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HYDRAULIC MODEL STUDIES FOR GRAND COULEE THIRD POWERPLANT FOREBAY AND TAILRACE CHANNELS

D. L. King
Engineering and Research Center
Bureau of Reclamation

February 1973



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| 16. ABSTRACT The water treaty with Canada, making possible additional water storage upstream from Grand Coulee Dam, and the historic large releases wasted over the spillway, contributed to the conception of a Third Powerplant at Grand Coulee. This powerplant will ultimately house twelve 600-Mw units. Six units have been authorized and construction has started, with three units to be installed in the initial phase. Because each unit has a discharge capacity of approximately 30,000 cfs, unusual problems of design in the forebay and tailrace of the new powerplant could be foreseen. A 1:120 scale model study showed the need for extensive revisions in the design of the forebay channel, and minor revisions in the tailrace configuration. A vortex formation noted above the penstock entrances prompted an additional study which will be reported separately. Observations and measurements were made in the forebay channel and tailrace for both 6- and 12-unit plant operation. Results of these studies are presented. | | | |
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GRAND COULEE THIRD POWERPLANT
FOREBAY AND TAILRACE CHANNELS**

by

D. L. King

February 1973

**Hydraulics Branch
Division of General Research
Engineering and Research Center
Denver, Colorado**

**UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION
Rogers C. B. Morton
Secretary**

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CONTENTS

| | Page |
|---------------------------------|------|
| Purpose | 1 |
| Conclusions | 1 |
| Applications | 1 |
| Introduction | 1 |
| The Model | 2 |
| Test Conditions | 3 |
| Investigation | 4 |
| Forebay Channel | 4 |
| Preliminary design | 4 |
| Recommended design | 6 |
| Tailrace | 9 |
| 6-unit plant | 9 |
| 12-unit plant | 15 |
| Tailrace backwater tests | 22 |
| Hydraulic transient tests | 22 |

LIST OF TABLES

Table

| | | |
|---|--|----|
| 1 | Velocities measured at points in Figure 18 | 11 |
| 2 | Velocities measured at points in Figure 19 | 12 |

LIST OF FIGURES

Figure

| | | |
|----|--|---|
| 1 | Grand Coulee Dam - Existing features | 2 |
| 2 | Third Powerplant - Artist's conception | 3 |
| 3 | Preliminary forebay channel | 4 |
| 4 | Flow pattern in preliminary forebay channel | 4 |
| 5 | Flow pattern at juncture between dams | 4 |
| 6 | Velocity distribution in preliminary forebay channel | 5 |
| 7 | Trial curved guide walls | 6 |
| 8 | Recommended dike | 7 |
| 9 | Velocity distribution at Section A with recommended dike | 7 |
| 10 | Variable topography at juncture between dams | 7 |
| 11 | Effect of juncture changes on velocity distribution at Section A | 8 |
| 12 | Velocity distribution at Section A with modified right wall in forebay channel | 8 |
| 13 | Recommended forebay channel | 8 |

CONTENTS—Continued

| Figure | | Page |
|--------|--|------|
| 14 | Velocity distribution in recommended forebay channel | 9 |
| 15 | Flow pattern within forebay channel | 9 |
| 16 | Surface flow pattern in forebay channel | 10 |
| 17 | Preliminary 6-unit tailrace configuration | 10 |
| 18 | Velocity measurements in preliminary 6-unit tailrace | 10 |
| 19 | Velocity measurements in recommended 6-unit tailrace | 11 |
| 20 | Flow conditions in the recommended 6-unit tailrace | 12 |
| 21 | Velocities in vicinity of anchor block | 14 |
| 22 | Cofferdam pad near anchor block | 15 |
| 23 | Preliminary 12-unit tailrace configuration | 15 |
| 24 | Flow patterns and instrumentation in preliminary 12-unit tailrace | 15 |
| 25 | Velocities in preliminary 12-unit tailrace | 16 |
| 26 | Velocities in recommended 12-unit tailrace | 19 |
| 27 | Water surface elevations in existing tailrace channel | 23 |
| 28 | Water surface elevations with 6-unit Third Powerplant | 24 |
| 29 | Total backwater between Left Powerplant and bridge gage, Banks A and B, steady flow | 25 |
| 30 | Backwater in existing and modified channels | 25 |
| 31 | Pitot tube and wave probe used in hydraulic transient test | 25 |
| 32 | Results of hydraulic transient test | 25 |



PURPOSE

The purpose of this study was to assist in developing the designs of the forebay channel and tailrace for both 6- and 12-unit plant configurations. In addition, effects of simultaneous operation of the new and existing features were determined.

CONCLUSIONS

1. The design of the forebay channel required modifications to improve the velocity distribution. The forebay channel floor was excavated to elevation 1110 and a dike at elevation 1150 was left at the upstream end of the channel, resulting in considerably improved velocity distribution. The right wall of the channel was moved inward as far as possible to minimize excavation. Excavation of the rock formation at the juncture between Grand Coulee Dam and Forebay Dam improved velocity distribution.

2. Guide walls in the upstream portion of the forebay channel improved the velocity distribution but created excessive head loss (up to 7 feet).

3. A low sill in the forebay channel between Units 24 and 25 created excessive surface disturbances and head loss. This sill was proposed to reduce excavation when the 6-unit forebay channel is extended for 12 units.

4. Vortices formed above some of the penstock entrances for water surfaces below elevation 1240. The occurrence and severity of the vortices increased with decreasing reservoir elevation and with an increase in the number of units operating. Additional studies were required for development of appurtenances to alleviate vortex formation in the event that prototype operation discloses a problem, and are described in a separate report.

5. Only minor modifications were required for the tailrace configurations of the 6- and 12-unit plants. The desired shape of the right bank was determined in each case, and velocities and wave heights were measured. The model study suggested that the concrete cofferdam pad near the anchor block between the Right Powerplant and the Third Powerplant should be retained as a permanent feature to block the movement of bed material into the draft tube discharge region of the Third Powerplant.

6. The effect of 6-unit tailrace configuration and downstream channel improvement on water surface elevations in the tailrace was determined. The measured water surface elevations were slightly higher (maximum of 1.6 feet) than those determined theoretically.

7. Measurement of transient velocity and water surface in the 6-unit tailrace during a plant startup procedure showed no sudden increases in velocity or turbulent fluctuations, or waves which could damage the bank material. Similar results would be expected for the 12-unit plant.

8. 700-megawatt (Mw) units are presently being discussed for installation at the remaining three authorized units (three 600-Mw units are under construction). Discharges corresponding to the larger units were not tested during this study; however, some increase in the severity of problems such as vortex formation and bed scour would be expected. Therefore, a change to 700-Mw units should not be made unless additional studies are made to evaluate these effects.

APPLICATIONS

The results of this study apply specifically to the Grand Coulee Third Powerplant, which is essentially unique.

INTRODUCTION

The existing Grand Coulee Dam, Figure 1, includes as its primary features a spillway, multiple outlets, and a powerplant on each bank. The spillway is designed for a maximum discharge of 1 million cubic feet per second (cfs) at maximum reservoir elevation 1290. Each powerplant has a capacity of approximately 1,000 Mw.

The Columbia River Treaty with Canada has made possible additional storage capacity upstream from Grand Coulee Dam. Previously, water has been wasted over the spillway. Therefore, the Third Powerplant was conceived as a very attractive addition to the Grand Coulee complex.

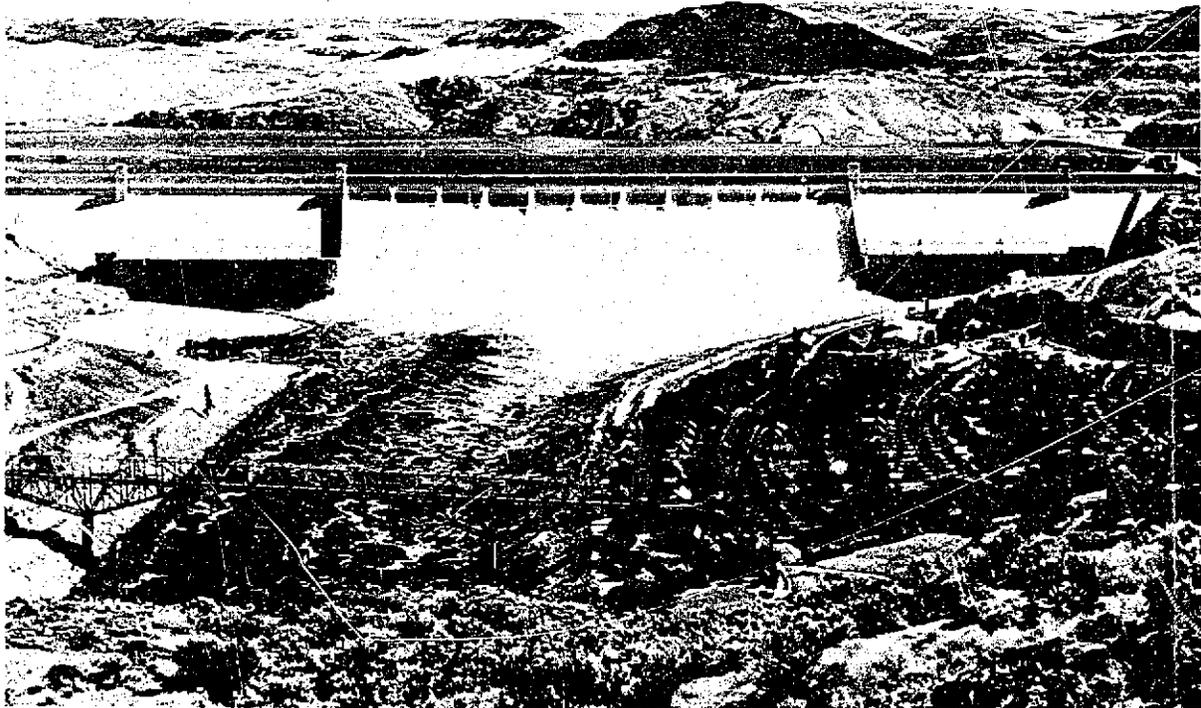


Figure 1. Grand Coulee Dam - Existing features. Photo TP222-D-9106

The Third Powerplant, Figure 2, will have an ultimate capacity of 7,200 Mw in the form of twelve 600-Mw units. Six units are presently authorized. This will be the most inexpensive hydroelectric power in the United States from a plant which is expected to be the world's largest for many years. Installation of the 12 units will occur in stages according to the growth in need for peaking power. Estimated completion for full capacity is 1992.

Three 600-Mw units are now under construction. Increasing the size of the remaining three authorized units to 700-Mw is being discussed. Though the exact effects are unknown, an increase in the severity of potential problems such as vortex formation and bed scour would be expected.

THE MODEL

The 1:120 scale model was constructed and tested in stages, according to the need for design information. The preliminary forebay channel for the 12-unit plant was installed and tested first. Later, the penstocks and

powerhouse structure were attached and the tailrace topography was installed. The model included the spillway and both existing powerplants from the start.

Water was supplied to the model through two risers which could be adjusted to modify the pattern of flow entering the model. Discharge was measured with permanent volumetrically calibrated venturi meters. Reservoir elevations were set by staff gages; head loss was measured with point gages. Tailwater elevations were also set with a staff gage. Water surface profiles in the tailrace were determined with piezometers mounted flush with the riverbed. The piezometers were connected to a pressure transducer. The output from the transducer was displayed on a digital voltmeter, with voltage corresponding to head on the transducer. Velocities in the forebay and tailrace were measured with a miniature propeller meter connected to an electronic counter and paper tape printer or with a pitot tube connected to a differential pressure transducer. Waves were recorded with capacitance-type probes connected to a direct-writing oscillograph recorder.

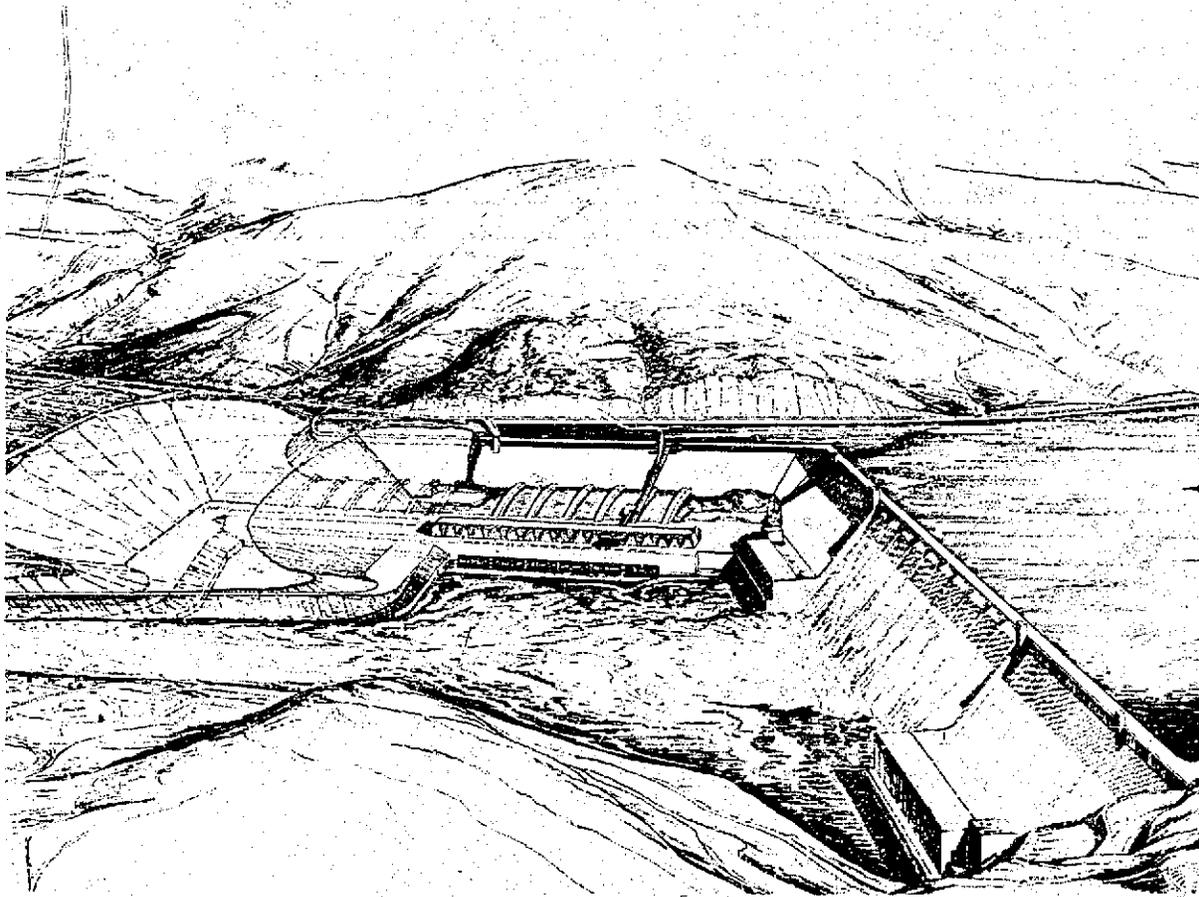


Figure 2. Third Powerplant - Artist's conception. Photo P1222-D-63800

TEST CONDITIONS

The following conditions were used in planning the model tests.

At minimum reservoir elevation 1208:

One unit operating - 29,200 cfs
 Twelve units operating - 330,000 cfs (27,500 cfs per unit)

At maximum reservoir elevation 1290:

One unit operating - 31,000 cfs
 Twelve units operating - 372,000 cfs (31,000 cfs per unit)

Right and Left Powerplants - 45,000 cfs each

Spillway - 1,000,000 cfs maximum

| Channel discharge cfs | Tailwater at bridge gage | |
|--------------------------|--------------------------|--------------------------|
| | Unimproved channel | With fill channel "D" |
| 60,000 | 950.1 | 950.6 |
| 80,000 | 951.9 | 952.2 |
| 160,000 | 959.4 | 960.8 |
| 240,000 | 966.4 | 968.6 |
| 300,000 | 971.1 | 973.9 |
| 500,000 | 984.8 | 988.7 |
| 750,000 | 999.4 | 1005.8 |
| 1,000,000 | 1012.5 | 1018.4 |

¹Fill channel "D" is one of several downstream channel configurations and was chosen for prototype construction. The theoretical tailwater corresponding to this configuration was used in the model study.

Information concerning these conditions became available at different times during the study. Therefore, this report may at times refer to somewhat different conditions.

INVESTIGATION

Forebay Channel

Preliminary design.—Figure 3 shows the initial configuration of the forebay channel. The upstream portions of the penstocks and the penstock entrances were simulated with 4-inch-diameter plastic tubes (40 feet, prototype) with slide gates on the topography at the upstream end of the forebay channel was included. Velocities were measured across the forebay channel on a line representing an extension of the upstream face of Grand Coulee Dam, and on lines perpendicular to the Forebay Dam approximately 300 and 600 feet downstream. Surface flow patterns in the forebay channel are represented by the confetti streaks in Figure 4. The total discharge through 12 units was 330,000 cfs, reservoir elevation 1208 (minimum). The confetti streaks indicate that the flow is directed toward the right side of the channel, with accompanying high velocities in that area. The eddy formed downstream from the corner at the juncture of the dams is apparent, as well as surface swirls along the face of the Forebay Dam. Figure 5 is a closer view of the eddy formed at the corner, for a discharge of 392,400 cfs, reservoir elevation 1290 (maximum). Nearly dead water occurs at the downstream end of the channel.

Velocity distributions for these conditions are shown in Figure 6. At reservoir elevation 1208, Figure 6A, upstream velocities to 3 feet per second (fps)

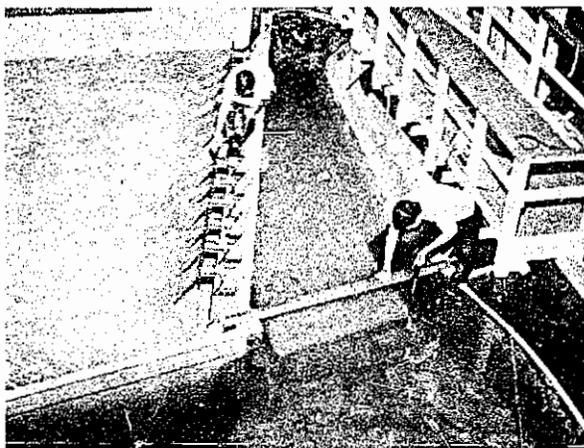


Figure 3. Preliminary forebay channel. Photo F1222-D-72991

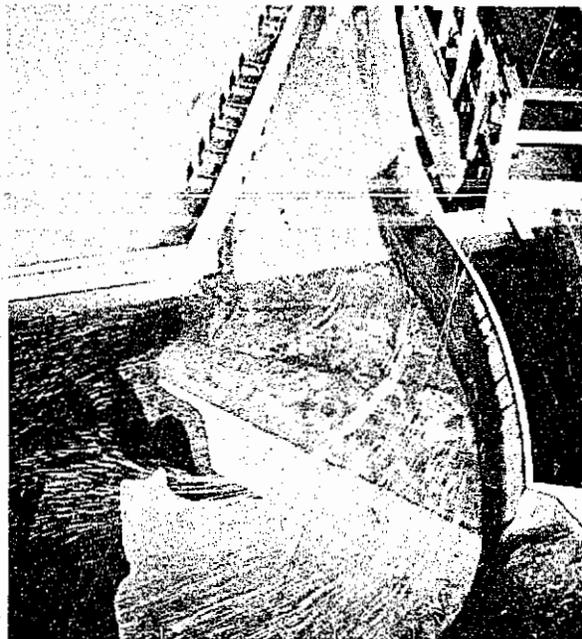


Figure 4. Flow pattern in preliminary forebay channel. Photo P1222-D-72992

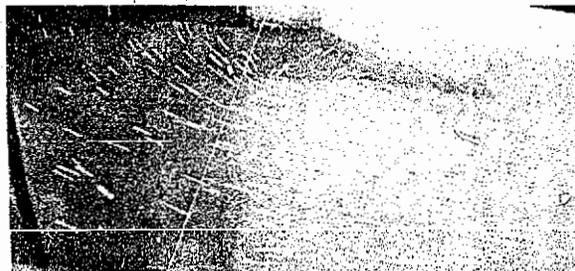
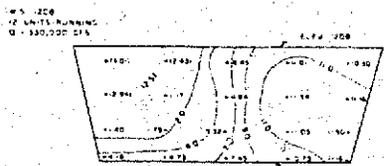
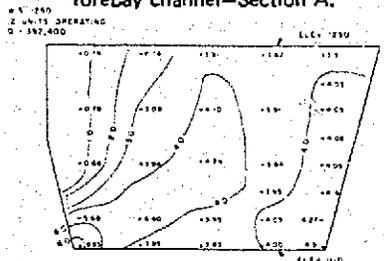


Figure 5. Flow pattern at juncture between dams. Photo P1222-D-72993

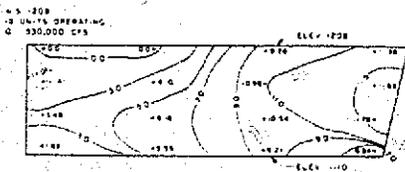
were observed near the Forebay Dam (left side of channel). Velocities over 11 fps occurred near the right side. These were average velocities; therefore, higher instantaneous velocities would be expected. Attempts were made to limit the velocity along the right side to less than 10 fps. At reservoir elevation 1290, the highest velocities occurred in a limited region near the lower left corner of the channel, Figure 6B. Both Figures 6A and 6B show that the corner eddy is primarily a surface phenomenon. Vortices formed above several of the penstock entrances at the minimum reservoir elevation. The change in water surface elevation from the main



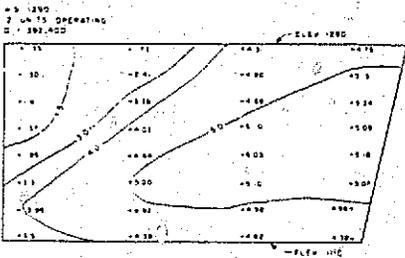
A. Velocity distribution in preliminary forebay channel—Section A.



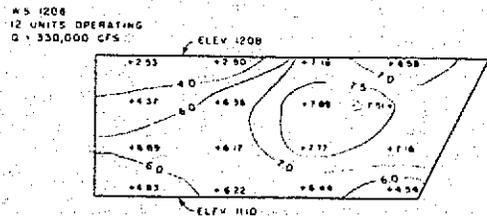
B. Velocity distribution in preliminary forebay channel—Section B.



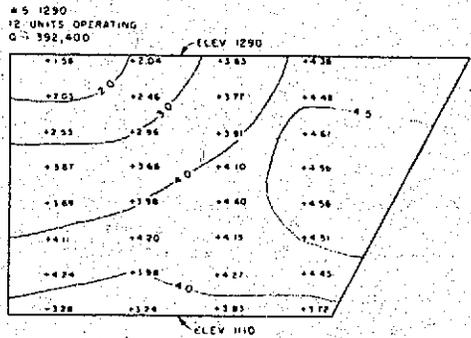
C. Velocity distribution in preliminary forebay channel—Section B.



D. Velocity distribution in preliminary forebay channel—Section B.



E. Velocity distribution in preliminary forebay channel—Section C.



F. Velocity distribution in preliminary forebay channel—Section C.

KEY

- + Point Velocity fps
- + () Reverse Velocity
- - - Reverse Velocity Contour

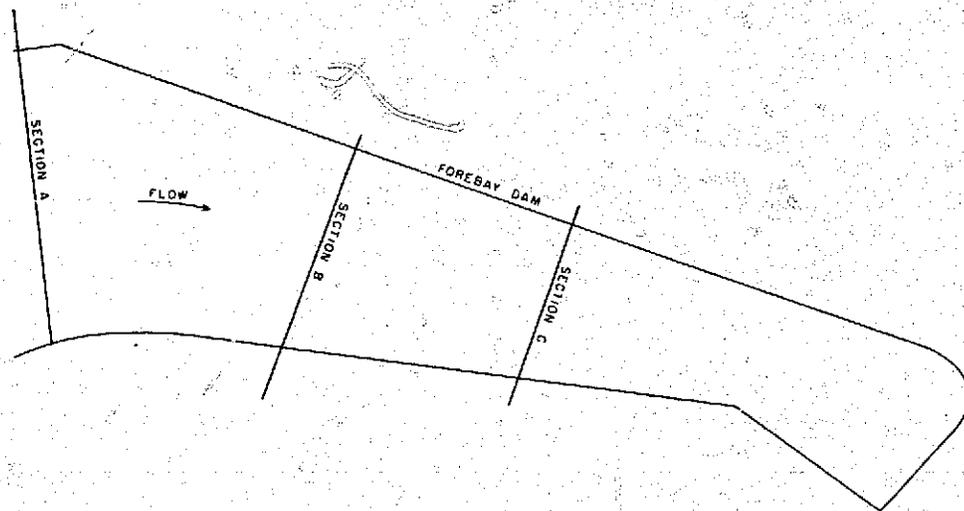


Figure 6. Velocity distribution in preliminary forebay channel.

body of the reservoir to the first unit was approximately 2 feet at minimum reservoir. The change was negligible at maximum reservoir.

Several modifications and appurtenances were tried in attempts to improve velocity distribution in the forebay channel. Rounding of the corner at the juncture of the dams had no effect. The remaining topography between the channel and the reservoir was installed for this test.

Guide walls placed in the channel, such as that shown in Figure 7A, were successful in improving the velocity distribution. Such structures would consist of unexcavated rock. Improving the velocity distribution allowed the right wall to be moved inward, as shown in Figure 7B. This arrangement improved the velocity distribution, but resulted in excessive head loss. Water surface drop from the reservoir was as much as 7 feet. Operation without the guide wall in the middle part of the channel suggested that some revision of the right wall configuration would be advantageous.

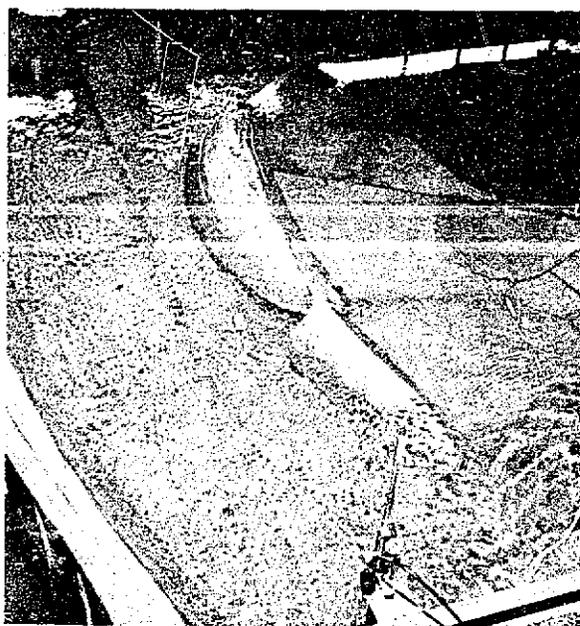
After several more trials, the configuration shown in Figure 8 was determined to be a necessary improvement. The channel floor was lowered to elevation 1110 and a curved rock dike, with its crest at elevation 1150, was placed across the channel entrance. The resulting velocity distribution is shown in Figure 9.

Lowering the topography at the corner from elevation 1250, Figure 10A, to elevation 1190, Figure 10C, further improved the velocity distribution, Figure 11. It was later determined that the topography could be lowered to elevation 1200 without an unreasonably large amount of excavation.

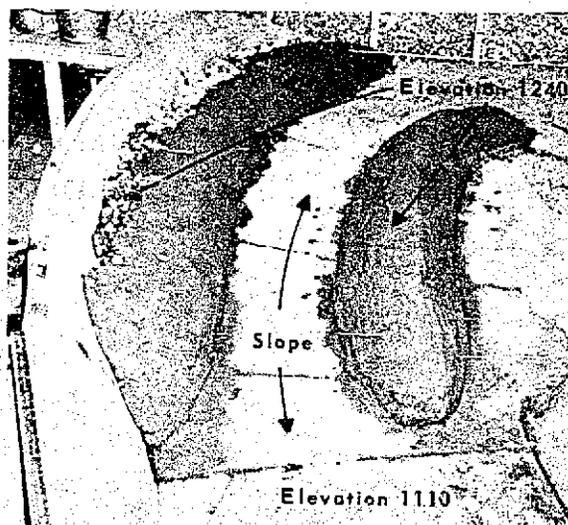
Moving the right wall inward 20 feet resulted in the velocity distribution of Figure 12. This change had no apparent effect on the velocity distribution.

Recommended design.—After several additional minor modifications, the forebay channel configuration shown in Figure 13 was recommended.

Velocity distributions for the 12-unit configuration are given in Figure 14 (the corner topography was at elevation 1225 during these measurements). Velocities of nearly 11 fps were measured along the right wall; however, these velocities were determined to be acceptable. Velocities of more than 13 fps are required to move 20-inch riprap. Since the blocks of rock in the wall of the forebay channel are equivalent to sizes much larger than 20 inches, the expected velocities should cause no problem.



A. Photo P1222-D-72995.



B. Photo P1222-D-72994.

Figure 7. Trial curved guide walls.

Figure 15 shows streaks caused by submerged pieces of confetti, with 12 units operating. The photograph shows that, at several points in the channel, the subsurface movement is nearly parallel



Figure 8. Recommended dike. Photo P1222-D-73005

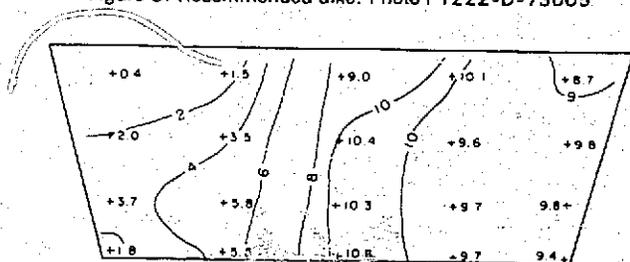


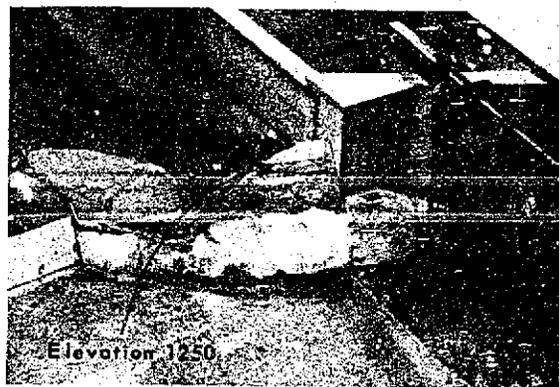
Figure 9. Velocity distribution at Section A with recommended dike.

to the face of the Forebay Dam. By measuring the exact camera shutter speed, the velocities could be determined by measuring the length of the streaks. These data were useful in designing the trashracks for the penstock intakes. Figure 16 shows surface flow patterns near the upstream units (19, 20, and 21) and near the downstream units (28, 29, and 30). Figure 16A shows a standing wave which causes rapid deceleration of the surface velocity. The shadow of this wave can be seen on the channel bottom. The surface eddy above Units 19, 20, and 21 is also apparent in this photograph.

The following observations on vortex formation were made for the 6-unit plant configuration:

Unit 19 operating alone at a discharge of 31,000 cfs:

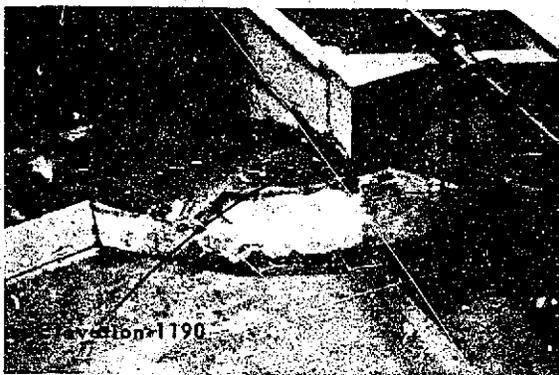
Dimpling of the water surface immediately after submergence of the entrance. Decreasing strength as the water surface rose to the minimum reservoir elevation 1208. Dimpling again noted at elevation 1213. Weak circulation with no surface dimpling at elevation 1250.



A. Photo P1222-D-73018.



B. Photo P1222-D-73016.



C. Photo P1222-D-73017.

Figure 10. Variable topography at juncture between dams.

Units 19, 20, and 21 operating, each at a discharge of 31,000 cfs:

Below elevation 1208, short duration, weak to strong vortices formed at times. Some air taken

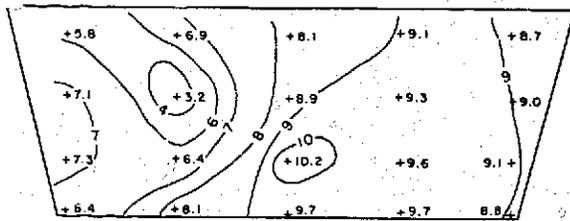


Figure 11. Effect of juncture changes on velocity distribution at Section A.

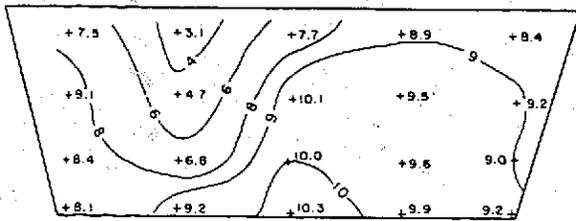


Figure 12. Velocity distribution at Section A with modified right wall in forebay channel.

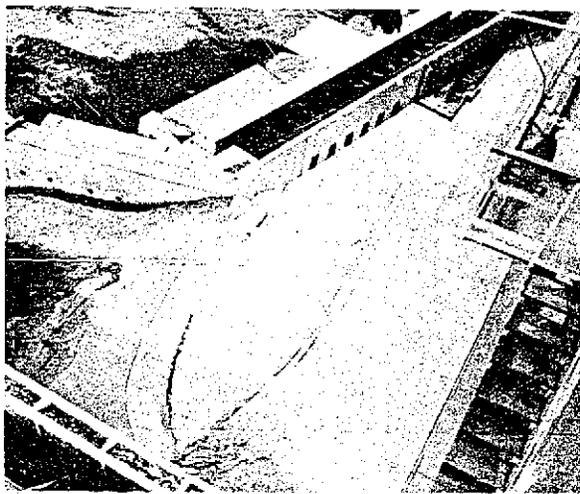


Figure 13. Recommended forebay channel. Barrier at mid-length represents end of channel for 6-unit plant. Photo P1222-D-73019.

into penstocks. At elevation 1208, a vortex formed above Unit 19 which took air and lasted for several seconds. At elevation 1223, surface dimpling was noted and most of the circulation was above Unit 19. A weak intermittent vortex formed above Unit 19 at elevation 1238. At elevation 1266, intermittent surface dimples formed above all three units.

Units 19, 20, 21, 22, 23, and 24 operating, each at a discharge of 31,000 cfs:

Occasional strong vortices formed below elevation 1208, primarily at Units 19, 20, 21, and 22. Surface dimpling at elevation 1213.

Strong, concentrated swirls at elevation 1220, no air taken. Short duration, strong vortex above Unit 19 at elevation 1226, took air. Observed again at elevations 1228, 1229, 1230, and 1234. Represents prototype vortex with a diameter of about 10 feet. Intermittent vortices above Unit 20 took air at elevation 1250, and again at elevation 1253. Deep, intermittent dimples above Unit 20 at elevation 1260, with strong counterclockwise circulation.

Observations were also made with all 12 units operating at reservoir elevation 1208, with varying discharge, as described below:

$Q = 330,000$ cfs:

Strong, unstable vortices above Units 19-24 took air for short periods through any of these six units. Moving dimples observed above Units 25-30, no air taken.

$Q = 284,000$ cfs:

Short duration, large vortex, took air into penstock of Unit 20. Incipient vortex formation above Units 21 and 22. Dimpled surface throughout the length of the channel.

$Q = 266,000$ cfs:

Short duration, large vortices above Units 20, 21, and 22 took air. Calm water surface above Unit 19. Dimpled surface throughout the length of the channel.

$Q = 252,000$ cfs:

Short duration, moderate vortices formed above Units 20 and 21, but much less frequently than for higher discharges. Small amounts of air taken. Dimpled surface throughout the length of the channel.

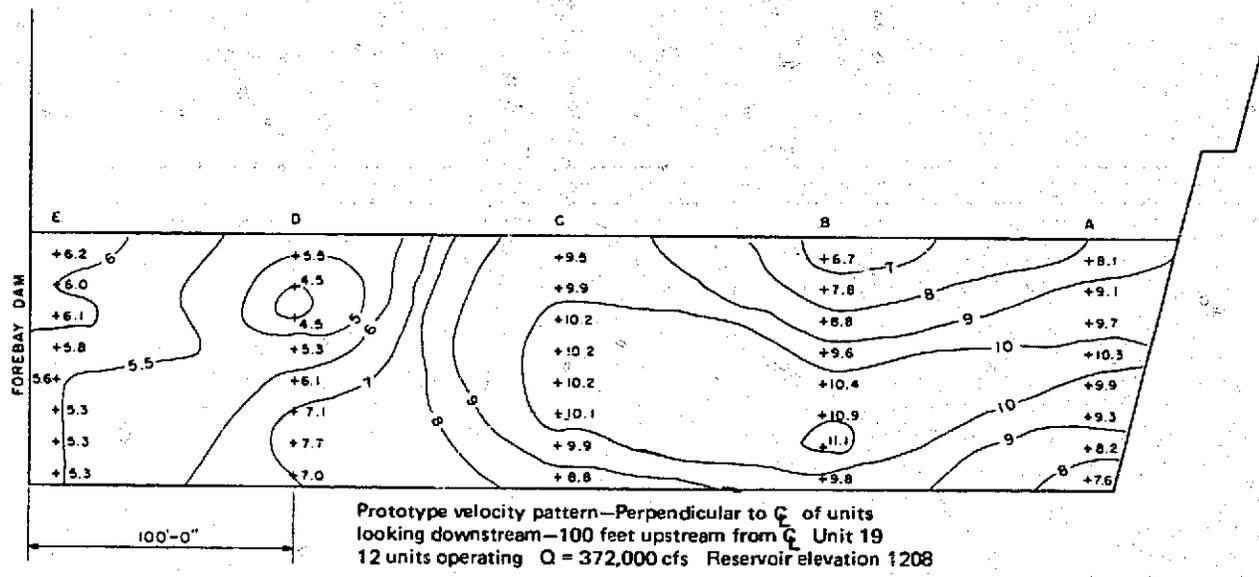


Figure 14. Velocity distribution in recommended forebay channel.



Figure 15. Flow pattern within forebay channel flow. Photo P1222-D-72999

$Q = 237,000$ cfs (representing 72 percent of full load):

Short duration, moderate vortices formed above Units 20, 21, 22; did not take air. However, vortices had deep cores. Small amount of air taken into penstock of Unit 20. Dimpled surface throughout the length of the channel.

The effects of these vortices on operation of the turbines could not be determined in this study. Also, the exact performance of the prototype fore-

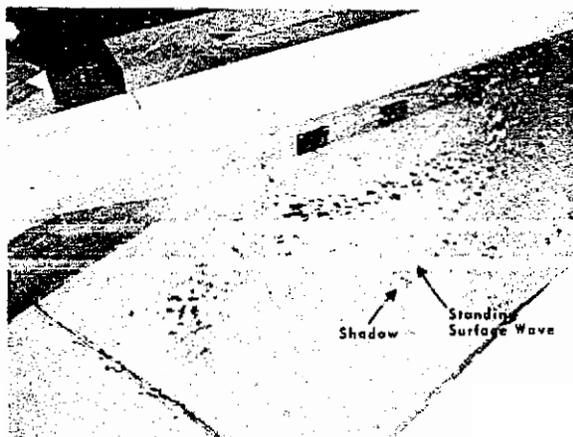
bay channel could not be determined because the laws of similitude for vortices are not yet well established. Additional studies on a larger model would be advisable for development of modifications and appurtenances to alleviate the vortex problem.

During the course of the forebay channel tests, the spacing between penstocks in each of the 6-unit groups was changed from 133.5 feet to 119 feet. This change had no effect on the test results.

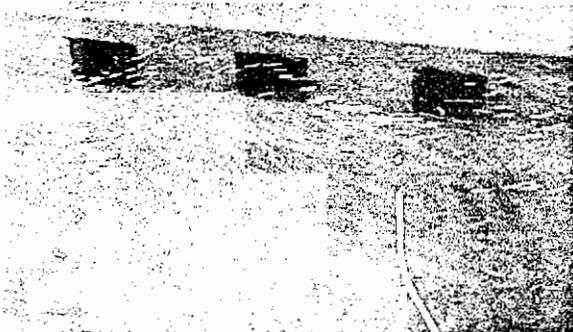
A proposal was made to leave a rock "weir" between Units 24 and 25, to reduce the required amount of underwater excavation. Such a structure was installed in the model, with the top of the structure at either elevation 1170 or 1200. For the lower structure, operation up to reservoir elevation 1250 resulted in very rough flow and large vortices in the channel adjacent to Units 25-30. Approximately 1 foot of head loss occurred across the structure at reservoir elevation 1262. For the higher structure, unsatisfactory flow conditions were observed up to reservoir elevation 1263.

Tailrace

Six-unit plant.—The model was modified to include the penstocks, powerhouse, and tailrace for the 6-unit plant, Figure 17.



A. Units 19-22. Photo P1222-D-72996



B. Units 19-21. Photo P1222-D-73900



C. Units 28-30. Photo P1222-D-73001
Figure 16. Surface flow pattern in forebay channel



Figure 17. Preliminary 6-unit tailrace configuration. Photo P1222-D-72997

Two configurations of the right bank of the tailrace channel were tested. Figure 18 shows the preliminary configuration of the right bank of the tailrace channel, along with locations of velocity measurements. Table 1 shows the velocity data. Velocities exceeding 15 fps were measured at several points. The maximum recorded velocity of 17 fps would cause movement of riprap material less than 42 inches in diameter.¹ Concern over the possible movement of channel bed material resulted in a modification to the right bank. The recommended configuration and locations of velocity measurements are shown in Figure 19. The resulting velocities are shown in Table 2. The maximum recorded velocity of 13.5 fps would move riprap less than 27 inches in diameter. Figure 20 shows several representative flow conditions in the recommended tailrace channel for the 6-unit plant.

The question was raised concerning the possible movement of bed material between the existing Right Powerplant and the tailrace of the Third Powerplant. Velocities measured in this area for

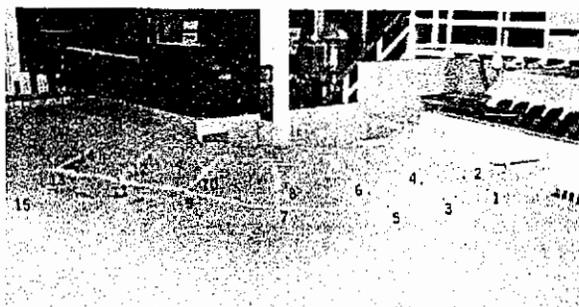


Figure 18. Velocity measurements in preliminary 6-unit tailrace. Photo P1222-D-73006

¹Figure 165, "Hydraulic Design of Stilling Basins and Energy Dissipators", Bureau of Reclamation Engineering Monograph No. 25, July, 1963.

Table 1

VELOCITIES MEASURED AT POINTS IN FIGURE 18

| Point No. | Run No. | Velocities - fps | | | | | | |
|-----------|---------|------------------|-----|-----|------|------|------|------|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 1 | | 5.8 | 5.3 | 4.5 | 4.4 | 3.7 | 3.6 | 2.3 |
| 2 | | 2.8 | 0.2 | 0.6 | 0.5 | 1.4 | 2.2 | 1.6 |
| 3 | | 3.5 | 1.7 | 2.8 | 3.0 | 2.5 | 1.7 | 0.8 |
| 4 | | 2.7 | 1.8 | 1.6 | 1.7 | 0.8 | 1.1 | 1.4 |
| 5 | | 3.7 | 3.5 | 3.5 | 3.5 | 3.6 | 1.6 | 0.8 |
| 6 | | 4.1 | 2.9 | 3.6 | 3.8 | 3.3 | 1.9 | 1.0 |
| 7 | | 2.8 | 3.2 | 4.4 | 5.3 | 6.4 | 5.4 | 4.8 |
| 8 | | 0.9 | 3.5 | 6.4 | 6.3 | 6.4 | 6.9 | 4.4 |
| 9 | | 1.8 | 3.2 | 4.3 | 4.8 | 6.4 | 7.5 | 10.4 |
| 10 | | 0.8 | 0.6 | 0.7 | 0.9 | 3.6 | 9.8 | 8.7 |
| 11 | | 2.8 | 4.0 | 5.6 | 7.8 | 9.1 | 12.2 | 13.3 |
| 12 | | 1.8 | 2.4 | 3.3 | 3.7 | 6.3 | 10.4 | 12.5 |
| 13 | | 4.1 | 4.8 | 6.9 | 7.3 | 10.4 | 15.1 | 17.0 |
| 14 | | 0.8 | 1.8 | 0.6 | 1.2 | 0.8 | 8.0 | 10.6 |
| 15 | | 4.2 | - | 9.2 | 12.1 | 10.7 | 15.4 | 16.5 |

| Run No. | Existing plants | 6-unit 3rd pp | Spillway | Total discharge | Bridge tailwater elevation | Backwater |
|---------|-----------------|---------------|----------|-----------------|----------------------------|-----------|
| 1 | 0 | * 93,000 | 0 | 93,000 | 953.8 | 1.2 |
| 2 | 0 | 186,000 | 0 | 186,000 | 963.5 | 1.8 |
| 3 | 90,000 | 150,000 | 0 | 240,000 | 968.6 | 2.4 |
| 4 | 90,000 | 186,000 | 24,000 | 300,000 | 973.9 | 3.0 |
| 5 | 90,000 | 186,000 | 224,000 | 500,000 | 988.7 | 4.2 |
| 6 | 90,000 | 186,000 | 474,000 | 750,000 | 1005.8 | 4.8 |
| 7 | 90,000 | 186,000 | 724,000 | 1,000,000 | 1018.4 | 3.6 |

*Units 22-24

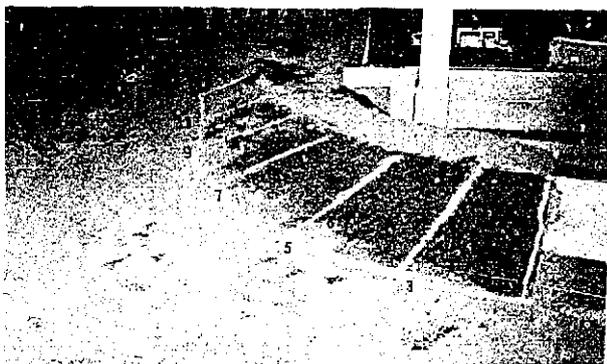


Figure 19. Velocity measurements in recommended 6-unit tailrace. Photo P1222-D-73007

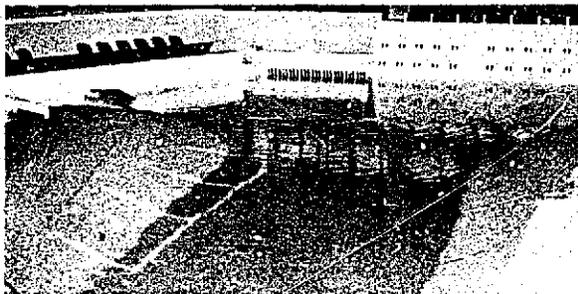
three representative flow conditions are shown in Figure 21. In cases where the model velocities were too low to measure with the miniature propeller meter, only flow patterns are shown. The magnitude of the velocities suggested that some of the material (less than about 4 inches in diameter) might tend to move into the Third Powerplant tailrace. Since a concrete pad was to be constructed for support of the cofferdam, it was suggested that this pad be left in place after completion of construction. The pad, shown in Figure 22, will tend to block the movement of material toward the Third Powerplant tailrace.

Table 2

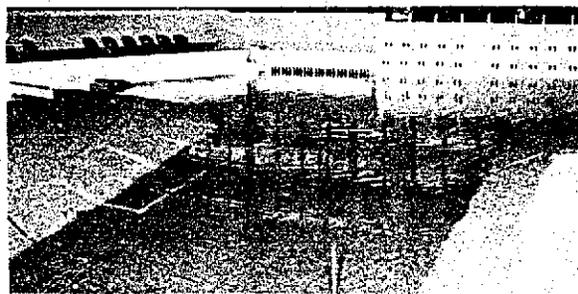
VELOCITIES MEASURED AT POINTS IN FIGURE 19

| Point No. / Run No. | Velocities - fps | | | | | | |
|---------------------|------------------|-----|-----|------|------|------|------|
| | 1A | 2A | 3A | 4A | 5A | 6A | 7A |
| 1 | 5.0 | 5.3 | 4.2 | 5.6 | 4.4 | 3.6 | 1.8 |
| 2 | 3.5 | 0.9 | 0.8 | 0.8 | 0.7 | 2.2 | 1.6 |
| 3 | 4.4 | 4.4 | 4.1 | 4.4 | 3.6 | 0.8 | 1.8 |
| 4 | 5.1 | 3.7 | 3.3 | 4.0 | 1.4 | 1.0 | 0.8 |
| 5 | 3.7 | 3.6 | 4.2 | 4.4 | 5.0 | 3.1 | 1.3 |
| 6 | 2.7 | 4.3 | 4.7 | 4.8 | 5.3 | 2.9 | 1.3 |
| 7 | 1.7 | 4.3 | 4.7 | 5.3 | 8.8 | 7.0 | 6.0 |
| 8 | 0.6 | 4.0 | 5.0 | 6.2 | 8.8 | 7.2 | 6.3 |
| 9 | 2.4 | 4.3 | 5.0 | 6.4 | 9.8 | 9.1 | 9.5 |
| 10 | 1.8 | 3.1 | 3.8 | 44.1 | 6.5 | 6.2 | 9.7 |
| 11 | 2.3 | 4.4 | 5.5 | 6.7 | 8.3 | 8.1 | 10.7 |
| 12 | 2.1 | 3.1 | 3.8 | 4.8 | 6.2 | 8.8 | 9.3 |
| 13 | 2.8 | 4.3 | 5.9 | 7.0 | 9.2 | 10.5 | 11.8 |
| 14 | 2.5 | 4.2 | 5.2 | 5.9 | 7.9 | 9.6 | 11.3 |
| 15 | 5.0 | 7.5 | 8.1 | 10.0 | 12.0 | 13.5 | 12.8 |

| Run No. | | Backwater |
|---------|----------------------------|-----------|
| 1A | Runs described on Table 1. | - |
| 2A | | - |
| 3A | | 2.4 |
| 4A | | 2.4 |
| 5A | | 3.6 |
| 6A | | 3.0 |
| 7A | | 2.4 |

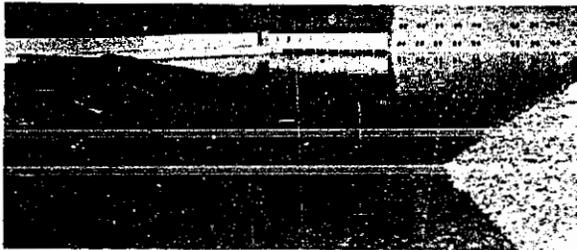


Units 27-24 of Third Powerplant, Q = 93,000 cfs, tailwater elevation 953.8. Photo P1222-D-73014

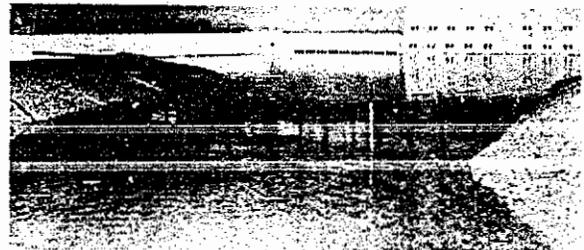


Units 19-24 of Third Powerplant, Q = 186,000 cfs, tailwater elevation 963.5. Photo P1222-D-73013

Figure 20. Flw conditions in the recommended 6-unit tailrace.



Units 19-24 at $Q = 150,000$ cfs plus existing plants at 90,000 cfs; tailwater elevation 968.6. Photo P1222-D-73012



Units 19-24 at $Q = 186,000$ cfs plus existing plants at 90,000 cfs, spillway at 24,000 cfs; tailwater elevation 973.9. Photo P1222-D-73011



Units 19-24 at $Q = 186,000$ cfs plus existing plants at 90,000 cfs, spillway at 224,000 cfs; tailwater elevation 988.7. Photo P1222-D-73010



Units 19-24 at $Q = 186,000$ cfs plus existing plants at 90,000 cfs; spillway at 474,000 cfs; tailwater elevation 1005.8. Photo P1222-D-73009



Units 19-24 at $Q = 186,000$ cfs plus existing plants at 90,000 cfs, spillway at 724,000 cfs; tailwater elevation 1018.4. Photo P1222-D-73008

Figure 20. Flow conditions in the recommended 6-unit tailrace.—Continued

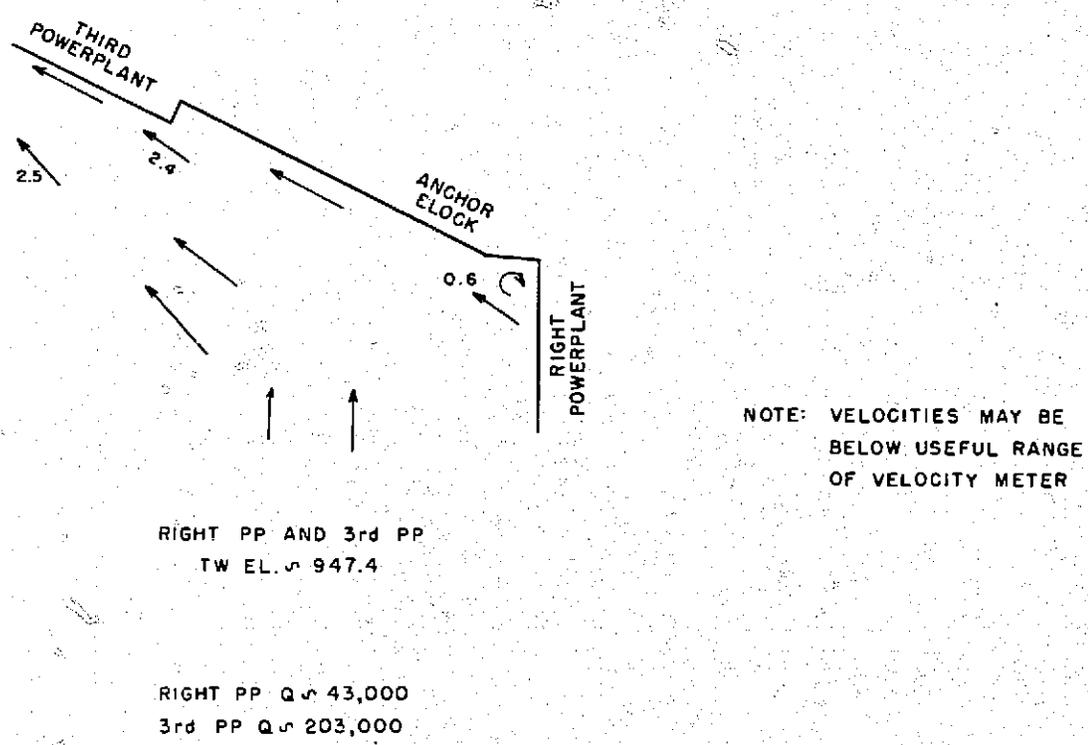
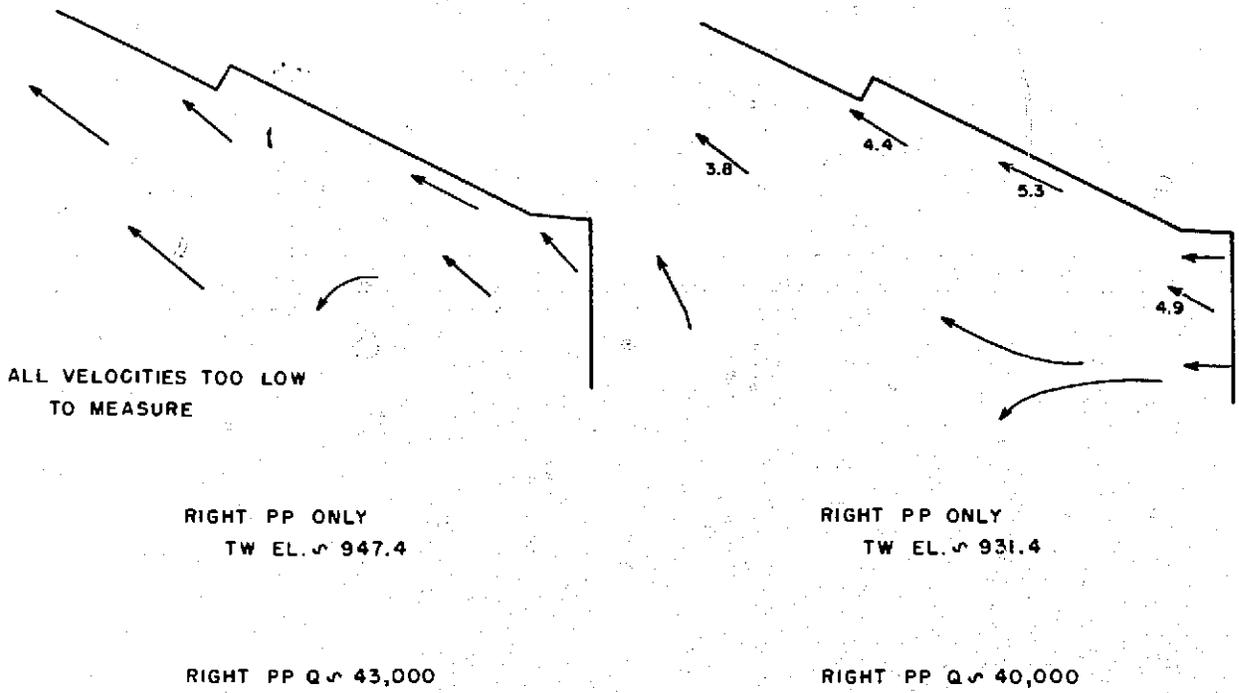


Figure 21. Velocities in vicinity of anchor block.

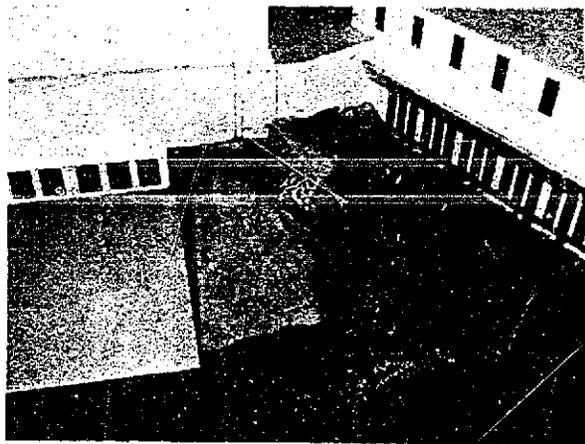
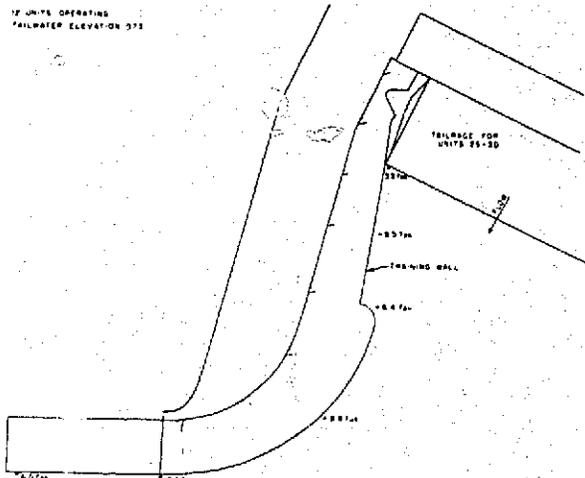


Figure 22. Cofferdam ped near anchor block. Photo P1222-D-72998

Twelve-unit plant.—Figure 23 shows the preliminary tailrace configuration for the 12-unit plant. The retaining wall at the base of the slope on the right bank was skewed 16.5° toward the channel. Figure 24 shows the location of velocity and wave-measuring instrumentation and surface flow patterns, as indicated by confetti, for three representative flow conditions. Figure 25 shows velocities and trough-to-crest wave heights in the preliminary tailrace. Velocities along the right bank approach 10 fps, suggesting the possible movement of bed material. The retaining wall was rotated so that its new location was perpendicular to the longitudinal axis of the powerplant. Velocities were again recorded, as shown in Figure 26. This configuration was recommended for the final design.



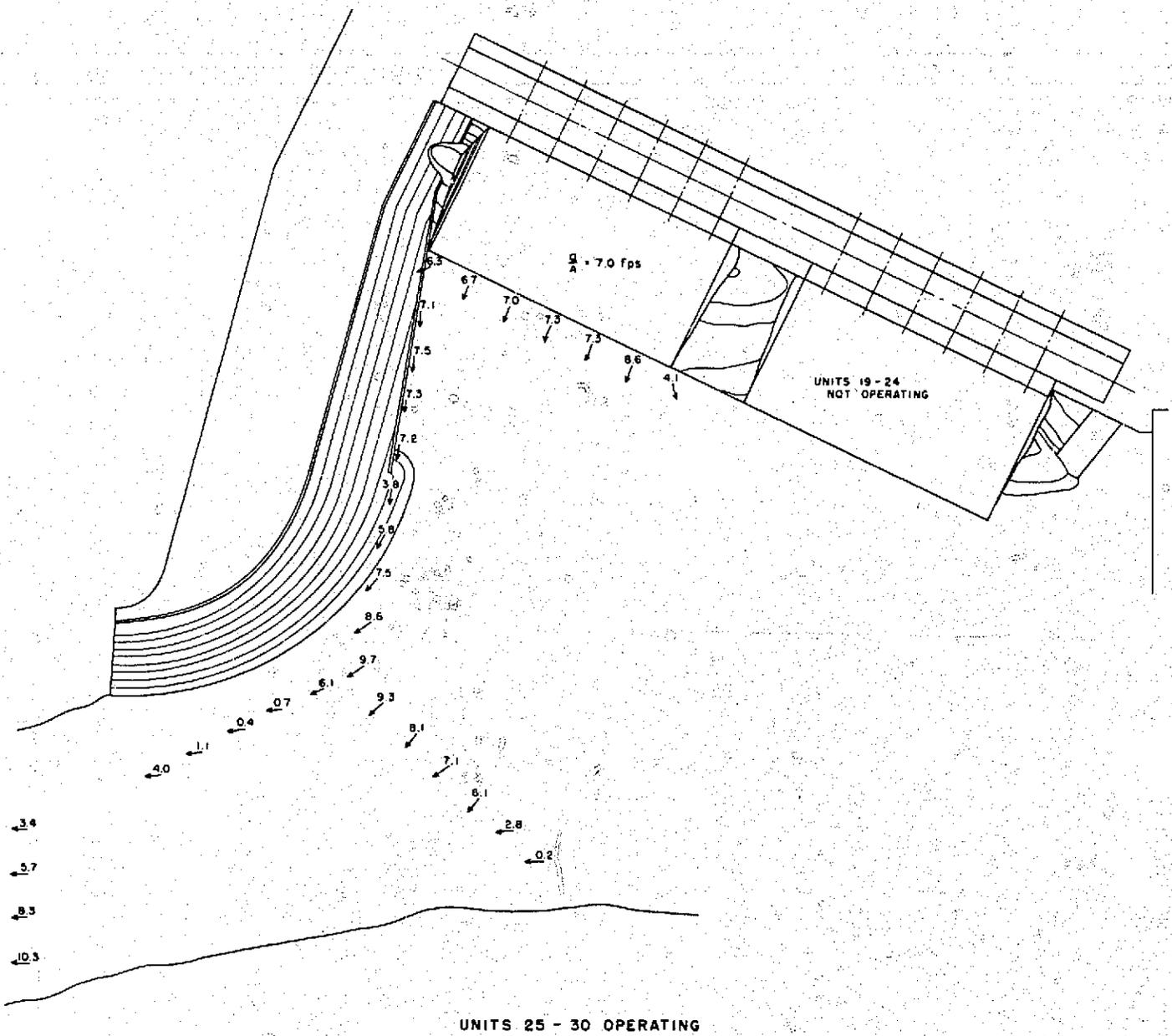


Figure 25. Velocities in preliminary 12-unit tailrace.

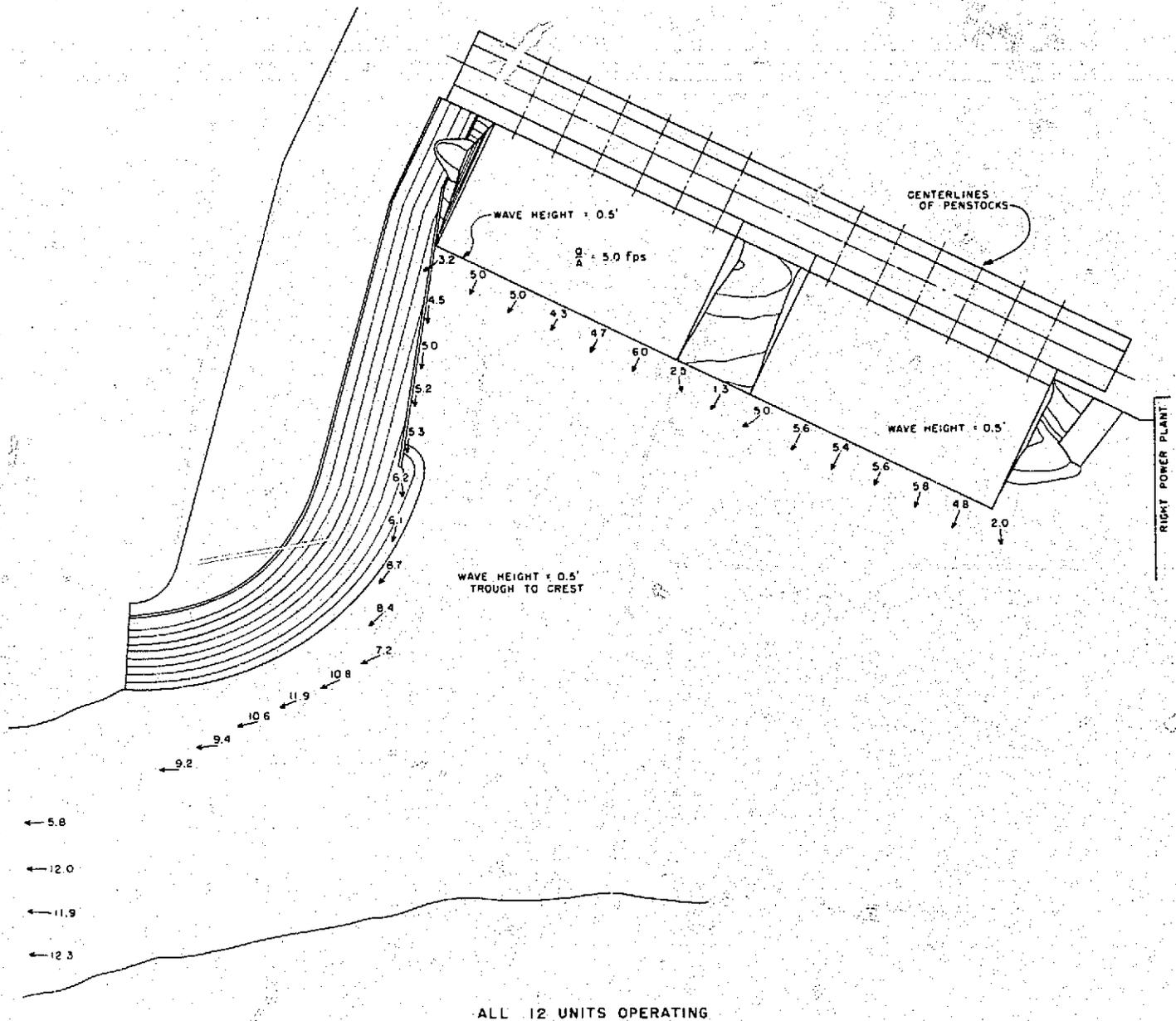
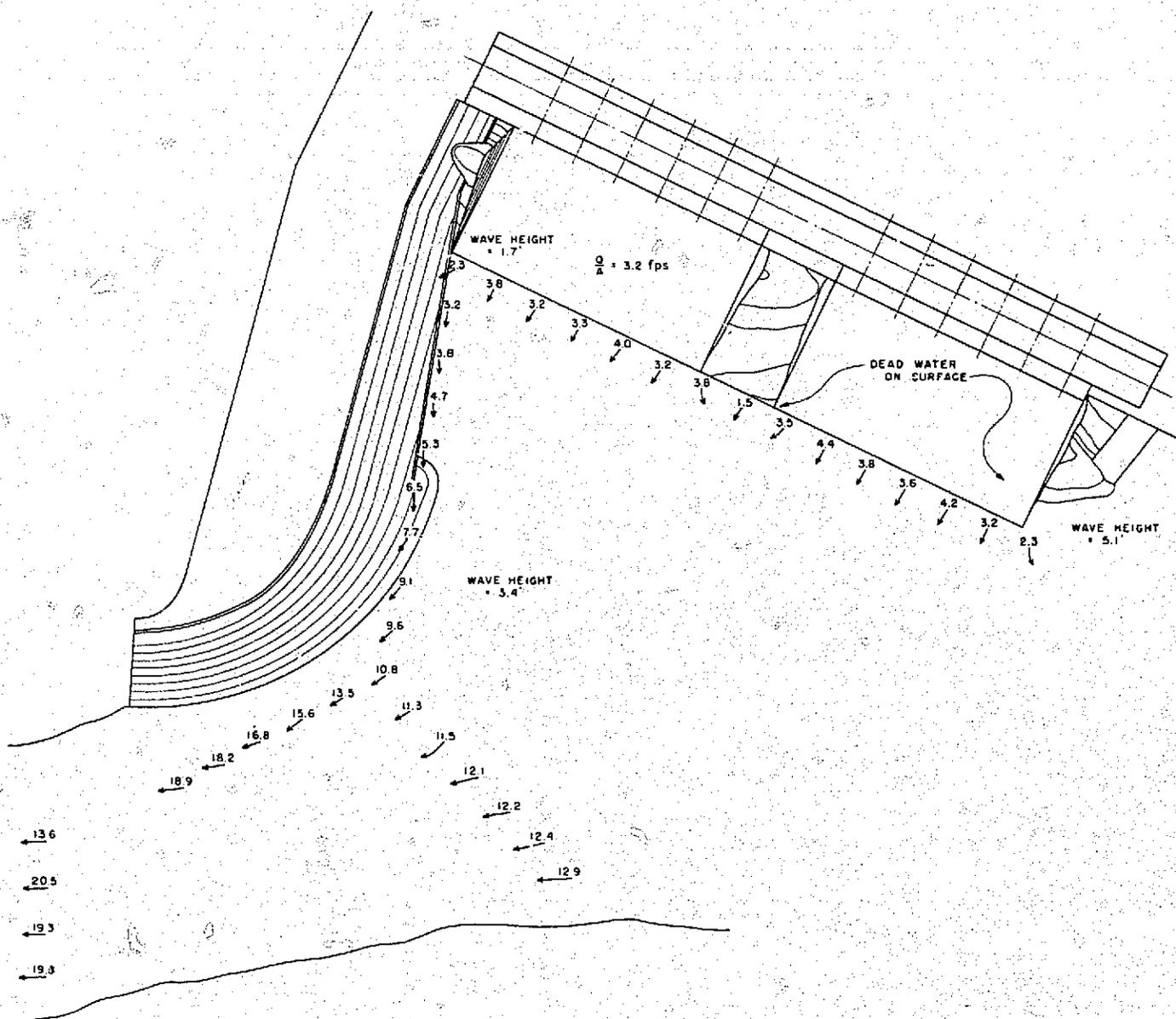


Figure 25. Velocities in preliminary 12-unit tailrace—Continued.



ALL 12 UNITS, EXISTING POWERPLANTS, AND SPILLWAY OPERATING

Figure 25. Velocities in preliminary 12-unit tailrace--Continued.

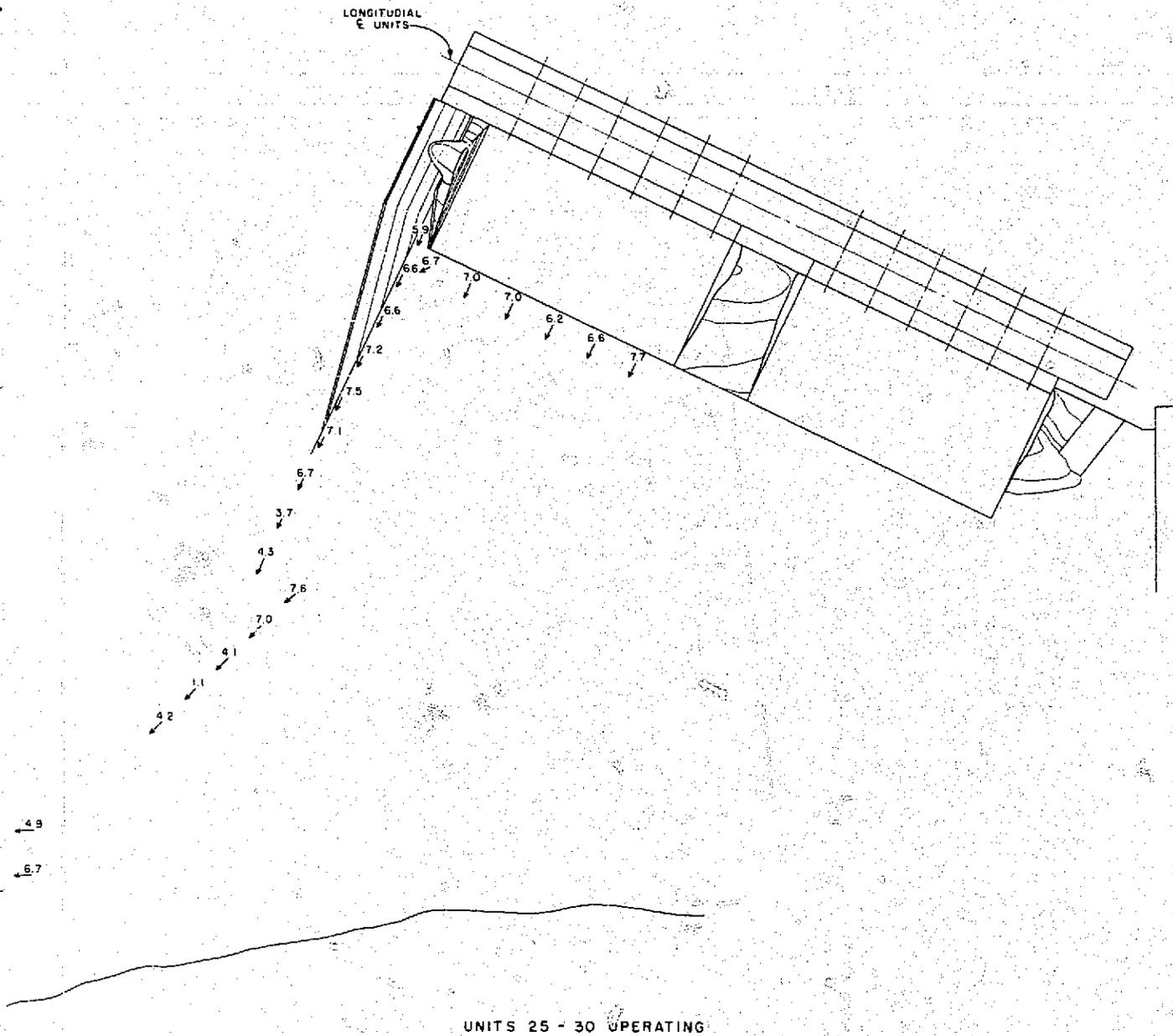


Figure 26. Velocities in recommended 12-unit tailrace.

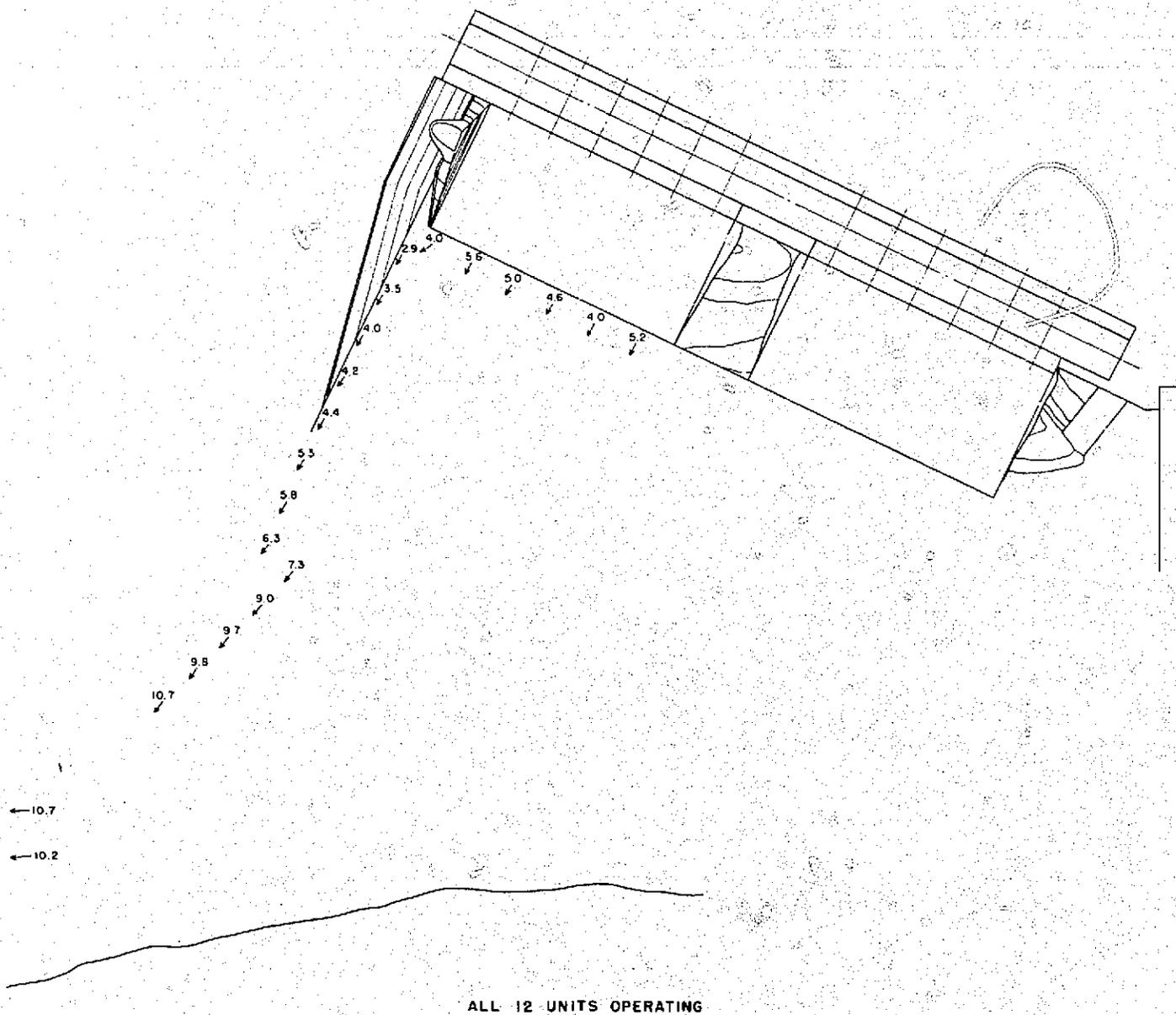


Figure 26. Velocities in recommended 12-unit tailrace—Continued.

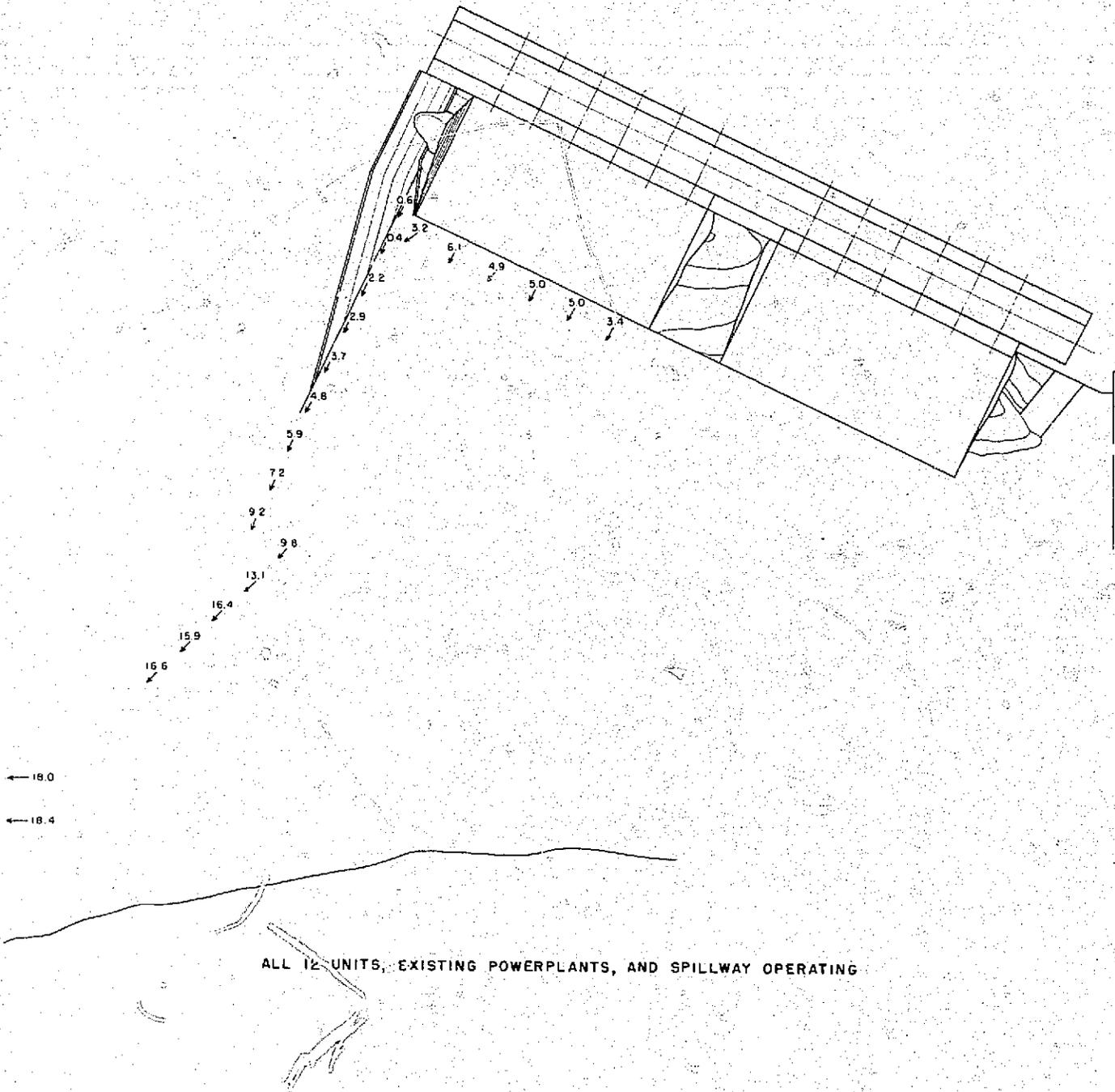


Figure 26. Velocities in recommended 12-unit tailrace—Continued.

During this phase of the testing, some movement of channel bed material was experienced in the prototype near the Left Powerplant. The model was used to evaluate the extent of this movement. Sand was placed in the model in the area adjacent to the Left Powerplant. After 1-1/2 hours of operation, with the Left Powerplant discharging alone at a capacity of 45,000 cfs, there was some indication of movement of sand toward the main channel. Also some beaching effect occurred at the water surface. However, no deposits were noted near the left training wall of the spillway. The model was then operated for about 1-1/2 hours with 45,000 cfs through the Left and Right Powerplants and about 750,000 cfs over the spillway. The tendency for the sand to move down the slope was noted. A sandbar was formed between the left tailrace channel and the main channel and a deposit existed on the downstream side of the roller bucket in the left one-third portion of the spillway. No deposit was noted near the left training wall.

Tailrace backwater tests.—Because of modifications to the channel banks downstream from the site, the need existed to evaluate the backwater effects of various bank configurations. If possible, attempts would be made to reduce the backwater to increase the power head. The channel was carefully shaped according to the latest cross section information; water surface elevation gages were located at positions corresponding to those in the prototype; and the model was operated at several required conditions. Water surface elevation gages in the model consisted of piezometer openings which were connected to a pressure transducer for very accurate measurement of the water surface.

The model was first operated with the existing tailrace configuration to determine model-prototype conformance. The data of Figure 27 show that this conformance was quite good. The correct water surface elevation was preset at the bridge gage.

The model was then operated with bridge gage water surface elevations set to correspond to computed elevations for operation with two different downstream channel configurations (A and B), and the tailrace configuration for the 6-unit Third Powerplant. The basic downstream channel configuration had been previously specified, and was denoted as fill channel "D". The water surface elevation data are shown in Figure 28. Figure 29

shows the total backwater existing between the Left Powerplant and the bridge gage, with downstream Channel A or B, for a full range of discharges from 0 to 1,000,000 cfs. These data show that Bank B is somewhat advantageous with respect to backwater effects. Comparison of the backwater effects of Banks A and B with the existing channel are shown in Figure 30.

Hydraulic transient tests.—The purpose of these tests was to determine the transient flow conditions occurring on the left bank of the tailrace channel during startup of the 6-unit Third Powerplant. The model was operated to simulate what was considered to be the most severe operating condition, with respect to startup of the units. The steady-state condition at the start of the test consisted of Unit 19 at full load with 31,500 cfs discharging. The existing plants were off. Units 20-24 were operated at a speed-no-load condition, 10 percent of the full-load discharge. The tailwater was set at elevation 949.2. Units 20-24 were then brought up to the full load in succession with each unit requiring 3 minutes (prototype). This operation would occur only under emergency conditions.

Instantaneous values of velocity, wave heights, and tailwater elevation were measured on the left bank near Station 27+77. This location was determined to be optimum for measurements by observing currents and by inspecting previous velocity data. The pitot tube and wave probe used for measuring velocity and waves are shown in Figure 31.

Two separate tests were performed. In the first test, an effort was made to simulate the tailwater change by operating the model tailgate. This proved to be unsatisfactory because (1) the exact relationship between time and tailwater elevation was not known, and (2) waves reflected from the moving tailgate affected results at the measuring point. A second test was performed in which the tailgate remained stationary. It was assumed that over the duration of the tests, waves did not have time to reach the downstream control point and travel back upstream to the model test section. If this assumption is incorrect, then the model represented a more severe condition than the prototype.

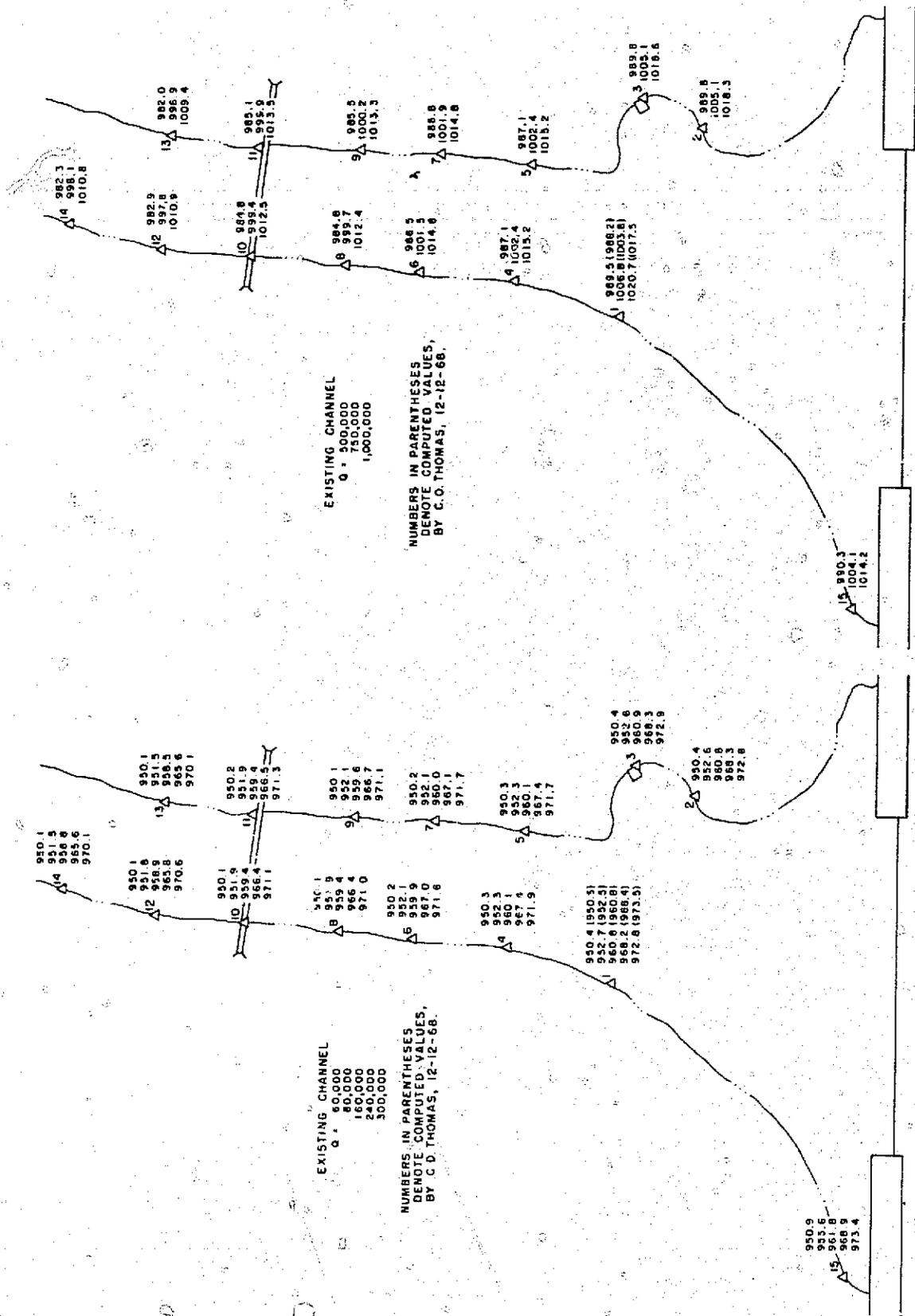


Figure 27. Water surface elevations in existing tailrace channel.

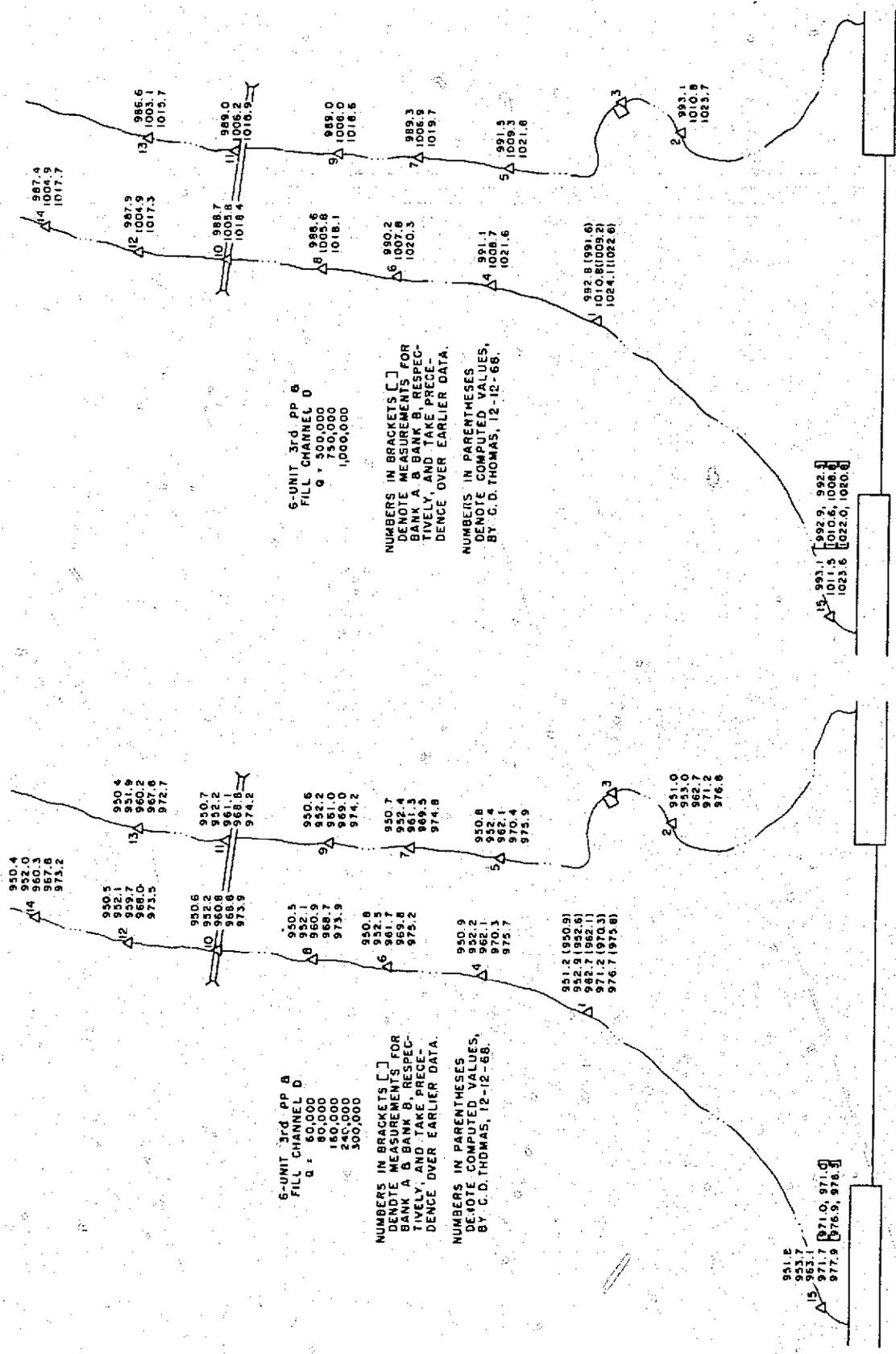


Figure 28. Water surface elevations with 6-unit Third Powerplant.

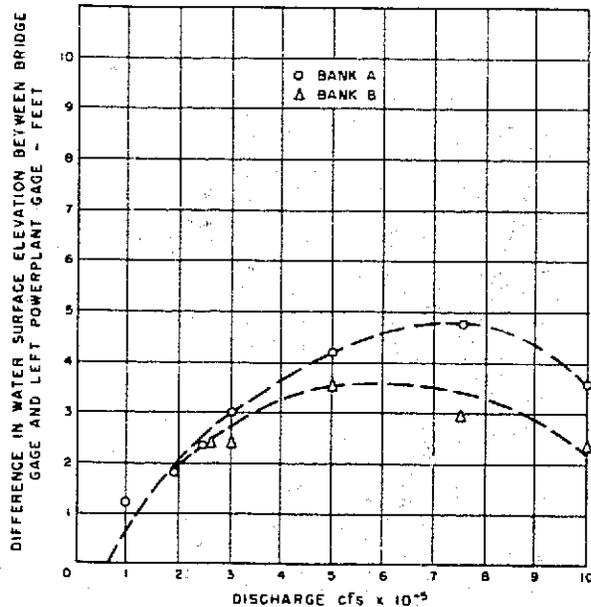


Figure 29. Total backwater between Left Powerplant and bridge gage, Banks A and B, steady flow.

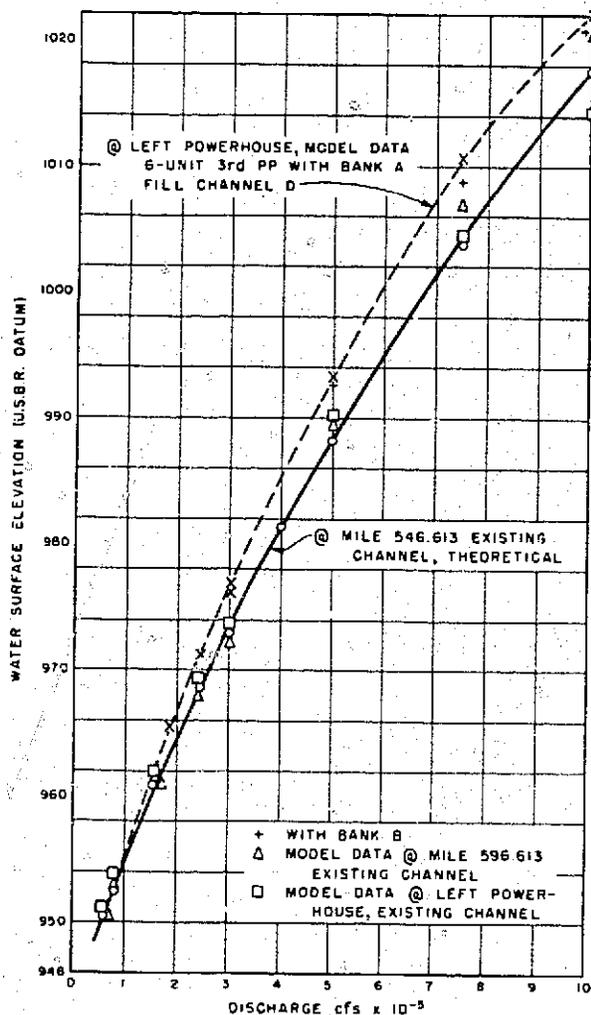


Figure 30. Backwater in existing and modified channels.

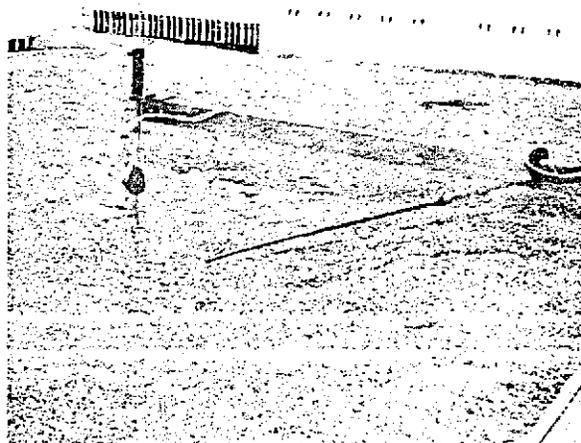


Figure 31. Pitot tube and wave probe used in hydraulic transient test. Photo P1222-D-73015

Wave and velocity data did not indicate the passage of a well-defined surge wave; instead, a gradual increase in the velocity and tailwater was indicated. Waves were too small to measure. The velocities were measured at about 20 feet and about 3 feet above the riverbed. These data are summarized in Figure 32. They do not indicate the presence of sudden increases in velocity or turbulent fluctuations which would cause damage to the bank material. Similar results would be expected for the 12-unit plant with gradual increase to the final velocities and tailwater level.

Figure 32 also shows that a near steady-state condition should occur about 30 minutes after the beginning of the operation. If the time required for the reflected wave to reach the tailrace is greater than 30 minutes, then the model results are valid. Otherwise, the measured velocities should be reduced to reflect the effect of the negative wave.

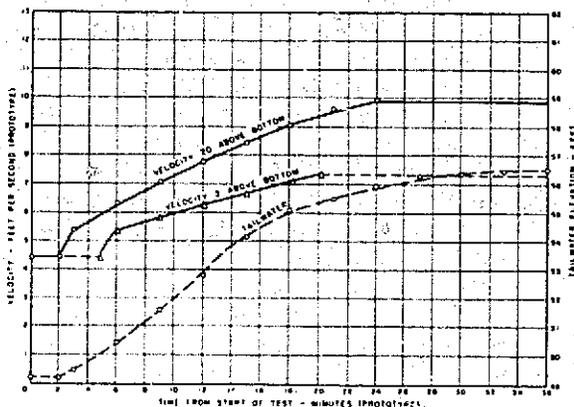


Figure 32. Results of hydraulic transient test.

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 | | 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 | 0.965873×10^{-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 | *4.4462 | 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 ² degree C |
| Btu ft/hr ft ² degree F (C, thermal conductance) | *1.4880 | Kg cal/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) | 18.7 | 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 | 0.001682 | Ohm-square millimeters per meter |
| Millifarads per cubic foot | *35.3147 | Millifarads per cubic meter |
| Milliamperes per square foot | *10.7639 | Milliamperes per square meter |
| Gallons per square yard | *4.527219 | Liters per square meter |
| Pounds per inch | *0.17858 | Kilograms per centimeter |

The water treaty with Canada, making possible additional water storage upstream from Grand Coulee Dam, and the historic large releases wasted over the spillway, contributed to the conception of a Third Powerplant at Grand Coulee. This powerplant will ultimately house twelve 600-Mw units. Six units have been authorized and construction has started, with three units to be installed in the initial phase. Because each unit has a discharge capacity of approximately 30,000 cfs, unusual problems of design in the forebay and tailrace of the new powerplant could be foreseen. A 1:120 scale model study showed the need for extensive revisions in the design of the forebay channel, and minor revisions in the tailrace configuration. A vortex formation noted above the penstock entrances prompted an additional study which will be reported separately. Observations and measurements were made in the forebay channel and tailrace for both 6- and 12-unit plant operation. Results of these studies are presented.

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ABSTRACT

REC-ERC-73-2

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Bur Reclam Rep REC-ERC-73-2, Div Gen Res, Feb 1973. Bureau of Reclamation, Denver, 25 p, 32 fig, 2 tab

DESCRIPTORS--/ *forebays/ gravity dams/ hydraulic structures/ angle of approach/ backwater/ channels/ eddies/ head losses/ *model tests/ open channel flow/ permissible velocity/ *tailrace/ vortices/ current meters/ instrumentation/ erosion/ hydroelectric power-plants/ hydraulic design/ velocity distribution

IDENTIFIERS--/ *Grand Coulee Powerplant, WA

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