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MODEL STUDY OF RIVERBED MATERIAL IN CANYON FERRY DAM SPILLWAY STILLING BASIN

BY

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MODEL STUDY OF RIVERBED MATERIAL IN CANYON FERRY DAM SPILLWAY STILLING BASIN

By

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ABSTRACT

Hydraulic model studies were made to determine the cause and recommend a solution for the deposit and movement of riverbed material into the Canyon Ferry Dam spillway stilling basin. Tests indicated that movement of riverbed material results 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 outlet to 3,000 ft^3/s (85 m^3/s). Studies were conducted to determine the effectiveness of the spillway discharge in clearing various amounts of deposited material from the basin. As a result of these studies, a recommended spillway discharge was applied to the Canyon Ferry stilling basin to clean 900 yd^3 (688 m^3) of riverbed material from the basin. Soundings of the basin were taken immediately after the suggested release and confirmed the model results.

INTRODUCTION

Canyon Ferry Dam is located 17 miles (27 kilometers) northeast of Helena, Montana, on the Missouri River. The dam is a concrete gravity-type structure approximately 1,000 feet (305 meters) in length with a maximum height of 225 feet (68.6 meters) above the foundation. The maximum water surface elevation in the reservoir is 3800 feet (1158 meters). The powerplant on the right side of the dam is rated at 50,000 kilowatts. The dam was constructed in the period 1949-1954.

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. The material was carried to a disposal site approximately 1 mile (1.6 kilometers) 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 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 meters) of the upstream reservoir, the dam, powerplant, Helena Valley Pumping Plant, and 450 feet (137 meters) 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. The scale relations based on the Froude Law can be expressed in terms of L_r, the length ratio, 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 that 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, figure 3, was modeled. 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 table 1. A major portion of the 1971 releases involved the river outlet works. The results of the test were compared with the September 1971 sounding of the prototype stilling basin and downstream river channel. 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.

The model tests included 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 test 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 deposit 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 meter), 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 96-inch (218-centimeter) 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 feet (1112.5 meters). Each conduit has a 77-inch (195.6-centimeter) 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 4A and 4B illustrate the downstream erosion and deposit of riverbed material in the basin after tests 1 and 14.

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 (85 to 269 m^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 (85 m^3/s) or less result in very little movement of riverbed material into the stilling basin, figure 4B.

Velocity measurements in the model determined the direction of flow (in or out) and the velocity of three half sections in the stilling basin for the 9,500 ft^3/s (269 m^3/s) river outlet release. As indicated earlier by the erosion patterns, a strong undercurrent moves upstream into the basin. At the end sill section, station 4+10, the core of the upstream current lies on the sill approximately 75 feet (23 meters) from the training wall. The core rises from elevation 3605 feet (1099 meters) at the sill to 3623 feet (1104 meters) 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.

The jet leaving the river outlet conduit stays in the upper 20 feet (6.1 meters) 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.

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). The erosion is more severe near the pumping plant 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 compared the operation of outlets No. 1 and 4 releasing a total discharge of 4,750 ft^3/s (135 m^3/s) with test 14, releasing a discharge of 3,000 ft^3/s (85 m^3/s) through four outlets. Operating all four outlets at 3,000 ft^3/s (85 m^3/s) produced less erosion and subsequent deposition than operating the two outside outlets at 4,750 ft^3/s. These tests indicate that all four river outlets should be operated uniformly to achieve the best flow distribution possible.

Spillway. - 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 determine if low spillway releases would carry riverbed material into the basin. There was 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.

Powerplant and Helena Valley Pumping Plant. - Test 6A determined the effect of 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 (170 m^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 (170 m^3/s) and the Helena Valley Pumping Plant 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 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.

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 ft^3/s (85 m^3/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 blood stream. 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 discharged 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.

Simultaneous operation of the two outside river outlets (Nos. 1 and 4) and the two center spillway gates (Nos. 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 ft^3/s (135 m3/s) through the two outside river outlet conduits and 4,750 (test 34) and 10,000 ft^3/s (283 m^3/s) (test 38), through the two center spillway gates. The simultaneous operation was successful in controlling the movement of riverbed material into the basin.

Severe erosion of the riverbed occurred with the 10,000 ft^3/s (283 m^3/s) release through the two center spillway gates. Periodic soundings immediately downstream from the basin would allow the project to monitor the extent of erosion of the bedrock in this area.

Riverbed Stability

The term "riverbed stability," as used in this paper, will refer to 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). 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.

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 practical 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.

Modification. - A series of three tests (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 river-bed 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 meters) 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 meters) 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. For each test the discharge was 9,500 ft^3/s (269 m^3/s) through the river outlets and 6,000 ft^3/s (170 m^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 (30 meters) downstream from the stilling basin end sill.

Studies 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 stilling basin indicated that a 12-foot (3.7 meters) high wall would be needed. There are some obvious disadvantages to the end sill wall 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 Basins

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 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 5 illustrate the relationship of the variables, spillway discharge (Q), time of spill (T), and volume of deposited material to be removed from the stilling basin (V_m).

The project office used the results of these tests to formulate the 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 flow of 28,200 ft^3/s (799 m^3/s) was released. The spillway discharged for 3 hours at 28,200 ft^3/s (799 m^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 material from being washed into the turbine draft tubes. The peak discharge into the river was approximately 34,500 ft^3/s (977 m^3/s) for 3 hours. Soundings taken on May 9 and 10 indicated that the spill was sucessful in flushing the 900 yd^3 (688 m^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 the exposed reinforcing bars.

Summary of Results

1. When the river outlet releases exceed 3,000 ft^3/s (85 m^3/s), riverbed material 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 the material from the stilling basin can be determined from figure 5.

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

5. Clearing the river bottom of loose riverbed material down to bedrock for a distance of 100 feet (30 meters) 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. Uniform operation of all four river outlets or all four spillway gates gave best results.

7. The simultaneous operation of the two center spillway gates (Nos. 2 and 3) with the two outside river outlets (Nos. 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.

Table 1

Log of Model Tests

Test No.		Time in hours: Model	Time in hours: Prototype	Comments	Operations: Spillway Gates	Operations: Spillway Discharge ft^3/s	Operations: River outlets Gates	Operations: River outlets Discharge ft^3/s	Operations: Powerplant Discharge ft^3/s	Operations: Pumping plant Discharge ft^3/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 ft^3/s decreasing to 2,000 ft^3/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 yd^3 debris in basin	1, 2, 3, 4	11,000	–	–	6,000	–
11		2.28	16	Initial condition, 400 yd^3 debris in basin	1, 2, 3, 4	20,800	–	–	–	–
12		1.37	9.5	Initial condition, 400 yd^3 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 yd^3 debris in basin	1, 2, 3, 4	24,300	–	–	–	–
18		1.20	8.3	Initial condition, 1,000 yd^3 debris in basin	1, 2, 3, 4	28,200	–	–	–	350
19		1.20	8.3	Initial condition, 1,000 yd^3 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	–	–	1, 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 yd^3 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	–

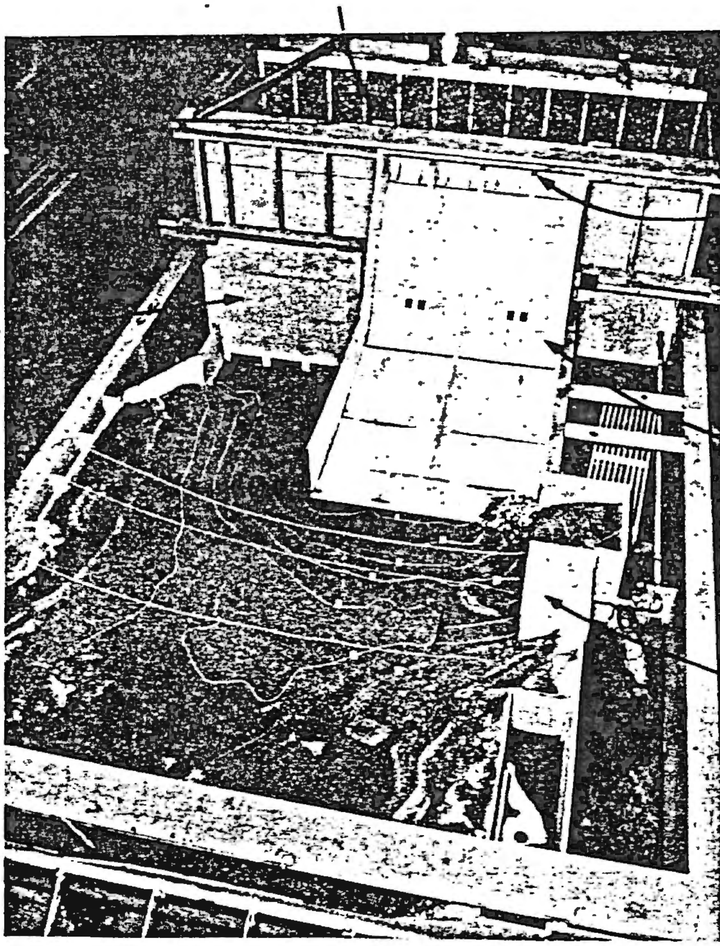


Figure 1. 1:48 Scale model layout of Canyon Ferry Dam. Photo P296-D-75729

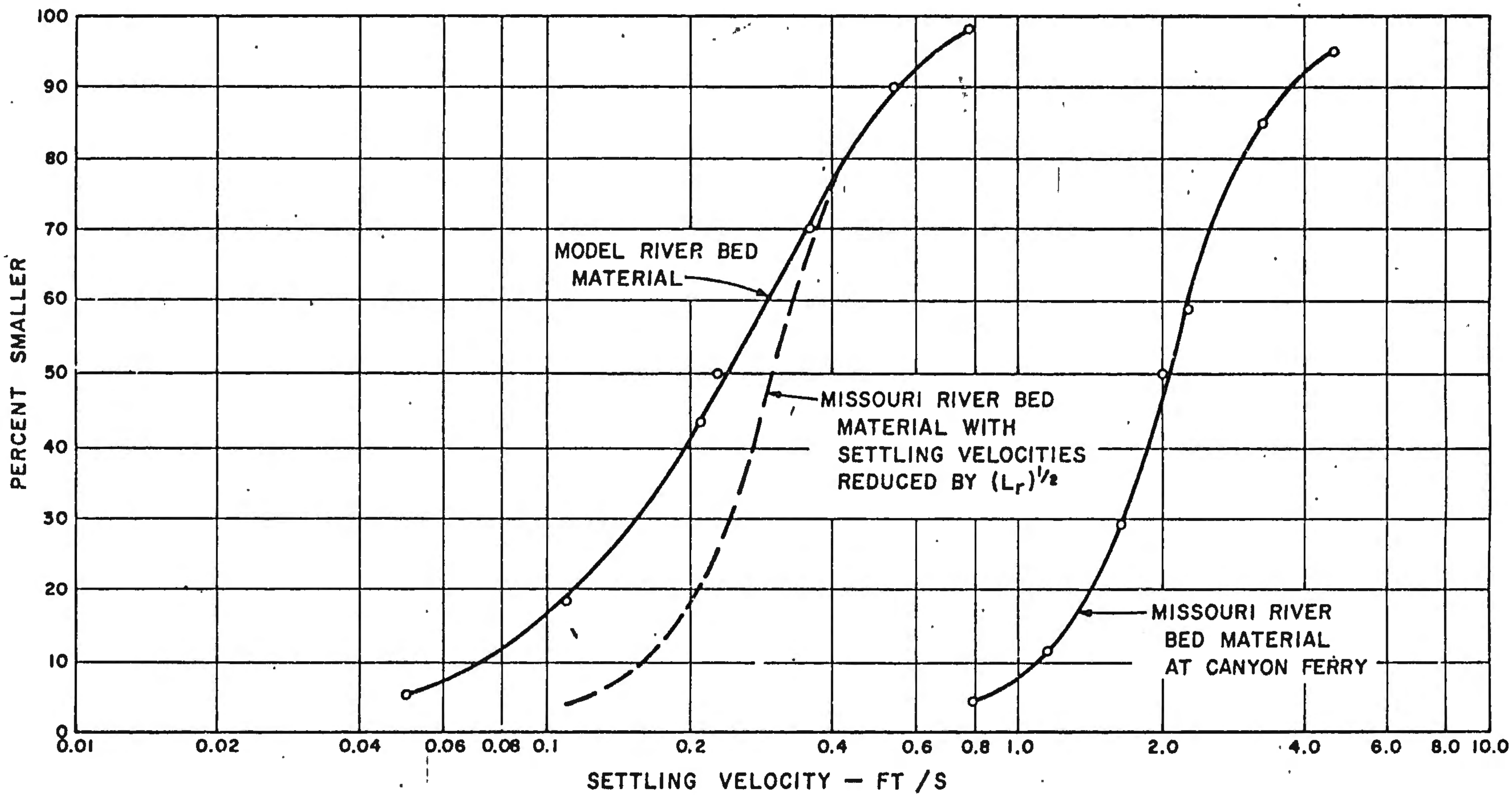


Figure 2. Comparison of settling velocities, Canyon Ferry model study.

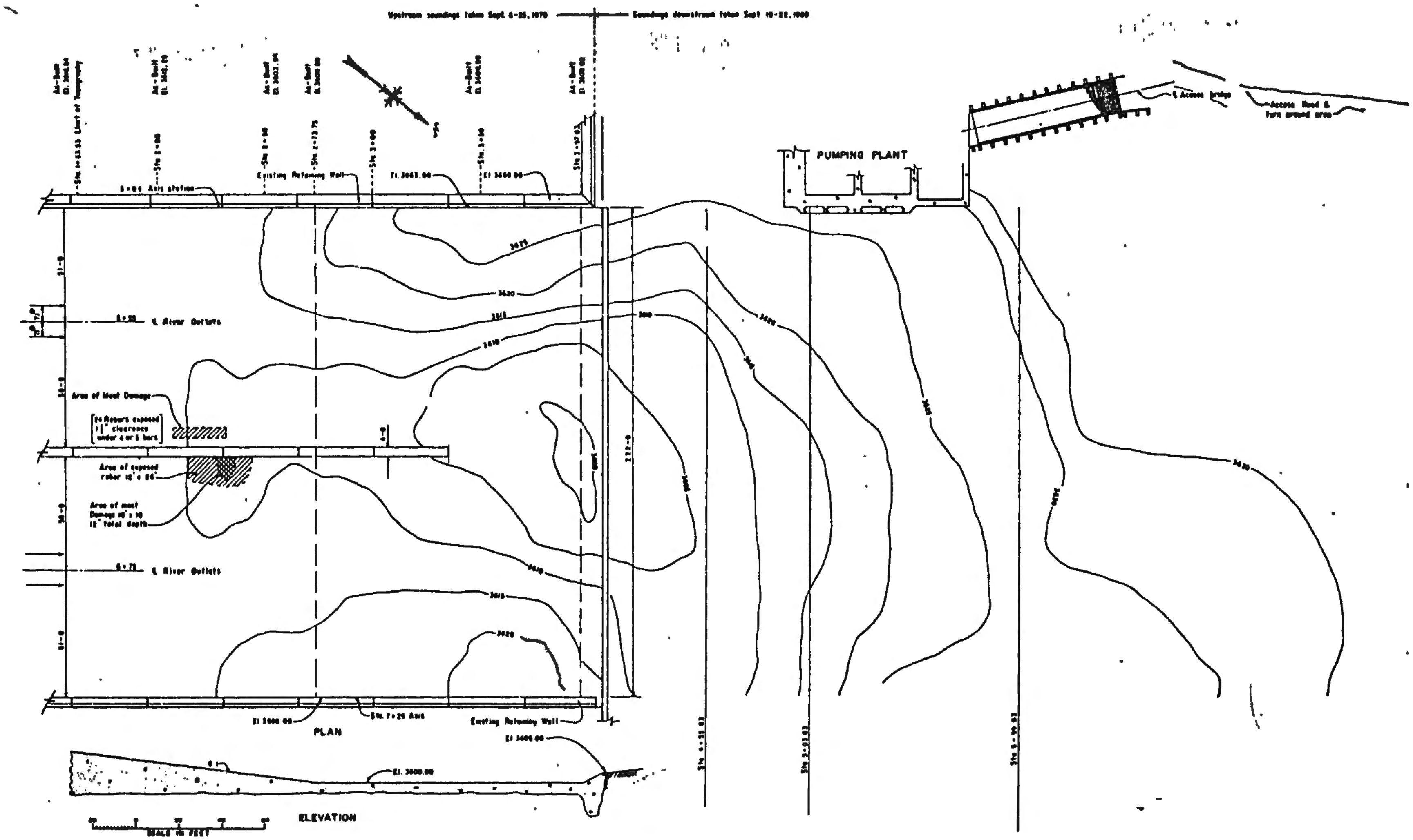
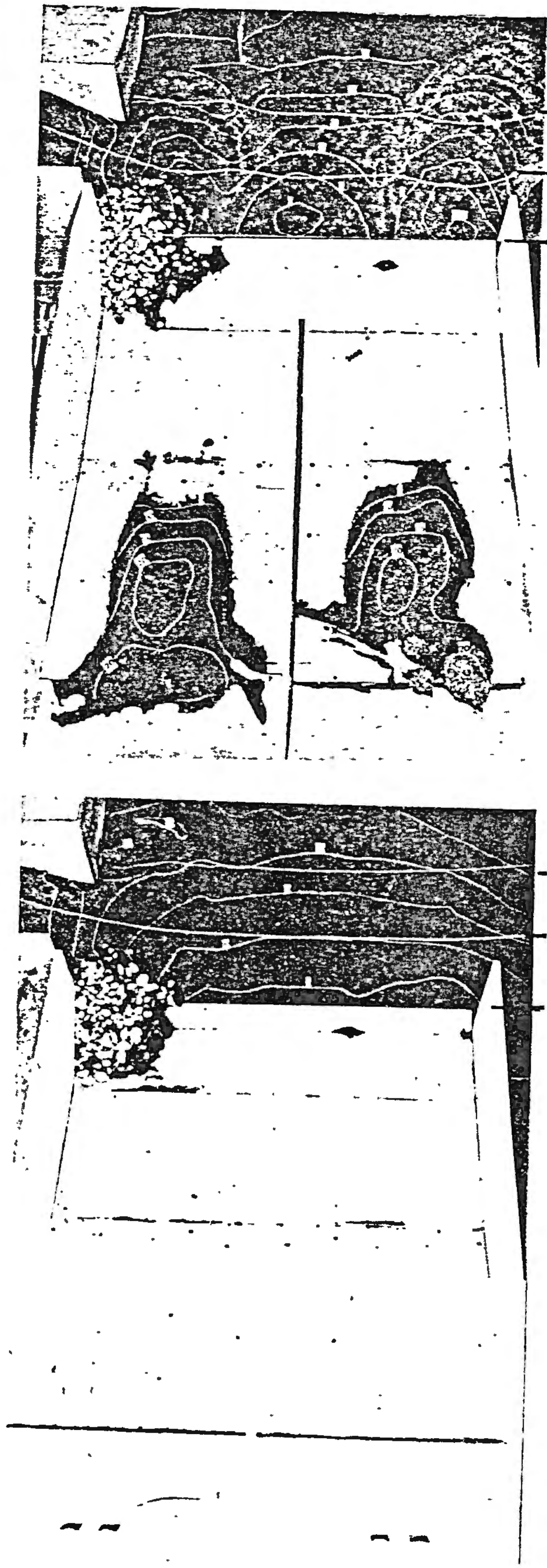


Figure 3. Canyon Ferry Dam stilling basin sounding, August 1970.



a. Results of test 1, Q = 9,500 ft^3/s.

b. Results of test 14, Q = 3,000 ft^3/s.

Figure 4 Results of river outlet releases

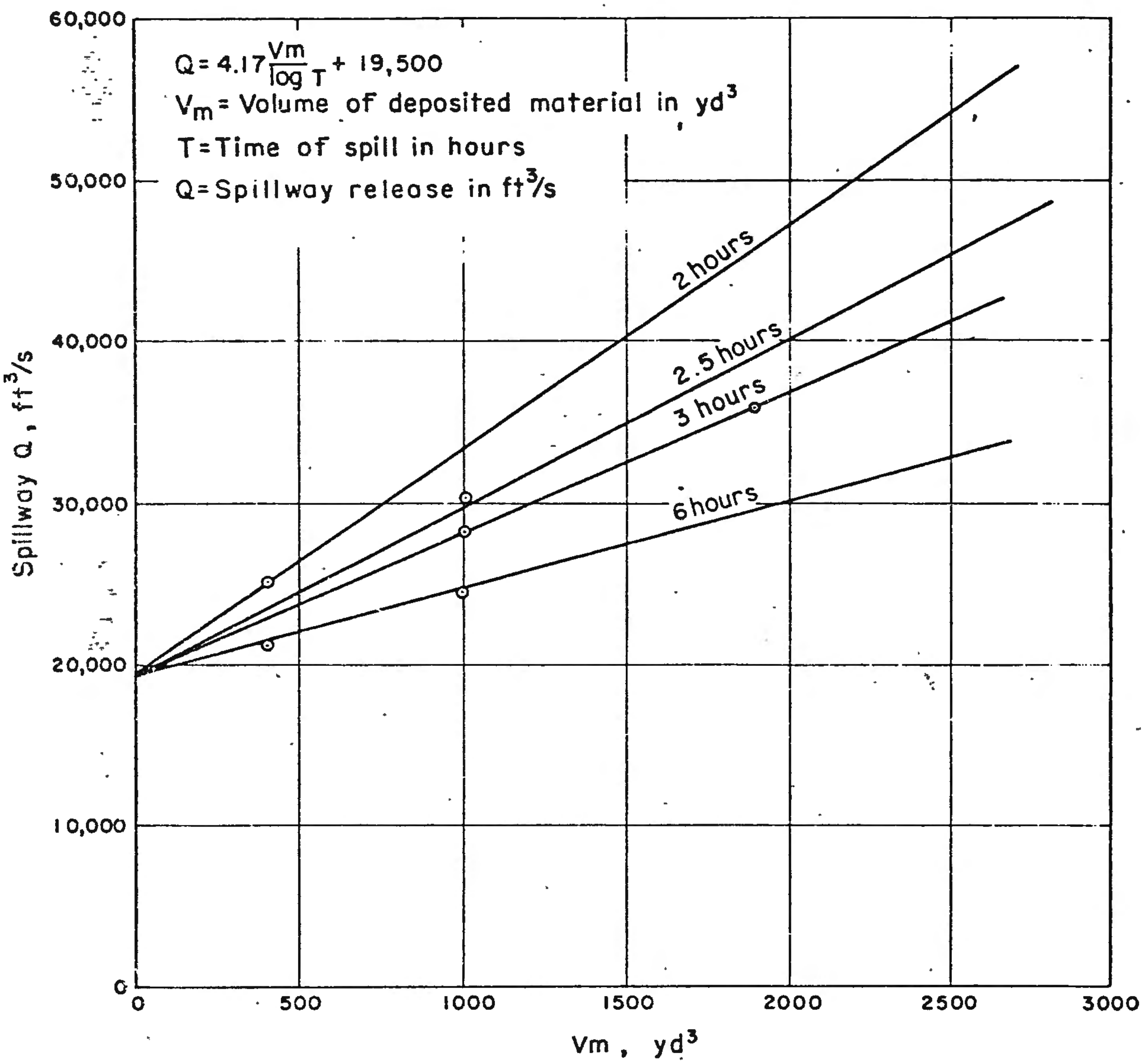


Figure 5 . Removal of riverbed material from stilling basin.