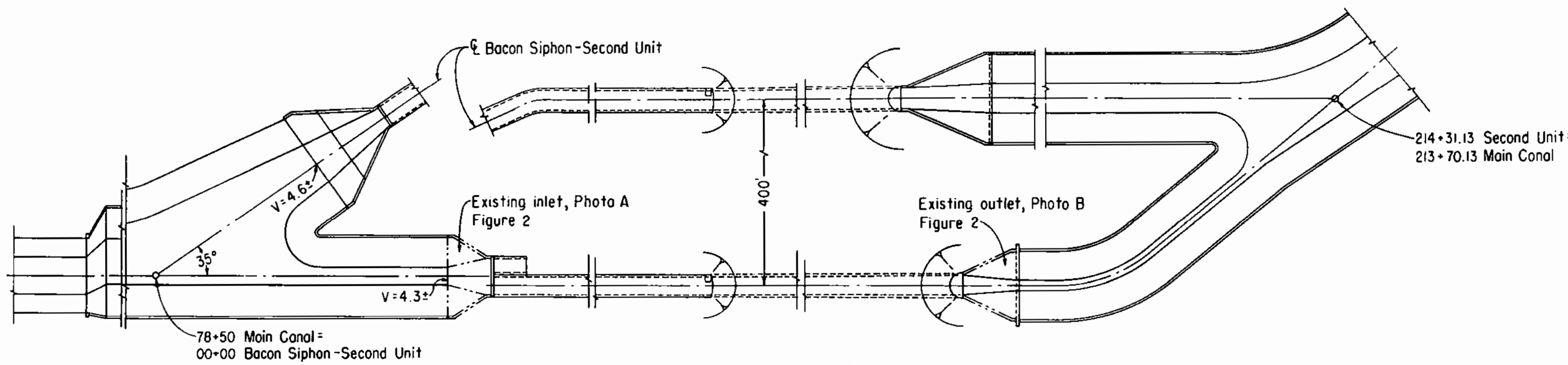


A. Siphon inlet, Sta. 93+00. Photo P222-D-71726



B. Tunnel outlet, Sta. 203+50. Photo P222-D-71727

Figure 2. Existing siphon discharging 6,930 cfs (196.5 cms).



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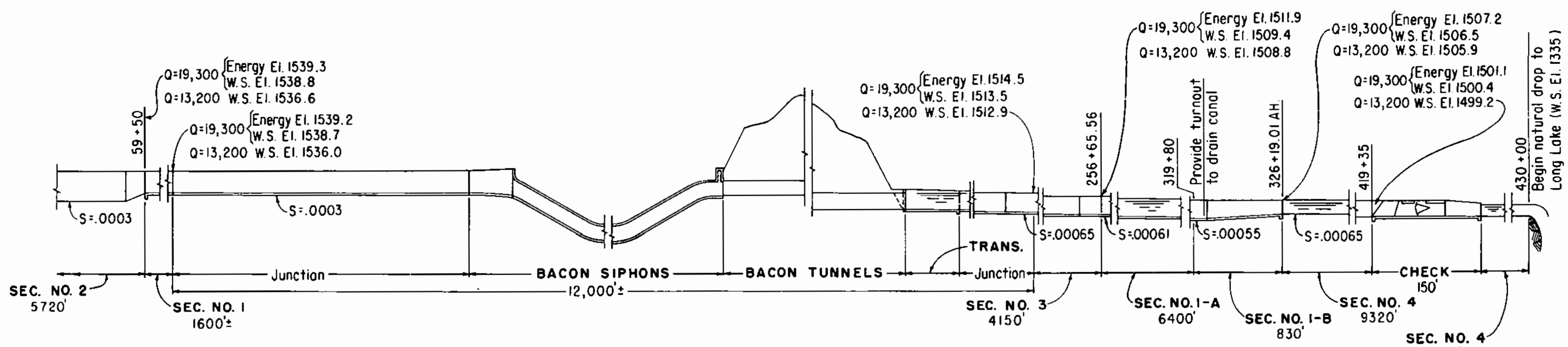


PROFILE

MODEL BUILT OPPOSITE HAND

Figure 3. General plan—Preliminary prototype plan and model from part of Drawing No. 222-CT-37. Elements of laboratory model are outlined.

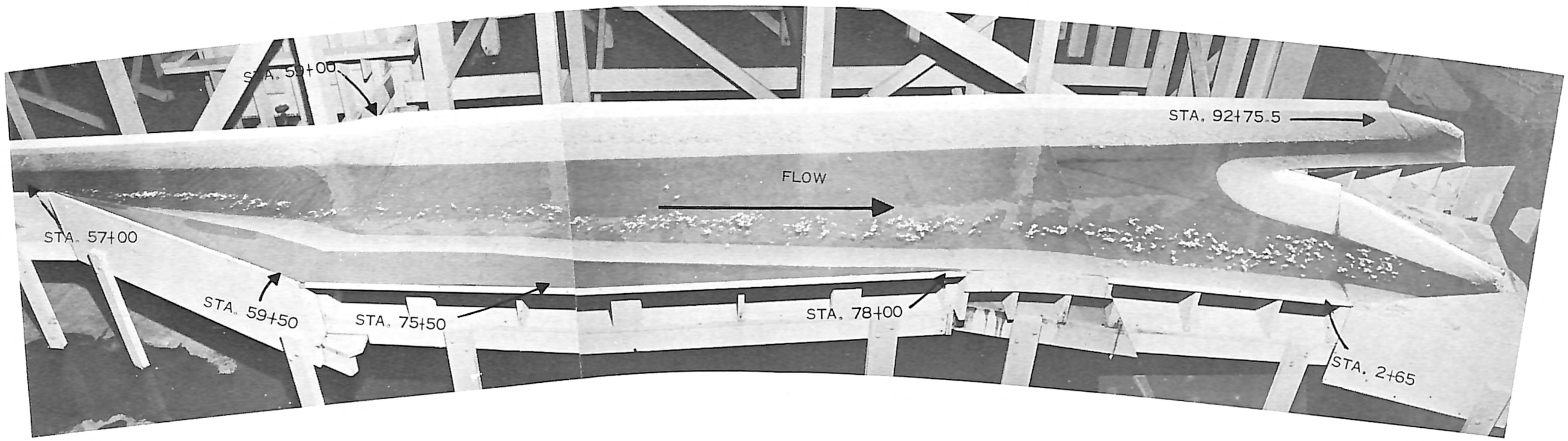
Looking downstream. Photo P222-D-71724

Looking upstream. Photo P222-D-71725

Note: The model is a mirror image of the prototype.

Figure 4. 1:49.8 scale model.

Photo P222-D-71736 Photo P222-D-71737 Photo P222-D-71738



19,300 cfs (546.5 cms)

Note: Confetti sprinkled on the water surface upstream shows flow currents.

Figure 5. Canal flow upstream of siphons.

Looking upstream. Photo P222-D-71746

Looking downstream. Photo P222-D-71747

Note: Depth gage at Sta. 216+02 with an adjustable horizontal orifice slot at Sta. 219+00 at end of model.

Figure 6. Canal flow downstream of siphons.

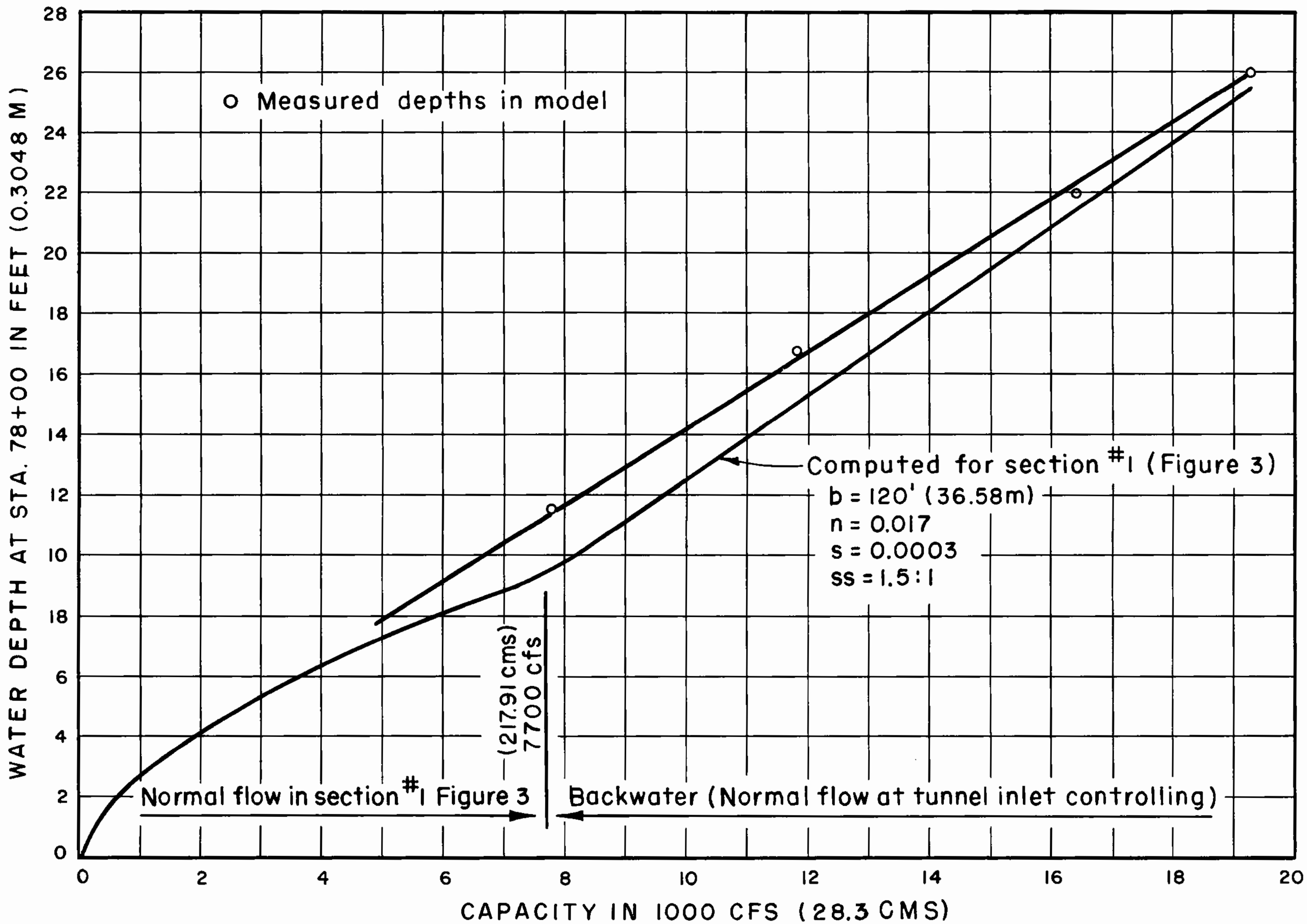


Figure 7. Measured flow depth vs discharge upstream of siphons.

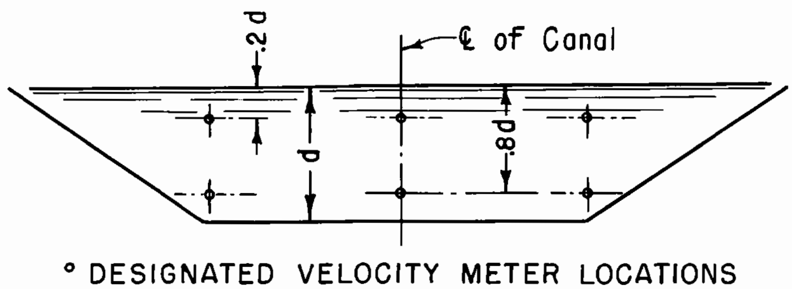


Figure 8. Velocity data points in a typical cross section.

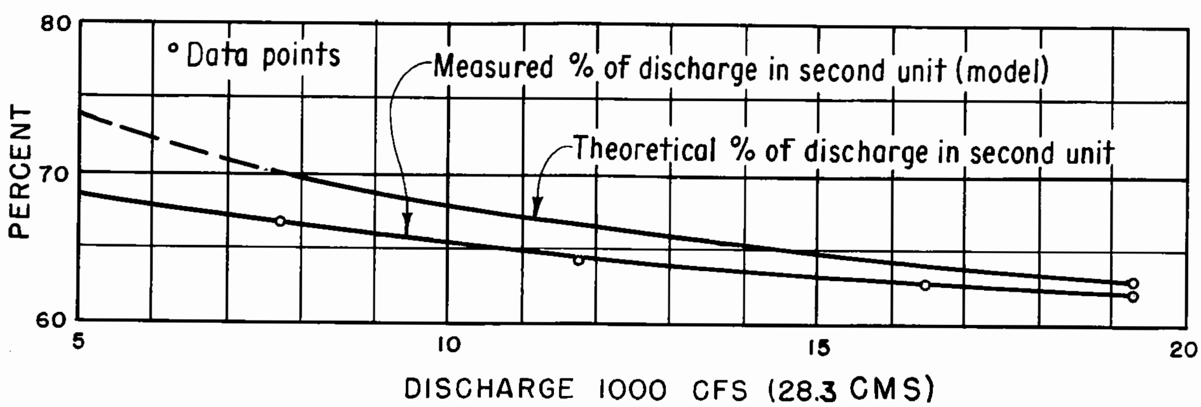


Figure 9. Percent of total flow in second siphon unit.

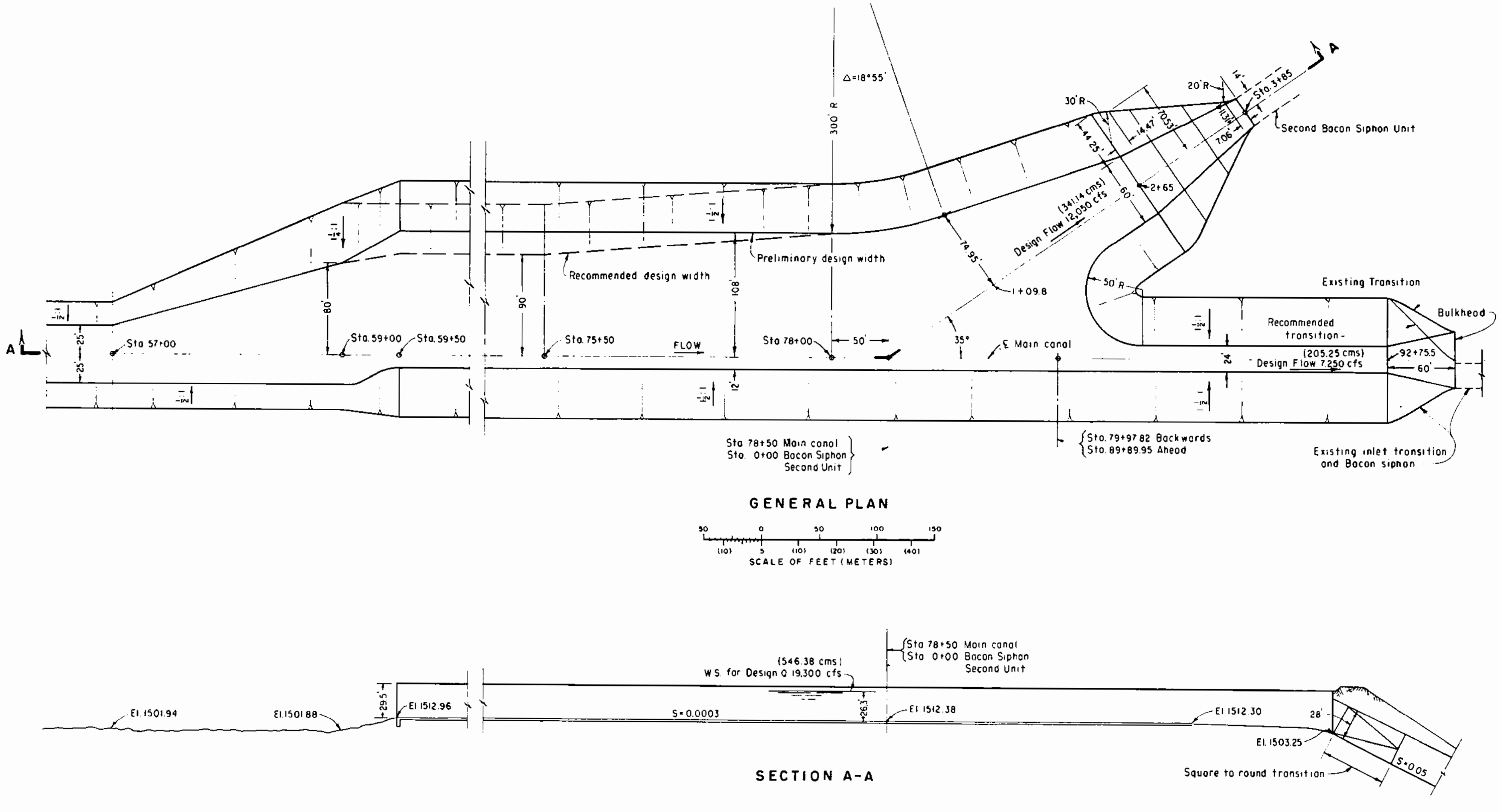
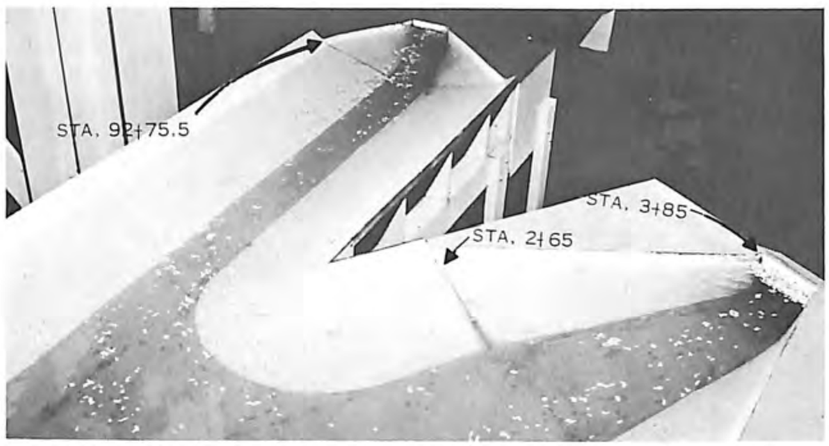


Figure 10. Preliminary and recommended design of upstream canals.

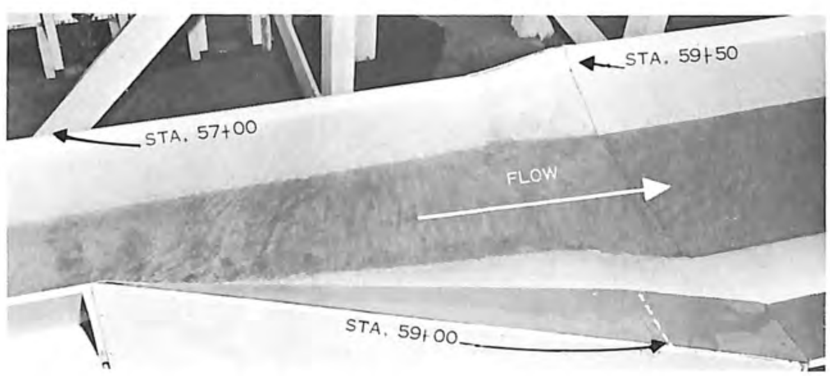
Looking downstream. Photo P222-D-71731

Inlet to second siphon. Photo P222-D-71734

Modified inlet to the existing siphon. Photo P222-D-71735



Canal bifurcation. Photo P222-D-71733

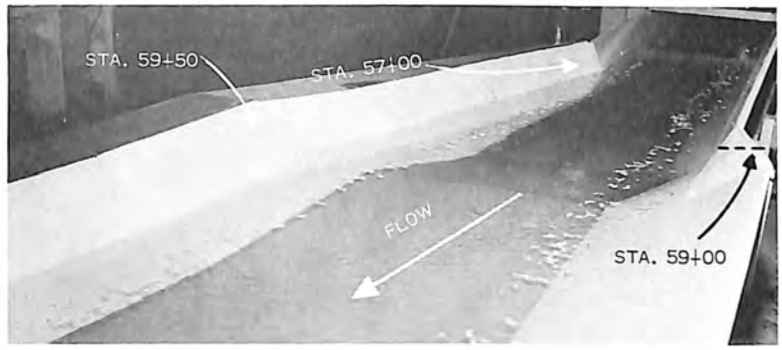


Canal transition. Photo P222-D-71732

Note: Confetti was sprinkled on the water surface to show flow currents.

Figure 11. 19,300 cfs (546.5 cms) in the recommended design upstream of siphons.

Looking downstream. Photo P222-D-71741



Canal transition—Looking upstream. Photo P222-D-71743

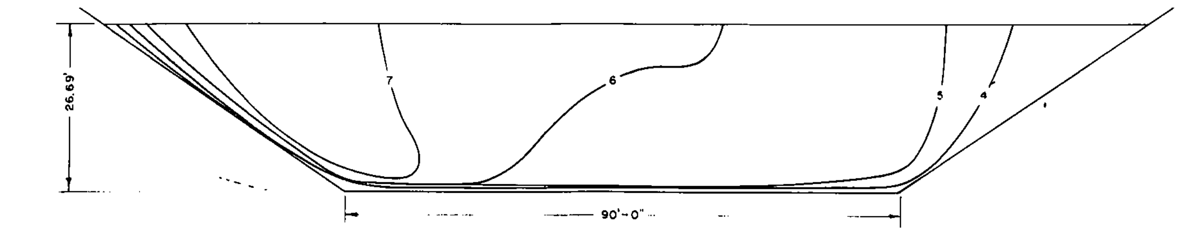
Canal bifurcation—Looking downstream. Photo P222-D-71742

Modified inlet to the existing siphon. Photo P222-D-71744

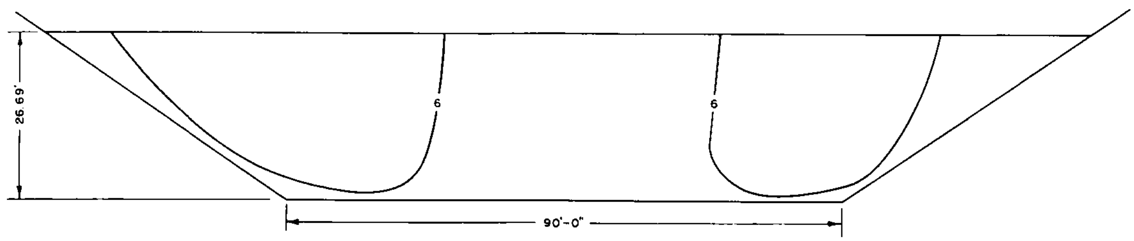
Inlet to the second siphon. Photo P222-D-71748

Note: Confetti was sprinkled on the water surface to show flow currents.

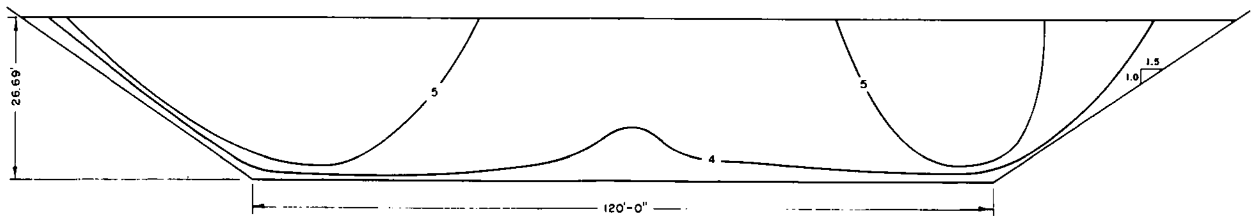
Figure 12. 12,000 cfs (339.8 cms) in the recommended design upstream of siphons.



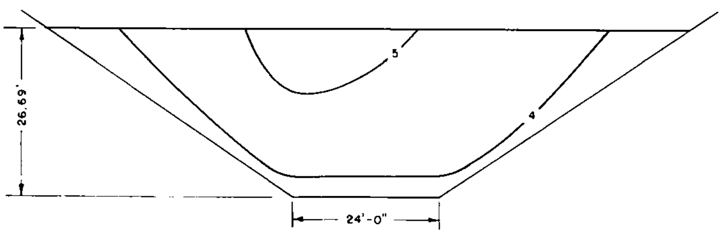
STA. 59+50



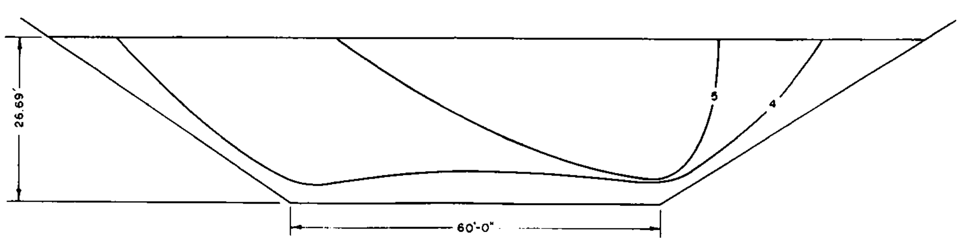
STA. 75+50



STA. 78+00



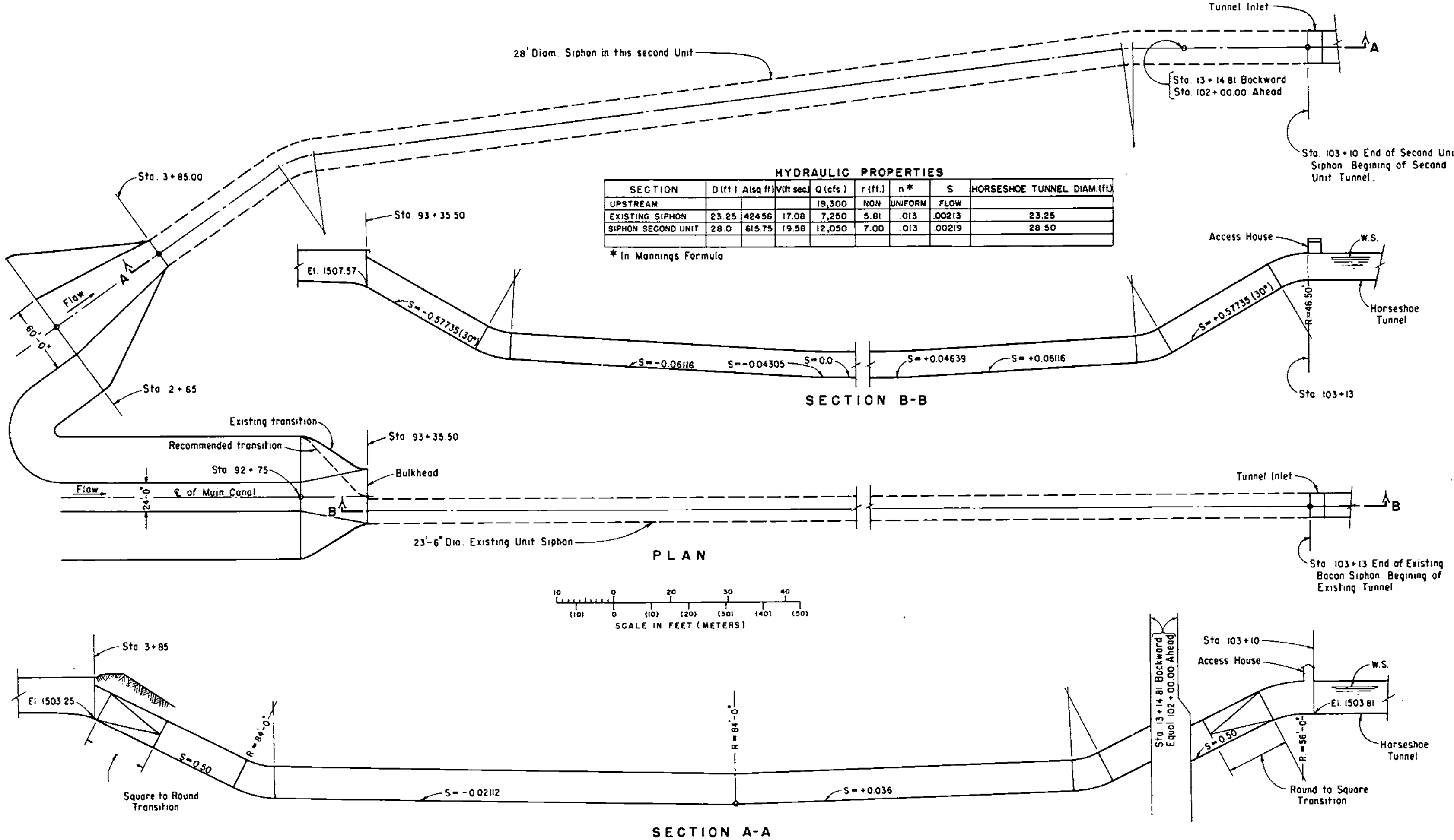
STA.90+65 EXISTING UNIT UPSTREAM OF SIPHON INLET



STA.2+65 SECOND UNIT UPSTREAM OF SIPHON INLET

Notes: Total discharge both units = 19,300 cfs (546.5 cms).
Velocity contours are plotted in feet per second. (The distributions represent an upstream view in the prototype.)

Figure 13. Velocity distribution diagrams in the recommended design upstream of siphons.



HYDRAULIC PROPERTIES

SECTION	D (ft.)	A (sq ft)	V (ft sec)	Q (cfs)	r (ft.)	n *	S	HORSESHOE TUNNEL DIAM. (ft.)
UPSTREAM				19,300	NON	UNIFORM	FLOW	
EXISTING SIPHON	23.25	42456	17.08	7,250	5.81	.013	.00213	23.25
SIPHON SECOND UNIT	28.0	615.75	19.58	12,050	7.00	.013	.00219	28.50

* In Mannings Formula

Figure 14. Preliminary and recommended design of siphons.

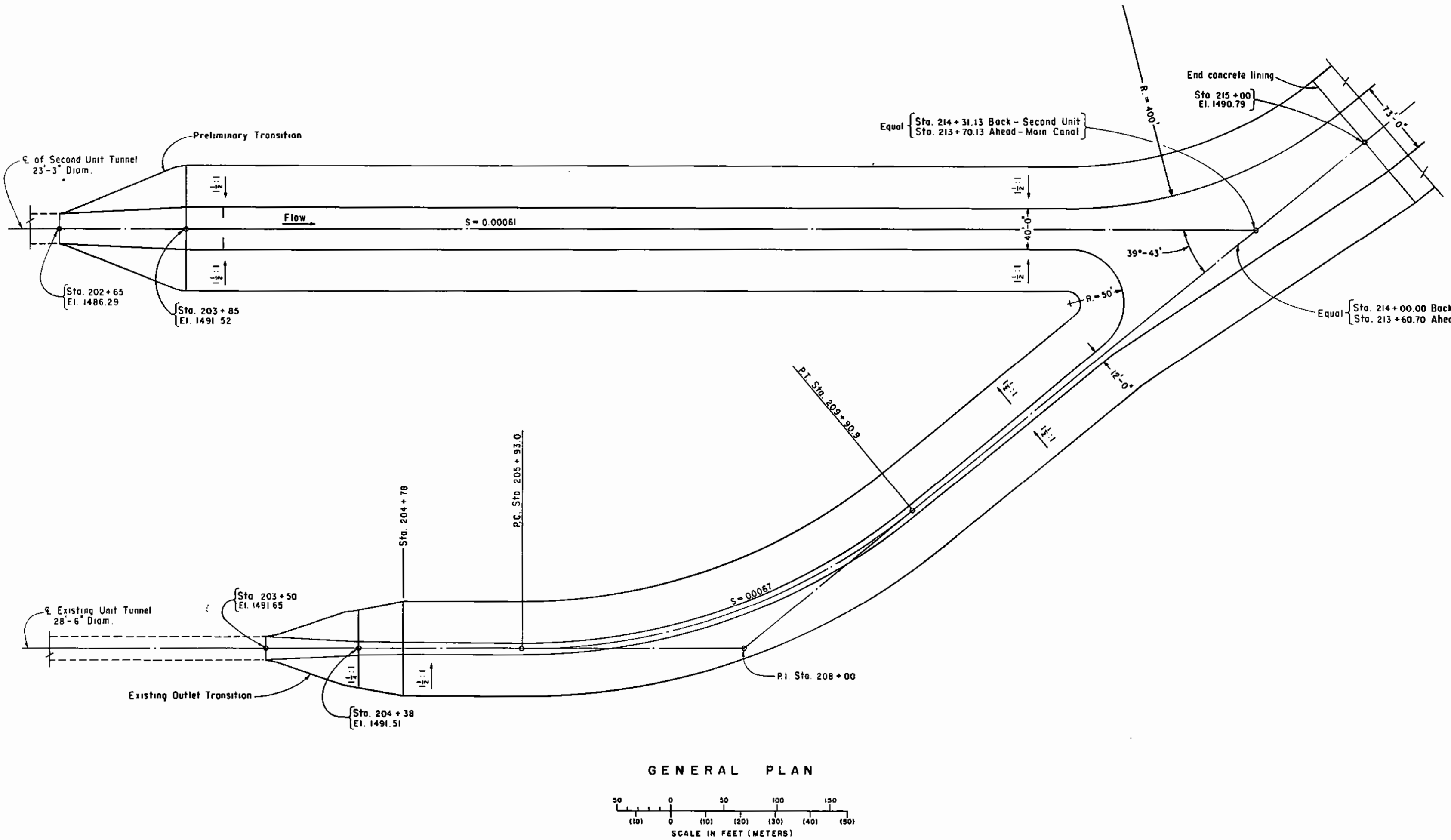


Figure 15. Preliminary design of downstream canals.

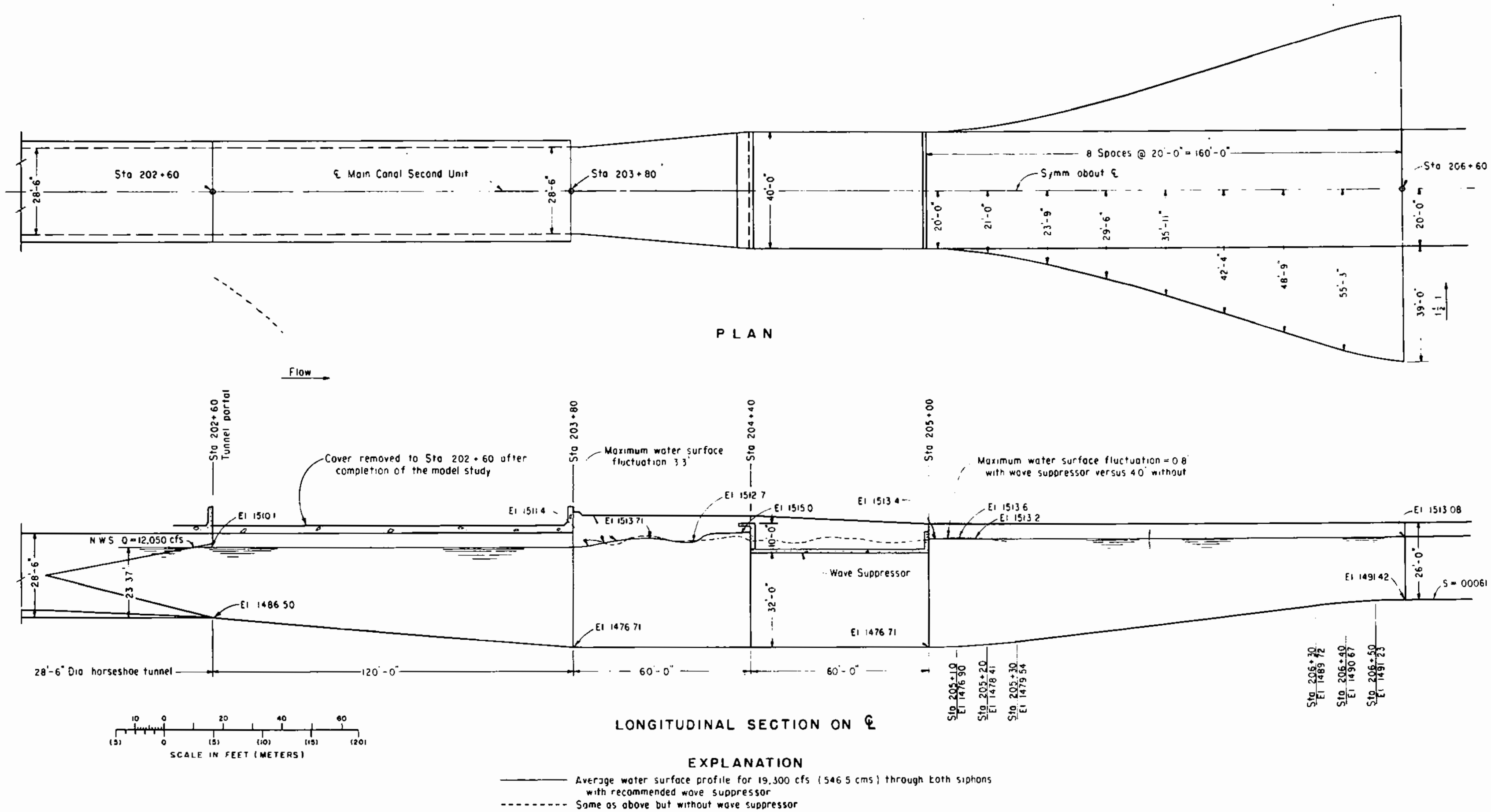
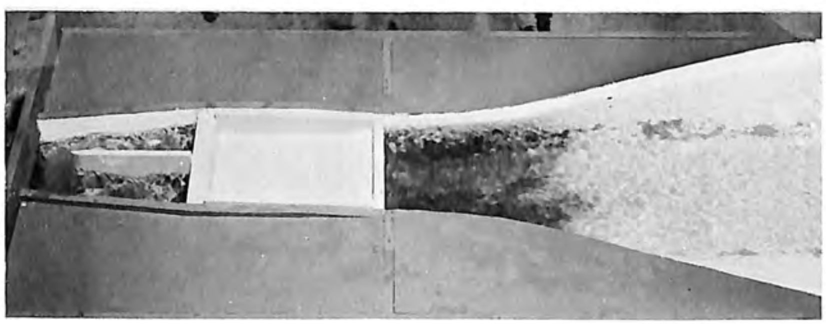


Figure 16. Recommended outlet transition and wave suppressor for the second unit; and water surface profiles.

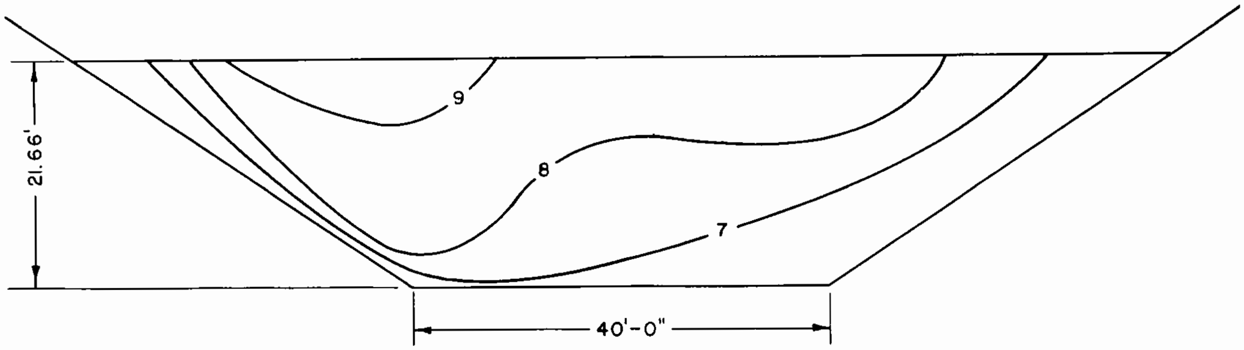
Without wave suppressor. Photo P222-D-71740



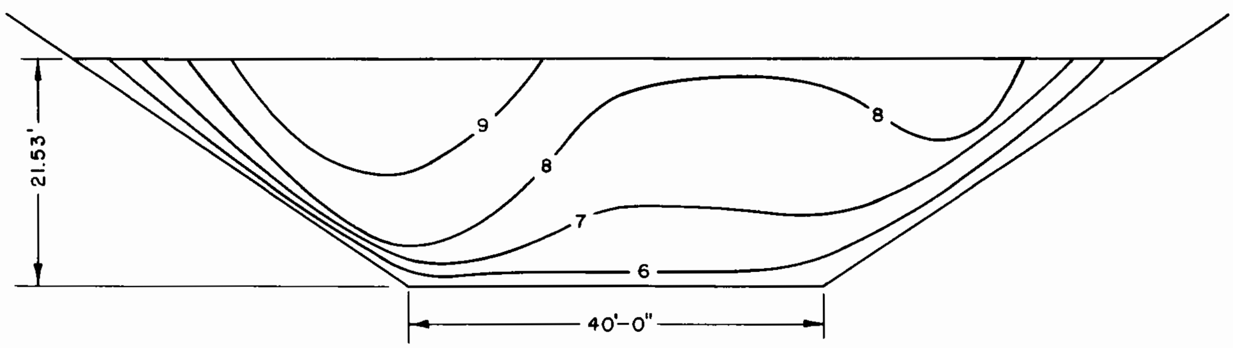
With recommended wave suppressor and proposed center pier. Photo P222-71730

Note: The downstream flow depth at Station 216+02 was set for a roughness coefficient of n = 0.025. Dye was injected into the flow to show improved flow distribution by use of the suppressor. The total flow (both units) is 19,300 cfs (546.5 cms).

Figure 17. Operation of the outlet transition and wave suppressor for the second siphon unit.



STA. 206+60 – SECOND UNIT



STA. 207+60 – SECOND UNIT

Notes: Total discharge is 19,300 cfs (546 cms) (both units) set for a flow depth of 20.6 ft (6.3 m) at Station 216+00, corresponding to a roughness coefficient of n = 0.025.
The distributions represent views in an upstream direction (prototype).

Figure 18. Velocity distribution diagrams in the second unit with the outlet transition and wave suppressor.

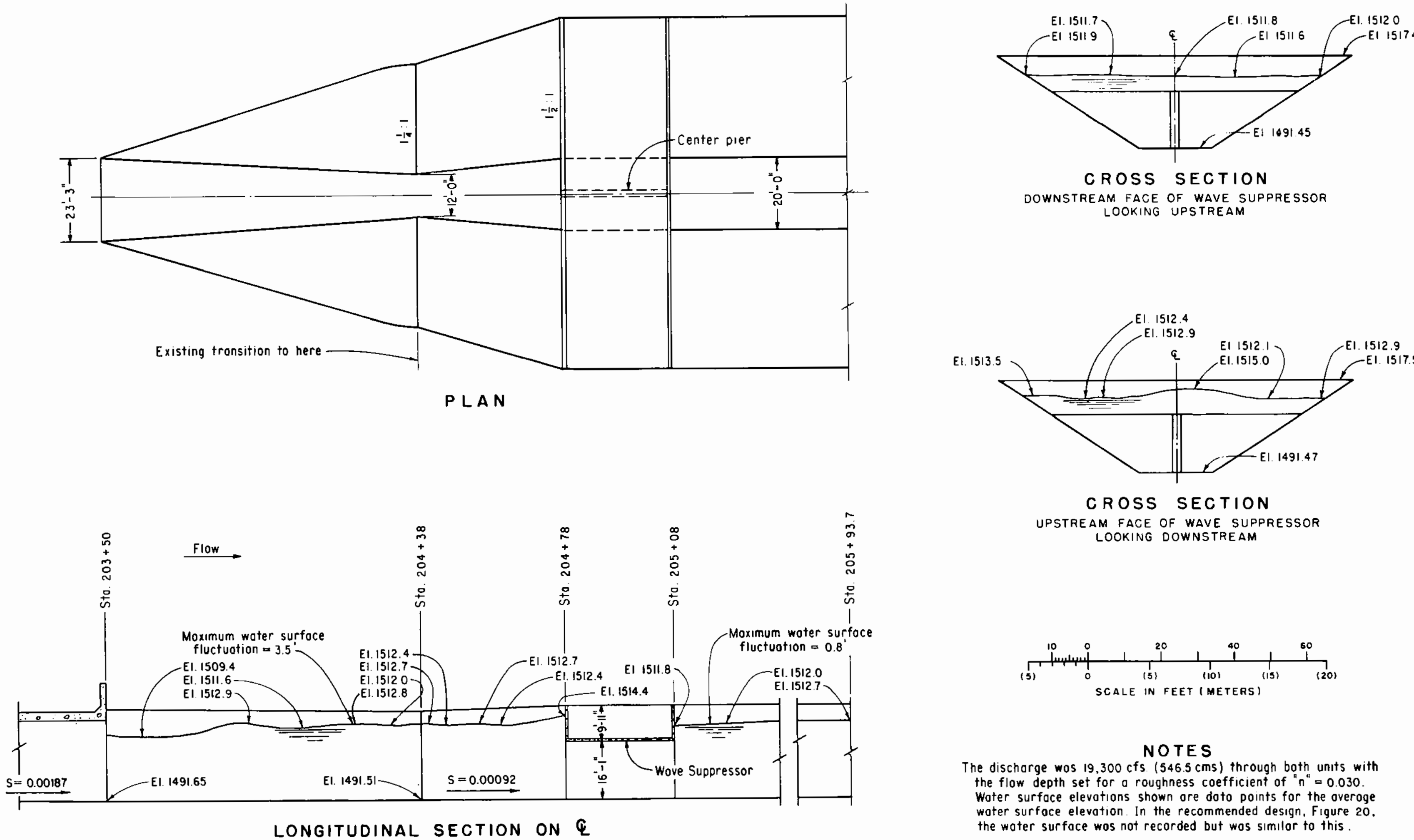


Figure 19. Water surface profiles in the outlet transition of the existing unit with wave suppressor added.

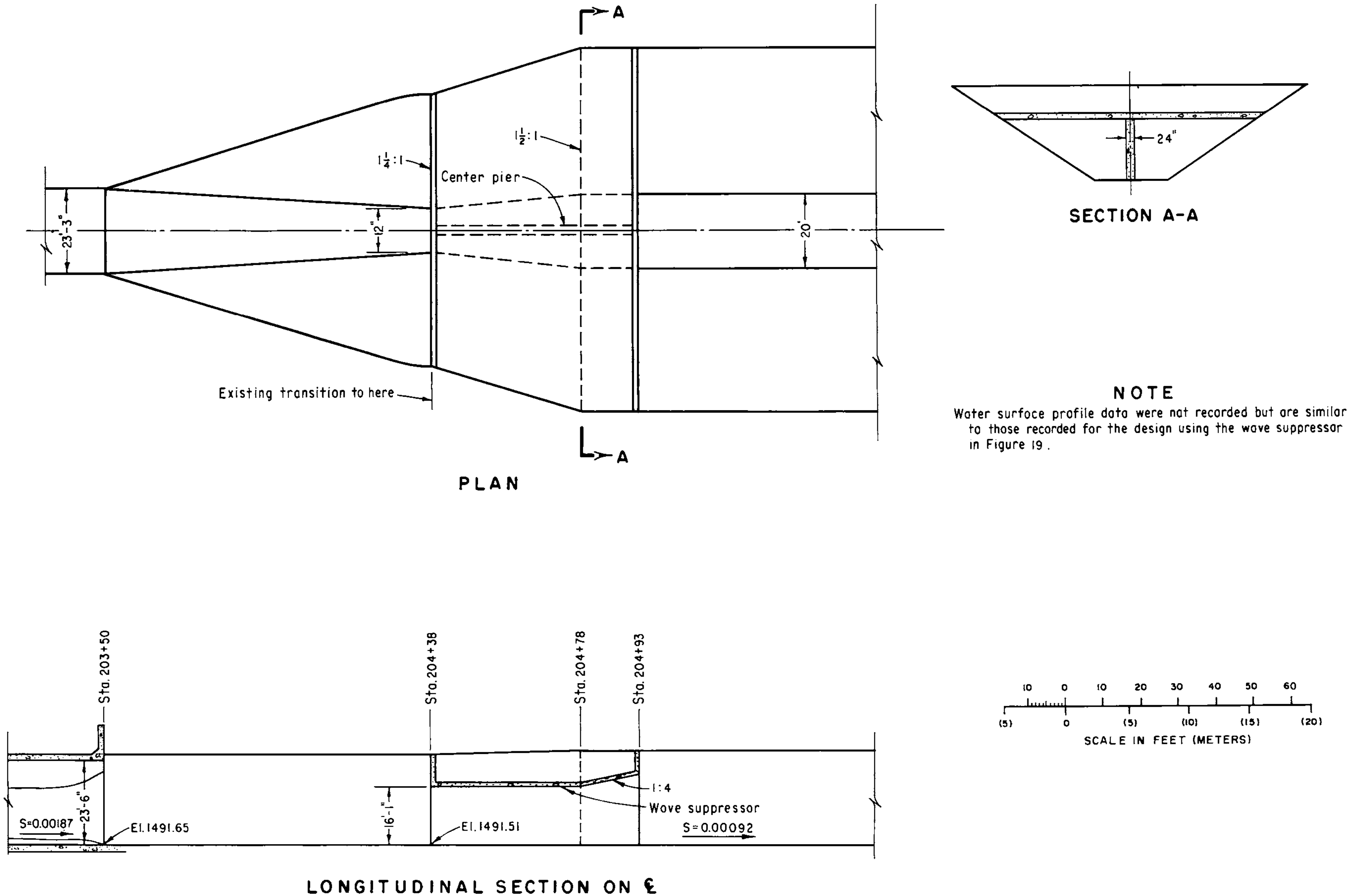


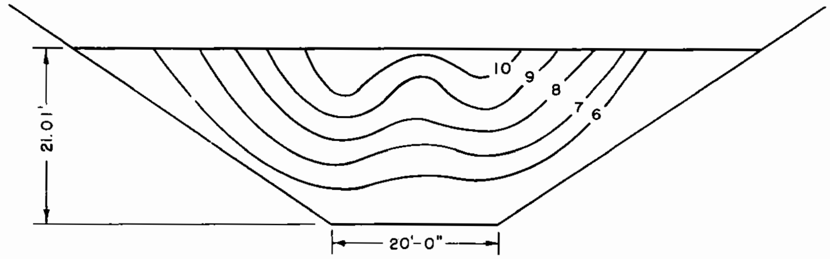
Figure 20. Recommended outlet transition and wave suppressor for the existing unit.

Without wave suppressor. Photo P222-D-71739

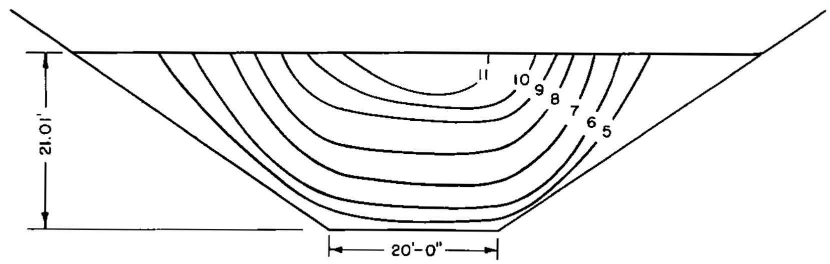
With recommended wave suppressor. Photo P222-D-71729

Note:. The flow depth was set for a roughness coefficient of n = 0.025. Dye was injected into the flow. Total flow for both units is 19,300 cfs (546.5 cms).

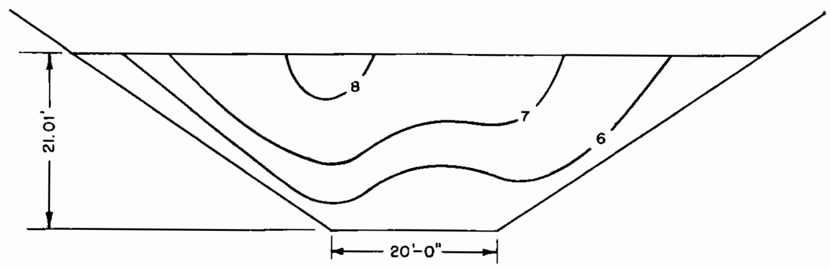
Figure 21. Operation of the recommended outlet transition and wave suppressor for the existing siphon unit.



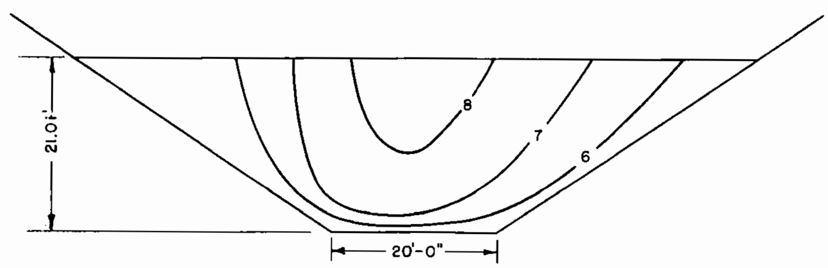
STA. 205+93.7 WITH RECOMMENDED WAVE SUPPRESSOR



STA. 205+93.7 WITHOUT WAVE SUPPRESSOR



STA. 206+93.7 WITH RECOMMENDED WAVE SUPPRESSOR



STA. 206+93.7 WITHOUT RECOMMENDED WAVE SUPPRESSOR

Note: Total discharge both units = 19,300 cfs (546.5 cms). Flow depth set at 20.6 ft (6.3 m) at Station 216+00 for roughness coefficient n = 0.025. Velocity contours are plotted in feet per second. The distributions represent views in an upstream direction (prototype).

Figure 22. Velocity distribution diagrams downstream from the recommended outlet transition for the existing unit.

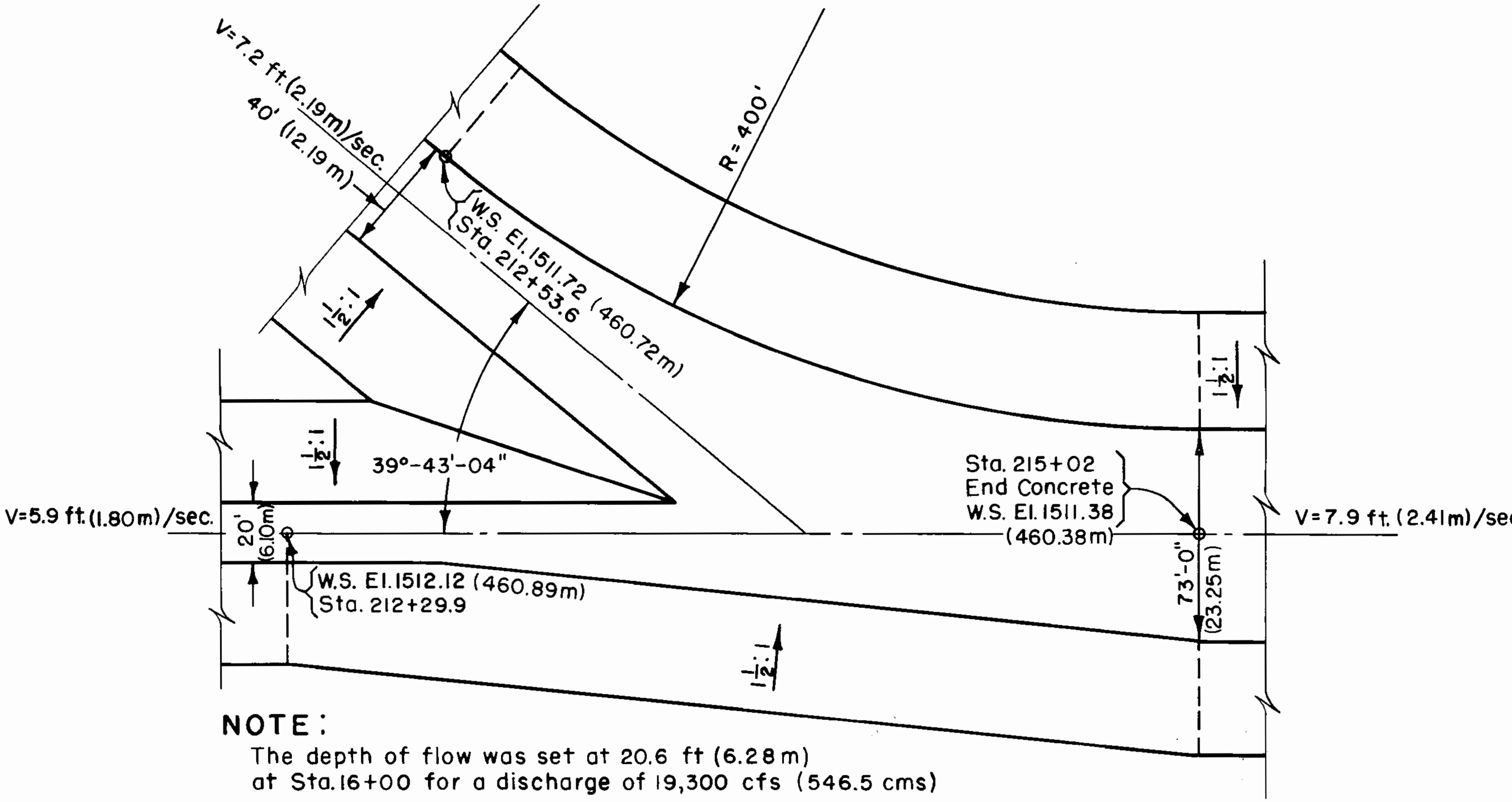
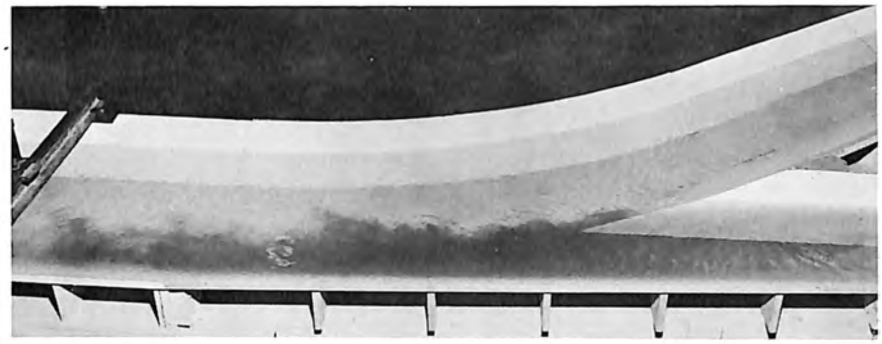
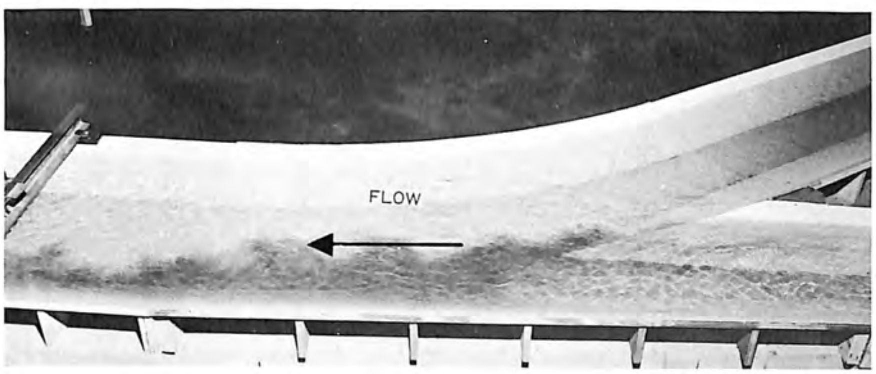


Figure 23. Measured water surface elevations at the recommended junction.



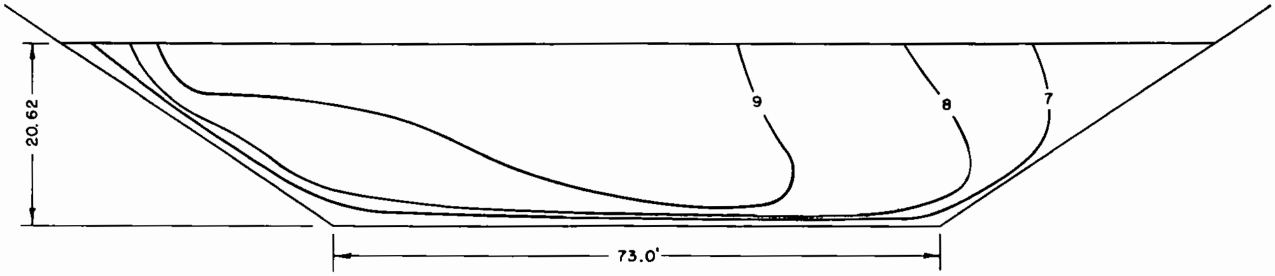
12,000 cfs (339.8 cms)—Flow depth 15.8 ft (4.8 m) set at Station 216+00. Photo P222-D-71745



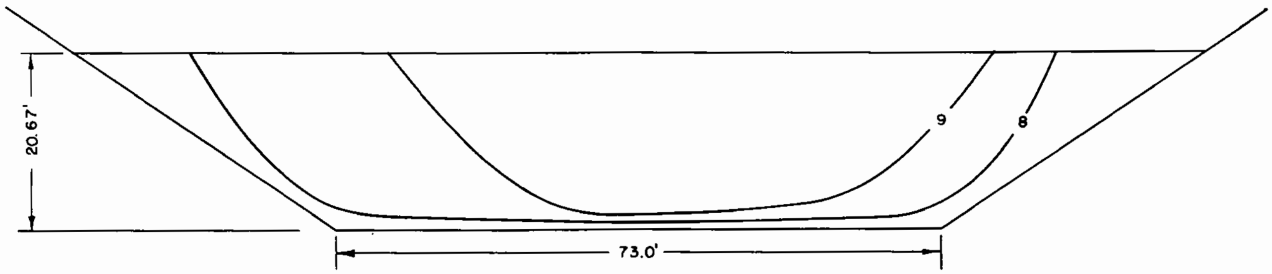
19,300 cfs (546.5 cms)—Flow depth 20.6 ft (6.28 m) set at Station 216+00. Photo P222-D-71728

Note: A dye cloud was injected into the flow from the existing unit.

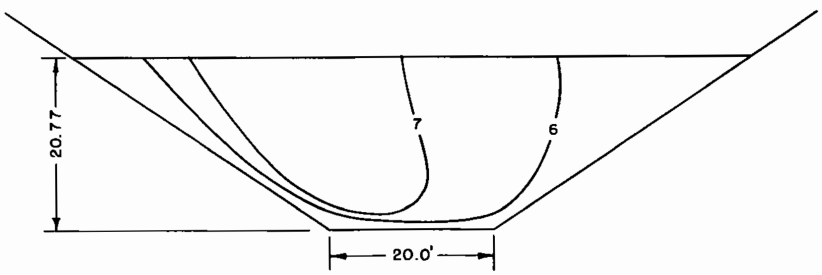
Figure 24. Recommended junction of the two units.



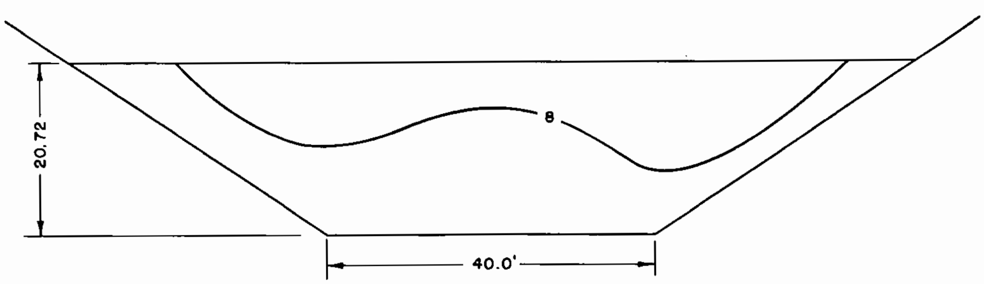
STA. 216+02 Units 1 & 2



STA. 215+02 Units 1 & 2



STA. 212+29.9 Unit 1



STA. 212+53.6 Unit 2

Note: Total discharge both units = 19,300 cfs (546.5 cms). Velocity contours are in feet per second. Flow depth set at Station 216+00 for roughness coefficient of n = 0.025. The distributions represent views in an upstream direction (prototype).

Figure 25. Velocity distribution diagrams upstream and downstream of the recommended junction.

CONVERSION FACTORS–BRITISH TO METRIC UNITS OF MEASUREMENT

The following conversion factors adopted by the Bureau of Reclamation are those published by the American Society for Testing and Materials (ASTM Metric Practice Guide, E 380-68) except that additional factors (*) commonly used in the Bureau have been added. Further discussion of definitions of quantities and units is given in the ASTM Metric Practice Guide.

The metric units and conversion factors adopted by the ASTM are based on the "International System of Units" (designated SI for Systeme International d'Unites), fixed by the International Committee for Weights and Measures; this system is also known as the Giorgi or MKSA (meter-kilogram (mass)-second-ampere) system. This system has been adopted by the International Organization for Standardization in ISO Recommendation R-31.

The metric technical unit of force is the kilogram-force; this is the force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 9.80665 m/sec/sec, the standard acceleration of free fall toward the earth's center for sea level at 45 deg latitude. The metric unit of force in SI units is the newton (N), which is defined as that force which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/sec/sec. These units must be distinguished from the (inconstant) local weight of a body having a mass of 1 kg, that is, the weight of a body is that force with which a body is attracted to the earth and is equal to the mass of a body multiplied by the acceleration due to gravity. However, because it is general practice to use "pound" rather than the technically correct term "pound-force," the term "kilogram" (or derived mass unit) has been used in this guide instead of "kilogram-force" in expressing the conversion factors for forces. The newton unit of force will find increasing use, and is essential in SI units.

Where approximate or nominal English units are used to express a value or range of values, the converted metric units in parentheses are also approximate or nominal. Where precise English units are used, the converted metric units are expressed as equally significant values.

Table I

QUANTITIES AND UNITS OF SPACE

Multiply	By	To obtain
	LENGTH	
Mil	25.4 (exactly)	Micron
Inches	25.4 (exactly)	Millimeters
Inches	2.54 (exactly)*	Centimeters
Feet	30.48 (exactly)	Centimeters
Feet	0.3048 (exactly)*	Meters
Feet	0.0003048 (exactly)*	Kilometers
Yards	0.9144 (exactly)	Meters
Miles (statute)	1,609.344 (exactly)*	Meters
Miles	1.609344 (exactly)	Kilometers
	AREA	
Square inches	6.4516 (exactly)	Square centimeters
Square feet	*929.03	Square centimeters
Square feet	0.092903	Square meters
Square yards	0.836127	Square meters
Acres	*0.40469	Hectares
Acres	*4,046.9	Square meters
Acres	*0.0040469	Square kilometers
Square miles	2.58999	Square kilometers
	VOLUME	
Cubic inches	16.3871	Cubic centimeters
Cubic feet	0.0283168	Cubic meters
Cubic yards	0.764555	Cubic meters
	CAPACITY	
Fluid ounces (U.S.)	29.5737	Cubic centimeters
Fluid ounces (U.S.)	29.5729	Milliliters
Liquid pints (U.S.)	0.473179	Cubic decimeters
Liquid pints (U.S.)	0.473166	Liters
Quarts (U.S.)	*946.358	Cubic centimeters
Quarts (U.S.)	*0.946331	Liters
Gallons (U.S.)	*3,785.43	Cubic centimeters
Gallons (U.S.)	3.78543	Cubic decimeters
Gallons (U.S.)	3.78533	Liters
Gallons (U.S.)	*0.00378543	Cubic meters
Gallons (U.K.)	4.54609	Cubic decimeters
Gallons (U.K.)	4.54596	Liters
Cubic feet	28.3160	Liters
Cubic yards	*764.55	Liters
Acre-feet	*1,233.5	Cubic meters
Acre-feet	*1,233,500	Liters

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
Short tons (2,000 lb)	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
Pounds per square inch	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
Pounds per square foot	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
Pounds per cubic foot	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
Inch-pounds	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
Foot-pounds	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
Feet per second	0.3048 (exactly)*	Meters per second
Feet per year	$^*0.965873 \times 10^{-6}$	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
Miles per hour	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	*0.3048	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	*0.028317	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	*0.453592	Kilograms
Pounds	*4.4482	Newtons
Pounds	$^*4.4482 \times 10^5$	Dynes

Table II—Continued

Multiply	By	To obtain
WORK AND ENERGY*		
British thermal units (Btu)	*0.252	Kilogram calories
British thermal units (Btu)	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	*1.35582	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 degree F (k, thermal conductivity)	1.442	Milliwatts/cm degree C
Btu in./hr ft^2 degree F (k, thermal conductivity)	0.1240	Kg cal/hr m degree C
Btu ft/hr ft^2 degree F	*1.4880	Kg cal m/hr m^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	0.568	Milliwatts/cm^2 degree C
Btu/hr ft^2 degree F (C, thermal conductance)	4.882	Kg cal/hr m^2 degree C
Degree F hr ft^2/Btu (R, thermal resistance)	1.761	Degree C cm^2/milliwatt
Btu/lb degree F (c, heat capacity)	4.1868	J/g degree C
Btu/lb degree F	*1.000	Cal/gram degree C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
Ft^2/hr (thermal diffusivity)	*0.09290	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor) transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

Multiply	By	To obtain
Cubic feet per square foot per day (seepage)	*304.8	Liters per square meter per day
Pound-seconds per square foot (viscosity)	*4.8824	Kilogram second per square meter
Square feet per second (viscosity)	*0.092903	Square meters per second
Fahrenheit degrees (change)*	5/9 exactly	Celsius or Kelvin degrees (change)*
Volts per mil	0.03937	Kilovolts per millimeter
Lumens per square foot (foot-candles)	10.764	Lumens per square meter
Ohm-circular mils per foot	0.001662	Ohm-square millimeters per meter
Millicuries per cubic foot	*35.3147	Millicuries per cubic meter
Milliamps per square foot	*10.7639	Milliamps per square meter
Gallons per square yard	*4.527219	Liters per square meter
Pounds per inch	*0.17858	Kilograms per centimeter

ABSTRACT

A 1:49.8 scale model was used to aid development of design modifications to increase the capacity of the Main Canal near Grand Coulee Dam in Washington. Portal-to-canal transitions with wave suppressors were developed for the tunnels from the 2 siphons. Flow characteristics in the canals upstream and downstream of the siphons and tunnels were studied to develop designs for the bifurcation and the canal junction, and to determine the proper cross-sectional size of the canals.

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REC-ERC-72-22
Beichley, G L
HYDRAULIC MODEL STUDIES OF THE CANAL STRUCTURES ADJACENT TO BACON SIPHON AND TUNNEL, COLUMBIA BASIN PROJECT, WASHINGTON
Bur Reclam Rep REC-ERC-72-22, Div Gen Res, July 1972, Bureau of Reclamation, Denver, 29 p, 25 fig, 1 ref

DESCRIPTORS—/ *siphons/ *canals/ tunnels/ *hydraulic models/ model tests/ Mannings Equation/ cross sections/ roughness coefficient/ waves/ standing waves/ velocity distribution/ water surface profiles/ transition flow/ outlets/ Washington/ *wave suppressors/ flow characteristics/ canal design/ bifurcations/ *hydraulic design
IDENTIFIERS—/ Columbia Basin Project, Wash/ Main Canal CBP, Wash

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