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HYDRAULIC MODEL STUDIES OF CANYON FERRY DAM SPILLWAY STILLING BASIN

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16. ABSTRACT

Hydraulic model studies were made to determine the cause and recommend a[illegible]ion for the deposit and movement of riverbed material into the Canyon Ferry Dam spillway stilling basin. Tests indicated that movement of riverbed material into the basin resulted from operation of the river outlet works at discharges greater than 3,000 ft^3/s (85 m^3/s). Several solutions to the problem are suggested, including a limitation on operation of the river outlets to 3,000 ft^3/s. Model tests estimated the spillway discharge and length of time required to clean the existing 900 yd^3 (688 m^3) of riverbed material from the basin. Soundings taken at Canyon Ferry Dam immediately after the suggested spillway release confirmed the model results.

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HYDRAULIC MODEL STUDIES OF CANYON FERRY DAM SPILLWAY STILLING BASIN

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UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION

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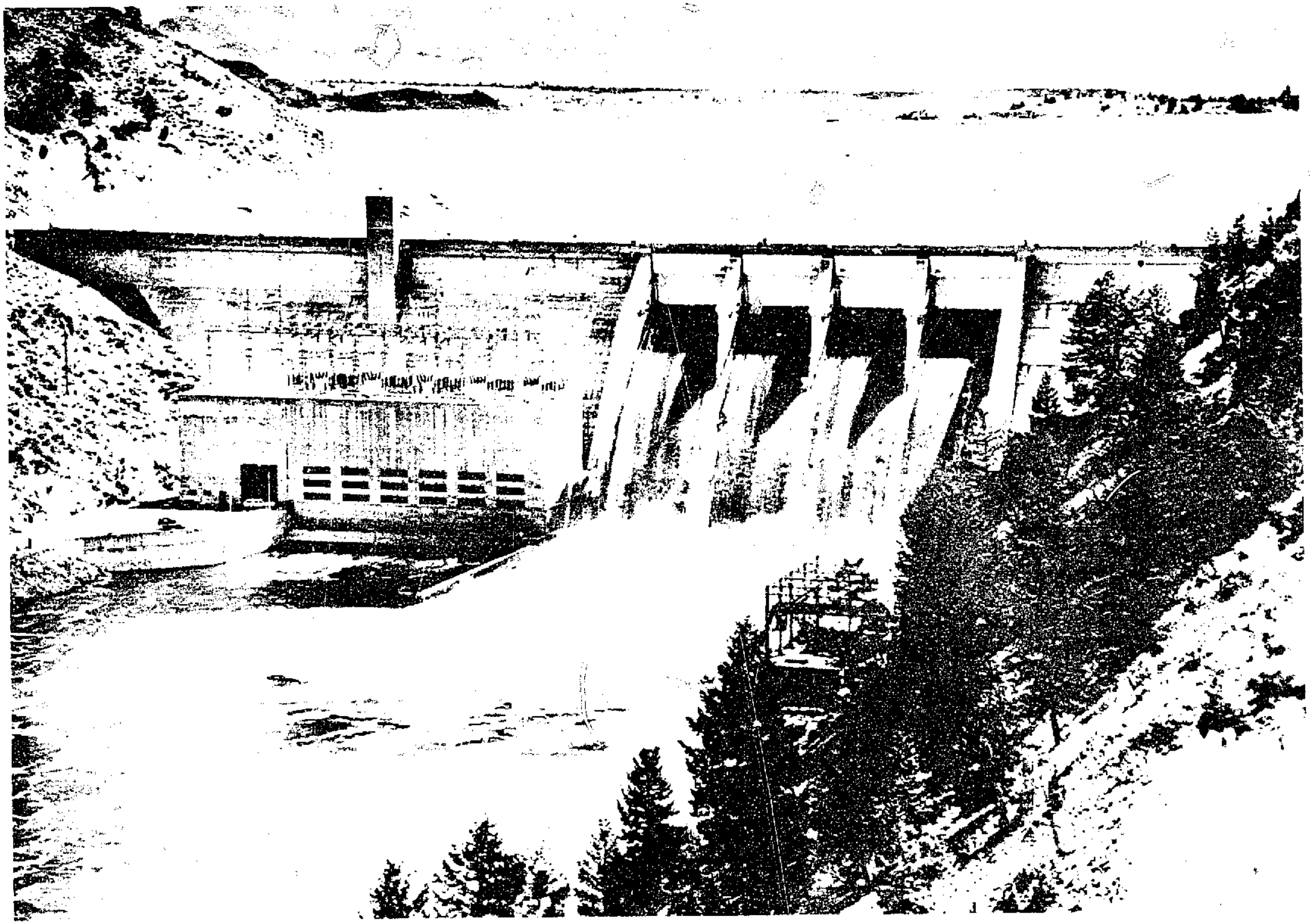

Frontispiece. Canyon Ferry Dam near Helena, Montana

CONTENTS

LIST OF FIGURES

CONTENTS—Continued

PURPOSE

These studies were conducted to determine the cause and recommend a solution for the movement of riverbed material into the Canyon Ferry Dam spillway stilling basin. Of primary importance were the determination of riverbed stability immediately downstream from the stilling basin and the effect of flow release methods on the movement of this riverbed material. Studies were also conducted to determine the time and amount of spillway release required to clean deposited material from the stilling basin.

RESULTS

1. When the river outlet releases exceed 3,000 ft^3/s (85 m^3/s), riverbed materials move into the spillway stilling basin.

2. Releases from the spillway, powerplant, or the Helena Valley Pumping Plant do not carry riverbed material into the stilling basin.

3. Model tests indicated that the deposited riverbed material could be cleared from the stilling basin with adequate spillway releases. The time and amount of spill required to clear this material from the stilling basin can be determined from figure 27.

4. The spilling technique developed in the model successfully cleared approximately 900 yd^3 (688 m^3) of riverbed material from the Canyon Ferry spillway stilling basin.

5. Clearing the river bottom of loose riverbed material down to bedrock for a distance of 100 feet (30 m) downstream from the end sill will prevent the movement of riverbed material into the basin for river outlet releases up to the design discharge of 9,500 ft^3/s (269 m^3/s).

6. Operation of two river outlets in either a symmetrical or asymmetrical pattern did not produce as good a flow distribution in the stilling basin as operating all four outlets uniformly.

7. Uniform operation of all four spillway gates gave best spilling results. Acceptable asymmetrical spillway releases through gates 2, 3, and 4 were too small, 4,000 ft^3/s (113 m^3/s) or less, to be considered as an alternate spillway release method.

8. The simultaneous operation of the two center spillway gates (No. 2 and 3) with the two outside river outlets (No. 1 and 4) may minimize the dissolved gas uptake. This simultaneous operation will also prevent the movement of riverbed material into the stilling basin. To prevent riverbed erosion downstream from the stilling basin, this simultaneous operation should be limited to a total release not to exceed 10,000 ft^3/s (283 m^3/s) over the spillway and 4,750 ft^3/s (135 m^3/s) through the river outlets. Observation of the simultaneous operation is required on the prototype to insure that the spillway nappe does not intersect with the river outlet jets, which could result in cavitation damage to the spillway surface. Analysis of the dissolved gas uptake will also have to be performed on the prototype.

RECOMMENDATIONS FOR RELEASE OF SURPLUS WATER

Releases Based on Results of Model Studies

1. *3,000 ft^3/s or less.*—Make the total release from river outlets, equally distributed through all four outlets.

2. *More than 3,000 ft^3/s.*—Make the total release from the spillway, equally distributed through all four spillway gates.

Alternate Methods of Release

To minimize gas supersaturation in the river downstream from Canyon Ferry Dam, simultaneous operation of the outside river outlets and the two center spillway gates is recommended for releases greater than 3,000 ft^3/s.

1. *3,000 ft^3/s or less.*—Make the total release from river outlets, equally distributed through all four outlets.

2. *More than 3,000 ft^3/s and less than 9,500 ft^3/s.*—Make equal releases from the two outside river outlets and the two inside spillway gates.

3. *More than 9,500 ft^3/s and less than 14,750 ft^3/s.*—2,750 ft^3/s from each of the two outside river outlets and 50 percent of the remainder through each of the two inside spillway gates.

4. *More than 14,750 ft^3/s.*—Make the total release from spillway, equally distributed through all four spillway gates.

5. When making releases simultaneously from both the river outlets and the spillway, be sure the water released from the spillway does not intersect the jet of the water released from the river outlets. If it

appears this is about to happen, close the two river outlets and make the total release equally through each of the four spillway gates.

6. Periodic soundings immediately downstream from the basin should be made after spillway discharges have exceeded 6,000 ft^3/s (170 m^3/s) in order to monitor any erosion of the river bottom which may occur in the area, due to the simultaneous operation.

APPLICATION

A method of cleaning riverbed material from the stilling basin, as determined from the model studies, has been successfully applied at Canyon Ferry Dam. Other results related to release methods to prevent riverbed material from entering the spillway stilling basin can be applied as a guide in future operations at Canyon Ferry Dam.

INTRODUCTION

Canyon Ferry Dam is a feature of the Pick-Sloan Missouri Basin Program and is located 17 miles (27 km) northeast of Helena, Montana, on the Missouri River. The dam is a concrete gravity-type structure approximately 1,000 feet (305 m) in length with a maximum height of 225 feet (68.6 m) above the foundation. The powerplant, on the right side of the dam, is rated at 50,000 kilowatts. The dam was constructed in the period 1949 through 1954.

Construction of the cofferdam for the Helena Valley Pumping Plant, which is immediately downstream from the spillway stilling basin, was started in May 1957. By June, the cofferdam was three-fourths complete when large releases, required to pass reservoir inflows, washed away a major part of the earth cofferdam. The cofferdam was reconstructed, and severe cutting and removal of sand and gravel occurred again during the 1958 releases.

Soundings have been taken of the stilling basin and of the river channel immediately downstream from the basin periodically since 1960. The soundings indicate that a considerable amount of riverbed material was carried into the stilling basin. In 1972 over 17,000 yd^3 (13,000 m^3) of material were removed from the basin with a 3-yd^3 (2.3-m^3) clam bucket mounted on a platform barge. The material was carried to a disposal site approximately 1 mile (1.6 km) downstream from the dam. Soundings taken in July 1973 indicated that approximately 900 yd^3 (688 m^3) of riverbed material were again deposited in the basin.

In 1974 hydraulic model studies were requested by the Upper Missouri Regional Director to:

(a) Determine the cause (what release method) for movement of riverbed material into the spillway stilling basin,

(b) Determine if the existing riverbed, downstream from the basin, had stabilized, and

(c) If not, what would be required to stabilize the riverbed or otherwise prevent the riverbed material from entering the spillway stilling basin.

THE MODEL

Description

The model, constructed to a scale of 1:48, included 190 feet (58 m) of the upstream reservoir, the dam, powerplant, Helena Valley Pumping Plant, and 450 feet (137 m) of the downstream river channel, figure 1. To properly model the various releases from the reservoir, provision for controlled releases from the spillway, river outlets, powerplant, and pumping plant were included in the model. Each control was calibrated before the test program started. A tailgate assembly and sand trap were used to control the downstream tailwater elevation and collect eroded sand and gravel. Water was supplied to the model through the permanent laboratory system. Discharges were measured by one of a bank of venturi meters installed in the laboratory.

Scale Relations

To express the mathematical relationship between the hydraulic quantities of the model and the prototype, the Froude Law of model similitude was applied. This law is expressed in equation (1). Hydraulic similitude is established when this equality is satisfied.

$$\frac{V_m}{\sqrt{g_m L_m}} = \frac{V_p}{\sqrt{g_p L_p}} \text{ or } \frac{V_r}{\sqrt{g_r L_r}} = 1 \qquad (1)$$

where:

V = velocity
g = gravitational acceleration
L = linear dimension, and

subscripts p and m denote prototype and model, respectively. The scale ratio is denoted by L_r, which means the ratio of the linear dimensions in the model to corresponding dimensions of the prototype, $L_r = \frac{L_m}{L_p}$. The scale relations, based on the Froude law, can be expressed in terms of L_r as shown below.

Dimension	Scale Ratio	
Length	L_r	= 1:48
Area	$(L_r)^2$	= 1:2,304
Velocity	$(L_r)^{1/2}$	= 1:6.93
Discharge	$(L_r)^{5/2}$	= 1:15,963
Time	$(L_r)^{1/2}$	= 1:6.93

The movement of riverbed materials was of special interest in this study. To properly represent the prototype conditions in the model, determination of the size, specific gravity, and in turn the settling velocity of the model riverbed material was very important.

Using the Froude Model Law, the settling velocity ratio of the model to prototype riverbed material was $(L_r)^{1/2}$ or 1:6.93. Figure 2 relates the settling velocity of the model and prototype riverbed material. The top 30 percent of the model material is very close to the scaled settling velocity of the prototype material. The lower 70 percent of the model material is lighter than the prototype material.

Verification

The scaling technique used to model the riverbed material indicated the model sand selected for the study adequately represented the prototype sands and gravels.

To verify the Canyon Ferry model, the August 1970 sounding of the prototype stilling basin and downstream river channel (fig. 3), was modeled (fig. 4a). The significant river outlet and spillway releases were applied to the model on a compressed time scale representing the 1971 releases from the prototype, test 5. (See Appendix for test conditions.) A major portion of the 1971 releases involved the river outlet works.

The results of the test (fig. 4b) were compared with the September 1971 sounding of the prototype stilling basin and downstream river channel (fig. 5). Although the test results did not fully duplicate the 1971 sounding, the configuration of the relocated material in the model was similar to that in the prototype. In both the model and prototype, the 1970 deposition moved away from the retaining walls and upstream onto the sloping apron of the basin. Compare figure 4a with figure 4b and figure 3 with figure 5.

During the course of the study, the Regional Director requested that model tests include a study of spillway releases required to clear approximately 900 yd^3 (688 m^3) of sand, gravel, and rock fragments from the basin. The tests predicted that a spill of 28,200 ft^3/s (799 m^3/s) for approximately 3 hours would sweep the basin clear of this riverbed material. Shortly after these model tests, the suggested release was made at Canyon Ferry Dam and soundings taken immediately after the spill verified this model test.

THE INVESTIGATION

Effect of Flow Release Methods on Riverbed Stability

Release of surplus water through the Canyon Ferry Dam spillway and river outlets has resulted in the deposits of riverbed material in the spillway stilling basin. The movement of this material has eroded the concrete floor of the basin. The areas of greatest concrete erosion, up to 1.5 feet (0.46 m), have occurred on the sloping apron of the stilling basin, figure 3. The model was tested to determine the effect of flow release methods on the movement and deposition of riverbed material.

River outlet works.—The river outlet works consist of four 86-inch (218-cm) diameter, horseshoe-shaped conduits placed horizontally through the spillway section, which exit on the face of the spillway chute at an invert elevation of 3649.91 (1112.5 m). Each conduit has a 77-inch (195.6-cm) high-pressure regulating gate. The design discharge for the four river outlets is 9,500 ft^3/s (269 m^3/s). Although the outlet conduits are symmetrical with the stilling basin center wall, they are not centered in the stilling basin bays, figure 3.

A series of tests, 1, 7, 8, 9, and 14, with releases of 9,500, 4,000, 5,000, 6,000, and 3,000 ft^3/s (269, 113, 142, 170, and 85 m^3/s), respectively, was conducted for time intervals representing 43 hours each in the prototype. Figures 6, 7, and 8 illustrate the downstream erosion and deposit of riverbed material in the basin after each test.

Tests 1, 7, and 14 initially had clean stilling basins, except for the grouted gravel in the downstream left corner of the stilling basin. The initial river bottom configuration for these tests was similar to figure 8.

Initial conditions for tests 8 and 9 were the conditions resulting from tests 7 and 8, figures 6b and 7a, respectively.

Erosion of the downstream river channel and deposition of the eroded material on the sloping apron of the stilling basin increased as the river outlet discharge increased from 3,000 to 9,500 ft^3/s. The test results clearly indicate that operation of the river outlets can carry large amounts of riverbed material into the stilling basin. River outlet releases limited to 3,000 ft^3/s or less result in very little movement of riverbed material into the stilling basin, figure 8.

Test 16 was conducted to determine the effect of a 3,000-ft^3/s river outlet release on the movement of riverbed material already deposited in the downstream section of the stilling basin. An initial discharge of 7,900 ft^3/s (224 m^3/s) through the river outlets carried material into the basin. The spillway gates were then opened releasing 15,000 ft^3/s (425 m^3/s), which moved the accumulated material into the downstream section of the basin, figure 9a. The river outlets were then operated at a reduced flow of 3,000 ft^3/s, which produced the deposition shown in figure 9b. In comparing figure 9b with figure 8, it is evident that more riverbed material will be carried upstream when there is an initial deposit in the lower section of the basin as compared to an initial clean basin.

Velocity measurements in the model determined the direction of flow (in or out) and the velocity at three half-sections in the stilling basin for the 9,500 ft^3/s river outlet release, figure 10. The flow pattern is assumed symmetrical about the basin centerline. As indicated earlier by the erosion patterns, a strong undercurrent moves upstream in the basin. At the sill section, Station 4+10, the core of the upstream current lies on the sill approximately 75 feet (23 m) from the training wall. The core rises from elevation 3605 at the sill to 3623 at Station 2+74. The core velocity of the undercurrent increases from 5 ft/s (1.5 m/s) at the sill, to 7.5 ft/s (2.3 m/s) at Station 2+74.

Figure 11 illustrates the general flow pattern in the basin. The jet leaving the river outlet conduit stays in the upper 20 feet (6.1 m) of the basin depth and does not penetrate to the floor of the basin. A large longitudinal eddy is established in the vertical plane, providing the means for carrying riverbed material into the basin.

Similar velocity measurements were also made at the sill, Station 4+10, for a river outlet release of 3,000 ft^3/s (85 m^3/s), figure 12. The core of the undercurrent was located about 95 feet (29 m) from the training wall and had a velocity of 3.1 ft/s (0.9 m/s).

Test 13 determined the effect of asymmetrical releases from the river outlets. The design capacity of 2,375 ft^3/s (67 m^3/s) was released through outlets No. 3 and 4 for a total discharge of 4,750 ft^3/s (135 m^3/s), figure 13. In comparing figure 13b with figure 6a, test 1, it is apparent that the erosion is more severe near the pumping plant and at the sheet piling with the asymmetrical operation. Although a comparable amount of material appeared to be carried into the basin on the left side, it was not all carried onto the sloping apron as in test 1. Approximately one-third remained in the downstream portion of the basin.

Test 15 (fig. 14) compared the operation of outlets No. 1 and 4, releasing a total discharge of 4,750 ft^3/s, with test 1, releasing the design discharge of 9,500 ft^3/s through four outlets, and with test 8, releasing a total discharge of 5,000 ft^3/s through four outlets. As expected, because of the smaller discharge, both the downstream erosion and the amount of material carried into the basin were less in test 15 than in test 1, figure 6a. However, test 8 showed less downstream erosion than test 15; compare figures 7a and 14. The total release was approximately the same for these two tests, but test 8 used all four river outlets, while test 15 used only outlets No. 1 and 4.

These tests indicate that all four river outlets should be operated uniformly to achieve the best flow distribution possible.

Spillway—It was noted early in the testing program that small spillway releases would not sweep the basin floor clean. Test 2, with a spillway release of 9,400 ft^3/s (266 m^3/s), did not clear the riverbed material initially in the basin, figure 15.

The results of test 2 indicated the possibility that riverbed material might be carried into the basin at low spillway releases. Since there was some material initially in the basin for test 2, it was difficult to determine whether the material present at the end of the test was, in fact, carried in. Tests 24 and 25, with spillway releases of 4,100 and 6,600 ft^3/s (116 and 187 m^3/s), respectively, were conducted to clear up the question. Figure 16 illustrates no significant movement of material into the basin at low spillway releases. However, material initially present in the basin will be exposed to secondary currents and will continue to erode the concrete floor when spillway releases are not large enough to sweep the basin clean, figure 15b.

Test 3 (fig. 17) was conducted with a spillway release of 24,000 ft³/s (680 m³/s) using the results of test 2 (fig. 15) as the initial condition. As figure 17 illustrates, the basin was swept clear of riverbed material. Minor erosion occurred in the channel immediately downstream from the stilling basin end sill. The spill required to clean various amounts of material from the basin, will be covered in a later section of this report.

Because of the spray associated with spillway operation and the resulting maintenance required on the electrical equipment located on top of the powerplant, it was requested that the model spillway be operated asymmetrically using gates 2, 3, and 4, with gate 1, closest to the powerplant, closed. Tests 26, 27, and 28 were conducted operating gates 2, 3, and 4 uniformly with total spills at 14,500, 8,300, and 3,900 ft³/s (411, 235, and 110 m³/s), respectively. During these tests, the powerplant released 6,000 ft³/s (170 m³/s). The larger spills of 14,500 and 8,300 ft³/s resulted in severe erosion downstream from the end sill, figures 18a and 18b. The 3,900 ft³/s spill caused an insignificant amount of erosion downstream from the basin, figure 18c. The only acceptable asymmetrical spillway release of 3,900 ft³/s was too small to be considered as an alternate method of spillway release. It is recommended that all four spillway gates be operated uniformly.

The center wall in the stilling basin was equipped with six piezometers to determine the pressure on the wall during the asymmetrical spillway operation of tests 26, 27, and 28. Figure 19 shows the piezometer locations and also indicates the average and maximum instantaneous differential heads on the wall for each test. The maximum instantaneous differential head occurred in test 26 at piezometer No. 6, where the pressure differential was 6.0 feet (1.83 m).

Powerplant and Helena Valley Pumping Plant.—Test 6A determined the effect of the powerplant operation on the movement of riverbed material near and in the stilling basin. Before the start of the test some very fine material was observed on the stilling basin floor. The powerplant discharged 6,000 ft³/s for approximately 31 hours (prototype time scale). There was no movement of the fine material initially present on the floor of the basin over this time span. Test 6B was an extension of test 6A with the powerplant discharging 6,000 ft³/s and the Helena Valley Pumping Plant turbines releasing 463 ft³/s (13 m³/s) into the downstream channel for a time span representing 10 hours in the prototype. Again, there was no indication of any movement of the fine material on the stilling basin floor. A local scour hole and buildup occurred in front of the turbine outlet for the Helena Valley Pumping Plant. However, this local scour phenomena did not affect the movement of riverbed material in or near the stilling basin. Figure 20 illustrates the results of Tests 6A and 6B.

Combined river outlet and spillway releases.—Model tests indicated that the movement of riverbed material can be controlled by limiting the four river outlets to a total release of 3,000 ft³/s. When larger releases are required, the river outlet works should be closed and all releases made over the spillway.

With the recent interest in the effect of gas supersaturation on fish life in the Columbia River, spillways with relatively deep stilling basins have become suspect. Water released over the spillway carries large quantities of air deep into the stilling basin. The hydrostatic pressure in the basin forces gas into solution, resulting in supersaturated water. Fish swimming in these waters take in dissolved gases through their gills and in turn these gases are transported into the body tissue by the bloodstream. Gas-bubble disease results when the fish swim into waters of lower pressure, where the dissolved gas returns to its gaseous state.

The Canyon Ferry river outlets discharge across the water surface of the stilling basin in contrast to the deep plunging-type discharge of the spillway. With respect to supersaturated water, the Canyon Ferry river outlets provide a more acceptable release method than the spillway.

In anticipation of future field tests to determine the effect of release methods on gas supersaturation, a laboratory test was conducted using the left river outlet to determine the effect of such a field test on riverbed stability. The test represented a 2-hour field test where the left (No. 4) river outlet would be opened in 10-minute intervals and held constant for 20-minute intervals for releases of 590, 1,180, 1,770, and 2,380 ft³/s (17, 33, 50, and 67 m³/s). During the field test, saturometer measurements will be recorded for the various outlet openings during the 20-minute hold intervals. The laboratory test indicated that the amount of debris carried into the basin would be minimal, less than that shown in figure 8.

Simultaneous operation of the two outside river outlets (No. 1 and 4) and the two center spillway gates (No. 2 and 3) should result in less gas supersaturation than spillway-only operation and also will result in less movement of riverbed material into the basin than river-outlets-only operation. Tests 34 and 38 were conducted releasing 4,750 ft³/s (135 m³/s) through

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Powerplant and Helena Valley Pumping Plant.—Test 6A determined the effect of the powerplant operation on the movement of riverbed material near and in the stilling basin. Before the start of the test some very fine material was observed on the stilling basin floor. The powerplant discharged 6,000 ft^3/s for approximately 31 hours (prototype time scale). There was no movement of the fine material initially present on the floor of the basin over this time span. Test 6B was an extension of test 6A with the powerplant discharging 6,000 ft^3/s and the Helena Valley Pumping Plant turbines releasing 463 ft^3/s (13 m^3/s) into the downstream channel for a time span representing 10 hours in the prototype. Again, there was no indication of any movement of the fine material on the stilling basin floor. A local scour hole and buildup occurred in front of the turbine outlet for the Helena Valley Pumping Plant. However, this local scour phenomena did not affect the movement of riverbed material in or near the stilling basin. Figure 20 illustrates the results of Tests 6A and 6B.

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The Canyon Ferry river outlets discharge across the water surface of the stilling basin in contrast to the deep plunging-type discharge of the spillway. With respect to supersaturated water, the Canyon Ferry river outlets provide a more acceptable release method than the spillway.

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Two possible adverse conditions which should be monitored at the prototype structure are: (1) cavitation damage to the spillway flow surface and (2) severe erosion of the riverbed. To prevent the formation of cavitation and the potential for concrete damage to the spillway flow surface, it is essential that the spillway nappe and the river outlet jets do not intersect. Such interaction could result in subatmospheric pressures on the spillway flow surface leading to cavitation and possible concrete erosion. Figure 21b illustrates the severe erosion of the riverbed material to bedrock downstream from the spillway stilling basin at the higher spillway release. Periodic soundings immediately downstream from the basin would allow the project to monitor any erosion of the bedrock in this area.

Riverbed Stability

The term "riverbed stability," as used in this report, will refer to the noticeable movement of riverbed material with time, and particularly in reference to material moving upstream into the stilling basin.

One objective of the study was to determine if the river channel downstream from the spillway stilling basin was stable. Tests 1, 7, 8, 9, and 14 indicated that the model riverbed was not stable when the river outlets released flows larger than 3,000 ft^3/s (85 m^3/s). In comparing figures 3 and 5, it is quite evident that the prototype riverbed is also not stable. Therefore, studies were conducted to determine what would be required to make the riverbed stable.

Natural channel.—Plywood was placed in the model to represent the location of bedrock in the prototype river channel. Three tests were conducted, releasing 9,500 ft^3/s (269 m^3/s) for a time representing 42 hours in the prototype. After each test riverbed material was removed from the stilling basin, measured, and not returned to the model. The material carried into the basin was 1,300, 700, and 530 yd^3 (994, 535, and 405 m^3) for tests 20, 21, and 22, respectively. Figure 22 illustrates the movement of riverbed material after tests 20 and 21.

The tests indicated that the riverbed downstream from the stilling basin will stabilize in time with repeated operation of the river outlets and subsequent removal of the riverbed material carried into the basin. However, this is not a practicable solution because of continued abrasion damage and high costs for material removal. As an alternative, the downstream river bottom could be artificially stabilized with concrete grout or bituminous grout.

Modifications.—A series of three tests (No. 29, 30, and 31) was conducted to determine the distance downstream from the basin end sill which would need to be cleared to bedrock to eliminate the movement of riverbed material into the basin. For each test the riverbed was cleared of material to the simulated bedrock, the full width of the basin extending 10 feet (3 m) beyond the right training wall. The lengths of riverbed cleared to bedrock downstream from the basin end sill were 50, 75, and 100 feet (15, 23, and 30 m) for tests 29, 30, and 31, respectively. Downstream from the cleared area, the invert sloped upward on a 4 to 1 slope to the existing riverbed, figure 23. For each test the discharge was 9,500 ft^3/s through the river outlets and 6,000 ft^3/s from the powerplant, for a time period representing 43 hours in the prototype. These tests indicated that the river bottom should be cleared to bedrock for a distance of 100 feet downstream from the stilling basin end sill, figure 24. The left riverbank between the stilling basin and the Helena Valley Pumping Plant would also require extensive stabilization to prevent the bank from sloughing into the excavated area.

Studies were also conducted to determine the height that would be required of a wall on top of the end sill to prevent movement of riverbed material into the stilling basin. Tests 32, 33, and 36 were conducted with the river outlets discharging 9,500 ft^3/s for time intervals representing 43 hours each. Test 32 consisted of two 5-foot (1.5-m) high, 20-foot (6.1-m) long walls, centered 65 feet (19.8 m) from the training walls. The walls in tests 33 and 36 were 8 feet (2.4 m) and 12 feet (3.7 m) high, respectively, and extended the full width of the basin. Figure 25 illustrates the results of each test. The riverbed material moved around the walls in test 32. In test 33 the riverbed material accumulated against the downstream face of the wall and then overtopped it. The 12-foot-high wall in test 36 was sufficiently high to prevent river material from overtopping into the basin. The small amount of material collected in the basin during the test is believed to have come in under the wall where it contacts the right training wall.

There are some obvious disadvantages to the end sill modification. The wall would make it very difficult to sweep the basin clear by spilling action and also might have a detrimental effect on the stilling action of the basin at larger spillway discharges.

Spill Required to Clean Stilling Basin

Since spillway or river outlet releases are necessary approximately 6 out of every 7 years at Canyon Ferry Dam, the idea of sweeping future deposits of material out of the basin by spillway releases was considered. Tests 10, 11, and 12 were conducted to determine the minimum spillway release required to sweep the basin clean with approximately 400 yd^3 (306 m^3) of material deposited on the sloping apron. Figure 7b illustrates the approximate initial condition for these tests. Figure 26 illustrates locations of the deposited riverbed material after spillway operation at discharges of 11,000, 20,800, and 24,400 ft^3/s (312, 589, and 691 m^3/s), tests 10, 11, and 12, respectively. The 24,400 ft^3/s spill essentially cleaned the basin in 2 hours as compared to 6 hours for the 20,800 ft^3/s.

Tests 17, 18, and 19 were conducted to determine the spillway discharge and time required to clear the basin of 1,000 yd^3 (765 m^3) of debris. The 24,300, 28,200, and 30,200 ft^3/s (688, 799, and 855 m^3/s) spills cleaned the basin in 6, 3, and 2-1/2 hours, respectively. These tests verified the fact that the larger releases cleared the basin of debris with less time and total water than the small releases. The curves in figure 27 illustrate the relationship of the variables, spillway discharge (Q), time of spill (T), and volume of deposited material to be removed from stilling basin (Vm).

The Upper Missouri Regional Office used the results of these tests to formulate an operating procedure to remove approximately 900 yd^3 (688 m^3) of debris from the Canyon Ferry Dam spillway stilling basin. On May 8, 1974, the Canyon Ferry Dam spillway gates were opened in increments of 5,000 ft^3/s (142 m^3/s) over a 10-minute period and held at each increment for 20 minutes until a total spillway discharge of 28,200 ft^3/s was achieved. The spillway discharged for 3 hours at 28,200 ft^3/s and then the gates were closed over an 18-minute interval. During the spill, the powerplant releases continued unchanged, discharging an additional 5,900 ft^3/s (167 m^3/s) into the downstream channel. The Helena Valley Pumping Plant turbine also operated to prevent riverbed materials from being washed into the turbine draft tubes. The peak discharge into the river was about 34,500 ft^3/s (977 m^3/s) for 3 hours. Four staff gages monitored the river level below Canyon Ferry Dam. The changes in stage at the gaging stations are shown in figure 28. Soundings taken on May 9 and 10 indicated that the spill was successful in flushing the 900 yd^3 of material from the basin. It was later verified by divers that the spill had swept the basin clean of all material except that material lodged under exposed reinforcement.

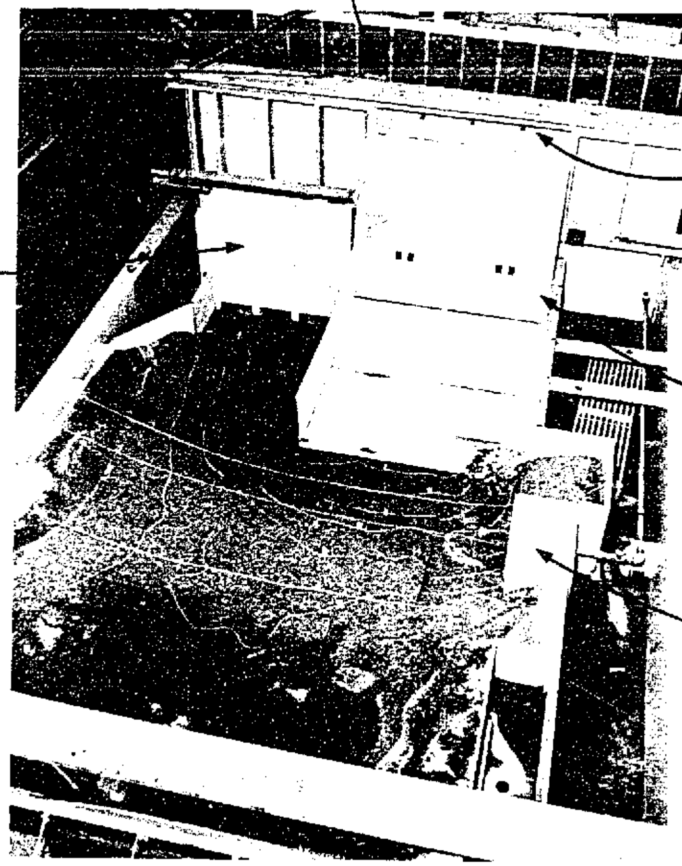


Figure 1. 1:48 Scale model layout of Canyon Ferry Dam. Photo P296-D-75729

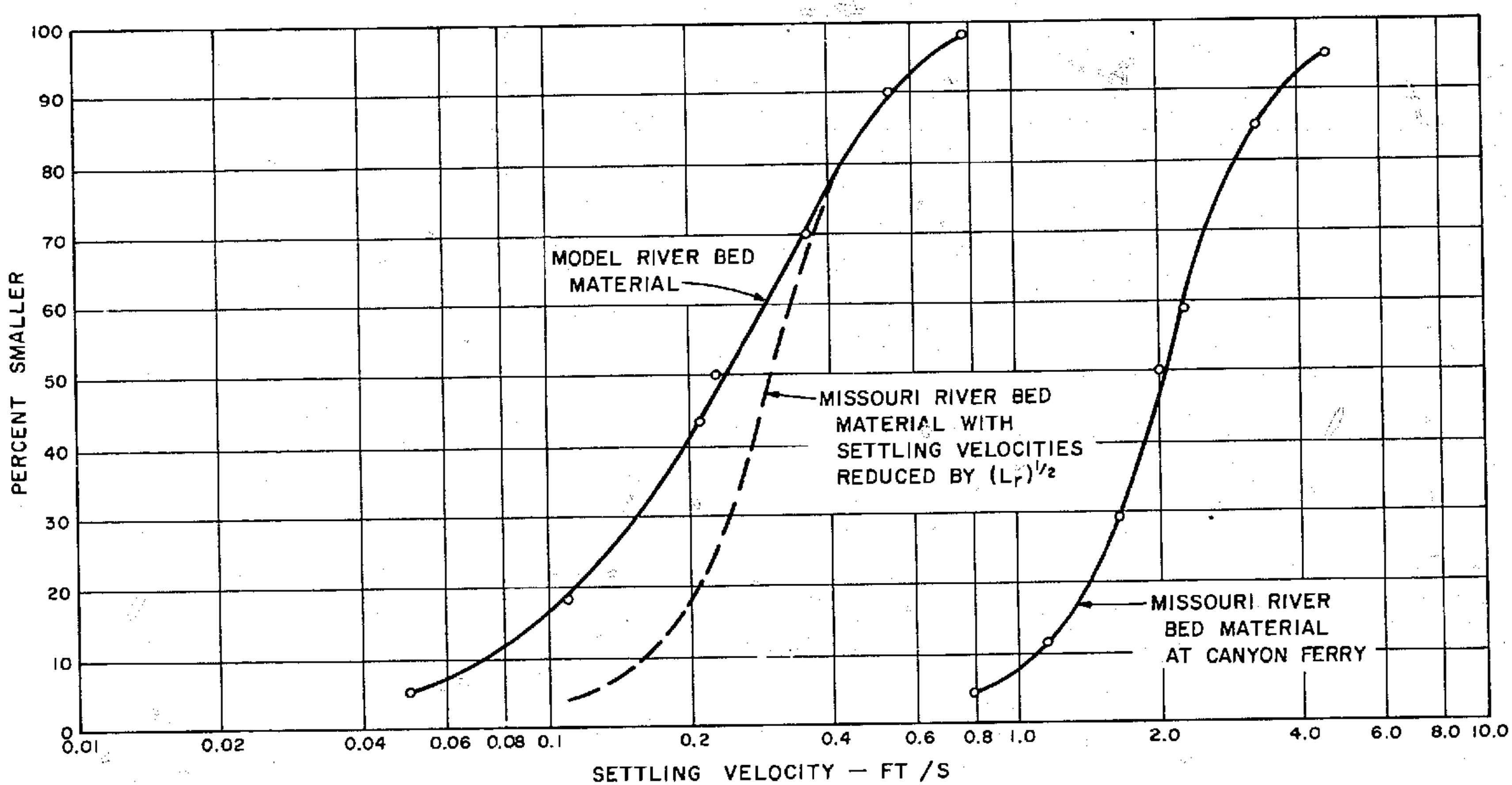


Figure 2. Comparison of settling velocities, Canyon Ferry model study.

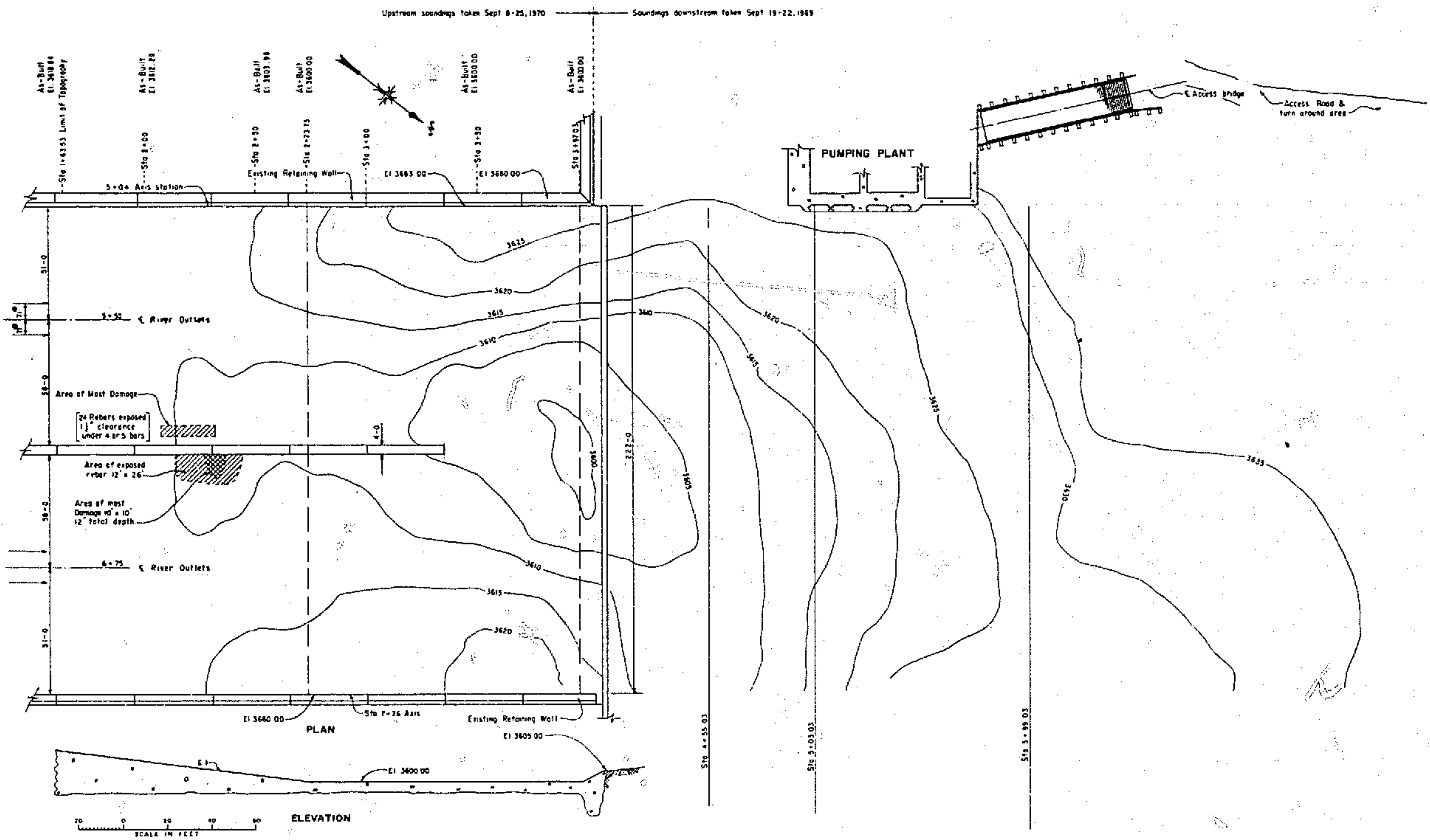
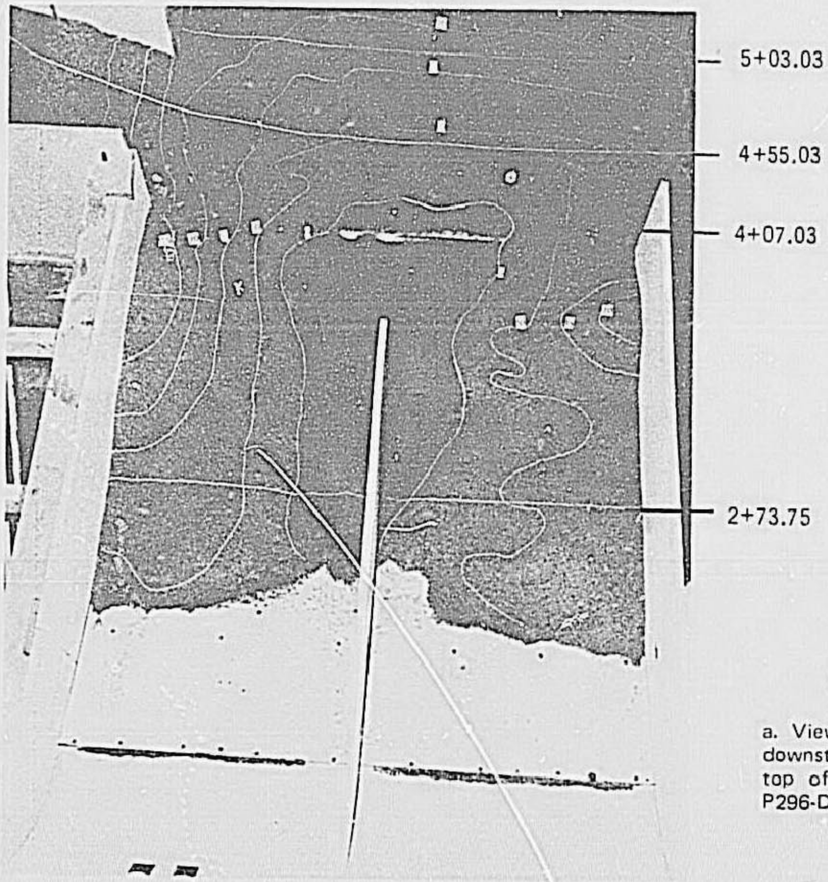
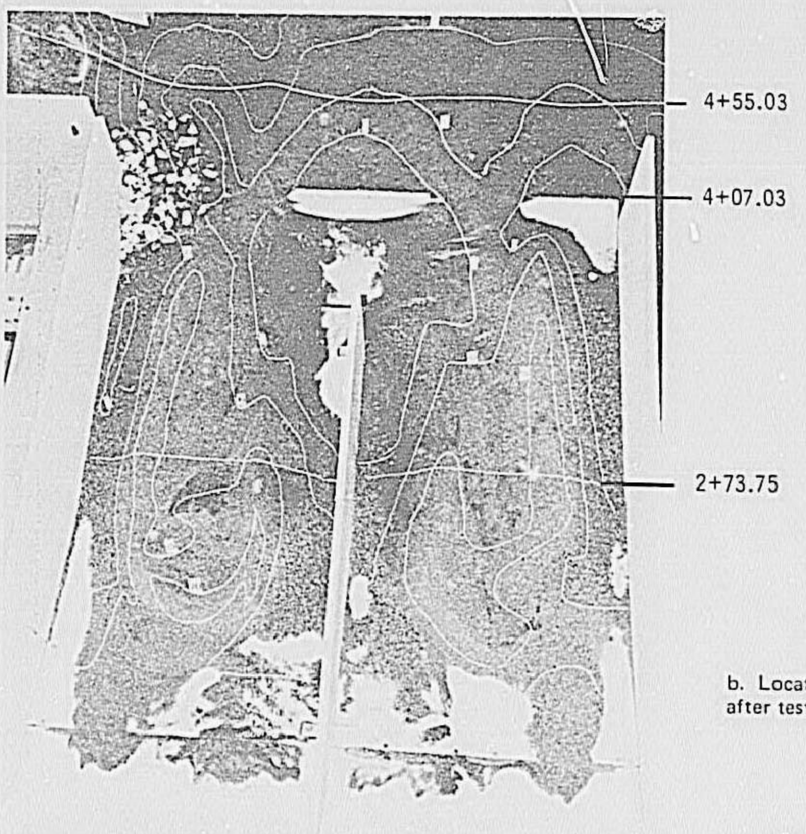


Figure 3. Canyon Ferry Dam stilling basin sounding, August 1970.



a. View of the stilling basin and downstream river channel from the top of the dam before test. Photo P296-D-75713



b. Location of riverbed material after test. Photo P296-D-75714

Figure 4. Model verification, test 5.

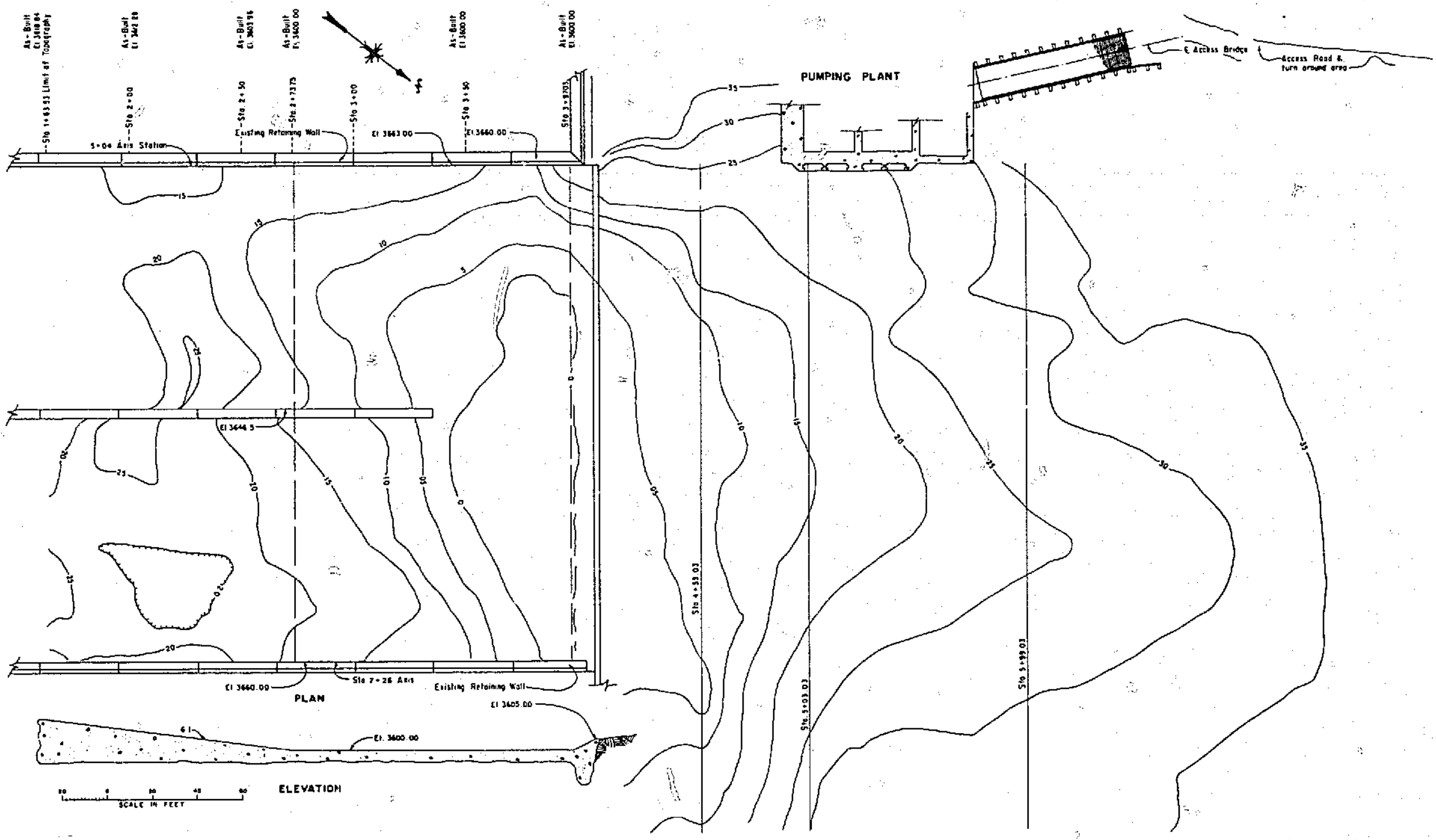
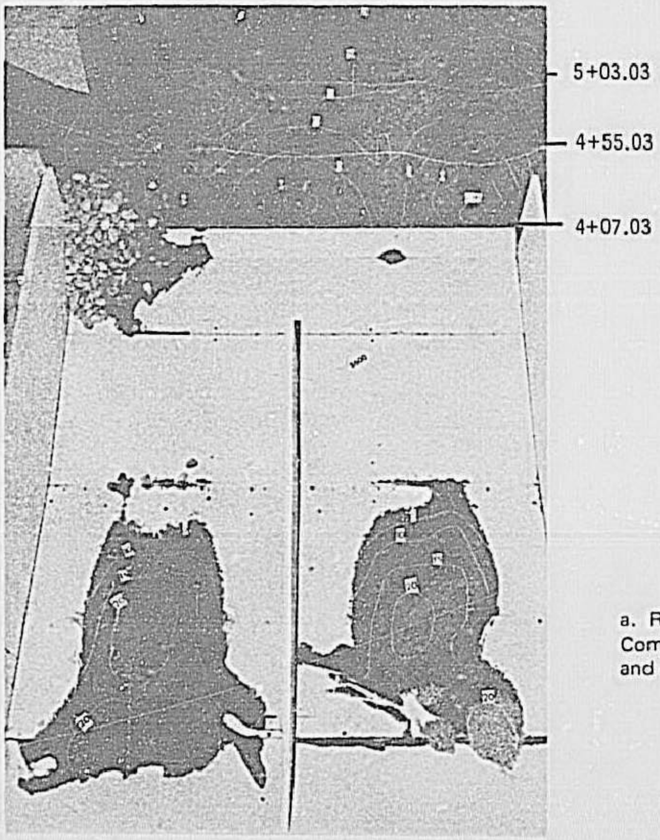


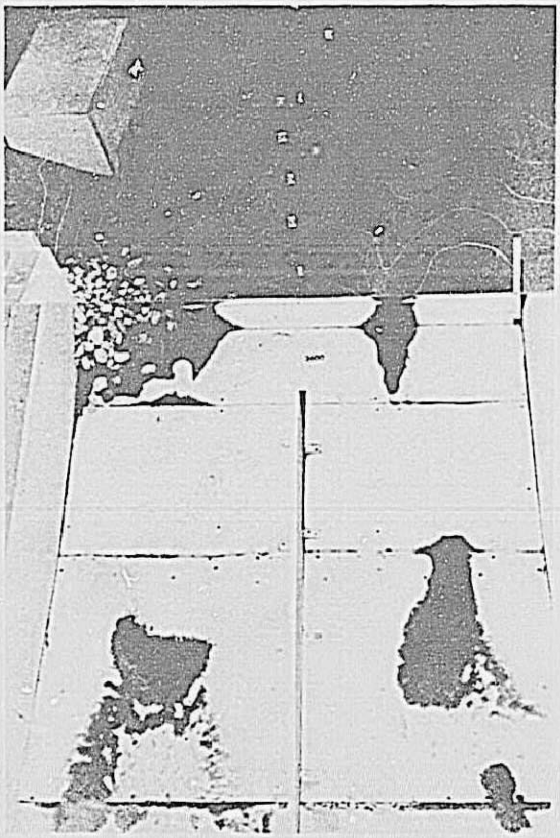
Figure 5. Canyon Ferry Dam stilling basin sounding, September 1971.



a. Results of test 1, $Q = 9{,}500\ ft^3/s$. Composite of photos P296-D-75707 and -75708

b. Results of test 7, $Q = 4{,}000\ ft^3/s$. Composite of photos P296-D-75716 and -75717

Figure 6. Results of river outlet releases, tests 1 and 7.



—4+07.03

a. Results of test 8, $Q = 5{,}000\ ft^3/s$. Composite of photos P296-D-75718 and -75719

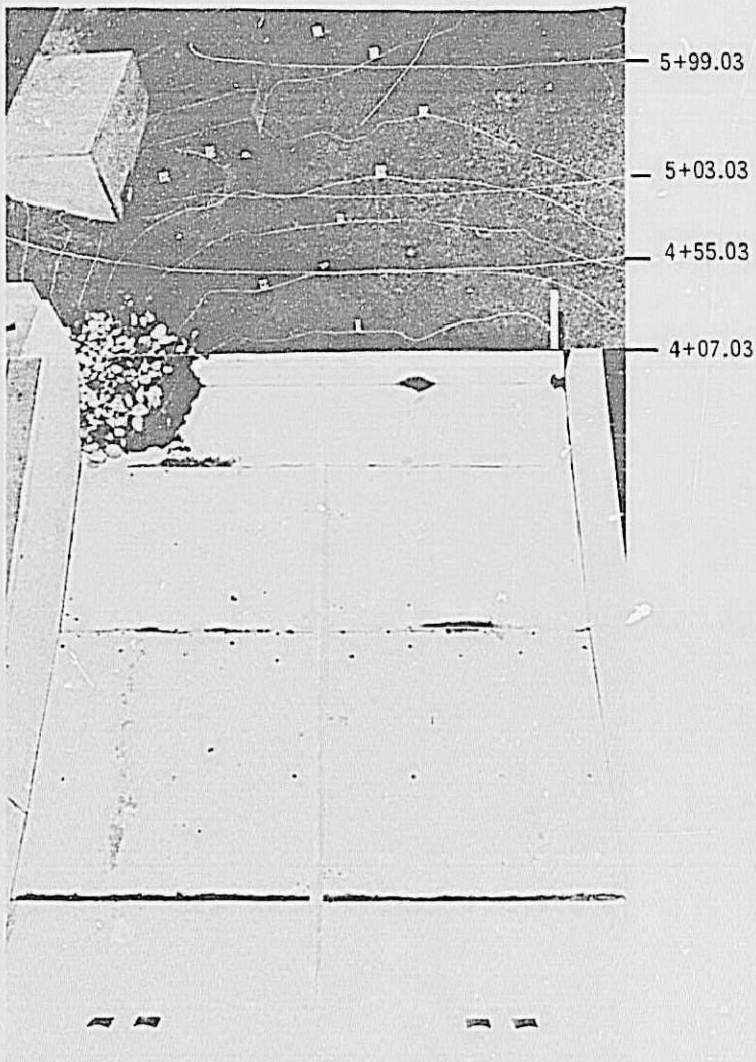
5+03.03

4+55.03

4+07.03

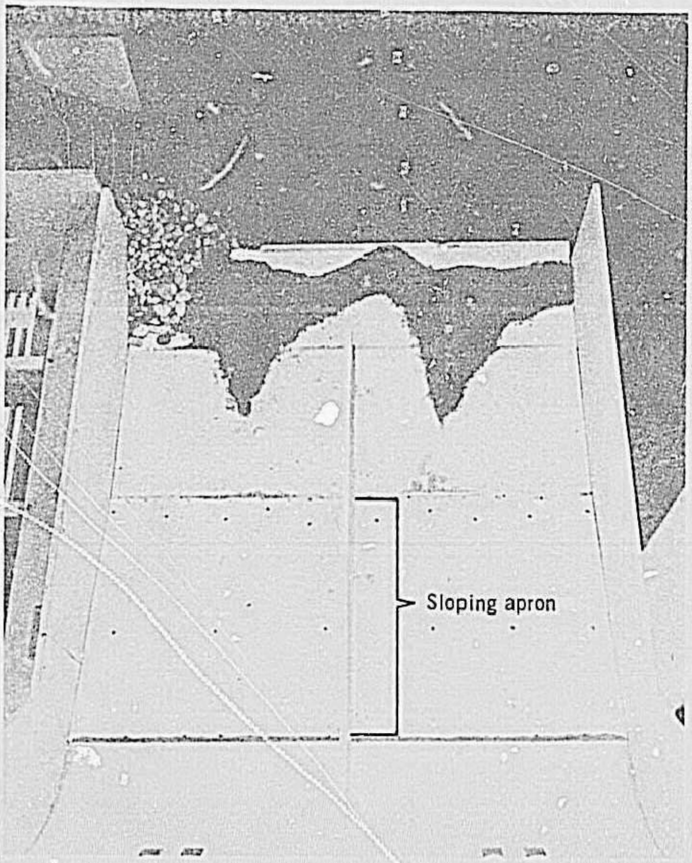
b. Results of test 9, $Q = 6{,}000\ ft^3/s$. Composite of photos P296-D-75720 and -75721

Figure 7. Results of river outlet releases, tests 8 and 9.

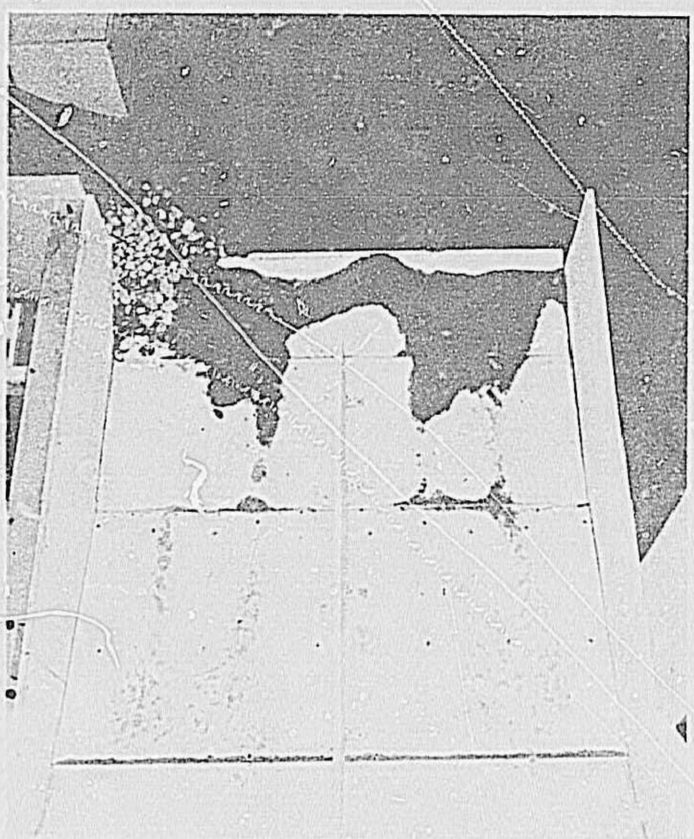


Q = 3,000 ft^3/s

Figure 8. Result of river outlet release, test 14. Composite of photos P296-D-75727 and -75728



a. Riverbed material deposited in lower half of the basin after 15,000 ft^3/s spillway discharge. Photo P296-D-75732



b. View of basin after operation of river outlets at 3,000 ft^3/s. Note riverbed material deposited on sloping apron. Photo P296-D-75733

Figure 9. Result of river outlet release with debris initially in the basin, test 16.

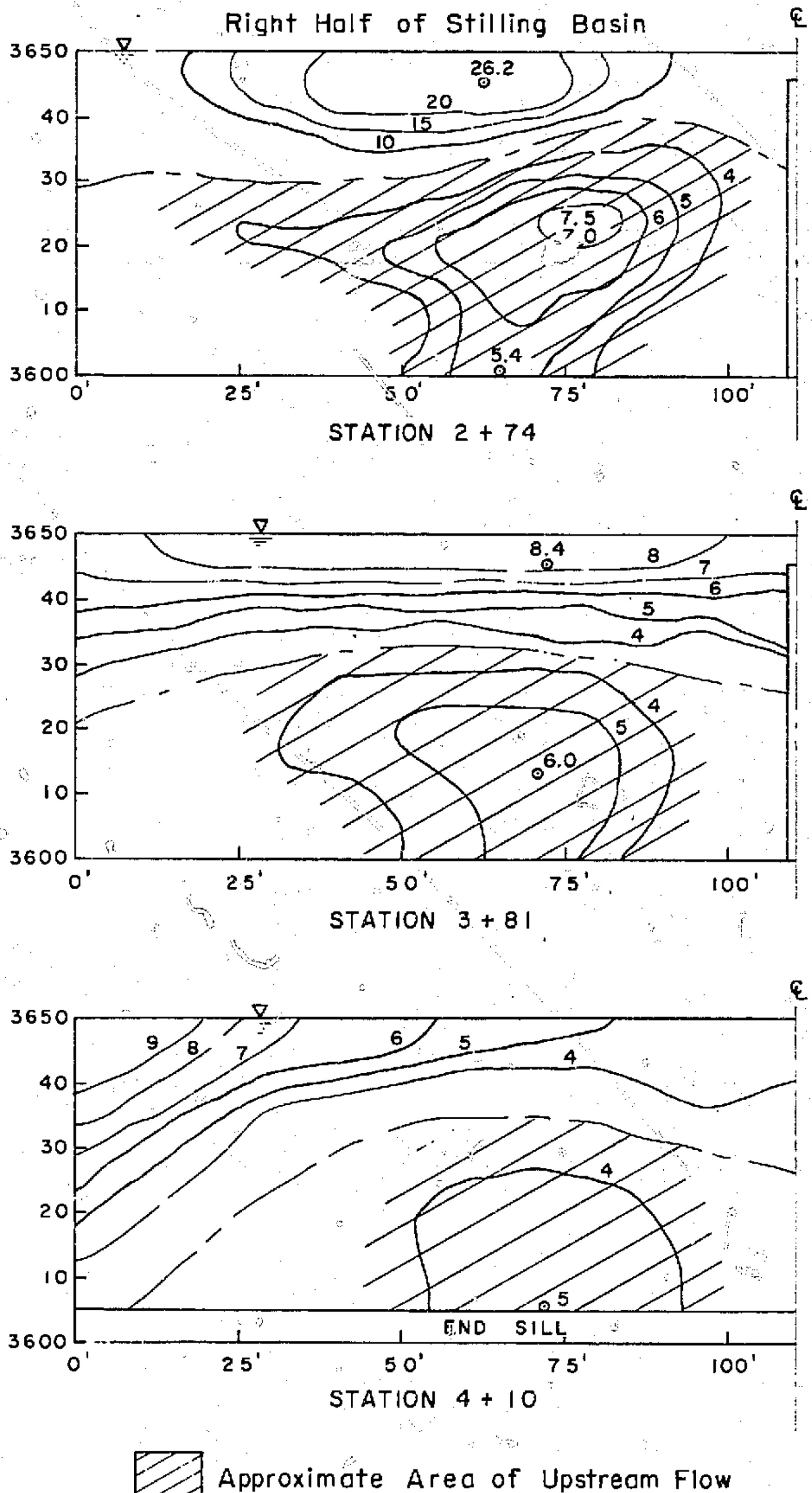


Figure 10. Isovels—river outlets $Q = 9{,}500\ ft^3/s$.

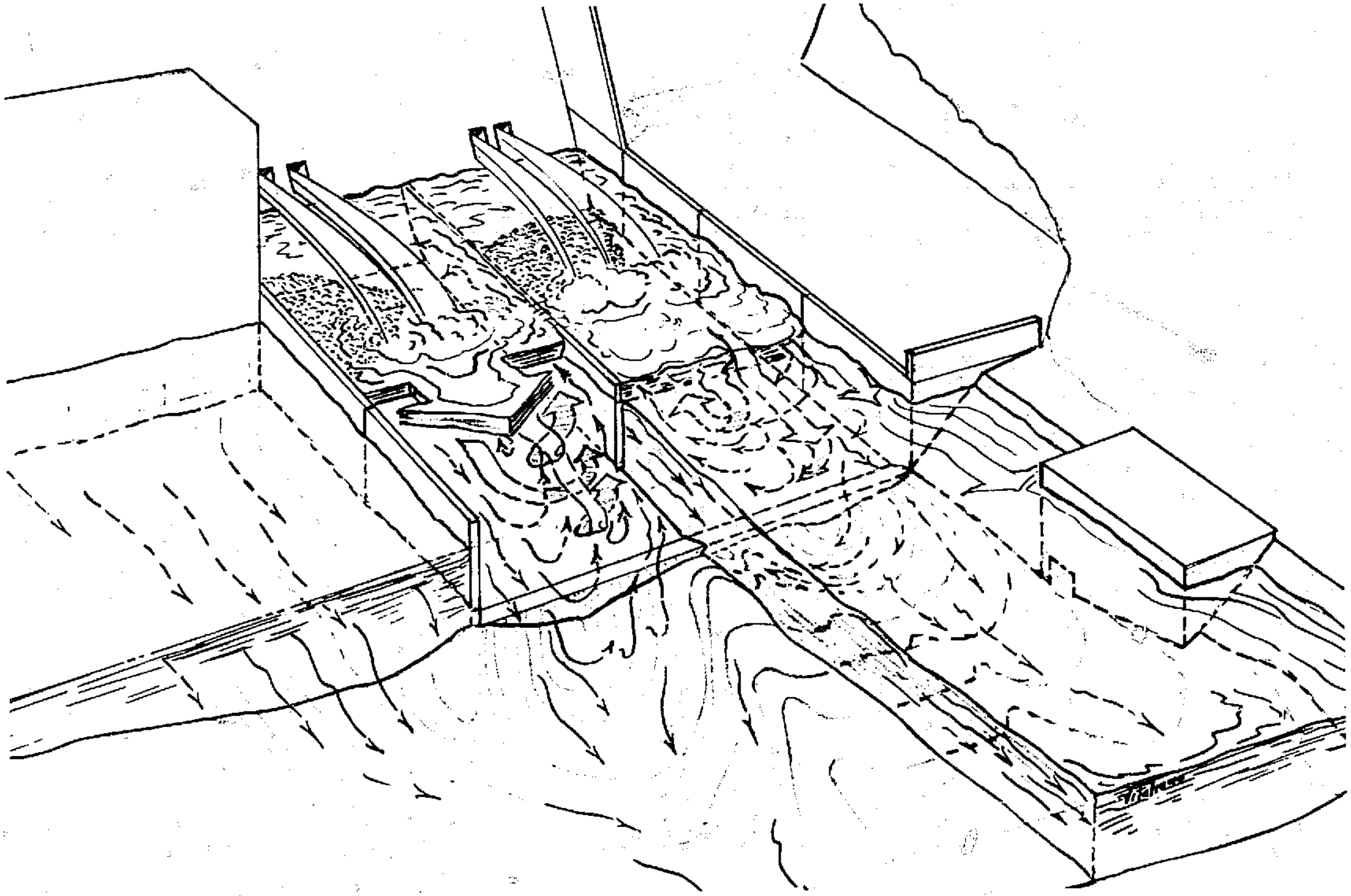


Figure 11. Flow patterns resulting from river outlet releases. Photo P296-D-75745

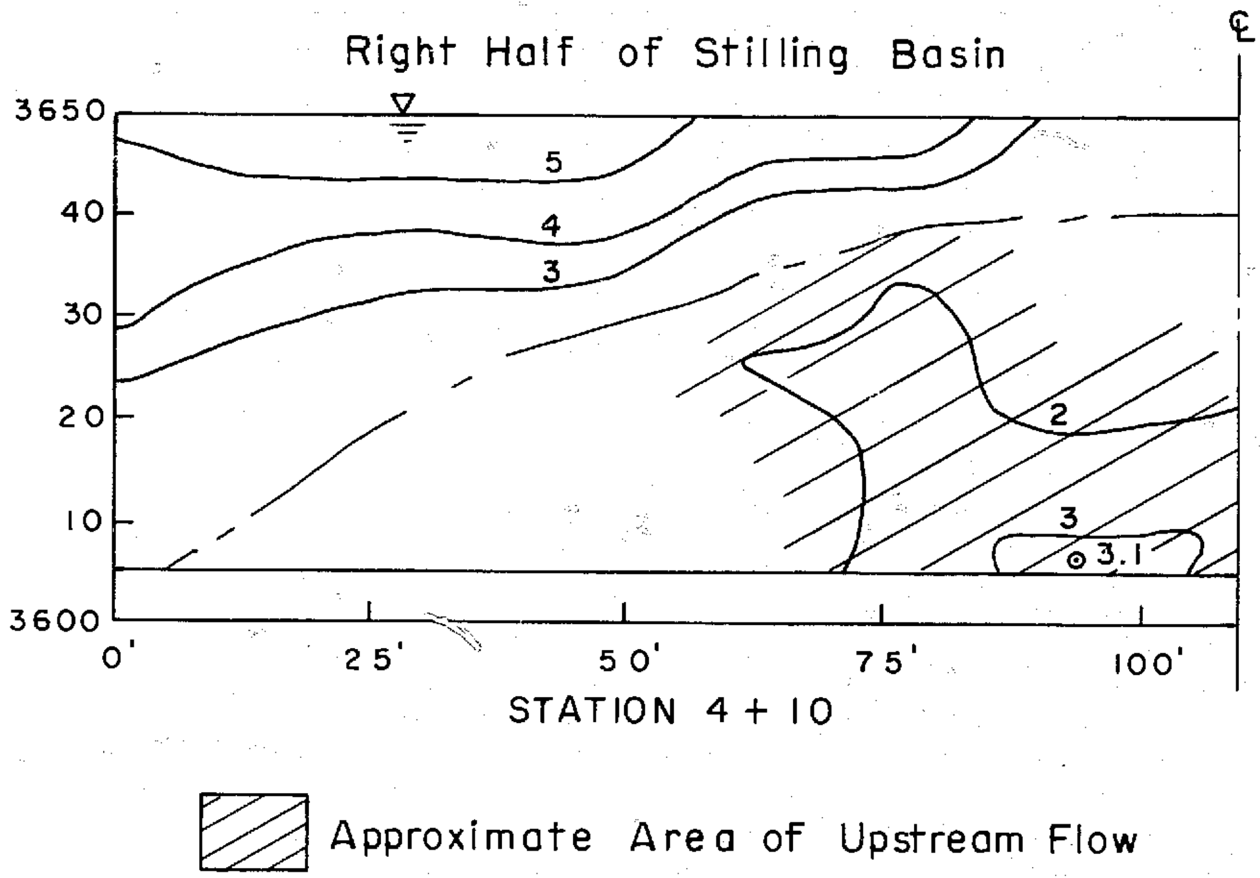
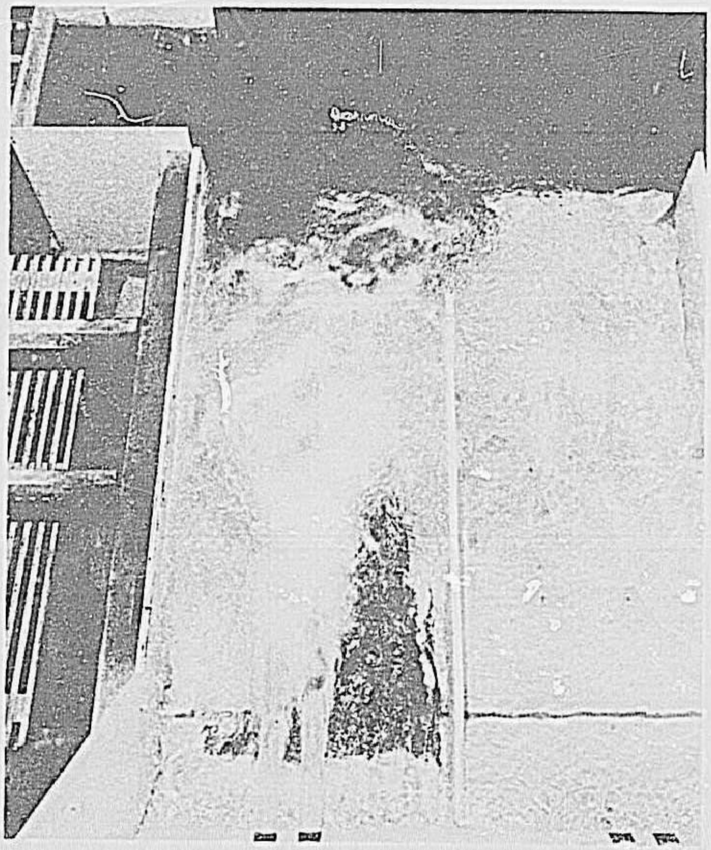
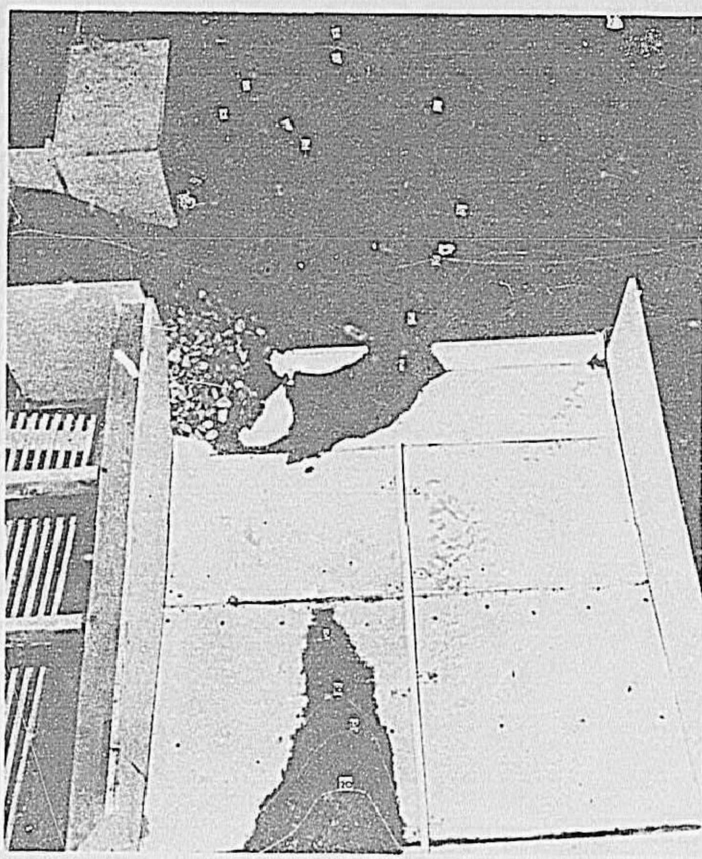


Figure 12. Isovels—river outlets Q = 3,000 ft^3/s.

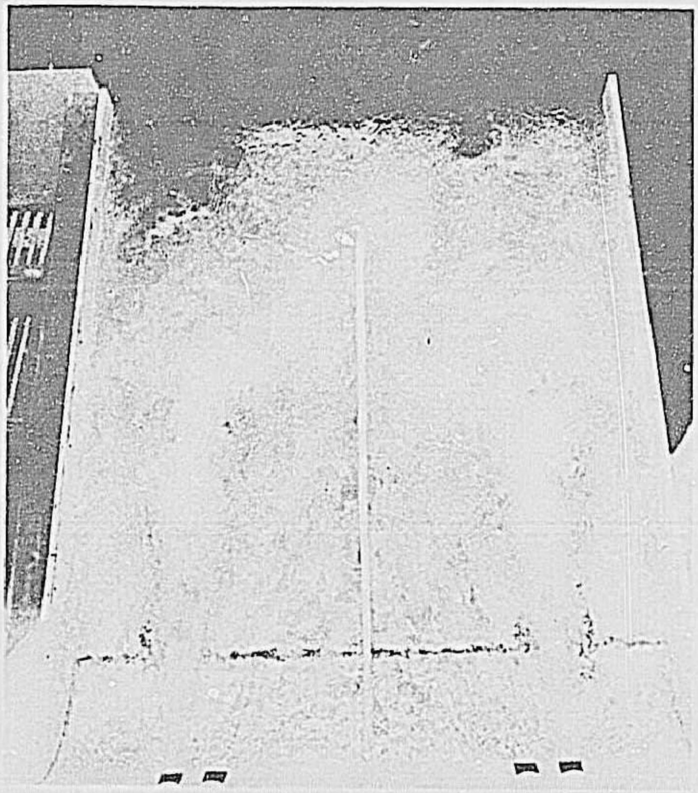


a. Outlets No. 3 and 4, total Q = 4,750 ft^3/s. Photo P296-D-75725



b. Results of test 13. Photo P296-D-75726

Figure 13. Asymmetrical operation of two river outlets, test 13.



a. Outlets No. 1 and 4, total Q = 4,750 ft^3/s. Photo P296-D-75730

b. Results of test 15. Photo P296-D-75731

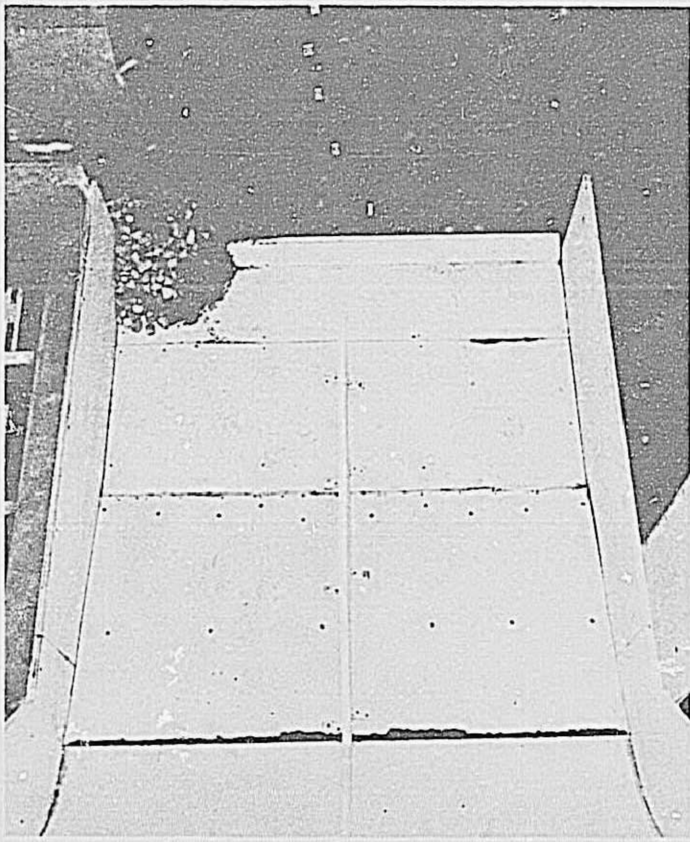
Figure 14. Symmetrical operation of two river outlets, test 15.

a. View of basin and downstream river channel before test 2. Photo P296-D-75709

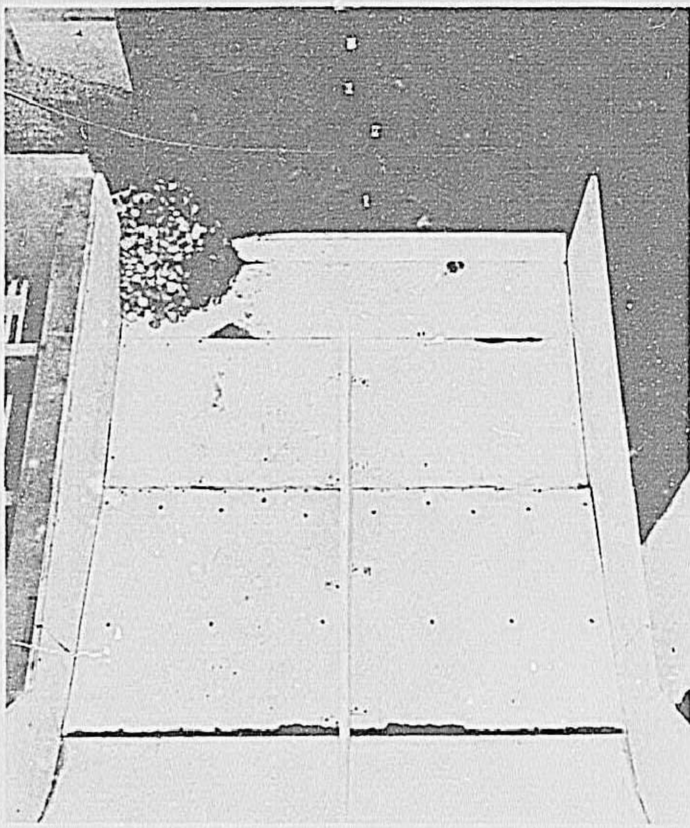
b. View of basin and downstream river channel after test 2. Photo P296-D-75710

$Q = 9{,}400 \ ft^3/s$

Figure 15. Result of spillway release, test 2.

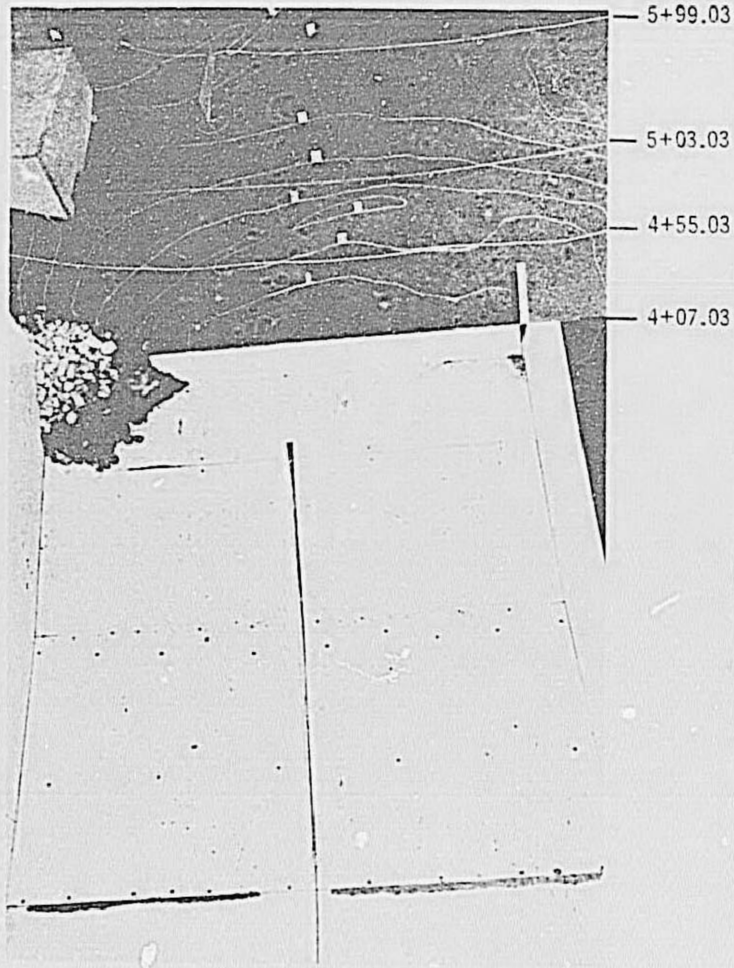


a. Results of test 24, Q = 4,100 ft^3/s. Photo P296-D-75738



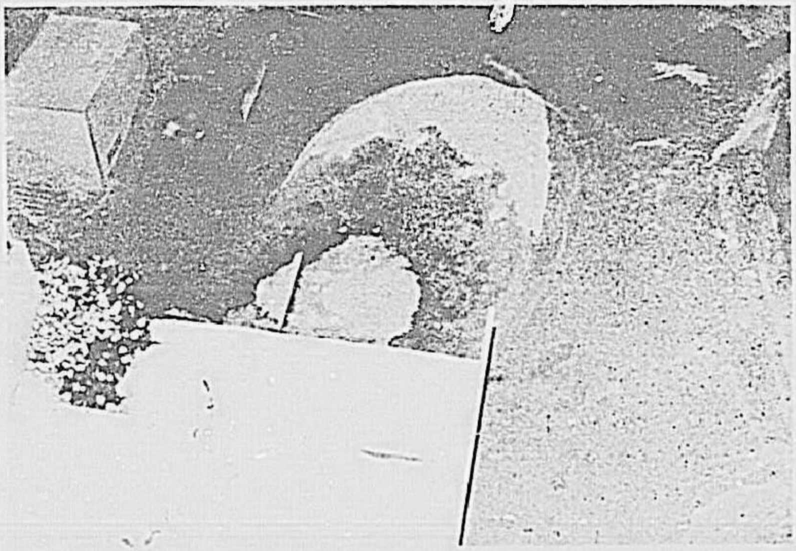
b. Results of test 25, Q = 6,600 ft^3/s. Photo P296-D-75739

Figure 16. Result of small spillway releases, tests 24 and 25.



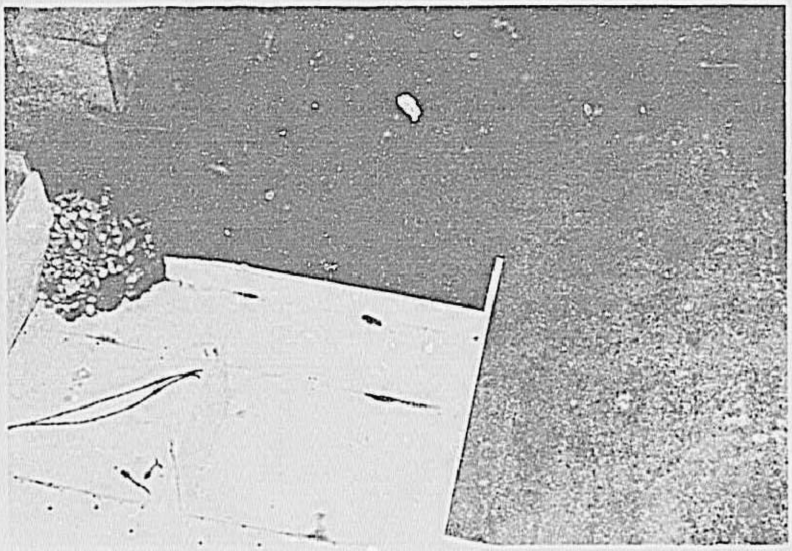
View of basin after test 3, basin swept clean with minor erosion downstream of end sill. Q = 24,000 ft^3/s. Composite of photos P296-D-75711 and -75712

Figure 17. Result of large spillway release, test 3.



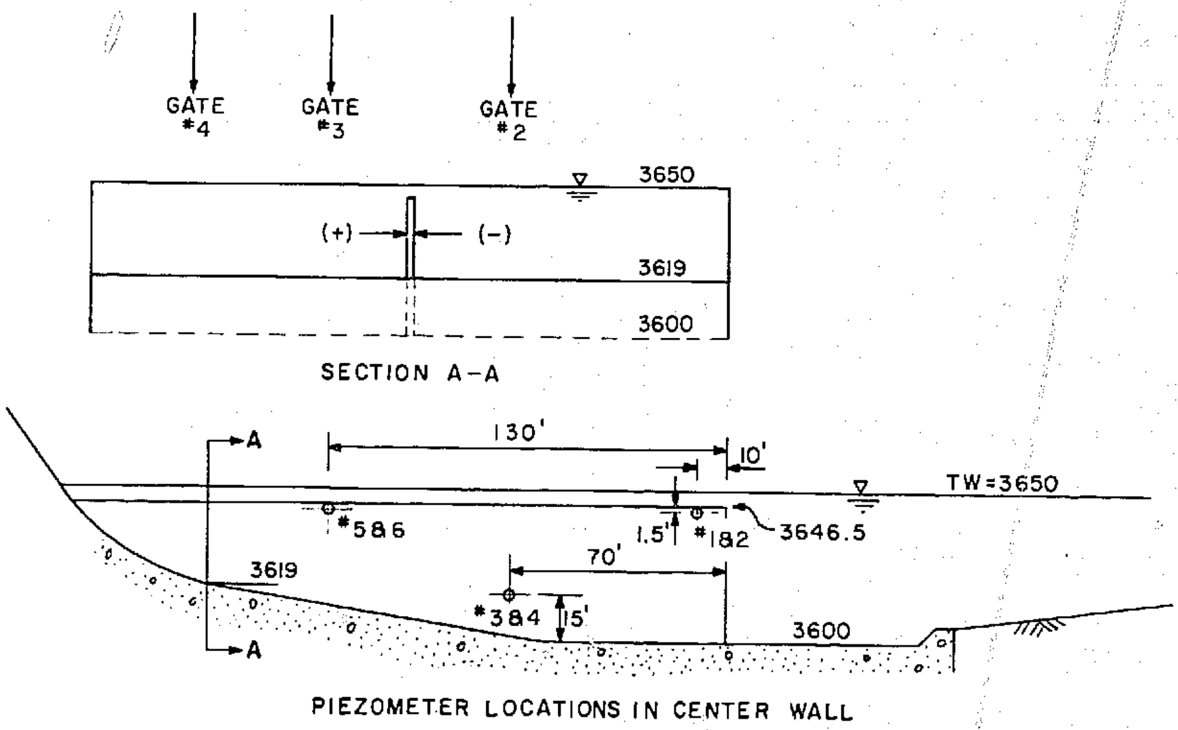
a. Results of test 26, gates 2, 3, and 4, total Q ≈ 14,500 ft^3/s. Photo P296-D-75740

b. Results of test 27, gates 2, 3, and 4, total Q = 8,300 ft^3/s. Note some riverbed material moved into right bay of basin. Photo P296-D-75741



c. Results of test 28, gates 2, 3, and 4, total Q = 3,900 ft^3/s. Photo P296-D-75742

Figure 18. Results of asymmetrical spillway operations, tests 26, 27, and 28.



DIFFERENTIAL PRESSURE READINGS (feet of water)

TEST #	PIEZ. #1 & 2			PIEZ. #3 & 4			PIEZ. #5 & 6		
	MAX. HEAD +	AVG.	MAX. HEAD −	MAX. HEAD +	AVG.	MAX. HEAD −	MAX. HEAD +	AVG.	MAX. HEAD −
26 Q=14,500ft³/s (4,833ft³/s) GATE	2.5 ft.	0	1.6ft.	4.5ft.	0	4.5ft.	1.2ft.	-1.5ft.	6.0ft
27 Q=8,300ft³/s (2,767ft³/s) GATE	2.0ft.	+0.5ft.	0.8ft.	2.8ft.	+0.4ft	2.4ft.	0.8ft.	-0.5ft.	2.0ft.
28 Q=3,900ft³/s (1,300ft³/s) GATE	0.3ft.	-0.05ft	0.5ft.	0.4ft.	-0.05ft	0.7ft.	0.3ft.	-0.2ft	0.6ft.

Figure 19. Basin center wall pressures with asymmetrical spillway operation.

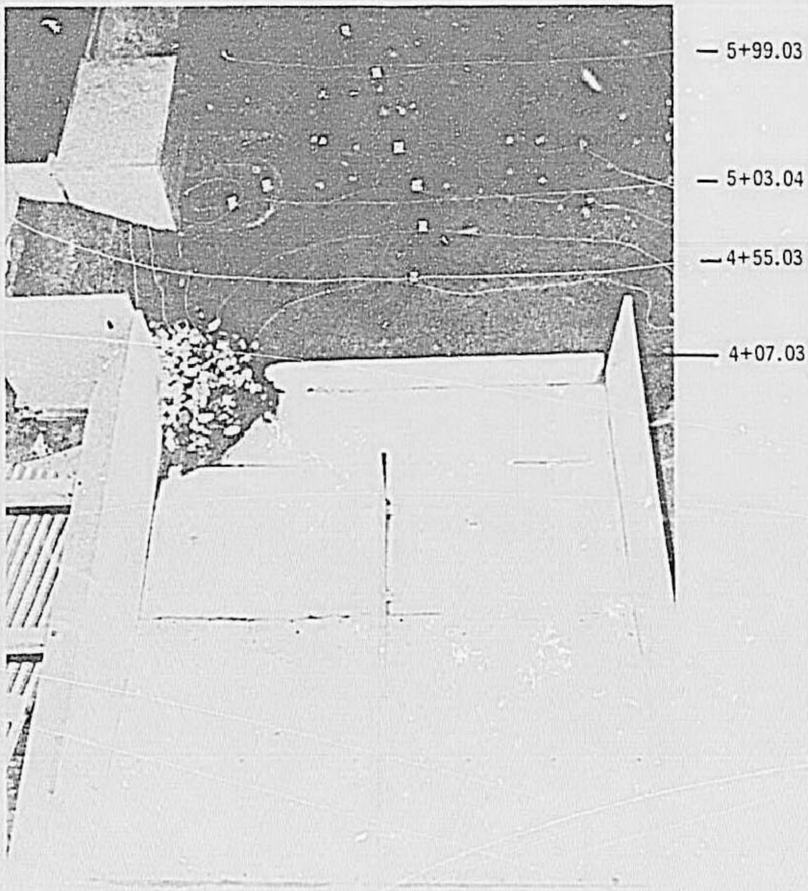
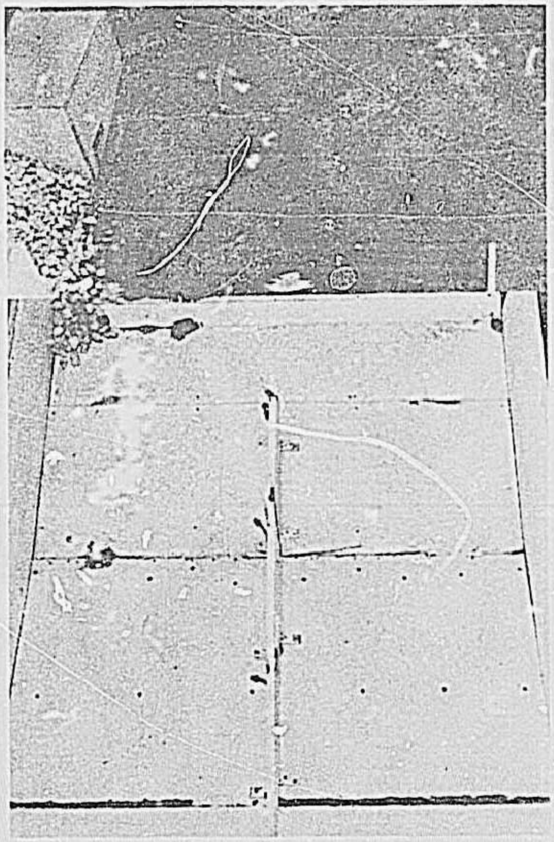
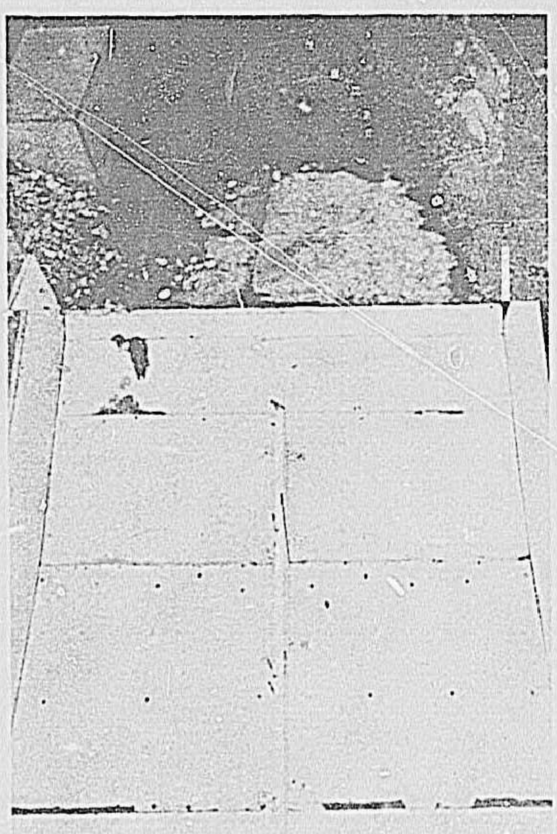


Figure 20. Results of powerplant and Helena Valley Pumping Plant operations, tests 6A and 6B. Photo P296-D-75715

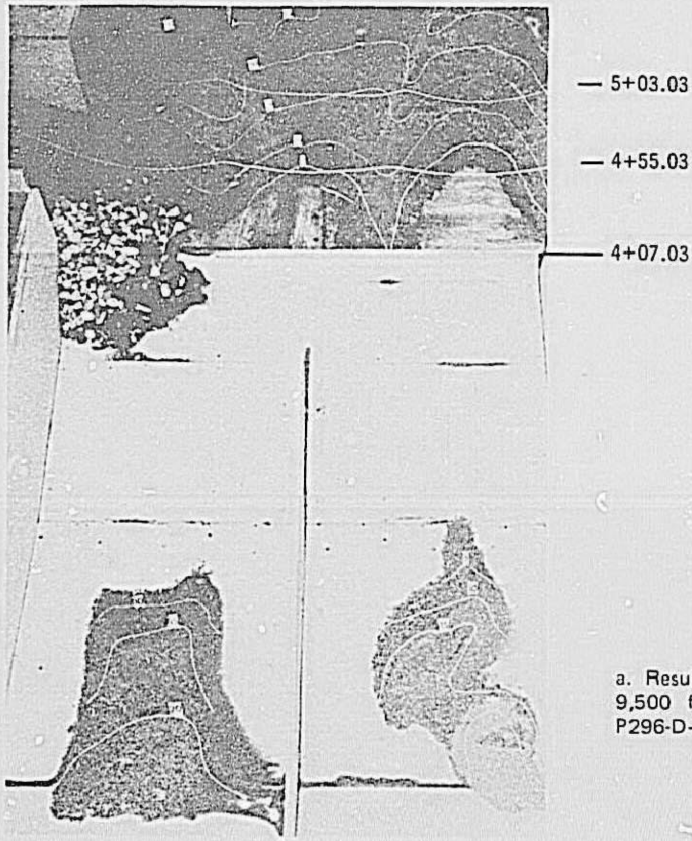


a. View of stilling basin after test 34. Spillway Q = 4,750 ft^3/s, river outlet Q = 4,750 ft^3/s. Composite of photos P296-D-75752 and -75753

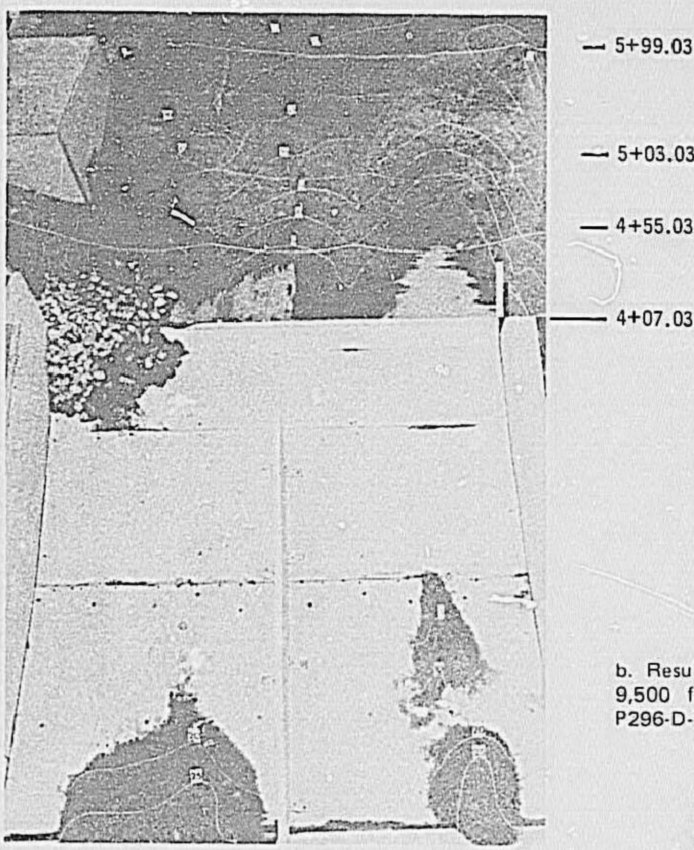


b. View of stilling basin after test 38. Spillway Q = 10,000 ft^3/s, river outlet Q = 4,750 ft^3/s. Composite of photos P296-D-75755 and -75756

Figure 21. Results of simultaneous spillway and river outlet operations, tests 34 and 38.



a. Results of test 20, river outlet Q = 9,500 ft^3/s. Composite of photos P296-D-75734 and -75735



b. Results of test 21, river outlet Q = 9,500 ft^3/s. Composite of photos P296-D-75736 and -75737

Figure 22. Stability of downstream river channel, tests 20 and 21.

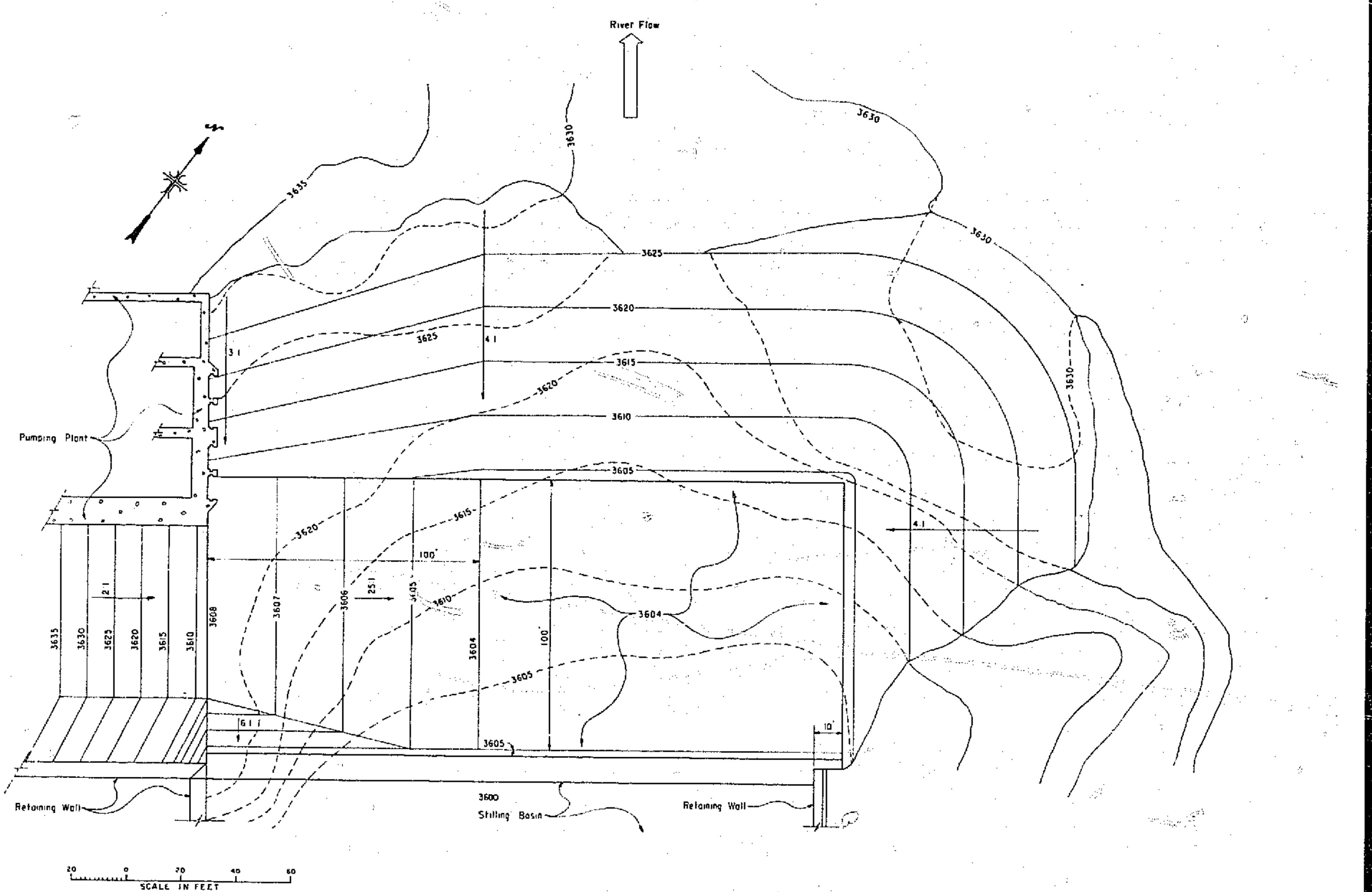
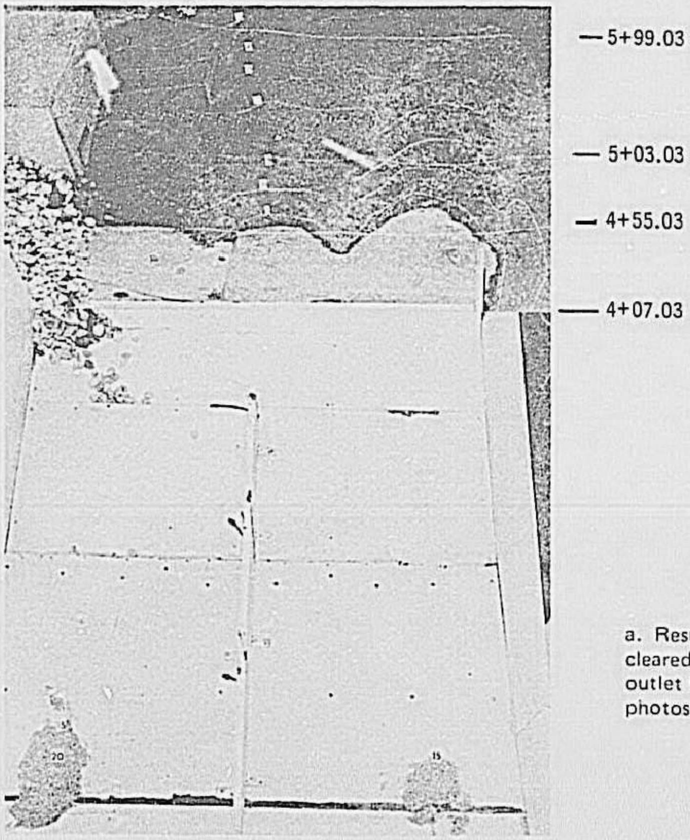
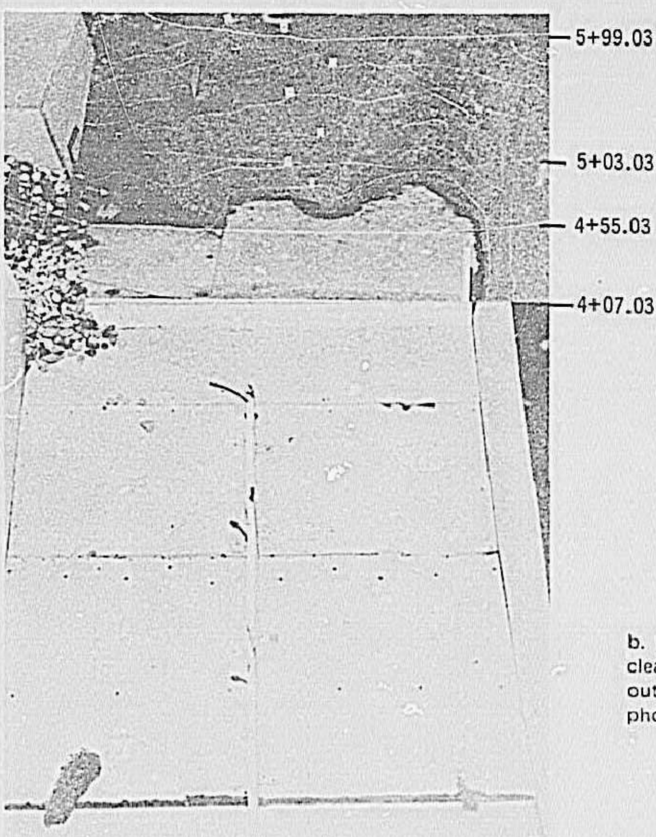


Figure 23. Modified downstream river channel.

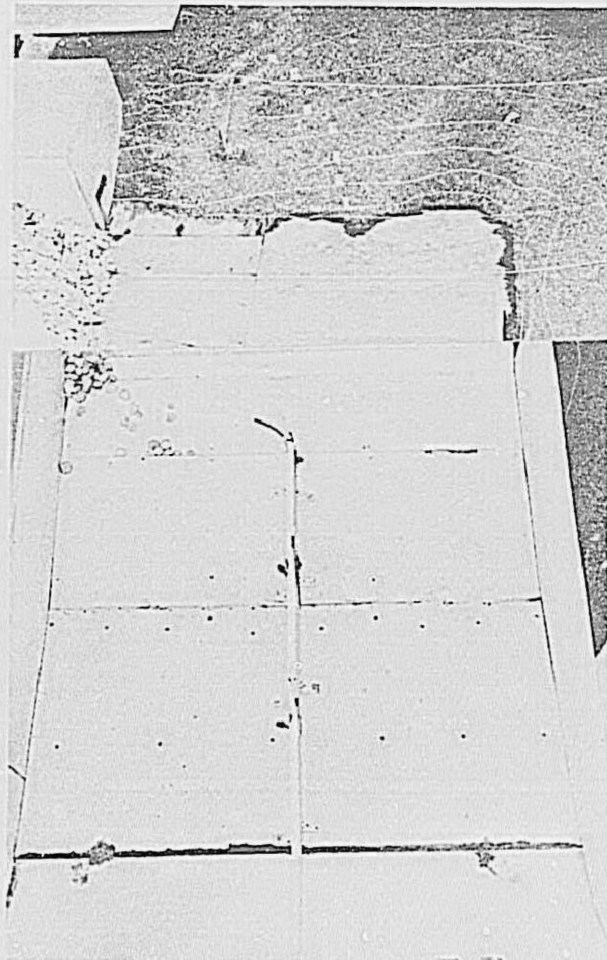


a. Results of test 29. Riverbed cleared to bedrock for 50 feet, river outlet Q = 9,500 ft^3/s. Composite of photos P296-D-75743 and -75744



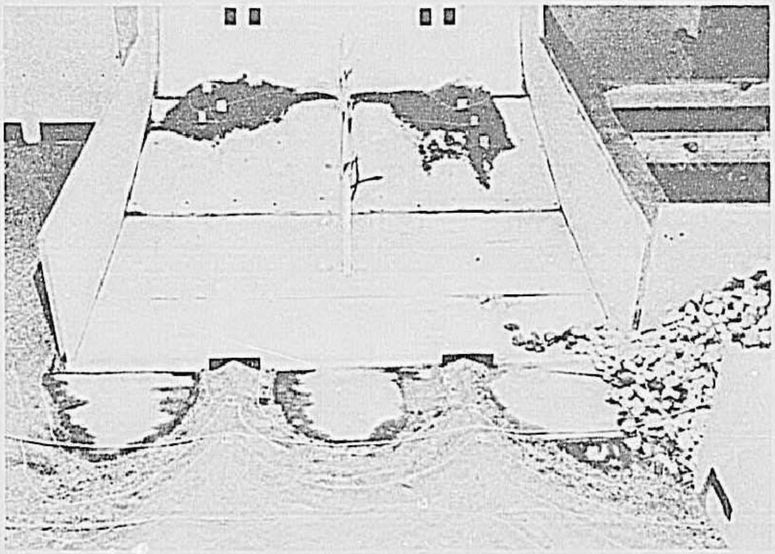
b. Results of test 30. Riverbed cleared to bedrock for 75 feet, river outlets Q = 9,500 ft^3/s. Composite of photos P296-D-75746 and -75747

Figure 24. Downstream river channel cleared to bedrock, tests 29, 30, and 31.

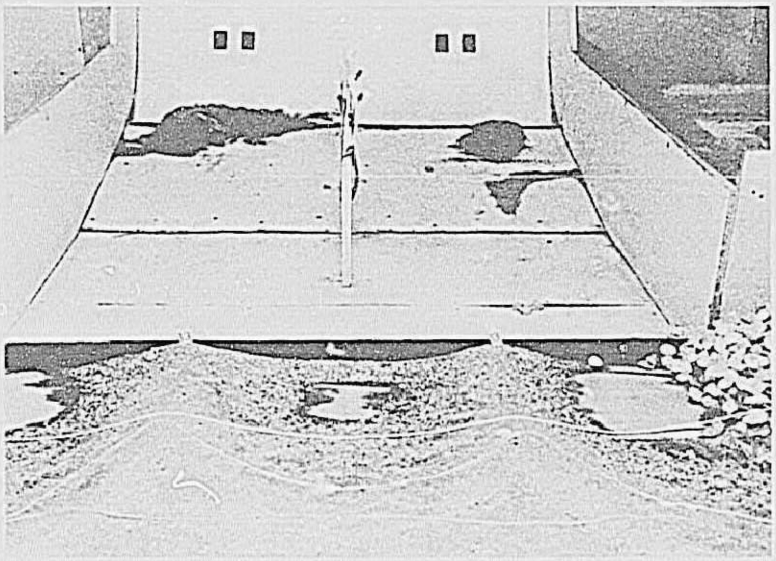


c. Results of test 31. Riverbed cleared to bedrock for 100 ft, river outlet Q = 9,500 ft^3/s. Composite of photos P296-D-75748 and -75749

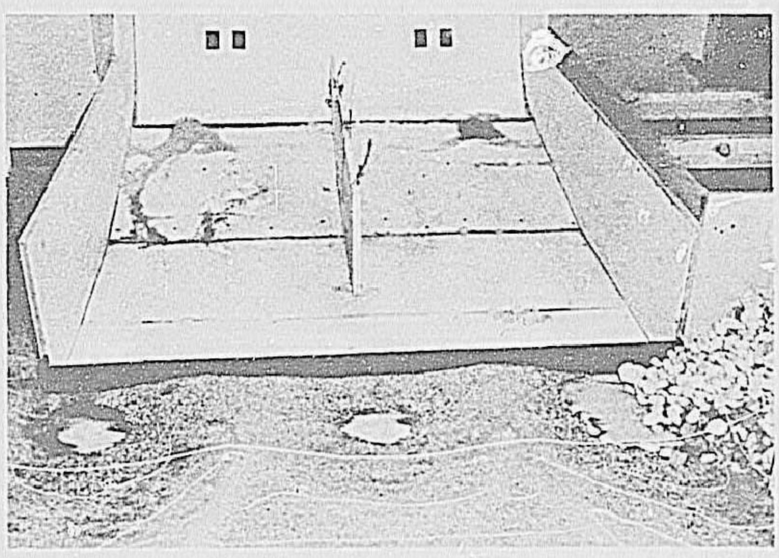
Figure 24. (continued).



a. Results of test 32. Two, 5-foot-high, 20-foot-long walls. Note material on sloping apron. Photo P296-D-75750



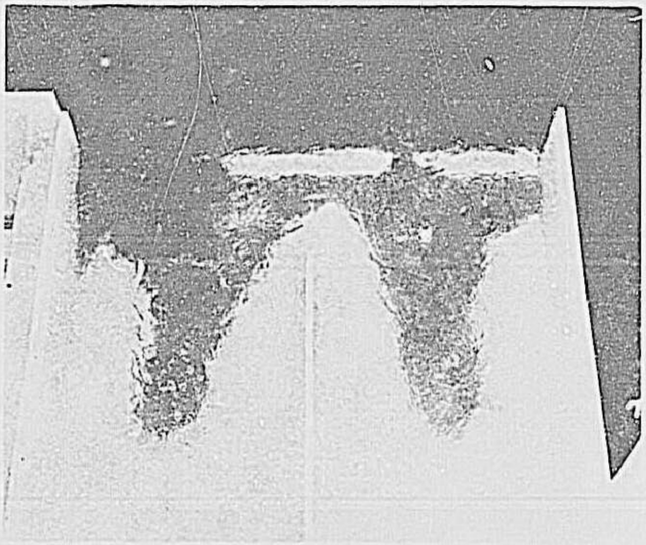
b. Results of test 33. One, 8-foot-high wall extending full width of basin. Note downstream riverbed material overtopped the end sill wall. Photo P296-D-75751



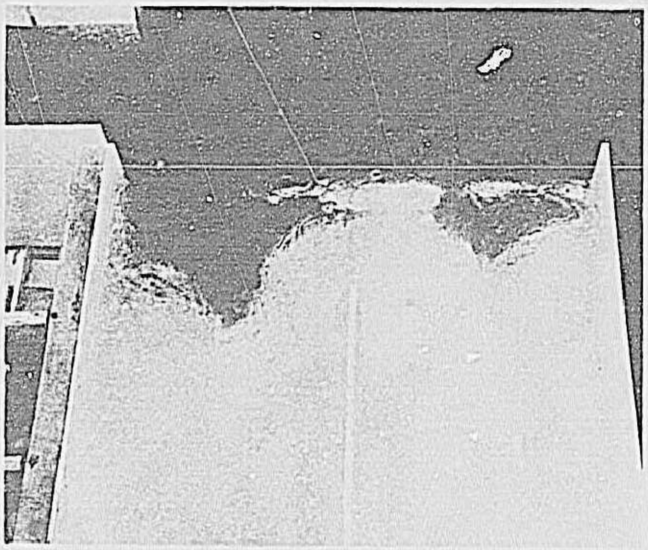
c. Results of test 36. One, 12-foot-high wall extending full width of basin. Photo P296-D-75754

Q = 9,500 ft^3/s

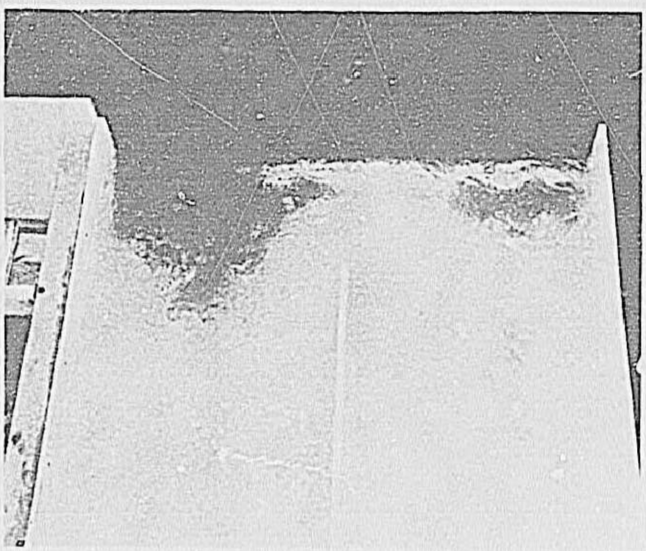
Figure 25. End sill wall studies, tests 32, 33, and 36.



a. Test 10, basin after 6 hours, Q = 11,000 ft^3/s. Photo P296-D-75722



b. Test 11, basin essentially cleaned after 6 hours, Q = 20,800 ft^3/s. Photo P296-D-75723



c. Test 12, basin essentially cleaned after 2 hours. Q = 24,400 ft^3/s. Photo P296-D-75724

Figure 26. Spill required to clean stilling basin of 400 yd^3, tests 10, 11, and 12.

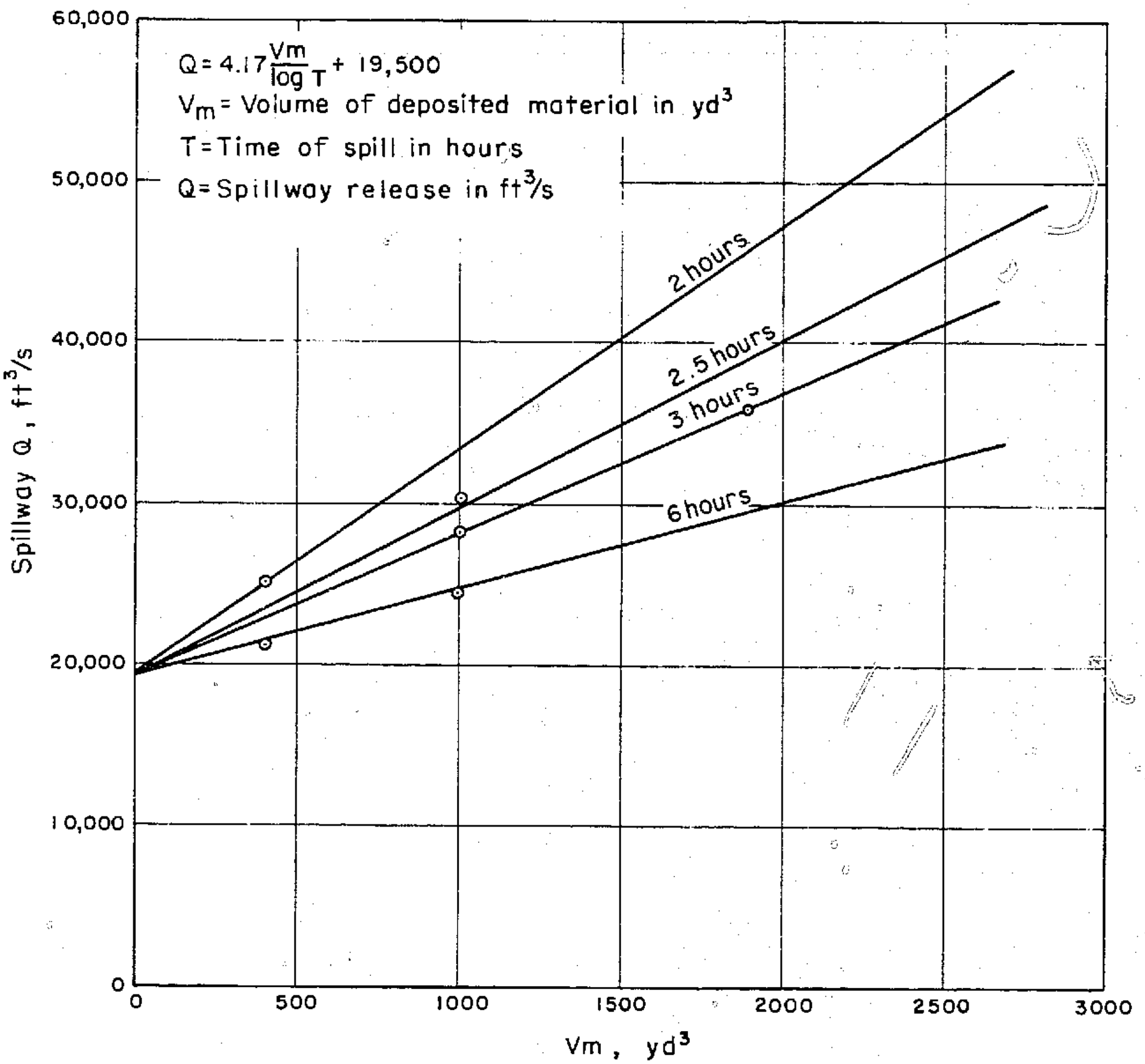


Figure 27. Removal of riverbed material from stilling basin.

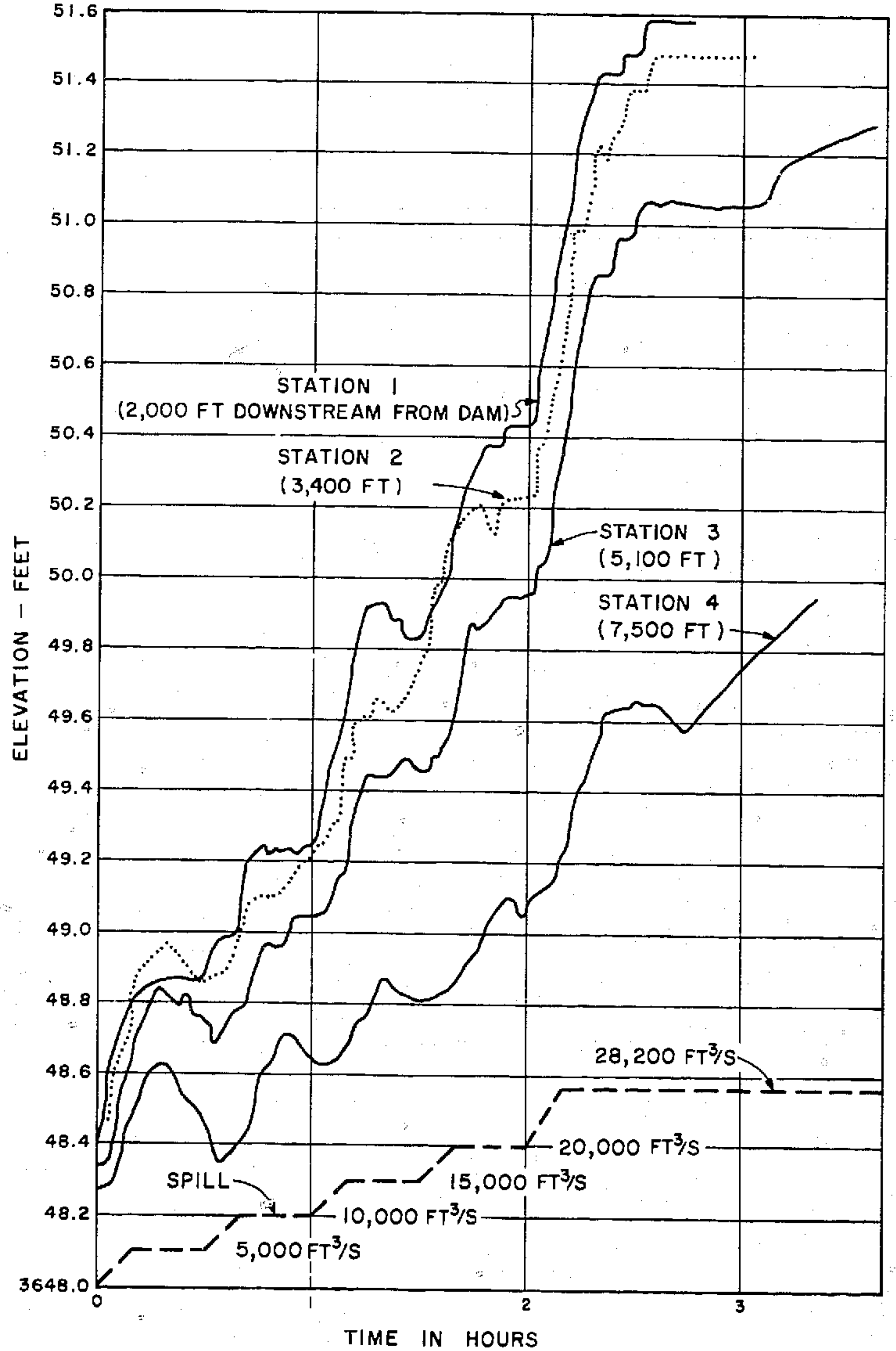


Figure 28. Water surface elevations below dam during spill.

APPENDIX

Log of Model Tests

Test No.		Time in hours: Model	Time in hours: Prototype	Comments	Operations: Spillway: Gates	Spillway: Discharge ft³/s	River outlets: Gates	River outlets: Discharge ft³/s	Powerplant: Discharge ft³/s	Pumping plant: Discharge ft³/s
1		6.25	43		–	–	1, 2, 3, 4	9,500	–	–
2		6.25	43		1, 2, 3, 4	9,400	–	–	–	–
3		6.00	41		1, 2, 3, 4	24,000	–	–	–	–
4	A	3.00	21		–	–	1, 2, 3, 4	8,000	6,000	–
	B	3.50	24		1, 2, 3, 4	7,400	–	–	6,000	–
5	A	8.00	55	Verification test	–	–	1, 2, 3, 4	7,300	6,000	–
	B	4.00	28		1, 2, 3, 4	8,000	–	–	–	–
	C	4.00	28	Gates 1, 2, 3, 4. 6,000 ft³/s decreasing to 2,000 ft³/s over 4 hours		–	*See Comments		6,000	–
6	A	4.50	31		–	–	–	–	6,000	–
	B	1.50	10		–	–	–	–	6,000	463
7		6.25	43		–	–	1, 2, 3, 4	4,000	6,000	–
8		6.25	43		–	–	1, 2, 3, 4	5,000	6,000	–
9		6.25	43		–	–	1, 2, 3, 4	6,000	6,000	–
10		2.75	19	Initial condition, 400 yd³ debris in basin	1, 2, 3, 4	11,000	–	–	6,000	–
11		2.28	16	Initial condition, 400 yd³ debris in basin	1, 2, 3, 4	20,800	–	–	–	–
12		1.37	9.5	Initial condition, 400 yd³ debris in basin	1, 2, 3, 4	24,400	–	–	–	–
13		6.58	46		–	–	3, 4	4,750	6,000	–
14		6.25	43		–	–	1, 2, 3, 4	3,000	6,000	350
15		5.75	40		–	–	1, 4	4,750	6,000	350
16	A	4.00	28		–	–	1, 2, 3, 4	7,900	6,000	350
	B	1.80	12		1, 2, 3, 4	15,000	–	–	–	–
	C	6.17	43		–	–	1, 2, 3, 4	3,000	–	–
17		1.20	8.3	Initial condition, 1,000 yd³ debris in basin	1, 2, 3, 4	24,300	–	–	–	–
18		1.20	8.3	Initial condition, 1,000 yd³ debris in basin	1, 2, 3, 4	28,200	–	–	–	350
19		1.20	8.3	Initial condition, 1,000 yd³ debris in basin	1, 2, 3, 4	30,200	–	–	–	350
20		6.25	43	Velocity measurements (bedrock installed)	–	–	1, 2, 3, 4	9,500	6,000	350
21		6.00	42		–	–	1, 2, 3, 4	9,500	6,000	–
22		6.00	42		–	–	1, 2, 3, 4	9,500	6,000	–
23				Velocity measurements	–	–	1, 2, 3, 4	3,000	6,000	350
24		6.25	43		1, 2, 3, 4	4,100	–	–	6,000	350
25		6.00	42		1, 2, 3, 4	6,600	–	–	6,000	350
26		3.00	21		2, 3, 4	14,500	–	–	6,000	–
27		3.00	21		2, 3, 4	8,300	–	–	6,000	–
28		3.00	21		2, 3, 4	3,900	–	–	6,000	–
29		6.25	43	Riverbed cleared to bedrock 50 feet downstream from basin	–	–	1, 2, 3, 4	9,500	6,000	–
30		6.25	43	Riverbed cleared to bedrock 75 feet downstream from basin	–	–	1, 2, 3, 4	9,500	6,000	–
31		6.25	43	Riverbed cleared to bedrock 100 feet downstream from basin	–	–	2, 3, 4	9,500	6,000	–
32		6.25	43	Two 5-foot-high, 20-foot-long walls on top of end sill	–	–	1, 2, 3, 4	9,500	6,000	–
33		6.25	43	8-foot-high wall on top of end sill, extended full width of basin	–	–	1, 2, 3, 4	9,500	6,000	–
34		6.25	43	Simultaneous operation	2, 3	4,750	1, 4	4,750	6,000	–
35		2.17	15	Initial condition, 1,900 yd³ debris in basin	1, 2, 3, 4	36,300	–	–	–	–
36		6.25	43	12-foot-high wall on top of end sill, extended full width of basin	–	–	1, 2, 3, 4	9,500	6,000	–
37		5.67	39	12-foot-high wall on top of end sill, extended full width of basin	1, 2, 3, 4	40,000	–	–	6,000	–
38		6.25	43	Simultaneous operation	2, 3	10,000	1,4	4,750	6,000	–

7-1750 (3-71)
Bureau of Reclamation

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

GPO 859 - 632

ABSTRACT

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