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BONNEVILLE OR DIV HYDRAULIC LAB JUL 83 TR-160-1

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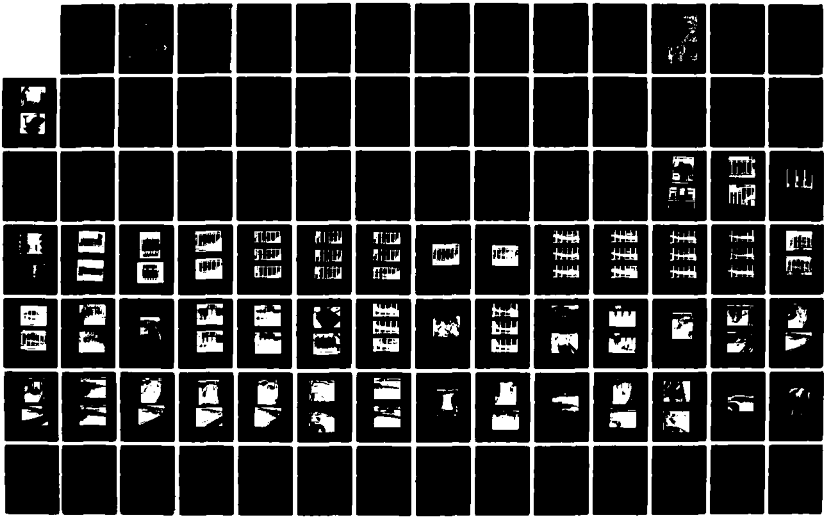

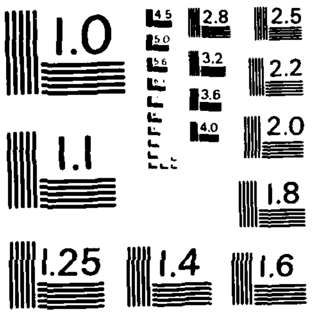

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HYDRAULIC MODEL INVESTIGATION

TECHNICAL REPORT NO. 160-1

AD-A134 635

Libby Reregulating Dam
Kootenai River, Montana

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U. S. ARMY CORPS OF ENGINEERS
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CONDUCTED BY
DIVISION HYDRAULIC LABORATORY
U. S. ARMY CORPS OF ENGINEERS
NORTH PACIFIC DIVISION
BONNEVILLE, OREGON

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US Army Corps of Engineers
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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The proposed Libby Reregulating Dam would be located on the Kootenai River 10 miles downstream from Libby Dam. One of the principal features of the project is combination of the spillway and powerhouse in a single structure. Design of the spillway/powerhouse was verified using three models--a 1:50-scale spillway model, a 1:35.33-scale spillway/powerhouse sectional model, and a 1:80-scale comprehensive model. Tests in both the sectional and comprehensive models were accomplished using both fixed and movable-bed boundaries.

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During early stages of project design, a baffled-chute spillway was developed which provided capability for reduction in nitrogen supersaturation. Evaluation of the design accomplished in a 1:25.11-scale model is included as an appendix to this report. The spillway exhibited adequate energy dissipation for discharges up to 903 cfs per foot and potential for reduction in gas supersaturation for discharges up to 181 cfs per foot. The concept was not pursued in final design due to economics combined with operating considerations at the upstream Libby Dam.

PREFACE

Model studies necessary to the design of the Libby Project Reregulating Dam were authorized on 20 August 1973 by the Office of the Chief of Engineers (DAEN) at the request of the Seattle District, Corps of Engineers (NPS). An investigation was initially undertaken to determine the potential for reduction of nitrogen supersaturation by means of spillway-flow aeration. A subsequent decision to employ a combined spillway/powerhouse configuration resulted in a detailed program of design-aid modeling. Three models were required to obtain the necessary design information--a 1:50-scale spillway preliminary model; a 1:35.33-scale, three-bay spillway/powerhouse sectional model; and a 1:80-scale comprehensive model with both fixed and movable boundaries.

The model studies were conducted at the North Pacific Division Hydraulics Laboratory (DHL) during the period from 1974 to 1980 under the supervision of Mr. P. M. Smith, Director. The detailed studies were conducted by Messrs. Smith, R. L. Johnson, B. B. Bradfield, and T. L. Edmister. This report was prepared by Northwest Hydraulic Consultants and the Seattle District Hydraulics Section.

TABLE OF CONTENTS

CONVERSION FACTORS, U.S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENTS

U.S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
miles	1.609344	kilometres
feet per second	0.3048	metres per second
cubic feet per second	0.0283168	cubic metres per second
pounds (mass)	0.4536	kilograms

LIBBY REREGULATING DAM, KOOTENAI RIVER, MONTANA

Hydraulic Model Investigations

PART I: INTRODUCTION

The Proposed Project

1. As part of the Libby Additional Units and Reregulating Dam (LAURD) Project, a reregulating dam was proposed to smooth out rapid fluctuations in Kootenai River flows resulting from hydroelectric power peaking operations at Libby Dam in northwestern Montana. Figure 1 shows the location of the proposed project. The secondary objective for the proposed reregulating dam includes the provision of hydroelectric generating units.

2. The general layout of the reregulating dam project is shown in figure 2 and plate 1. One of the principal features of the project is the combination of the powerhouse and spillway into a single structure. The powerhouse includes four bulb turbines located directly below the four left-side spillway bays. The five-bay spillway will pass the probable maximum flood (PMF) peak discharge of 210,000 cubic feet per second (cfs) with a head of 47.8 feet (reservoir surcharged approximately 10 feet above the normal full-pool elevation of 2130 feet). In order to provide adequate space for power units, a spillway crest shape was selected which conforms to the Corps of Engineers' low-head ogee shape for a design head of 107.36 feet. The maximum spillway discharge at normal full-pool elevation is 154,000 cfs at a head of 37.5 feet (79 percent of the head at PMF conditions); this capacity is 2.3 times greater than the estimated standard project flood (SPF) peak discharge. Spillway flows are controlled with radial gates which are 39 feet wide and 39.8 feet high. The spillway has one 14-foot-wide main pier located between the first two right-side bays; the remaining main piers are 9 feet wide. Each spillway has an intermediate pier 7 feet in width which is located in the center of each bay upstream from the radial gates. These intermediate piers provide guides for bulkheads and emergency-closure gates

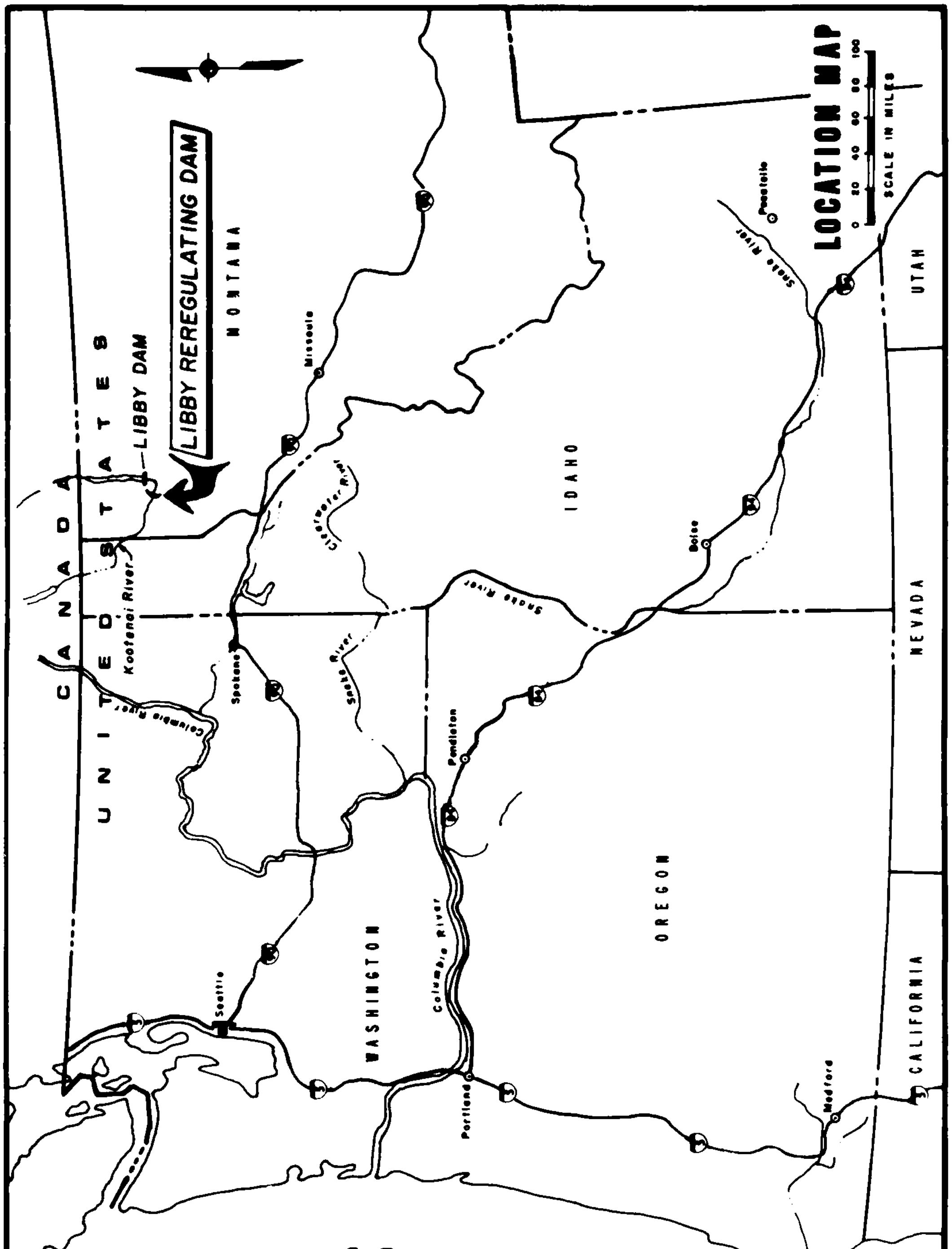

LOCATION MAP
0 20 40 60 80 100
SCALE IN MILES
LIBBY REREGULATING DAM
LIBBY DAM
CANADA
UNITED STATES
MONTANA
IDAHO
WASHINGTON
OREGON
NEVADA
UTAH
CALIFORNIA
Pacific Ocean
Kootenai River
Columbia River
Columbia River
Snake River
Snake River
Snake River
Clearwater River
Missoula
Spokane
Pendleton
Boise
Pocatello
Seattle
Portland
Medford

Figure 1

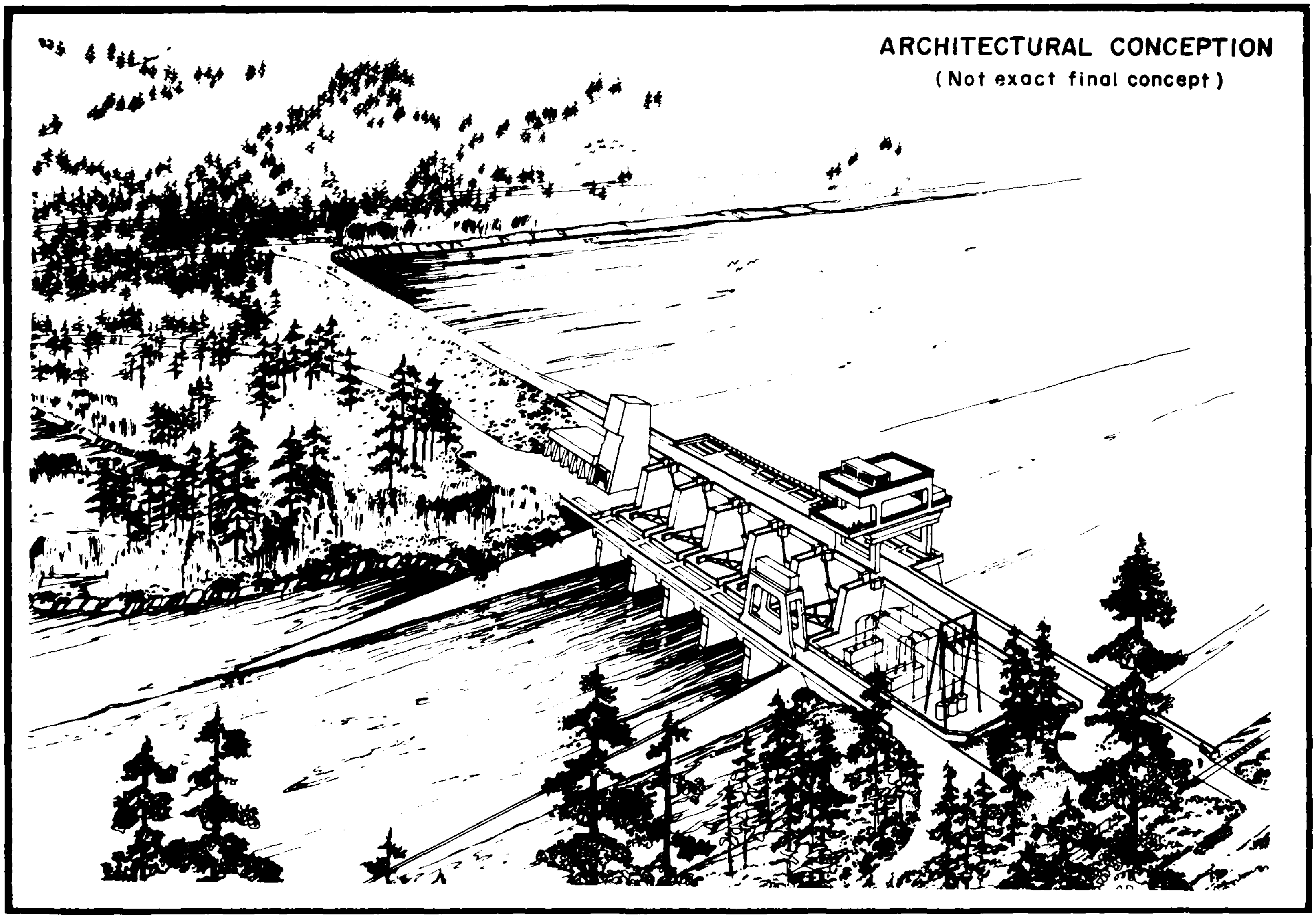


Figure 2

for the turbine intakes. A sloped-floor tailrace basin provides energy dissipation for spillway flows and/or turbine discharges.

Purpose of Model Studies

3. As an integral part of design development of the Libby Reregulating Dam, physical model studies were required to aid in the optimization of the hydraulic performance of the project. Tests were conducted with a comprehensive model (approach-channel and tailrace-channel flow distributions, scour potential, and riprap stability in the tailrace channel), with spillway and power unit sectional models (discharge capacity, energy dissipation, flow distribution, and boundary-pressure distribution), and with baffled-chute spillway models (energy dissipation and aeration characteristics). At a ver early stage of design, the baffled-chute spillway models were investigated regarding potential for reduction in nitrogen supersaturati levels by means of shallow-flow air entrainment. The final design o the reregulating dam does not incorporate nitrogen-reduction facilities; the baffled-chute model testing program is documented in Appendix A to this report.

PART II: DESCPIPTION OF THE MODELS

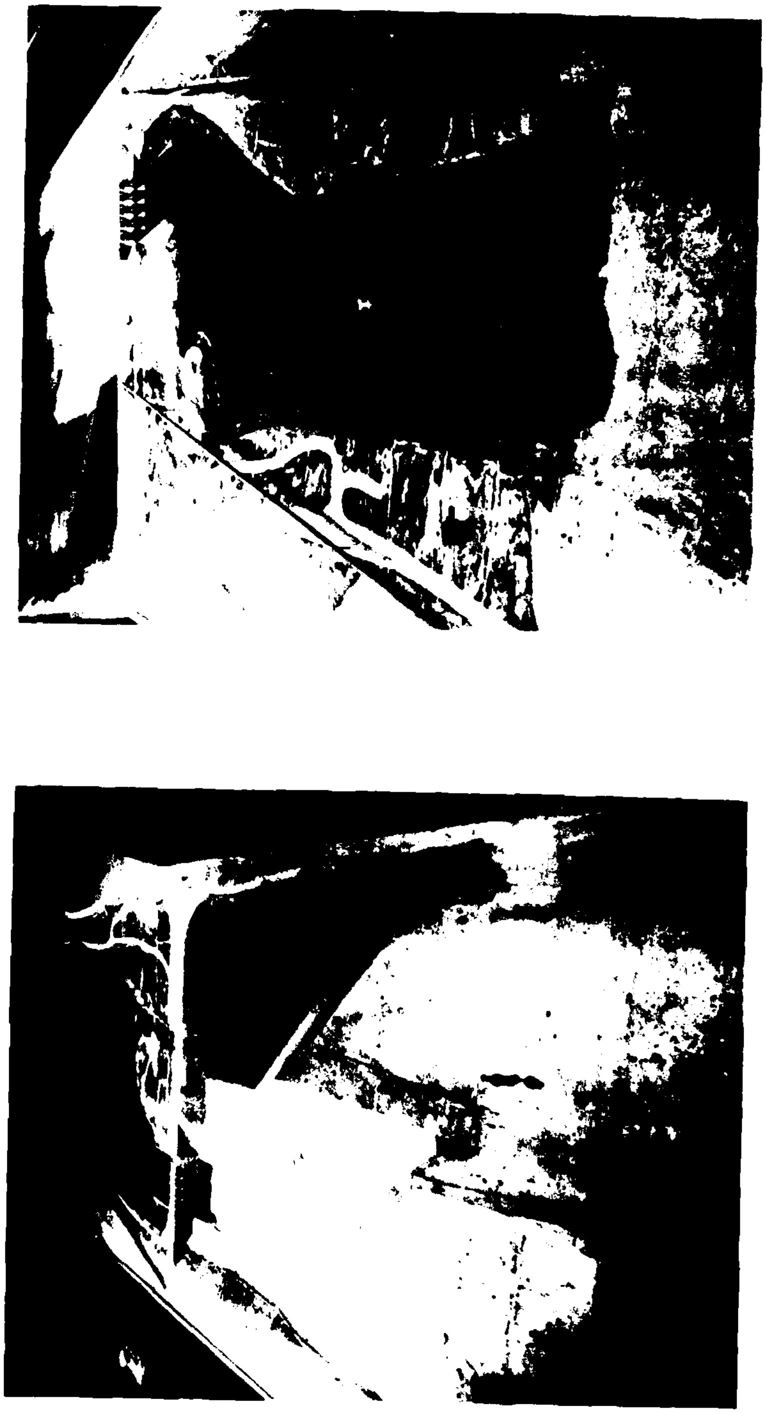
Comprehensive Model

4. A 1:80-scale undistorted model (see figure 3) reproduced approximately 2,500 feet of forebay, the final design Plan B spillway/powerhouse, and approximately 14,000 feet of the downstream reach including the tailrace channel. During the course of the testing program, various model modifications were made including addition of a railroad shoo-fly embankment along the left flood plain; placement of fill to simulate a disposal site downstream from the right abutment; and addition of a diagonal dike upstream from the right abutment to simulate the second-stage diversion cofferdam. Site topography was reproduced in concrete molded between templates to conform to field survey data and design excavation features, structures were constructed of wood. In the tailrace area, erodible material was employed to form the channel boundaries and to simulate the side-slope riprap.

Spillway and Power Unit Models

5. A 1:50-scale model was employed for preliminary testing of the low-head ogee spillway. This model, shown in photograph 1 and plate 2, reproduced a single bay without gates and served as a pilot model to guide the development of spillway conceptual designs which were subsequently tested in more detail. The model was constructed of plastic and placed in a flume having glass on one side for viewing. The tailrace invert was constructed of wood. Modifications made to the pilot model during testing included variations in bay width, crest shape, pier width and location, and tailrace configuration.

6. A 1:35.33-scale model simulating three spillway bays was used for detailed studies of the spillway crest, tailrace geometry, diversion sluice, and power unit intakes and draft tubes. The model was located in the wooden flume which had previously been used for the 1:50-scale model. The spillway, piers, and gates were constructed of plastic. For the tailrace geometry studies, the wooden invert was overlain with loose crushed rock to simulate the fragmented bedrock



Comprehensive (1:80-scale) model of dam and spillway/powerhouse structure

Figure 3

existing in the prototype. The original design Plan A spillway model is shown in photographs 2 and 3 and on plate 3. The sectional model was modified to reproduce diversion sluice geometry as shown in photographs 4, 5, and 6 and on plate 4. Model power units (see photographs 7, 8, 9, and 10 and plate 5) were incorporated into the center and left bays of the three-bay model.

7. Water used for the models was supplied by a recirculating system. Tailwater in the models was adjusted by an overflow gate to conform to tailwater rating data furnished by NPS. Discharges were measured by orifices in supply lines, and velocities were determined by propeller meters. Pressures were measured by piezometers connected to 1/2-inch-diameter fast-acting water manometers. Power units were calibrated to discharge 6,250 cfs each at pool elevation 2130 feet and average tailwater.

Model Similitude

8. The similarity criterion employed in all model design and testing was the equivalence of the Froude Number ($V/\sqrt{gL}$) in model and prototype. The resulting scale relationships are tabulated below:

Quantity	Scale Relationship	Spillway Sectional Model	Spillway Preliminary Model	Comprehensive Model
Length	L_r	1:35.33	1:50	1:80
Area	L_r^2	1:1,248	1:2,500	1:6,400
Velocity	$L_r^{1/2}$	1:5.94	1:7.07	1:8.94
Time	$L_r^{1/2}$	1:5.94	1:7.07	1:8.94
Discharge	$L_r^{5/2}$	1:7,419	1:17,680	1:57,250

PART III: MODELING PROGRAM AND RESULTS

Spillway

Preliminary Studies

9. Basic design features of the Libby reregulating spillway were studied in a single-bay, 1:50-scale model. The results of these preliminary model studies were used in sizing the spillway and tailrace to be investigated in greater detail in a three-bay, 1:35.33-scale model. Discharge characteristics were determined for various crest shapes, pier shapes and sizes, and bay widths. Flow conditions were observed with various flow deflectors and downstream excavation plans.

10. A series of eight variations on preliminary design were tested. During this sequence, a design evolved which incorporated a flow deflector at the downstream end of the ogee to direct the high-velocity flow parallel to the tailrace water surface. The flow deflector reduced air entrainment in the tailrace and created acceptably low velocities near the draft tube exits, while providing good energy dissipation. The addition of the deflector allowed the tailrace invert to be raised to elevation 2017 feet (from the original-design elevation 2000 feet) with no degradation in performance of the tailrace basin.

Original (Plan A) Design

11. As a result of the preliminary testing program, the Plan A spillway design (see plate 3) evolved and was subsequently tested in detail in a three-bay, 1:35.33-scale sectional model. The forebay level at the PMF discharge of 210,000 cfs was unacceptably high at elevation 2141.28 feet. The PMF forebay level was lowered to elevation 2140.49 by making the upstream invert slope flatter (1V on 4H rather than the original 40°) and covering the bulkhead and emergency gate slots. Also, testing revealed that more easily constructed flat-nosed piers could be used in place of the Plan A piers with no loss in hydraulic efficiency. Water-surface profiles along the faces of the main piers indicated that the gate trunnions could be lowered

to elevation 2107.5 feet. The Plan B spillway discussed in the next section of this report incorporates all of the previously mentioned modifications.

Final (Plan B) Design

12. The Plan B spillway shown on plate 6 was tested with a three-bay sectional model at a scale of 1:35.33 for the conditions summarized in table A. Tailrace flow conditions were observed with gated flows ranging from 10,000 to 70,000 cfs (see photographs 11 to 15). Tailrace velocity measurements made for gated flows of 28,500 cfs, 50,000 cfs, and 67,000 cfs are presented on plates 7 and 8. Flow conditions for ungated discharges ranging from 5,000 to 210,000 cfs are shown in photographs 16 to 21, and velocity measurements for an ungated flow of 210,000 cfs are presented on plate 8. Tailrace velocities as high as 32 feet per second (fps) were evident; the extension of the horizontal deflector (at the downstream edge of the spillway) by as much as 25 feet provided no reduction in near-bed velocities and produced unstable flow in the tailrace as evidenced in photograph 22.

13. Due to the high velocities existing in the tailrace and the presence of the highly jointed, fractured bedrock in the prototype, the need for redesign of the tailrace geometry became apparent. As an alternative to paving of the tailrace runout, various schemes of enlarging the tailrace were tested in an attempt to increase the potential for energy dissipation. The effect of the enlarged tailraces was evaluated by incorporating a crushed-rock, movable bed along the runout invert. This movable bed, consisting of 1-4.5 feet (prototype) rock, was loosely placed in the model to simulate the fractured bedrock expected in the tailrace excavation area. The loosely placed rock was assumed to result in a "worst condition;" i.e., it would scour more easily than the actual fragmented bedrock existing in the prototype. As a criteria in redesign of the tailrace, the designers considered that no movement of the crushed-rock bed should exist for flows up to 67,000 cfs (SPF). The final design tailrace runout geometry developed through these series of tests is

shown in photograph 23. Plates 9 and 10 show velocities existing in the tailrace for spillway discharges ranging between 28,500 and 67,000 cfs. Plate 11 illustrates the minor amount of bed movement which occurred along the final design tailrace runout for the SPF discharge of 67,000 cfs. Tailrace flow conditions were observed for the series of tests summarized in table A and shown in photographs 24 to 35. With spillway discharges exceeding the SPF, greater amounts of bed movement occurred (see photographs 36 through 39 and plate 12). With these higher flows, material was eroded from the downstream end of the tailrace and deposited both up and downstream in the tailrace. The deposited material was within 50 feet of the spillway structure but did not move into the draft tubes. The material did not wash away with subsequent operation of the power units with no spill. Subsequent to these tests, designers incorporated a 3-foot-deep rock trap at the draft tube exit (see plate 13). This change had no significant effect on tailrace flow conditions.

14. Structural design constraints dictated the use of a 14-foot-wide pier between Bays D and E (see plate 1 for location of spillway bays), and tests were conducted in the spillway sectional model to determine the effect of this change. PMF pool level remained unchanged, and no effect on tailrace flow conditions was discernible. Minor upwelling occurred at the downstream face of the 14-foot pier (see photographs 40 and 41).

15. The final design spillway approach configuration incorporated a reduced excavation depth in the approach channel immediately upstream of Bays D and E, as shown in photograph 42. Testing revealed no change in the discharge rating curve for Bay E. No impingement of flow occurred on the bottom of the roadway support beam during simulations of unbalanced flows in Bays D and E or with flow around the right abutment (see photographs 43 to 46). At a discharge of 210,000 cfs, flow occasionally impinged upon the trunnion blocks.

16. With only the spillway operating, flow through the Plan B structure was smooth and stable with discharges up to 110,000 cfs (pool elevation 2130.0 ft). Water-surface profiles along the main pier for SPF and PMF conditions are shown on plate 14. Flow

conditions with the SPF prior to lowering the gate trunnion (see paragraph 11) are shown in photographs 47 and 48. The spillway discharge rating curve is shown on plate 15. The spillway passes the PMF discharge at pool elevation 2140.5 feet. Maximum gated flow at pool elevation 2130.0 was 140,000 cfs at a gate opening of 24.3 feet. Tests revealed that openings greater than 26.0 feet would probably not hold pool due to loss of control associated with upstream surging. Pier and crest mean pressures were measured at the locations indicated on plate 16 with a discharge of 210,000 cfs. The pressures, summarized in table B, are all positive.

17. Diversion sluice ratings with one, two, and three sluices operating are presented on plate 17. Sluice wall pressures measured at the locations indicated on plate 4 are presented in table C; all pressures were positive. Maximum head on the bulkhead slot covers was 7.3 feet occurring with flow through one sluice and a spill of 15,000 cfs.

Power Units

18. Flow conditions in the power units, the approach channel, and tailrace were investigated in the 1:35.33-scale sectional model. Model power units calibrated to pass 6,250 cfs each were located in the center and left bays of the three-bay model; only entrance and exit conditions were simulated for the power unit in the right bay. Tailrace flow conditions with combined spillway and power unit flows are shown in photographs 49 to 55. In all instances, the division of flow between the power units and the spillway created less turbulent tailrace flow conditions than those existing with the equivalent total discharge conveyed by the spillway only. Flow distributions at the power unit trashrack, intake, and draft tube exits are shown on plates 18 to 24. Velocities along the approach slope are indicated on plate 25. Power unit mean pressures measured at the locations shown by plate 26 are summarized on tables D to G. One instance of negative pressure (-4.4 feet water) occurred, and was located just below the stationary runner blades.

Approach Channel

Original Design

19. The original design approach channel is shown on photograph 56. It featured a trapezoidal depression immediately upstream from the structure to allow unrestricted flow to the powerhouse intakes. The left wall of the deepened channel was vertical; the right wall was sloped at 2.86V on 1H. Preliminary testing indicated that flow approaching the intakes was well aligned except near the right abutment where a distinct cross flow was apparent near Unit D (see photograph 57). This condition was improved considerably by reducing the depth of excavation upstream from spillway Bay E and by moving the second-stage diversion dike 20 ft closer to the structure. A considerable contraction of flow near the left abutment of the spillway (see photograph 58) was reduced in severity by means of a 20-foot extension of the left abutment (see photograph 59). Power intake approach flow was observed with several variations of left-wall side slope; the most satisfactory conditions occurred with a 4V on 1H side slope.

Final (Plan B) Design

20. Flow characteristics in the final design approach channel (Plan B - see plate 27) were observed for the combinations of power unit discharge, spillway discharge, and pool elevation summarized in table H. Flow direction and magnitude for each test case are presented on plates 28 through 41. Approach-channel flow conditions with normal pool (elevation 2130.0) and PMF (210,000 cfs at elevation 2140.5) conditions were judged to be satisfactory. Average approach velocities in the channel were 1 fps or less with total discharges of 25,000 and 44,000 cfs, from 1 to 2 fps with 67,000 cfs, 3 fps with 105,000 cfs, and 4 to 5 fps with 210,000 cfs. The flow approaching each power intake was normal to the entrance and was 5 fps for all conditions. With PMF conditions, eddies occurred adjacent to the nonoverflow monoliths and periodic, minor upwelling occurred near the outer upstream corners of both abutments; though notable, these

conditions were not objectionable. With minimum regulated pool (elevation 2100.0) approach-channel velocities were less than 1 fps with a total discharge of 12,500 cfs (two power units operating) and between 1 and 2 fps with 25,000 cfs (four power units operating). At the lower discharge, a large eddy was observed near the right abutment; at the higher discharge, eddies were evident near both abutments. Approach flow to the power units was the same as at normal pool conditions.

Tailrace

Original Design

21. The original tailrace channel design (Plan A), as shown on plate 42, featured 329-foot-long training walls bordering the runout area and a runout longitudinal profile developed during movable bed tests in a 1:35.33-scale sectional model. Preliminary testing with this (Plan A) scheme indicated that while minor flow problems existed (primarily relating to circulation near the downstream face of the dam on the right bank) the length of the training walls was longer than necessary to provide erosion protection for the adjacent banks. A revised design--Plan B (shown on plate 43)--was developed which incorporated a 300-foot-wide runout (40 feet narrower than Plan A) and a raised area on the right bank between the dam and the disposal berm to prevent any overflow. Tests were completed with various training wall lengths, heights, and top slopes. Unstable flow conditions due to overtopping of the training walls by return flow associated with side eddies (see photograph 60) were seen to diminish with an increase in training wall height and length. The best overall performance was observed with 200-foot-long training walls with top elevations of 2102.0 at the structure and 2097.0 at the downstream ends.

Final (Plan C) Design

22. The final design Plan C tailrace (shown in plate 44 and photographs 61 and 62) was similar to Plan B except that it incorporated training walls with vertical inner faces and 5V on 1H slopes on

the downstream ends. Flow conditions in the Plan C tailrace were evaluated in the model with the final design (Plan B) approach channel. Flow characteristics for the conditions summarized in table I are presented in plates 45 through 55 and photographs 63 through 74. With only the power units operating, the maximum bottom velocity was 5 fps. With the power units closed and the spillway flow uniformly distributed through all bays, maximum bottom velocities were 16 fps with 67,000 cfs and 20 fps with 210,000 cfs. Maximum velocity adjacent to the riprapped side slope of the exit channel was 14 fps, and maximum velocity at the toe of the slope was 18 fps--both conditions occurring with a discharge of 210,000 cfs. Wave heights were less than 1 foot with the power units operating, and 3 and 5 feet with spillway flows of 67,000 and 210,000 cfs, respectively. Wave rideup on the side slopes was 1, 4, and 6 feet, respectively, for these same conditions. In the natural river channel (River Miles 207.8 to 208.3) downstream from the tailrace channel, flow conditions were similar to those observed without the dam and spillway/powerhouse structure present. Unbalanced distribution of spillway flows resulted in the formation of strong, large-scale eddies in the tailrace channel as evident in photographs 75 and 76. With only Bay A operating, a single eddy formed on the right side of the tailrace and the maximum observed bottom velocity was 29 fps. With only Bay C operating, two smaller eddies formed and maximum bottom velocities and wave rideup were slightly reduced. With Bays A, B, and C operating, maximum bottom velocities were 17 fps on the tailrace runout and 11 fps on the side slopes. With normal tailwater (elevation 2102.2) during PMF conditions, skimming flow of the spillway nappe occurred in the tailrace channel (see photograph 77). When the tailwater elevation was lowered to 2100.5 feet (photograph 78), plunging of the nappe occurred and the maximum observed bottom velocity was 39 fps. The tailwater rating curve zones in which skimming and plunging flows occurred are identified on plate 56.

Movable Bed Studies

23. Movable-bed model tests were conducted to determine the location and extent of potential scour in the tailrace channel and to assess the adequacy of riprap along the side slopes. The movable-bed model limits are shown on plate 57 and photograph 79. Model materials used were mason sand (to represent overburden) and crushed gravel with specific gravity of 2.74 (to represent invert rock riprap). Model/prototype gradation curves were closely matched except for the finer fractions of the overburden. Based on past experience with scour modeling, it was concluded that a good representation of overburden scour would be obtained despite the fact that the finer fractions were somewhat coarser in the model than in the prototype. As discussed in paragraph 12, the model rock was loosely placed and was thus more erodible than fractured and keyed prototype rock. A summary of the movable-bed tests performed is presented in table J. These tests included fixed stage flows for various combinations of spillway/power unit operation, plus simulations of the rising limbs of the SPF and PMF hydrographs (see plates 58 and 59).

24. In all fixed-stage tests, movement of overburden, invert rock, and riprap was negligible. Erosion of the invert rock occurred at a discharge of 55,000 cfs on the rising limb of the SPF hydrograph. The scour occurred near the end of the training walls, and the displaced invert rock was deposited both upstream and downstream from the scour zone. The deformation of the tailrace channel continued as the SPF hydrograph progressed to the 67,000-cfs peak discharge. Plate 60 shows the configuration of the tailrace channel after completion of the SPF hydrograph test. Localized scour of the overburden occurred to depths of 4 and 5 feet near the toes of the left and right banks, respectively, causing minor sloughing of the riprap toe protection.

25. Testing with the PMF hydrograph commenced with the bed in the post-SPF condition. Testing was suspended at a discharge of 150,000 cfs due to the significant erosion and deposition which had taken place up to that point (see plate 61 and photographs 80 and 81). The erosion of invert rock was somewhat exaggerated due to its loose

and unkeyed placement which resulted in exaggerated patterns of rock deposition and overburden movement in the tailrace area and the downstream channel. For instance, tests indicated that scour would extend to elevation 2038 in an area 900 feet downstream from the dam; however, bedrock would limit actual scour depth to elevation 2060. Significant rock deposition occurred within 35 feet of the structure (see photograph 81) and near the end of the invert, and scour occurred across the invert near the end of the training walls. Adjacent to the left bank, maximum depth of scour was to elevation 2060 and extended about 400 feet downstream from the end of the invert. This was accompanied by major losses of riprap from the left side slope over a 600-foot reach downstream from the training wall (see photograph 82). Significant erosion occurred along the right bank with deepest scour to elevation 2060 at a distance of 2,600 feet downstream from the dam axis. Minor sloughing of toe riprap occurred about 500 feet upstream from the location of maximum scour.

26. In order to ensure realistic results in the downstream portion of the tailrace channel, the remaining testing was accomplished with the invert rock fixed in place following restoration of the movable bed areas. A constant discharge of 67,000 cfs (SPF peak) was maintained for 134 hours which resulted in a bed configuration quite similar to that created by the SPF hydrograph (paragraph 25). Maximum scour depths in the overburden were about the same with both the constant discharge SPF and SPF hydrograph tests. The fixed invert rock acted to limit the amount of bed material available for transport downstream, so that generally less shoaling and scouring occurred during the constant discharge case (see plate 62) and no failure of riprap was evident. Testing with the PMF hydrograph commenced with the model in the configuration resulting from the 67,000-cfs (constant discharge) test with fixed invert rock. At a discharge of 150,000 cfs, minor movement of side-slope riprap occurred near the ends of the training walls with some of the eroded material being swept upstream toward the structure. At 180,000 cfs, more extensive failure of riprap occurred along the left bank with subsequent deposition of rock adjacent to the left training wall near its midpoint (see

photographs 83 and 84). Sloughing of toe riprap occurred along the right bank at a point 2,100 feet downstream from the dam axis. Plate 63 and photographs 85 and 86 show the model configuration after the peak (210,000 cfs) of the PMF hydrograph. Zones where overburden scour were limited by fixed model boundaries, including the fixed invert rock, are delineated on plate 63.

Riprap Stability

27. Stability of side-slope riprap was tested with SPF and PMF hydrograph events with three different gradations of rock (see plate 64) which had maximum sizes of 500, 750, and 1,000 pounds. Downstream from the structure, riprap was placed for a distance of 2,000 feet along the left bank and 550 feet along the right bank. Riprap was placed two layers thick over a rigid, slightly roughened boundary with a 1V on 2H slope. In the excavated channel area invert rock was fixed and extended beneath the side-slope riprap. Initial movement of rock was monitored during the rising limbs of the SPF and PMF hydrographs. Except in the case of the 1,000-pound rock, testing ceased upon initial failure of the slope protection, and the location and extent of riprap movement were documented. Initial failure was defined as the displacement of a major portion of the riprap blanket; random displacement of a few individual pieces was not considered to be a failure of the revetment system. Initial failure of the 500-pound riprap occurred near the left training wall at the peak of the SPF hydrograph; the location and extent of failure are delineated on plate 65. Failure of the 750-pound rock occurred at a discharge of 105,000 cfs during the PMF event (see plate 66). Initial failure of the 1,000-pound rock took place at 150,000 cfs during the PMF (see plate 67 and photograph 87). Testing with the PMF hydrograph was continued to the peak discharge (210,000 cfs) with the 1,000-pound rock; the results of the testing beyond the point of initial displacement are discussed in paragraph 22. In all cases, initial failure of the revetment occurred at locations where the mean velocity was less than the maximum observed along the toe but where turbulence levels were high.

Miscellaneous

Comprehensive Model Verification

28. The 1:80-scale model of the existing river reach was verified by comparing model water-surface profiles with observed and/or computed prototype water-surface profiles at discharges ranging from 10,000 to 96,000 cfs. A summary of verification data is presented in table K. Gage locations are shown on plates 68 and 69. First-stage dam construction would require the addition of a railroad shoo-fly along the terrace to the left of the channel downstream from the dam (see photograph 88). Water-surface profiles and flow characteristics were again observed with and without the shoo-fly for discharges of 25,000 and 50,000 cfs; no significant deviations from existing conditions were evident.

Second-Stage Diversion

29. Observation was made of the flow patterns with second-stage diversion conditions. With the diversion plan shown on plate 70, flow was passed through skeleton Bays A, B, and C and all spillway bays. Flow distributions are presented on plates 71 through 74 (approach channel) and plate 75 (Plan C tailrace).

PART IV: SUMMARY

30. The Libby Additional Units and Reregulation Dam project was proposed to smooth out rapid fluctuations in Kootenai River flows due to power peaking operations at Libby Dam in northwestern Montana. The project design discharge is 210,000 cfs, and the maximum energy head at this flow is 47.8 feet. Due to space limitations, the power units were located beneath a low-head ogee spillway in a combined powerhouse/spillway configuration. Two sectional models (1:50 and 1:35.33 scale) and a comprehensive model (1:80 scale) were employed to investigate powerhouse/spillway hydraulic performance and to ensure acceptable flow conditions in the approach channel and tailrace areas.

31. The addition of a flow deflector on the downstream lip of the spillway and the deepening of the downstream portion of the tailrace allowed adequate energy dissipation to occur while minimizing aeration caused by plunging of spillway flow into the tailrace; these modifications also resulted in a reduction of 17 feet in the depth of tailrace excavation adjacent to the structure. Tailrace training walls were revised to eliminate flow instability and potential bank erosion problems. Modifications to spillway details included the adaptation of a simplified pier-nose shape, the addition of bulkhead and emergency gate slot covers, and the lowering of radial-gate trunnion blocks. Pressure distributions on the piers, spillway crest, power units, and sluices were determined to be acceptable. Approach-flow conditions were improved by revision to the approach-channel geometry, relocation of the second-stage diversion dike, and extension of the spillway left abutment. The addition of a railroad shoo-fly in the left overbank area downstream from the dam had no perceptible effect on water-surface profiles at a discharge of 50,000 cfs.

TABLE A

PLAN B SPILLWAY TEST SUMMARY

Total Discharge (cfs)	Discharge Per Bay (cfs)	Tailwater Elevation (ft)	Control	Tailrace Design
10,000	2,000	2076.10	Gated	Preliminary
28,500	5,700	2081.00	Gated	Preliminary and Final
44,000	8,800	2083.80	Gated	Preliminary and Final
50,000	10,000	2084.75	Gated	Preliminary and Final
67,000	13,400	2087.30	Gated	Preliminary and Final
70,000	14,000	2087.70	Gated	Preliminary
5,000	1,000	2074.10	Ungated	Preliminary
28,500	5,700	2081.00	Ungated	Preliminary
50,000	10,000	2084.75	Ungated	Preliminary
100,000	20,000	2091.40	Ungated	Preliminary
150,000	30,000	2096.90	Ungated	Preliminary
210,000	42,000	2102.25	Ungated	Preliminary

TABLE B

PIER AND CREST PRESSURES

River discharge 210,000 cfs
Discharge per bay 42,000 cfs
Pool elev 2138.28[1], tailwater elev 2102.25

Piezometer Number[2]	Water-surface Elevations	Pressure in Feet of Water
P 1	2136.5	+61.7
P 2	2135.4	+59.5
P 3	2128.2	+47.6
P 4	2136.1	+61.3
P 5	2134.4	+58.3
P 6	2137.8	+58.7
P 7	2131.8	+51.2
P 8	2129.9	+47.0
P 9	2111.7	+19.8
P10	2102.5	+ 9.5
P11	2102.8	+ 9.6
P12	2105.0	+12.1
P13	2104.9	+12.6

Piezometer Number[2]	Water-surface Elevations	Pressure in Feet of Water
C1	2111.7	+20.3
C2	2101.0	+ 8.5
C3	2100.5	+ 7.8
C4	2104.3	+11.9
C5	2104.4	+12.6
C6	2102.0	+12.2
C7	2101.0	+14.3
C8	2106.2	+28.4
C9	2088.1	+16.6

[1] Energy grade line (EGL) elev 2140.49.

[2] See plate 16 for piezometer locations.

TABLE C

PRESSURES AND HEADS

Plan B Diversion Sluice[1]

Total River Discharge CFS	Diversion Sluice Operation	Total Diversion Discharge CFS	Total Spill Discharge CFS	Pool Elev	Tailwater Elev	Piezometers[1]									Head on Upstream Slot Covers Ft of Water	Head on Downstream Slot Covers Ft of Water
						1	2	3	4	5	6	7	8	9		
						Pressure in Feet of Water										
						Diversion flow only										
16,000	1	16,000	0	2091.0	2078.0	16.4	13.4	11.9	8.2	46.4	48.1	27.2	49.9	63.3	4.5	5.4
26,000	2	26,000	0	2089.3	2080.5	14.4	13.4	9.9	8.2	46.6	48.6	35.8	53.8	66.2	2.5	3.4
39,000	3	39,000	0	2091.7	2080.3	16.8	15.4	12.3	10.4	48.7	50.8	37.7	55.9	68.2	2.9	3.6
						Diversion flow and spill										
19,700	1	17,950	1,750	2094.8	2079.0	20.2	16.1	15.7	10.7	48.7	50.6	23.3	49.7	64.1	5.6	6.7
36,000	1	21,000	15,000	2101.3	2082.4	29.2	23.4	24.4	18.3	55.8	57.7	21.2	52.2	68.3	7.3	7.8
37,283	2	33,700	3,583	2095.9	2082.6	21.3	18.1	16.8	12.8	50.8	52.9	29.5	53.5	67.3	4.7	5.7
56,567	2	29,400	17,167	2101.9	2085.8	27.4	23.0	22.8	18.4	55.8	57.8	28.7	55.9	70.4	5.9	6.1
52,956	3	47,900	5,056	2096.9	2085.2	22.4	19.9	17.9	14.6	52.7	54.8	35.1	56.8	70.3	4.0	5.0
75,378	3	57,100	18,278	2102.6	2088.6	28.0	24.8	23.3	19.6	57.3	59.3	34.2	59.1	73.2	4.7	5.4

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[1] See plate 4 for sluice details and piezometer locations.

TABLE D

POWER UNIT PRESSURES

Original Design Power Unit
Four-unit Operation, Discharge 25,000 CFS

Piezometer Number[1]	Hydraulic Grade Line	Pressure in Feet of Water	Piezometer Number[1]	Hydraulic Grade Line	Pressure in Feet of Water
River discharge 25,000 cfs, spillway closed Pool elev 2130.0, tailwater elev 2080.3					
PU-1	2130.0	55.4	PU-17	2126.4	106.4
PU-2	2129.4	56.3	PU-18	2125.6	116.8
PU-3	2130.0	50.9	PU-20	2106.4[2]	77.5
PU-4	2129.3	51.9	PU-21	2106.4[2]	86.0
PU-5	2128.7	89.5	PU-21A	2106.4[2]	86.0
PU-6	2128.8	91.8	PU-22	2106.4[2]	92.5
PU-7	2129.4	108.9	PU-23	2035.5[2]	6.9
PU-7A	2129.4	108.9	PU-24	2035.5[2]	14.1
PU-8	2129.4	124.4	PU-24A	2035.5[2]	14.1
PU-13	2125.8	92.6	PU-25	2035.5[2]	21.3
PU-14	2125.9	105.9	PU-26	2080.1	41.5
PU-15	2126.1	117.3	PU-27	2080.7	51.7
PU-16	2126.3	93.1	PU-28	2080.6	61.2
River discharge 44,000 cfs, spillway discharge 19,000 cfs Pool elev 2130.0, tailwater elev 2083.8					
PU-1	2130.0	55.4	PU-17	2126.7	106.7
PU-2	2129.5	56.4	PU-18	2125.9	117.1
PU-3	2129.9	50.8	PU-20	2107.7[2]	78.8
PU-4	2129.4	52.0	PU-21	2107.7[2]	87.3
PU-5	2129.1	89.9	PU-21A	2107.7[2]	87.3
PU-6	2129.0	92.0	PU-22	2107.7[2]	93.8
PU-7	2129.5	109.0	PU-23	2040.2[2]	11.6
PU-7A	2129.6	109.1	PU-24	2040.2[2]	18.8
PU-8	2129.6	124.6	PU-24A	2040.2[2]	18.8
PU-13	2126.4	93.2	PU-25	2040.2[2]	26.0
PU-14	2126.2	106.2	PU-26	2082.6	44.0
PU-15	2126.5	117.7	PU-27	2083.3	54.3
PU-16	2126.7	93.5	PU-28	2083.4	64.0

[1] Piezometer locations shown on plate 26.

[2] Average of four-piezometer ring.

TABLE E

POWER UNIT PRESSURES

Original Design Power Unit
Four-unit Operation, Discharge 25,000 CFS

Piezometer Number[1]	Hydraulic Grade Line	Pressure in Feet of Water	Piezometer Number[1]	Hydraulic Grade Line	Pressure in Feet of Water
River discharge 67,000 cfs, spillway discharge 42,000 cfs Pool elev 2130.0, tailwater elev 2087.3					
PU-1	2129.9	55.3	PU-17	2127.1	107.1
PU-2	2129.6	56.5	PU-18	2126.4	117.6
PU-3	2129.8	50.7	PU-20	2108.6[2]	79.7
PU-4	2129.5	52.1	PU-21	2108.6[2]	88.2
PU-5	2129.4	90.2	PU-21A	2108.6[2]	88.2
PU-6	2129.5	92.5	PU-22	2108.6[2]	94.7
PU-7	2129.8	109.3	PU-23	2042.6[2]	14.0
PU-7A	2129.	109.3	PU-24	2042.6[2]	21.2
PU-8	2129.8	124.8	PU-24A	2042.6[2]	21.2
PU-13	2126.6	93.4	PU-25	2042.6[2]	28.4
PU-14	2126.6	106.6	PU-26	2084.0	45.4
PU-15	2126.8	118.0	PU-27	2084.6	55.6
PU-16	2126.9	93.7	PU-28	2084.6	65.2

[1] Piezometer locations shown on plate 26.

[2] Average of four-piezometer ring.

TABLE F

POWER UNIT PRESSURES

Original Design Power Unit
One-unit Operation, Discharge 6,250 CFS

Piezometer Number[1]	Hydraulic Grade Line	Pressure in Feet of Water	Piezometer Number[1]	Hydraulic Grade Line	Pressure in Feet of Water
River discharge 6,250 cfs, spillway closed Pool elev 2130.0, tailwater elev 2074.7					
PU-1	2130.0	55.4	PU-17	2126.0	106.0
PU-2	2129.5	56.4	PU-18	2125.2	116.4
PU-3	2130.0	50.9	PU-20	2103.6[2]	74.7
PU-4	2129.2	51.8	PU-21	2103.6[2]	83.2
PU-5	2128.8	89.6	PU-21A	2103.6[2]	83.2
PU-6	2129.0	92.0	PU-22	2103.6[2]	89.7
PU-7	2129.4	108.9	PU-23	2024.2[2]	- 4.4
PU-7A	2129.5	109.0	PU-24	2024.2[2]	2.8
PU-8	2129.5	124.5	PU-24A	2024.2[2]	2.8
PU-13	2125.6	92.4	PU-25	2024.2[2]	10.0
PU-14	2125.5	105.5	PU-26	2074.3	35.7
PU-15	2125.6	116.8	PU-27	2074.8	45.8
PU-16	2125.9	92.7	PU-28	2074.8	55.4
River discharge 44,000 cfs, spillway discharge 37,750 cfs Pool elev 2130.0, tailwater elev 2083.8					
PU-1	2129.8	55.2	PU-17	2126.6	106.6
PU-2	2129.5	56.4	PU-18	2125.7	116.9
PU-3	2129.8	50.7	PU-20	2105.9[2]	77.0
PU-4	2129.4	52.0	PU-21	2105.9[2]	85.5
PU-5	2129.0	89.8	PU-21A	2105.9[2]	85.5
PU-6	2129.3	92.3	PU-22	2105.9[2]	92.0
PU-7	2129.6	109.1	PU-23	2032.7[2]	4.1
PU-7A	2129.6	109.1	PU-24	2032.7[2]	11.3
PU-8	2129.6	124.6	PU-24A	2032.7[2]	11.3
PU-13	2126.2	93.0	PU-25	2032.7[2]	18.5
PU-14	2126.2	106.2	PU-26	2078.8	40.2
PU-15	2126.4	117.6	PU-27	2079.4	50.4
PU-16	2126.5	93.3	PU-28	2079.5	60.1

[1] Piezometer locations shown on plate 26.

[2] Average of four-piezometer ring.

TABLE G

POWER UNIT PRESSURES

Original Design Power Units
One-unit Operation, Discharge 6,250 CFS

Piezometer Number[1]	Hydraulic Grade Line	Pressure in Feet of Water	Piezometer Number[1]	Hydraulic Grade Line	Pressure in Feet of Water
River discharge 67,000 cfs, spillway discharge 60,750 cfs Pool elev 2130.0, tailwater elev 2087.3					
PU-1	2129.7	55.1	PU-17	2126.8	106.8
PU-2	2129.5	56.4	PU-18	2126.1	117.3
PU-3	2129.5	50.4	PU-20	2106.6[2]	77.7
PU-4	2129.4	52.0	PU-21	2106.6[2]	86.2
PU-5	2128.9	89.7	PU-21A	2106.6[2]	86.2
PU-6	2129.4	92.4	PU-22	2106.6[2]	92.7
PU-7	2129.8	109.3	PU-23	2035.1[2]	6.5
PU-7A	2129.8	109.3	PU-24	2035.1[2]	13.7
PU-8	2129.8	124.8	PU-24A	2035.1[2]	13.7
PU-13	2126.4	93.2	PU-25	2035.1[2]	20.9
PU-14	2126.4	106.4	PU-26	2079.7	41.1
PU-15	2126.6	117.8	PU-27	2080.4	51.4
PU-16	2126.8	93.6	PU-28	2080.4	61.0

[1] Piezometer locations shown on plate 26.

[2] Average of four-piezometer ring.

TABLE H

APPROACH CHANNEL TEST SUMMARY

Powerhouse		Spillway Discharge (cfs)	Total Discharge (cfs)	Pool Elevation (ft)
Units Operating	Discharge (cfs)			
(A,B,C,D)	25,000	--	25,000	2130.0
(A,D)	12,500	31,500	44,000	2130.0
(B,C)	12,500	31,500	44,000	2130.0
(A,B,C,D)	25,000	19,000	44,000	2130.0
	--	44,000	44,000	2130.0
(A,D)	12,500	54,500	67,000	2130.0
(B)	12,500	54,500	67,000	2130.0
(A,B,C,D)	25,000	42,000	67,000	2130.0
	--	67,000	67,000	2130.0
	--	105,000	105,000	2130.0
	--	210,000	210,000	2140.5
(A,D)	12,500	--	12,500	2100.0
(B,C)	12,500	--	12,500	2100.0
(A,B,C,D)	25,000	--	25,000	2100.0

TABLE I

TAILRACE FLOW CONDITIONS

Powerhouse		Spillway	
Units Operating	Discharge (cfs)	Bays Operating	Discharge (cfs)
(A,B,C,D)	25,000	--	--
--	--	(A,B,C,D,E)	50,000
--	--	(A,B,C,D,E)	67,000
--	--	(A,B,C,D,E)	105,000
--	--	(A,B,C,D,E)	210,000
--	--	(A)	5,000
--	--	(A)	12,500
--	--	(A)	29,700
--	--	(C)	29,700
--	--	(A,B,C)	44,000

TABLE J

TAILRACE MOVABLE-BED TEST SUMMARY

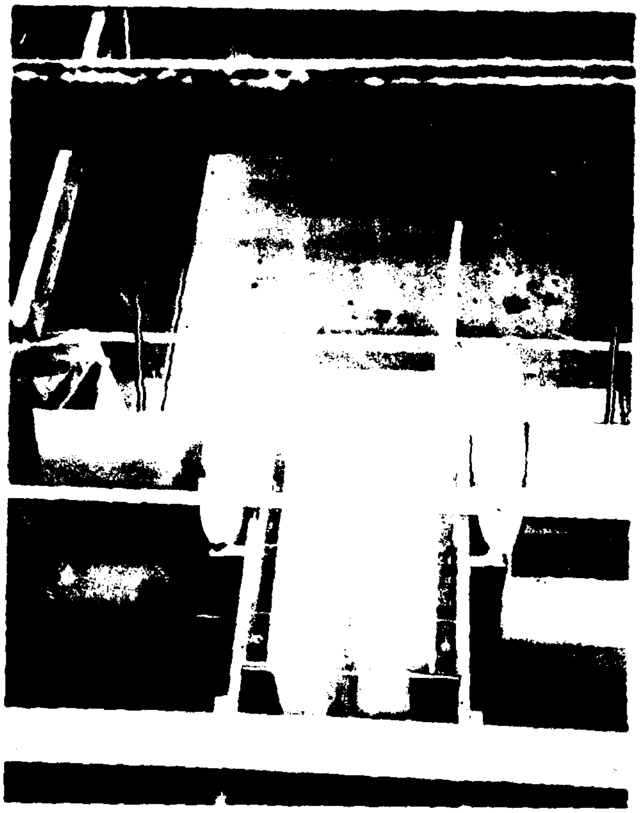
Flow Condition	Test Configuration
PMF Hydrograph	Spillway Only (Bays A to E)
SPF Hydrograph	Spillway Only (Bays A to E)
67,000 cfs (SPF Peak)	Spillway Only (Bays A to E)
50,000 cfs	Power Units A to D; Spillway Bays A to E
44,000 cfs	Power Units A to D; Spillway Bays A to E
44,000 cfs	Skeleton Bays A, B, C; Spillway Bays A to E
25,000 cfs	Power Units A to D

TABLE K

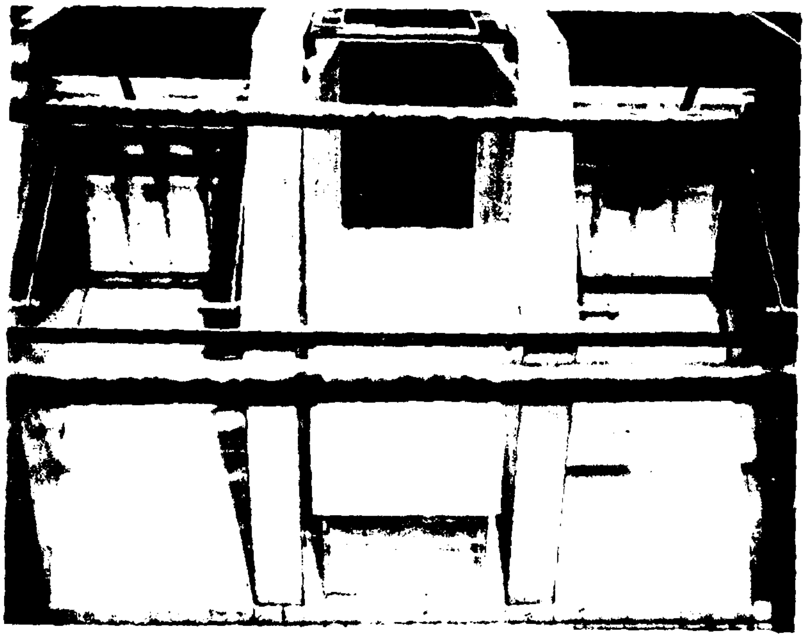
WATER-SURFACE ELEVATIONS
Kootenai River

River Mile	Gage No.	Water Surface					
		Prototype Elev	Model Elev	Difference ft	Prototype Elev	Model Elev	Difference ft
		River Discharge 10,000 cfs			River Discharge 22,200 cfs		
206.4	TW		2067.3			2070.3	
206.6	SS	2067.3	2067.3	0	2070.5	2070.5	0
207.2	QQ	2069.0	2069.0	0	2072.5	2072.3	-0.2
207.8	PP	2071.7	2071.5	-0.2	2074.9	2074.8	-0.1
208.0	OO	2073.6	2073.7	+0.1	2076.3	2076.3	0
208.6	HH-1	2075.1	2075.3	+0.2	2077.9	2077.9	0
209.1	DD	2076.7	2077.0	+0.3	2079.5	2079.4	-0.1
		River Discharge 40,000 cfs			River Discharge 65,000 cfs		
206.4	TW		2073.3			2076.9	
206.6	SS	2073.8	2073.8	0	2077.6	2077.6	0
207.2	QQ	2076.0	2076.2	+0.2	2080.2	2080.2	0
207.8	PP	2078.3	2078.4	+0.1	2082.1	2082.1	0
208.0	OO	2079.3	2079.4	+0.1	2083.0	2082.8	-0.2
208.6	HH-1	2080.9	2081.0	+0.1	2084.3	2084.2	-0.1
209.1	DD	2082.6	2082.6	0	2086.2	2086.0	-0.2
		River Discharge 96,000 cfs					
206.4	TW		2081.2				
206.6	SS	2082.0	2082.0	0			
207.2	QQ	2085.0	2084.9	-0.1			
207.8	PP	2086.6	2086.6	0			
208.0	OO	2087.2	2087.1	-0.1			
208.6	HH-1	2088.2	2087.8	-0.4			
209.1	DD	2090.5	2089.7	-0.8			

Gage locations shown on plates 68 and 69.



Overhead view



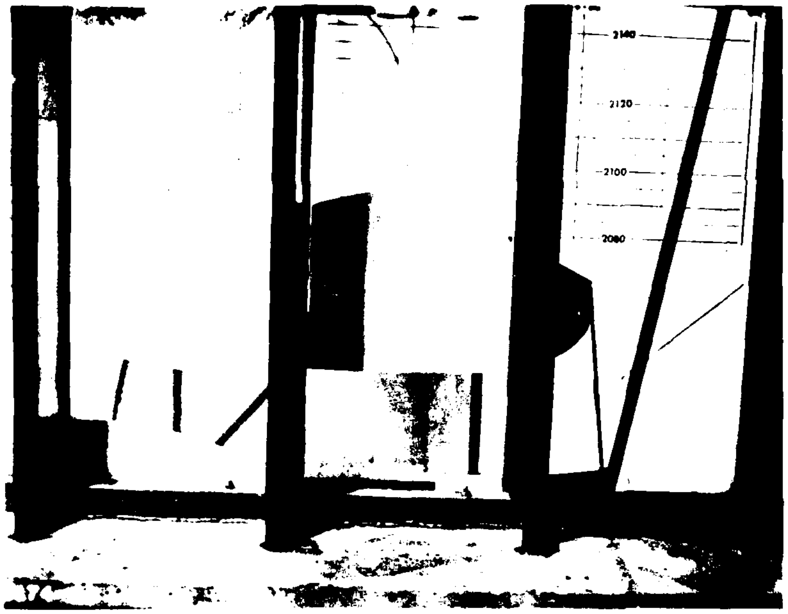
Downstream view

Photograph 1. 1:50-scale spillway model

Photograph 2. Side view

Photograph 3. Upstream oblique view

1:35.33-scale model, original design

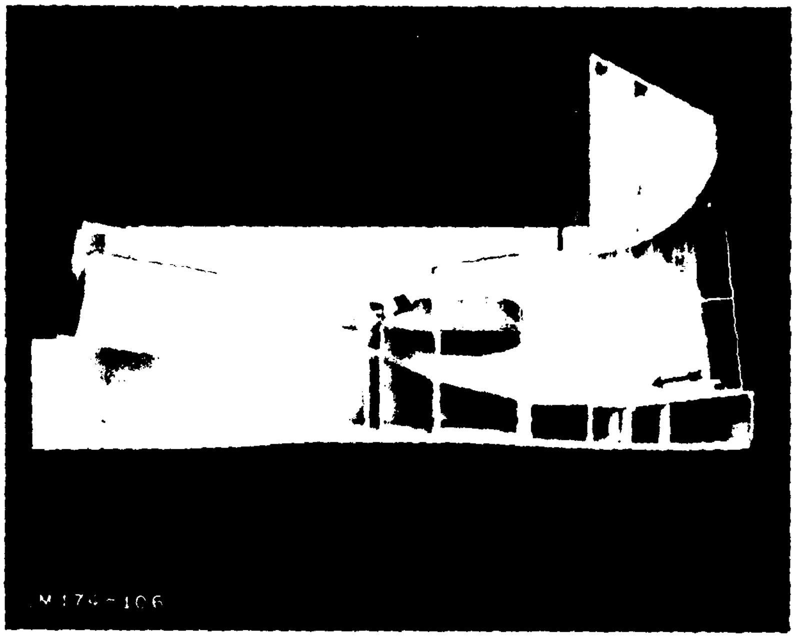


Photograph 4. Side view of diversion sluice

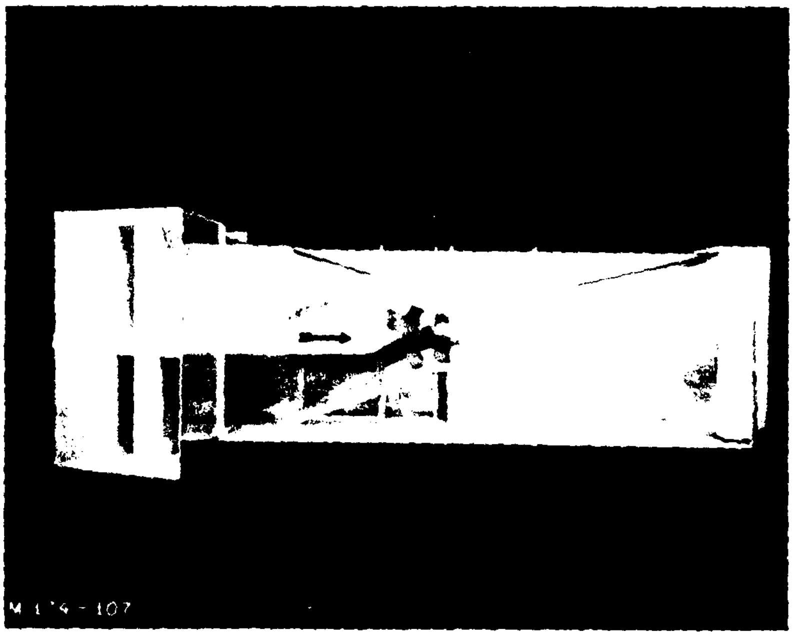
Photograph 5. Downstream face

Photograph 6. Upstream face

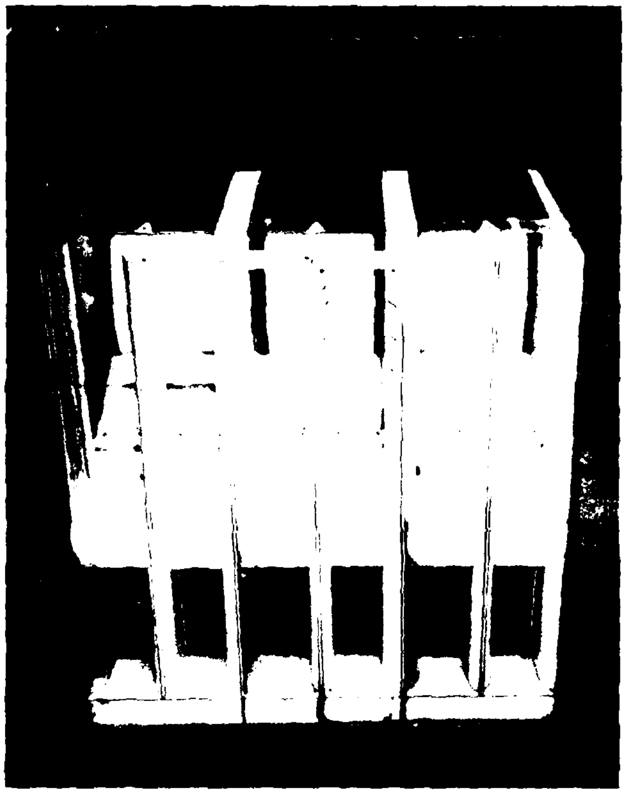
Diversion sluice, dry bed



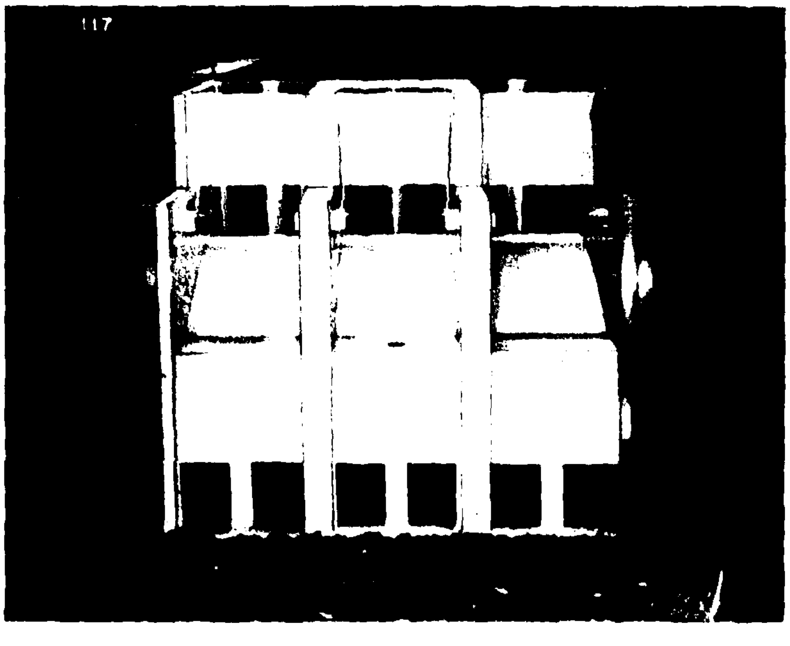
Photograph 7. Side view of power unit model



Photograph 8. Overhead view of power unit model



Photograph 9. Upstream view



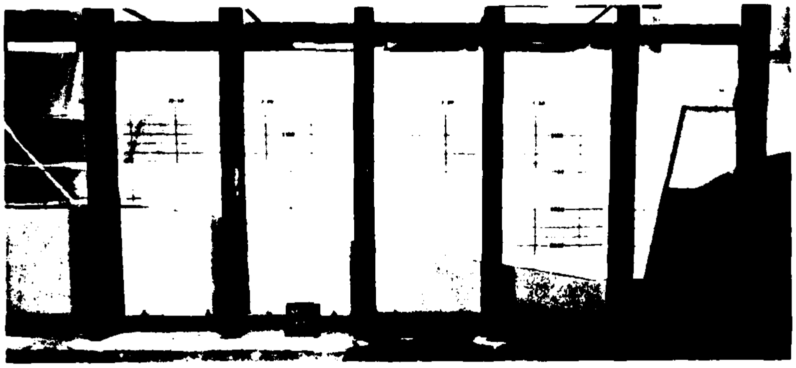
Photograph 10. Downstream view

1:35.33-scale model with power units installed

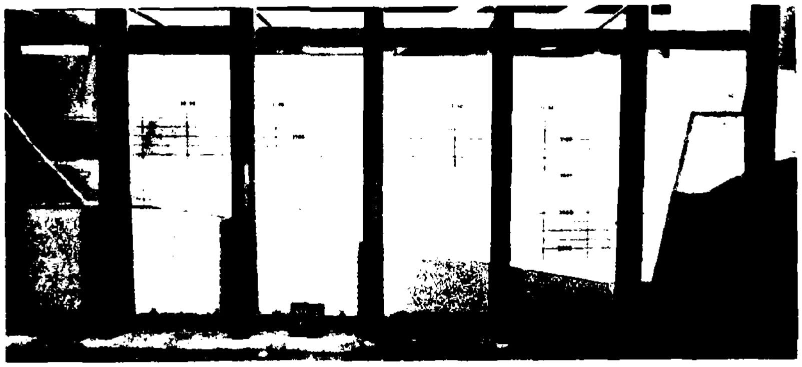
Photograph 11. Discharge per bay 2,000 cfs;
river discharge 10,000 cfs;
tailwater elevation 2076.10

Photograph 12. Discharge per bay 5,700 cfs;
river discharge 28,500 cfs;
tailwater elevation 2081.00

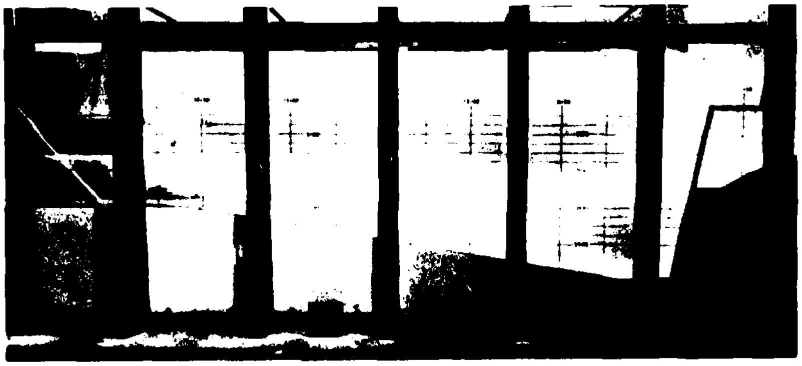
Flow conditions in preliminary tailrace with gated spillway operation



Photograph 13. Discharge per bay 8,800 cfs; river discharge 44,000 cfs; tailwater elevation 2083.80

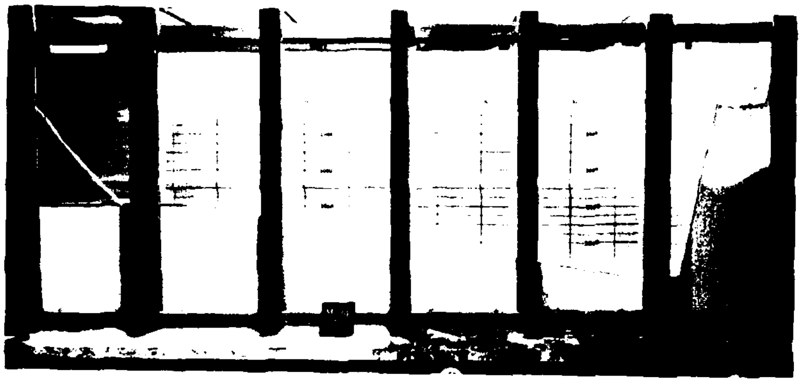


Photograph 14. Discharge per bay 10,000 cfs; river discharge 50,000 cfs; tailwater elevation 2084.75

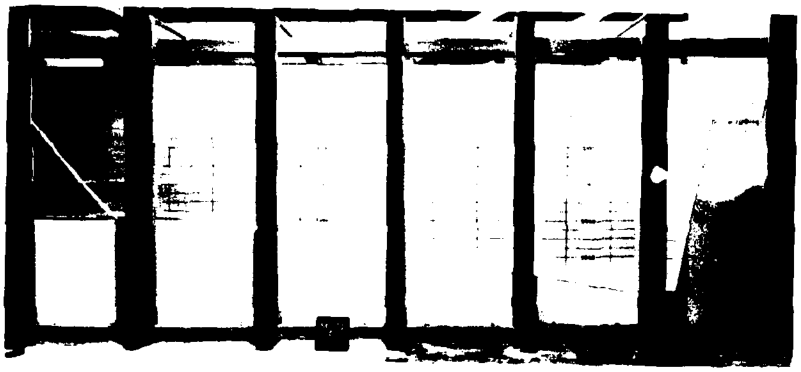


Photograph 15. Discharge per bay 14,000 cfs; river discharge 70,000 cfs; tailwater elevation 2087.70

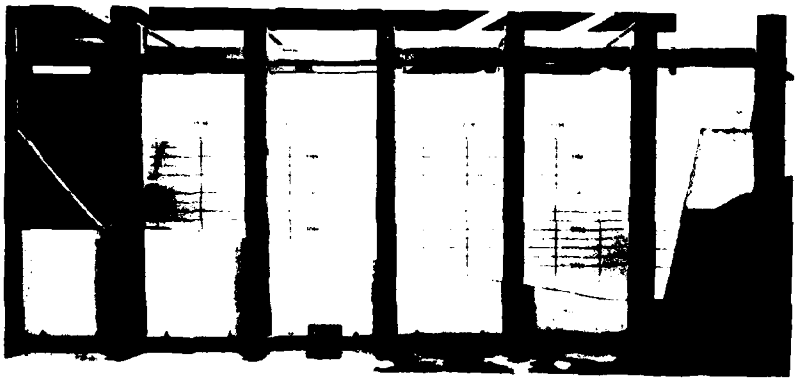
Flow conditions in preliminary tailrace with gated spillway operation



Photograph 16. Discharge per bay 1,000 cfs;
river discharge 5,000 cfs;
tailwater elevation 2074.10



Photograph 17. Discharge per bay 5,700 cfs;
river discharge 28,500 cfs;
tailwater elevation 2081.00

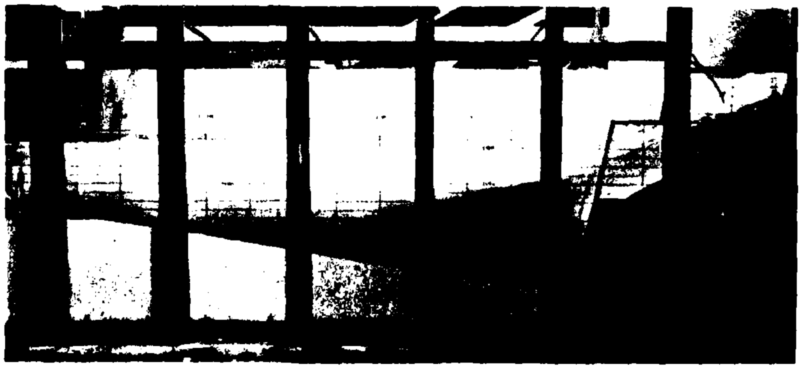


Photograph 18. Discharge per bay 10,000 cfs;
river discharge 50,000
tailwater elevation 2084.75

Flow conditions in preliminary tailrace with ungated spillway operation

Photograph 19. Discharge per bay 20,000 cfs; river discharge 100,000 cfs; tailwater elevation 2091.40

Photograph 20. Discharge per bay 30,000 cfs; river discharge 150,000 cfs; tailwater elevation 2096.90



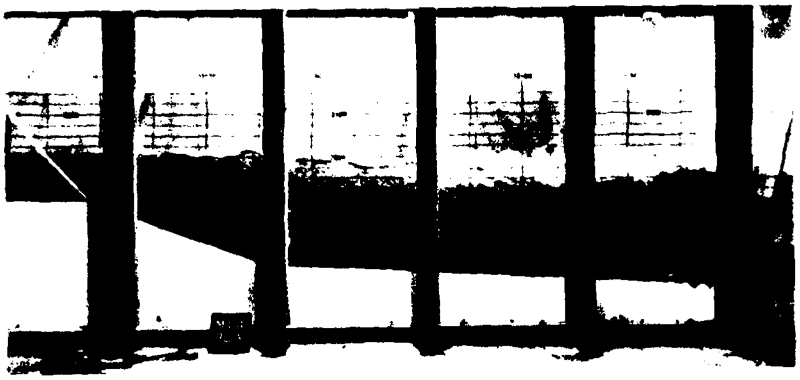
Photograph 21. Discharge per bay 42,000 cfs: river discharge 210,000 cfs; tailwater elevation 2102.25

Flow conditions in preliminary tailrace with ungated spillway operation

Photograph 22. Unstable flow in preliminary tailrace; 25-foot long horizontial deflector with river discharge 210,000 cfs; discharge per bay 42,000 cfs; tailwater elevation 2102.25

Photograph 23. Dry bed of final design tailrace runout showing movable bed

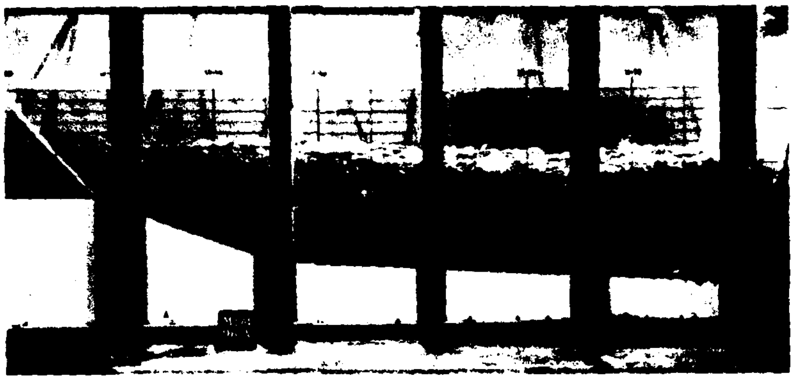
Photograph 24. Gated spillway operation; pool elevation 2120



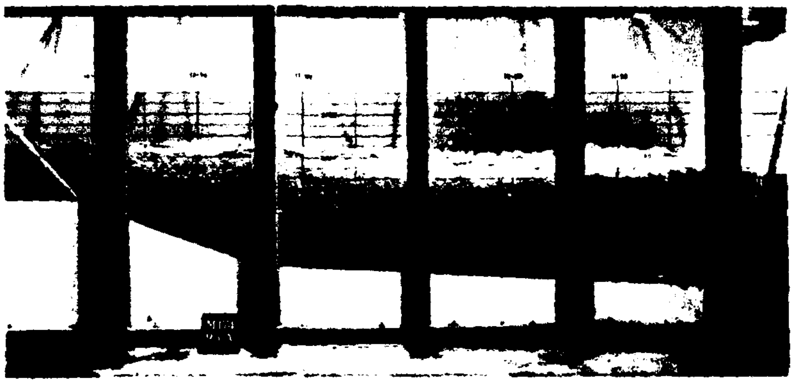
Photograph 25. Gated spillway operation; pool elevation 2130

Photograph 26. Ungated spillway operation; pool elevation 2105.1

Flow conditions in final design tailrace with river discharge 28,500 cfs (5,700 cfs/bay)



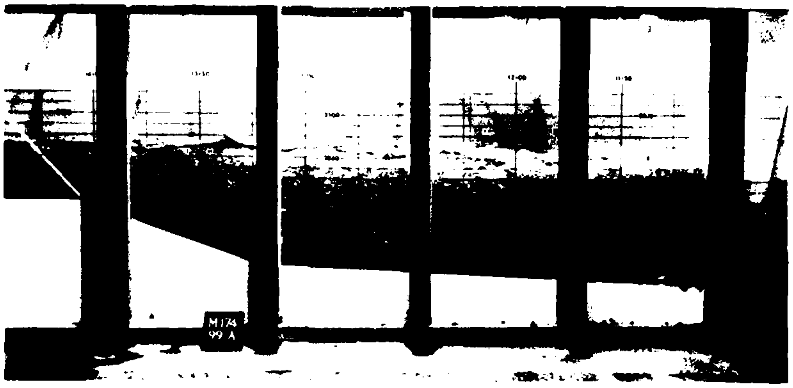
Photograph 27. Gated spillway operation;
pool elevation 2120



Photograph 28. Gated spillway operation;
pool elevation 2130

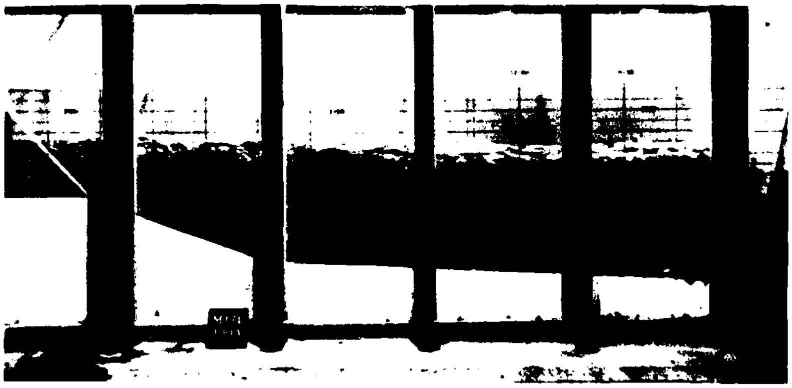
Photograph 29. Ungated spillway operation;
pool elevation 2109

Flow conditions in final design tailrace with river discharge 44,000 cfs (8,800 cfs/bay)



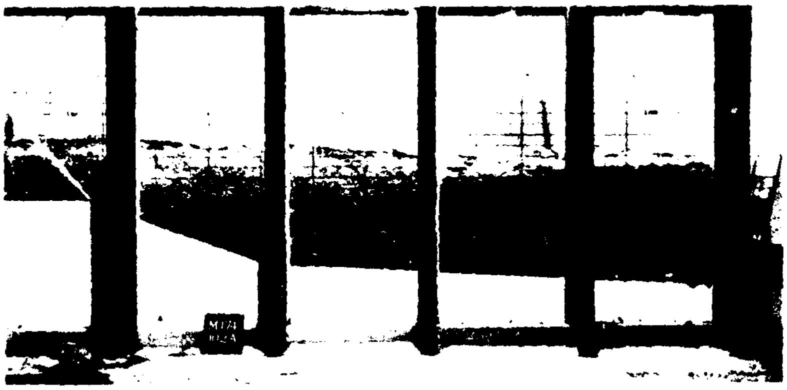
Photograph 30. Gated spillway operation;
pool elevation 2120

Photograph 31. Gated spillway operation;
pool elevation 2130



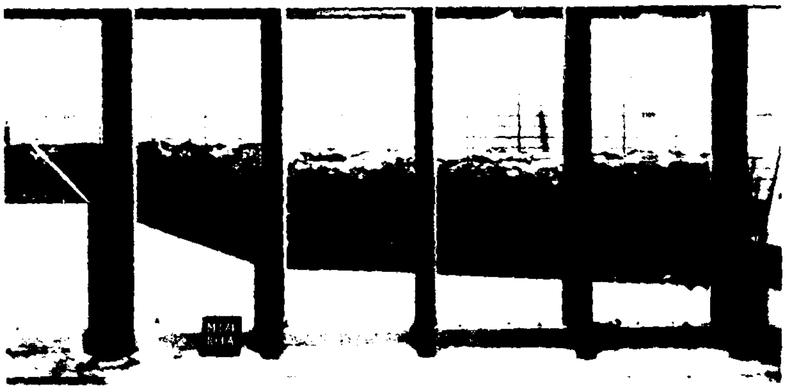
Photograph 32. Ungated spillway operation;
pool elevation 2110.3

Flow conditions in final design tailrace with
river discharge 50,000 cfs (10,000 cfs/bay)



Photograph 33. Gated spillway operation;
pool elevation 2120

Photograph 34. Gated spillway operation;
pool elevation 2130



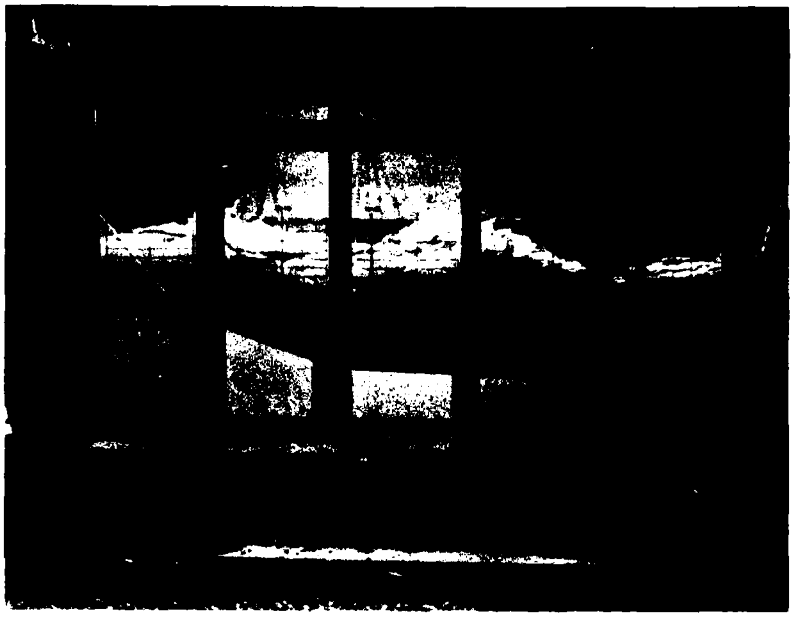
Photograph 35. Ungated spillway operation;
pool elevation 2113.8

Flow conditions in final design tailrace with SPF, discharge 67,000 cfs (13,400 cfs/bay)

Photograph 36. Flow conditions

Photograph 37. Bed configuration following 6-hour test

Final design tailrace with river discharge 105,000 cfs (21,000 cfs/bay)



Photograph 38. Flow conditions

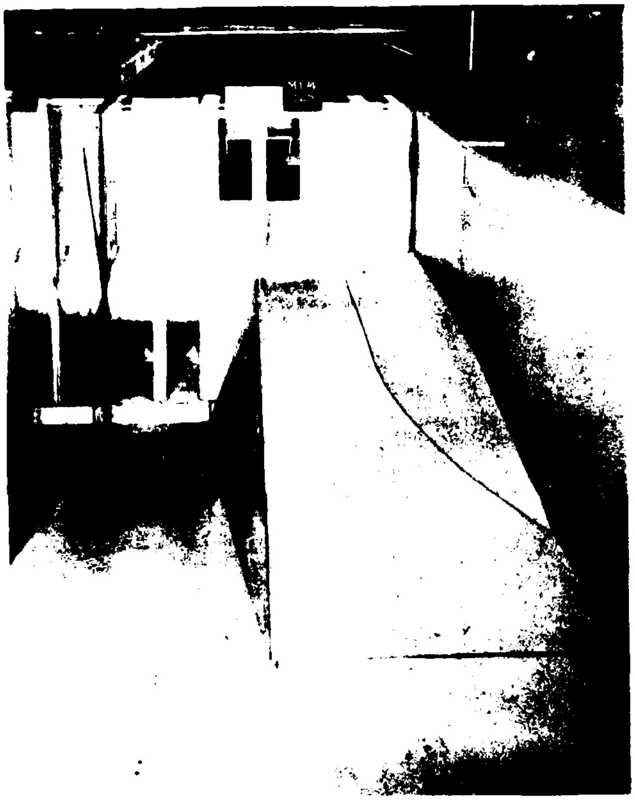
Photograph 39. Bed configuration following 6-hour test

Final design tailrace with PMF discharge
210,000 cfs (42,000 cfs/bay)

Photograph 40. Upstream view

Photograph 41. Downstream view

Flow conditions with 14-foot wide spillway pier between Bays D and E, SPF discharge (67,000 cfs)



Photograph 42. Upstream view of final design spillway approach upstream of Bays D and E

Photograph 43. Bay E operating

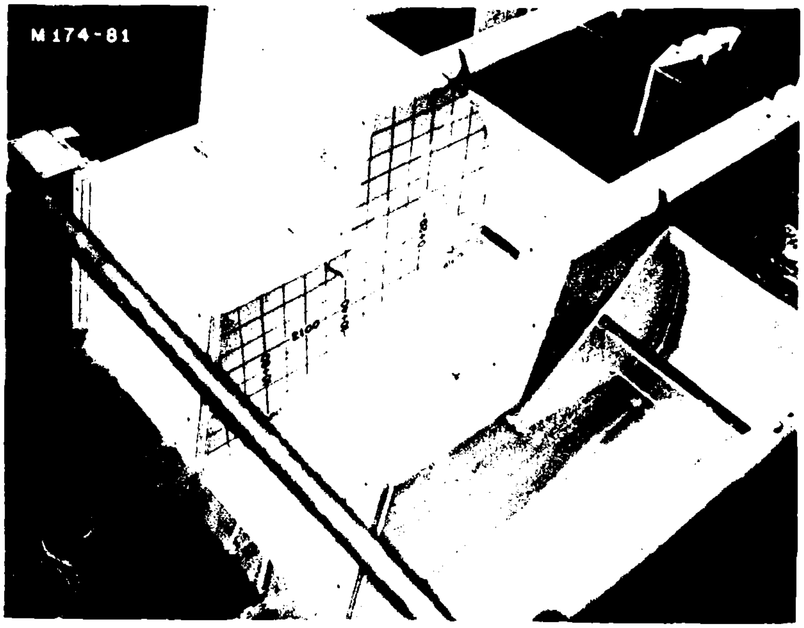
Photograph 44. Bays D and E operating

Spillway flow conditions with final design approach, pool elevation 2113.8, SPF condition (13,400 cfs/bay)

Photograph 45. Bay E operating

Photograph 46. Bays D and E operating

Spillway flow conditions with final design approach, PMF condition (42,000 cfs/bay)



Photograph 47. Ungated flow nappe profile (not final design trunnion location)

Photograph 48. Gate controlled operation at pool elevation 2130

Spillway flow condition with SPF (13,400 cfs/bay)

Photograph 49. No spillway discharge;
river discharge 25,000 cfs

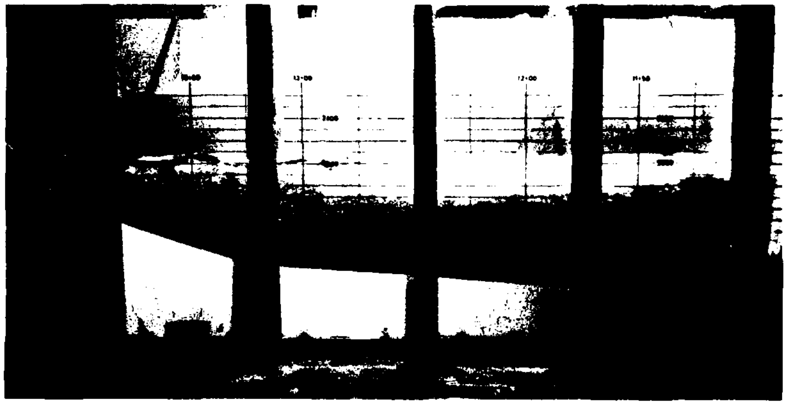
Photograph 50. Spillway discharge 19,000 cfs;
river discharge 44,000 cfs

Photograph 51. Spillway discharge 42,000 cfs;
river discharge 67,000 cfs

Flow conditions in final design tailrace with pool elevation 2130 and power discharge 25,000 cfs (4-units)

Photograph 52. Flow condition immediately downstream of spillway with combined spillway/powerhouse operation at pool elevation 2130; spillway discharge 42,000 cfs; powerhouse discharge 25,000 cfs;

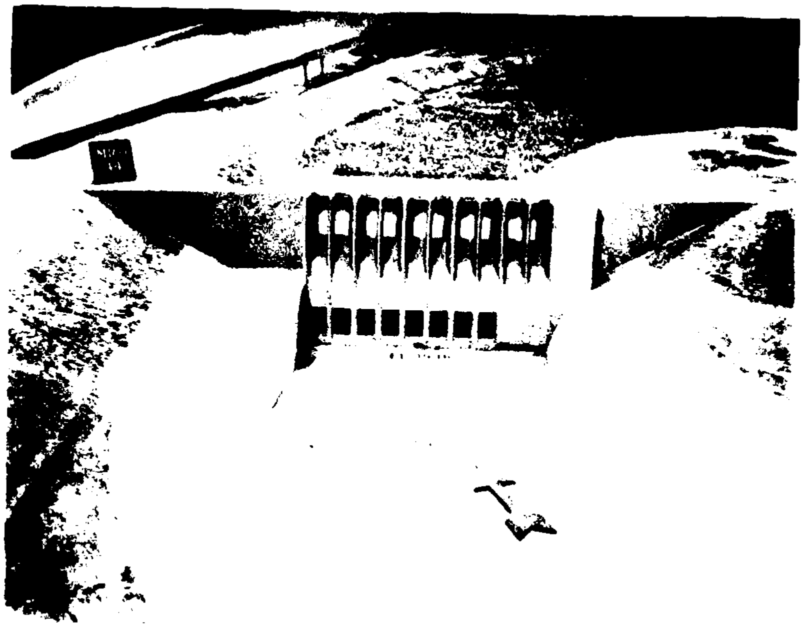
Photograph 53. No spillway discharge;
river discharge 6,250 cfs



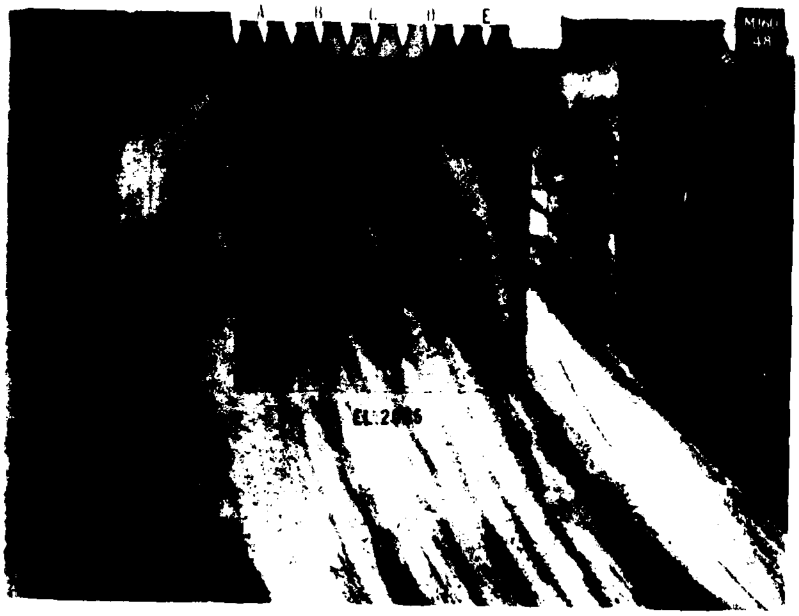
Photograph 54. Spillway discharge 37,750 cfs;
river discharge 44,000 cfs

Photograph 55. Spillway discharge 60,750 cfs;
river discharge 67,000 cfs

Flow conditions in final design tailrace with pool elevation 2130 and power discharge 6,250 cfs (1-unit)

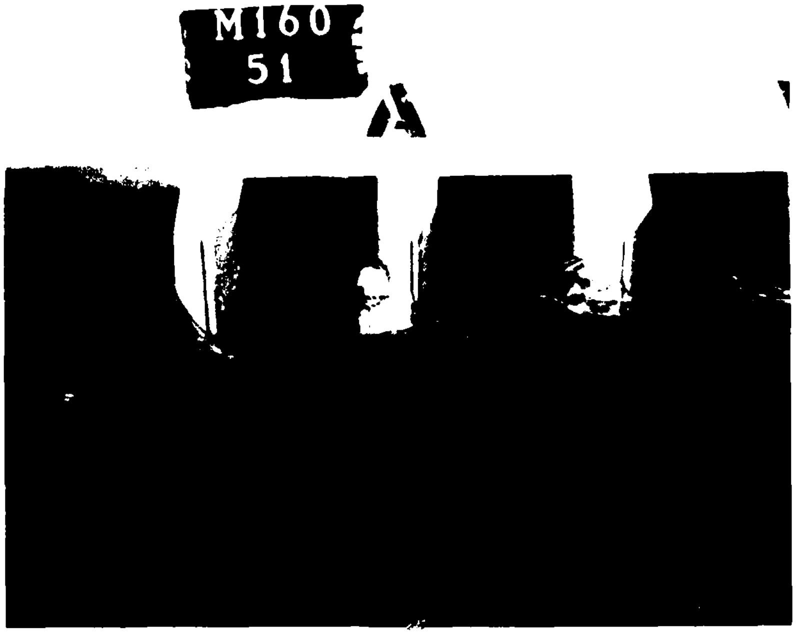


Photograph 56. Dry bed

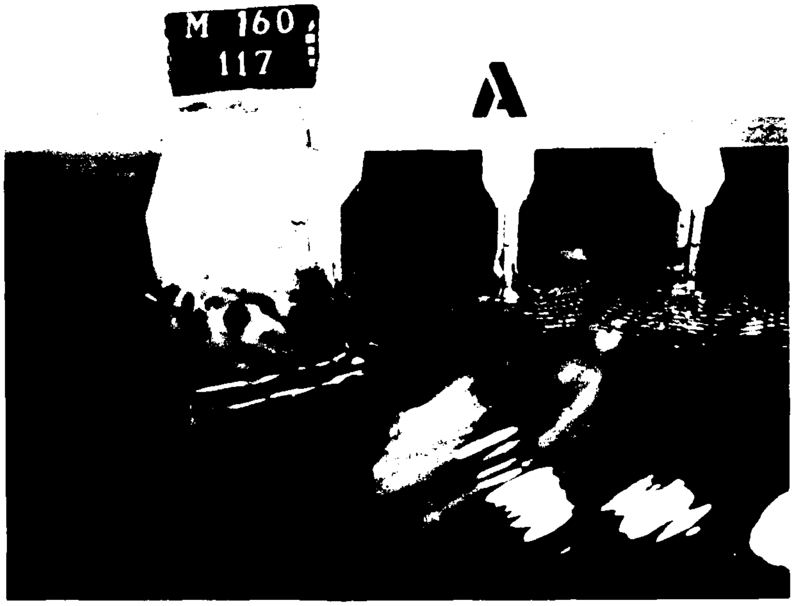


Photograph 57. Approach flow condition, powerhouse discharge 25,000 cfs

Original design approach channel



Photograph 58. Original design abutment

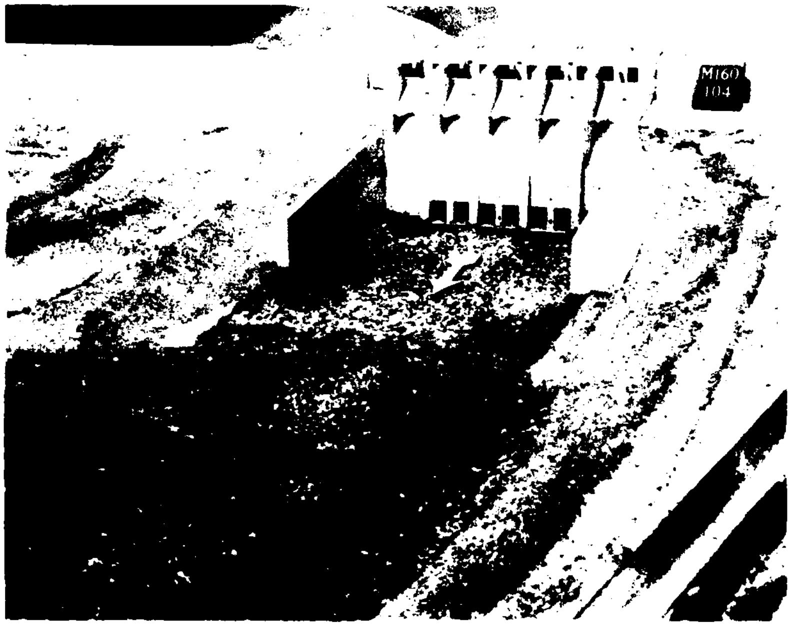


Photograph 59. Final design abutment

Approach flow condition at left abutment
of spillway with PMF condition (210,000 cfs)

Photograph 60. Plan B tailrace showing side eddy and return flow overtopping of training wall.

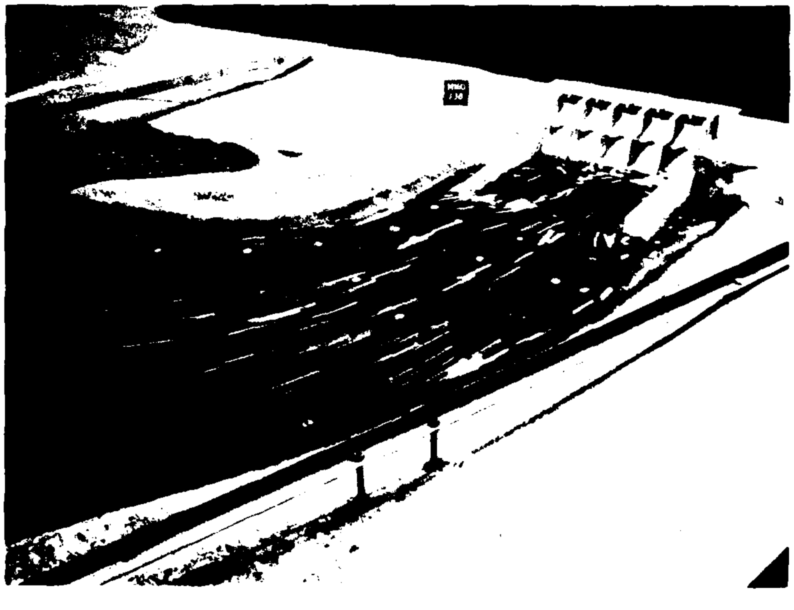
Photograph 61. Overhead view



Photograph 62. Upstream view

Dry bed of final design tailrace with 200-foot long training walls. Fragmented bed rock simulated by loose rock.

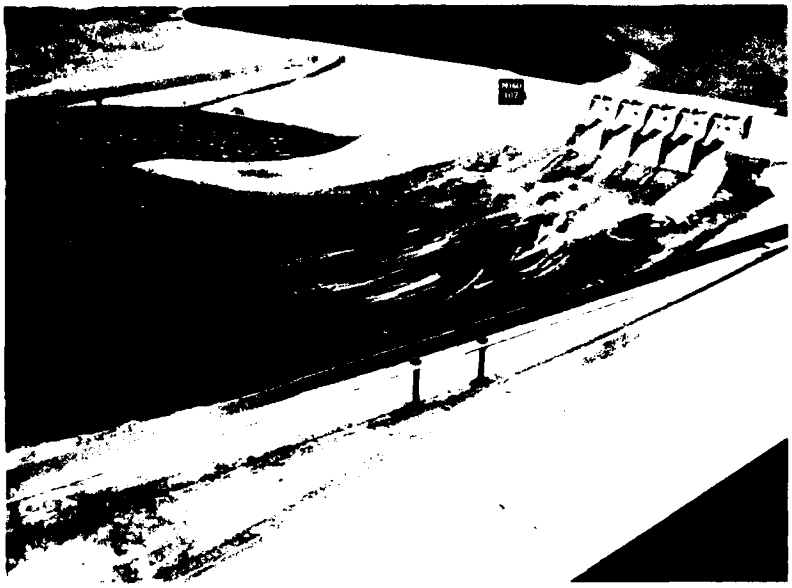
Photograph 63. Aerial view



Photograph 64. Upstream view

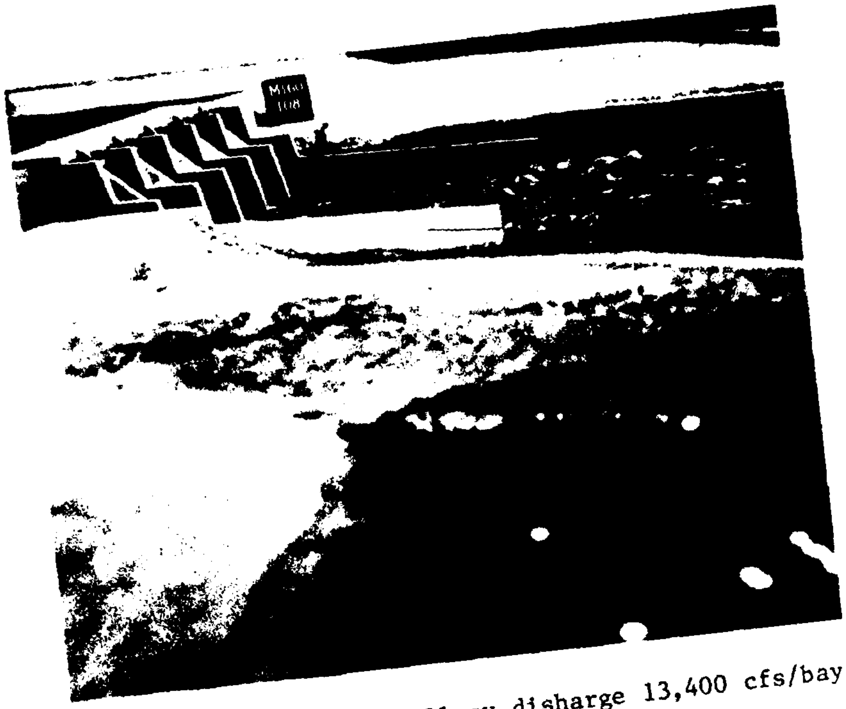
Surface flow conditions in final design tailrace with uniform powerhouse operation at maximum hydraulic capacity (25,000 cfs) and pool elevation 2130; no spillway discharge

Photograph 65. Aerial view

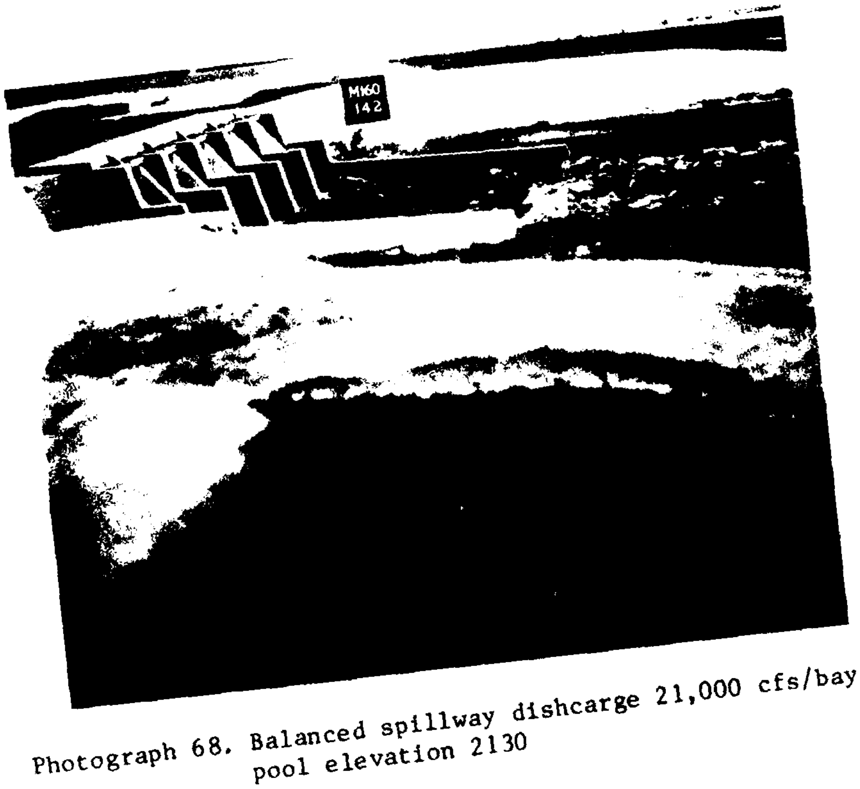


Photograph 66. Upstream view

Surface flow conditions in final design tailrace with balanced spillway operation at SPF (67,000 cfs) and pool elevation 2130; no power discharge

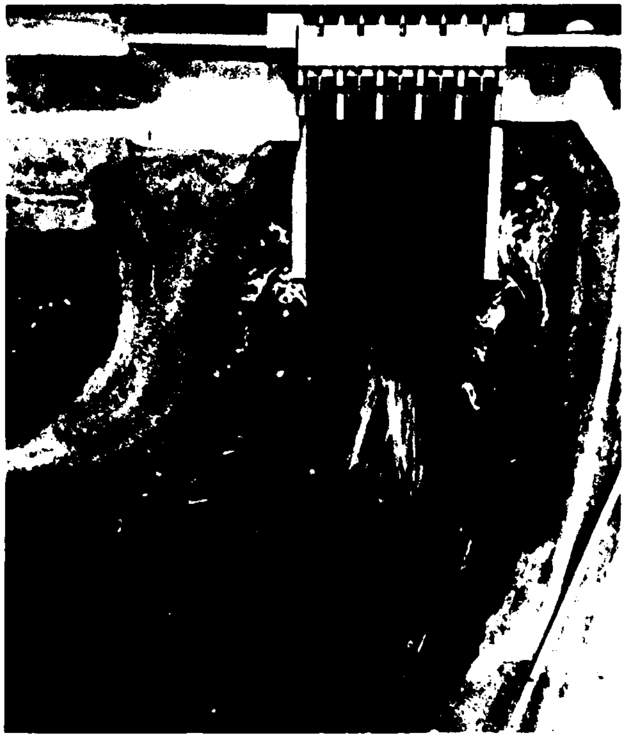


Photograph 67. Balanced spillway disharge 13,400 cfs/bay; pool elevation 2130

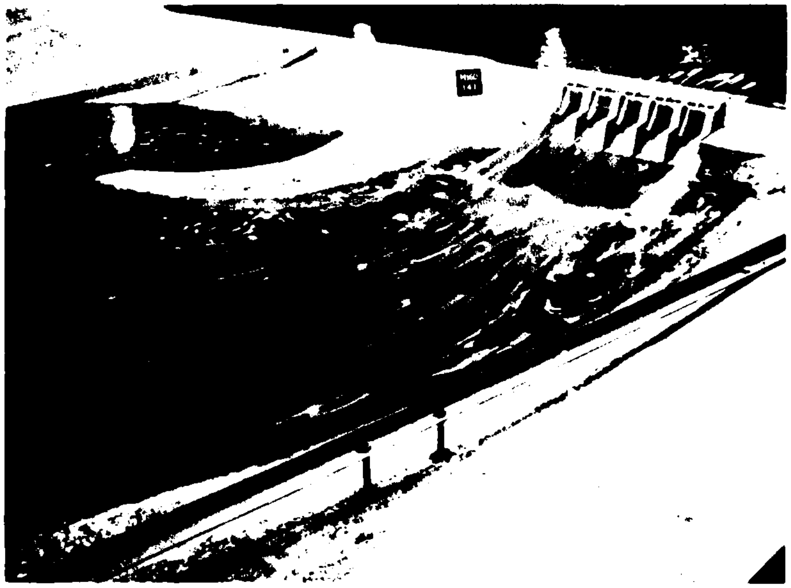


Photograph 68. Balanced spillway dishcarge 21,000 cfs/bay; pool elevation 2130

Surface flow conditions in final design tailrace; no power discharge

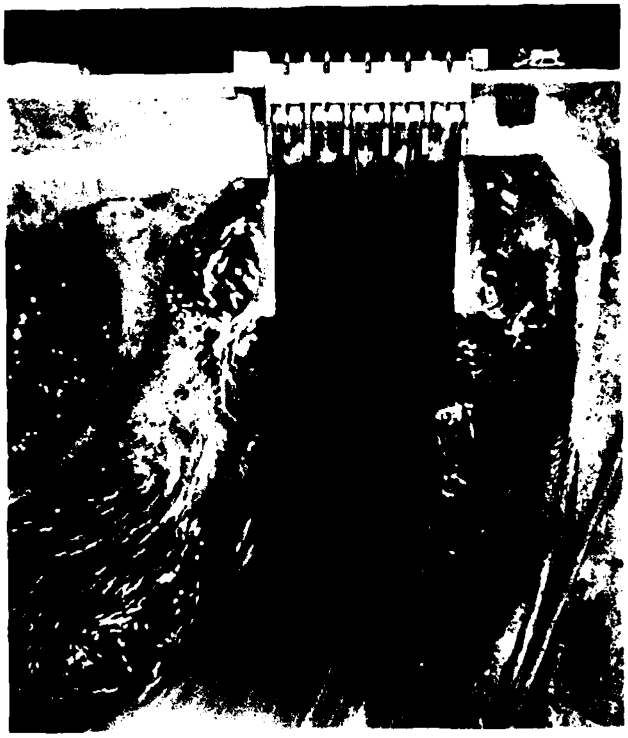


Photograph 69. Aerial view



Photograph 70. Upstream view

Surface flow conditions in final design tailrace with balanced spillway operation at 105,000 cfs and pool elevation 2130; no power discharge

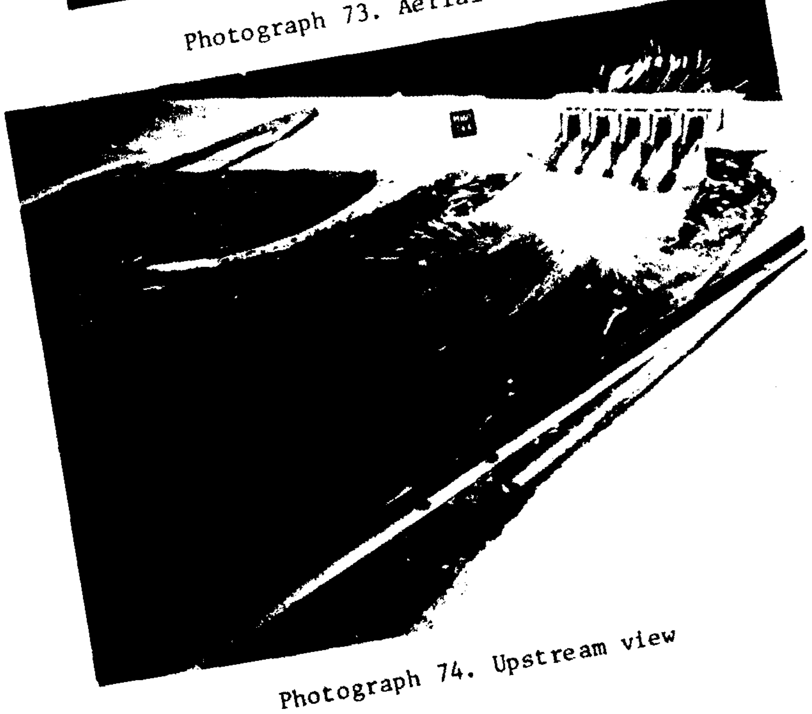


Photograph 71. Aerial view

Photograph 72. Upstream view

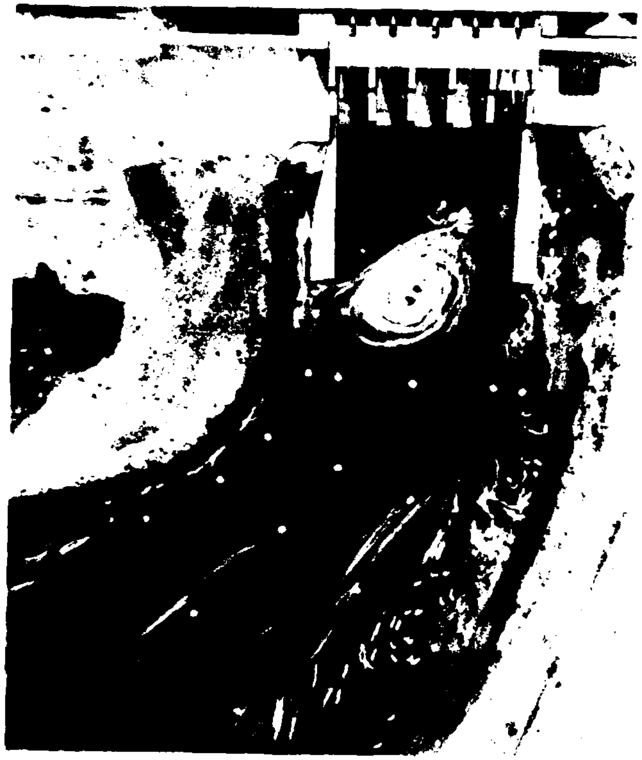
Surface flow conditions in final design tailrace with
PMF discharge 210,000 cfs and tailwater elevation 2102.2

Photograph 73. Aerial view

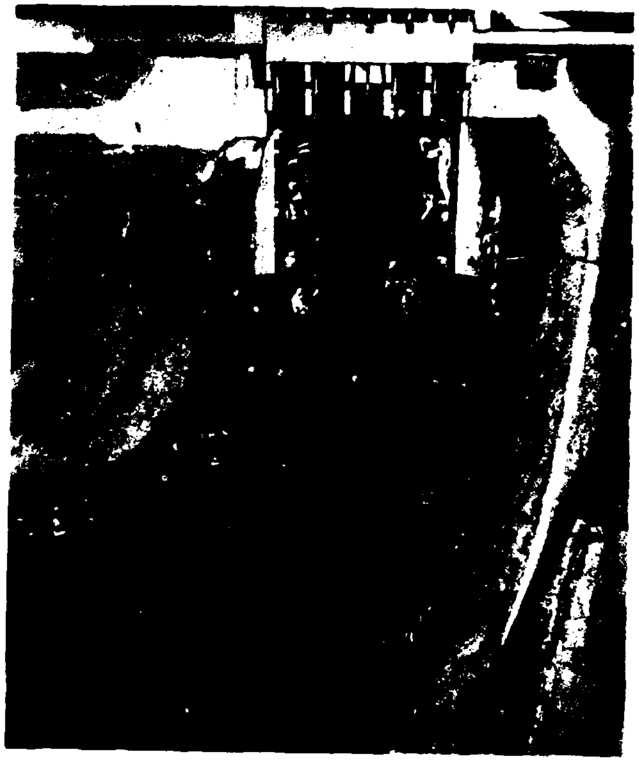


Photograph 74. Upstream view

Surface flow conditions in final design tailrace with PMF discharge 210,000 cfs and tailwater elevation 2100.5

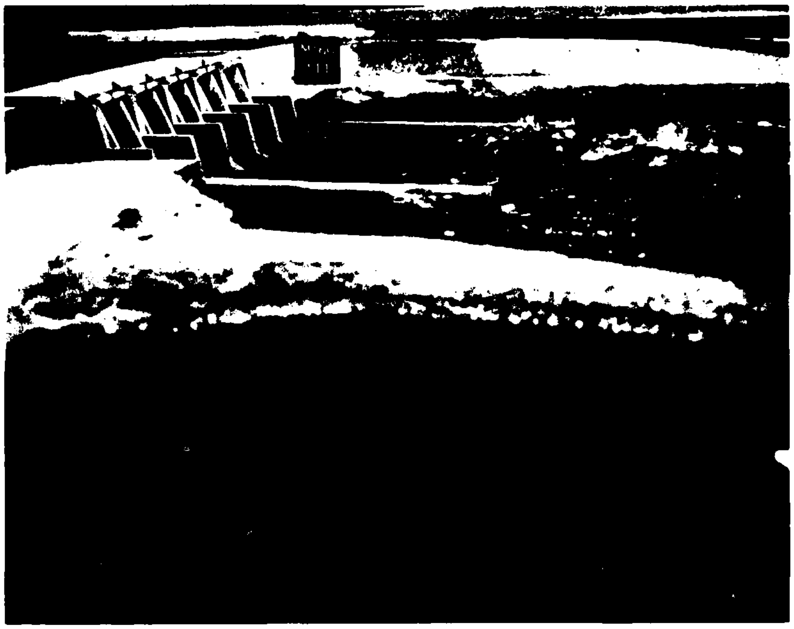


Photograph 75. Bay A operating

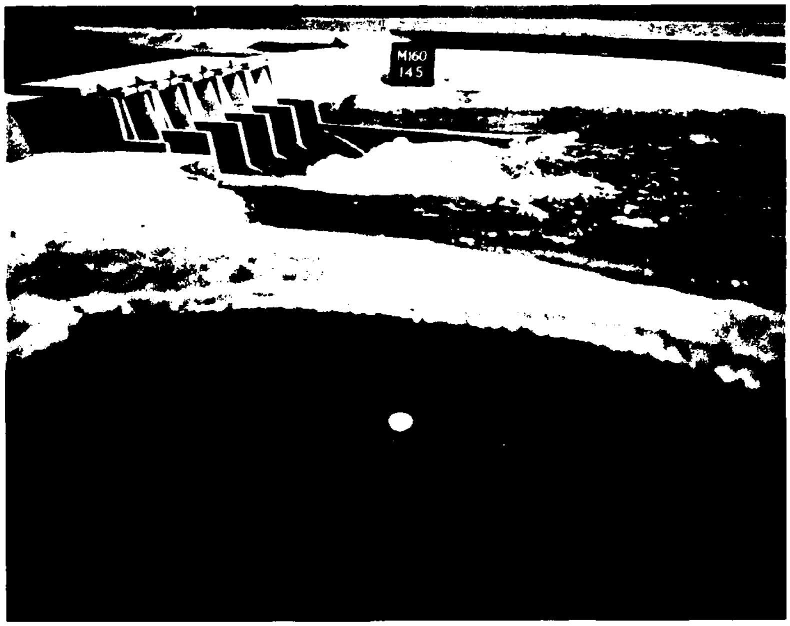


Photograph 76. Bay C operating

Flow conditions in final design tailrace with unbalanced spillway operation; discharge 29,700 cfs; pool elevation 2130; no powerhouse discharge

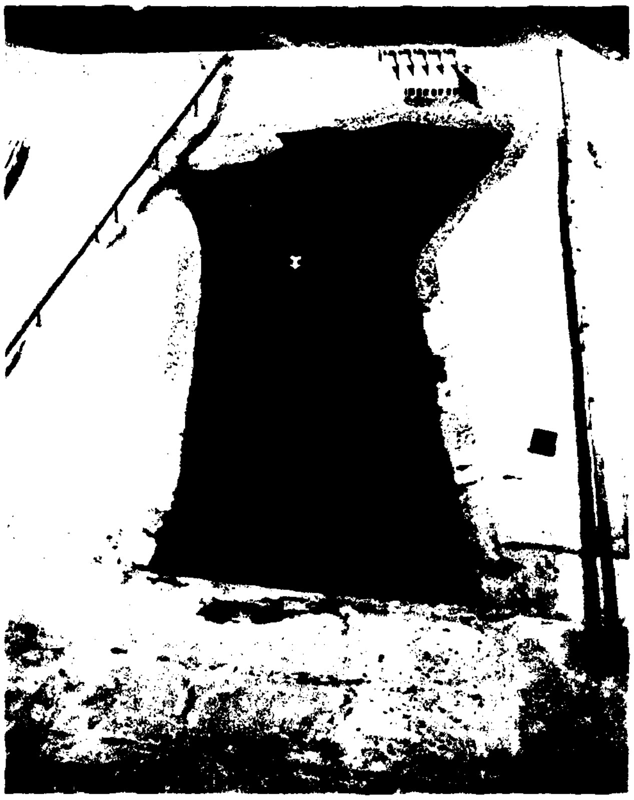


Photograph 77. Tailwater elevation 2102.2;
spillway discharge 210,000 cfs



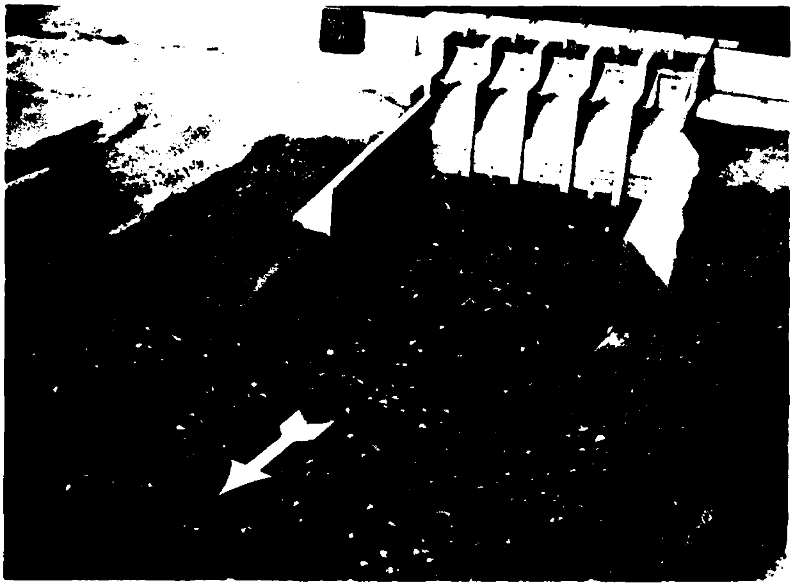
Photograph 78. Tailwater elevation 2100.5;
spillway discharge 210,000 cfs

Surface flow conditions in final design tailrace
showing tailwater influence on skimming or plunging flow



Photograph 79. Movable bed in 1:80-scale model

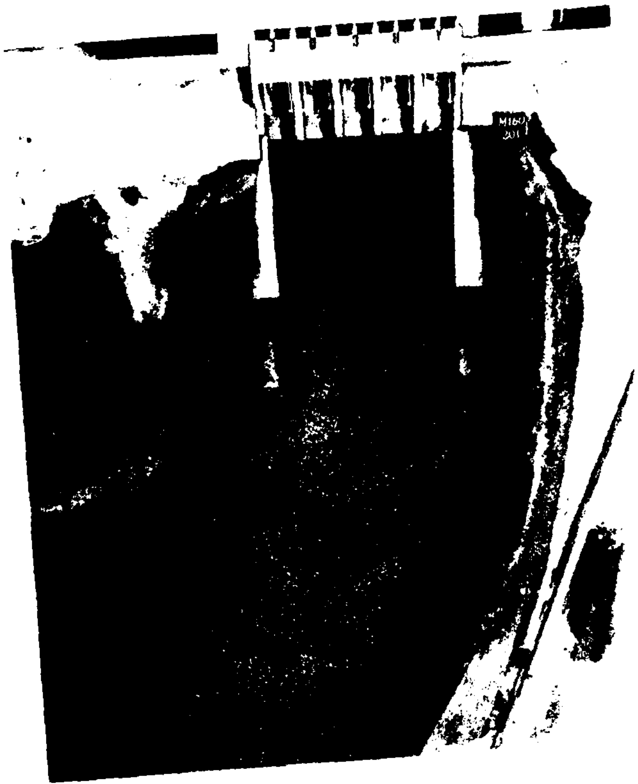
Photograph 80. Downstream channel after 150,000 cfs



Photograph 81. Tailrace after 150,000 cfs

Scour pattern during PMF hydrograph

Photograph 82. Riprap failure along left bank after 150,000 cfs during PMF hydrograph

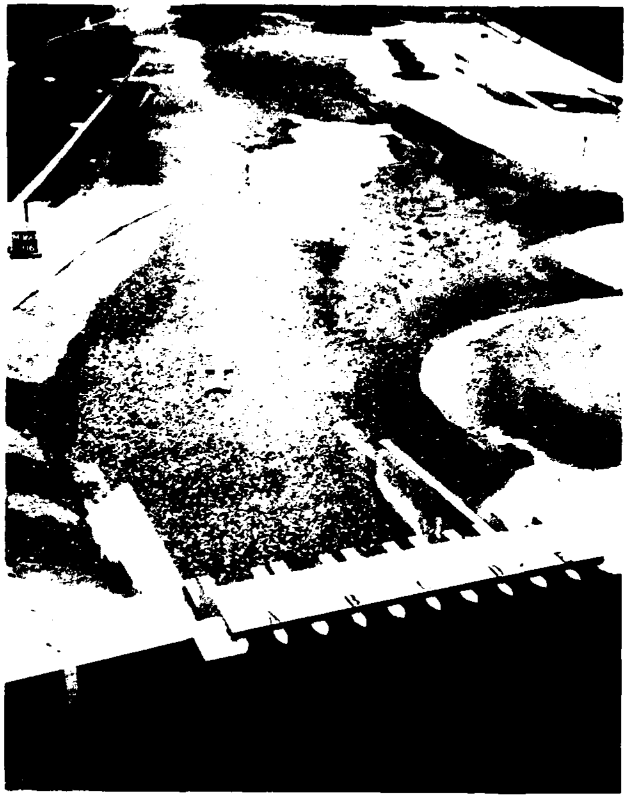


Photograph 83. Aerial view

Photograph 84. Left bank

Areas of riprap failure after 180,000 cfs during PMF hydrograph with fixed invert rock

Photograph 85. Upstream view

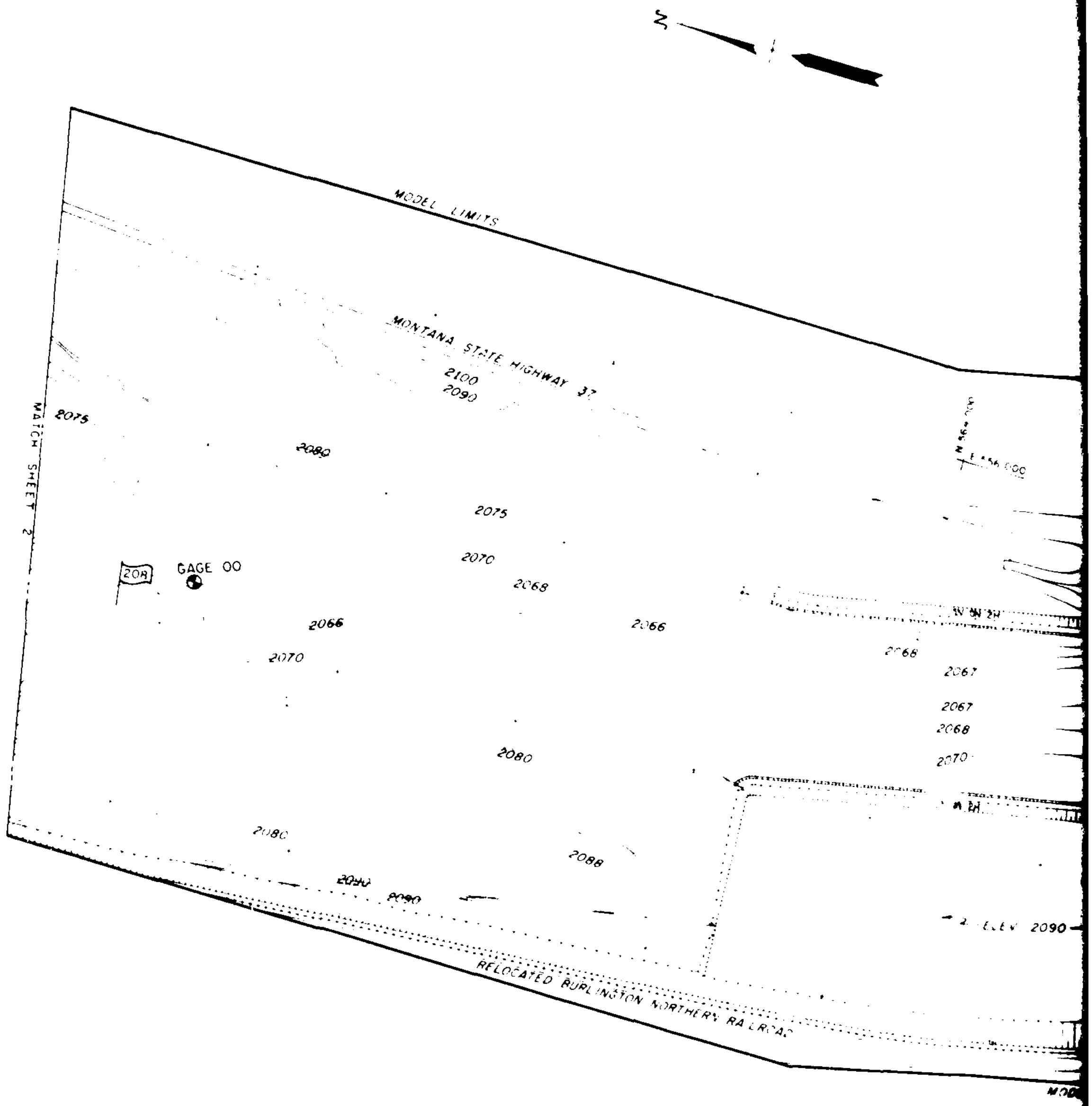


Photograph 86. Downstream view

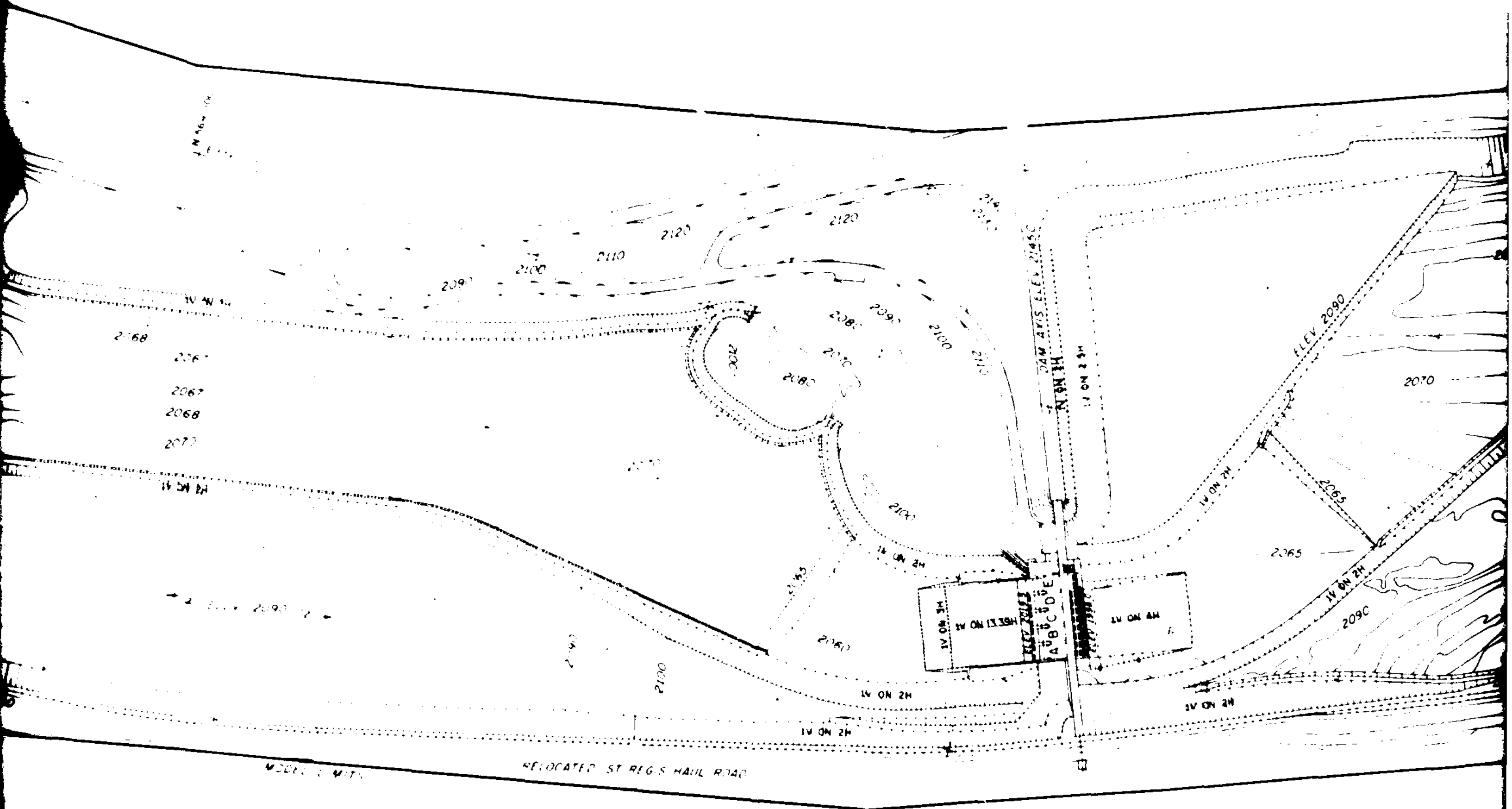
Scour patterns in tailrace and downstream channel following PMF
hydrograph with fixed invert rock

Photograph 87. Initial movement of 1000-lb riprap near end of left training wall following 150,000 cfs during PMF hydrograph. The large failure further downstream is from a previous test at 180,000 cfs

Photograph 88. Surface flow conditions with first-stage construction railroad shoofly; 50,000 cfs

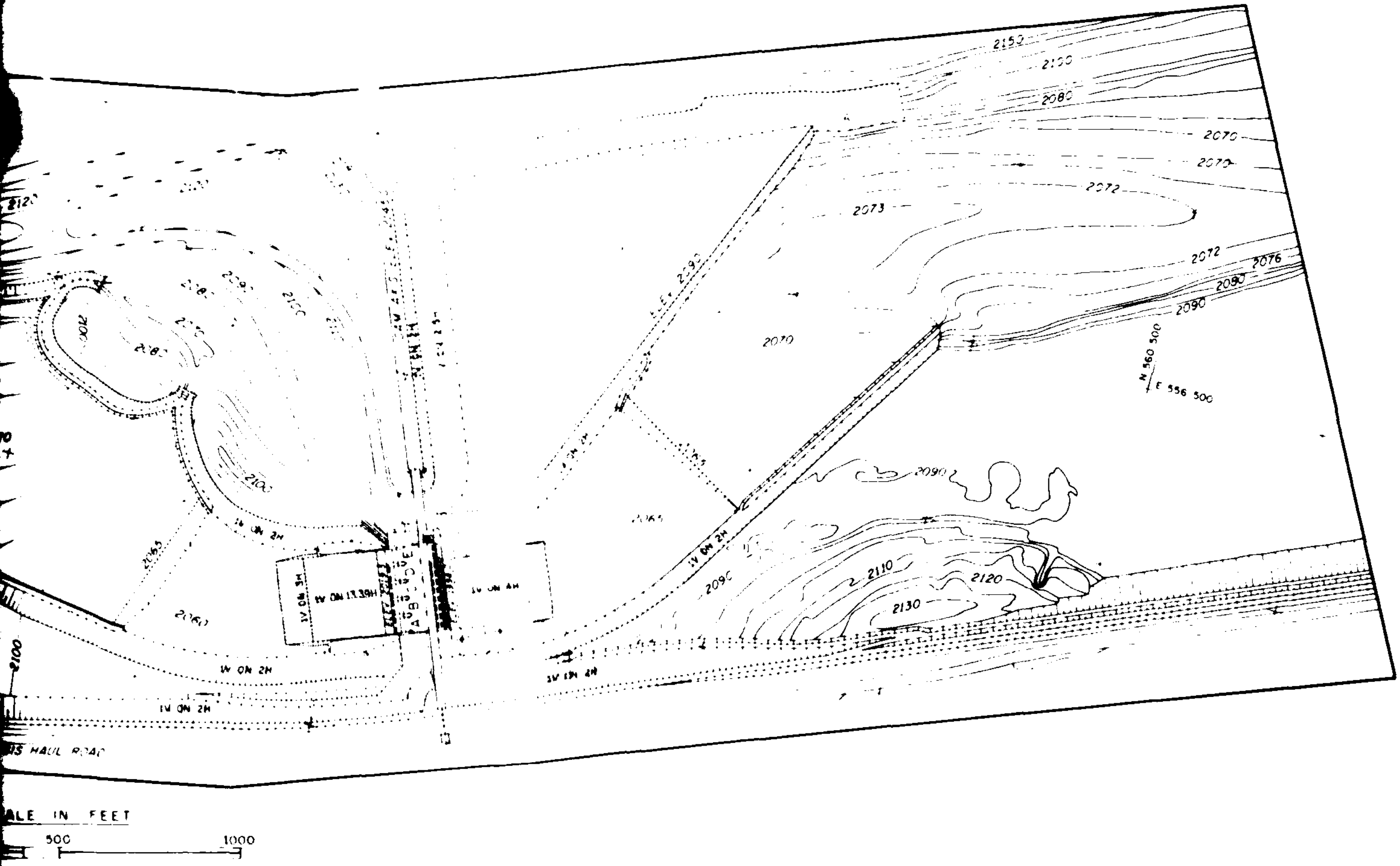

N
MODEL LIMITS
MONTANA STATE HIGHWAY 37
MATCH SHEET 2
2100
2090
2075
2080
2075
2070
2068
2066
20A
GAGE 00
2066
2070
2066
2068
2067
2067
2068
2070
2080
2080
2088
2090
2090
ELEV 2090
N 566,000
E 1,556,000
RELOCATED BURLINGTON NORTHERN RAILROAD

1


DAM AXIS ELEV 2145C
1V ON 3H
1V ON 2.5H
ELEV 2090
1V ON 2H
2065
2070
2090
2100
2110
2120
2080
2068
2067
2070
2060
1V ON 13.39H
1V ON 4H
A B C D E
RELOCATED ST REGIS HAUL ROAD
SCALE IN FEET
0
500
1000

1

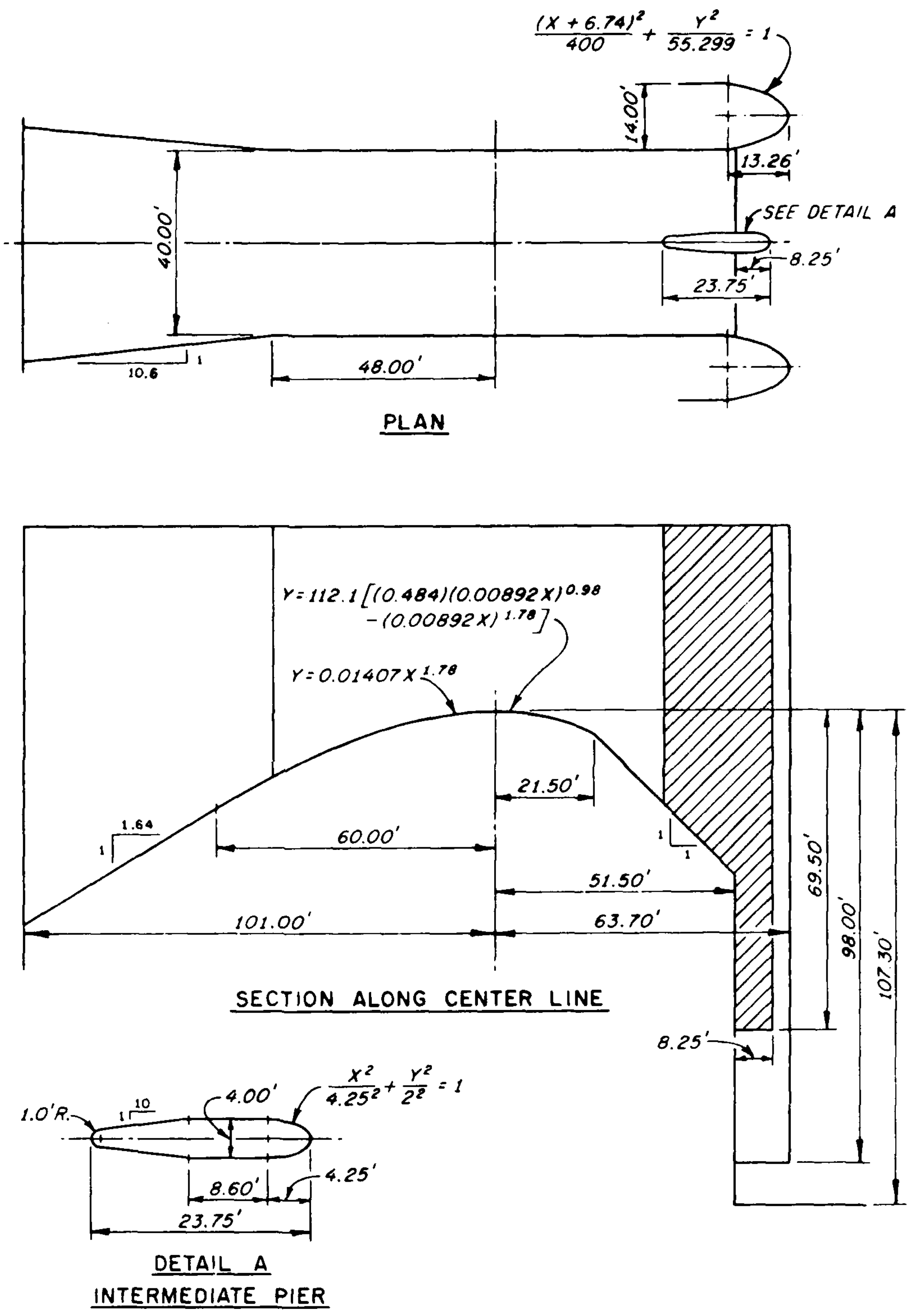
2



GENERAL PLAN
(MODEL LAYOUT)

PLATE 1

3


PLAN

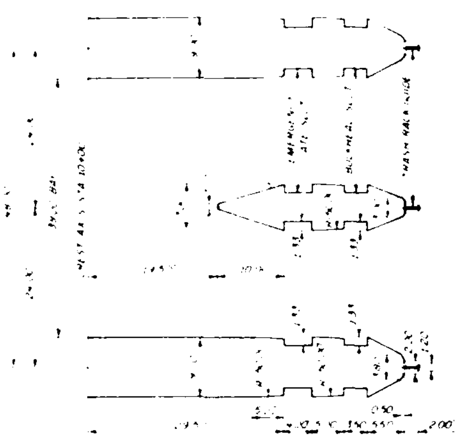
SECTION ALONG CENTER LINE

DETAIL A

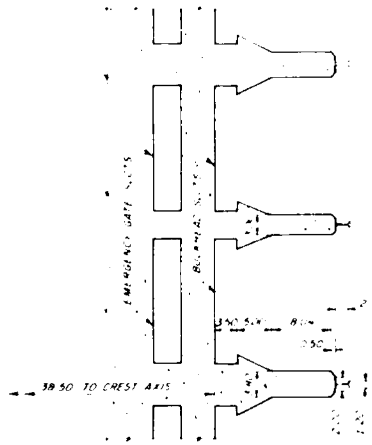
INTERMEDIATE PIER

1:50 SCALE

SPILLWAY MODEL



PLAN OF PIERS AT ELEV 2145.00



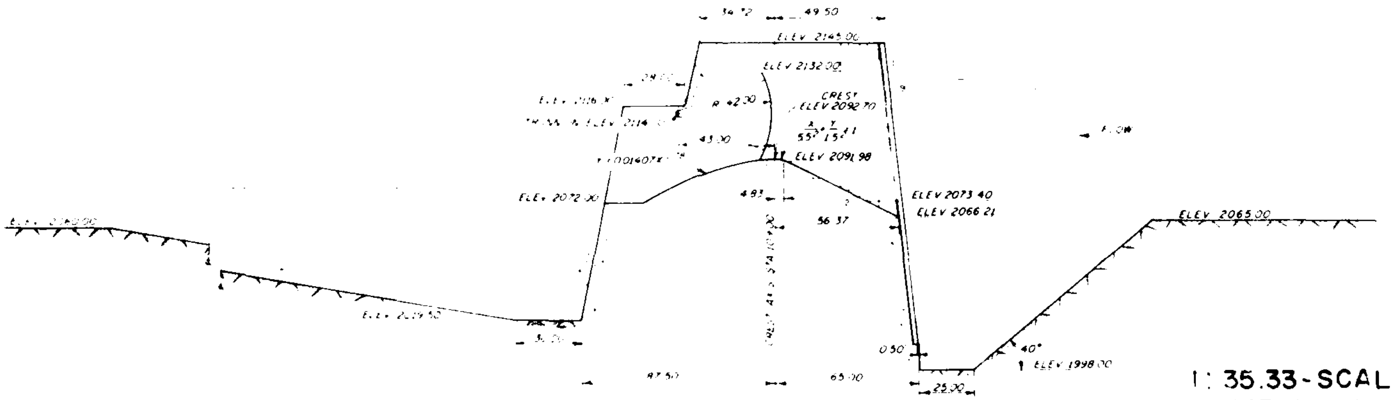
SECTION THROUGH PIERS AT ELEV 2073.40

SCALE

5 10 20 30 40 50 FT

NOTE

PIER DIMENSIONS ARE TYPICAL UNLESS NOTED

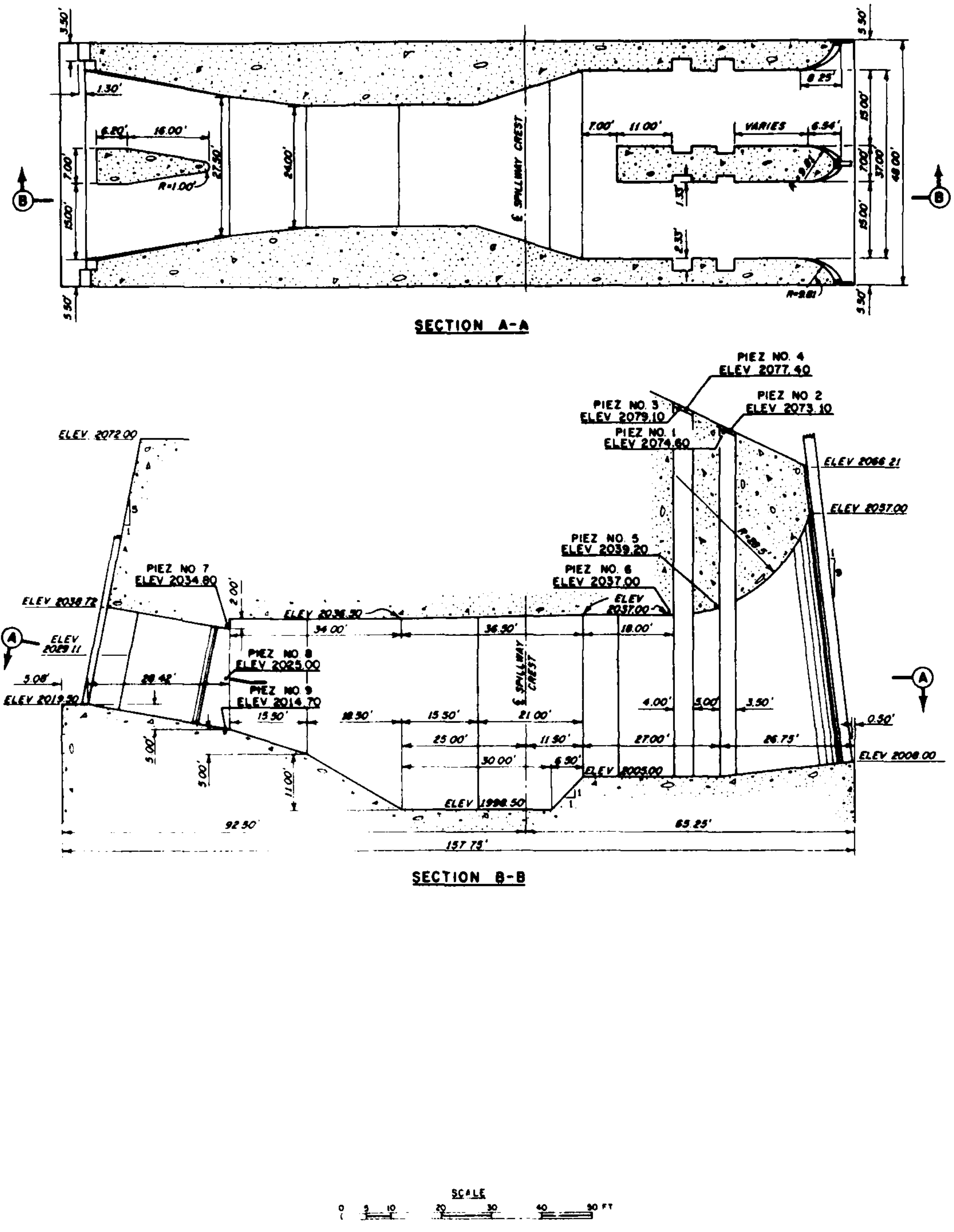


SECTION THROUGH SPILLWAY

SCALE

0 10 20 30 40 50 75 100 FT

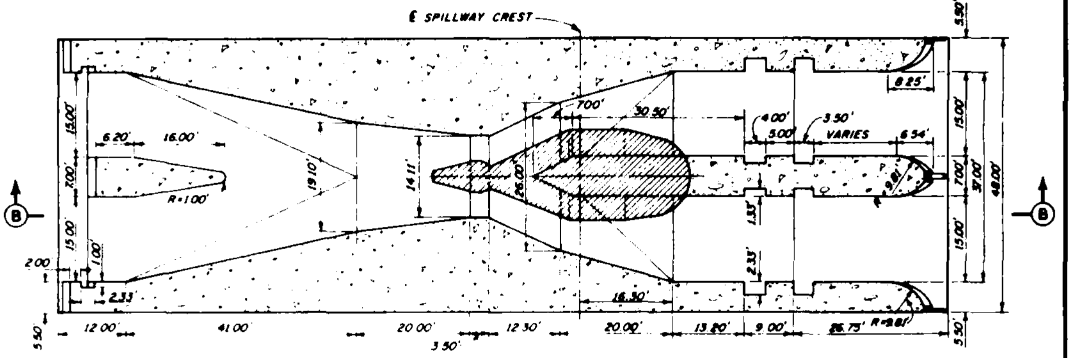
1:35.33-SCALE MODEL
CREST AND PIER DETAILS
PLAN A


SECTION A-A

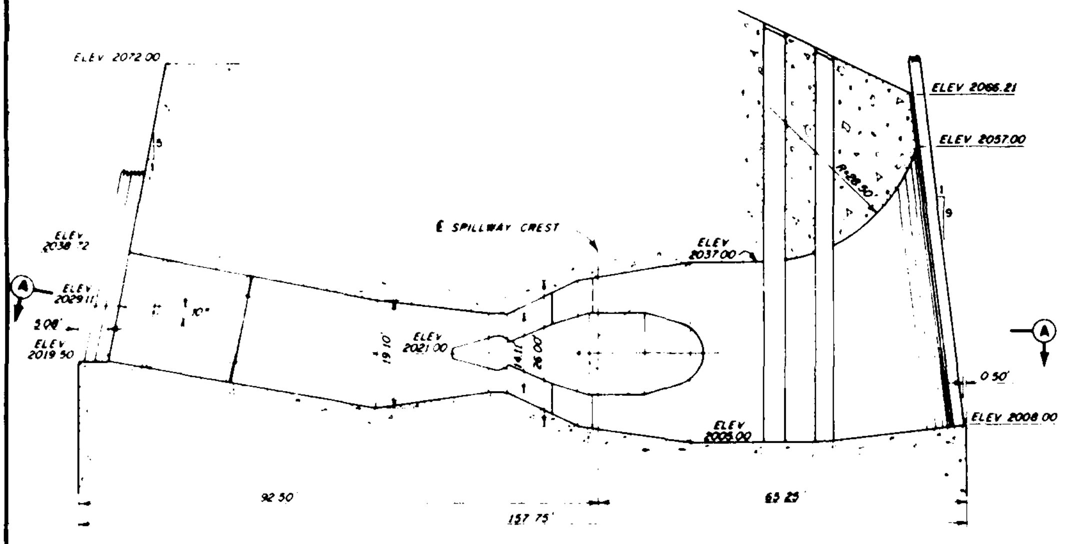
SECTION B-B

1: 35.33-SCALE MODEL
DIVERSION SLUICE
AND PIEZOMETER LOCATIONS

PLATE 4



SECTION A-A

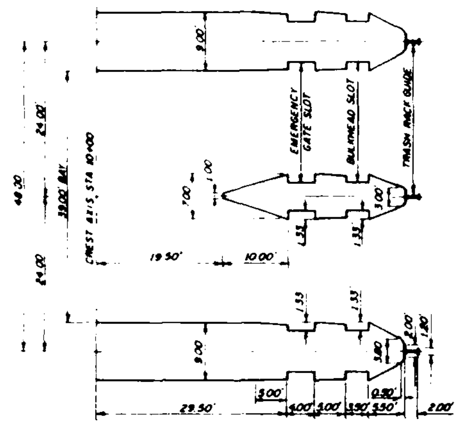


SECTION B-B

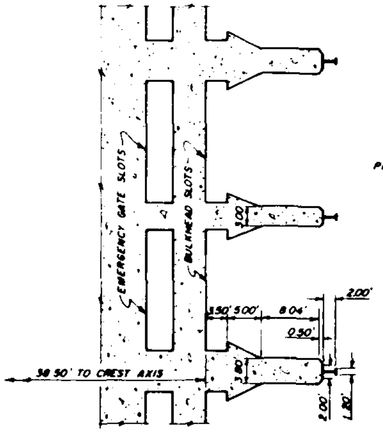
SCALE

0 5 10 20 30 40 50 FT

1:35.33-SCALE MODEL
POWER UNIT DETAILS



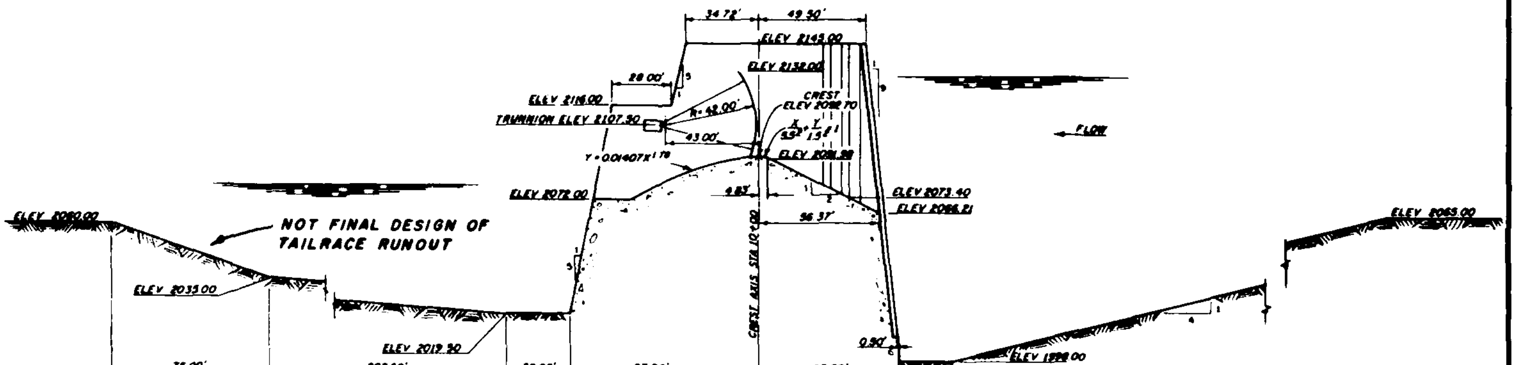
PLAN OF PIERS AT ELEV 2145.0C



NOTE
PIER DIMENSIONS ARE TYPICAL UNLESS NOTED

SECTION THROUGH PIERS AT ELEV 2073.40

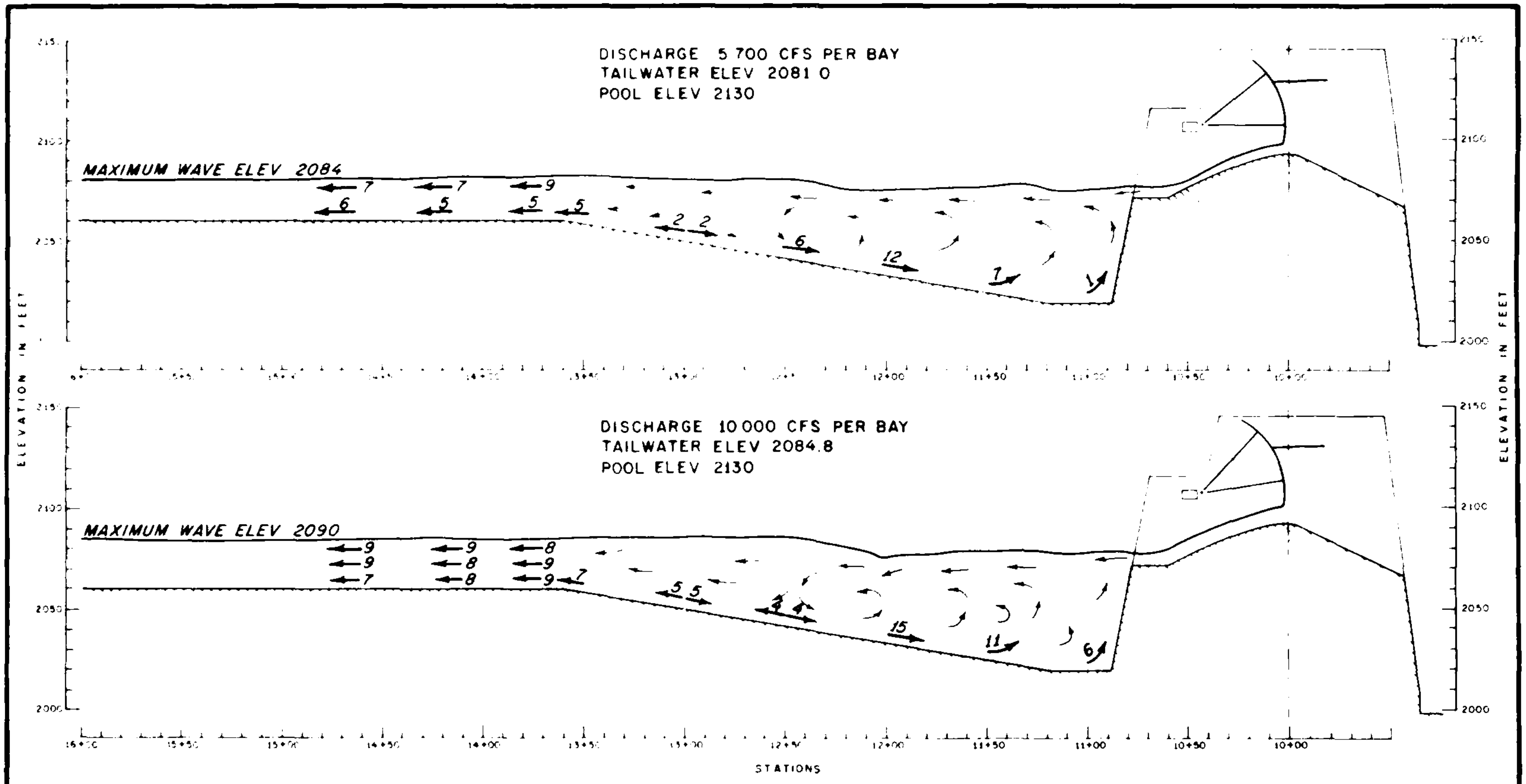
SCALE
0 5 10 20 30 40 50 FT



SECTION THROUGH SPILLWAY

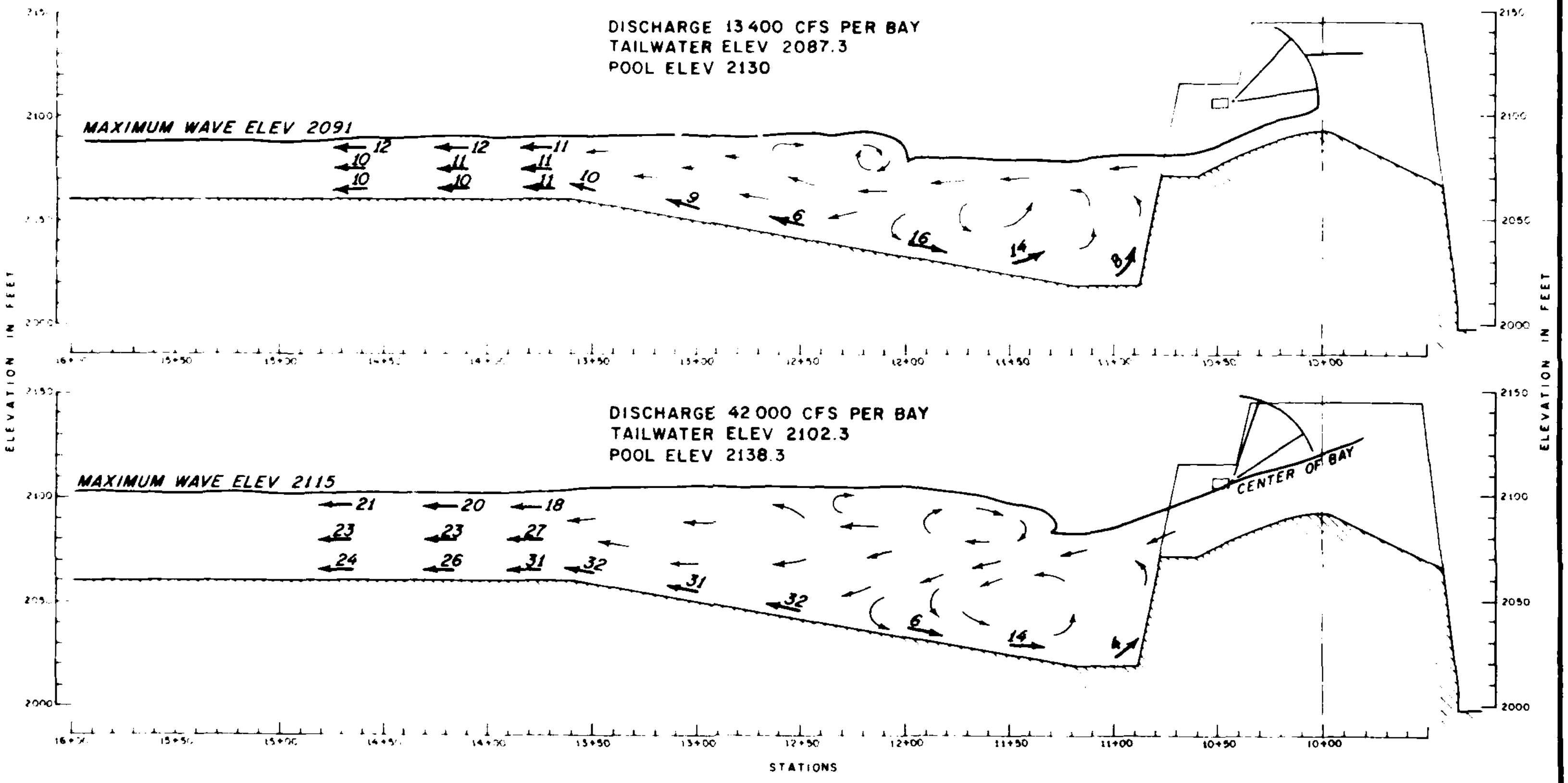
SCALE
0 10 20 30 40 50 75 100 FT

SPILLWAY
CREST AND PIER DETAILS
FINAL (PLAN B) DESIGN



FLOW CONDITIONS WITH PRELIMINARY TAILRACE RUNOUT

RIVER DISCHARGES 28 500 AND 50 000 CFS

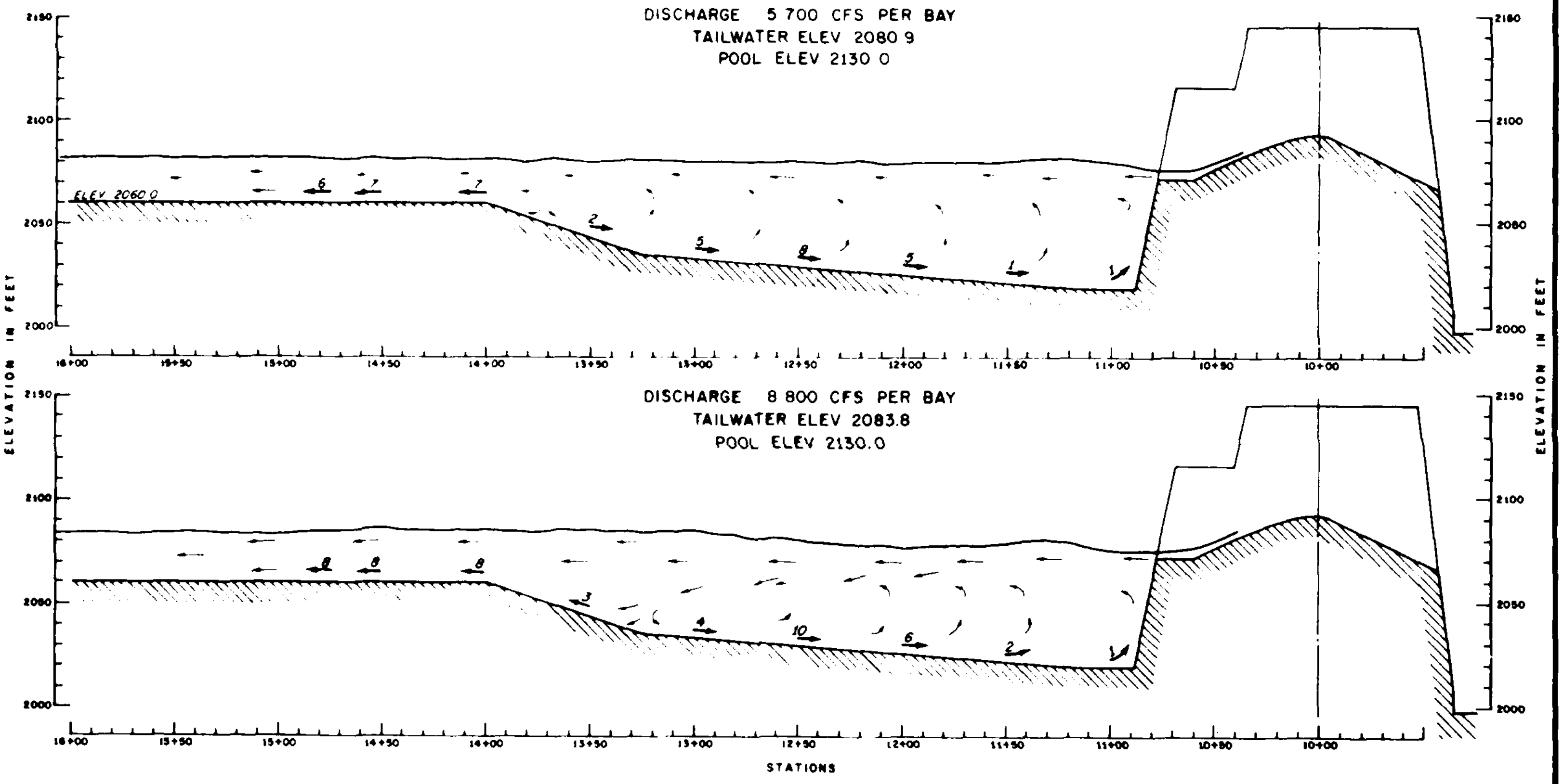


LEGEND

21 VELOCITY IN FPS

FLOW CONDITIONS WITH PRELIMINARY TAILRACE RUNOUT

RIVER DISCHARGES 67000 AND 210000 CFS



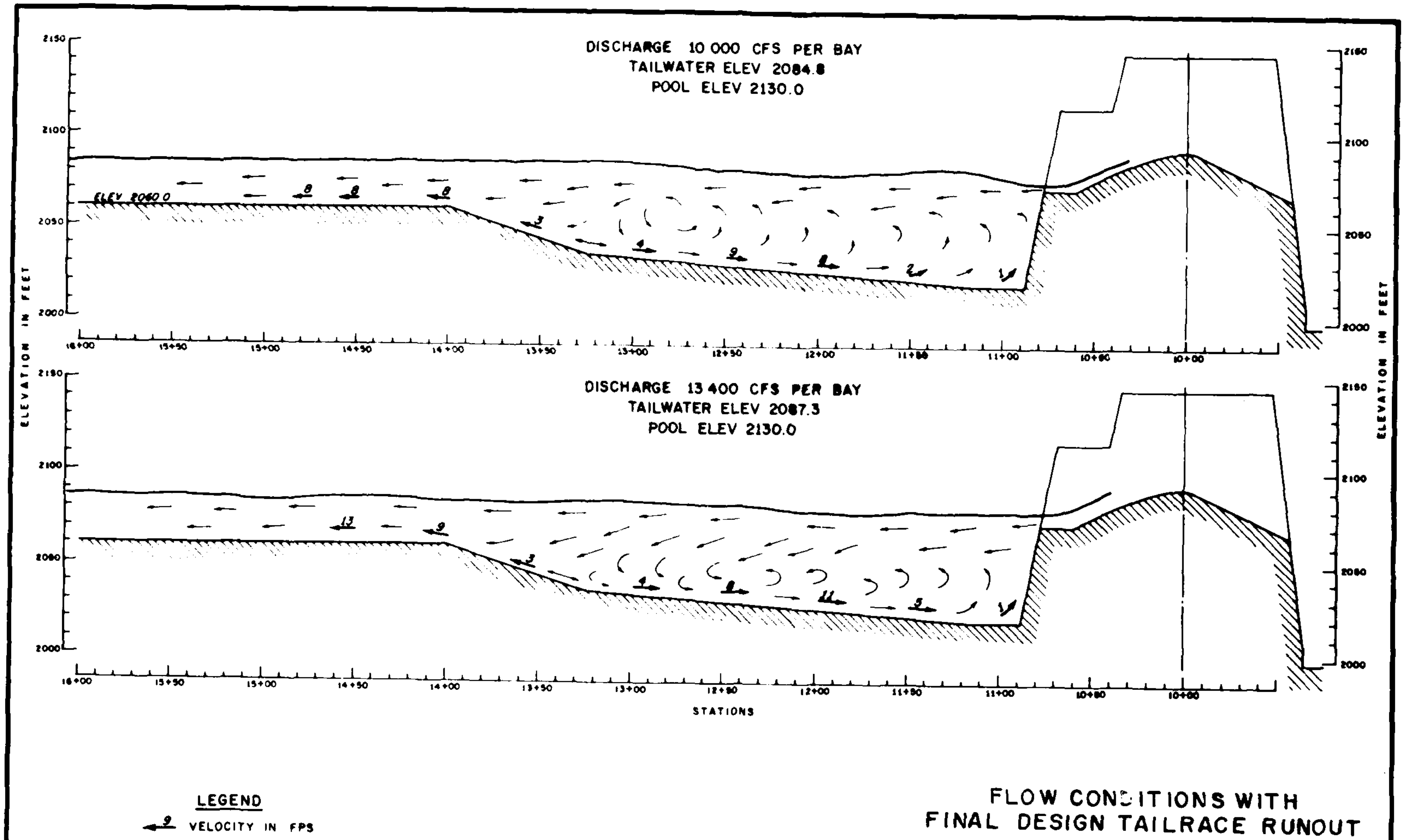
LEGEND

VELOCITY IN FPS

FLOW CONDITIONS WITH FINAL DESIGN TAILRACE RUNOUT

RIVER DISCHARGES 28500 AND 44000 CFS

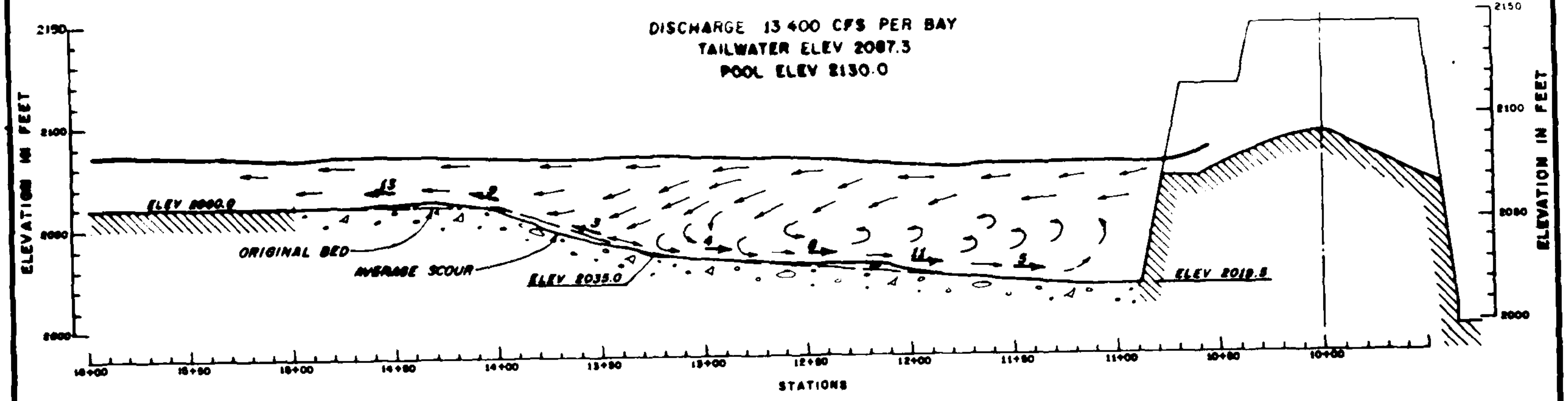
PLATE 9



FLOW CONDITIONS WITH FINAL DESIGN TAILRACE RUNOUT

RIVER DISCHARGES 50 000 AND 67 000 CFS

PLATE 10

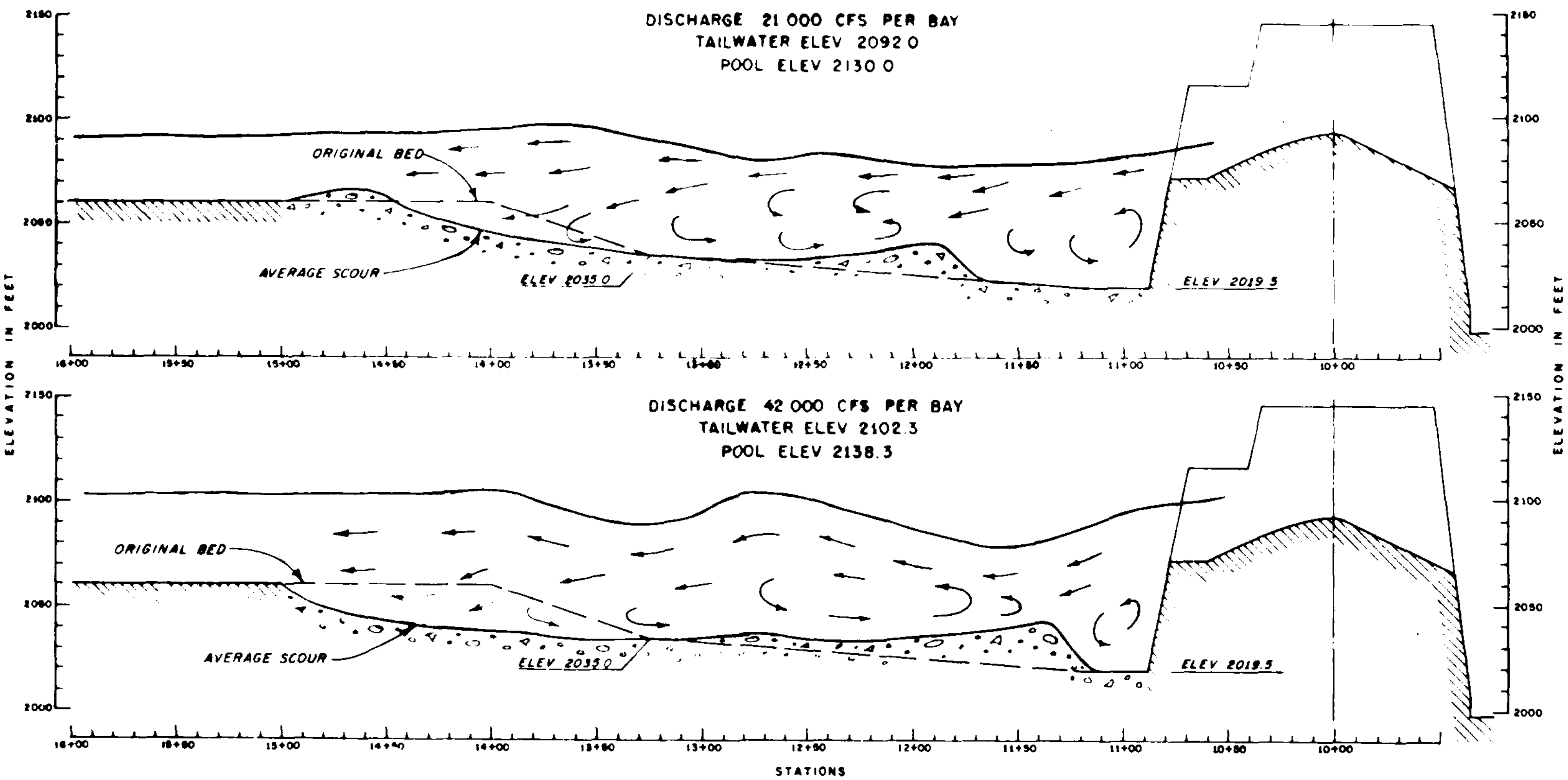


LEGEND

9 VELOCITY IN FPS

EROSION WITH FINAL DESIGN TAILRACE RUNOUT

RIVER DISCHARGE 67 000 CFS

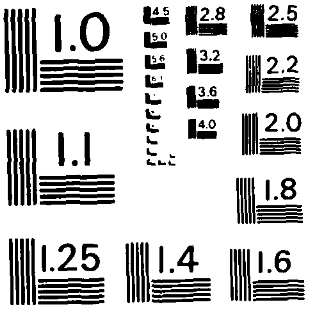


EROSION WITH
FINAL DESIGN TAILRACE RUNOUT

RIVER DISCHARGES 105 000 AND 210 000 CFS

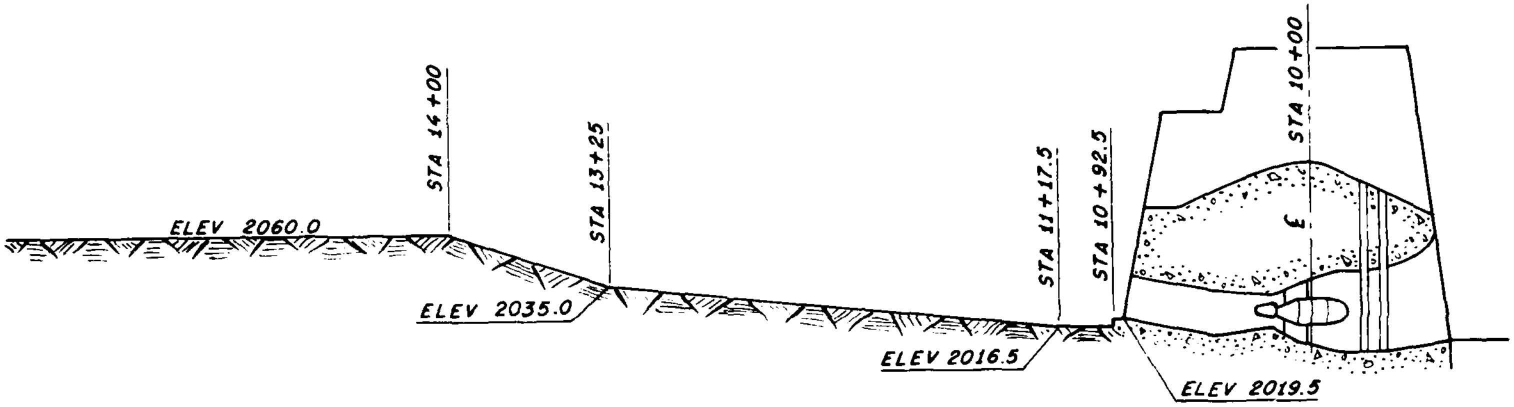
PLATE 12

AD-A134 635 LIBBY REREGULATING DAM KOOTENAI RIVER MONTANA HYDRAULIC 2/3
MODEL INVESTIGATION(U) ARMY ENGINEER DIV NORTH PACIFIC
BONNEVILLE OR DIV HYDRAULIC LAB JUL 83 TR-160-1
UNCLASSIFIED F/G 13/13 NL

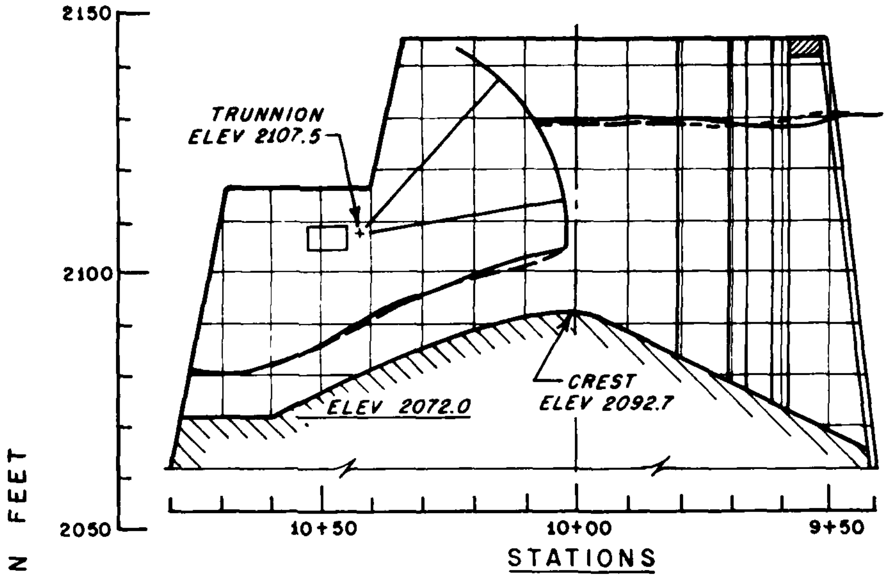


MICROCOPY RESOLUTION TEST CHART

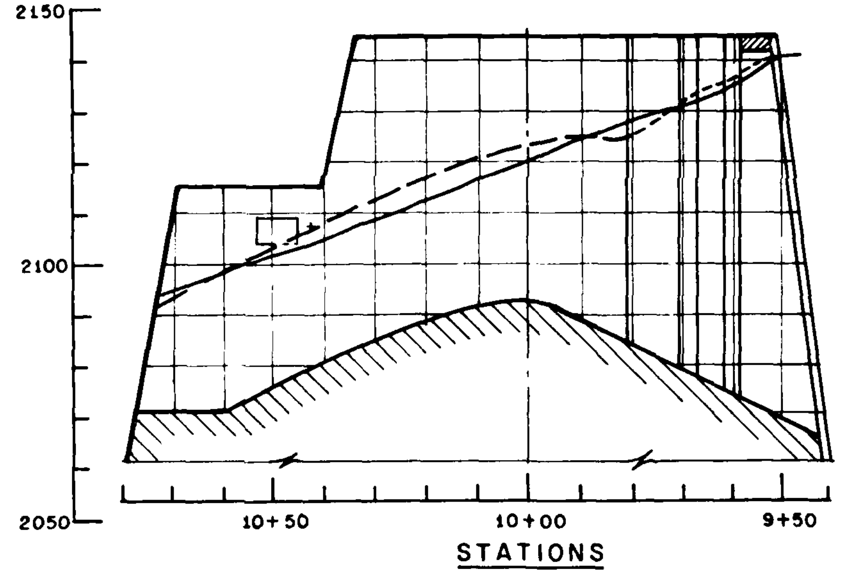
NATIONAL BUREAU OF STANDARDS - 1963 - A



FINAL DESIGN TAILRACE RUNOUT



RIVER DISCHARGE 67000 CFS
DISCHARGE PER BAY 13 400 CFS
GATE OPENING 11.80 FEET, POOL ELEV 2130



RIVER DISCHARGE 210000 CFS
DISCHARGE PER BAY 42000 CFS
FREE FLOW, POOL ELEV 2138.28

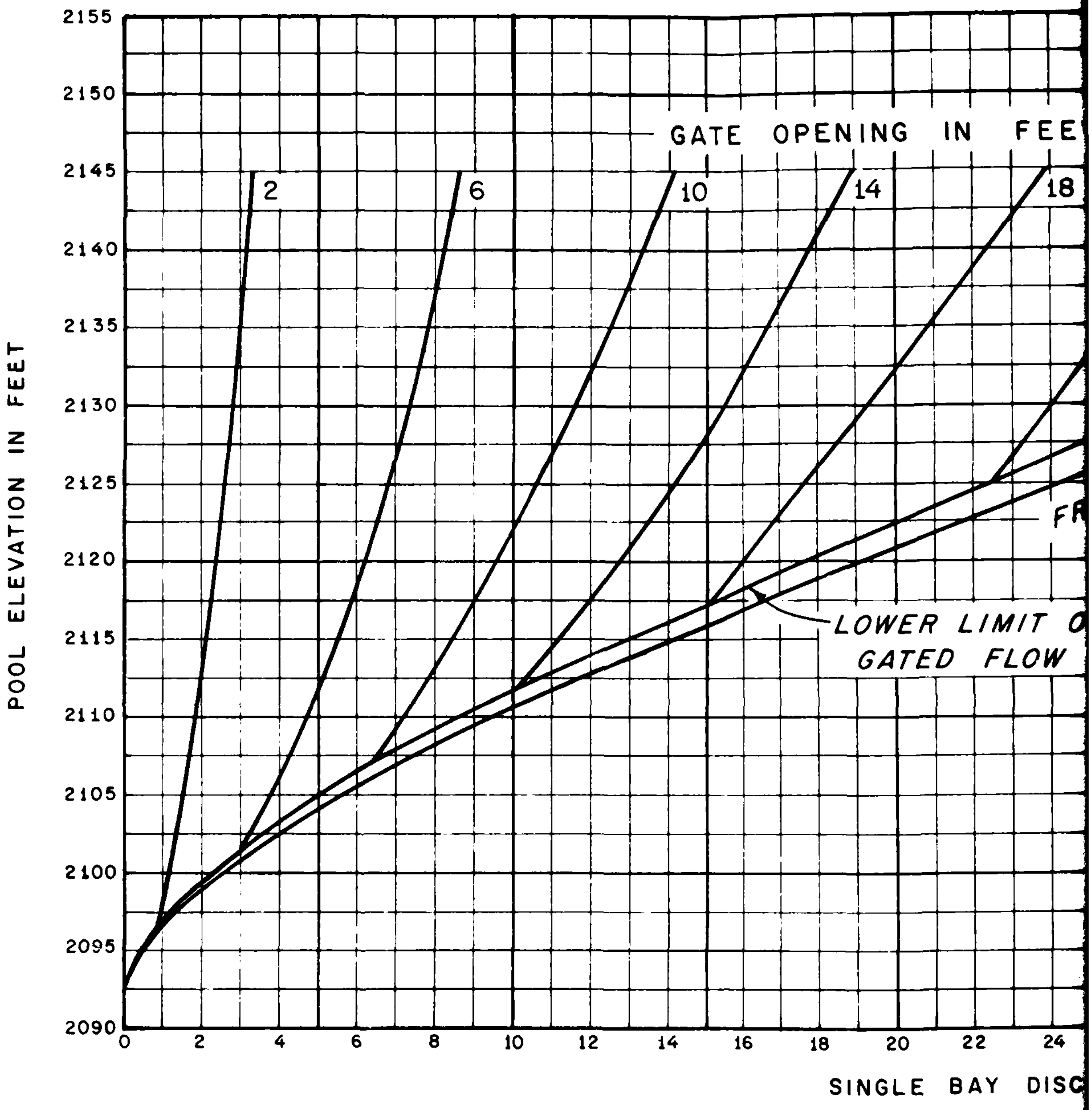
LEGEND

——— PROFILE, MAIN PIER
- - - - - - PROFILE, INTERMEDIATE PIER
— — — PROFILE, CENTER LINE OF BAY

WATER-SURFACE PROFILES
PLAN B SPILLWAY PIERS

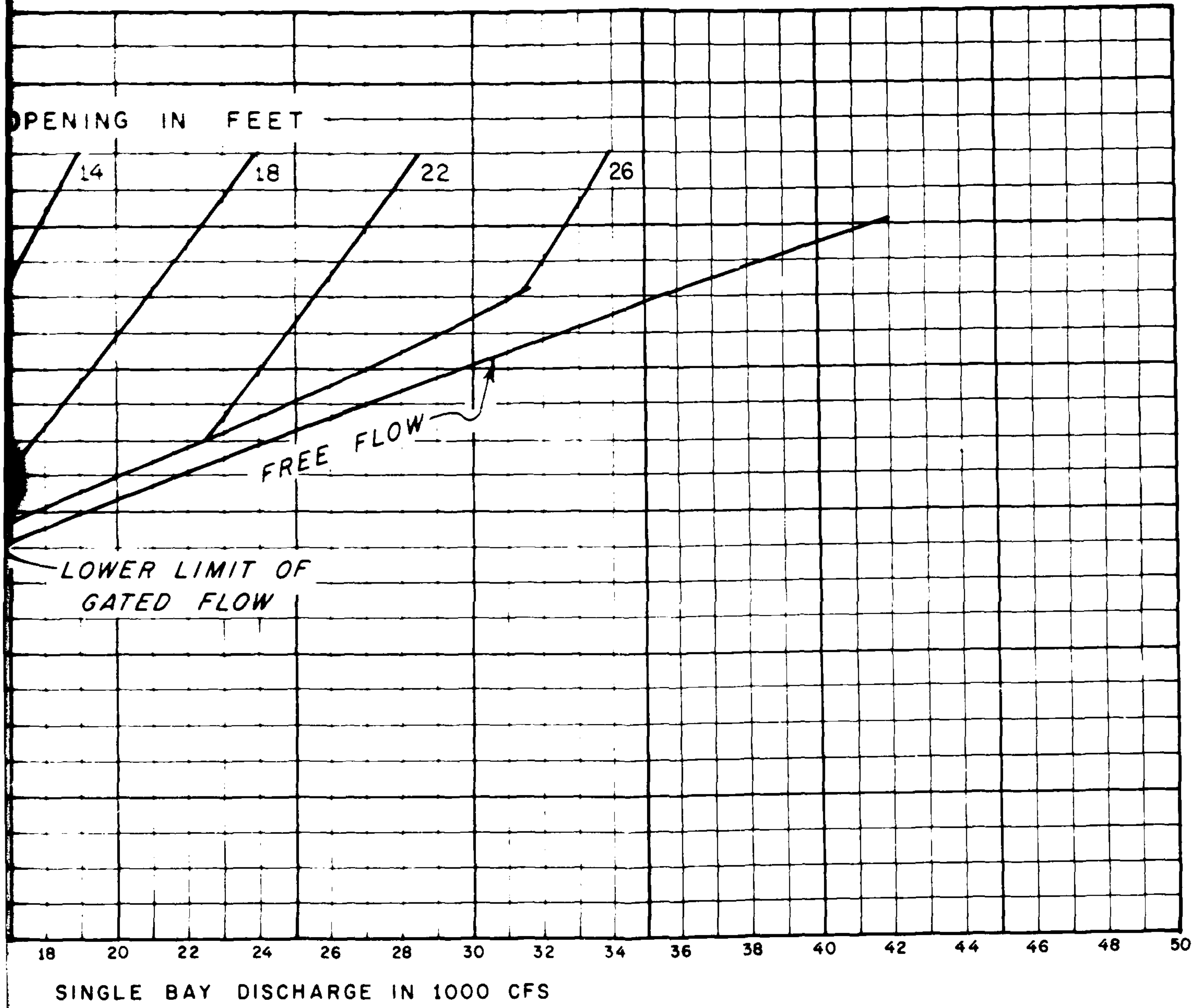
RIVER DISCHARGES 67000 AND 210000 CFS

PLATE 14



NOTE

GATE SLOTS CLOSED

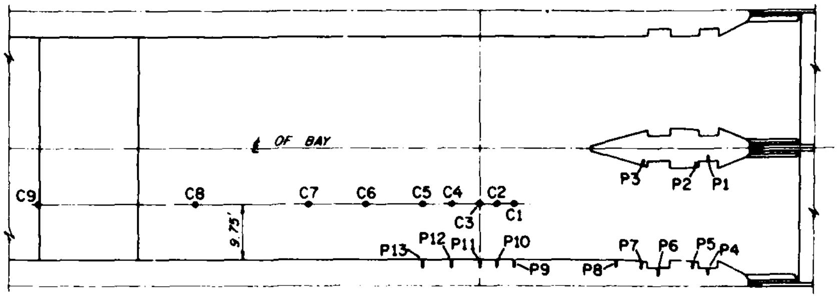


SPILLWAY RATING CURVE

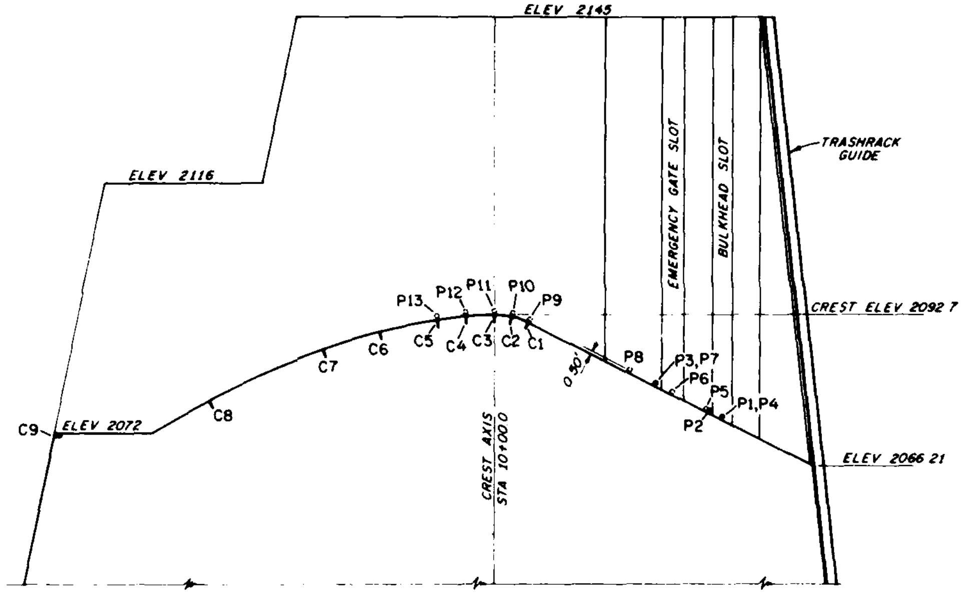
PLATE 15

1

2



PLAN



SECTION

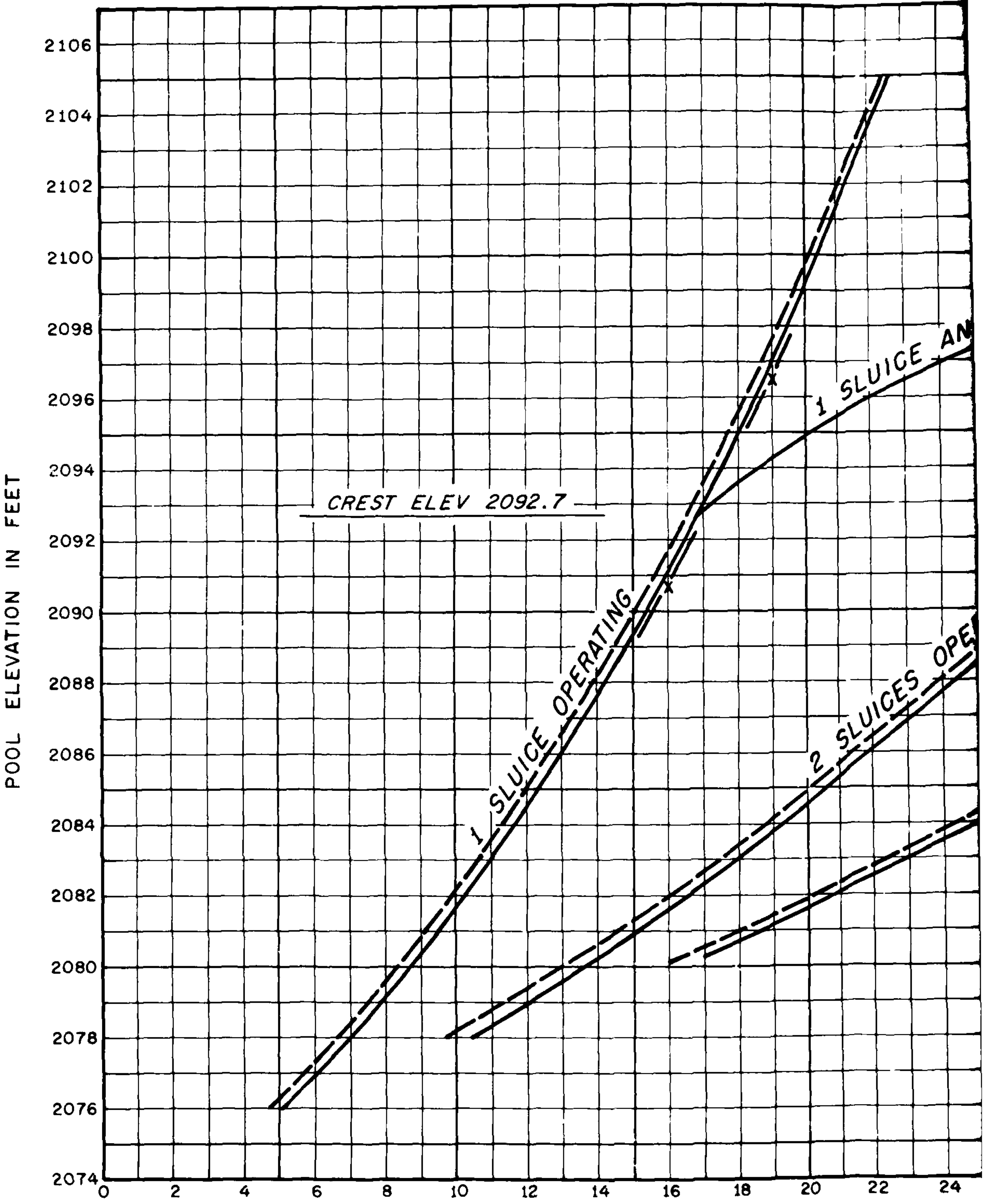
PIEZOMETER LOCATIONS		
PIEZ NO.	STATION	ELEVATION
P1	9 + 59.77	2074.78
P2	9 + 62.00	2075.90
P3	9 + 71.50	2080.65
P4	9 + 59.77	2074.78
P5	9 + 62.50	2076.15
P6	9 + 68.50	2079.15
P7	9 + 71.50	2080.65
P8	9 + 76.00	2082.90
P9	9 + 94.00	2091.90
P10	9 + 97.00	2092.96
P11	10 + 00.00	2093.20
P12	10 + 05.00	2092.95
P13	10 + 10.00	2092.35
C1	9 + 94.00	2091.40
C2	9 + 97.00	2092.46
C3	10 + 00.00	2092.70
C4	10 + 05.00	2092.45
C5	10 + 10.00	2091.85
C6	10 + 20.00	2089.79
C7	10 + 30.00	2086.71
C8	10 + 50.00	2077.83
C9	10 + 77.42	2071.50

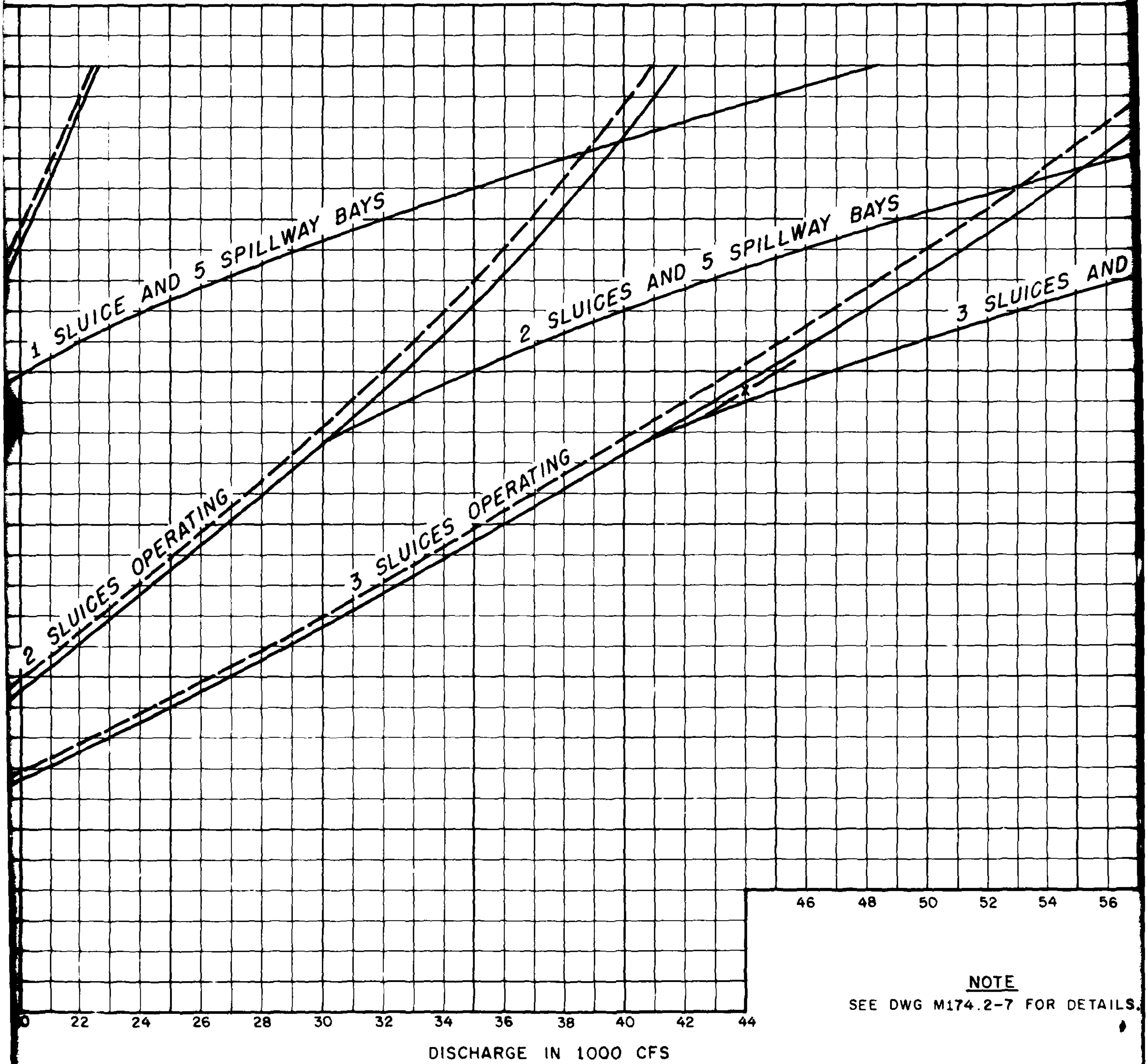
SCALE

PIEZOMETER LOCATIONS

PIERS AND CREST

PLATE 16

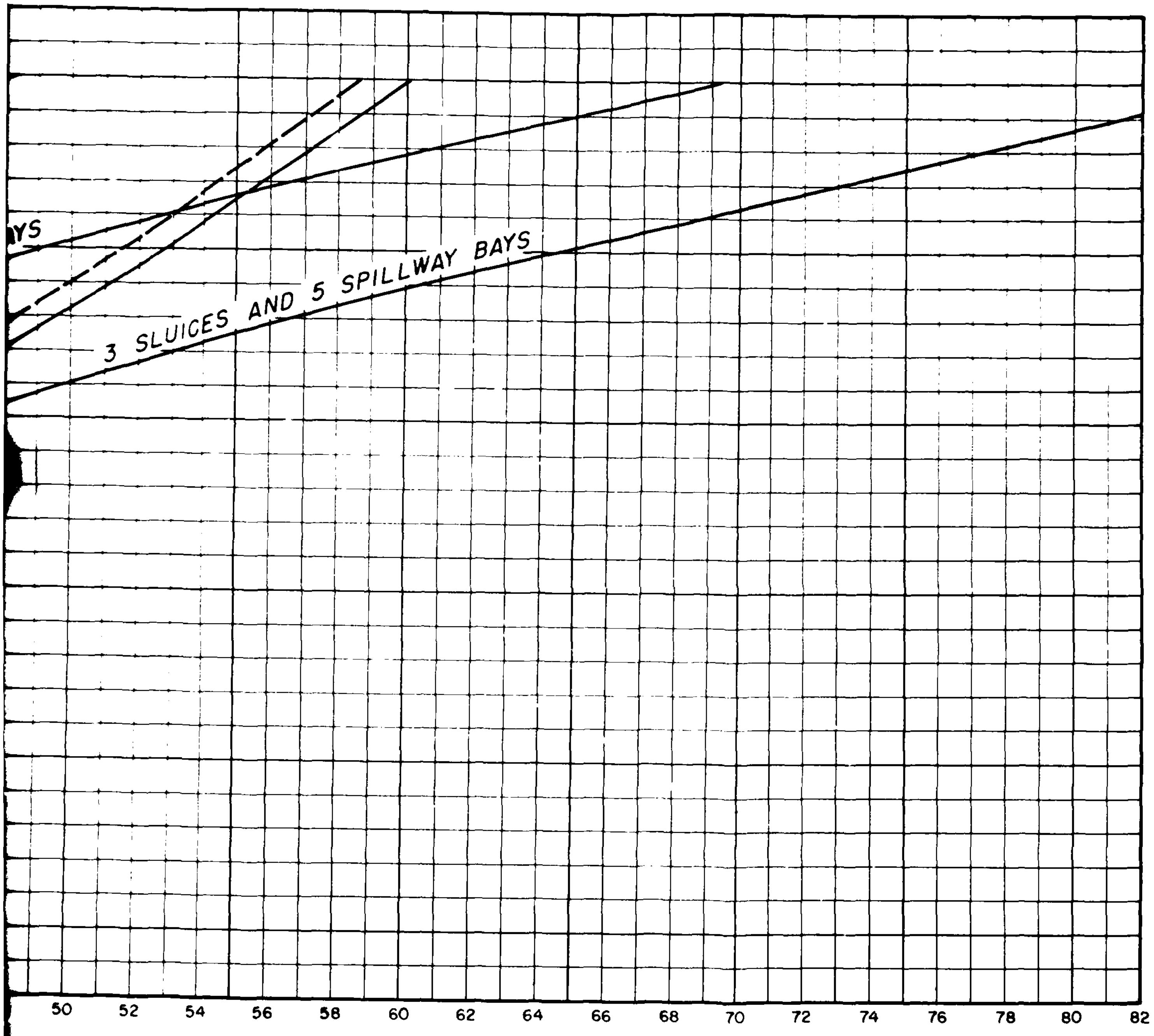

POOL ELEVATION IN FEET
2106
2104
2102
2100
2098
2096
2094
2092
2090
2088
2086
2084
2082
2080
2078
2076
2074
0
2
4
6
8
10
12
14
16
18
20
22
24
CREST ELEV 2092.7
1 SLUICE OPERATING
1 SLUICE AN
2 SLUICES OPE



NOTE

SEE DWG M174.2-7 FOR DETAILS.

2



NOTE

DWG M174.2-7 FOR DETAILS.

LEGEND

——— GATE SLOTS CLOSED

– – – GATE SLOTS OPEN

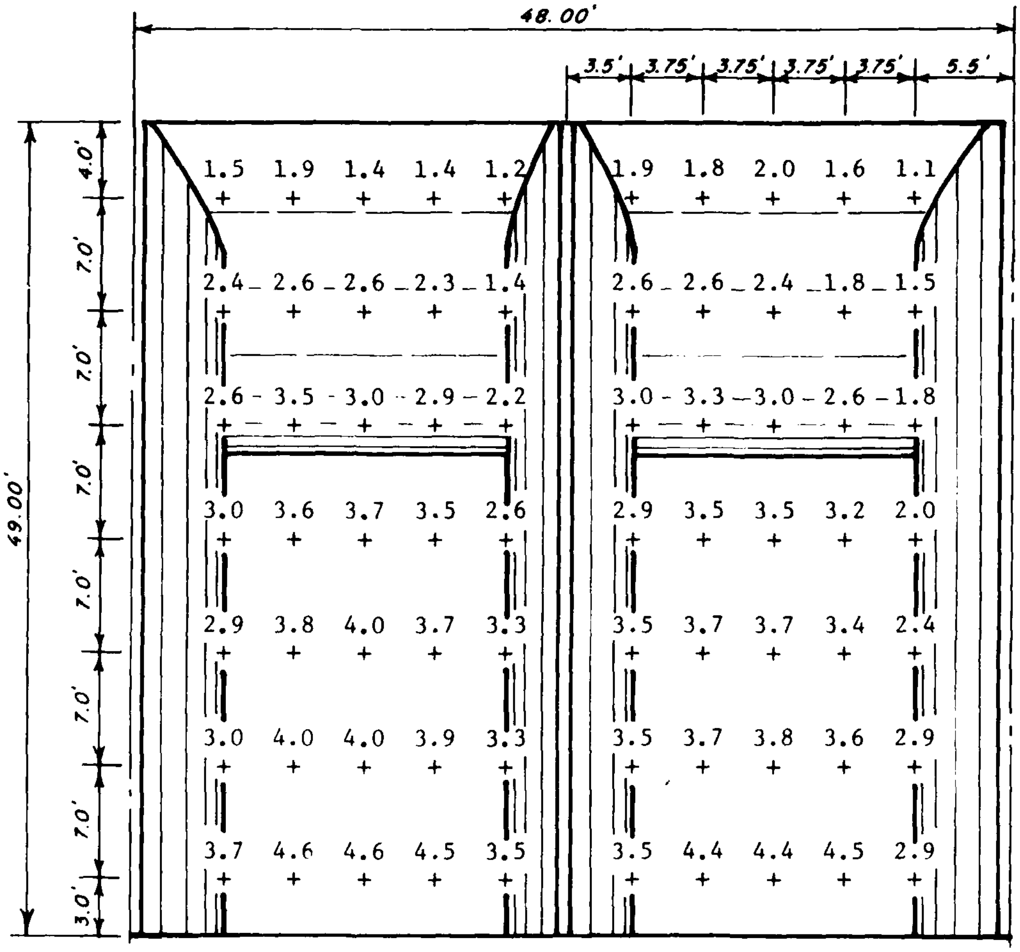
—X— PLAN B-1 INVERT

DIVERSION SLUICE RATING

1

3

Original Design Power Unit
Four-unit Operation, Discharge 25,000 CFS



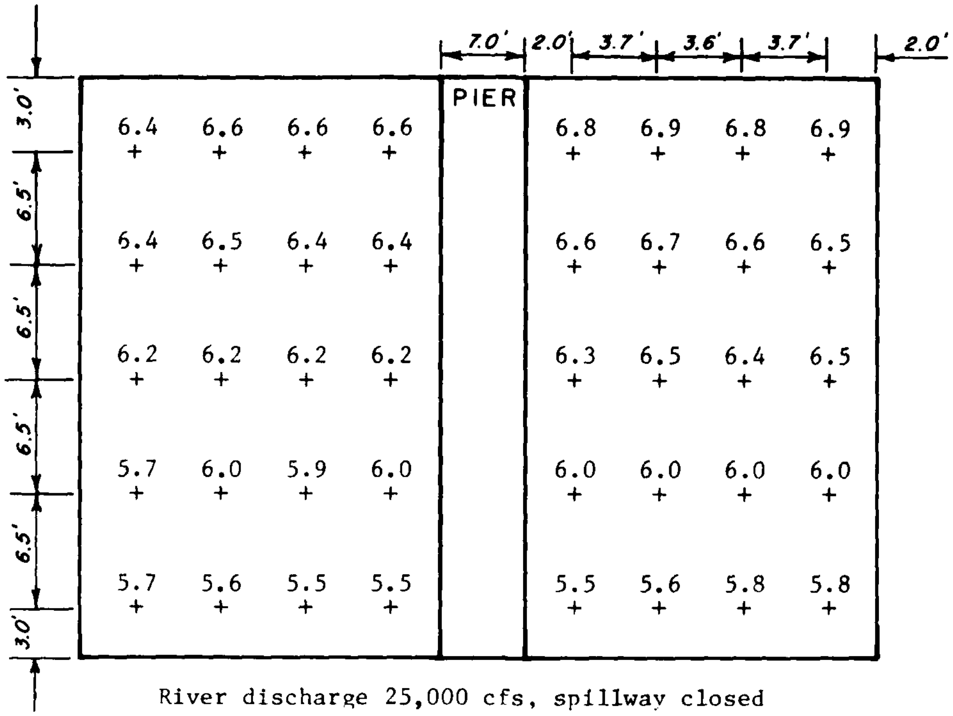
1.5	1.9	1.4	1.4	1.2	1.9	1.8	2.0	1.6	1.1
2.4	2.6	2.6	2.3	1.4	2.6	2.6	2.4	1.8	1.5
2.6	3.5	3.0	2.9	2.2	3.0	3.3	3.0	2.6	1.8
3.0	3.6	3.7	3.5	2.6	2.9	3.5	3.5	3.2	2.0
2.9	3.8	4.0	3.7	3.3	3.5	3.7	3.7	3.4	2.4
3.0	4.0	4.0	3.9	3.3	3.5	3.7	3.8	3.6	2.9
3.7	4.6	4.6	4.5	3.5	3.5	4.4	4.4	4.5	2.9

River discharge 25,000 cfs, spillway closed
Pool elev 2130.0, tailwater elev 2080.3

NOTE: Velocities in fps, looking downstream.

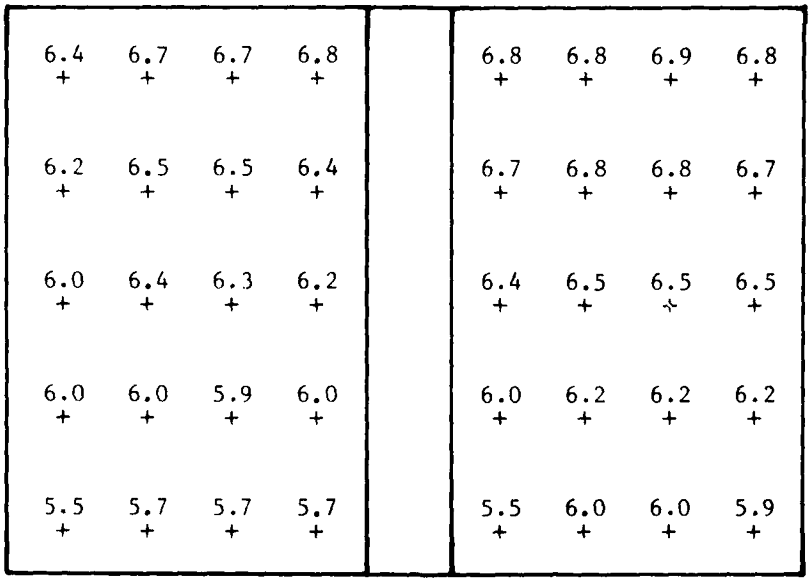
POWER UNIT TRASHRACK VELOCITIES

Original Design Power Unit
Four-unit Operation, Discharge 25,000 CFS



6.4	6.6	6.6	6.6	6.8	6.9	6.8	6.9
6.4	6.5	6.4	6.4	6.6	6.7	6.6	6.5
6.2	6.2	6.2	6.2	6.3	6.5	6.4	6.5
5.7	6.0	5.9	6.0	6.0	6.0	6.0	6.0
5.7	5.6	5.5	5.5	5.5	5.6	5.8	5.8

River discharge 25,000 cfs, spillway closed
Pool elev 2130.0, tailwater elev 2080.3



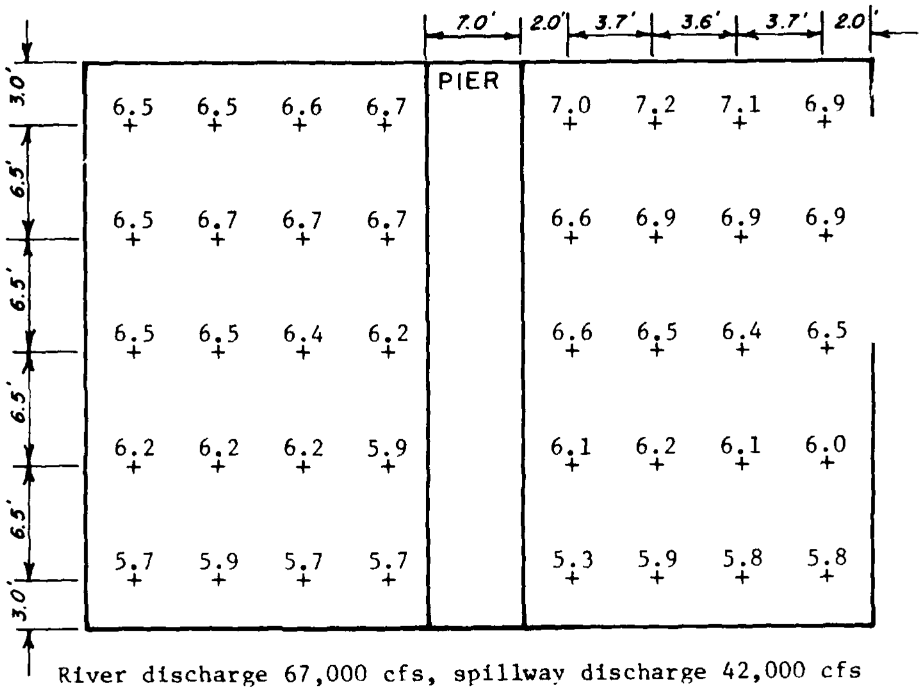
6.4	6.7	6.7	6.8	6.8	6.8	6.9	6.8
6.2	6.5	6.5	6.4	6.7	6.8	6.8	6.7
6.0	6.4	6.3	6.2	6.4	6.5	6.5	6.5
6.0	6.0	5.9	6.0	6.0	6.2	6.2	6.2
5.5	5.7	5.7	5.7	5.5	6.0	6.0	5.9

River discharge 44,000 cfs, spillway discharge 19,000 cfs
Pool elev 2130.0, tailwater elev 2083.8

NOTE: Velocities in fps, looking downstream.

POWER UNIT INTAKE VELOCITIES

Original Design Power Unit
Four-unit Operation, Discharge 25,000 CFS



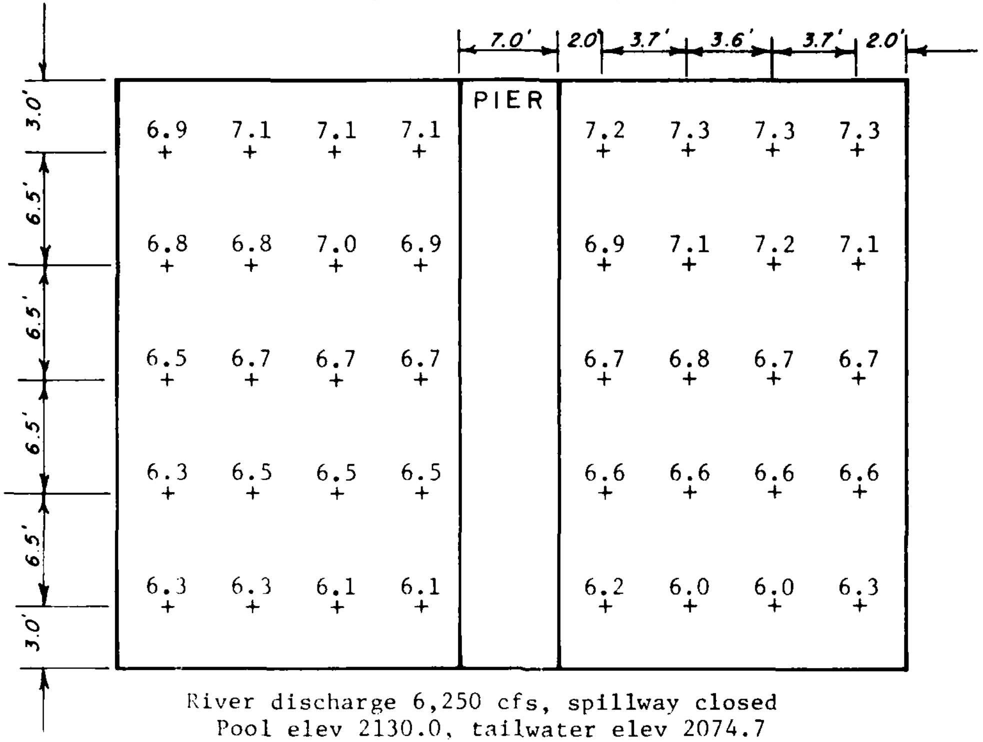
6.5	6.5	6.6	6.7	PIER	7.0	7.2	7.1	6.9
6.5	6.7	6.7	6.7		6.6	6.9	6.9	6.9
6.5	6.5	6.4	6.2		6.6	6.5	6.4	6.5
6.2	6.2	6.2	5.9		6.1	6.2	6.1	6.0
5.7	5.9	5.7	5.7		5.3	5.9	5.8	5.8

River discharge 67,000 cfs, spillway discharge 42,000 cfs
Pool elev 2130.0, tailwater elev 2087.3

NOTE: Velocities in fps; looking downstream.

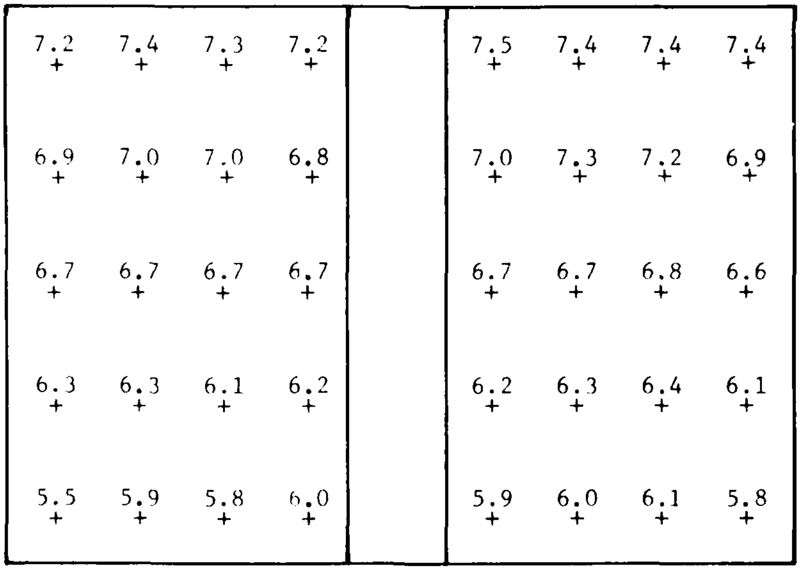
**POWER UNIT INTAKE
VELOCITIES**

Original Design Power Unit
One-unit Operation, Discharge 6,250 CFS



6.9	7.1	7.1	7.1	7.2	7.3	7.3	7.3
6.8	6.8	7.0	6.9	6.9	7.1	7.2	7.1
6.5	6.7	6.7	6.7	6.7	6.8	6.7	6.7
6.3	6.5	6.5	6.5	6.6	6.6	6.6	6.6
6.3	6.3	6.1	6.1	6.2	6.0	6.0	6.3

River discharge 6,250 cfs, spillway closed
Pool elev 2130.0, tailwater elev 2074.7



7.2	7.4	7.3	7.2	7.5	7.4	7.4	7.4
6.9	7.0	7.0	6.8	7.0	7.3	7.2	6.9
6.7	6.7	6.7	6.7	6.7	6.7	6.8	6.6
6.3	6.3	6.1	6.2	6.2	6.3	6.4	6.1
5.5	5.9	5.8	6.0	5.9	6.0	6.1	5.8

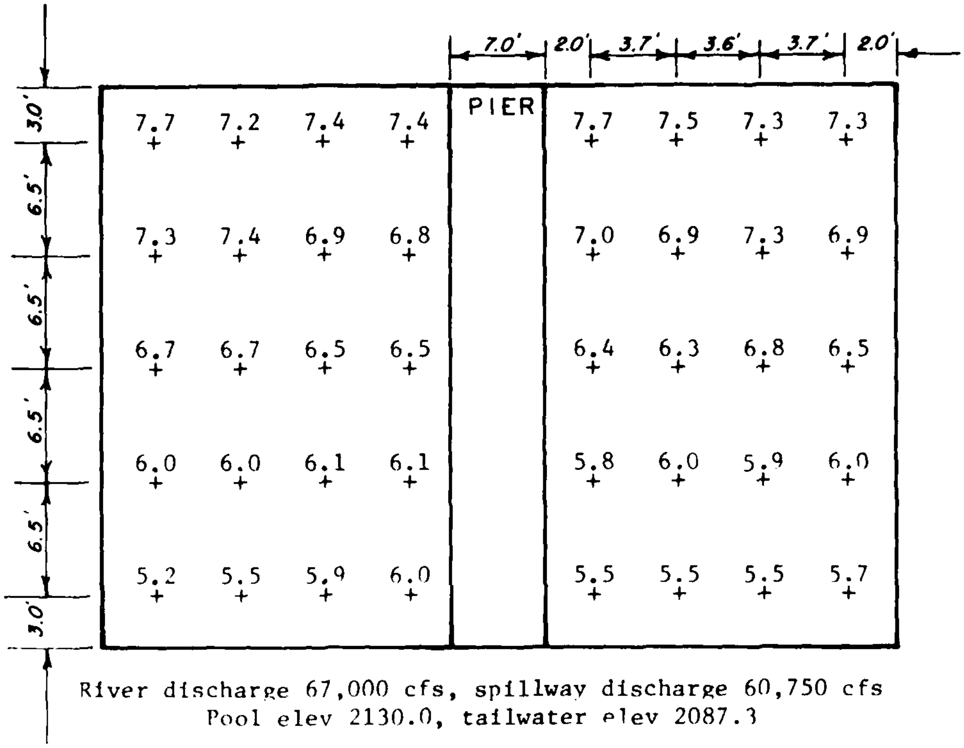
River discharge 44,000 cfs, spillway discharge 37,750 cfs
Pool elev 2130.0, tailwater elev 2083.8

NOTE: Velocities in fps; looking downstream.

POWER UNIT INTAKE VELOCITIES

PLATE 21

Original Design Power Unit
One-unit Operation, Discharge 6,250 CFS



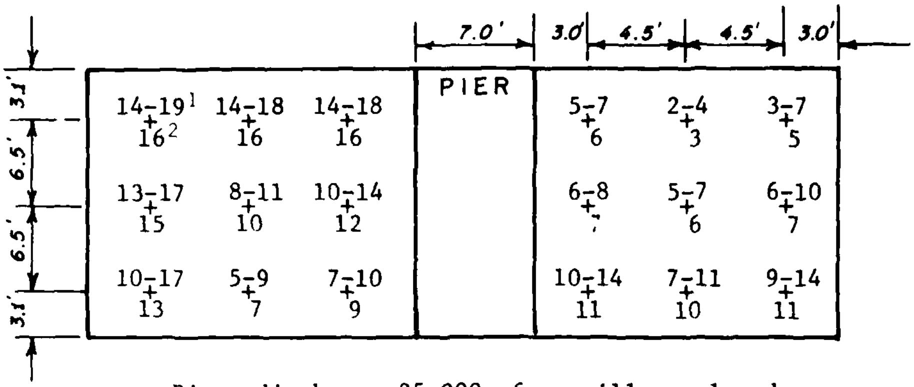
7.7	7.2	7.4	7.4	PIER	7.7	7.5	7.3	7.3
7.3	7.4	6.9	6.8		7.0	6.9	7.3	6.9
6.7	6.7	6.5	6.5		6.4	6.3	6.8	6.5
6.0	6.0	6.1	6.1		5.8	6.0	5.9	6.0
5.2	5.5	5.9	6.0		5.5	5.5	5.5	5.7

River discharge 67,000 cfs, spillway discharge 60,750 cfs
Pool elev 2130.0, tailwater elev 2087.3

NOTE: Velocities in fps; looking downstream.

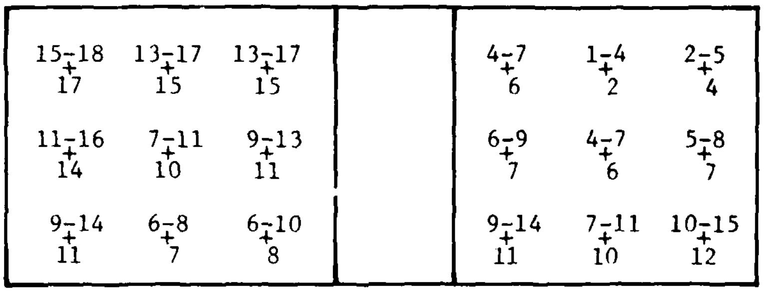
POWER UNIT INTAKE VELOCITIES

Original Design Power Unit
Four-unit Operation, Discharge 25,000 CFS



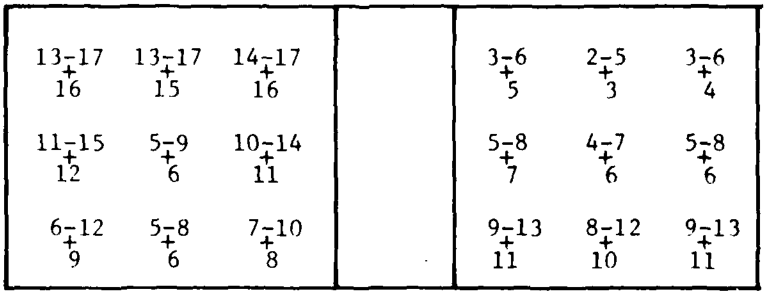
14-19[1] + 16[2]	14-18 + 16	14-18 + 16	PIER	5-7 + 6	2-4 + 3	3-7 + 5
13-17 + 15	8-11 + 10	10-14 + 12		6-8 + 7	5-7 + 6	6-10 + 7
10-17 + 13	5-9 + 7	7-10 + 9		10-14 + 11	7-11 + 10	9-14 + 11

River discharge 25,000 cfs, spillway closed
Pool elev 2130.0, tailwater elev 2080.3



15-18 + 17	13-17 + 15	13-17 + 15		4-7 + 6	1-4 + 2	2-5 + 4
11-16 + 14	7-11 + 10	9-13 + 11		6-9 + 7	4-7 + 6	5-8 + 7
9-14 + 11	6-8 + 7	6-10 + 8		9-14 + 11	7-11 + 10	10-15 + 12

River discharge 44,000 cfs, spillway discharge 19,000 cfs
Pool elev 2130.0, tailwater elev 2083.8



13-17 + 16	13-17 + 15	14-17 + 16		3-6 + 5	2-5 + 3	3-6 + 4
11-15 + 12	5-9 + 6	10-14 + 11		5-8 + 7	4-7 + 6	5-8 + 6
6-12 + 9	5-8 + 6	7-10 + 8		9-13 + 11	8-12 + 10	9-13 + 11

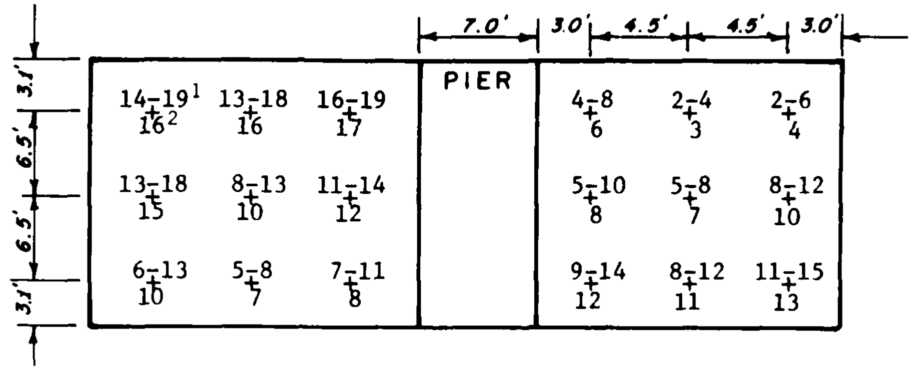
River discharge 67,000 cfs, spillway discharge 42,000 cfs
Pool elev 2130.0, tailwater elev 2087.3

[1] Range of fluctuating velocities.
[2] Average velocity.

NOTE: Velocities in fps; looking downstream

POWER UNIT DRAFT TUBE VELOCITIES

Original Design Power Unit
One-unit Operation, Discharge 6,250 CFS



14-19[1] 16[2]	13-18 16	16-19 17	PIER	4-8 6	2-4 3	2-6 4
13-18 15	8-13 10	11-14 12		5-10 8	5-8 7	8-12 10
6-13 10	5-8 7	7-11 8		9-14 12	8-12 11	11-15 13

River discharge 6,250 cfs, spillway closed
Pool elev 2130.0, tailwater elev 2074.7

11-16 14	11-14 13	13-17 14		3-6 5	2-4 3	4-6 5
10-14 12	6-10 8	9-13 11		6-9 7	5-7 6	5-10 7
7-13 10	5-9 8	7-10 7		8-13 11	8-13 11	10-14 12

River discharge 44,000 cfs, spillway discharge 37,750 cfs
Pool elev 2130.0, tailwater elev 2083.8

13-17 14	11-14 12	11-15 13		4-7 5	2-5 3	2-5 3
10-15 13	7-11 8	9-11 10		5-10 7	5-7 6	4-10 7
8-15 11	5-8 7	6-9 8		8-13 11	7-11 10	8-14 12

River discharge 67,000 cfs, spillway discharge 60,750 cfs
Pool elev 2130.0, tailwater elev 2087.3

[1] Range of fluctuating velocities.
[2] Average velocity.

NOTE: Velocities in fps; looking downstream.

POWER UNIT DRAFT TUBE VELOCITIES

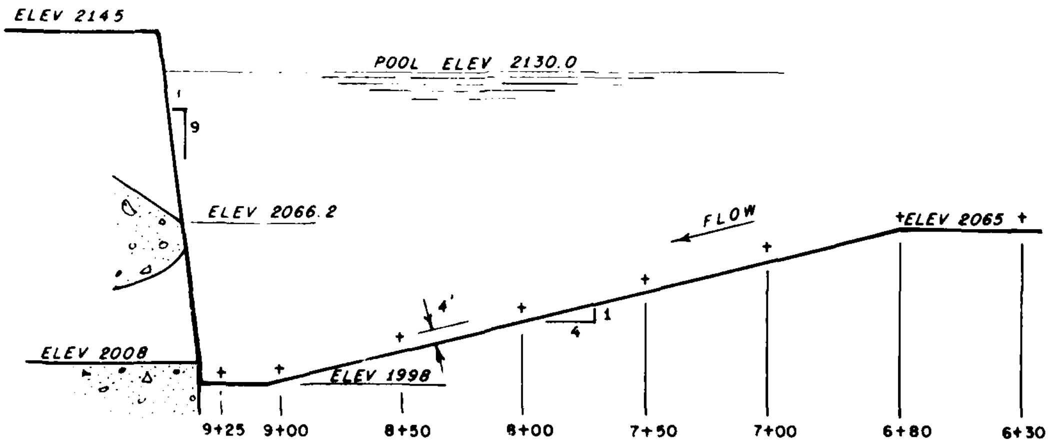
PLATE 24

Original Design Power Unit
Plan B Approach Slope
Pool elev 2130.0

Station	Four Units			One Unit		
	River discharge in CFS			River discharge in CFS		
	25,000	44,000	67,000	6,250	44,000	67,000
	Power discharge in CFS			Power discharge in CFS		
	25,000	25,000	25,000	6,250	6,250	6,250
	Spillway discharge in CFS			Spillway discharge in CFS		
	0	19,000	42,000	0	37,750	60,750
	Velocities in FPS					
9+25	<1	<1	<1	<1	1[1]	<1[2]
9+00	<1	<1	<1	<1	1[1]	<1[2]
8+50	<1	<1	<1	<1	<1	<1
8+00	<1	<1	<1	<1	<1	<1
7+50	<1	<1	<1	<1	<1	1
7+00	<1	1	1	<1	<1	1
6+80	2	2	3	<1	2	4
6+30	1	2	3	<1	2	3

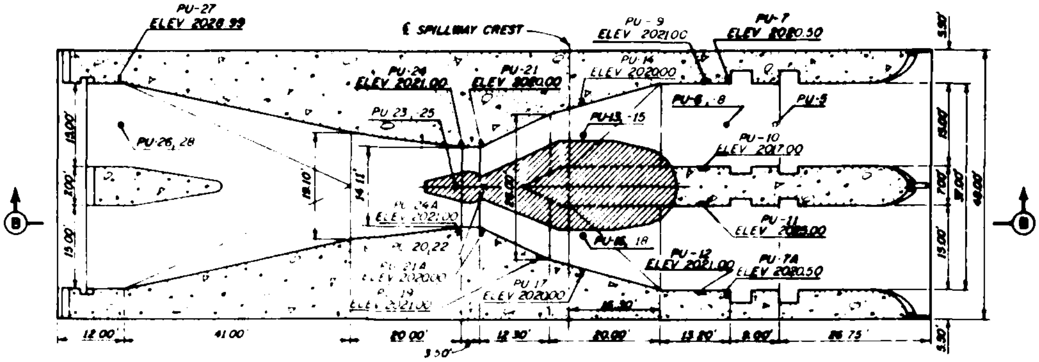
[1] Flow direction 90° to the right.

[2] Flow direction 180° upstream. All other flows downstream.

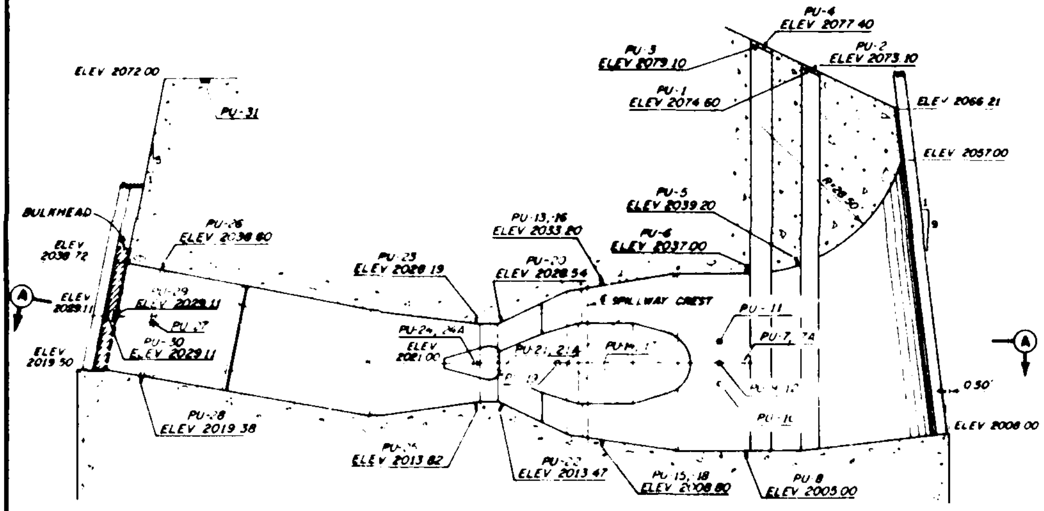


POWERHOUSE APPROACH
VELOCITIES

PLATE 25



SECTION A-A



SECTION B-B

SCALE

0 5 10 20 30 40 50 FT

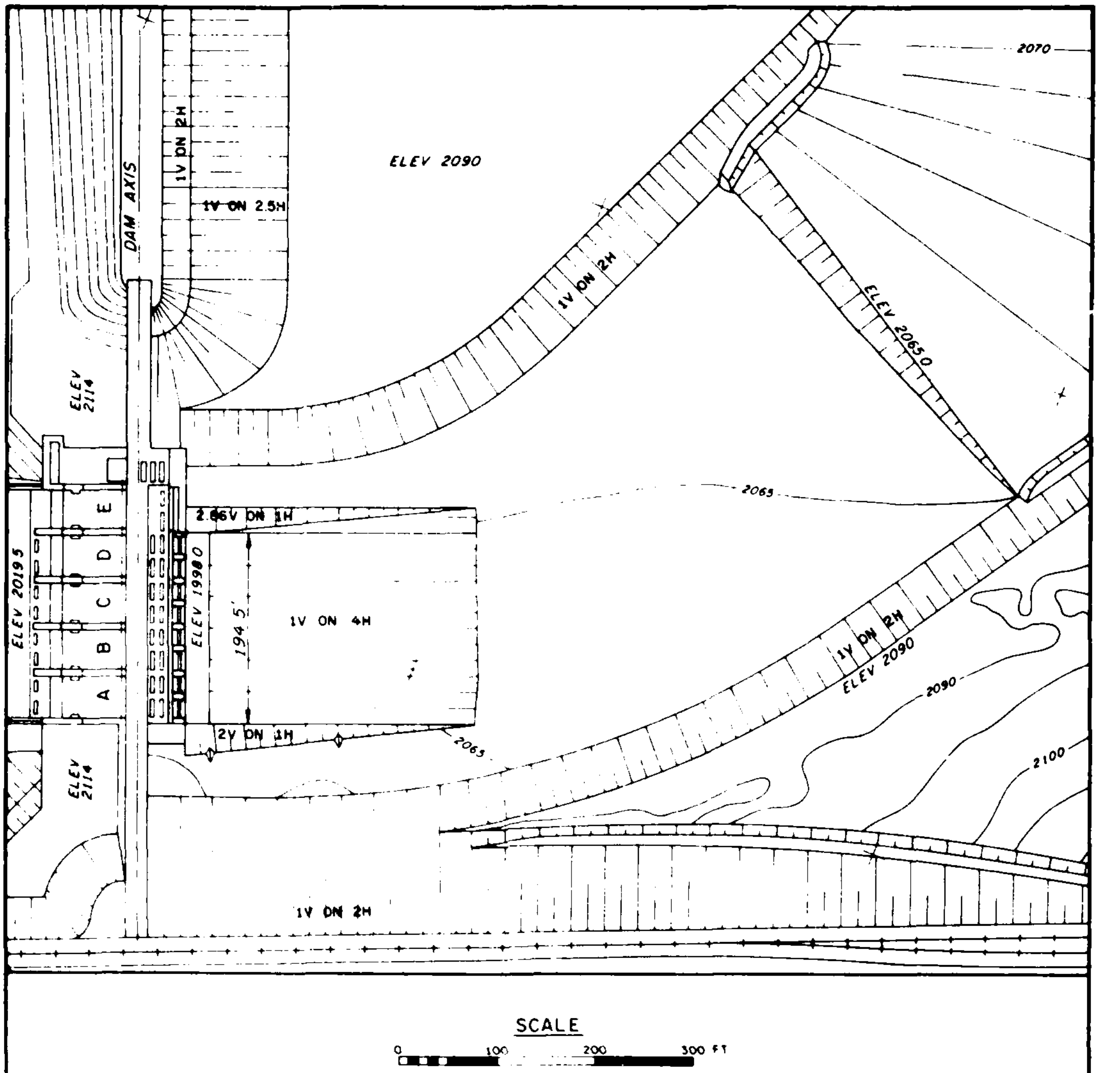
NOTE

PIEZOMETERS PU [illegible] 30, [illegible]

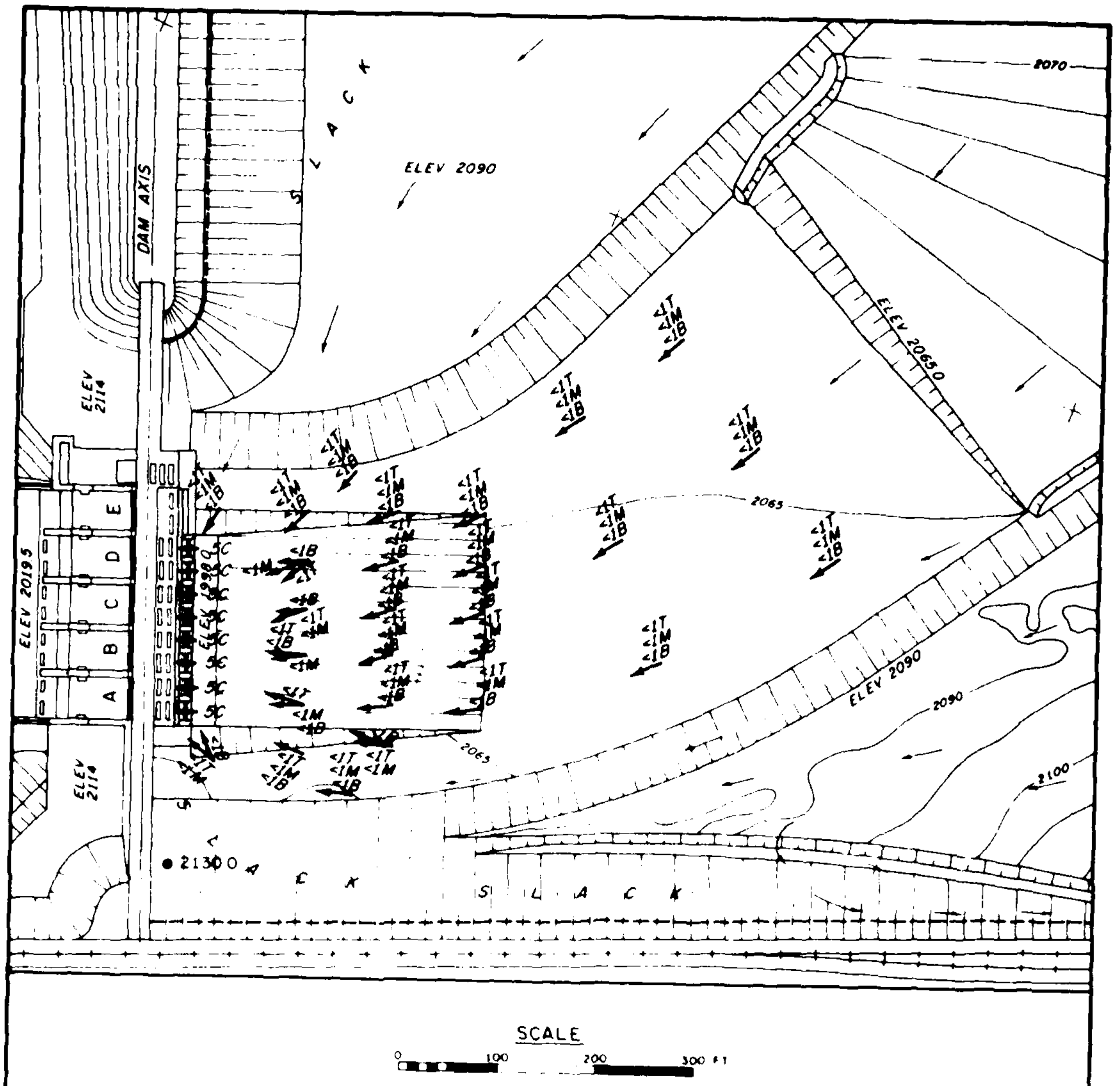
PIEZOMETER LOCATIONS

POWER UNIT

PLATE 26



APPROACH LAYOUT
FINAL (PLAN B) DESIGN



FLOW DISTRIBUTION

POWERHOUSE UNITS A TO D	25,000 CFS
SPILLWAY BAYS	CLOSED

LEGEND

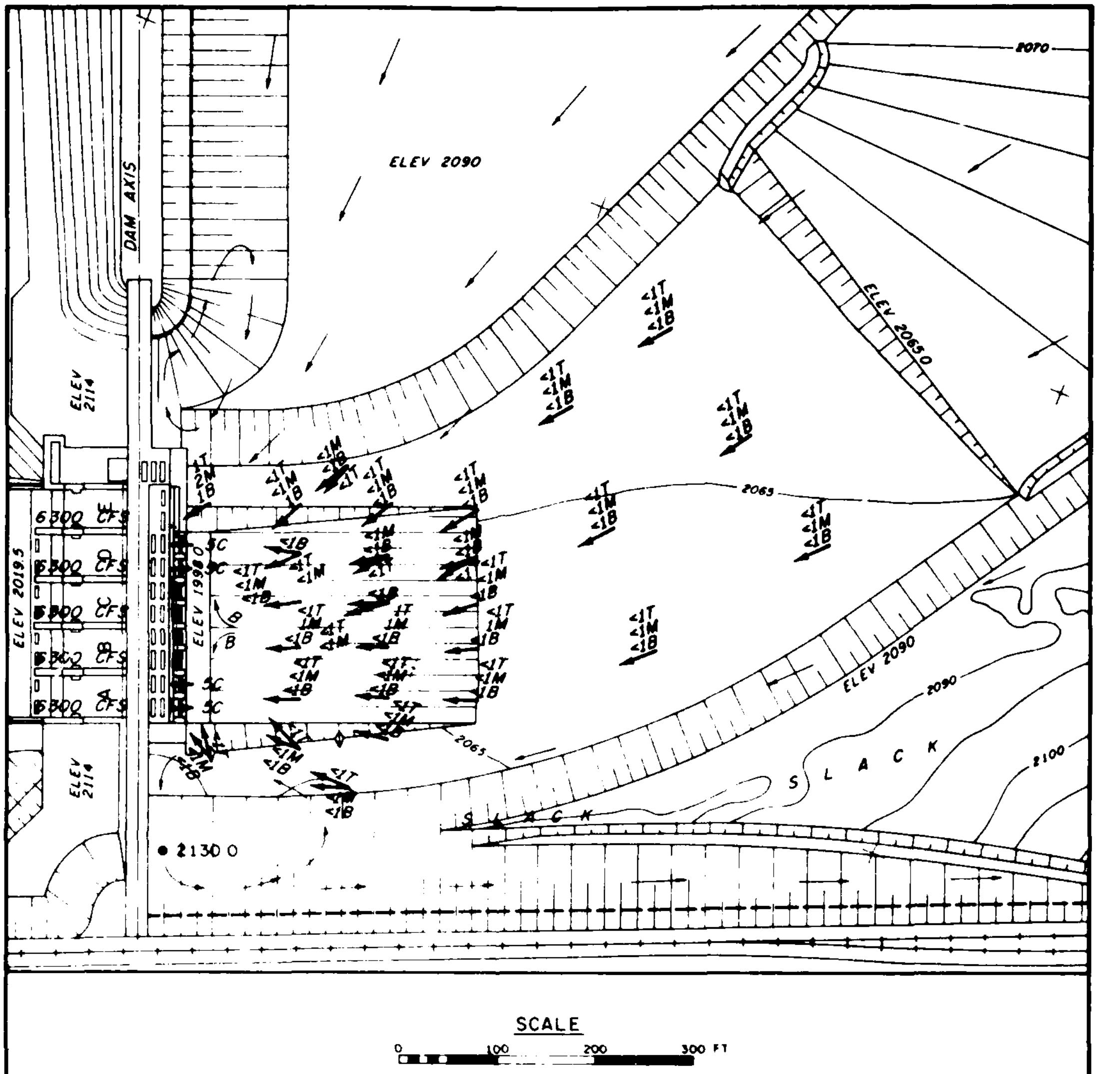
←4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
C	MID-POINT AND 6.7 FT UPSTREAM OF POWER UNIT ENTRANCE
2130.0 ●	WATER-SURFACE ELEVATION

POWER UNITS A TO D
POOL ELEV 2130.0

APPROACH FLOW CONDITIONS

PLAN B

RIVER DISCHARGE 25,000 CFS



FLOW DISTRIBUTION

POWERHOUSE UNITS A AND D	12 500 CFS
SPILLWAY BAYS A TO E	31 500 CFS

POWER UNITS A AND D
POOL ELEV 2130.0

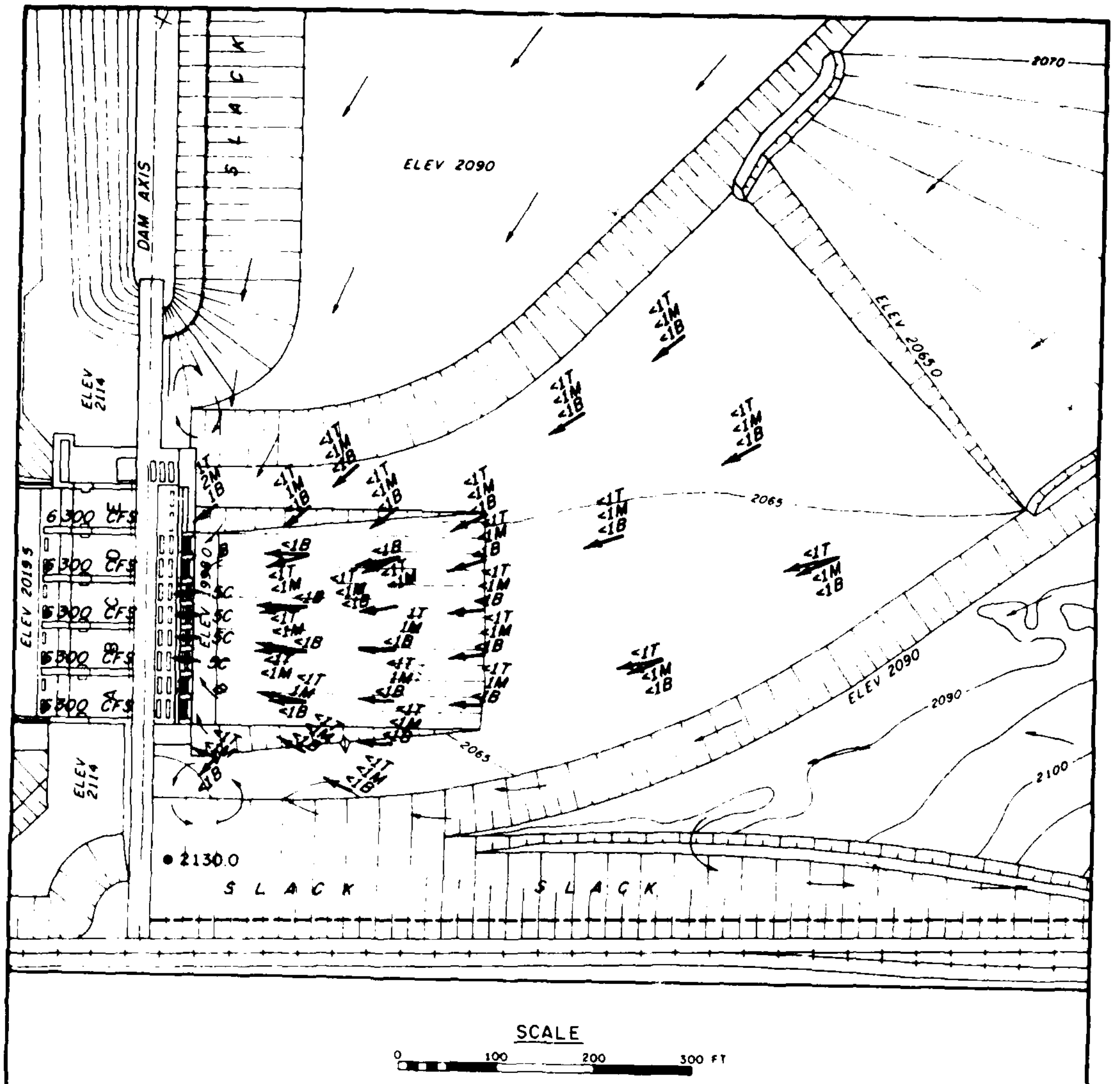
LEGEND

←4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
C	MID-POINT AND 6.7 FT UPSTREAM OF POWER UNIT ENTRANCE
2130.0 ●	WATER-SURFACE ELEVATION

APPROACH FLOW CONDITIONS

PLAN B

RIVER DISCHARGE 44 000 CFS



FLOW DISTRIBUTION

POWERHOUSE UNITS B AND C	12500 CFS
SPILLWAY BAYS A TO E	31500 CFS

LEGEND

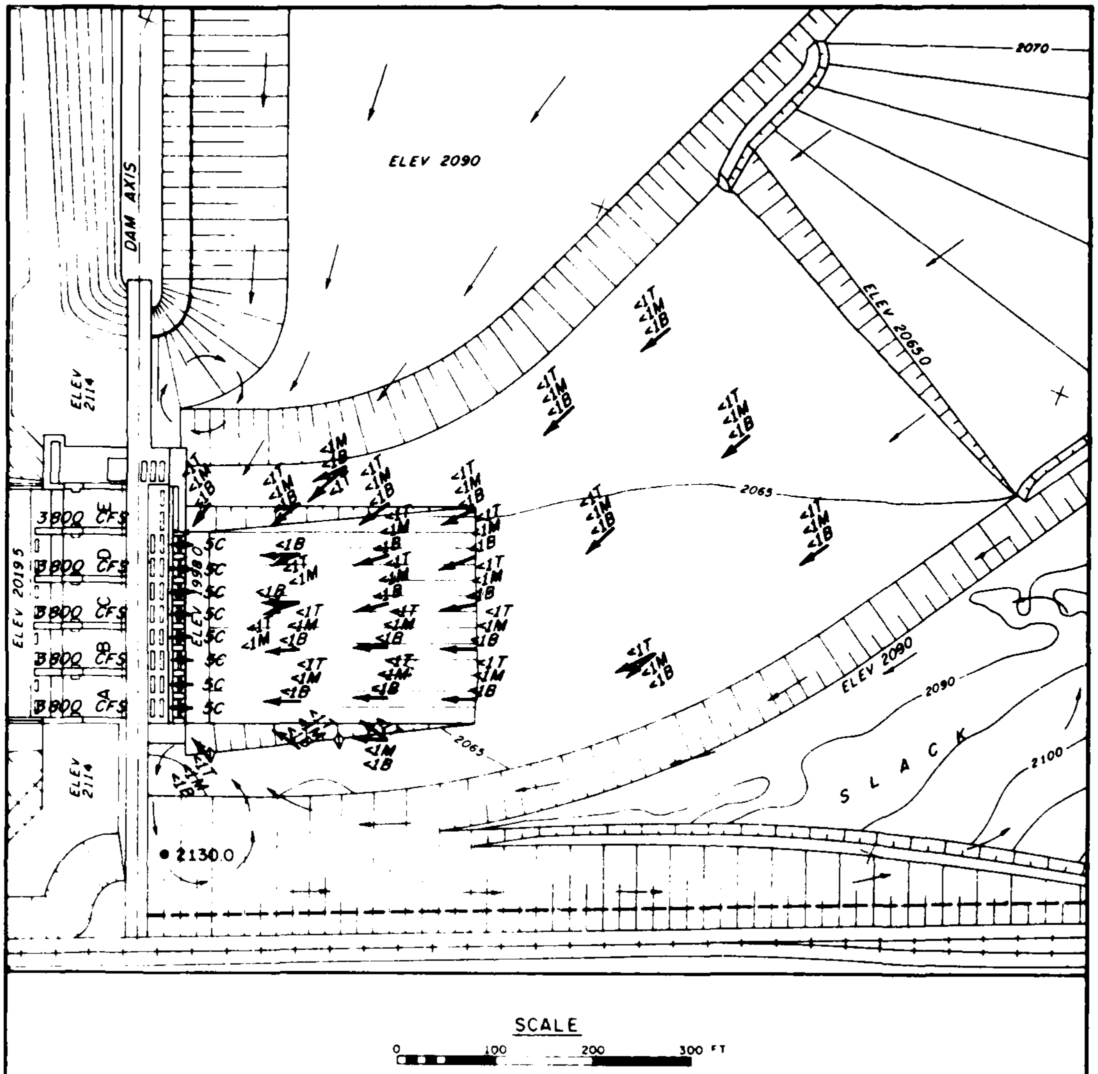
← 4	VELOCITIES IN FPS
T	5 FT DEPTH
M	MID DEPTH
B	5 FT ABOVE BOTTOM
C	MID-POINT AND 6.7 FT UPSTREAM OF POWER UNIT ENTRANCE
2130.0 ●	WATER-SURFACE ELEVATION

POWER UNITS B AND C
POOL ELEV 2130.0

APPROACH FLOW CONDITIONS

PLAN B

RIVER DISCHARGE 44000 CFS



FLOW DISTRIBUTION

POWERHOUSE UNITS A TO D	25000 CFS
SPILLWAY BAYS A TO E	19000 CFS

LEGEND

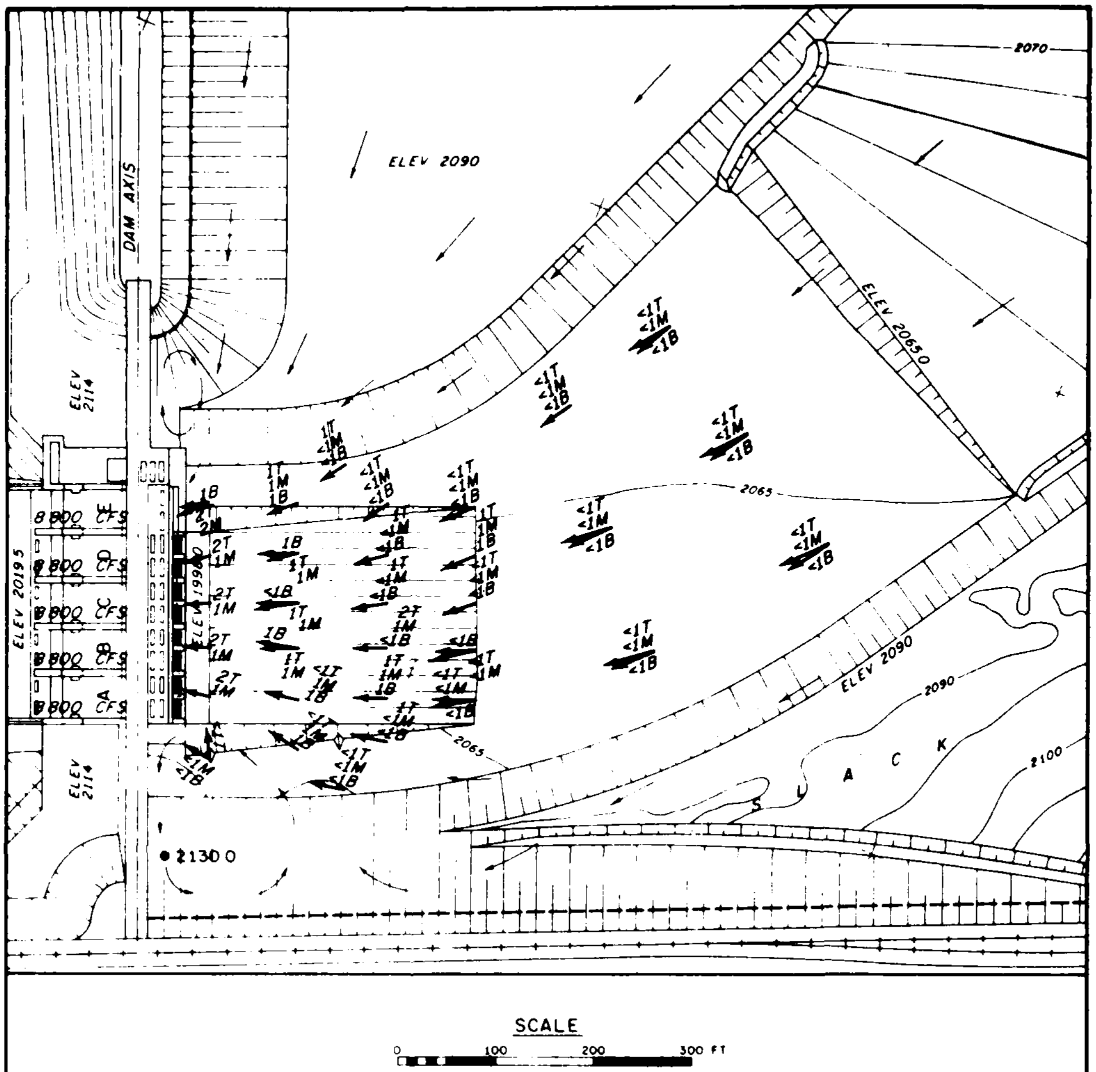
←4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
C	MID-POINT AND 6.7 FT UPSTREAM OF POWER UNIT ENTRANCE
2130.0 ●	WATER-SURFACE ELEVATION

POWER UNITS A TO D
POOL ELEV 2130.0

APPROACH FLOW CONDITIONS

PLAN B

RIVER DISCHARGE 44000 CFS



FLOW DISTRIBUTION

POWERHOUSE UNITS	CLOSED
SPILLWAY BAYS A TO E	44000 CFS

LEGEND

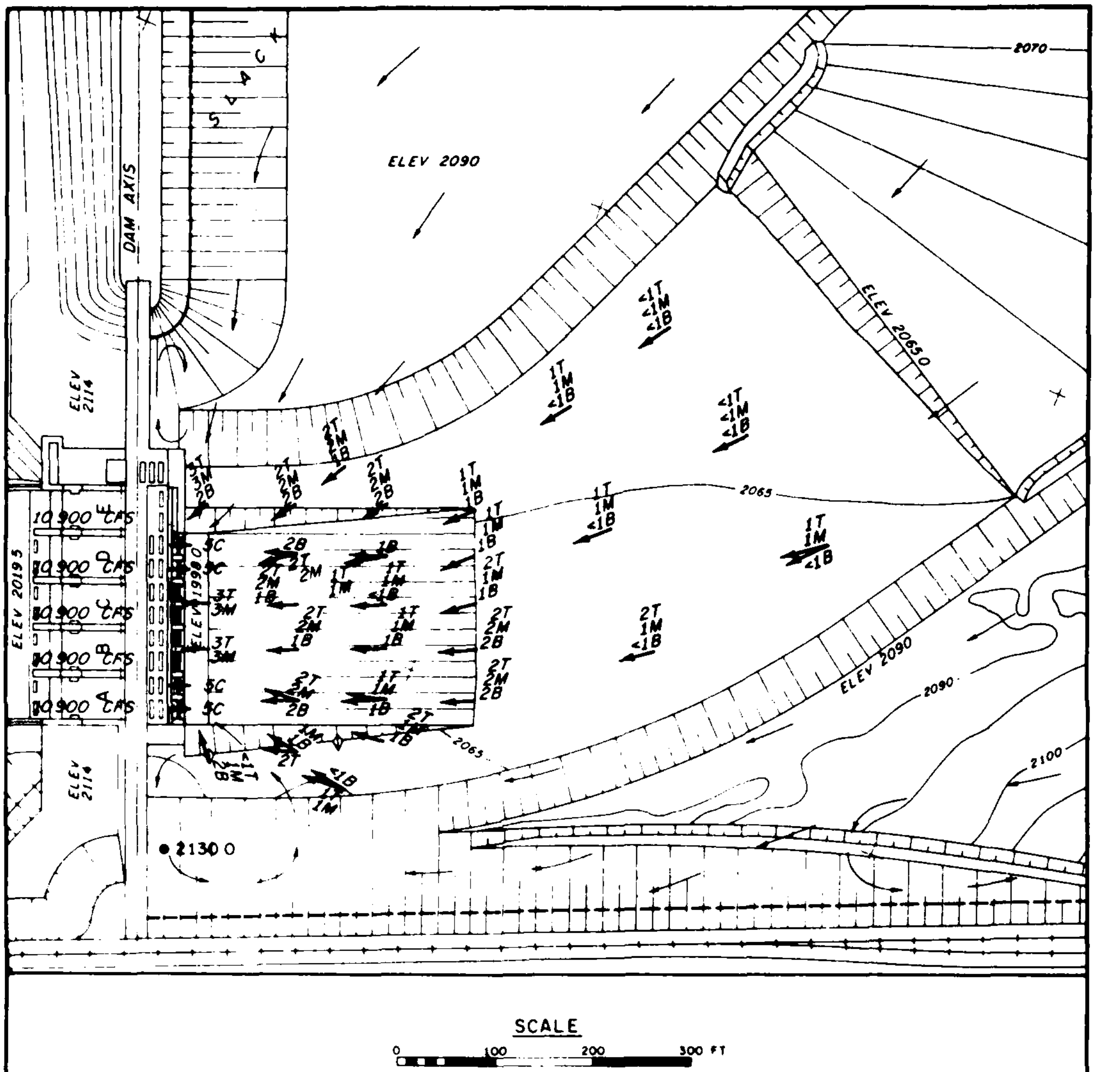
← 4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
2130.0 ●	WATER-SURFACE ELEVATION

SPILL ONLY
POOL ELEV 2130.0

APPROACH FLOW CONDITIONS

PLAN B

RIVER DISCHARGE 44000 CFS



FLOW DISTRIBUTION

POWERHOUSE UNITS A AND D	12,500 CFS
SPILLWAY BAYS A TO E	54,500 CFS

LEGEND

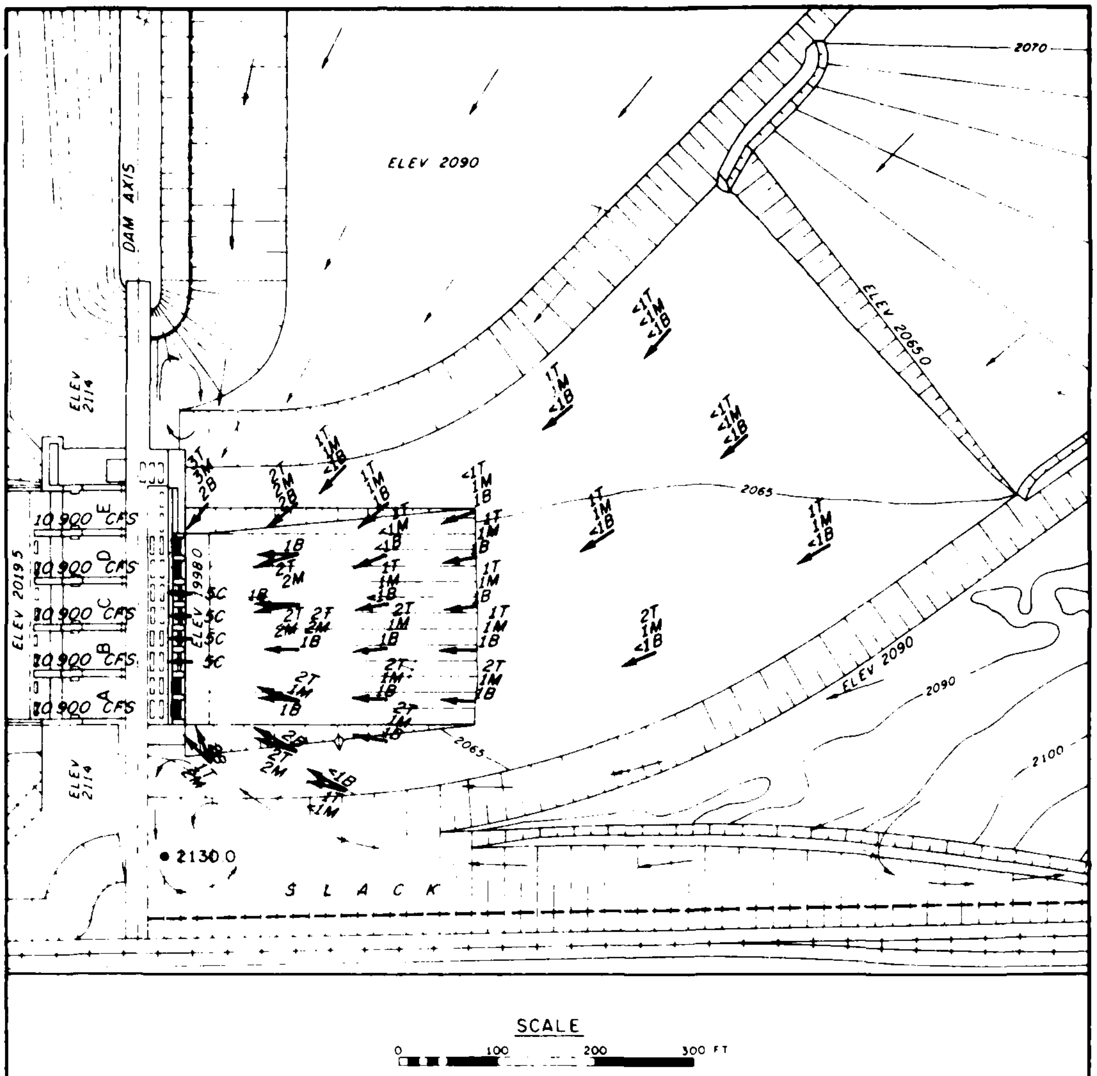
←4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
C	MID-POINT AND 6.7 FT UPSTREAM OF POWER UNIT ENTRANCE
2130.0 ●	WATER-SURFACE ELEVATION

POWER UNITS A AND D
POOL ELEV 2130.0

APPROACH FLOW CONDITIONS

PLAN B

RIVER DISCHARGE 67,000 CFS



FLOW DISTRIBUTION

POWERHOUSE UNITS B AND C	12 500 CFS
SPILLWAY BAYS A TO E	54 500 CFS

LEGEND

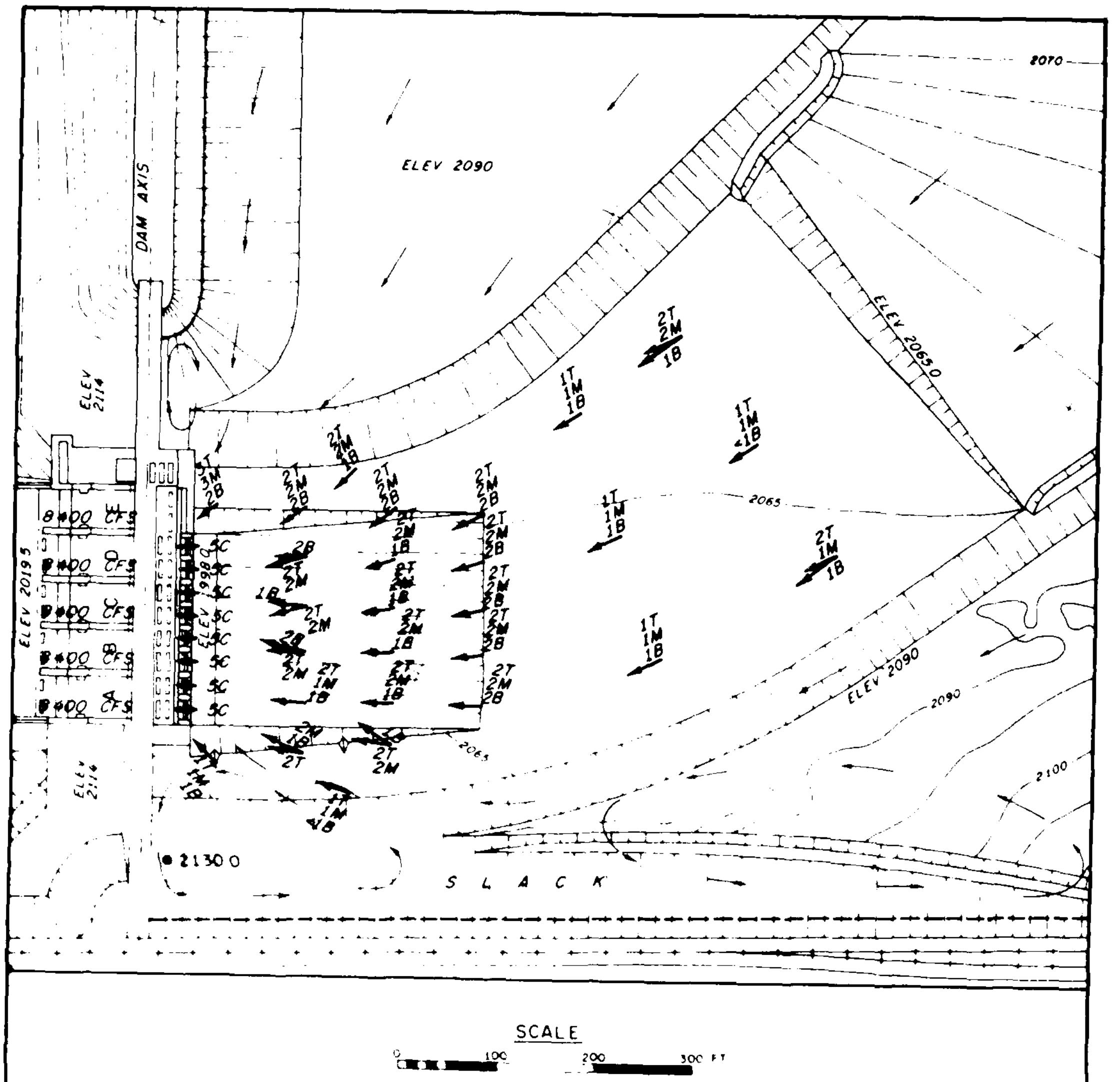
←4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID DEPTH
B	5 FT ABOVE BOTTOM
C	MID-POINT AND 6.7 FT UPSTREAM OF POWER UNIT ENTRANCE
2130.0 ●	WATER-SURFACE ELEVATION

POWER UNITS B AND C
POOL ELEV 2130.0

APPROACH FLOW CONDITIONS

PLAN B

RIVER DISCHARGE 67 000 CFS



FLOW DISTRIBUTION

POWERHOUSE UNITS A TO D	25,000 CFS
SPILLWAY BAYS A TO E	42,000 CFS

LEGEND

←4	VELOCITIES IN FPS
T	5 FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
C	MID-POINT AND 6.7 FT UPSTREAM OF POWER UNIT ENTRANCE
2130.0 ●	WATER-SURFACE ELEVATION

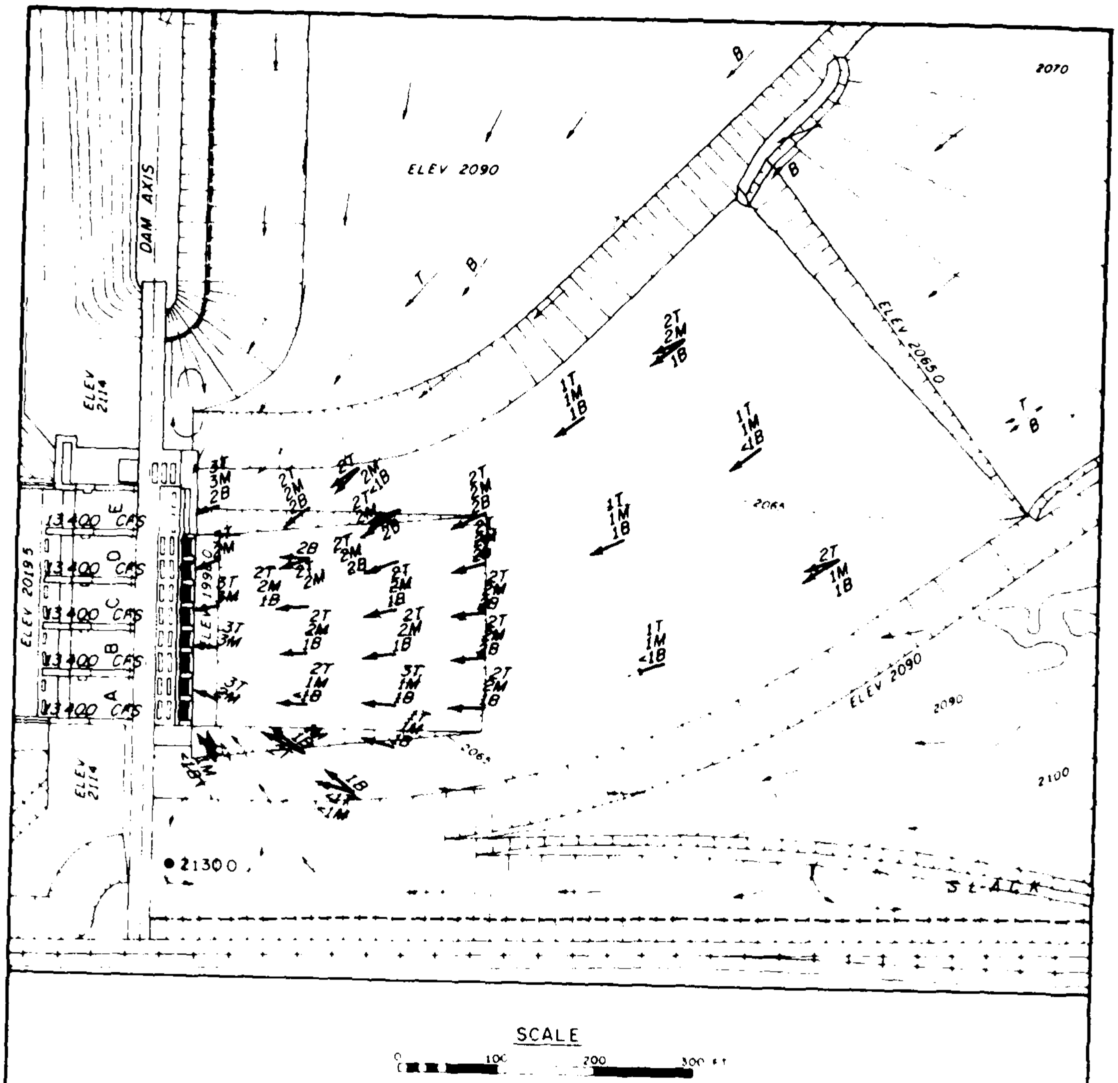
POWER UNITS A TO D
POOL ELEV 2130.0

APPROACH FLOW CONDITIONS

PLAN B

RIVER DISCHARGE 67,000 CFS

PLATE 35



FLOW DISTRIBUTION

POWERHOUSE UNITS CLOSED
SPILLWAY BAYS A TO E 67,000 CFS

LEGEND

←4	VELOCITIES IN FPS
T	5 FT DEPTH
M	MID DEPTH
B	5 FT ABOVE BOTTOM
2130.0 ●	WATER SURFACE ELEVATION

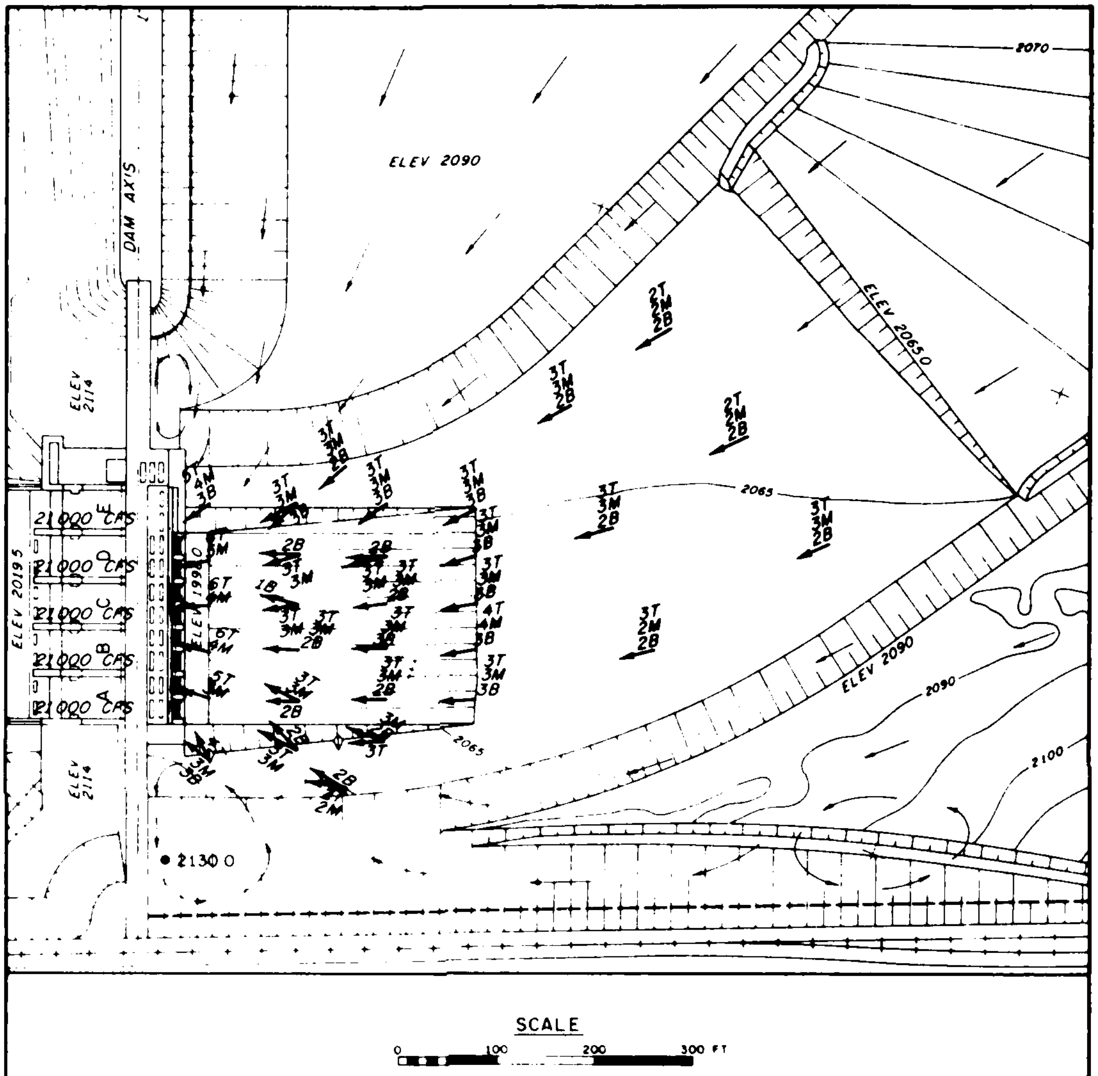
SPILL ONLY
POOL ELEV 2130.0

APPROACH FLOW CONDITIONS

PLAN B

RIVER DISCHARGE 67,000 CFS

PLATE 36



FLOW DISTRIBUTION

POWERHOUSE UNITS	CLOSED
SPILLWAY BAYS A TO E	105,000 CFS

LEGEND

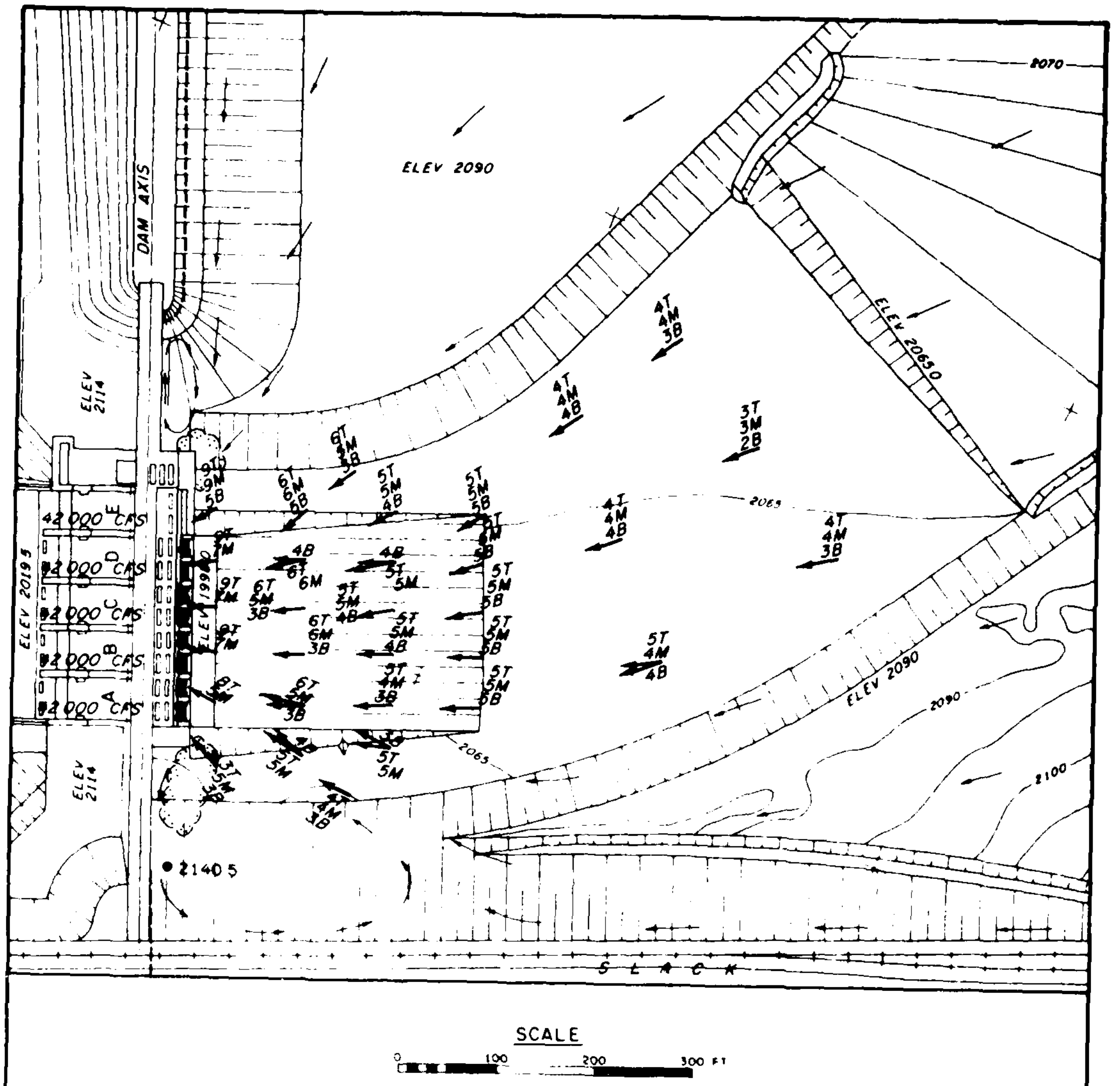
←4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
2130.0	WATER-SURFACE ELEVATION

SPILL ONLY
POOL ELEV 2130.0

APPROACH FLOW CONDITIONS

PLAN 8

RIVER DISCHARGE 105,000 CFS



FLOW DISTRIBUTION

POWERHOUSE UNITS	CLOSED
SPILLWAY BAYS A TO E	210,000 CFS

LEGEND

⟵4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
2140.5 ●	WATER-SURFACE ELEVATION
⌒⌒⌒	BOIL OUTLINE

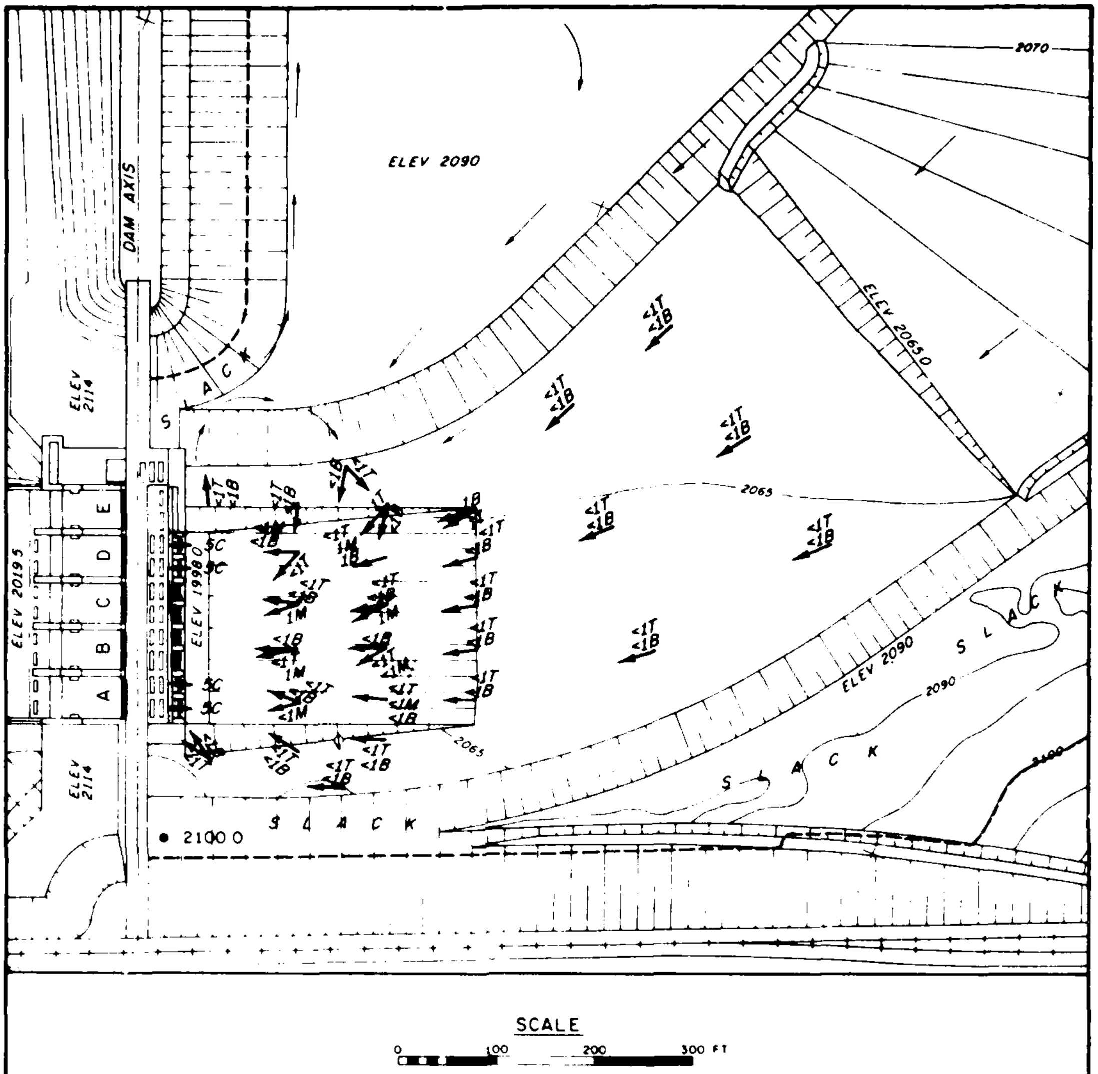
SPILL ONLY

APPROACH FLOW CONDITIONS

PLAN B

RIVER DISCHARGE 210,000 CFS

PLATE 38



FLOW DISTRIBUTION

POWERHOUSE UNITS A AND D	12500 CFS
SPILLWAY BAYS	CLOSED

LEGEND

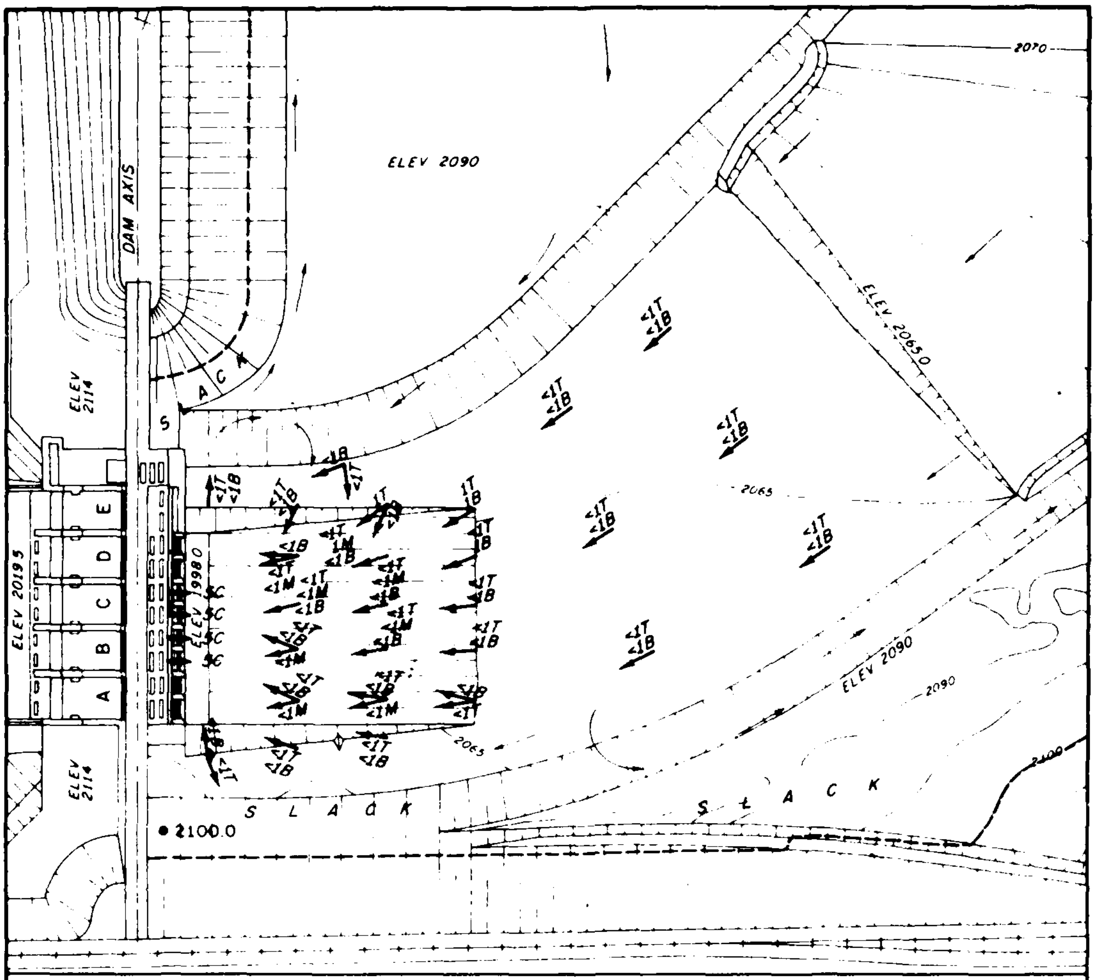
←4	VELOCITIES IN FPS
T	5 FT DEPTH
M	MID DEPTH
B	5 FT ABOVE BOTTOM
.	MID-POINT AND 6.7 FT UPSTREAM OF POWER UNIT ENTRANCE
2100.0 ●	WATER-SURFACE ELEVATION

POWER UNITS A AND D
POOL ELEV 2100.0

APPROACH FLOW CONDITIONS

PLAN B

RIVER DISCHARGE 12500 CFS



SCALE

0 100 200 300 FT

FLOW DISTRIBUTION

POWERHOUSE UNITS B AND C	12 500 CFS
SPILLWAY BAYS	CLOSED

POWER UNITS B AND C
POOL ELEV 2100.0

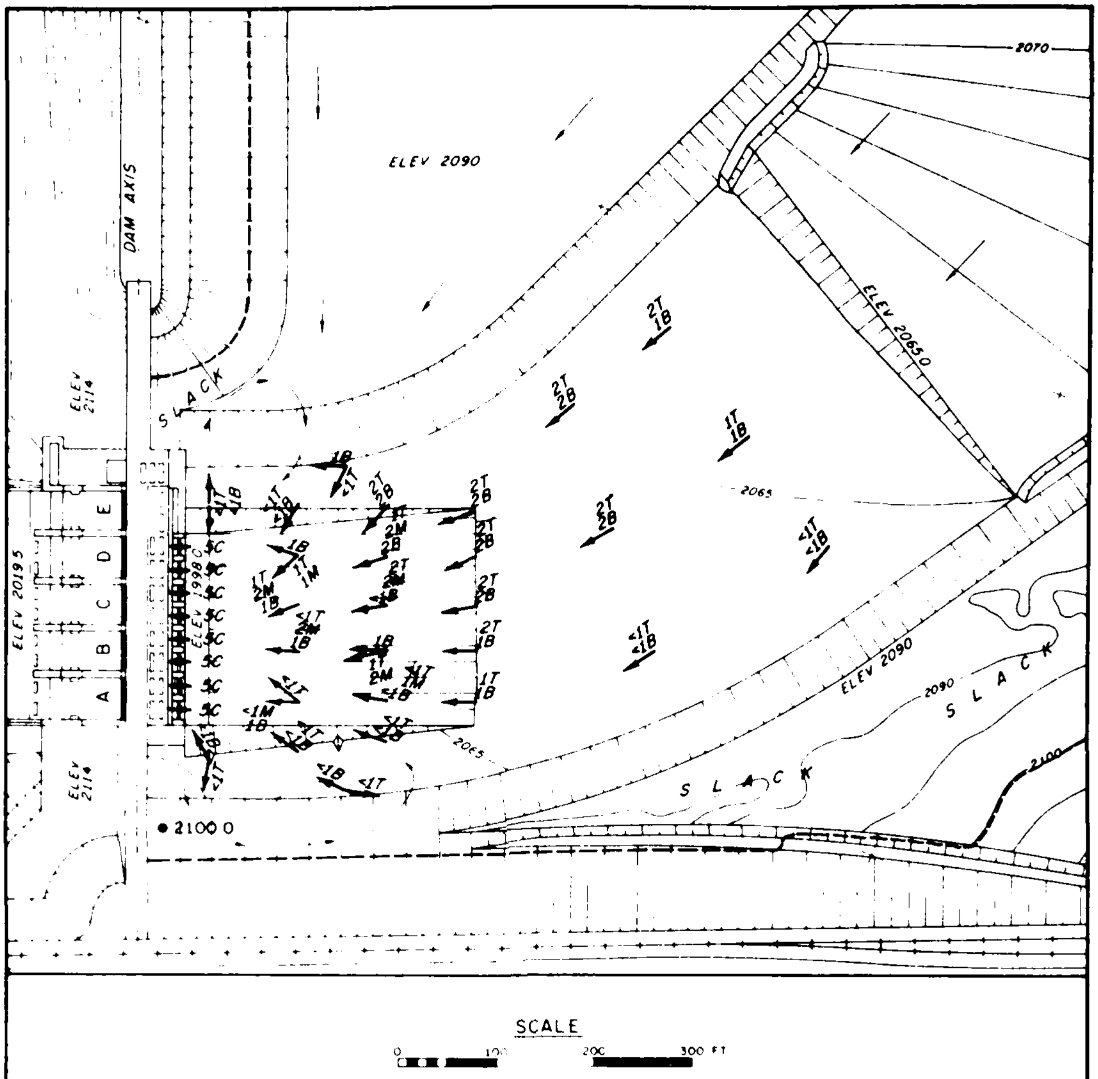
LEGEND

←4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
C	MID-POINT AND 6.7 FT UPSTREAM OF POWER UNIT ENTRANCE
2100.0 ●	WATER-SURFACE ELEVATION

APPROACH FLOW CONDITIONS

PLAN B

RIVER DISCHARGE 12 500 CFS



FLOW DISTRIBUTION

POWERHOUSE UNITS A TO D	25,000 CFS
SPILLWAY BAYS	CLOSED

LEGEND

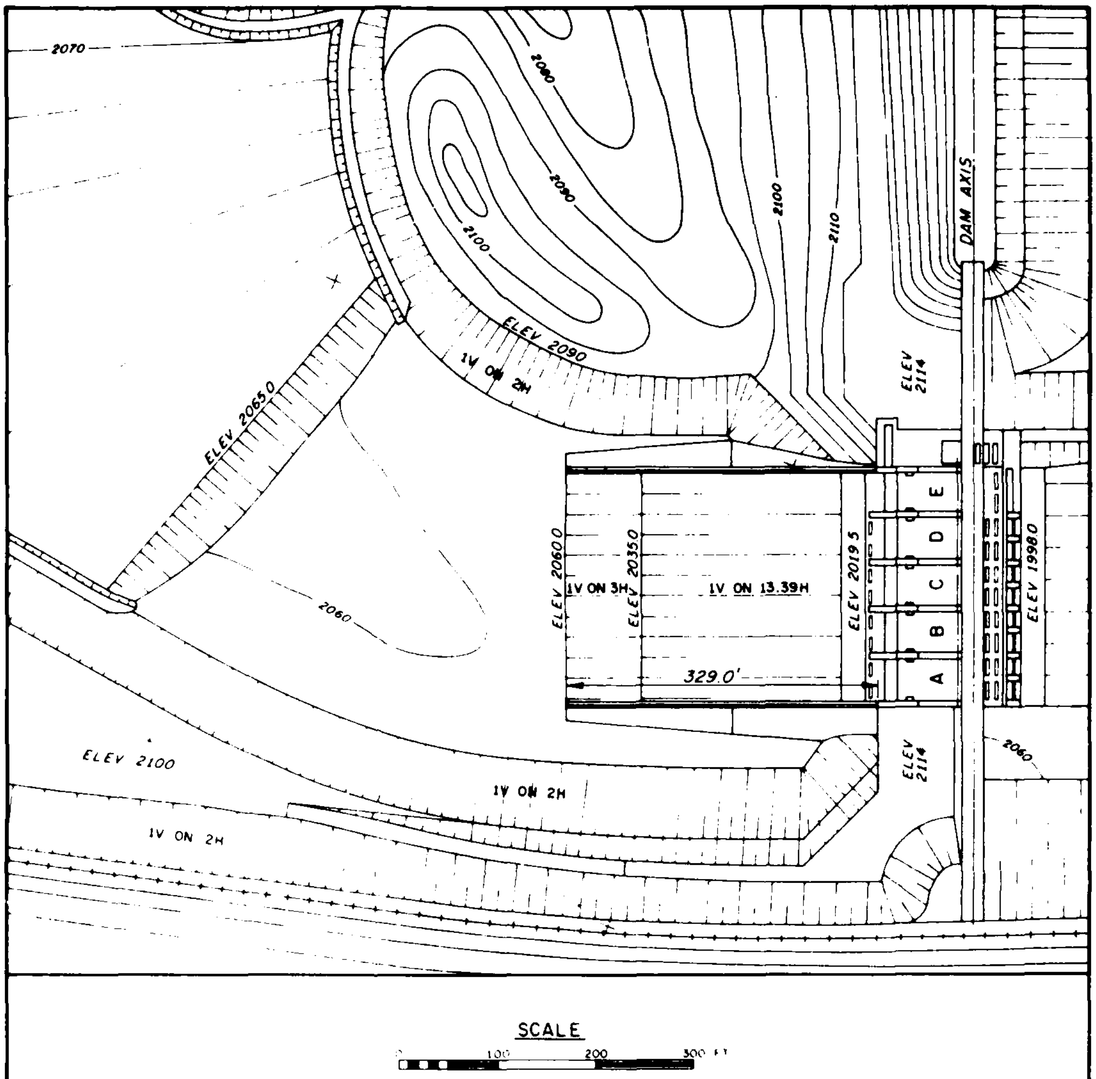
←4	VELOCITIES IN FPS
T	5 FT DEPTH
M	MID DEPTH
B	5 FT ABOVE BOTTOM
C	MID POINT AND 6.7 FT UPSTREAM OF POWER UNIT ENTRANCE
2100.0 ●	WATER SURFACE ELEVATION

POWER UNITS A TO D
POOL ELEV 2100.0

APPROACH FLOW CONDITIONS

PLAN B

RIVER DISCHARGE 25,000 CFS

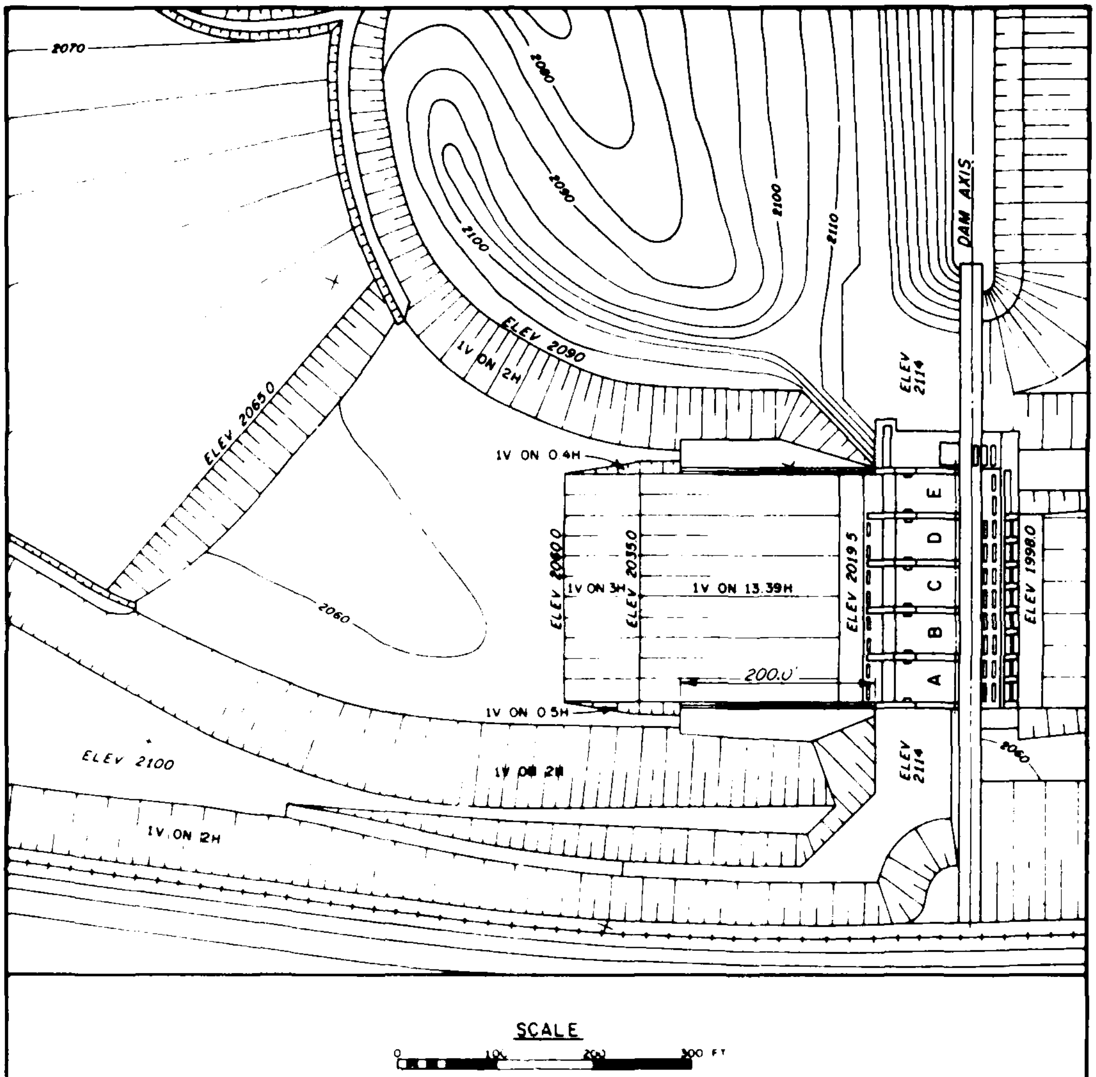


NOTE

TRAINING WALL HEIGHT
ELEV 2102.0 AT STRUCTURE
ELEV 2085.0 AT DOWNSTREAM END

TAILRACE LAYOUT
ORIGINAL DESIGN

PLATE 42



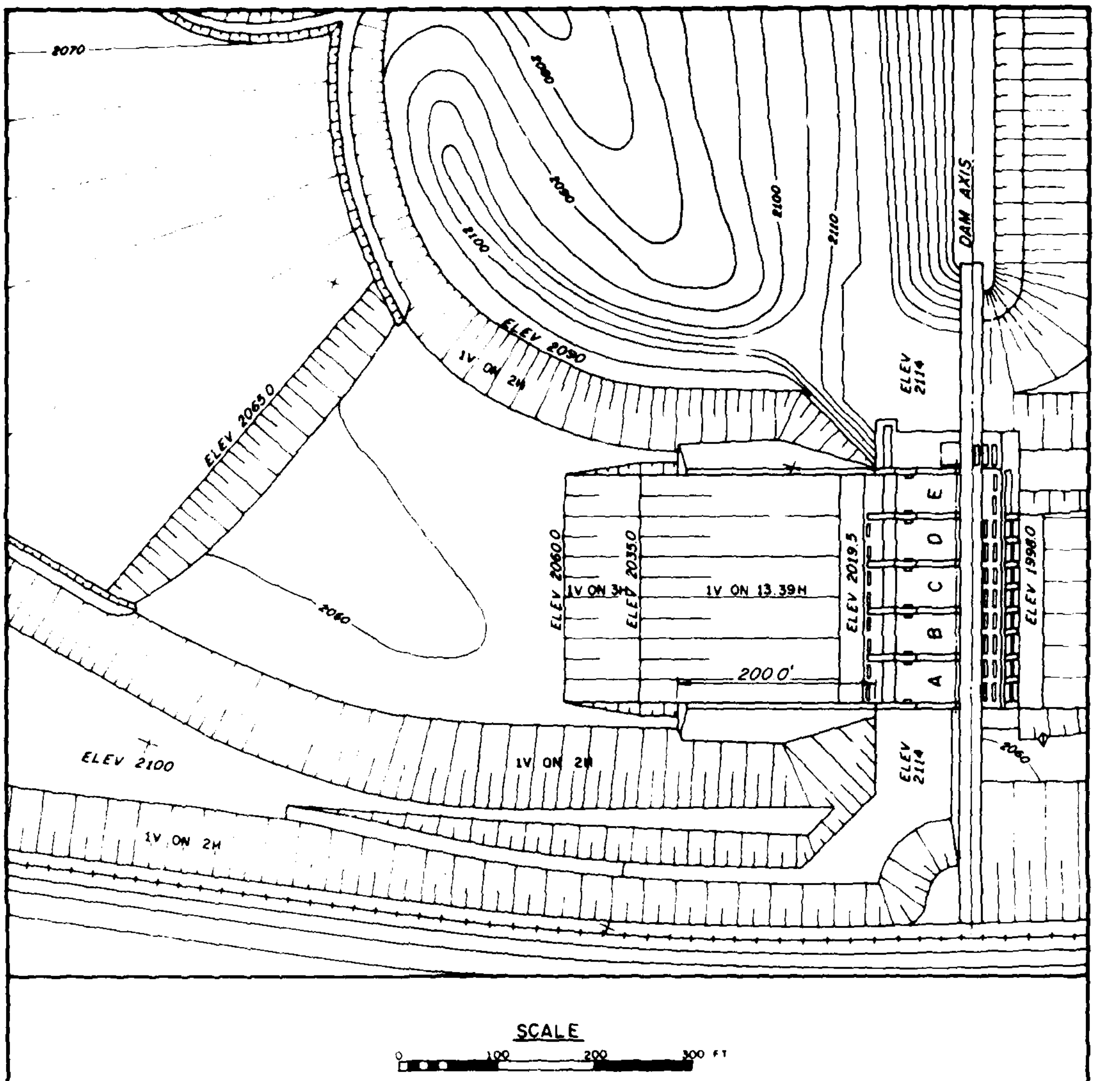
NOTE

TRAINING WALL HEIGHT
ELEV 2102.0 AT STRUCTURE
ELEV 2097.0 AT DOWNSTREAM END

TAILRACE LAYOUT

PLAN B

PLATE 43

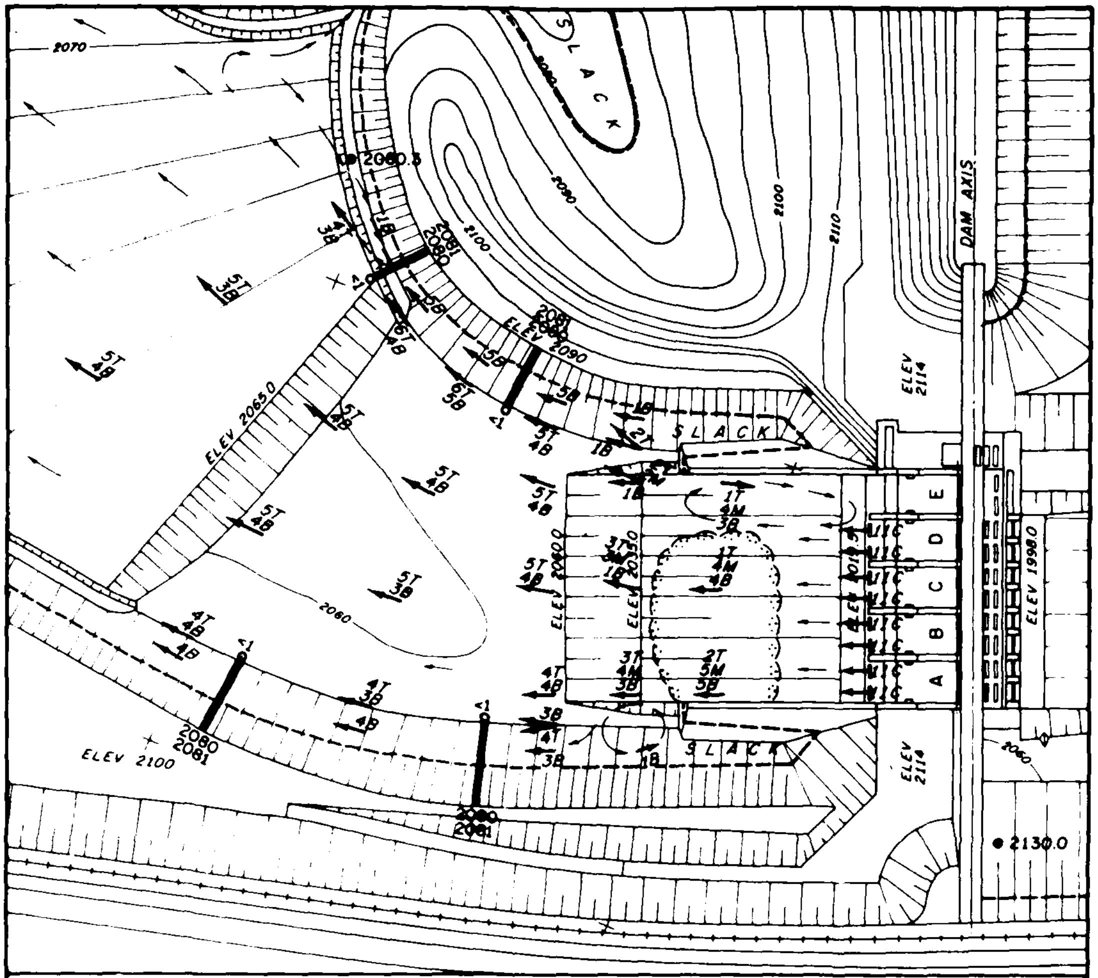


NOTE

TRAINING WALL HEIGHT
ELEV 2102.0 AT STRUCTURE
ELEV 2097.0 AT DOWNSTREAM END

TAILRACE LAYOUT
FINAL (PLAN C) DESIGN

PLATE 44



SCALE

0 100 200 300 FT

FLOW DISTRIBUTION

POWERHOUSE UNITS A TO D	25 000 CFS
SPILLWAY BAYS	CLOSED

LEGEND

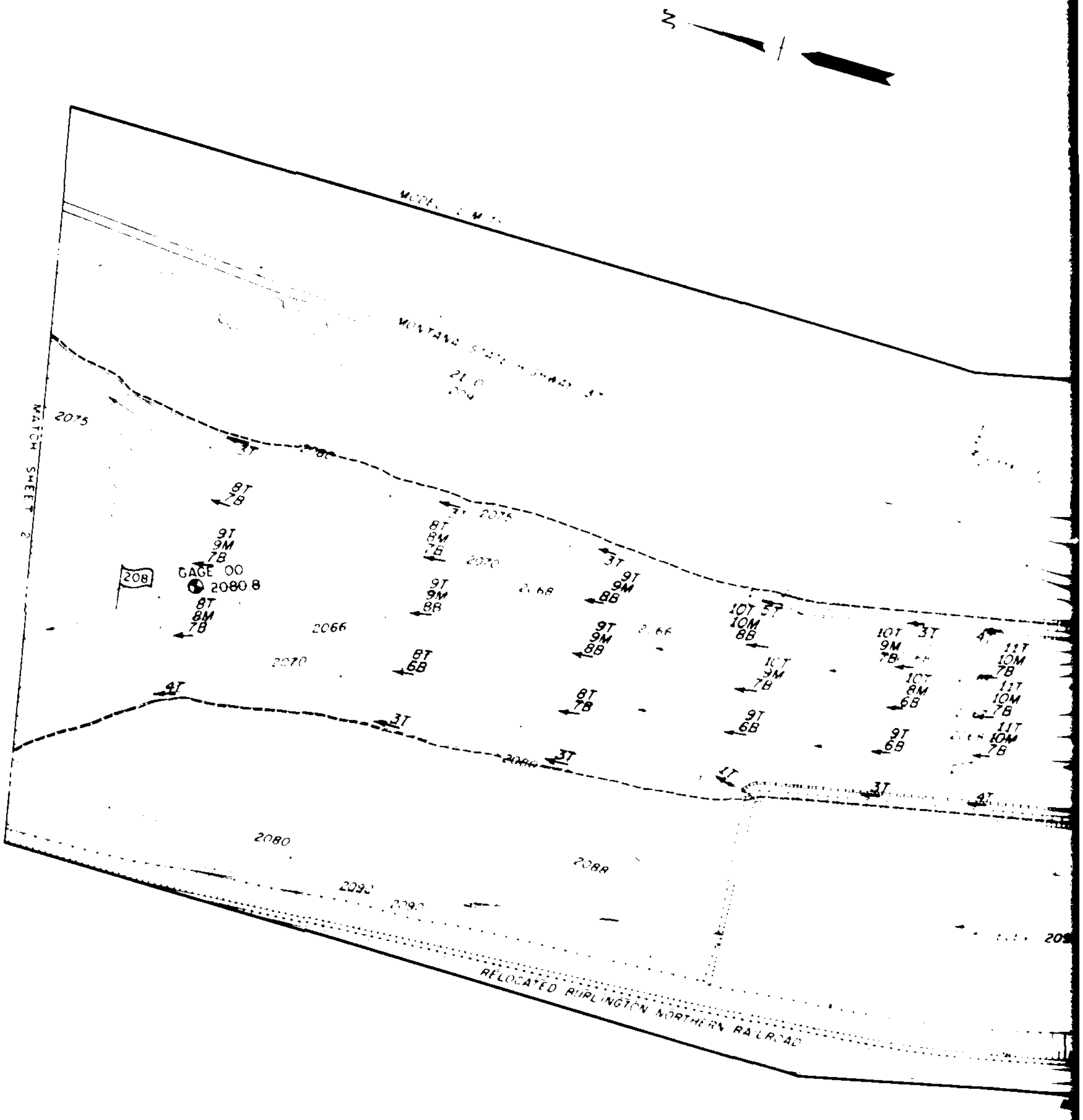
←4—	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
C	MID-POINT AND 6.7 FT DOWNSTREAM OF POWER UNIT EXIT
2080.0 ●	WATER-SURFACE ELEVATIONS
2.0 ○	WAVE HEIGHTS IN FT
⌒⌒⌒	BOIL OUTLINE
▮ 2080 2081	RIDEUP ELEVATIONS

POWER UNITS A TO D
POOL ELEV 2130.0

TAILRACE FLOW CONDITIONS

RIVER DISCHARGE 25 000 CFS

PLATE 45

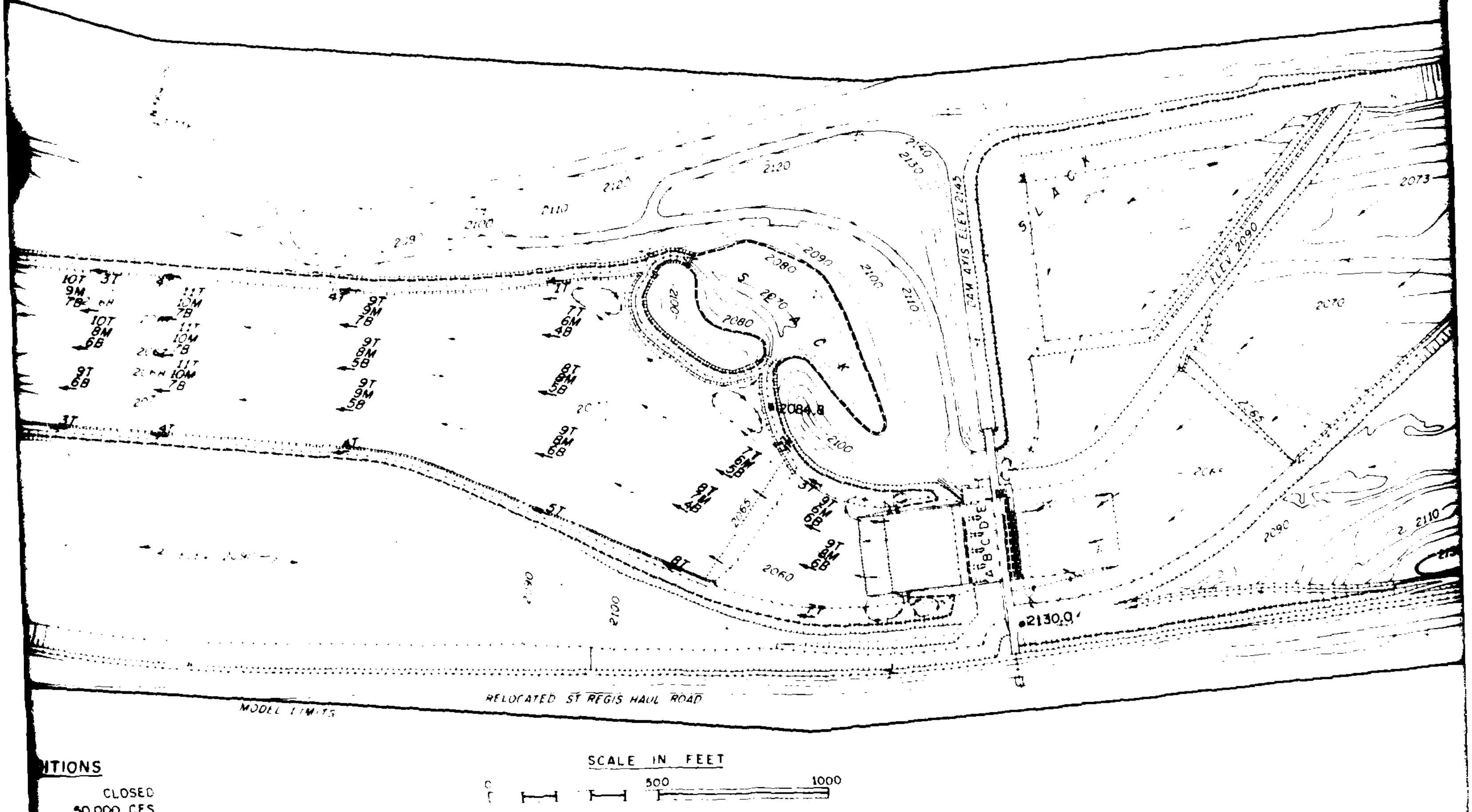


LEGEND

← 4	VELOCITIES IN FPS
T	2-FT DEPTH
M	MID-DEPTH
B	2 FT ABOVE BOTTOM
2080 8 ●, ⊕	WATER-SURFACE ELEVATIONS

OPERATING CONDITIONS

POWERHOUSE UNITS	CLOSE
SPILLWAY BAYS A TO E (UNIFORM SPILL)	50,000 CFS

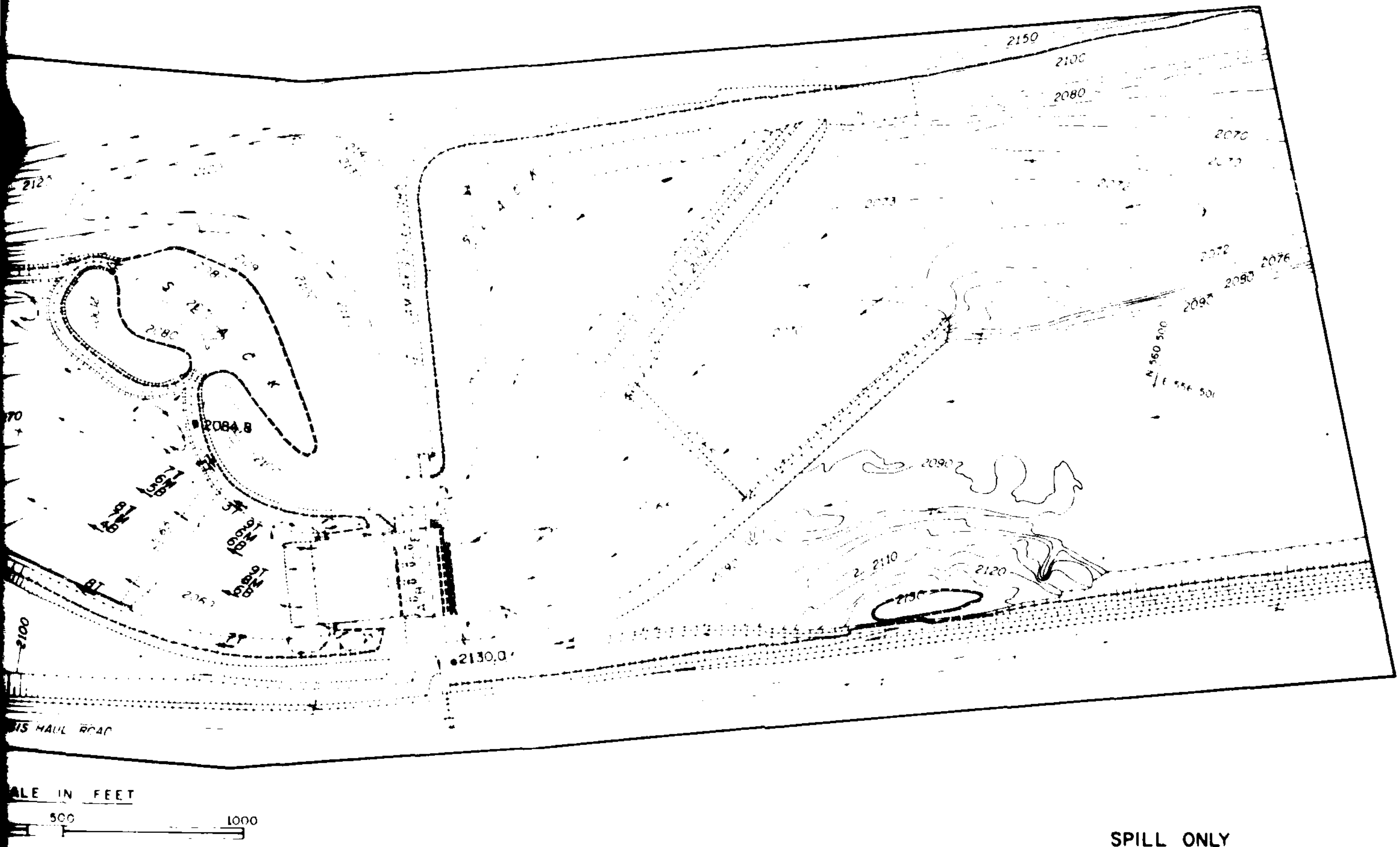


ITIONS

CLOSED
50 000 CFS

1

2



SPILL ONLY

TAILRACE FLOW CONDITIONS

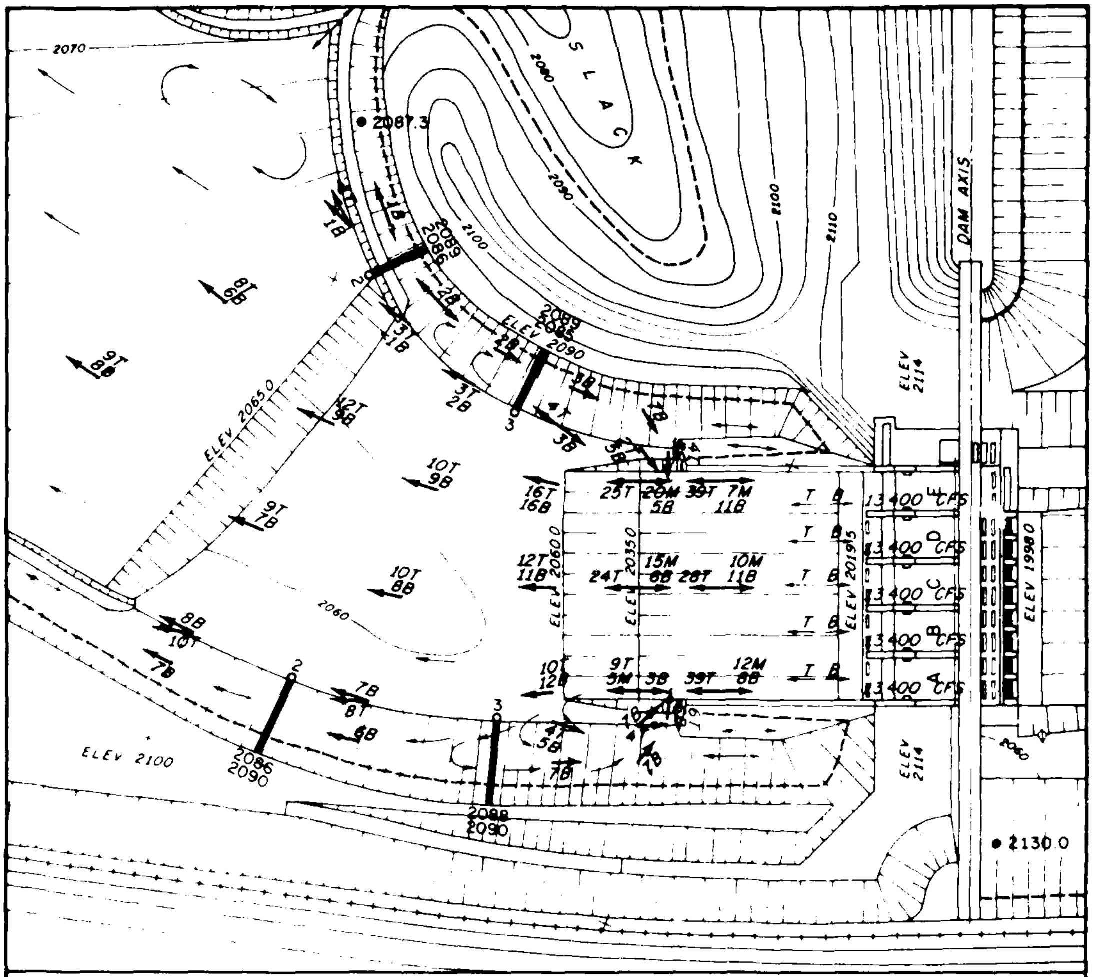
RIVER DISCHARGE 50000 CFS

PLATE 46

2

1

3



SCALE

100 200 300 FT

FLOW DISTRIBUTION

POWERHOUSE UNITS	CLOSED
SPILLWAY BAYS A TO E	67000 CFS

LEGEND

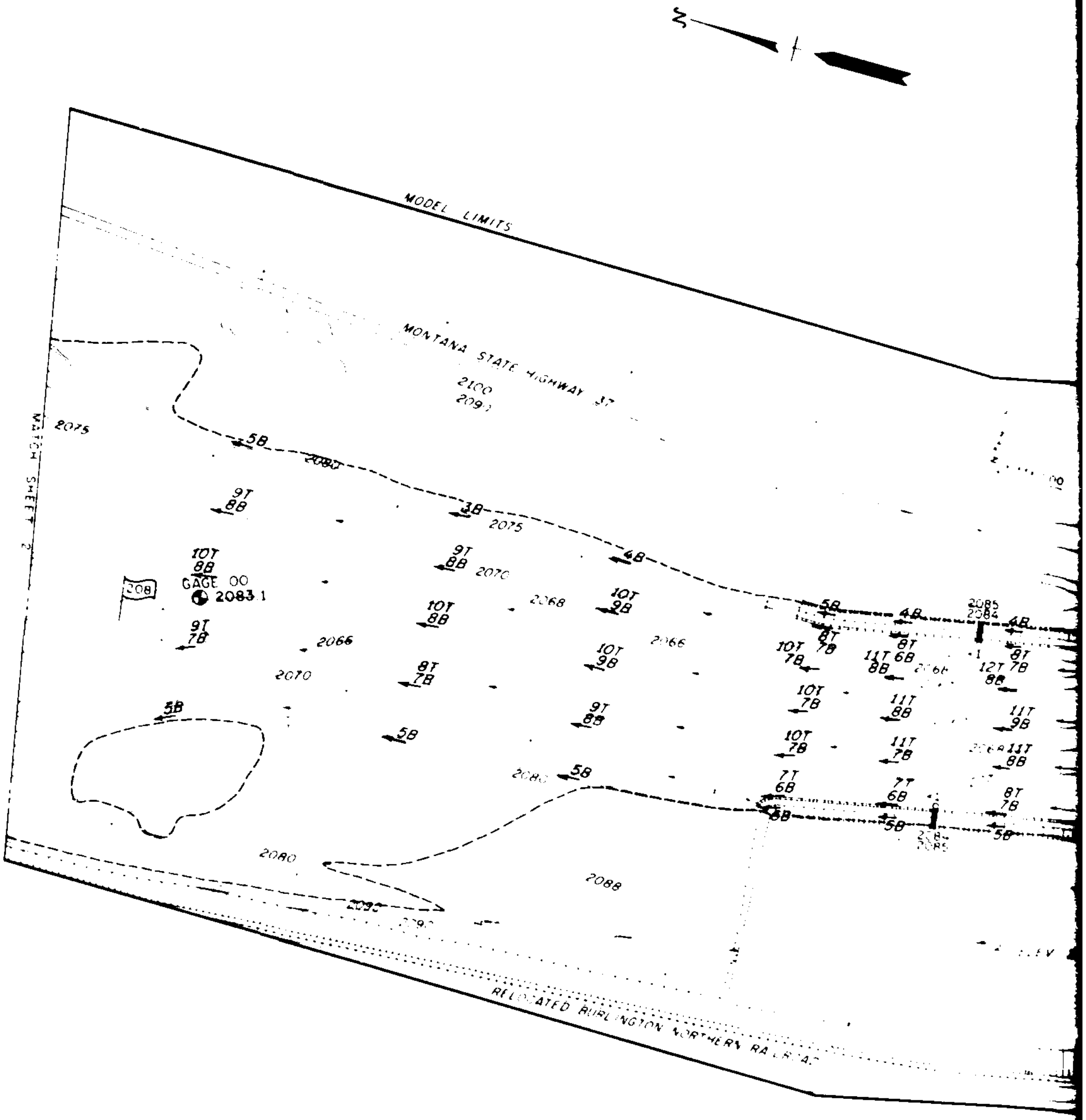
← 4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
2080.0 ●	WATER-SURFACE ELEVATIONS
2.0 ○	WAVE HEIGHTS IN FT
▮ 2086 2087	RIDEUP ELEVATIONS

SPILL ONLY

TAILRACE FLOW CONDITIONS

RIVER DISCHARGE 67000 CFS

PLATE 47

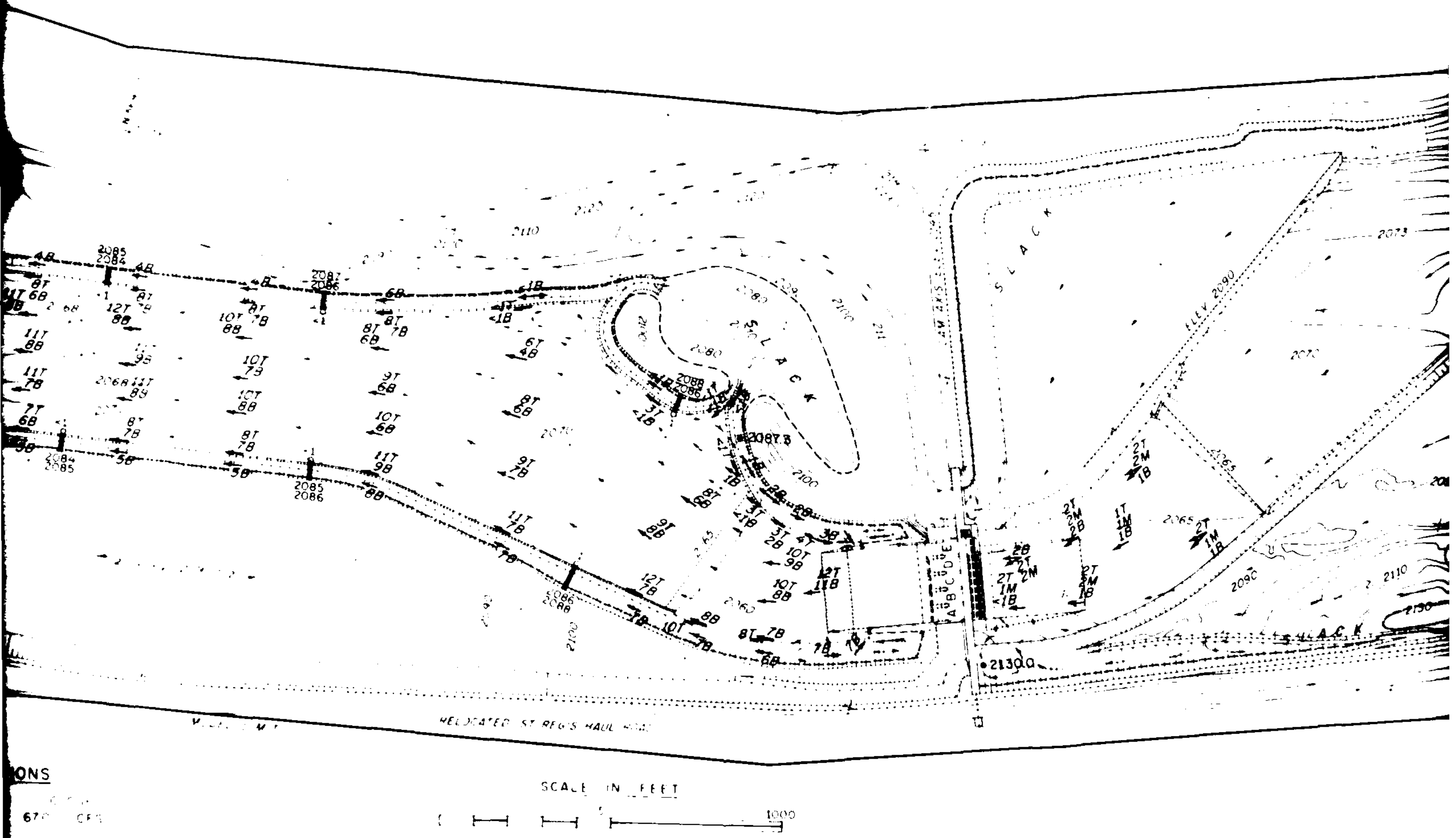


LEGEND

←4	VELOCITIES IN FPS
T	2-FT DEPTH
M	MID-DEPTH
B	2 FT ABOVE BOTTOM
2083.1 ●, ◕	WATER SURFACE ELEVATIONS
1.0	WAVE HEIGHTS IN FT
▌ 2086 2087	RIDEUP ELEVATIONS

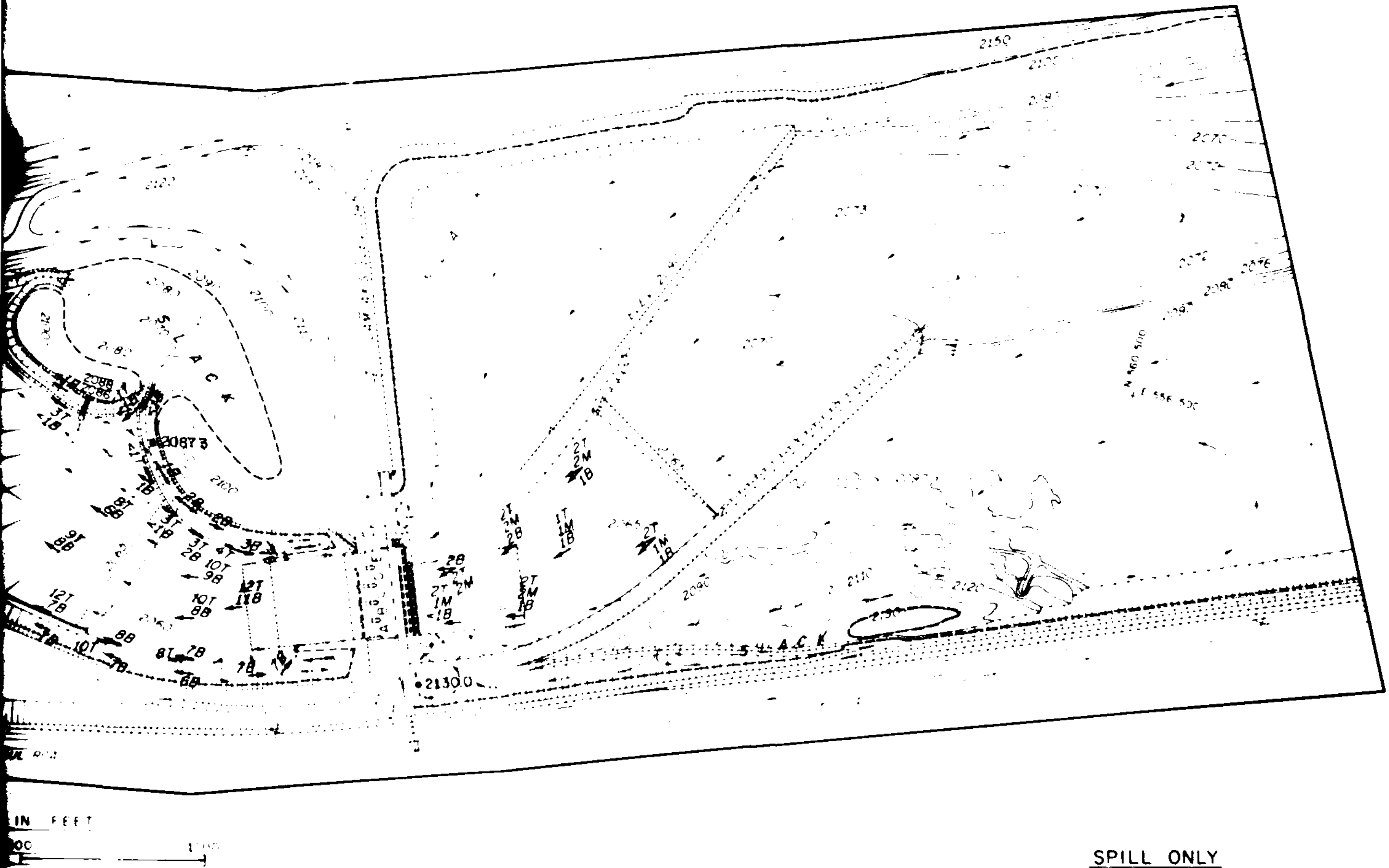
OPERATING CONDITIONS

POWERHOUSE UNITS	[illegible]
SPILLWAY BAYS A TO E (UNIFORM SPILL)	[illegible]


SLACK
SLACK
SLACK
2110
2100
2080
2070
2073
2065
2060
2090
2110
2130
2087.8
2130.0
2085
2084
2087
2086
2088
2086
2084
2085
2085
2086
2086
2088
4B
6B
8T
7B
12T
8B
10T
11T
9B
1B
6T
4B
3T
2T
2M
1M
1B
2B
A B C D E
RELOCATED ST REGIS HAUL ROAD
ONS
670 CFS
SCALE IN FEET
1000

1

2



SPILL ONLY

TAILRACE FLOW CONDITIONS

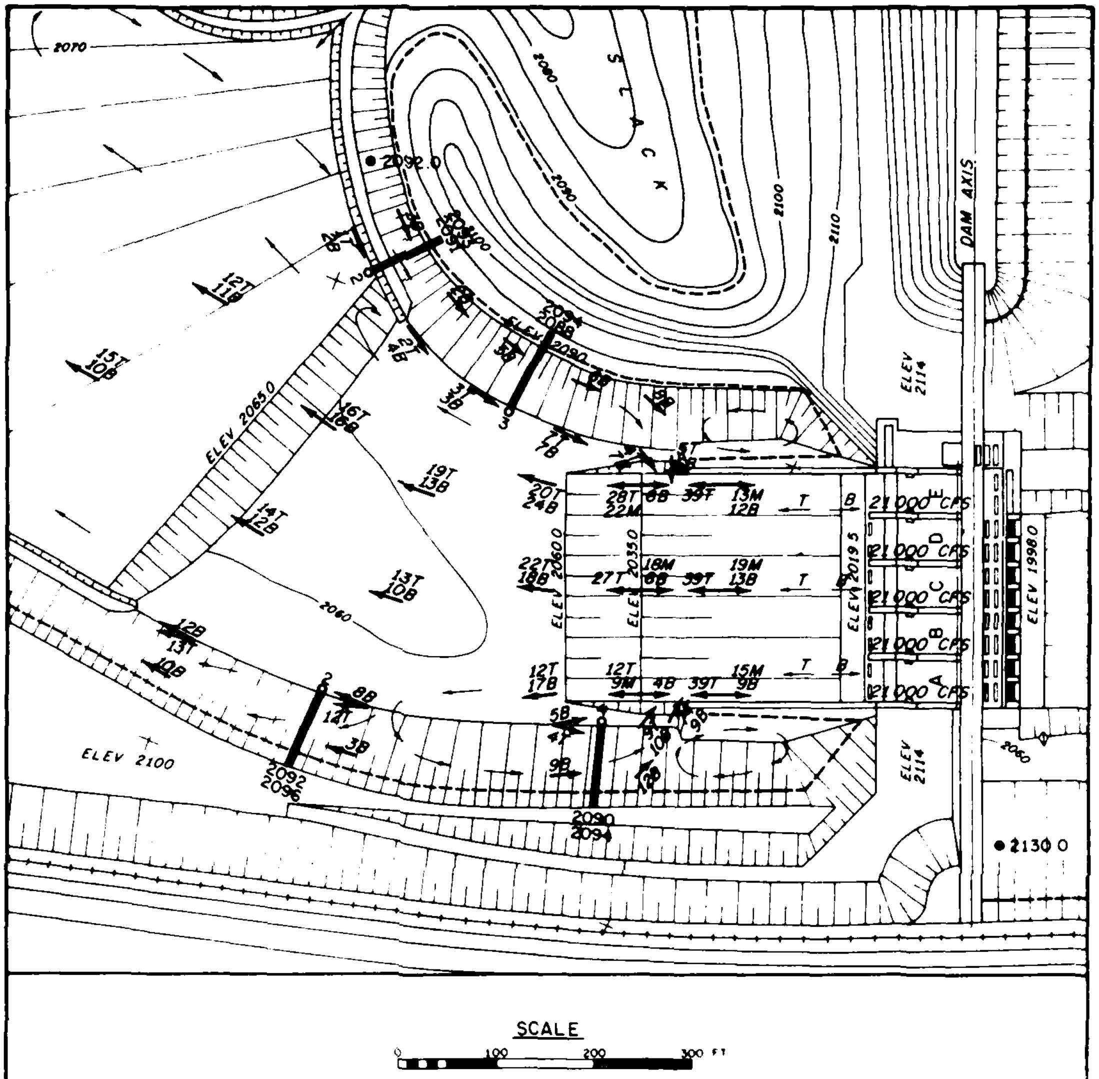
RIVER DISCHARGE 67000 CFS

PLATE 48

2

1

3



FLOW DISTRIBUTION

POWERHOUSE UNITS	CLOSED
SPILLWAY BAYS A TO E	105 000 CFS

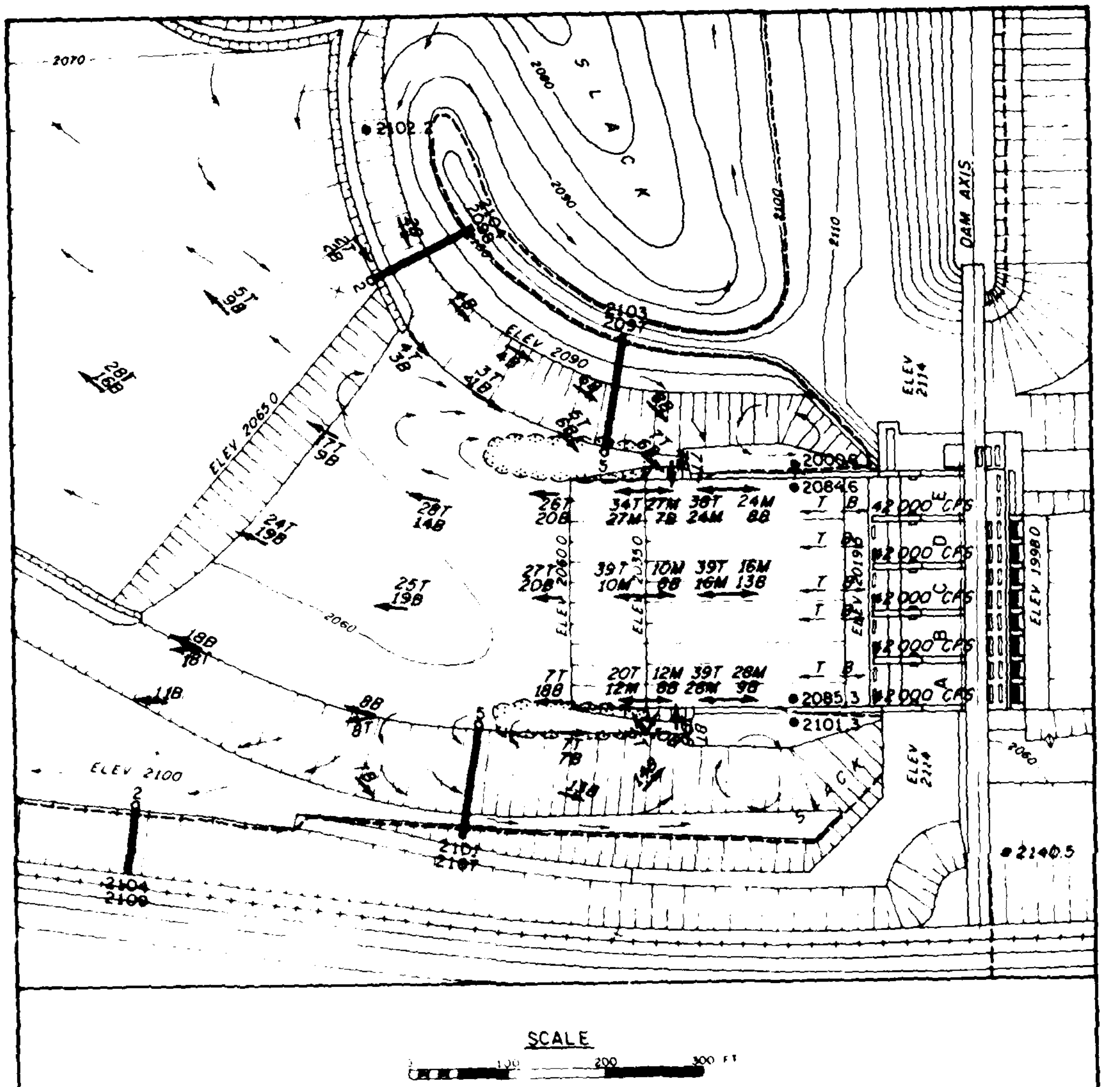
LEGEND

← 4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
2080.0 ●	WATER-SURFACE ELEVATIONS
2.0 ○	WAVE HEIGHTS IN FT
▮ 2092 2096	RIDEUP ELEVATIONS

SPILL ONLY

TAILRACE FLOW CONDITIONS

RIVER DISCHARGE 105000 CFS



FLOW DISTRIBUTION

POWERHOUSE UNITS	CLOSED
SPILLWAY BAYS A TO E	210,000 CFS

LEGEND

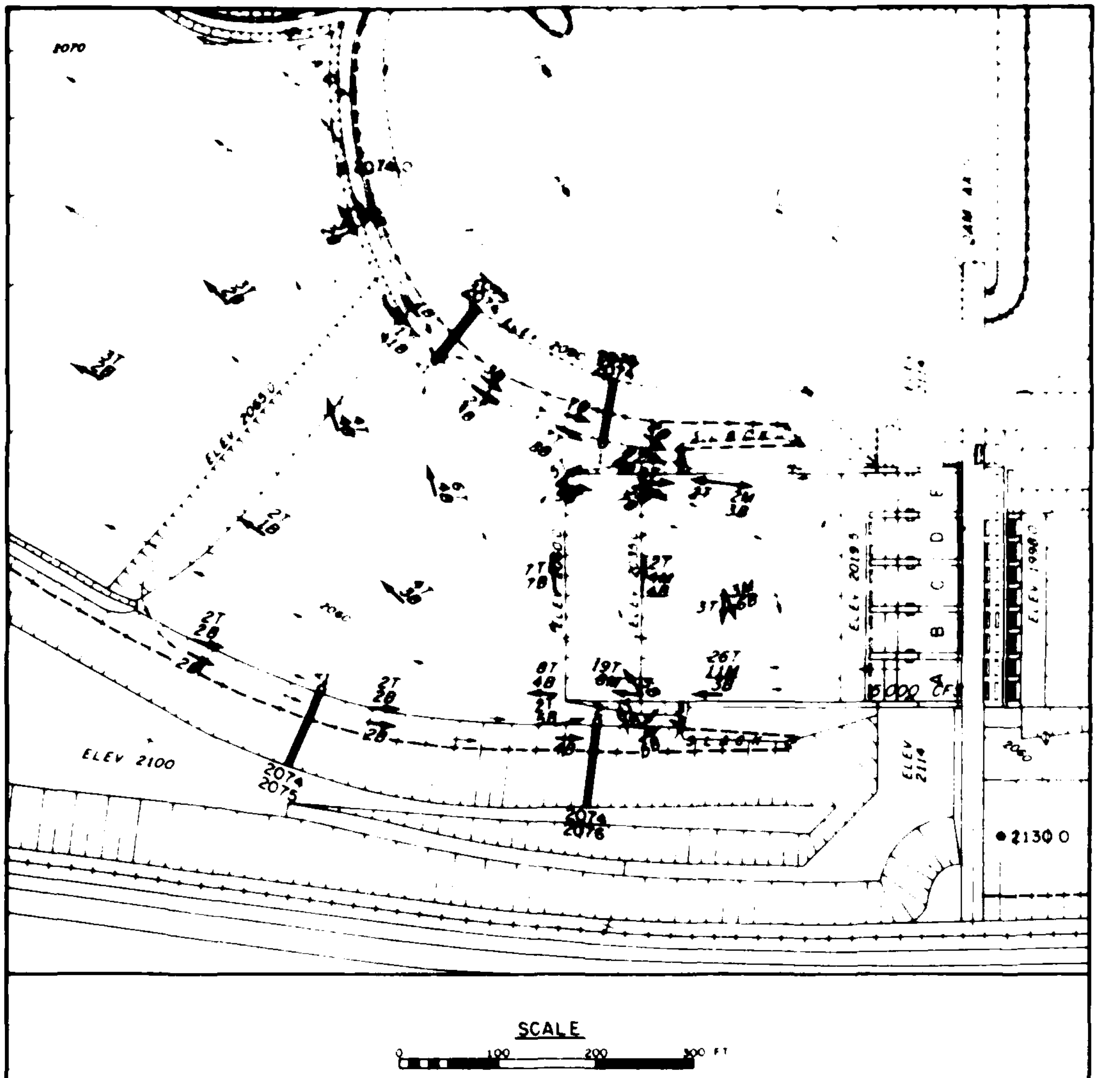
← 4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
2080.0 ●	WATER-SURFACE ELEVATIONS
2.0 ○	WAVE HEIGHTS IN FT
⌒⌒⌒	BOIL OUTLINE
▮ 2103 2109	RIDEUP ELEVATIONS

SPILL ONLY

TAILRACE FLOW CONDITIONS

RIVER DISCHARGE 210,000 CFS

PLATE 50



FLOW DISTRIBUTION

POWERHOUSE UNITS	CLOSED
SPILLWAY BAY A	5,000 CFS

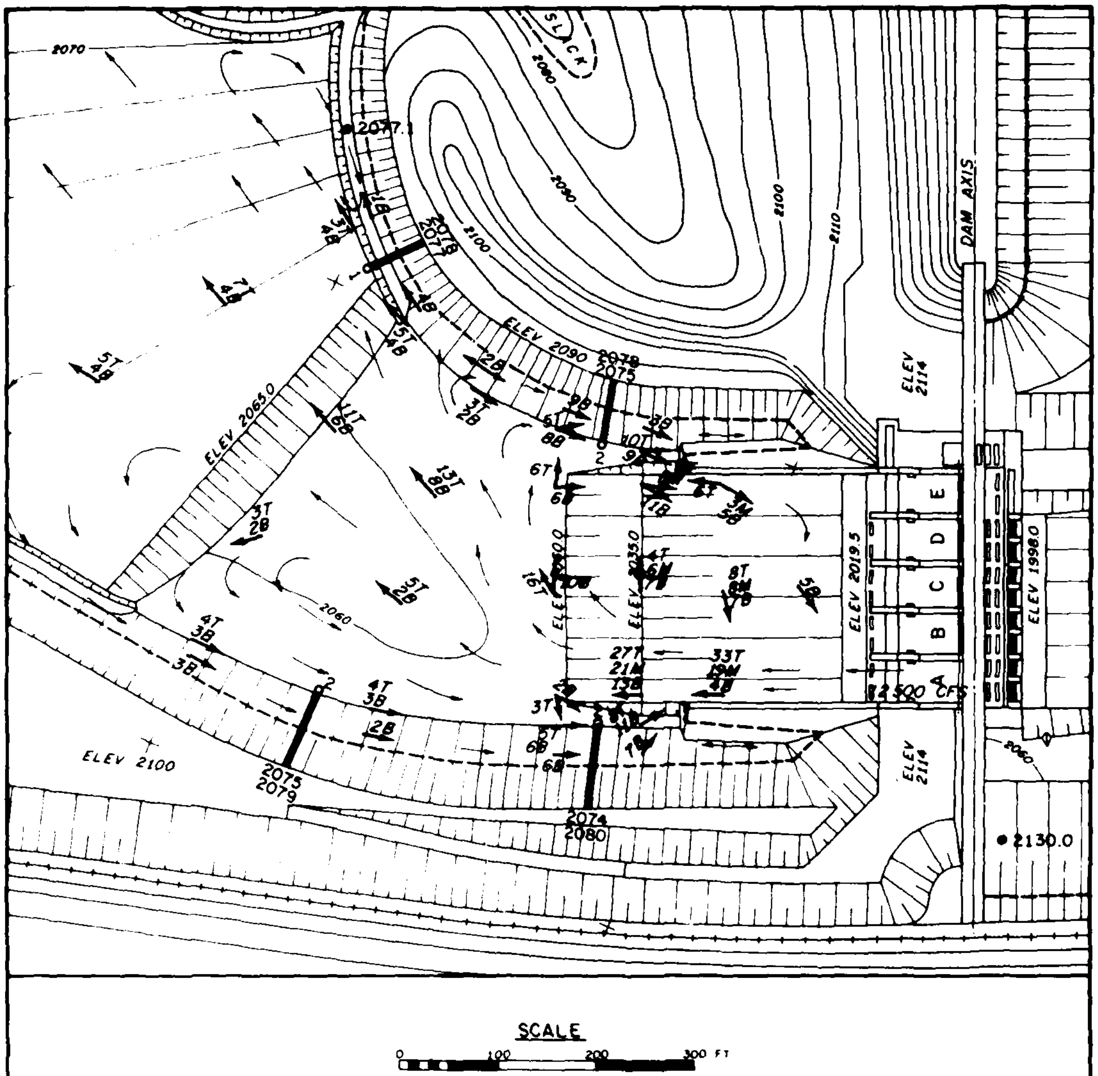
LEGEND

◄ 4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
2080.0 ●	WATER-SURFACE ELEVATIONS
2.0 ○	WAVE HEIGHTS IN FT
▮ 2074 2075	RIDEUP ELEVATIONS

SPILLWAY BAY A
POOL ELEV 2130.0

TAILRACE FLOW CONDITIONS

RIVER DISCHARGE 5,000 CFS



FLOW DISTRIBUTION

POWERHOUSE UNITS	CLOSED
SPILLWAY BAY A	12 500 CFS

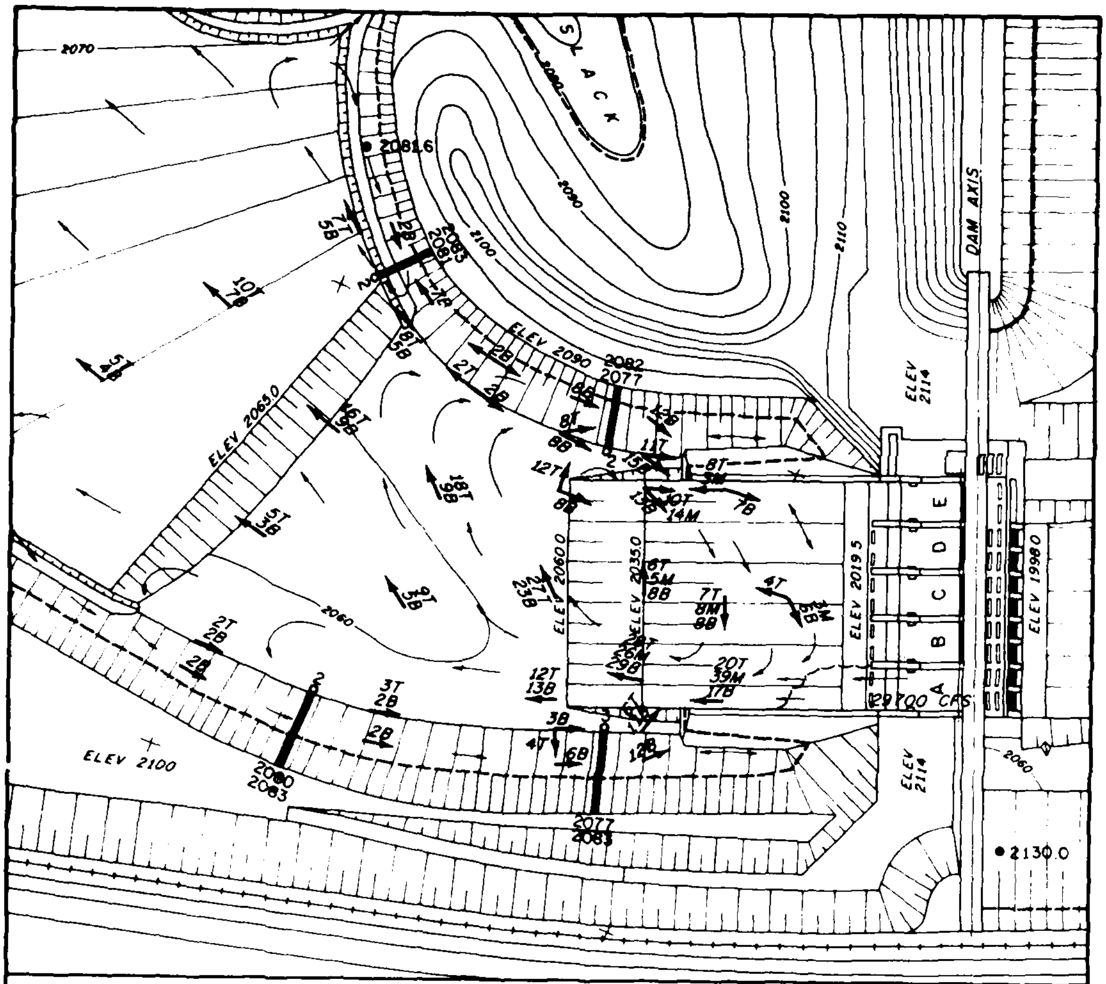
LEGEND

← 4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
2080.0 ●	WATER-SURFACE ELEVATIONS
2.0 ○	WAVE HEIGHTS IN FT
▮ 2075 2079	RIDEUP ELEVATIONS

SPILLWAY BAY A
POOL ELEV 2130.0

TAILRACE FLOW CONDITIONS

RIVER DISCHARGE 12 500 CFS



SCALE

0 100 200 300 FT

FLOW DISTRIBUTION

POWERHOUSE UNITS	CLOSED
SPILLWAY BAY A	29 700 CFS

LEGEND

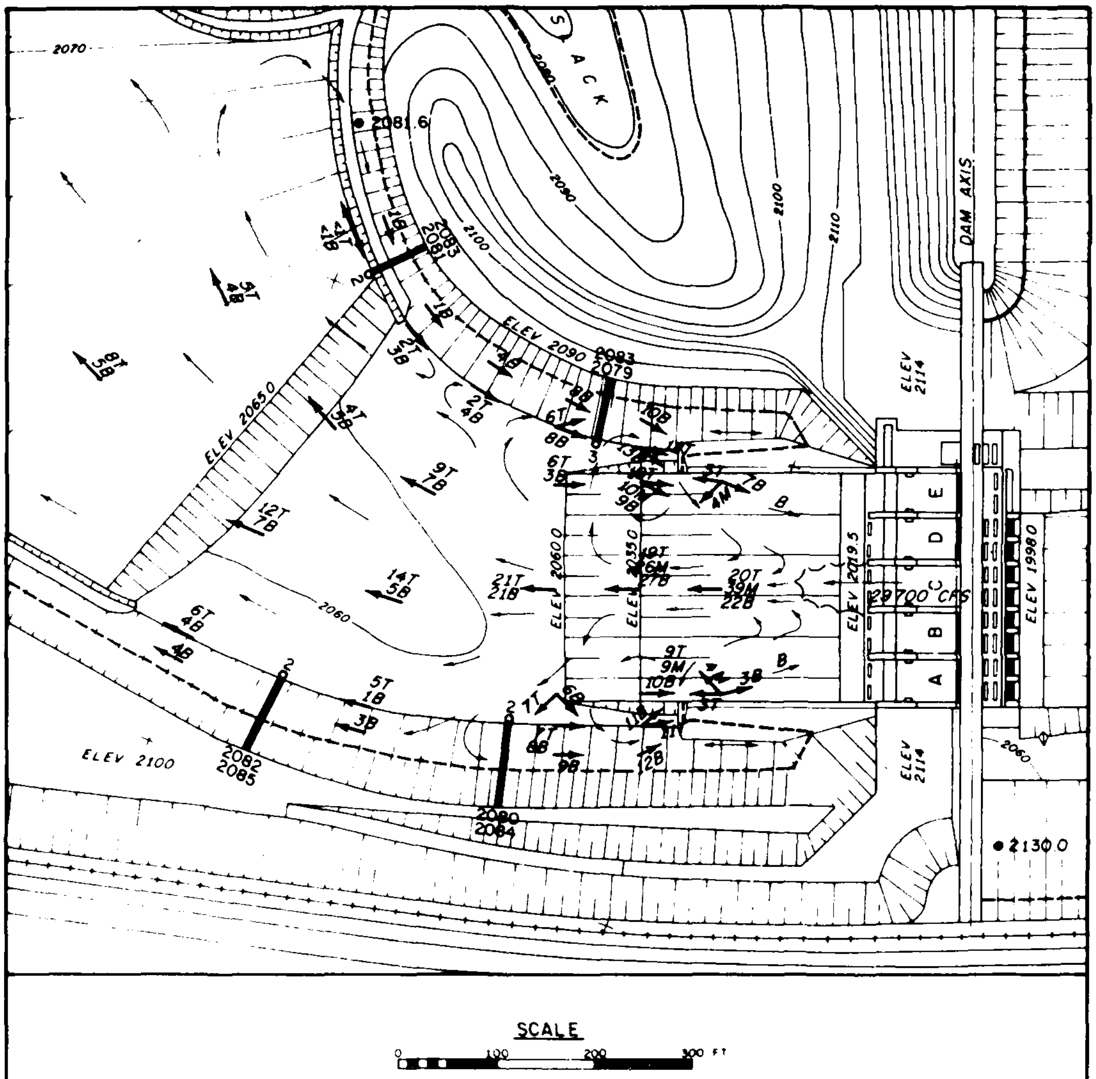
← 4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
2080.0 ●	WATER-SURFACE ELEVATIONS
2 ○	WAVE HEIGHTS IN FT
▮	RIDEUP ELEVATIONS
2080 2083	

SPILLWAY BAY A
POOL ELEV 2130.0

TAILRACE FLOW CONDITIONS

RIVER DISCHARGE 29 700 CFS

PLATE 53



FLOW DISTRIBUTION

POWERHOUSE UNITS	CLOSED
SPILLWAY BAY C	29 700 CFS

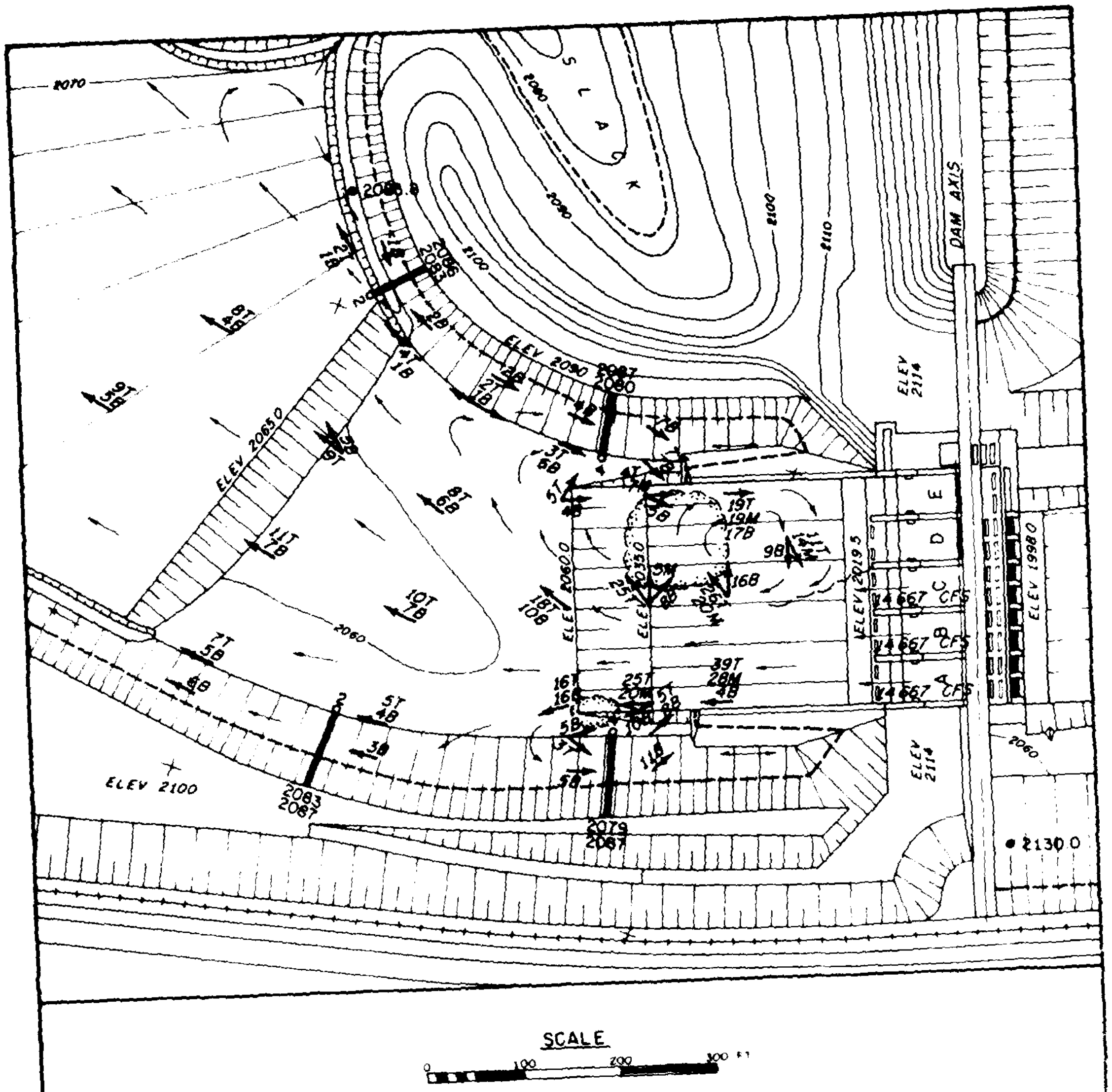
LEGEND

◄─ 4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
2080.0 ●	WATER-SURFACE ELEVATIONS
2.0 ○	WAVE HEIGHTS IN FT
▌ 2082 2085	RIDEUP ELEVATIONS

SPILLWAY BAY C
POOL ELEV 2130.0

TAILRACE FLOW CONDITIONS

RIVER DISCHARGE 29 700 CFS



FLOW DISTRIBUTION

POWERHOUSE UNITS	CLOSED
SPILLWAY BAYS A TO C	44000 CFS

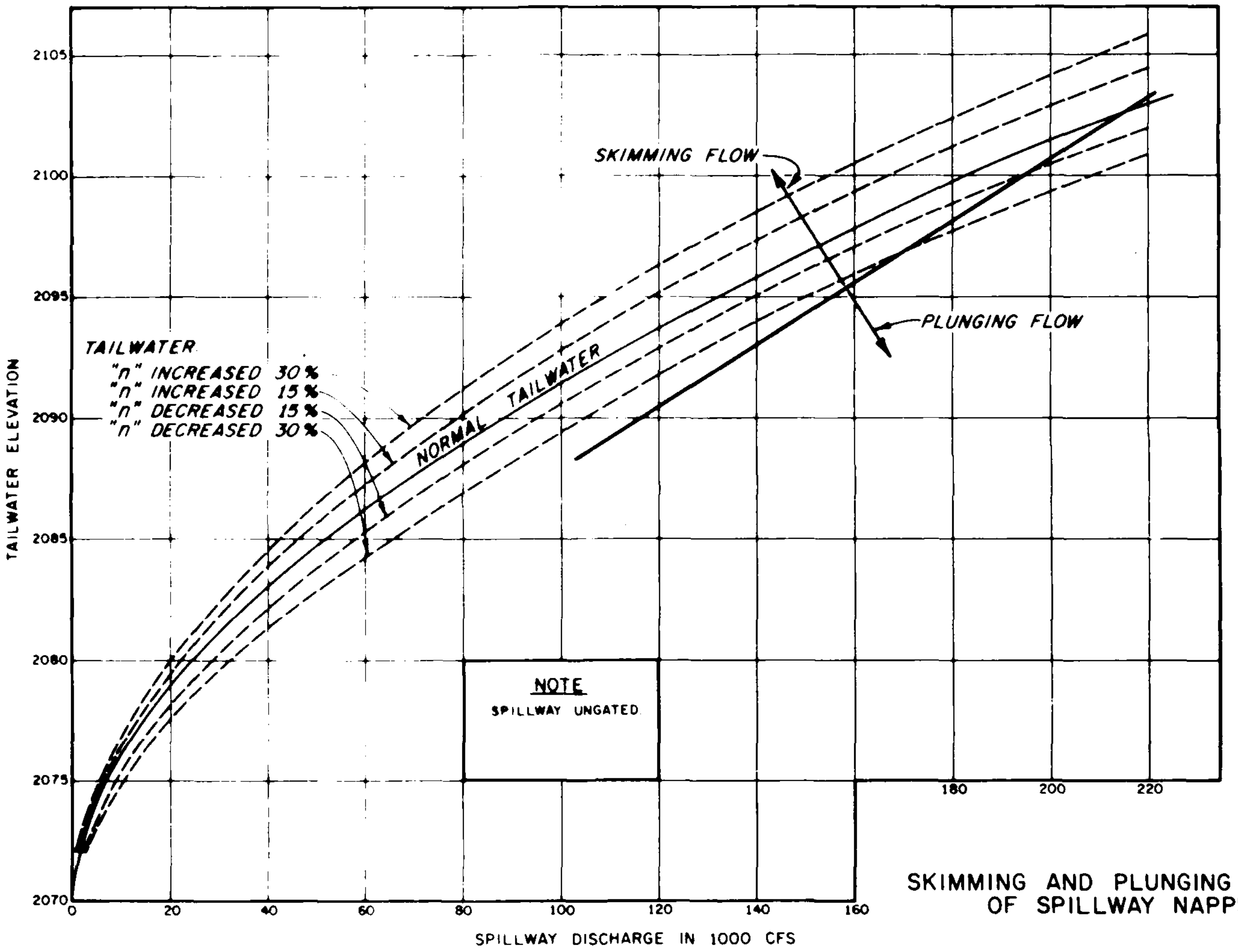
LEGEND

← 4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
2080.0 ●	WATER-SURFACE ELEVATIONS
2.0 ○	WAVE HEIGHTS IN FT
	BOIL OUTLINE
▮ 2083 2087	RIDEUP ELEVATIONS

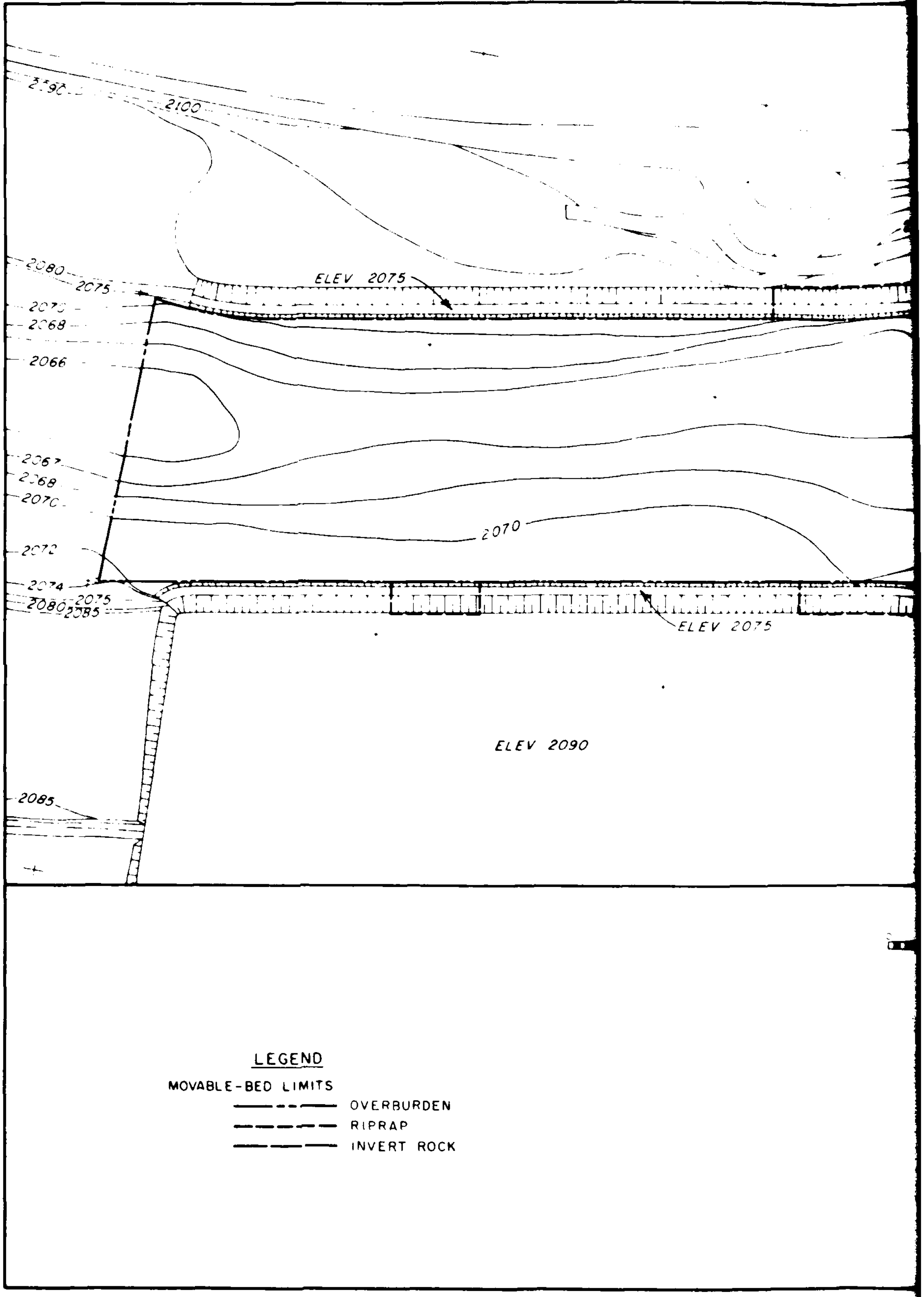
SPILLWAY BAYS A TO C
POOL ELEV 2130.0

TAILRACE FLOW CONDITIONS

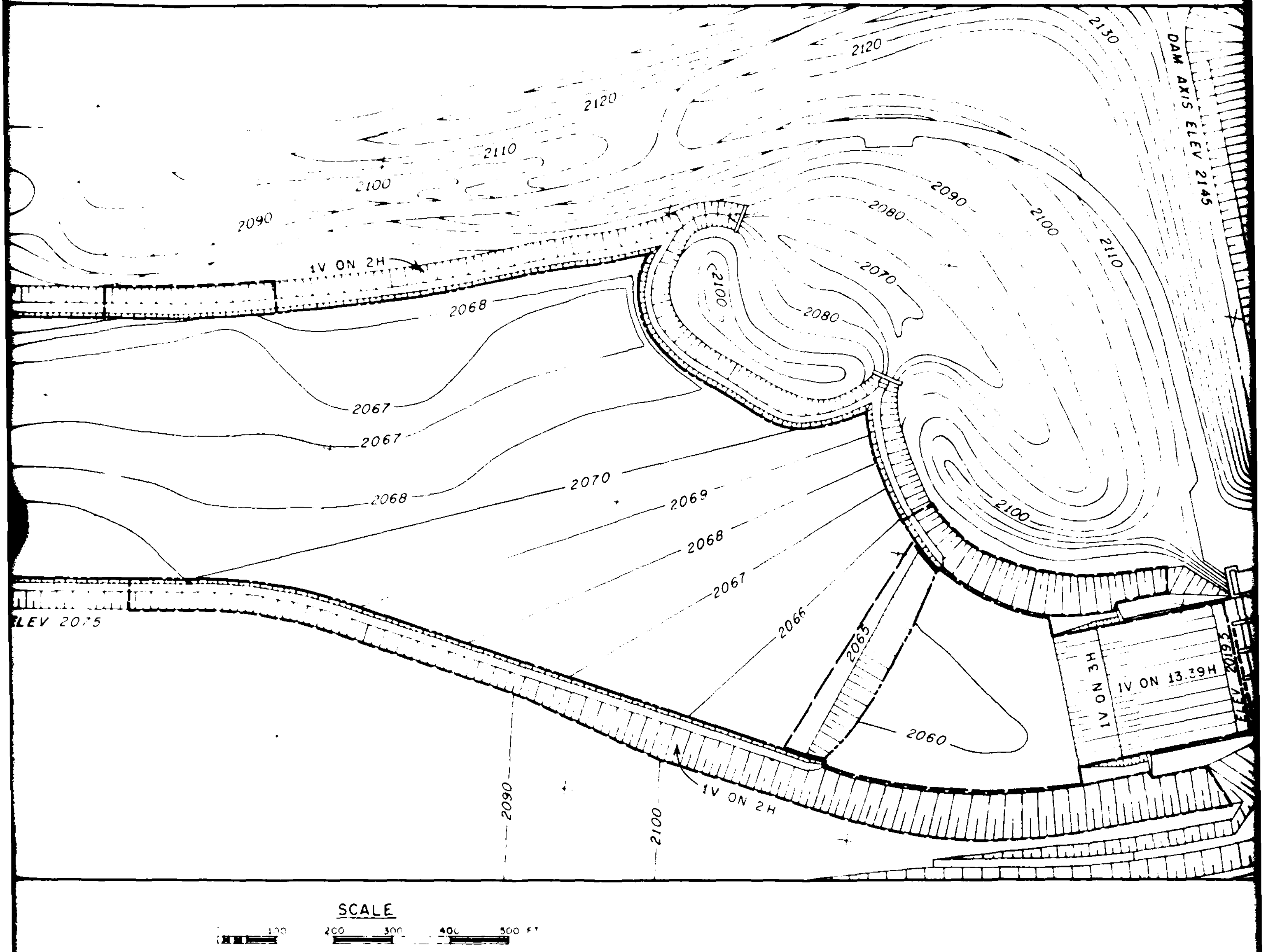
RIVER DISCHARGE 44000 CFS



SKIMMING AND PLUNGING LIMITS
OF SPILLWAY NAPPE


2090
2100
2080
2075
2070
2068
2066
2067
2068
2070
2070
2072
2074
2075
2080
2085
ELEV 2075
ELEV 2075
ELEV 2090
2085
LEGEND
MOVABLE-BED LIMITS
OVERBURDEN
RIPRAP
INVERT ROCK

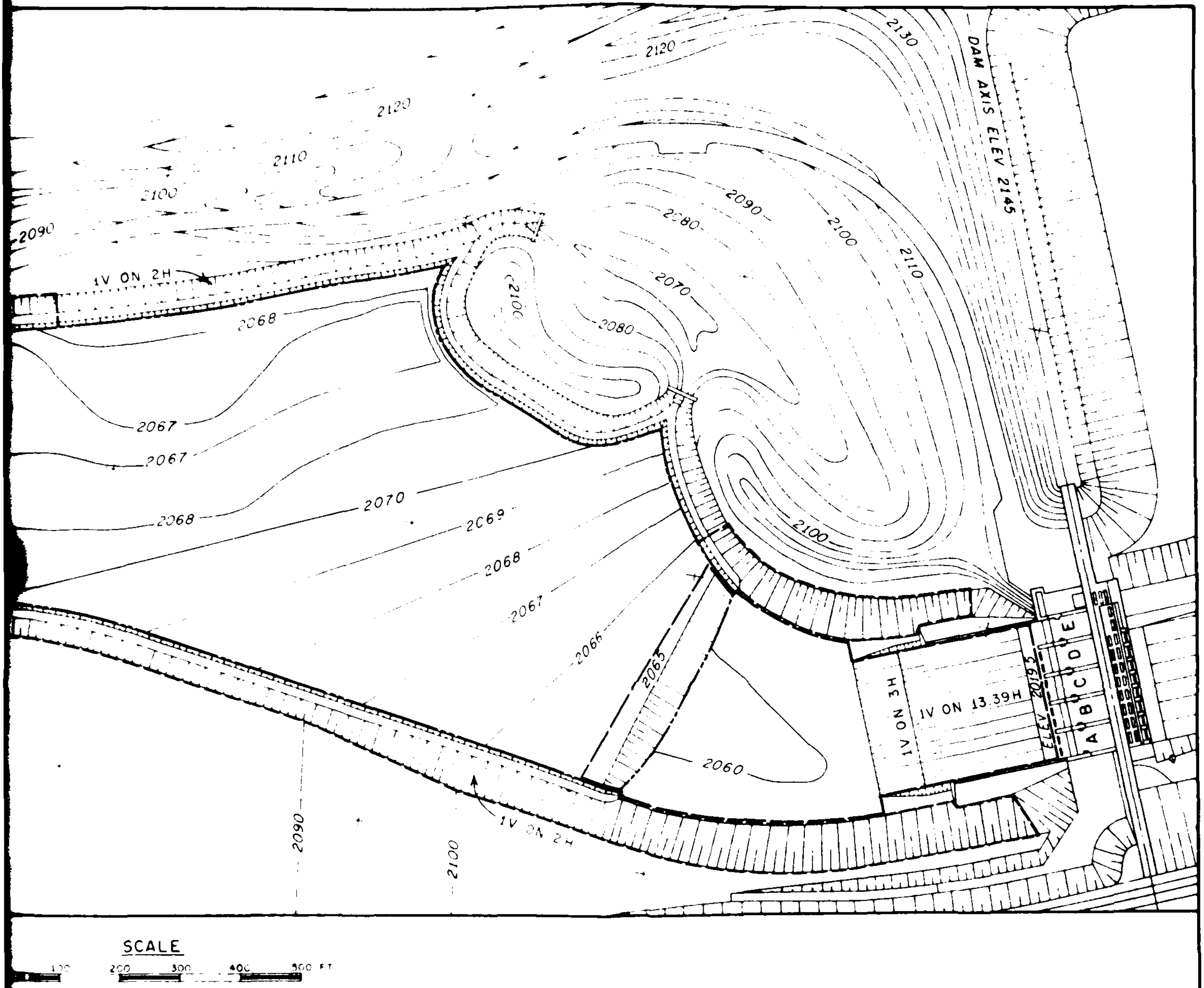
1



DOWNSTREAM
MOVABLE BED

1

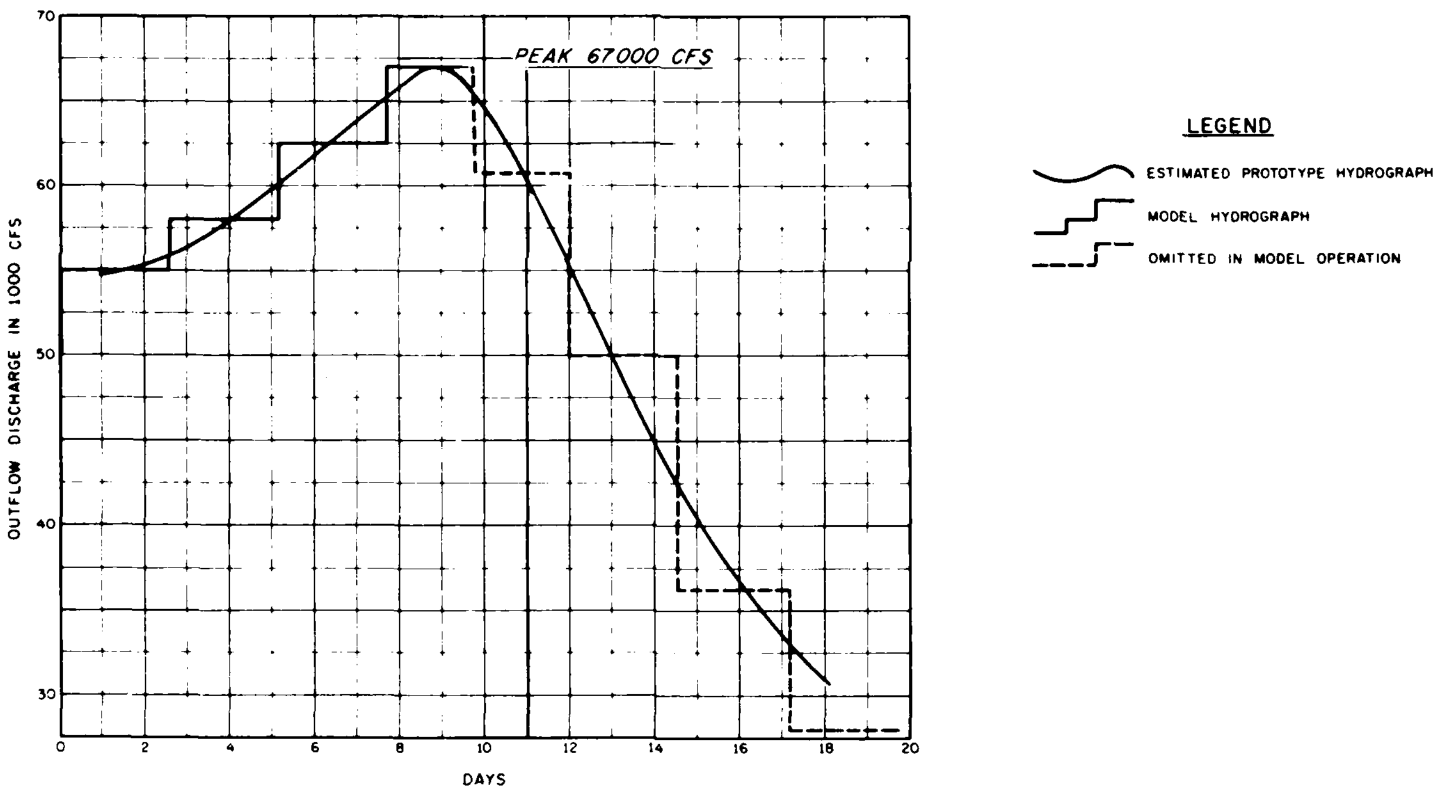
2



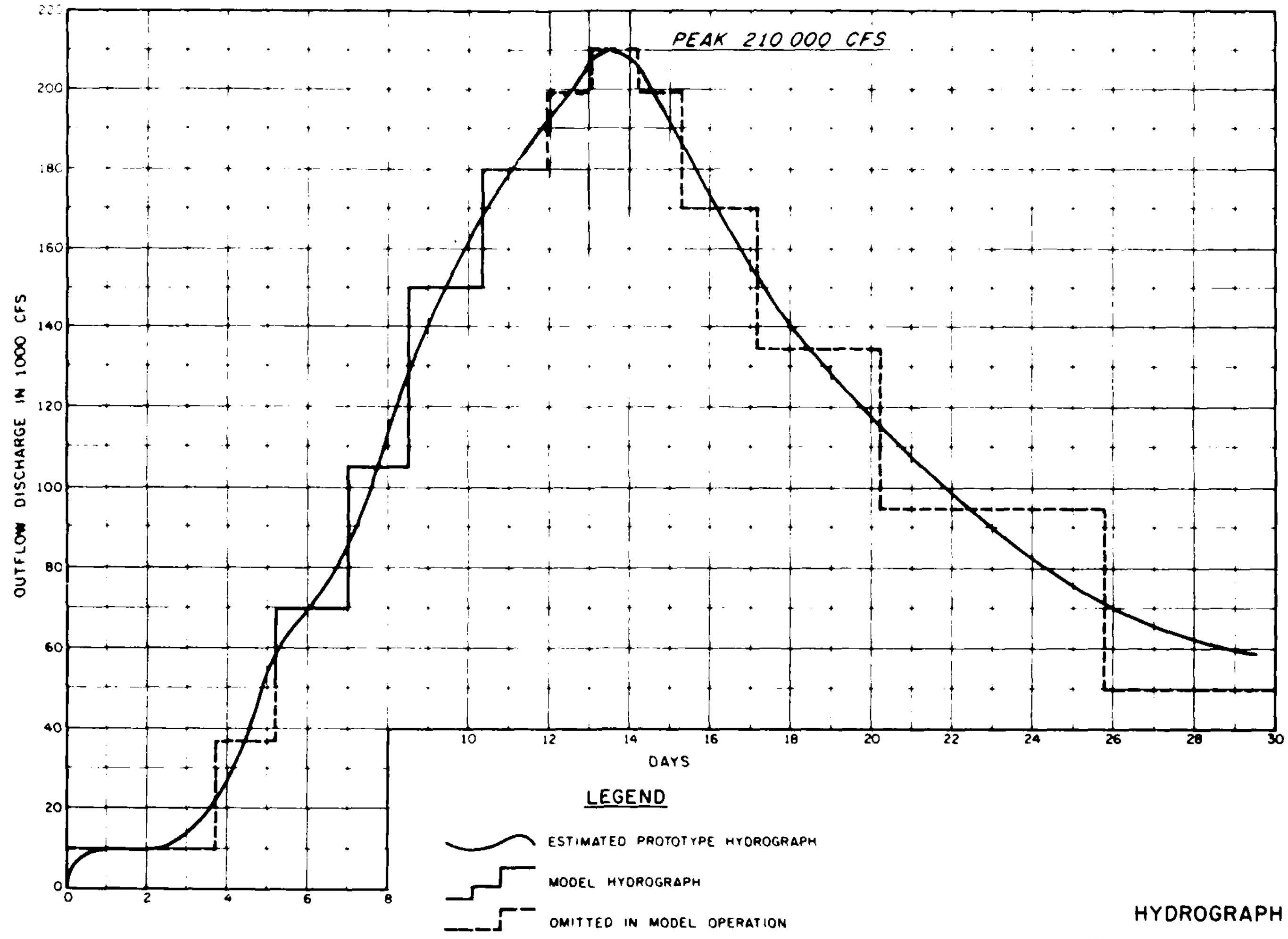
DOWNSTREAM CHANNEL
MOVABLE BED LAYOUT

1

1 3

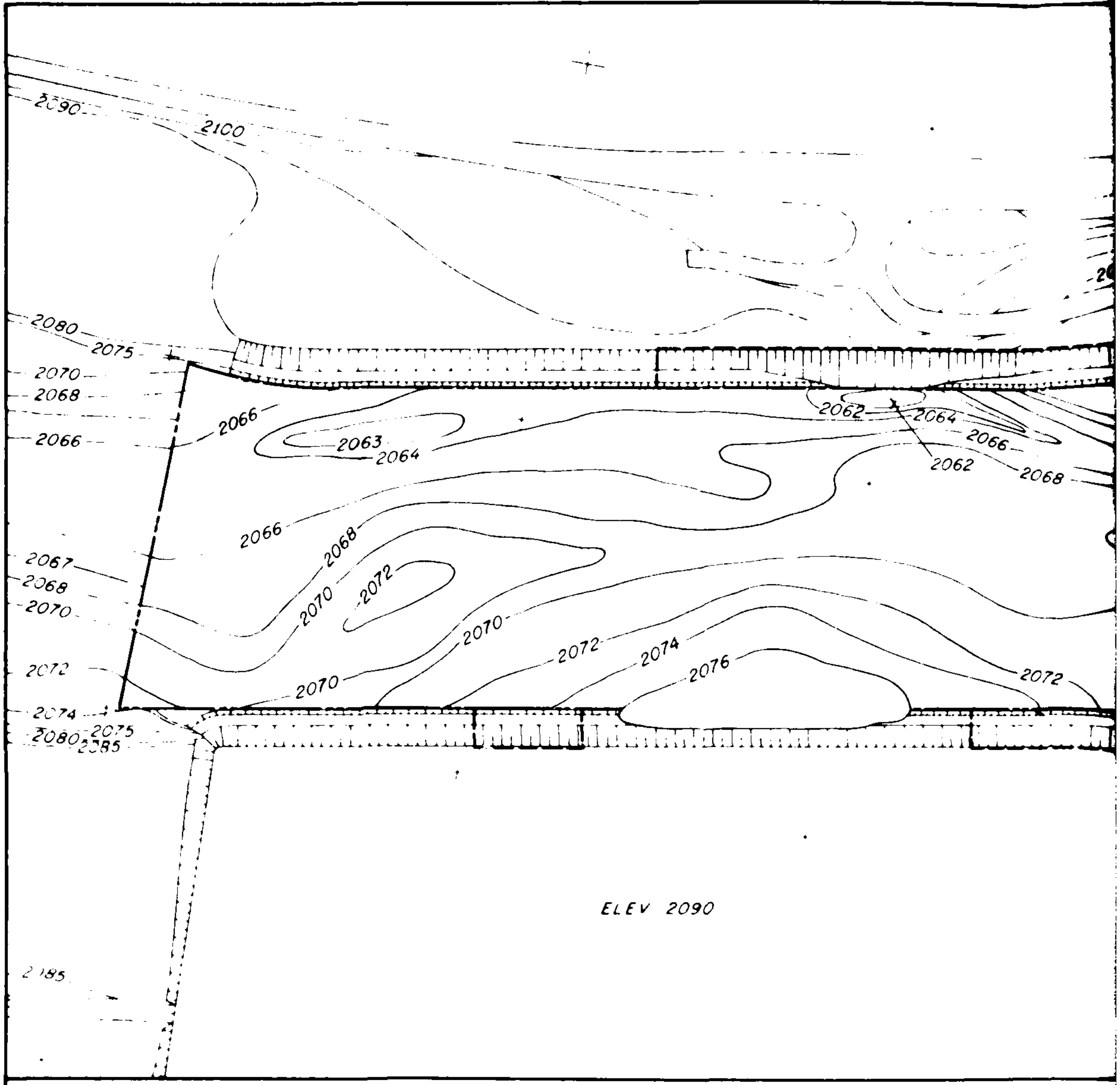


HYDROGRAPH
STANDARD PROJECT FLOOD



HYDROGRAPH
PROBABLE MAXIMUM FLOOD

PLATE 59



LEGEND

MOVABLE-BED LIMITS

OVERBURDEN

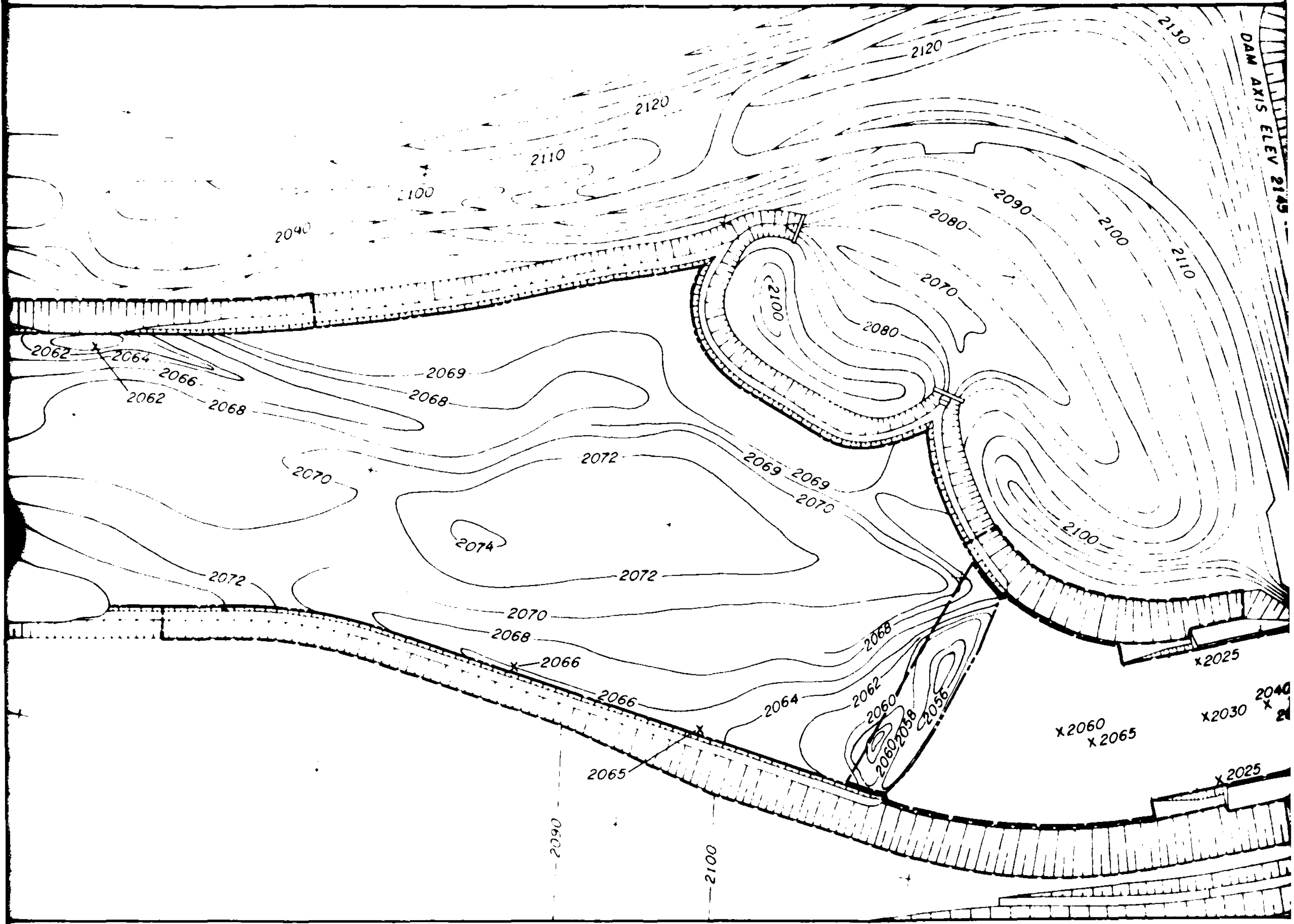
RIPRAP

INVERT ROCK

FLOW DISTRIBUTION

POWERHOUSE UNITS A TO D CLOSE

SPILLWAY BAYS A TO E UNIFORMLY OPE



SCALE

40

FLOW DISTRIBUTION

USE UNITS A TO D CLOSED
BAYS A TO E UNIFORMLY OPEN

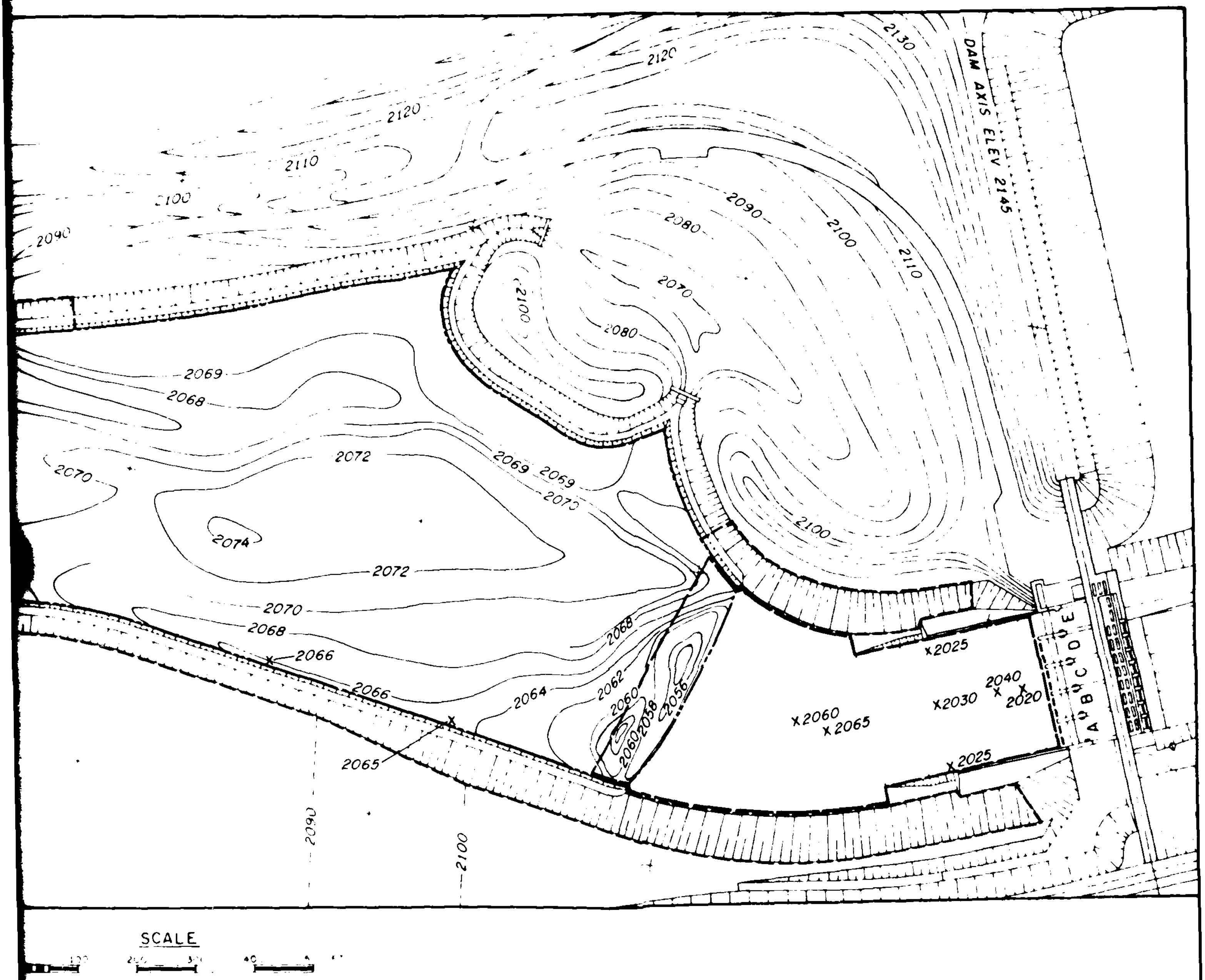
SPILL
MOVABLE BE

DOWNSTRE

SPF K

1

2



SPILL ONLY

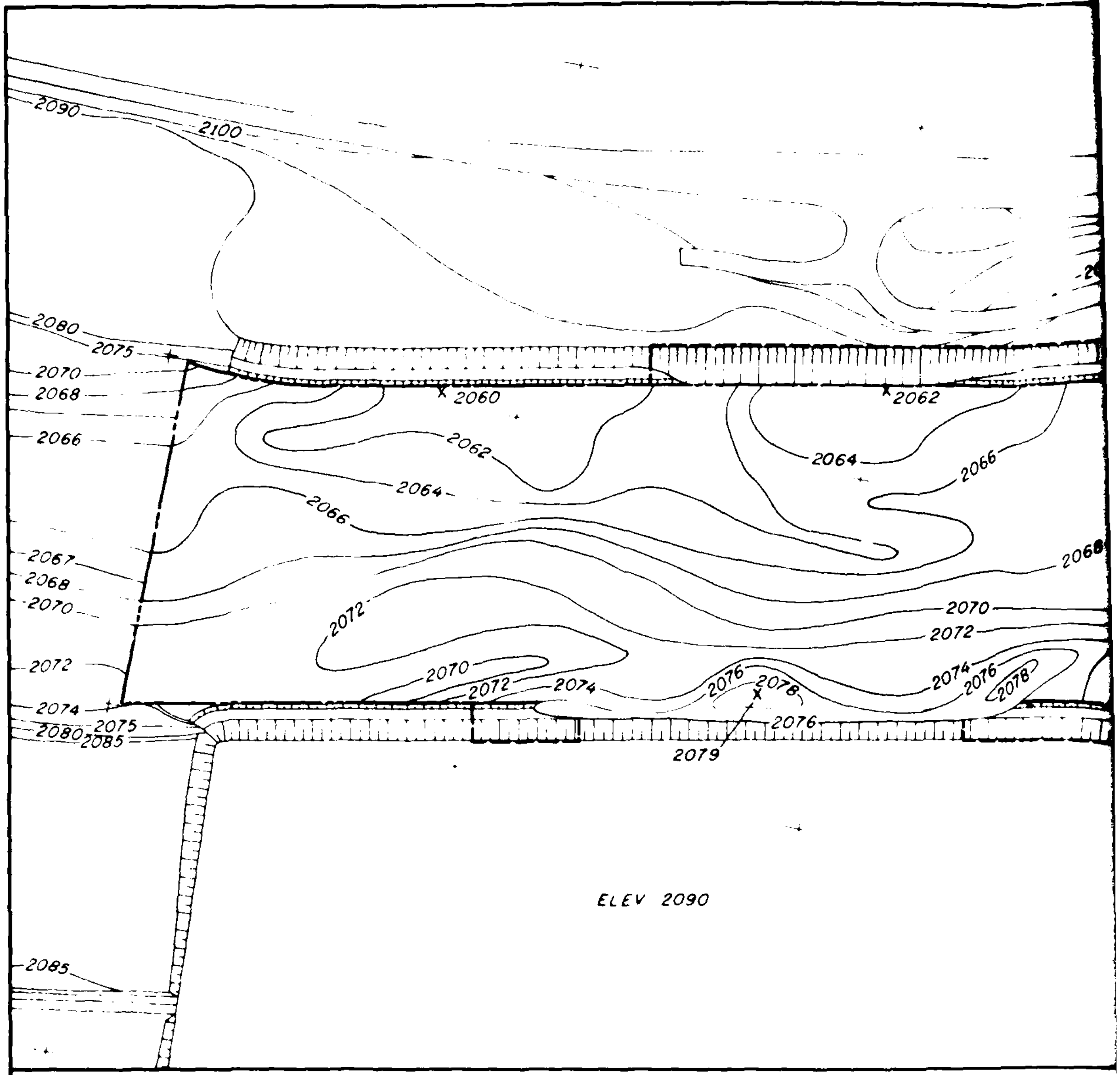
MOVABLE BED IN TAILRACE

ED
EN

DOWNSTREAM EROSION

SPF HYDROGRAPH

1 2 1 3



LEGEND

MOVABLE-BED LIMITS

—·—·— OVERBURDEN

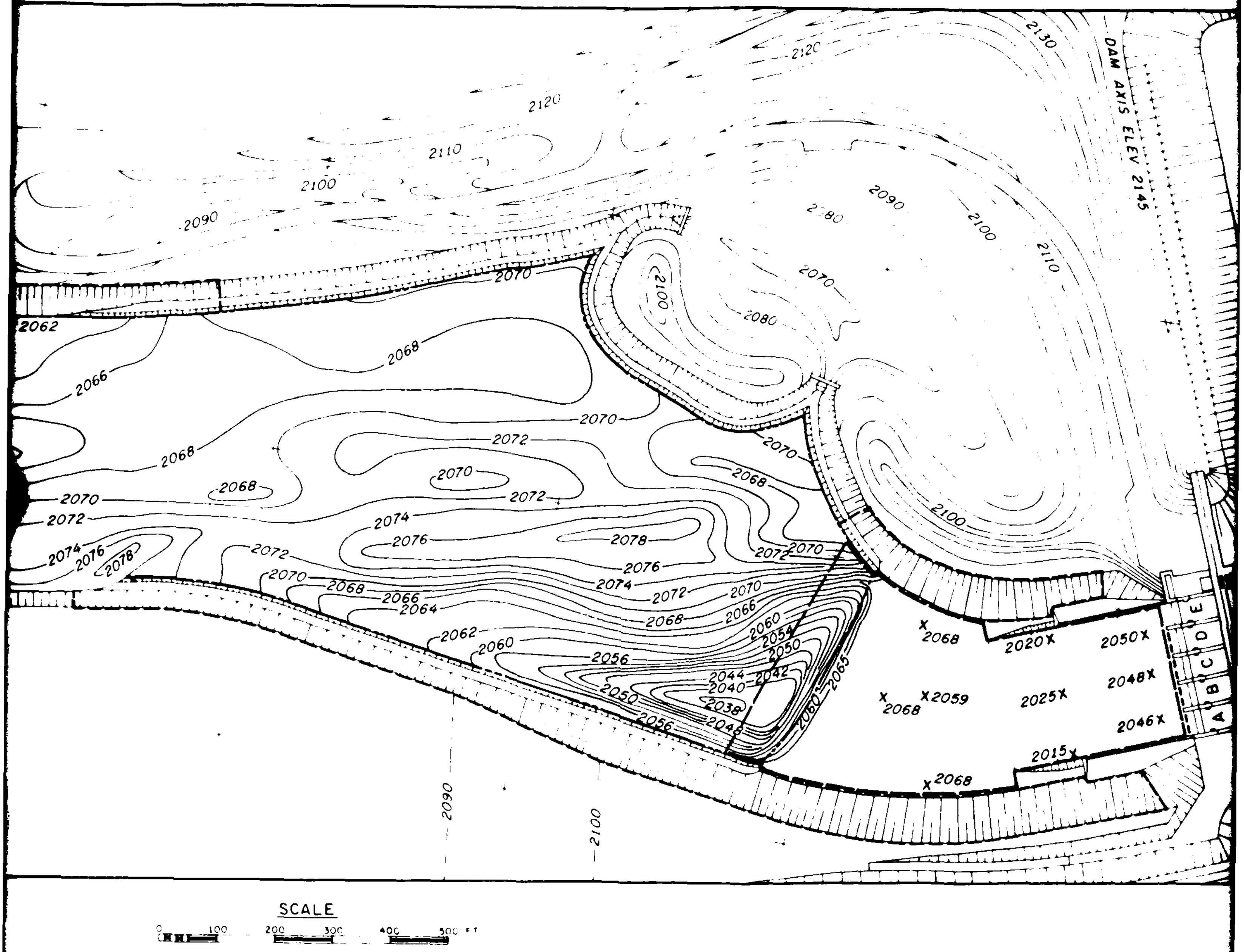
— — — RIPRAP

——— INVERT ROCK

FLOW DISTRIBUTION

POWERHOUSE UNITS A TO D CLOSED

SPILLWAY BAYS A TO E 150 000 CFS



ISTRIBUTION

A TO D   CLOSED
TO E   150 000 CFS

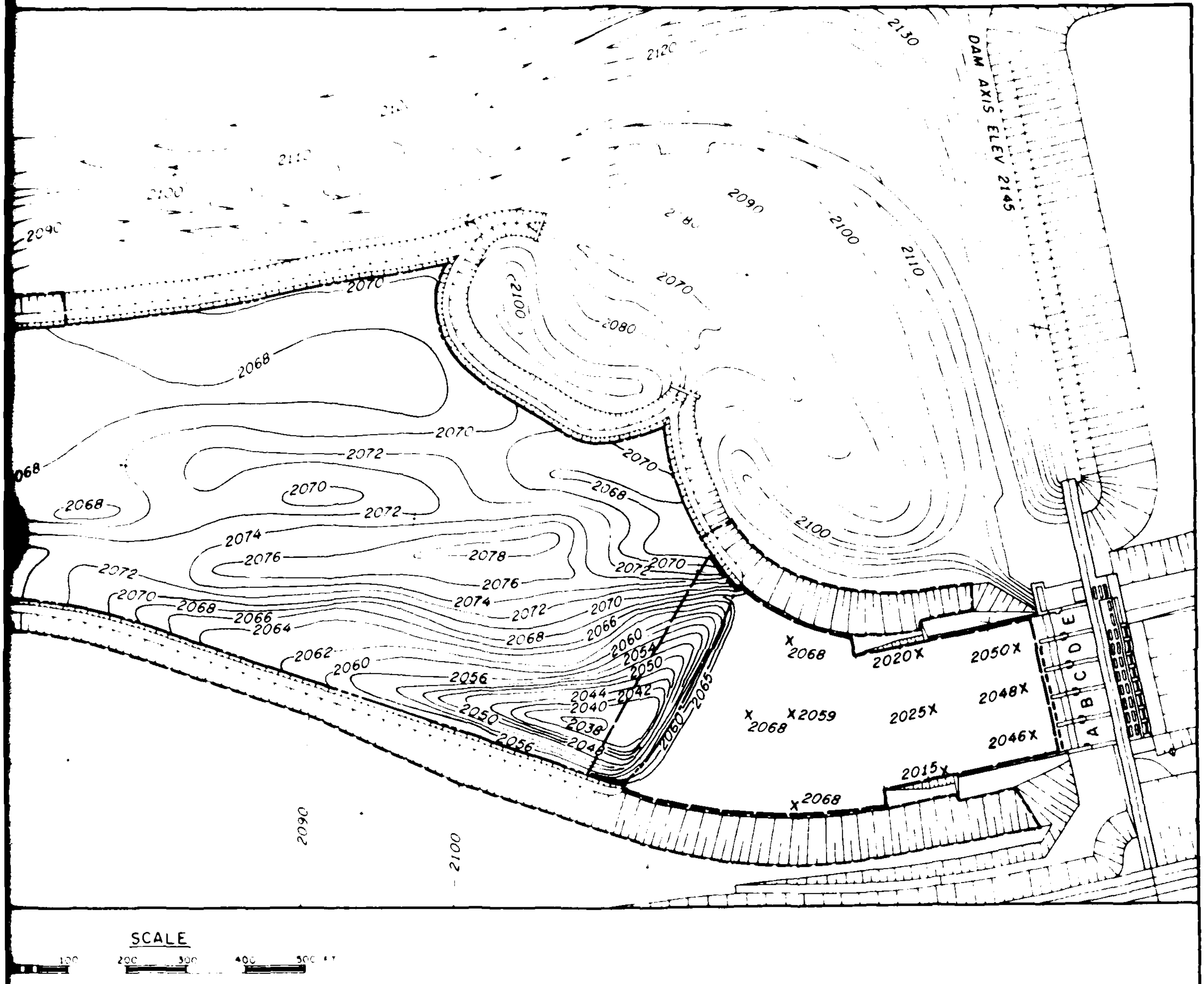
NOTE:
SCOUR SHOWN EXTENDING BELOW APPROXIMATE ELEVATION 2060 IN THE MOVABLE BED MODEL DOES NOT NECESSARILY SIMULATE PROTOTYE CONDITIONS DUE TO THE PRESENCE OF BEDROCK AT THAT ELEVATION.

SPILL ONLY
MOVABLE BED IN TA

DOWNSTREAM ER

RIVER DISCHARGE 150

PL



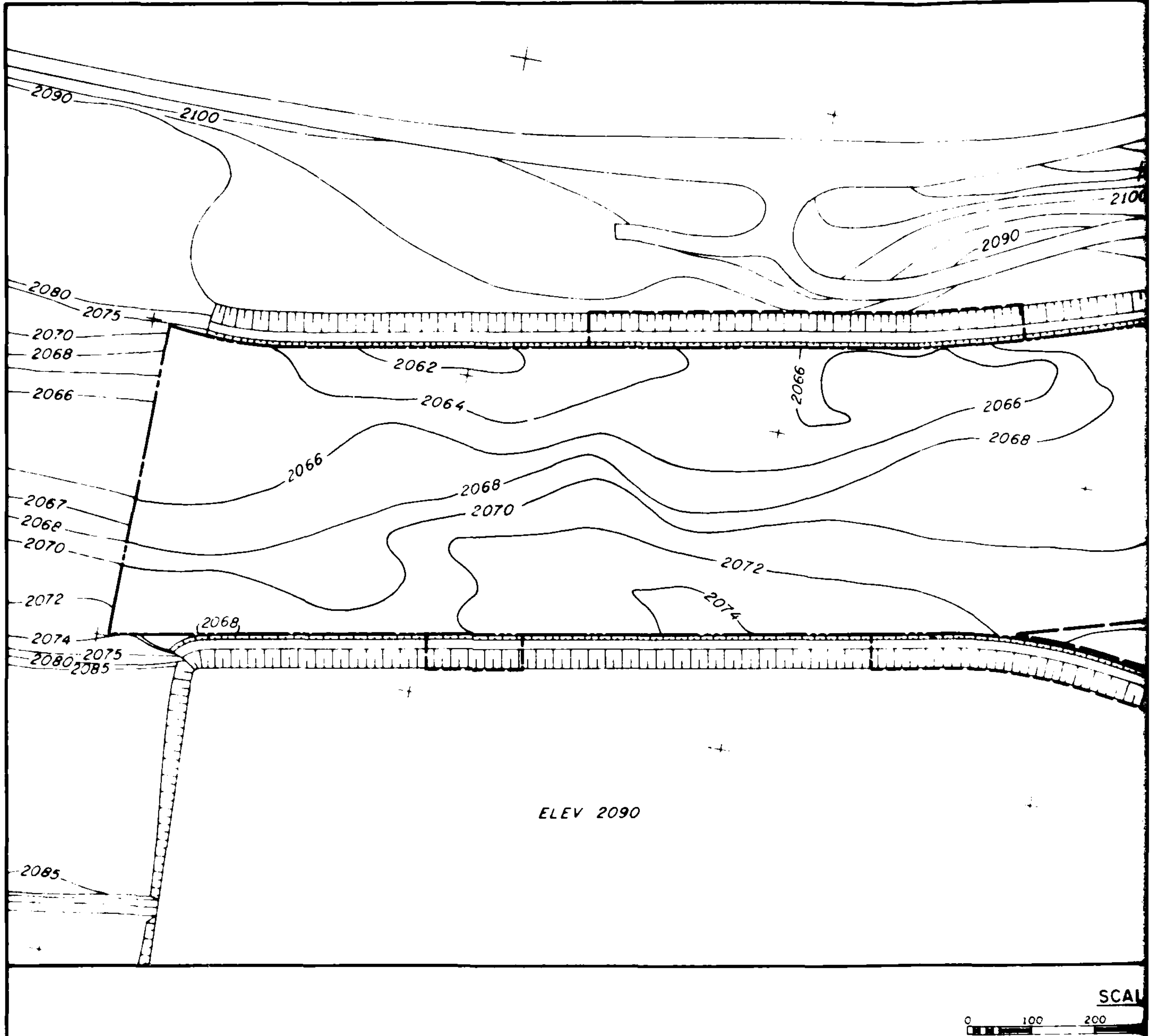
NOTE
SCOUR SHOWN EXTENDING BELOW APPROXIMATE ELEVATION 2060 IN THE MOVABLE BED MODEL DOES NOT NECESSARILY SIMULATE PROTOTYE CONDITIONS DUE TO THE PRESENCE OF BEDROCK AT THAT ELEVATION.

SED
CFS

SPILL ONLY
MOVABLE BED IN TAILRACE

DOWNSTREAM EROSION

RIVER DISCHARGE 150 000 CFS



LEGEND

MOVABLE-BED LIMITS:

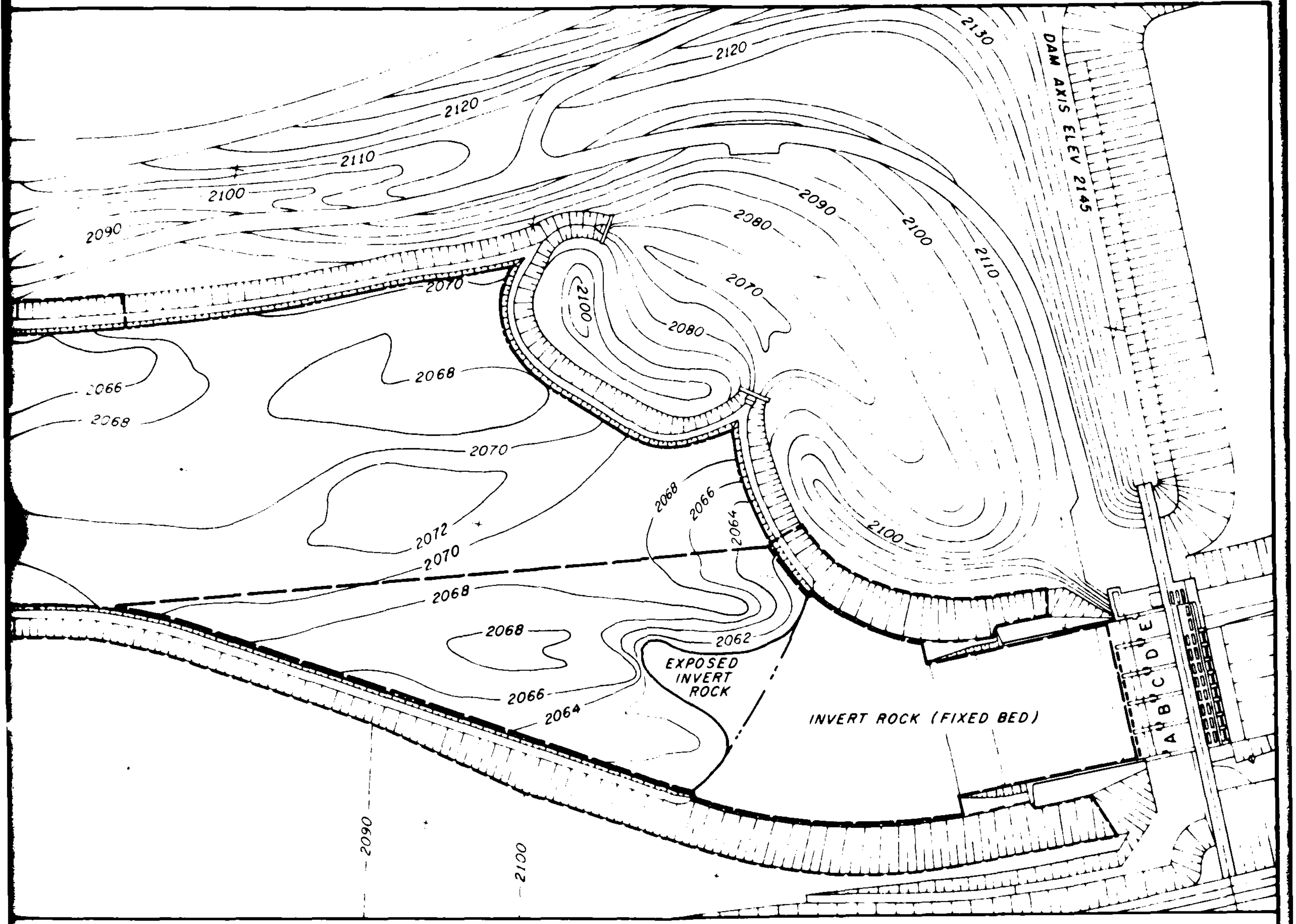
—— - - —— OVERBURDEN

— — — — RIPRAP

—— —— —— INVERT ROCK

FLOW DISTRIBUTION

POWERHOUSE UNITS A TO D	CLOSED
SPILLWAY BAYS A TO E	67 000 CFS



SCALE

0 100 200 300 400 500 FT

CLOSED
7 000 CFS

NOTES

1 NO RIPRAP FAILURE
2 DURATION OF FLOW 134 HRS

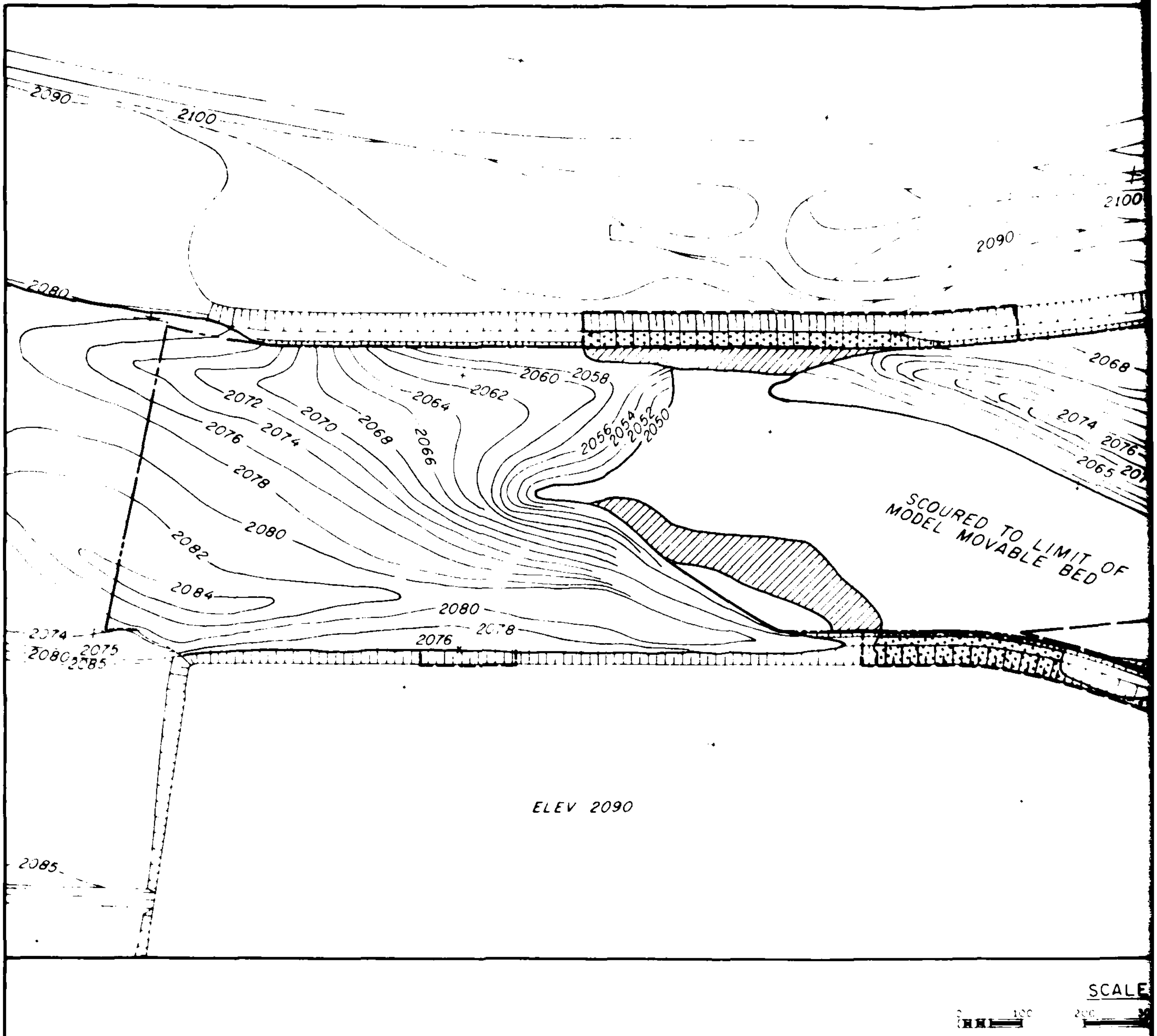
SPILL ONLY
FIXED-BED INVERT ROCK

DOWNSTREAM EROSION

STANDARD PROJECT FLOOD
RIVER DISCHARGE 67 000 CFS

PLATE 6

2



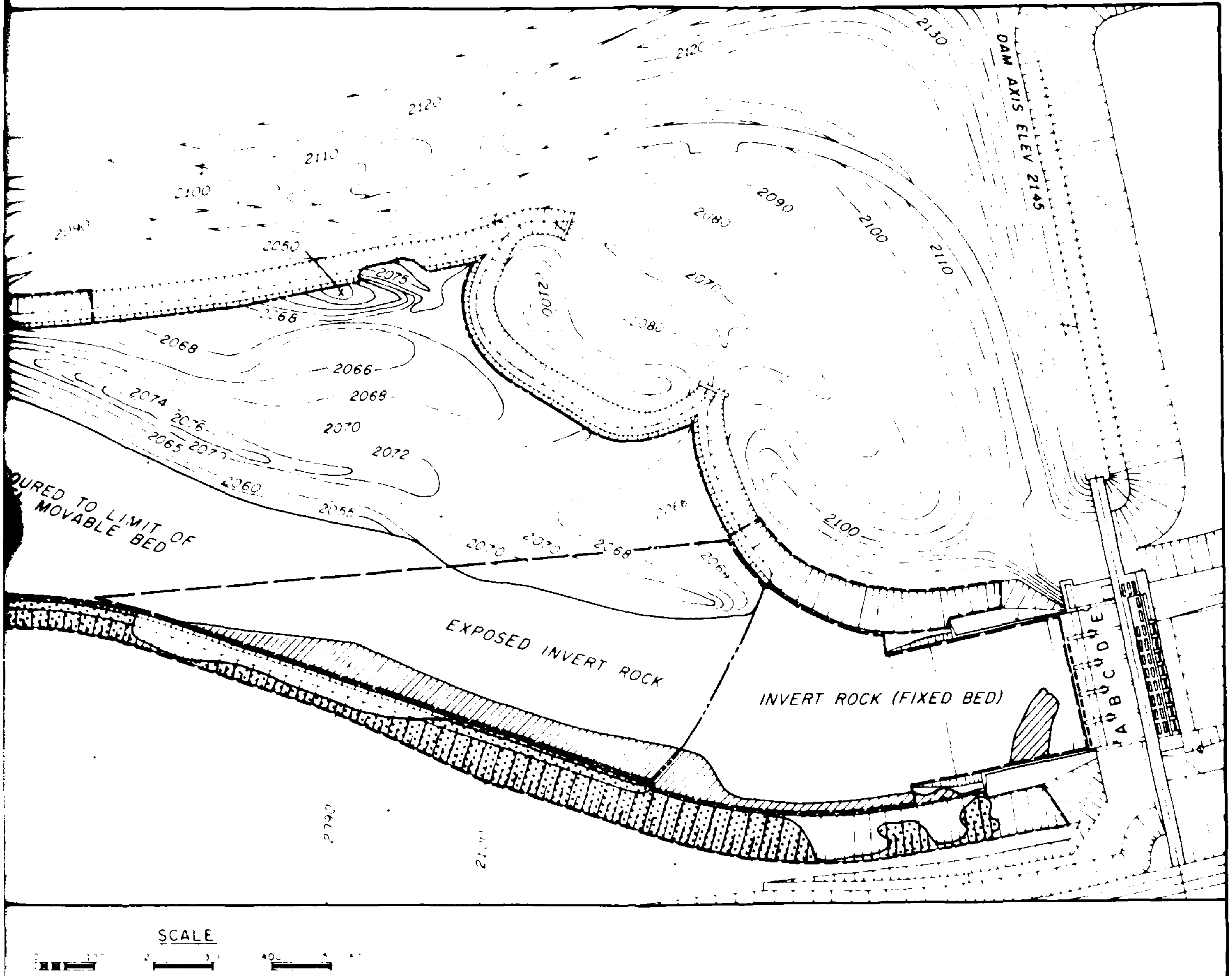
LEGEND

MOVABLE-BED LIMITS:

- —— - - —— OVERBURDEN
- — — — — RIPRAP
- ——— ——— INVERT ROCK
- ▩ RIPRAP MOVEMENT
- ▨ RIPRAP DEPOSITION

FLOW DISTRIBUTION

POWERHOUSE UNITS A TO D CLOSED
SPILLWAY BAYS A TO E UNIFORM SPILL



D
SPILL

SPILL ONLY

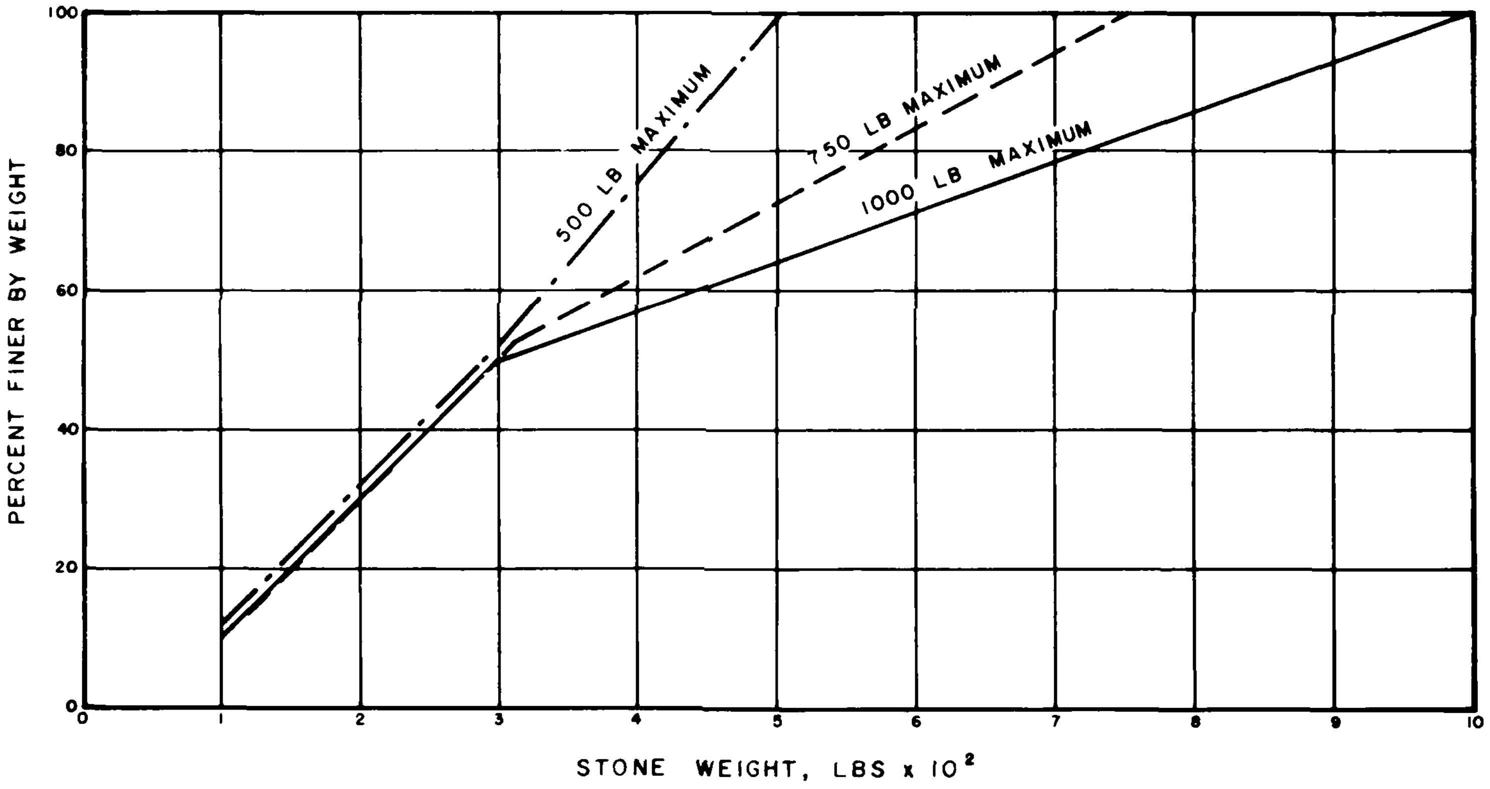
FIXED-BED INVERT ROCK

DOWNSTREAM EROSION

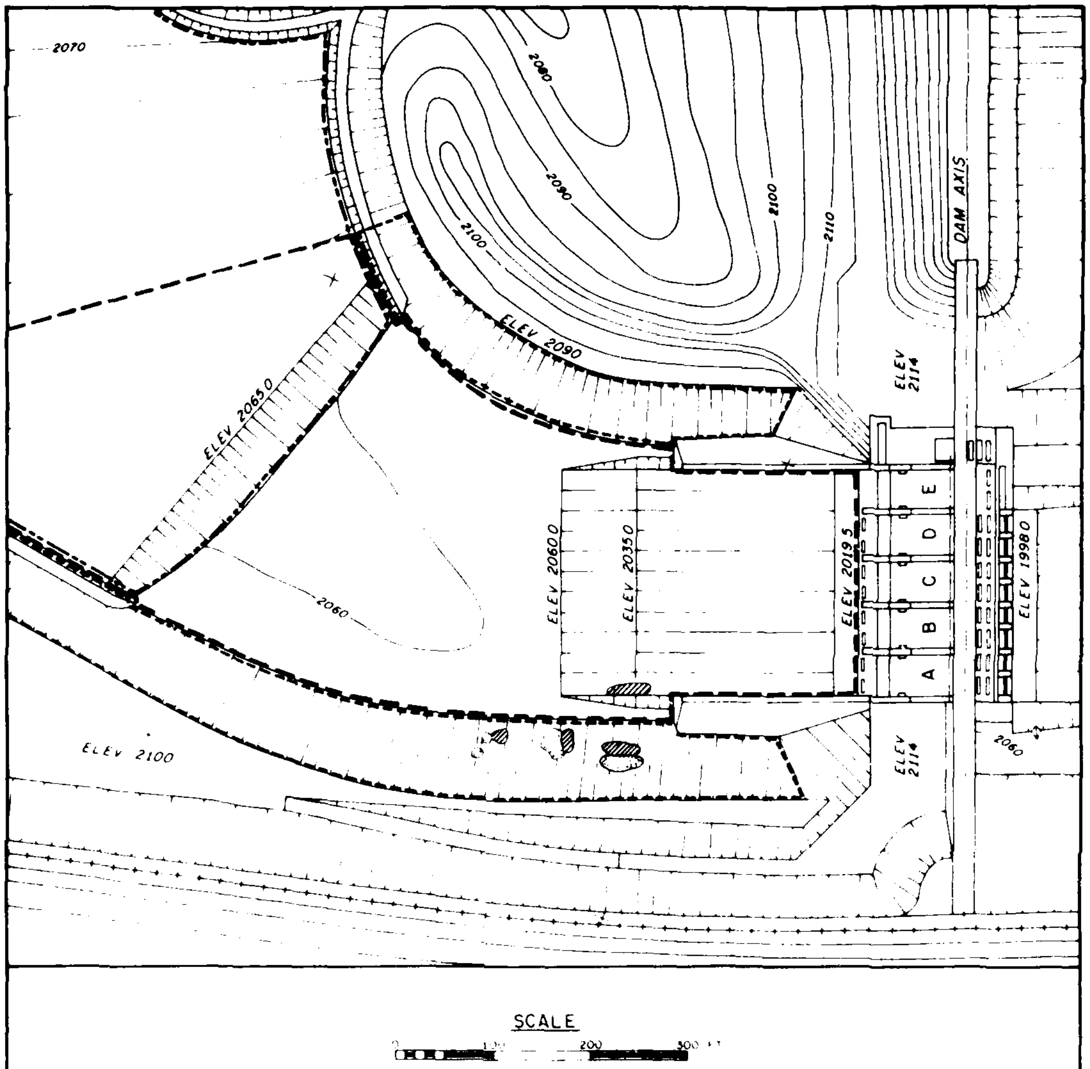
PMF HYDROGRAPH

PLATE 63

2



RIPRAP GRADATIONS



FLOW DISTRIBUTION

POWERHOUSE UNITS A TO D CLOSED
SPILLWAY BAYS A TO E UNIFORM SPILL

SPILL ONLY
FIXED-BED INVERT ROCK

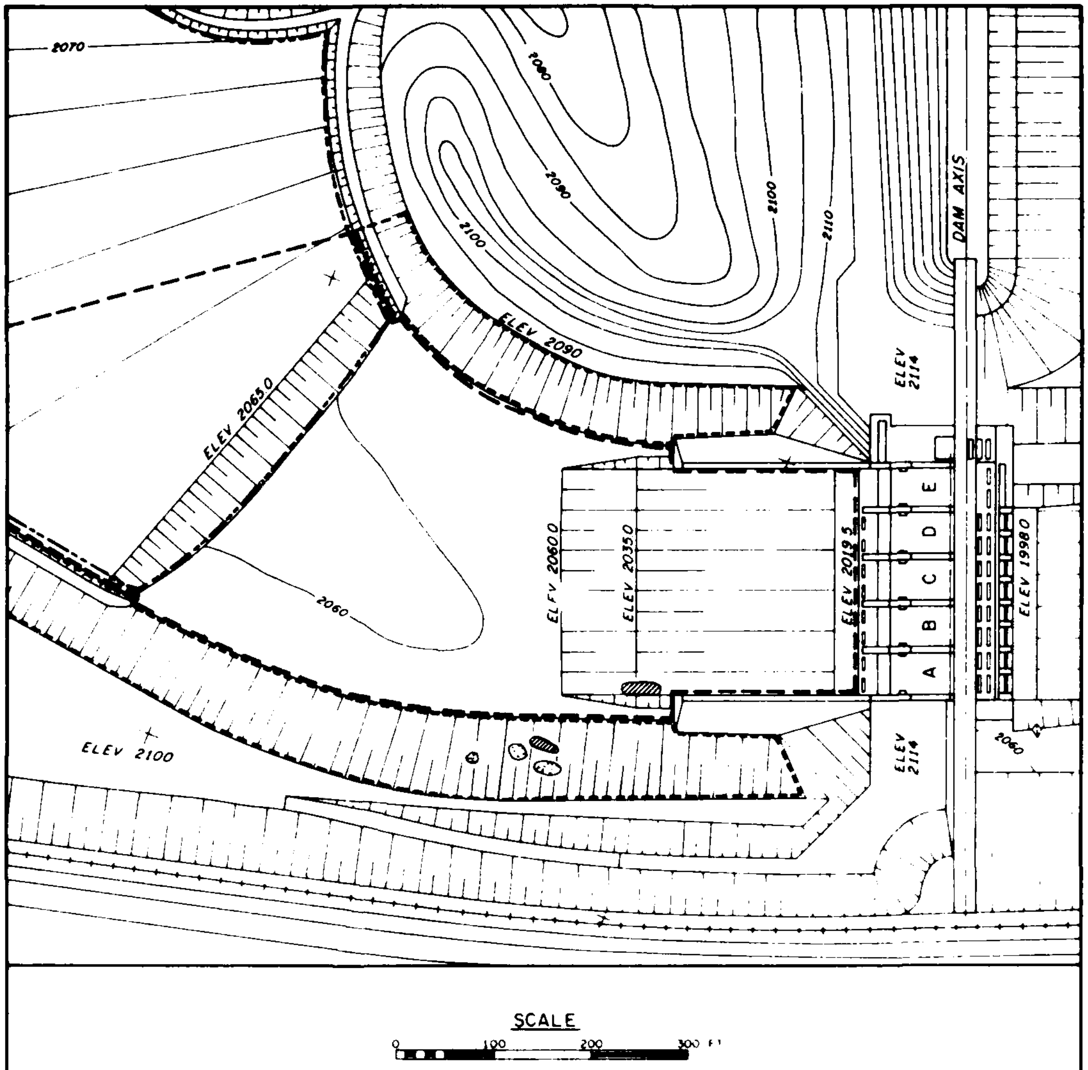
LEGEND

MOVABLE BED LIMITS
- - - - OVERBURDEN
- - - - RIPRAP
— — — INVERT ROCK
INITIAL RIPRAP MOVEMENT
▨ RIPRAP DEPOSITION

INITIAL RIPRAP MOVEMENT
MAXIMUM SIZE 500 LBS

RIVER DISCHARGE 67000 CFS

PLATE 65



FLOW DISTRIBUTION

POWERHOUSE UNITS A TO D CLOSED
SPILLWAY BAYS A TO E UNIFORM SPILL

SPILL ONLY
FIXED-BED INVERT ROCK

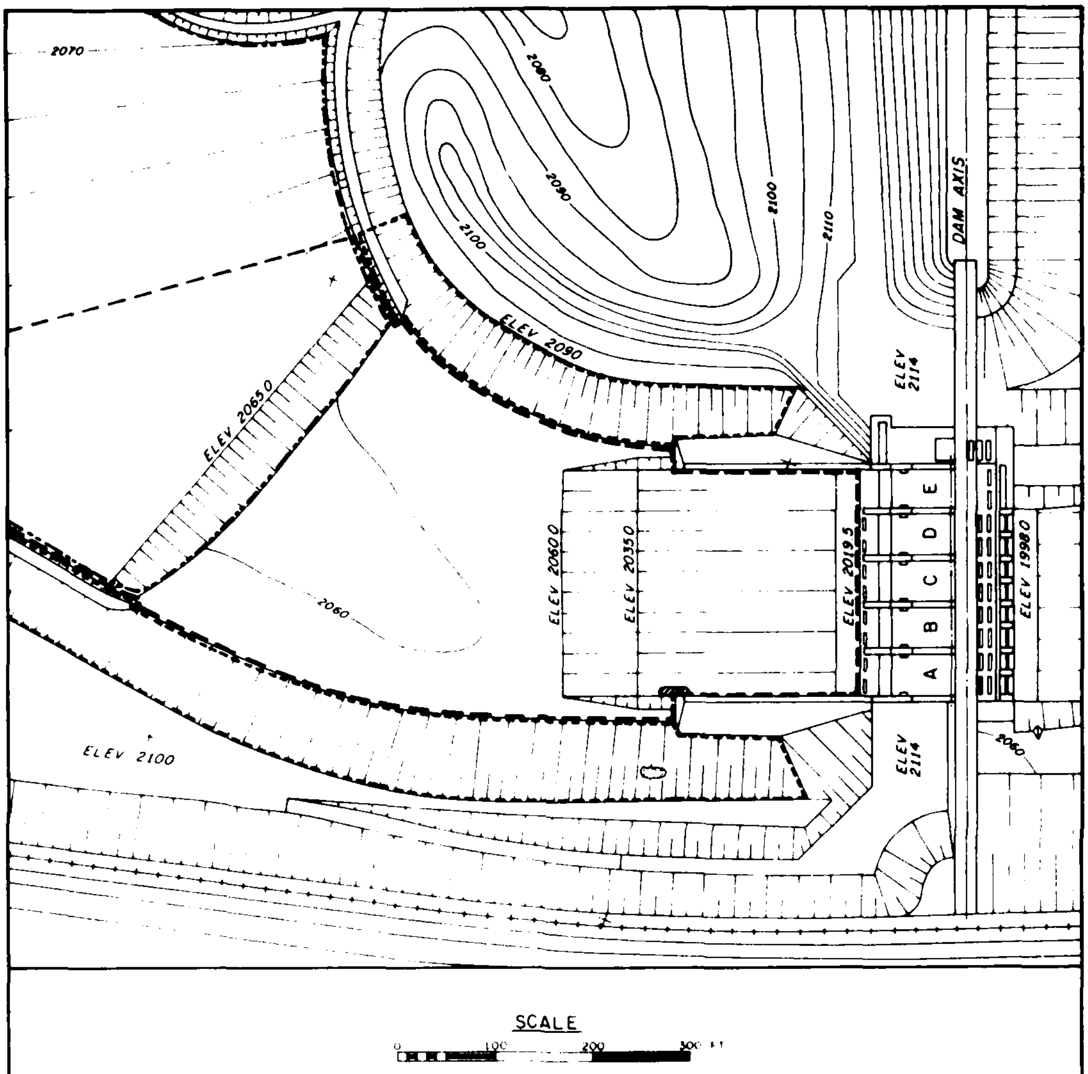
LEGEND

MOVABLE-BED LIMITS
- - - - OVERBURDEN
- - - - RIPRAP
— — — INVERT ROCK
○ INITIAL RIPRAP MOVEMENT
▨ RIPRAP DEPOSITION

INITIAL RIPRAP MOVEMENT
MAXIMUM SIZE 750 LBS

RIVER DISCHARGE 105000 CFS

PLATE 66



FLOW DISTRIBUTION

POWERHOUSE UNITS A TO D CLOSED
SPILLWAY BAYS A TO E UNIFORM SPILL

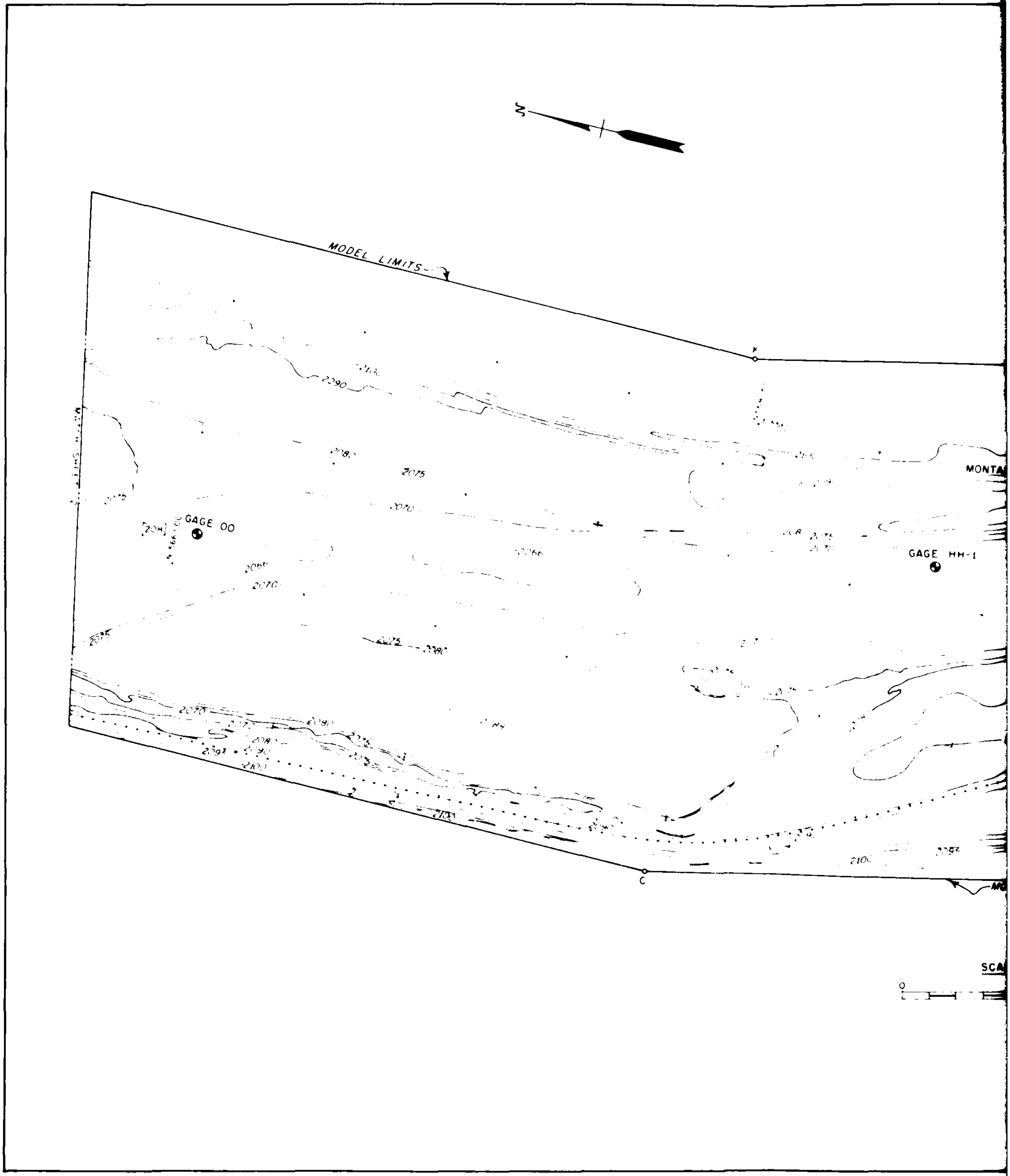
SPILL ONLY
FIXED-BED INVERT ROCK

LEGEND

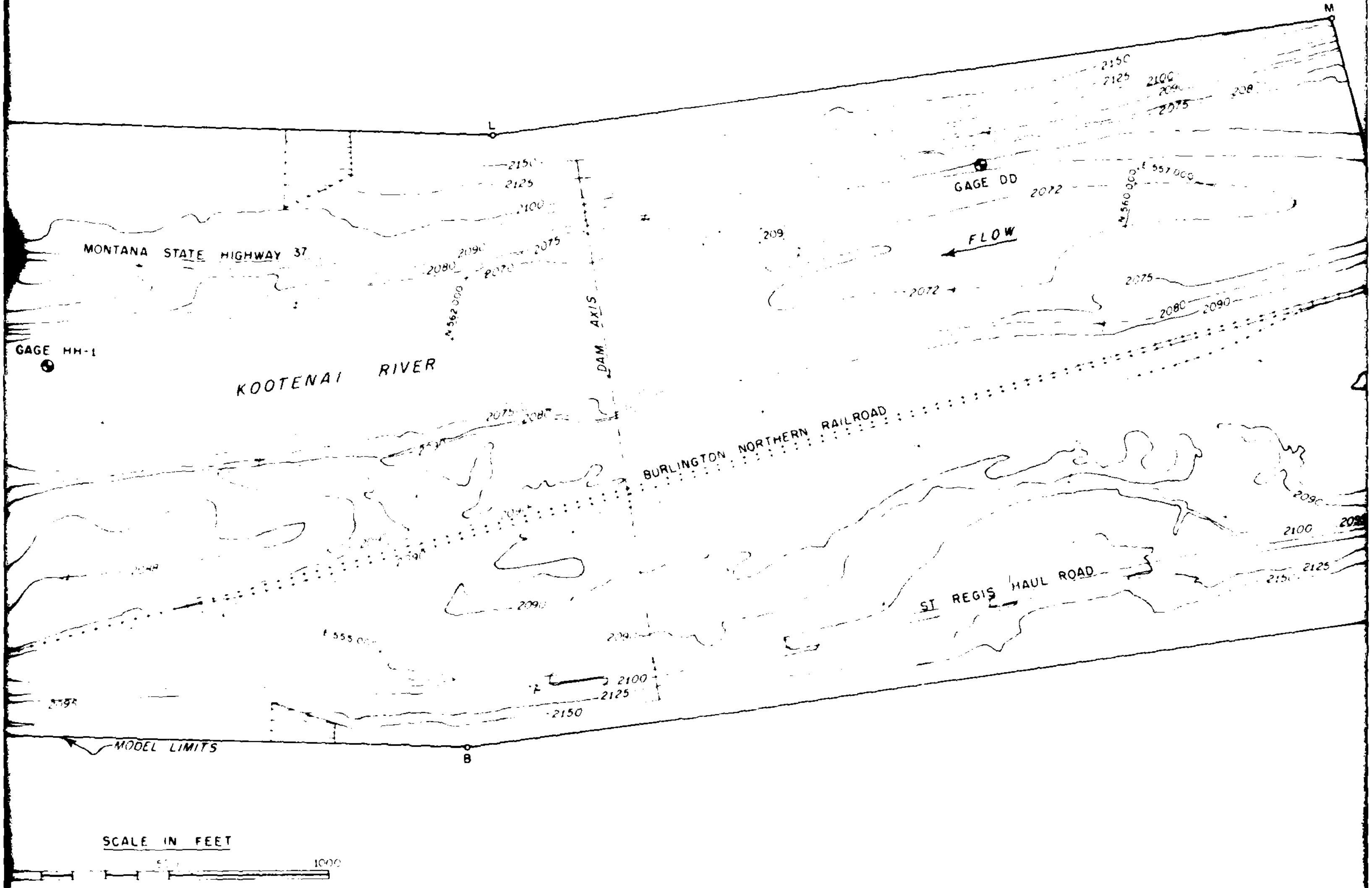
MOVABLE BED LIMITS
- ·--- OVERBURDEN
- ---- RIPRAP
- ▬ ▬ ▬ INVERT ROCK
- ○ INITIAL RIPRAP MOVEMENT
- ▨ RIPRAP DEPOSITION

INITIAL RIPRAP MOVEMENT
MAXIMUM SIZE 1000 LBS

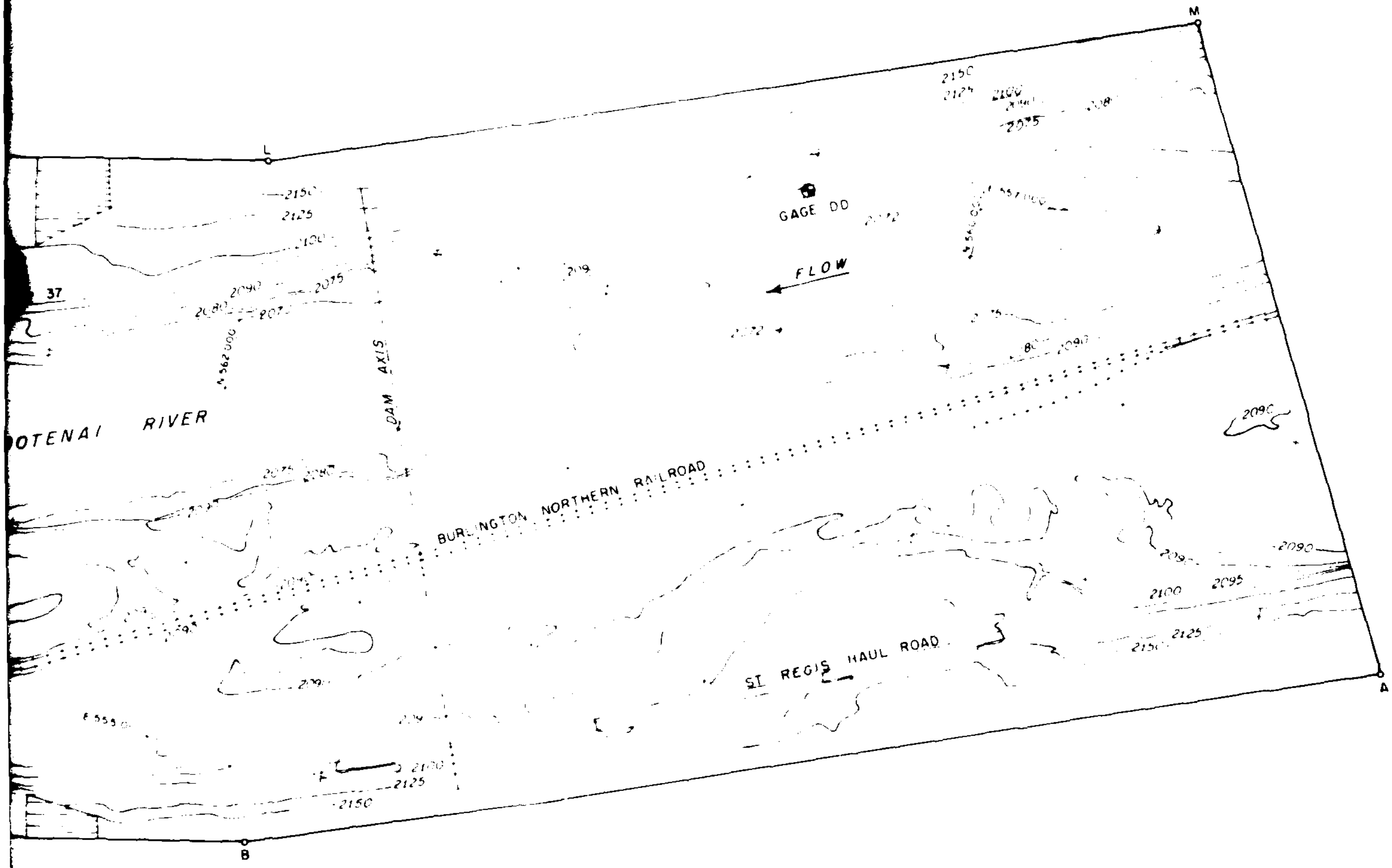
RIVER DISCHARGE 150 000 CFS


MODEL LIMITS
GAGE OO
GAGE HH-1
MONTA
SCA
0
2090
2080
2075
2070
2066
2075
2070
2080
2100
2100
2070
2080
2090
2100

1


M
L
B
2150
2125
2100
2090
2080
2075
2070
2072
209
N 562,000
N 560,000
E 557,000
E 555,000
MONTANA STATE HIGHWAY 37
GAGE HH-1
KOOTENAI RIVER
DAM AXIS
GAGE DD
FLOW
BURLINGTON NORTHERN RAILROAD
ST REGIS HAUL ROAD
MODEL LIMITS
SCALE IN FEET
500
1000

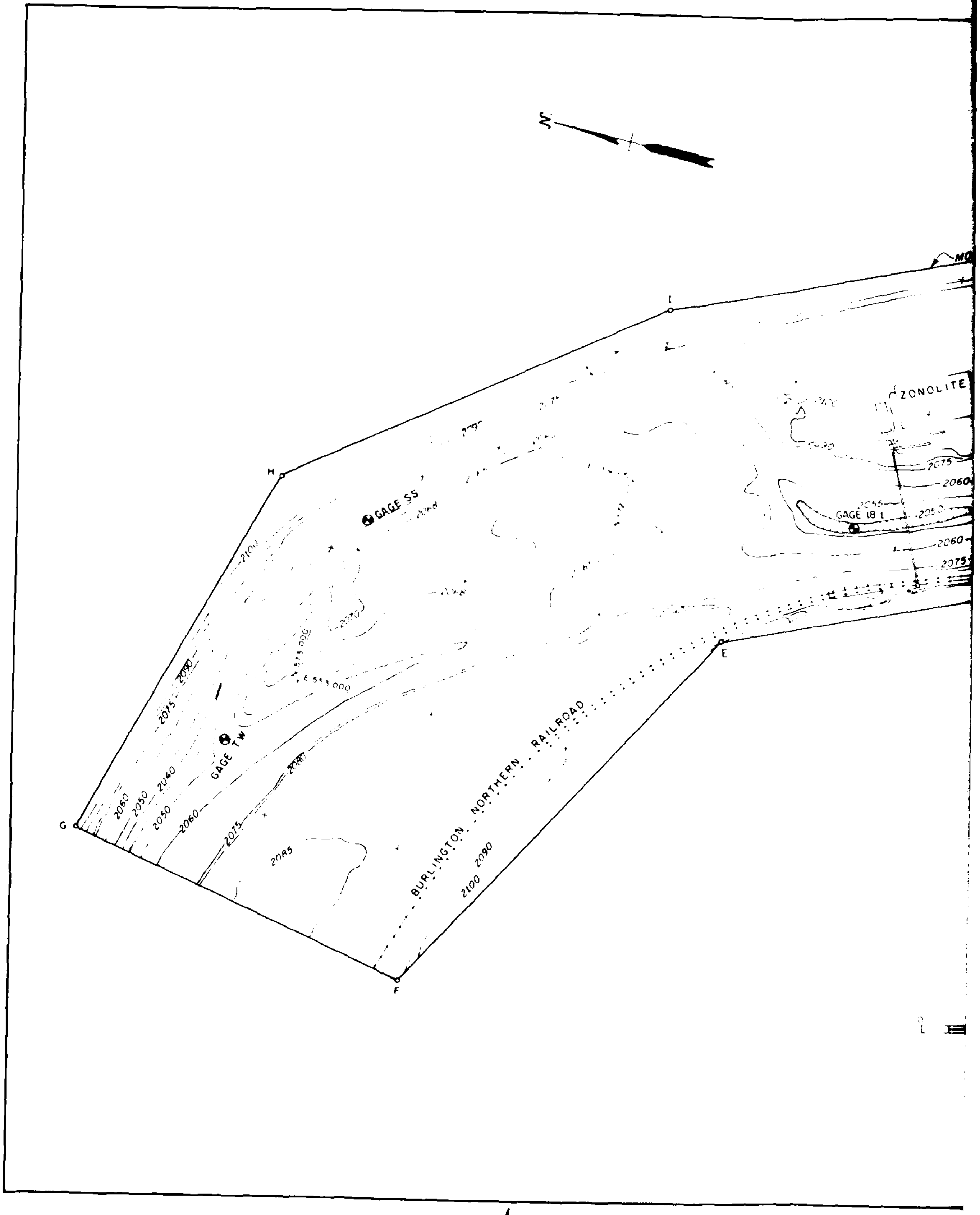
GAGE

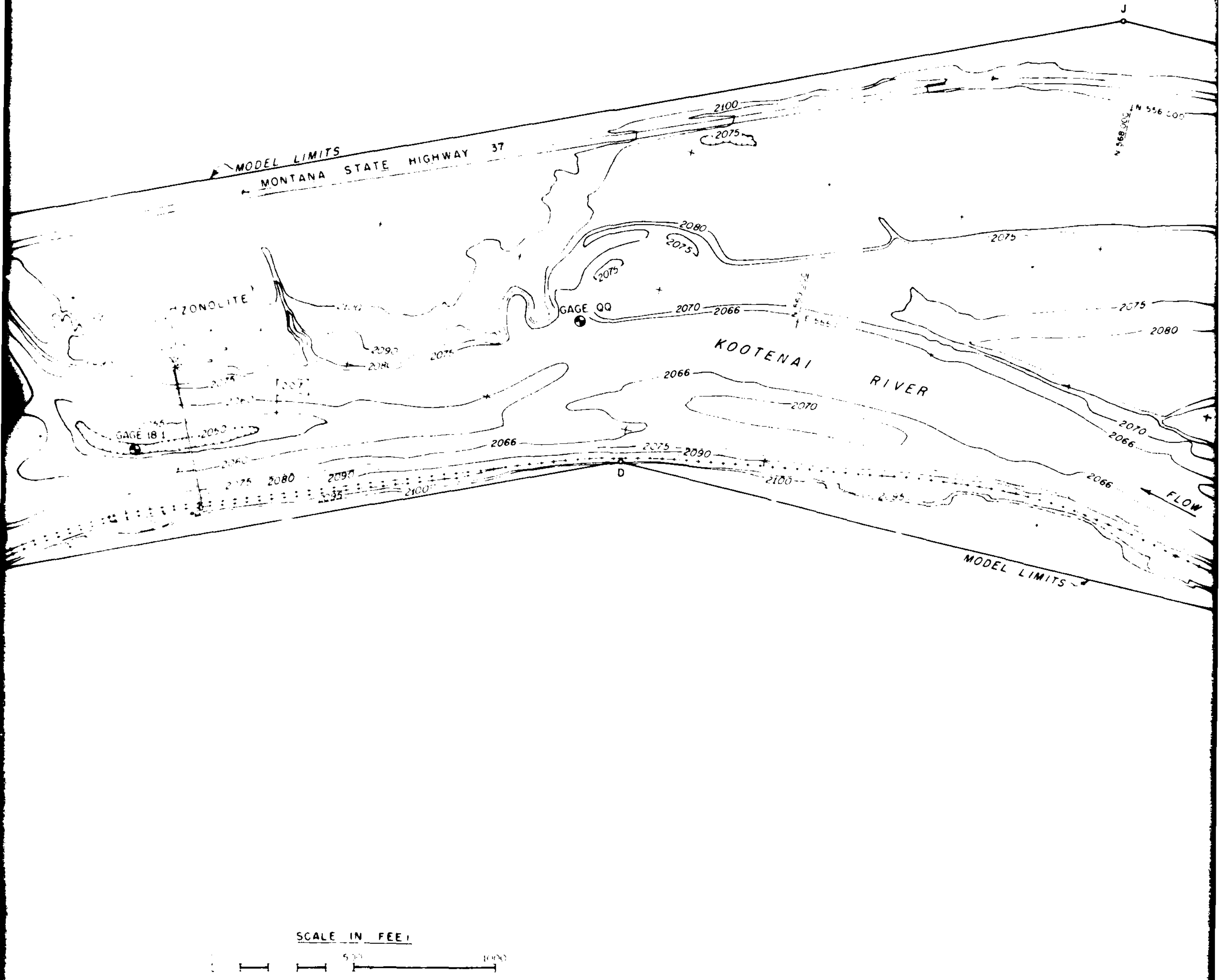


GAGE LOCATIONS

PLATE 68

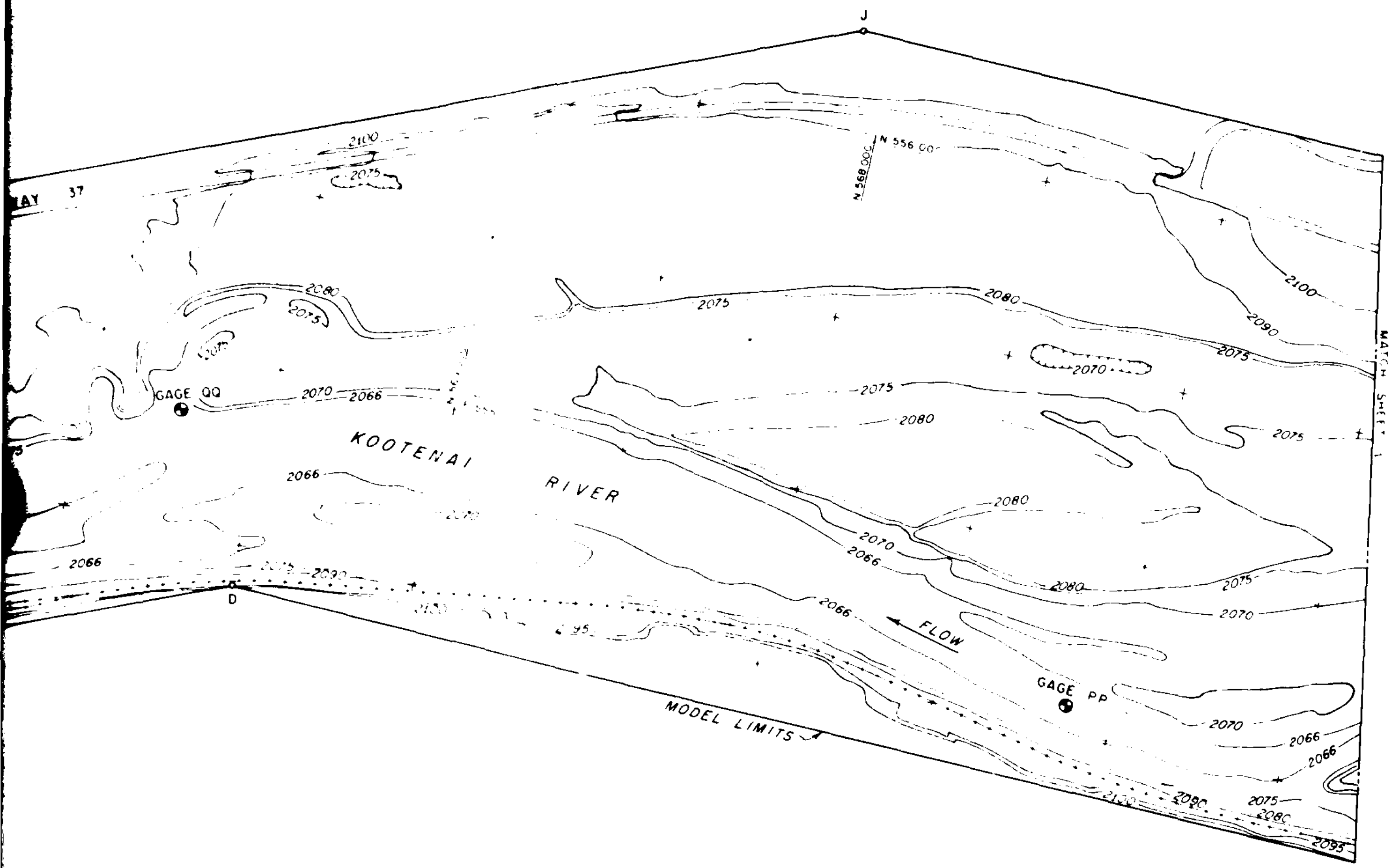
1 3


N
MO
I
ZONOLITE
H
GAGE SS
GAGE 18
2075
2060
2055
2050
2060
2075
2100
2070
2090
2075
E
GAGE TW
2060
2050
2040
2050
2060
2075
2080
2085
G
BURLINGTON NORTHERN RAILROAD
2090
2100
F


MODEL LIMITS
MONTANA STATE HIGHWAY 37
J
2100
2075
N 556,000
E 568,000
2080
2075
2075
2075
2080
ZONOLITE
GAGE QQ
2070
2066
2090
2075
2080
KOOTENAI
RIVER
2066
2070
2070
2066
2066
FLOW
GAGE 18.1
2055
2050
2060
2066
2075
2080
2090
2095
2100
D
2075
2090
2100
2095
MODEL LIMITS
SCALE IN FEET
500
1000

1

2

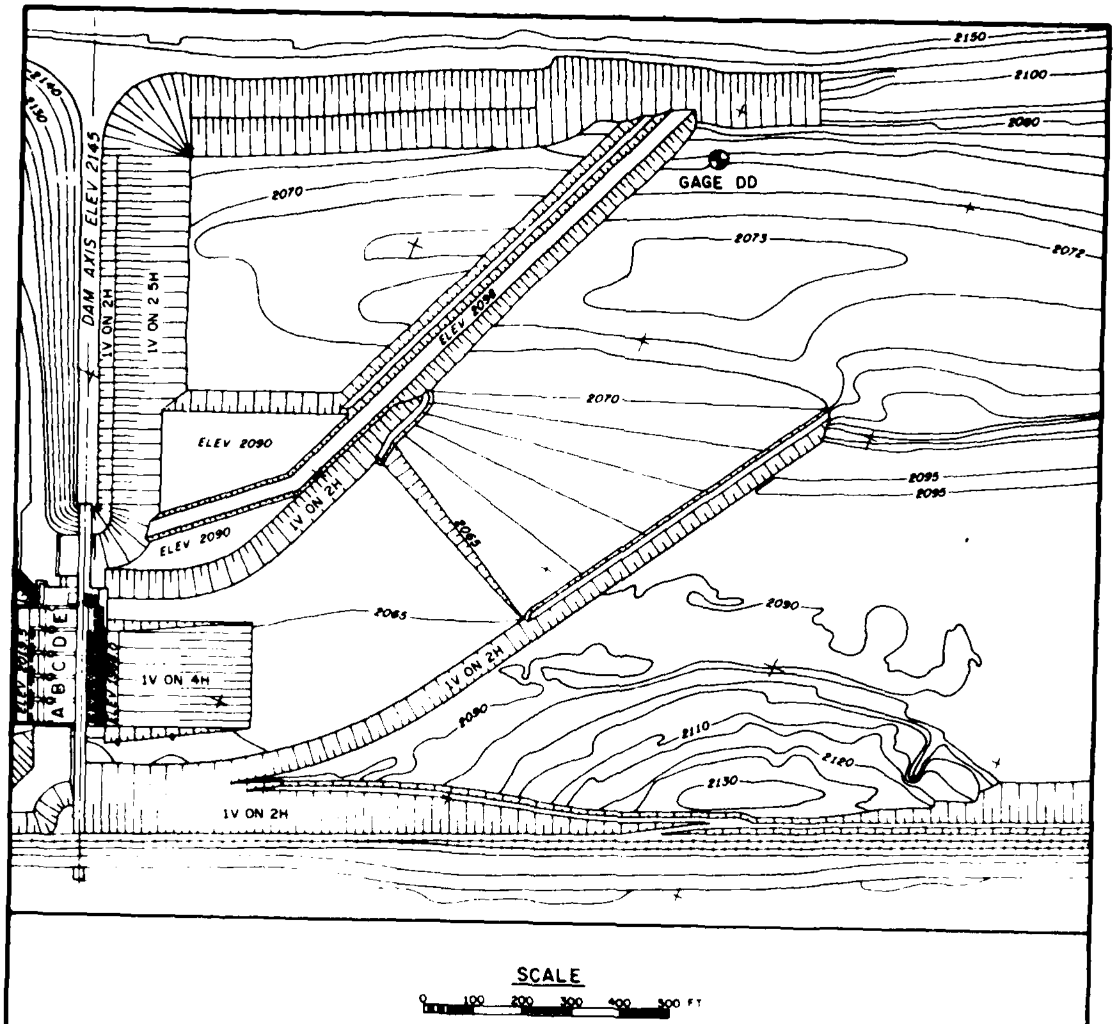


GAGE LOCATIONS

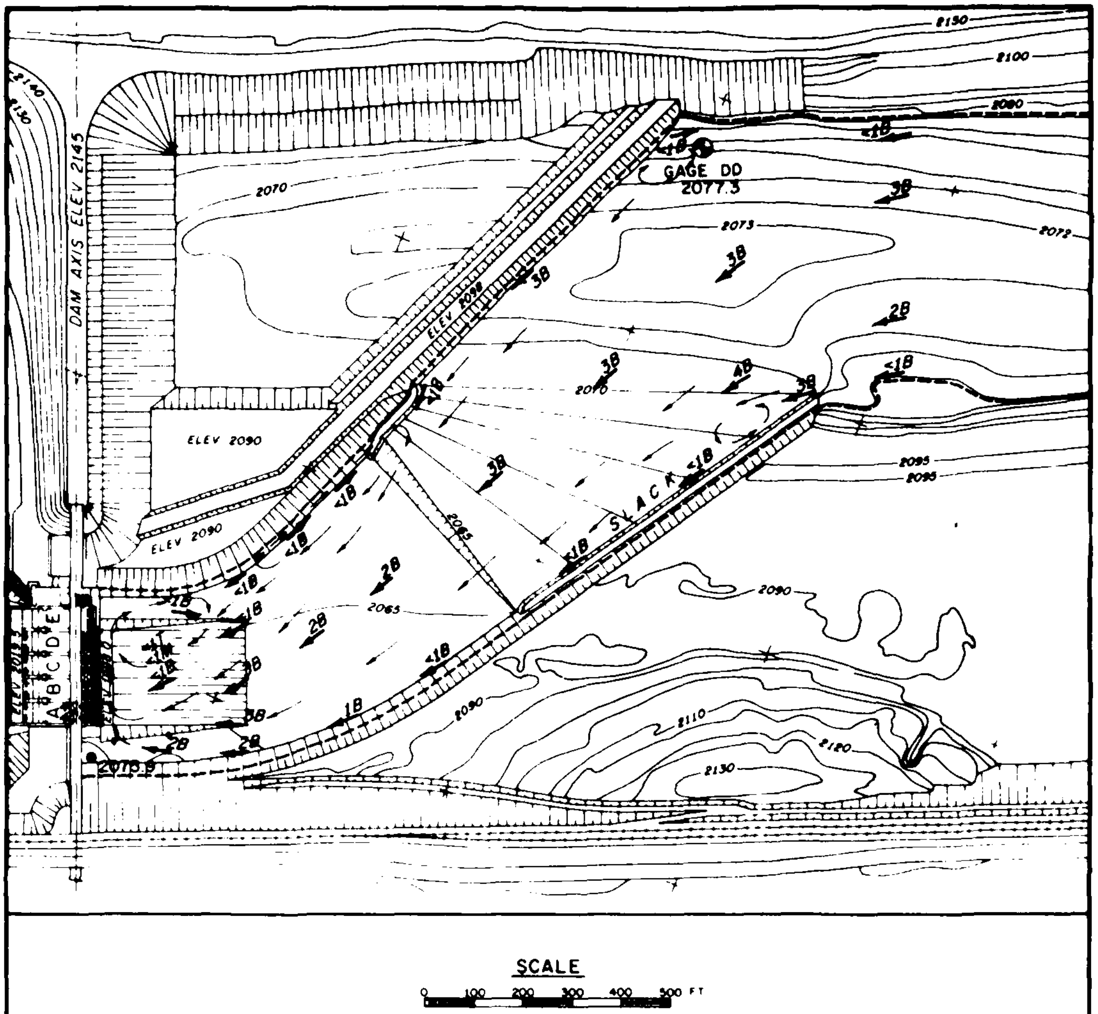
PLATE 69

2

3



SECOND-STAGE DIVERSION LAYOUT



LEGEND

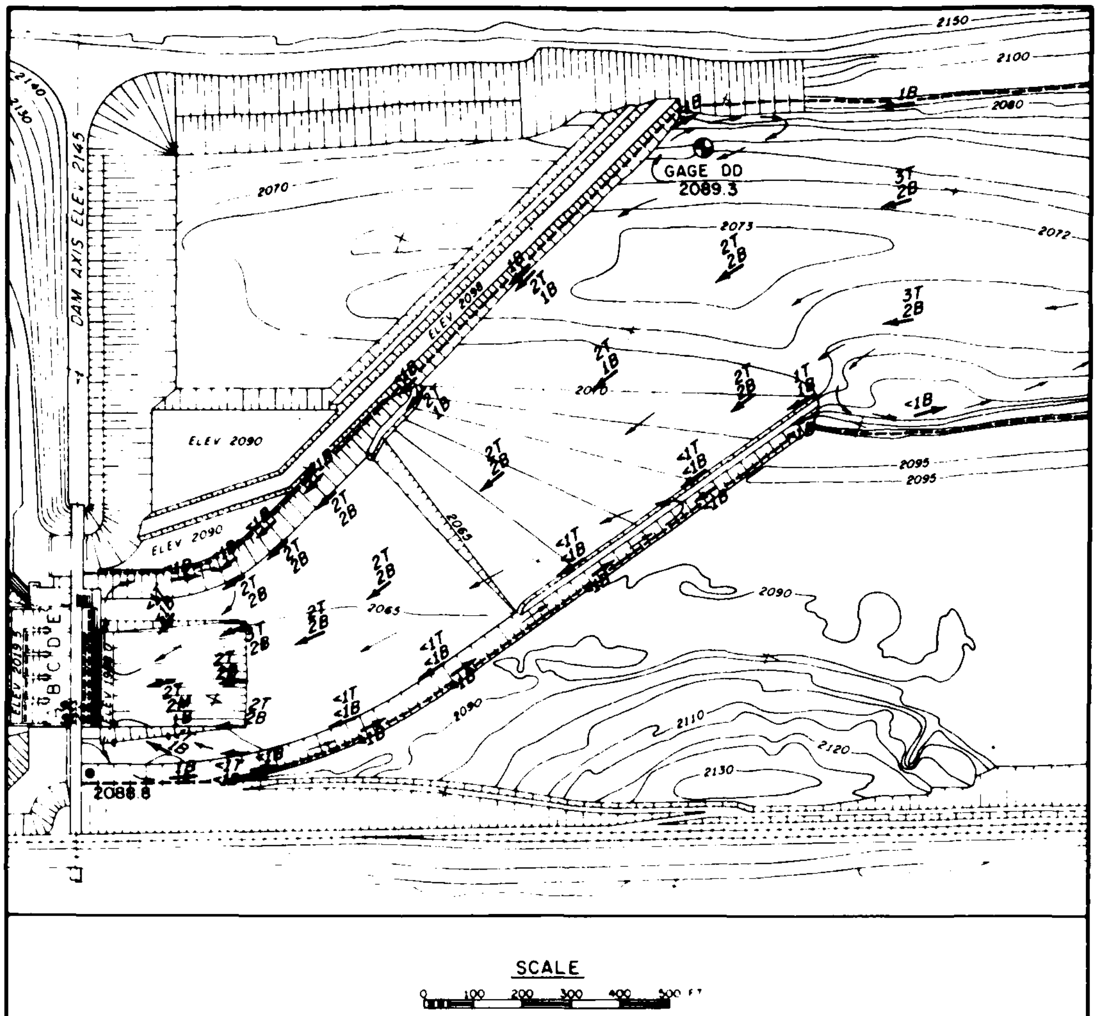
← 4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
C	MID-POINT AND 6.7 FT UPSTREAM OF SKELETON BAY ENTRANCE
2075.9 ●	WATER-SURFACE ELEVATION

SKELETON BAY A

SECOND-STAGE DIVERSION FLOW

RIVER DISCHARGE 5000 CFS

PLATE 71



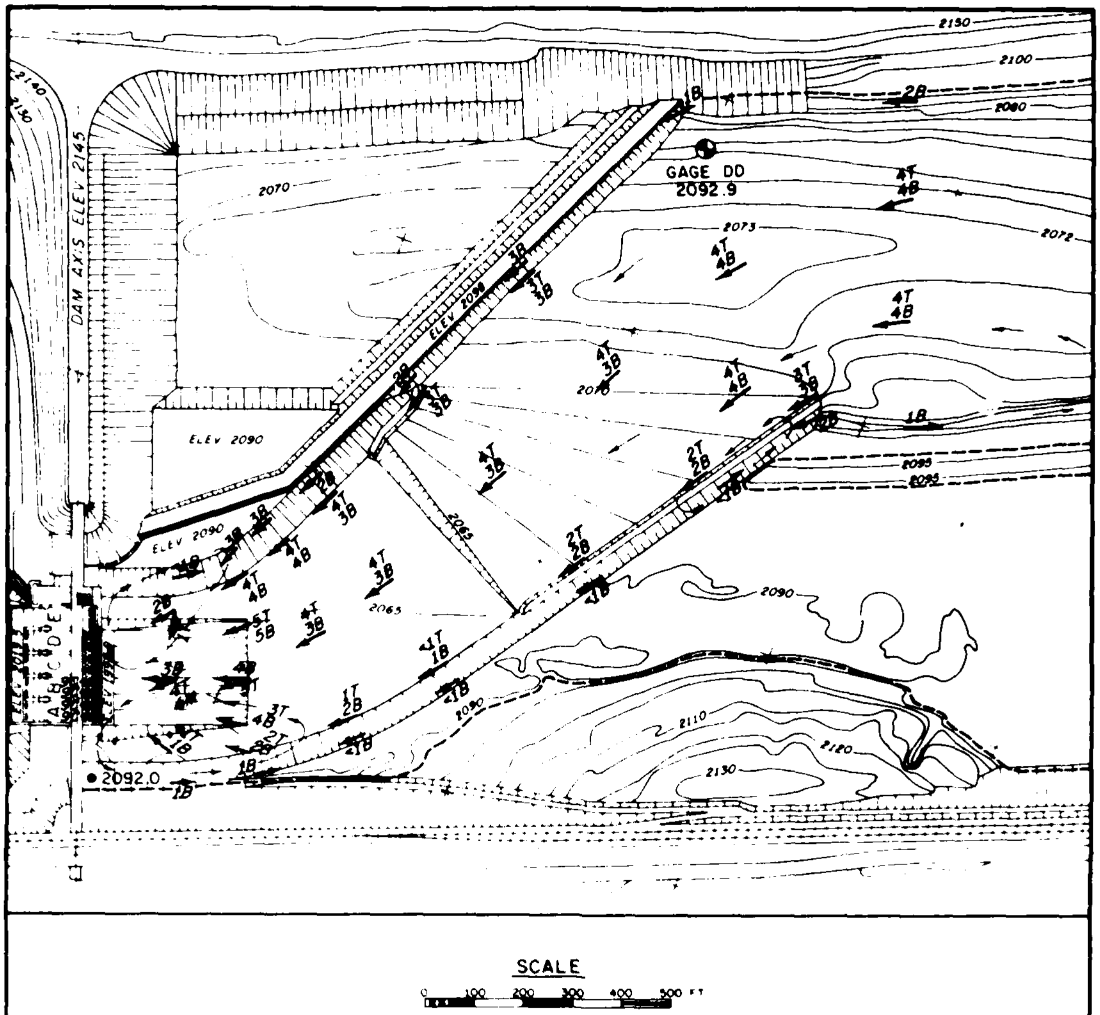
LEGEND

← 4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
C	MID-POINT AND 6.7 FT UPSTREAM OF SKELETON BAY ENTRANCE
2088.8 ●	WATER-SURFACE ELEVATION

SKELETON BAY A

SECOND-STAGE DIVERSION FLOW

RIVER DISCHARGE 14 700 CFS



LEGEND

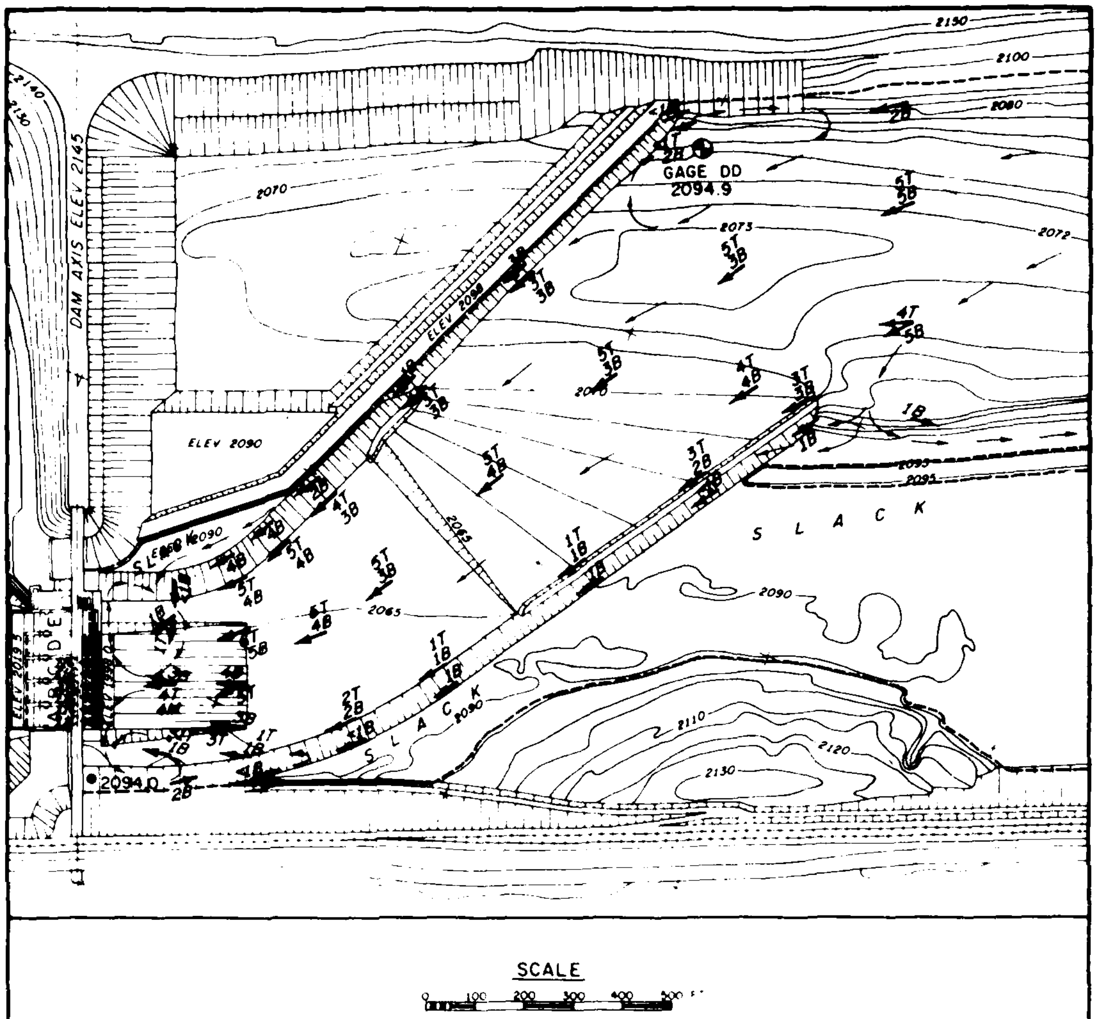
4 VELOCITIES IN FPS
T 5-FT DEPTH
M MID-DEPTH
B 5 FT ABOVE BOTTOM
C MID-POINT AND 6.7 FT UPSTREAM OF SKELETON BAY ENTRANCE
2092.0 ● WATER-SURFACE ELEVATION

SKELETON BAYS A AND B

SECOND-STAGE DIVERSION FLOW

RIVER DISCHARGE 29,300 CFS

PLATE 73



LEGEND

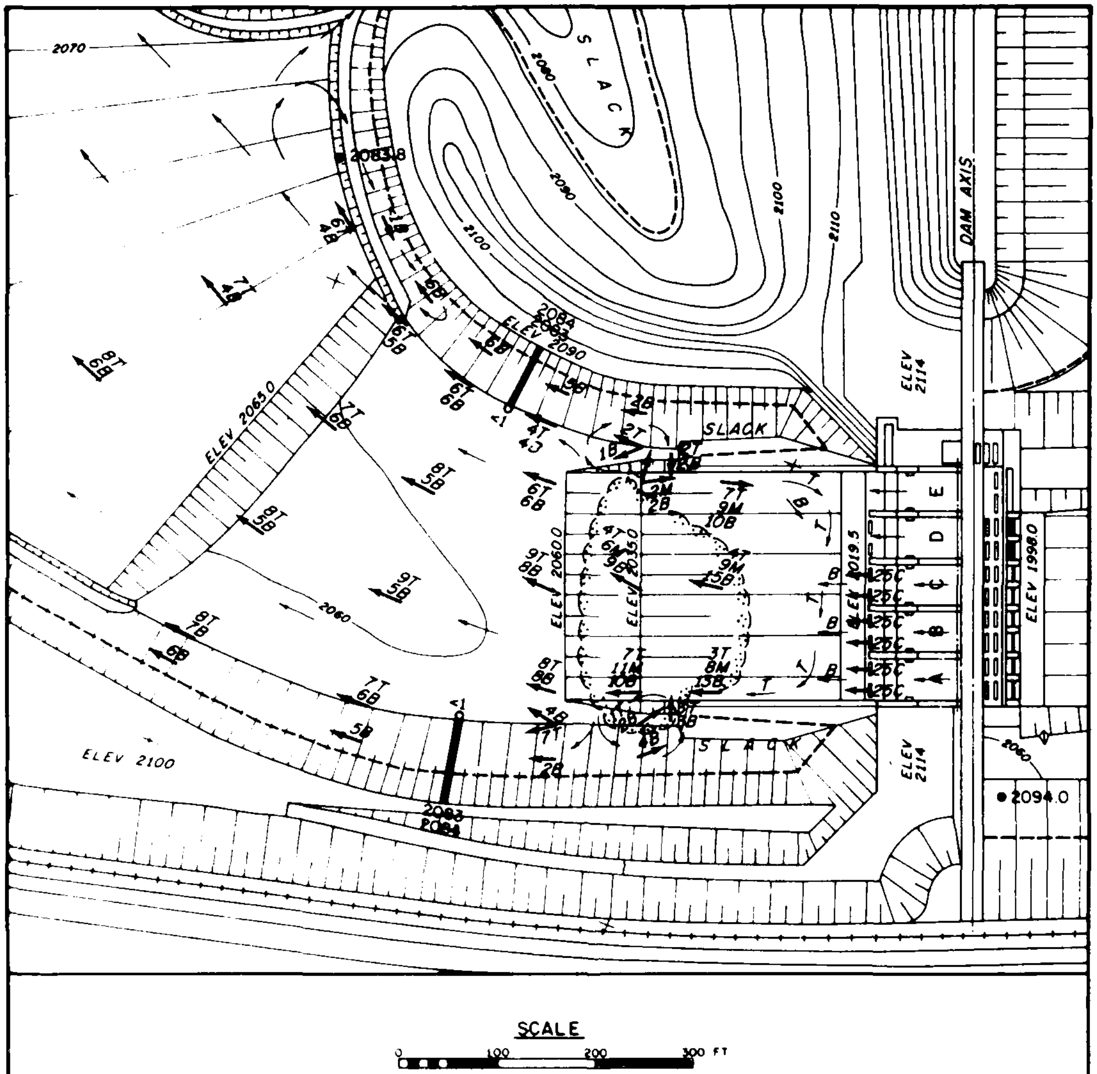
← 4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
C	MID-POINT AND 6.7 FT UPSTREAM OF SKELETON BAY ENTRANCE
2094.0 ●	WATER-SURFACE ELEVATION

SKELETON BAYS A TO C
SPILLWAY BAYS A TO E

SECOND-STAGE DIVERSION FLOW

RIVER DISCHARGE 44,000 CFS

PLATE 74



LEGEND

←4	VELOCITIES IN FPS
T	5-FT DEPTH
M	MID-DEPTH
B	5 FT ABOVE BOTTOM
C	MID-POINT AND 6.7 FT DOWNSTREAM OF SKELETON BAY EXIT
2080.0 ●	WATER-SURFACE ELEVATIONS
2.0 ○	WAVE HEIGHTS IN FT
⌒⌒⌒	BOIL OUTLINE
▮ 2083 2084	RIDEUP ELEVATIONS

SKELETON BAYS A TO C
SPILLWAY BAYS A TO E

SECOND-STAGE DIVERSION FLOW

RIVER DISCHARGE 44000 CFS

PLATE 75

APPENDIX A

BAFFLED-CHUTE SPILLWAY

Purpose of Model

A1. An initial objective for the Libby reregulating dam project was to provide the capability for reduction in any nitrogen supersaturation which might be caused by the operation of the flood control sluices and spillway at the upstream Libby Dam project. In general, unacceptably high concentrations of nitrogen result when aerated spillway flow plunges deep into a tailrace pool forcing nitrogen (and other) gases into solution under high pressure. This condition, known as nitrogen supersaturation, can be offset by aeration of the supersaturated water at near-atmospheric pressure. Field and laboratory investigations undertaken by the U.S. Bureau of Reclamation, and field tests conducted by personnel from DHL and NPS at Conconully Dam (in north-central Washington) indicated that baffled-chute spillways could be used to reduce nitrogen supersaturation and provide satisfactory energy dissipation. During the design-development stage of the Libby reregulating dam project, a baffled-chute spillway was thus investigated as a means to provide shallow-flow entrainment of air. Hydraulic modeling was employed to determine a baffle configuration and layout which would provide effective aeration and energy dissipation of spillway flows.

Nitrogen-Reduction Investigation

A2. The nitrogen-reduction efficiency of various baffled-chute designs was measured in a flume by observing nitrogen saturation levels at the upstream and downstream ends of the chute. Supersaturation was attained by injecting compressed air into the water supply system. Total gas pressure and dissolved oxygen concentration were measured (with a Weiss gas saturometer and a Yellow Springs Model 54 oxygen meter; see photograph A1), and these quantities in turn yielded the level of nitrogen supersaturation.

A3. Several baffle shapes were tested in a preliminary assessment of aeration efficiency. Preliminary testing was accomplished in a 3.36-foot-wide flume having a slope 1V on 2.13H with a total vertical drop of 5.48 feet. Two preliminary baffle designs similar to that in use at Conconully Dam were developed and tested. Types A and B, shown in plate A1 and photographs A2 and A3, were 3.0 feet in height and prismatic in shape. The Type A baffle scheme resulted in uniform energy dissipation, excellent flow aeration (see photograph A4), and a maximum reduction in nitrogen supersaturation of 7.1 percent with a discharge of 3.0 cfs. Type B baffles (see photograph A5) were tested in an attempt to increase unit discharge. Unfortunately, the result was poor aeration of the flow and nitrogen saturation levels were therefore not measured.

A4. In a further attempt to develop a design which would allow an increase in discharge per unit width, the Type C baffle evolved (see plate A2). The basic departures from the preliminary designs were the addition of an upward-sloping front face to enhance vertical mixing, and a flat back face normal to the flow separation to insure atmospheric pressure over the full height of the back of the baffle. The Type C baffle was determined to be effective in causing aeration to the full depth of the flow while allowing a relatively high discharge per unit width. The Type C baffle was tested at half size (Plan C-1, photographs A6 through A9), then doubled in length (Plan C-2, photographs A10 through A13), and then doubled in chute width (Plan C-3, plate A3 and photographs A14 through A19)--all at the same chute slope of 1V:1.127H. The Plan D configuration (plate A4 and photographs A20 through A25) employed the half size Type C baffles on a 1V:4H slope. Test flow conditions and the resulting reductions in nitrogen supersaturation level are summarized in tables A1 and A2; table A3 presents the pressures measured at the locations indicated on plate A3. Plate A5 reflects the comparison between nitrogen saturation levels in forebay and tailwater for all test configurations.

Baffled-Chute Spillway

Preliminary Studies

A5. A two-bay section of a proposed structure consisting of a five-bay tainter gate controlled spillway, a hydraulic-jump stilling basin, and a baffled chute, was reproduced at a scale of 1:25.11 and tested at discharges up to 42,000 cfs per bay (PMF conditions). The original design (Plan A, shown in plate A6) features a 50-foot-long stilling basin with its floor at spillway crest level, 46.5-foot-wide bays, and a 2.5-foot-high end sill leading to a baffled chute and baffled runout slope incorporating the Type C baffles. Initial testing revealed that at flows of 4,000 cfs or greater per bay, the hydraulic jump would be swept out of the stilling basin resulting in unacceptable flow conditions downstream. Modifications made to the Plan A design in an attempt to overcome this problem included the following: the addition of baffles of various shapes and spacing on the stilling basin floor, an increase in stilling basin length, an increase in end sill height, and the addition of a berm between the end sill and the baffled chute.

A6. As a result of these modifications, the Plan B design shown in plate A7 was developed. Stilling basin length was increased to 64 feet, end sill height was raised to 6 feet, a 20-foot-long berm was provided between the end sill and the baffled chute, chute length was reduced, and runout configuration was modified. Performance of the stilling basin was adequate up to the design discharge, but downstream from the chute a large standing wave developed and velocities were excessive.

Final (Plan C) Design

A7. The Plan C design was similar to Plan B except that the end sill height was 7 feet and the berm between the chute and stilling basin was 16 feet. In addition, the baffled-chute length was reduced to 110 feet and a horizontal runout with two rows of conventional shaped baffles (see plate A8 and photographs A26 and A27) was added. Flow conditions and energy dissipation in the basin and chute were judged to be generally adequate at all flow conditions (see plate A9 and photographs A28 to A51). Energy dissipation in the stilling basin and chute was adequate at discharges up to the PMF of 42,000 cfs per bay (903 cfs per foot). Thorough agitation of water existed along the entire length of the baffled chute for discharges up to 8,400 cfs per bay (181 cfs per foot) which would be the portion of the SPF discharged over the spillway. Such agitation was considered to simulate excellent mixing and aeration characteristics in the prototype with subsequent reduction in gas supersaturation. Similar flow characteristics were exhibited only in the lower half of the chute for discharges up to 15,000 cfs per bay (322 cfs/foot) indicating a lesser effectiveness in gas supersaturation reduction at that higher discharge. Discharge ratings for gated and ungated flows are shown on plates A10 and A11. Spillway floor velocities are presented on plate A12; the maximum observed velocity was 16 fps with PMF conditions. A minimum apron length of 75 feet was considered a necessity in order to provide protection against high velocities downstream from the runout area. Pressures on the Type C baffles were measured (at the locations shown on plate A13) for three baffle positions and are summarized in table A4. Hydraulic loads on the baffles in the longitudinal (streamwise) and lateral directions were estimated by imposing maximum and minimum observed pressures on opposite faces of the baffle. Maximum longitudinal and lateral loads were 31.9 kips and 2.7 kips, respectively. These computed loads are summarized for several flow conditions in tables A5 through A13. A baffle similar in shape to the Type C baffle but 2.25 feet shorter exhibited generally satisfactory flow conditions except the baffles were overtopped with the SPF resulting in reduced aeration action.

Summary

A8. A gated spillway and baffled-chute design expected to reduce the nitrogen supersaturation level of water impounded in the forebay of the Libby Reregulating Dam was developed on the basis of hydraulic model investigations. The design is also expected to prevent any increase in nitrogen level which could occur if the spillway nappe were allowed to plunge into a deep stilling basin. The spillway exhibited good aeration and mixing characteristics for discharges up to 181 cfs per foot of crest length and adequate energy dissipation for flows as high as 903 cfs per foot.

A9. Due to space limitations, the powerhouse of the Libby Reregulating Dam was eventually situated beneath the spillway. The economics of incorporating a baffled chute into this configuration combined with the infrequency of Libby Dam spills and resultant high supersaturation levels precluded the use of the baffled chute spillway concept.

TABLE A1

NITROGEN SATURATION

BAFFLE LAYOUT PLANS C, C-1 to C-3

Baffle Layout	Discharge CFS	Head on Crest Feet	Tailwater Depth Feet	Water Temp °C	Saturation, Percent				
					Oxygen		Nitrogen plus Argon		
					Forebay	Tailbay	Forebay	Tailbay	Reduction
Plan C	3.9	0.5	1.6	14.2	105.7	104.7	103.3	101.8	1.5
			1.6	18.3	100.8	99.8	10[illegible].6	102.8	0.8
			1.5	16.5	102.9	100.9	107.1	104.2	2.9
			1.7	14.5	110.1	106.2	107.5	104.3	3.2
			1.5	16.0	105.0	102.1	109.7	106.0	3.7
			1.4	16.8	110.5	105.3	110.2	105.1	5.1
			1.4	16.6	113.1	107.0	112.8	107.8	5.0
			1.5	16.5	111.0	103.8	113.8	108.4	5.4
			1.3	15.0	118.9	109.0	116.9	110.0	6.9
	11.0	1.0	1.5	15.6	97.1	98.1	101.4	101.7	-0.3
			1.6	15.1	99.7	100.7	101.7	101.7	0.0
			1.6	16.4	100.3	99.2	106.1	104.5	1.6
			1.7	16.0	104.9	103.9	106.9	104.1	2.8
			1.2	12.9	105.9	104.0	107.4	103.7	3.7
			1.7	17.2	105.3	102.2	108.8	105.2	3.6
			1.7	16.8	106.4	103.4	109.0	105.3	3.7
			1.9	16.4	109.0	105.9	110.7	106.3	4.4
			1.7	16.2	107.0	102.0	111.2	107.1	4.1
Plan C-1	1.9	0.5	0.8	15.2	103.2	102.9	103.6	102.5	1.1
			0.8	15.1	102.7	102.2	104.0	102.6	1.4
			0.8	16.0	104.8	102.8	105.9	104.0	1.9
			0.8	16.7	103.5	101.9	105.9	104.1	1.8

			1.7	17.2	105.3	102.2	108.8	105.2	3.6
			1.7	16.8	106.4	103.4	109.0	105.3	3 7
			1.9	16.4	109.0	105.9	110.7	106.3	4.4
			1.7	16.2	107.0	102.0	111.2	107.1	4.1
Plan C-1	1.9	0.5	0.8	15.2	103.2	102.9	103.6	102.5	1.1
			0.8	15.1	102.7	102.2	104.0	102.6	1.4
			0.8	16.0	104.8	102.8	105.9	104.0	1.9
			0.8	16.7	103.5	101.9	105.9	104.1	1.8
			0.8	17.2	104.1	102.0	107.1	104.8	2.3
			0.8	15.0	101.9	99.9	107.3	105.3	2.0
			0.8	17.9	103.6	102.5	107.6	105.7	1.9
			0.9	18.2	101.1	100.0	109.9	107.6	2.3
			0.8	15.4	112.3	106.3	110.3	109.2	1.1
			0.7	16.0	115.8	110.8	113.2	110.5	2.7
			0.8	14.1	113.7	109.8	113.2	111.0	2.2
			0.8	15.0	109.9	107.9	113.3	110.5	2.8
			0.9	17.2	123.6	113.7	116.2	114.4	1.8
			0.9	16.8	115.3	109.2	117.4	115.0	2.4
	1.1	0.3	0.9	19.1	108.9	103.5	115.1	112.0	3.1
Plan C-2	1.9	0.5	0.9	20.1	101.6	100.7	102.0	101.2	0.8
			0.9	20.7	103.0	101.4	103.0	102.0	1.0
			0.9	21.3	111.2	106.7	109.0	103.4	5.6
			0.8	20.5	121.4	110.9	109.9	103.5	6.4
			0.9	20.4	108.8	102.7	111.5	104.8	6.7
			0.9	21.0	117.8	107.2	114.4	105.9	8.5
			0.9	19.9	110.6	102.9	114.4	105.9	8.5
			1.0	22.3	117.6	107.2	114.8	106.4	8.4
			1.0	20.0	121.6	107.8	116.6	108.3	8.3
			1.0	20.0	121.6	107.3	116.6	108.2	8.4
			1.1	18.1	120.0	106.3	120.5	110.6	9.9
Plan C-3	3.9	0.5	0.7	25.0	103.9	102.1	104.9	102.0	2.9
			0.9	24.1	103.9	100.4	109.1	104.0	5.1
			0.9	23.2	109.5	103.1	109.3	103.7	5.6
			0.8	24.1	105.8	101.6	110.3	104.2	6.1
			0.9	25.6	109.6	104.7	110.7	103.5	7.2
			0.9	25.1	110.3	103.6	112.3	105.3	7.0
			0.9	20.8	116.1	108.3	112.8	106.4	6.4
			1.4	26.0	118.7	107.0	113.5	107.6	5.9
			0.7	27.6	112.7	103.2	115.1	106.4	8.7
			0.7	24.8	119.2	107.2	116.0	106.3	9.7
			1.0	26.0	114.7	103.6	116.0	107.5	8.5

			0.8	15.4	112.3	106.3	110.3	109.2	1.1
			0.7	16.0	115.8	110.8	113.2	110.5	2.7
			0.8	14.1	113.7	109.8	113.2	111.0	2.2
			0.8	15.0	109.9	107.9	113.3	110.5	2.8
			0.9	17.2	123.6	113.7	116.2	114.4	1.8
			0.9	16.8	115.3	109.2	117.4	115.0	2.4
	1.1	0.3	0.9	19.1	108.9	103.5	115.1	112.0	3.1
Plan C-2	1.9	0.5	0.9	20.1	101.6	100.7	102.0	101.2	0.8
			0.9	20.7	103.0	101.4	103.0	102.0	1.0
			0.9	21.3	111.2	106.7	109.0	103.4	5.6
			0.8	20.5	121.4	110.9	109.9	103.5	6.4
			0.9	20.4	108.8	102.7	111.5	104.8	6.7
			0.9	21.0	117.8	107.2	114.4	105.9	8.5
			0.9	19.9	110.6	102.9	114.4	105.9	8.5
			1.0	22.3	117.6	107.2	114.8	106.4	8.4
			1.0	20.0	121.6	107.8	116.6	108.3	8.3
			1.0	20.0	121.6	107.3	116.6	108.2	8.4
			1.1	18.1	120.0	106.3	120.5	110.6	9.9
Plan C-3	3.9	0.5	0.7	25.0	103.9	102.1	104.9	102.0	2.9
			0.9	24.1	103.9	100.4	109.1	104.0	5.1
			0.9	23.2	109.5	103.1	109.3	103.7	5.6
			0.8	24.1	105.8	101.6	110.3	104.2	6.1
			0.9	25.6	109.6	104.7	110.7	103.5	7.2
			0.9	25.1	110.3	103.6	112.3	105.3	7.0
			0.9	20.8	116.1	108.3	112.8	106.4	6.4
			1.4	26.0	118.7	107.0	113.5	107.6	5.9
			0.7	27.6	112.7	103.2	115.1	106.4	8.7
			0.7	24.8	119.2	107.2	116.0	106.3	9.7
			1.0	26.0	114.7	103.6	116.0	107.5	8.5
			1.0	22.3	114.8	104.5	116.2	107.6	8.6
			1.7	27.0	115.6	105.7	116.2	107.2	9.0
			1.2	27.0	113.9	103.9	116.5	107.5	9.0

NOTE: Nitrogen saturation data shown as curves on plate A5.

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TABLE A2

NITROGEN SATURATION

BAFFLE LAYOUT PLAN D

Discharge 3.9 cfs, Head on Crest 0.6 Feet

Tailwater Depth Feet	Water Temp °C	Saturation, Percent				
		Oxygen		Nitrogen plus Argon		
		Forebay	Tailbay	Forebay	Tailbay	Reduction
	Water temperature 11 to 13°C					
1.4	11.9	104.6	103.2	110.0	105.0	5.0
1.2	12.0	101.8	100.2	110.6	105.7	4.9
1.2	12.0	101.5	100.8	110.7	105.7	5.0
1.3	12.0	103.4	102.4	112.6	106.6	6.0
1.3	11.9	100.9	99.1	113.3	107.8	5.5
1.3	12.1	103.0	101.2	115.0	107.1	7.9
1.4	12.0	114.8	106.5	118.6	110.5	8.1
1.2	12.0	119.5	108.0	120.2	112.2	8.0
1.3	11.8	115.6	107.4	120.9	112.6	7.6
1.3	12.2	121.1	109.2	121.7	113.3	8.4
1.2	12.0	122.1	109.7	122.0	113.9	8.1
2.5	11.4	122.3	112.3	123.7	115.9	7.8
	Water temperature 21 to 25°C					
1.2	23.4	106.2	102.7	105.8	103.1	2.8
1.0	23.4	103.0	99.5	107.3	104.3	3.0
1.0	24.8	109.4	105.8	108.9	103.7	5.2
1.2	22.4	109.3	103.5	110.7	105.1	5.6
1.1	23.2	111.7	105.9	111.4	105.1	6.3
1.0	22.8	107.2	102.6	111.6	105.5	6.1
1.1	23.4	111.0	107.5	112.5	105.1	7.4
1.2	21.4	113.0	103.9	114.4	107.5	6.9
1.2	23.0	112.0	104.4	116.1	107.9	8.2

NOTE: Nitrogen saturation data shown as curves on plate A5.

TABLE A3

PRESSURES

BAFFLE LAYOUT PLANS C-1, C-2, and D

Piezometer Number	Baffle Layout							
	Plan C-1		Plan C-2		Plan D			
	Discharge in CFS							
	1.9				11.5		3.9	
	Head on Crest in Feet							
	0.5				1.1		0.6	
	Pressure in Feet of Water							
	Low	High	Low	High	Low	High	Low	High
1	-1.0	-0.1	-0.9	-0.3	-1.4	-0.6	-0.8	-0.5
2	-0.5	-0.1	-0.5	-0.1	-1.2	-0.6	-0.5	-0.3
3	-0.3	-0.1	-0.4	-0.1	-0.8	-0.2	-0.5	-0.3
4	-0.1	0.0	-0.1	0.0	-0.4	-0.2	-0.1	-0.1
5	0.5	0.6	0.5	0.7	0.5	0.5	0.2	0.3
6	0.5	0.6	0.5	0.6	0.4	0.8	0.2	0.2

NOTE: Piezometer locations shown on plate A2.

TABLE A4

PRESSURES

Plan C Spillway

Gated Flow Pool Elev 2130, Free Flow Pool Energy Grade Line Elev 2138.1

Piezometer Number	Gated Flow		Free Flow	
	Spill per Bay in CFS			
	8,400		42,000	
	Pressure in Feet of Water			
	Low	High	Low	High
C1	57.3	57.3	40.3	41.1
C2	29.3	29.5	25.6	26.4
C3	37.6	37.7	36.4	36.8
C4	33.9	34.1	38.5	38.8
P1	38.0	38.5	36.2	37.0
P2	38.6	38.9	33.6	34.7
P3	38.3	38.6	34.5	35.6
P4	37.7	37.8	35.5	36.1
P5	36.6	36.9	36.4	36.7
P6	33.3	33.7	37.9	38.1
P7	38.1	38.3	35.4	36.2
P8	37.3	37.6	35.9	36.7
P9	36.5	36.8	36.8	37.5

NOTES: 1. Piezometer locations shown on plate A10.

2. Pool elevation and energy grade line measured 231 ft upstream from crest axis.

TABLE A5

PRESSURE AND HYDRAULIC LOADS ON BAFFLES

Plan C Spillway

Pool Elev 2130, Discharge Per Bay 1,000 cfs

Baffle Row	Piezometer No.	Area* Sq Ft	Pressure Ft of Water		Hydraulic Load (Kips)		Total Hydraulic Load (Kips)	
			High	Low	High	Low	High	Low
Front, Upper Section								
First	16	1.60	-	-				
	17	2.36	-	-				
	18	3.11	-	-				
Front, Lower Section								
	19	2.28	1.57	1.37	0.22	0.19		
	20	1.78	1.95	1.55	0.22	0.17		
	21	1.60	4.46	3.46	0.45	0.35	0.89	0.71
Sides, Lower Section								
	22	1.73	1.30	1.20	0.14	0.13		
	23	2.03	1.41	1.31	0.18	0.17		
	24	2.03	2.58	1.98	0.33	0.25		
	25	2.51	1.05	0.95	0,16	0.15		
	26	1.35	2.49	1.49	0.21	0.13		
	27	2.51	1.96	1.66	0.31	0.26	1.32	1.09
Back, Upper Section								
	28	4.50	-	-				
Back, Lower Section								
	29	4.50	-	-				
	30	4.41	-	-				

	28	4.50	-	-				
			Back, Lower Section					
	29	4.50	-	-				
	30	4.41	-	-				
			Front, Upper Section					
Third	31	1.60	-	-				
	32	2.36	-	-				
	33	3.11	-	-				
			Front, Lower Section					
	34	2.28	2.19	1.39	0.31	0.20		
	35	1.78	5.57	2.37	0.62	0.26		
	36	1.60	8.12	7.42	0.81	0.74	1.74	1.20
			Sides, Lower Section					
	37	1.73	1.14	0.34	0.12	0.04		
	38	2.03	1.09	0.99	0.14	0.13		
	39	2.03	1.15	0.95	0.15	0.12		
	40	2.51	1.11	0.81	0.17	0.13		
	41	1.35	.32	1.22	0.11	0.10		
	42	2.51	1.72	1.02	0.27	0.16	0.96	0.68
			Back, Upper Section					
	43	4.50	-	-				
			Back, Lower Section					
	44	4.50	-	-				
	45	4.41	-	-				
			Front, Upper Section					
Fifth	46	1.60	-	-				
	47	2.36	-	-				
	48	3.11	-	-				
			Front, Lower Section					
	49	2.28	2.80	0.90	0.40	0.13		
	50	1.78	5.90	3.30	0.66	0.37		
	51	1.60	8.96	6.16	0.89	0.62	1.95	1.12
			Sides, Lower Section					
	52	1.73	1.05	0.55	0.11	0.06		
	53	2.03	1.06	0.66	0.13	0.08		
	54	2.03	1.24	0.74	0.16	0.09		

	38	2.03	1.09	0.99	[illegible]	0.15		
	39	2.03	1.15	0.95	0.15	0.12		
	40	2.51	1.11	0.81	0.17	0.13		
	41	1.35	1.32	1.22	0.11	0.10		
	42	2.51	1.72	1.02	0.27	0.16	0.96	0.68
			Back, Upper Section					
	43	4.50	-	-				
			Back, Lower Section					
	44	4.50	-	-				
	45	4.41	-	-				
			Front, Upper Section					
Fifth	46	1.60	-	-				
	47	2.36	-	-				
	48	3.11	-	-				
			Front, Lower Section					
	49	2.28	2.80	0.90	0.40	0.13		
	50	1.78	5.90	3.30	0.66	0.37		
	51	1.60	8.96	6.16	0.89	0.62	1.95	1.12
			Sides, Lower Section					
	52	1.73	1.05	0.55	0.11	0.06		
	53	2.03	1.06	0.66	0.13	0.08		
	54	2.03	1.24	0.74	0.16	0.09		
	55	2.51	0.28	-1.92	0.04	-0.30		
	56	1.35	1.64	1.34	0.14	0.11		
	57	2.51	2.68	1.28	0.42	0.20	1.00	0.24
			Back, Upper Section					
	58	4.50	-	-				
			Back, Lower Section					
	59	4.50	-	-				
	60	4.41	-	-				

* Surface area affected by pressure at piezometer.

\- Piezometer exposed to air.

NOTES: 1. Baffle locations shown on plate A8.

2. Piezometer locations shown on plate A13.

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TABLE A5

AD-A134 635 LIBBY REREGULATING DAM KOOTENAI RIVER MONTANA HYDRAULIC MODEL INVESTIGATION(U) ARMY ENGINEER DIV NORTH PACIFIC BONNEVILLE OR DIV HYDRAULIC LAB JUL 83 TR-160-1 3/3

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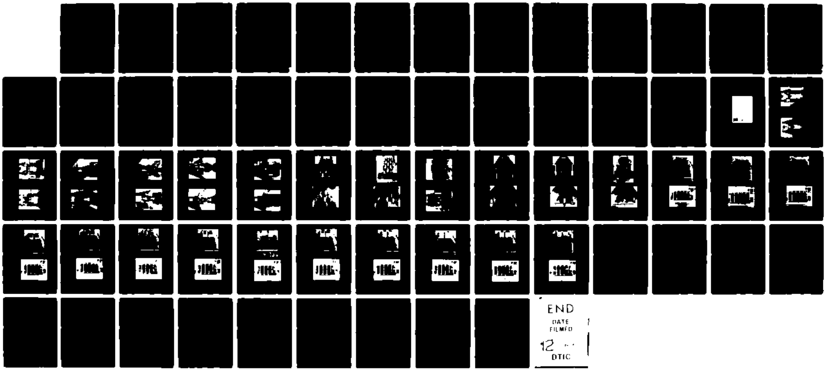

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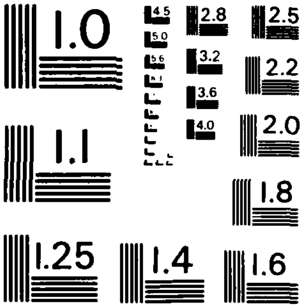

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TABLE A6

PRESSURE AND HYDRAULIC LOADS ON BAFFLES

Plan C Spillway

Pool Elev 2130, Discharge Per Bay 3,000 cfs

Baffle Row	Piezometer No.	Area Sq Ft	Pressure Ft of Water		Hydraulic Load (Kips)		Total Hydraulic Load (Kips)	
			High	Low	High	Low	High	Low
			Front, Upper Section					
First	16	1.60	-	-				
	17	2.36	-	-				
	18	3.11	-	-				
			Front, Lower Section					
	19	2.28	4.07	2.77	0.58	0.39		
	20	1.78	5.45	4.35	0.61	0.48		
	21	1.60	8.06	7.16	0.80	0.71	1.99	1.58
			Sides, Lower Section					
	22	1.73	3.30	2.70	0.36	0.29		
	23	2.03	3.01	2.41	0.38	0.31		
	24	2.03	4.88	4.08	0.62	0.52		
	25	2.51	1.85	0.75	0.29	0.12		
	26	1.35	3.19	2.69	0.27	0.23		
	27	2.51	4.66	2.96	0.73	0.46	2.65	1.93
			Back, Upper Section					
	28	4.50	-	-				
			Back, Lower Section					
	29	4.50	-	-				

			Back, Upper Section					
	28	4.50	-	-				
			Back, Lower Section					
	29	4.50	-	-				
	30	4.41	-	-				
			Front, Upper Section					
Third	31	1.60	2.80	1.50	0.28	0.15		
	32	2.36	1.12	0.92	0.16	0.14		
	33	3.11	2.40	1.20	0.47	0.23	0.91	0.52
			Front, Lower Section					
	34	2.28	8.89	6.09	1.26	0.87		
	35	1.78	8.37	5.37	0.93	0.60		
	36	1.60	11.92	11.12	1.19	1.11	3.38	2.58
			Sides, Lower Section					
	37	1.73	3.14	1.14	0.34	0.12		
	38	2.03	2.69	1.69	0.34	0.21		
	39	2.03	3.45	2.15	0.44	0.27		
	40	2.51	1.61	-0.19	0.25	-0.03		
	41	1.35	2.82	1.72	0.24	0.14		
	42	2.51	2.82	1.42	0.44	0.22	2.05	0.93
			Back, Upper Section					
	43	4.50	-	-				
			Back, Lower Section					
	44	4.50	-	-				
	45	4.41	-	-				
			Front, Upper Section					
Fifth	46	1.60	1.41	0.81	0.14	0.08		
	47	2.36	-	-	-	-		
	48	3.11	2.84	1.34	0.55	0.26	0.69	0.34
			Front, Lower Section					
	49	2.28	7.70	5.40	1.10	0.77		
	50	1.78	8.90	7.50	0.99	0.83		
	51	1.60	13.96	12.06	1.39	1.20	3.48	2.80
			Sides, Lower Section					
	52	1.73	2.75	1.05	0.30	0.11		
	53	2.03	2.36	1.56	0.30	0.20		
	54	2.03	3.44	2.44	0.44	0.31		

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	39	2.03	3.45	2.15	[illegible]	0.27		
	40	2.51	1.61	-0.19	0.25	-0.03		
	41	1.35	2.82	1.72	0.24	0.14		
	42	2.51	2.82	1.42	0.44	0.22	2.05	0.93
			Back, Upper Section					
	43	4.50	-	-				
			Back, Lower Section					
	44	4.50	-	-				
	45	4.41	-	-				
			Front, Upper Section					
Fifth	46	1.60	1.41	0.81	0.14	0.08		
	47	2.36	-	-	-	-		
	48	3.11	2.84	1.34	0.55	0.26	0.69	0.34
			Front, Lower Section					
	49	2.28	7.70	5.40	1.10	0.77		
	50	1.78	8.90	7.50	0.99	0.83		
	51	1.60	13.96	12.06	1.39	1.20	3.48	2.80
			Sides, Lower Section					
	52	1.73	2.75	1.05	0.30	0.11		
	53	2.03	2.36	1.56	0.30	0.20		
	54	2.03	3.44	2.44	0.44	0.31		
	55	2.51	1.08	-0.02	0.17	-0.00		
	56	1.35	4.04	2.44	0.34	0.21		
	57	2.51	3.98	2.58	0.62	0.40	2.17	1.23
			Back, Upper Section					
	58	4.50	-	-				
			Back, Lower Section					
	59	4.50	-	-				
	60	4.41	-	-				

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* Surface area affected by pressure at piezometer.

\- Piezometer exposed to air.

NOTES: 1. Baffle locations shown on plate A8.

2. Piezometer locations shown on plate A13.

TABLE A6

TABLE A7

PRESSURE AND HYDRAULIC LOADS ON BAFFLES

Plan C Spillway

Pool Elev 2130, Discharge Per Bay 5,000 cfs

Baffle Row	Piezometer No.	Area* Sq Ft	Pressure Ft of Water		Hydraulic Load (Kips)		Total Hydraulic Load (Kips)	
			High	Low	High	Low	High	Low
			Front, Upper Section					
First	16	1.60	2.13	1.23	0.21	0.12		
	17	2.36	1.25	0.95	0.18	0.14		
	18	3.11	3.53	2.63	0.69	0.51	1.08	0.77
			Front, Lower Section					
	19	2.28	8.47	6.57	1.21	0.93		
	20	1.78	9.35	7.65	1.04	0.85		
	21	1.60	11.96	9.76	1.19	0.97	3.44	2.75
			Sides, Lower Section					
	22	1.73	5.30	4.30	0.57	0.46		
	23	2.03	4.61	3.71	0.58	0.47		
	24	2.03	6.98	5.58	0.88	0.71		
	25	2.51	4.75	2.05	0.74	0.32		
	26	1.35	4.89	3.99	0.41	0.34		
	27	2.51	7.06	4.96	1.11	0.78	4.29	3.08
			Back, Upper Section					
	28	4.50	-	-	-	-		
			Back, Lower Section					
	29	4.50	-	-	-	-		
	30	4.41	-	-	-	-		

	26	1.35	4.89	3.99	[illegible].41	0.34	
	27	2.51	7.06	4.96	1.11	0.78	4.29	3.08
	Back, Upper Section							
	28	4.50	-	-	-	-		
	Back, Lower Section							
	29	4.50	-	-	-	-		
	30	4.41	-	-	-	-		
	Front, Upper Section							
Third	31	1.60	3.80	2.30	0.38	0.23		
	32	2.36	3.02	1.92	0.44	0.28		
	33	3.11	4.65	3.25	0.90	0.63	1.72	1.14
	Front, Lower Section							
	34	2.28	10.89	9.10	1.55	1.29		
	35	1.78	12.17	7.97	1.35	0.89		
	36	1.60	16.12	14.92	1.61	1.49	4.51	3.67
	Sides, Lower Section							
	37	1.73	4.14	1.34	0.45	0.14		
	38	2.03	3.19	2.59	0.40	0.33		
	39	2.03	4.65	3.45	0.59	0.44		
	40	2.51	2.01	0.60	0.31	0.90		
	41	1.35	3.72	2.32	0.31	0.20		
	42	2.51	4.02	2.32	0.63	0.36	2.69	2.37
	Back, Upper Section							
	43	4.50	-	-	-	-		
	Back, Lower Section							
	44	4.50	-	-	-	-		
	45	4.41	-	-	-	-		
	Front, Upper Section							
Fifth	46	1.60	3.61	2.21	0.36	0.22		
	47	2.36	1.83	1.13	0.27	0.17		
	48	3.11	7.54	5.14	1.46	1.00	2.09	1.39
	Front, Lower Section							
	49	2.28	11.70	10.20	1.66	1.45		
	50	1.78	12.80	11.40	1.42	1.27		
	51	1.60	17.86	15.66	1.78	1.56	4.86	4.28
	Sides, Lower Section							

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	39	2.03	4.65	3.45	0.59	0.44		
	40	2.51	2.01	0.60	0.31	0.90		
	41	1.35	3.72	2.32	0.31	0.20		
	42	2.51	4.02	2.32	0.63	0.36	2.69	2.37
			Back, Upper Section					
	43	4.50	-	-	-	-		
			Back, Lower Section					
	44	4.50	-	-	-	-		
	45	4.41	-	-	-	-		
			Front, Upper Section					
Fifth	46	1.60	3.61	2.21	0.36	0.22		
	47	2.36	1.83	1.13	0.27	0.17		
	48	3.11	7.54	5.14	1.46	1.00	2.09	1.39
			Front, Lower Section					
	49	2.28	11.70	10.20	1.66	1.45		
	50	1.78	12.80	11.40	1.42	1.27		
	51	1.60	17.86	15.66	1.78	1.56	4.86	4.28
			Sides, Lower Section					
	52	1.73	3.85	1.85	0.42	0.20		
	53	2.03	3.36	2.46	0.43	0.31		
	54	2.03	4.84	4.04	0.61	0.51		
	55	2.51	2.08	0.58	0.33	0.09		
	56	1.35	5.54	4.04	0.47	0.34		
	57	2.51	6.68	5.68	1.05	0.89	3.31	2.34
			Back, Upper Section					
	58	4.50	-	-	-	-		
			Back, Lower Section					
	59	4.50	-	-	-	-		
	60	4.41	-	-	-	-		

* Surface area affected by pressure at piezometer.

\- Piezometer exposed to air.

NOTES: 1. Baffle locations shown on plate A8.

2. Piezometer locations shown on plate A13.

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TABLE A7

TABLE A8

PRESSURE AND HYDRAULIC LOADS ON BAFFLES

Plan C Spillway

Pool Elev 2130, Discharge Per Bay 8,400 cfs

Baffle Row	Piezometer No.	Area* Sq Ft	Pressure Ft of Water		Hydraulic Load (Kips)		Total Hydraulic Load (Kips)	
			High	Low	High	Low	High	Low
	Front, Upper Section							
First	16	1.60	9.23	7.23	0.92	0.72		
	17	2.36	7.75	5.65	1.14	0.83		
	18	3.11	11.46	8.43	2.22	1.64	4.28	3.19
	Front, Lower Section							
	19	2.28	14.17	10.97	2.02	1.56		
	20	1.78	13.65	11.45	1.52	1.27		
	21	1.60	14.76	12.66	1.47	1.26	5.01	4.09
	Sides, Lower Section							
	22	1.73	8.50	7.70	0.92	0.83		
	23	2.03	6.81	5.91	0.86	0.75		
	24	2.03	10.28	8.98	1.30	1.14		
	25	2.51	6.45	4.45	1.01	0.70		
	26	1.35	6.69	5.79	0.56	0.49		
	27	2.51	10.06	7.76	1.58	1.22	6.23	5.13
	Back, Upper Section							
	28	4.50	-	-	-	-		
	Back, Lower Section							
	29	4.50	-	-	-			

		Back, Upper Section						
	28	4.50	-	-	-	-		
		Back, Lower Section						
	29	4.50	-	-	-	-		
	30	4.41	-	-	-	-		
		Front, Upper Section						
Third	31	1.60	8.00	5.70	0.80	0.57		
	32	2.36	4.82	3.82	0.71	0.56		
	33	3.11	8.25	5.85	1.60	1.14	3.11	2.27
		Front, Lower Section						
	34	2.28	16.49	14.09	2.35	2.00		
	35	1.78	17.17	14.17	1.91	1.57		
	36	1.60	20.92	19.42	2.09	1.94	6.35	5.51
		Sides, Lower Section						
	37	1.73	7.34	5.14	0.79	0.55		
	38	2.03	5.59	5.09	0.71	0.64		
	39	2.03	8.65	7.65	1.10	0.97		
	40	2.51	4.61	3.20	0.72	0.19		
	41	1.35	6.62	4.72	0.56	0.40		
	42	2.51	8.72	5.02	1.37	0.79	5.25	3.54
		Back, Upper Section						
	43	4.50	-	-	-	-		
		Back, Lower Section						
	44	4.50	-	-	-	-		
	45	4.41	-	-	-	-		
		Front, Upper Section						
Fifth	46	1.60	10.51	8.61	1.05	0.86		
	47	2.36	6.93	5.93	1.02	0.87		
	48	3.11	11.54	9.84	2.24	1.91	4.31	3.64
		Front, Lower Section						
	49	2.28	16.50	14.60	2.35	2.08		
	50	1.78	17.00	15.60	1.89	1.73		
	51	1.60	22.06	19.56	2.20	1.95	6.44	5.76
		Sides, Lower Section						
	52	1.73	8.15	4.75	0.88	0.51		

	40 41 42	2.51 1.35 2.51	4.61 6.62 8.72	3.20 4.72 5.02	[illegible].72 0.56 1.37	0.19 0.40 0.79	5.25	3.54
			Back, Upper Section					
	43	4.50	-	-	-	-		
			Back, Lower Section					
	44 45	4.50 4.41	- -	- -	- -	- -		
			Front, Upper Section					
Fifth	46 47 48	1.60 2.36 3.11	10.51 6.93 11.54	8.61 5.93 9.84	1.05 1.02 2.24	0.86 0.87 1.91	4.31	3.64
			Front, Lower Section					
	49 50 51	2.28 1.78 1.60	16.50 17.00 22.06	14.60 15.60 19.56	2.35 1.89 2.20	2.08 1.73 1.95	6.44	5.76
			Sides, Lower Section					
	52 53 54 55 56 57	1.73 2.03 2.03 2.51 1.35 2.51	8.15 6.06 9.24 5.18 7.44 10.98	4.75 5.16 8.04 3.68 6.44 7.68	0.88 0.77 1.17 0.81 0.63 1.72	0.51 0.65 1.02 0.58 0.54 1.20	5.98	4.50
			Back, Upper Section					
	58	4.50	-	-	-	-		
			Back, Lower Section					
	59 60	4.50 4.41	- -	- -	- -	- -		

* surface area affected by pressure at piezometer.

- Piezometer exposed to air.

NOTES: 1. Baffle locations shown on plate A8.

2. Piezometer locations shown on plate A13.

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TABLE A8

TABLE A9

PRESSURE AND HYDRAULIC LOADS ON BAFFLES

Plan C Spillway

Pool Elev 2130, Discharge Per Bay 10,000 cfs

Baffle Row	Piezometer No.	Area* Sq Ft	Pressures Ft of Water		Hydraulic Load (Kips)		Total Hydraulic Load (Kips)	
			High	Low	High	Low	High	Low
	Front, Upper Section							
First	16	1.60	11.03	9.13	1.10	0.91		
	17	2.36	11.45	8.05	1.69	1.19		
	18	3.11	13.88	10.86	2.69	0.52	5.48	2.62
	Front, Lower Section							
	19	2.28	15.67	12.67	2.23	1.80		
	20	1.78	14.85	12.25	1.65	1.36		
	21	1.60	16.36	12.76	1.63	1.27	5.51	4.43
	Sides, Lower Section							
	22	1.73	9.60	8.10	1.04	0.87		
	23	2.03	7.81	6.51	0.99	0.82		
	24	2.03	11.48	9.48	1.80	1.48		
	25	2.51	6.95	4.35	0.88	0.55		
	26	1.35	7.79	6.29	0.66	0.53		
	27	2.51	11.36	7.86	1.78	1.23	7.15	5.48
	Back, Upper Section							
	28	4.50	-	-	-	-		
	Back, Lower Section							

	27	2.51	11.36	7.86	.78	1.23	7.15	5.48
	Back, Upper Section							
	28	4.50	-	-	-	-		
	Back, Lower Section							
	29	4.50	-	-	-	-		
	30	4.41	-	-	-	-		
	Front, Upper Section							
Third	31	1.60	11.70	9.30	1.17	0.93		
	32	2.36	7.52	5.82	1.11	0.86		
	33	3.11	11.15	9.05	2.16	1.76	4.44	3.55
	Front, Lower Section							
	34	2.28	19.59	16.69	2.79	2.37		
	35	1.78	19.97	17.97	2.22	2.00		
	36	1.60	22.82	21.22	2.28	2.12	7.29	6.49
	Sides, Lower Section							
	37	1.73	9.34	5.84	1.01	0.63		
	38	2.03	6.79	5.89	0.86	0.75		
	39	2.03	10.25	9.25	1.30	1.17		
	40	2.51	6.21	4.90	0.97	0.78		
	41	1.35	8.12	6.32	0.68	0.53		
	42	2.51	10.62	7.02	1.66	1.10	6.48	4.96
	Back, Upper Section							
	43	4.50	-	-	-	-		
	Back, Lower Section							
	44	4.50	-	-	-	-		
	45	4.41	-	-	-	-		
	Front, Upper Section							
Fifth	46	1.60	12.21	10.61	1.22	1.06		
	47	2.36	9.43	8.43	1.39	1.24		
	48	3.11	13.24	12.14	2.5		5.18	4.66
	Front, Lower Section							
	49	2.28	18.70	16.50	2.66	2.35		
	50	1.78	19.60	17.80	2.18	1.98		
	51	1.60	24.16	21.56	2.41	2.15	7.25	6.48
	Sides, Lower Section							
	52	1.73	8.65	6.35	0.93	0.69		

	38	2.03	6.79	5.89	[illegible]	0.75		
	39	2.03	10.25	9.25	1.30	1.17		
	40	2.51	6.21	4.90	0.97	0.78		
	41	1.35	8.12	6.32	0.68	0.53		
	42	2.51	10.62	7.02	1.66	1.10	6.48	4.96
	Back, Upper Section							
	43	4.50	-	-	-	-		
	Back, Lower Section							
	44	4.50	-	-	-	-		
	45	4.41	-	-	-	-		
	Front, Upper Section							
Fifth	46	1.60	12.21	10.61	1.22	1.06		
	47	2.36	9.43	8.43	1.39	1.24		
	48	3.11	13.24	12.14	2.57	2.36	5.18	4.66
	Front, Lower Section							
	49	2.28	18.70	16.50	2.66	2.35		
	50	1.78	19.60	17.80	2.18	1.98		
	51	1.60	24.16	21.56	2.41	2.15	7.25	6.48
	Sides, Lower Section							
	52	1.73	8.65	6.35	0.93	0.69		
	53	2.03	6.86	6.36	0.87	0.81		
	54	2.03	10.44	9.74	1.32	1.23		
	55	2.51	6.88	5.18	1.08	0.81		
	56	1.35	8.34	7.54	0.70	0.64		
	57	2.51	12.68	10.48	1.99	1.64	6.89	5.82
	Back, Upper Section							
	58	4.50	-	-	-	-		
	Back, Lower Section							
	59	4.50	-	-	-	-		
	60	4.41	-	-	-	-		

* Surface area affected bv pressure at piezometer.

\- Piezometer exposed to air.

NOTES: 1. Baffle locations shown on plate A8.

2. Piezometer locations shown on plate A13.

TABLE A9

TABLE A10

PRESSURE AND HYDRAULIC LOADS ON BAFFLES

Plan C Spillway

Pool Elev 2130, Discharge Per Bay 15,000 cfs

Baffle Row	Piezometer No.	Area* Sq Ft	Pressure Ft of Water		Hydraulic Load (Kips)		Total Hydraulic Load (Kips)	
			High	Low	High	Low	High	Low
	Front, Upper Section							
First	16	1.60	15.13	12.73	1.51	1.27		
	17	2.36	14.55	12.25	2.14	1.80		
	18	3.11	15.52	13.00	3.01	2.52	6.66	5.59
	Front, Lower Section							
	19	2.28	19.97	16.37	2.84	2.33		
	20	1.78	16.45	12.95	1.83	1.44		
	21	1.60	18.26	12.96	1.82	1.29	6.49	5.06
	Sides, Lower Section							
	22	1.73	11.80	9.80	1.27	1.06		
	23	2.03	9.91	8.31	1.26	1.05		
	24	2.03	13.08	11.48	1.66	1.45		
	25	2.51	9.25	5.65	1.45	0.88		
	26	1.35	10.39	8.69	0.88	0.73		
	27	2.51	12.76	8.86	2.00	1.39	8.52	6.56
	Back, Upper Section							
	28	4.50	-1.48	-4.19	-0.42	-1.18	-0.42	-1.18
	Back, Lower Section							
	29	4.50	2.91	0.61	0.82	0.17		

	Back, Upper Section							
	28	4.50	-1.48	-4.19	-0.42	-1.18	-0.42	-1.18
	Back, Lower Section							
	29	4.50	2.91	0.61	0.82	0.17		
	30	4.41	2.99	1.09	0.82	0.30	1.64	0.47
	Front, Upper Section							
Third	31	1.60	14.80	14.10	1.48	1.41		
	32	2.36	12.20	14.72	1.80	2.17		
	33	3.11	15.85	13.95	3.08	2.71	6.36	6.29
	Front, Lower Section							
	34	2.28	23.09	19.09	3.29	2.72		
	35	1.78	22.07	19.57	2.45	2.17		
	36	1.60	24.12	22.62	2.41	2.26	8.15	7.15
	Sides, Lower Section							
	37	1.73	12.84	10.04	1.39	1.08		
	38	2.03	8.59	7.89	1.09	1.00		
	39	2.03	12.95	11.95	1.64	1.51		
	40	2.51	9.41	6.11	1.47	0.96		
	41	1.35	9.52	8.02	0.80	0.68		
	42	2.51	14.72	11.62	2.31	1.82	8.70	7.05
	Back, Upper Section							
	43	4.50	-0.89	-0.97	-0.25	-0.27	-0.25	-0.27
	Back, Lower Section							
	44	4.50	-0.04	-0.24	-0.01	-0.07		
	45	4.41	-0.06	-0.36	-0.02	-0.10	-0.03	-0.17
	Front, Upper Section							
Fifth	46	1.60	16.41	14.41	1.64	1.44		
	47	2.36	13.43	12.53	1.98	1.85		
	48	3.11	16.84	14.94	3.27	2.90	6.89	6.19
	Front, Lower Section							
	49	2.28	22.90	20.30	3.26	2.89		
	50	1.78	22.70	21.30	2.52	2.37		
	51	1.60	27.76	22.70	2.77	2.27	8.55	7.53
	Sides, Lower Section							
	52	1.73	12.85	10.45	1.39	1.13		
	[illegible]	2.03	9.26	8.36	1.17	1.06		

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	38	2.03	8.59	7.89	[illegible]	1.00		
	39	2.03	12.95	11.95	1.64	1.51		
	40	2.51	9.41	6.11	1.47	0.96		
	41	1.35	9.52	8.02	0.80	0.68		
	42	2.51	14.72	11.62	2.31	1.82	8.70	7.05
	Back, Upper Section							
	43	4.50	-0.89	-0.97	-0.25	-0.27	-0.25	-0.27
	Back, Lower Section							
	44	4.50	-0.04	-0.24	-0.01	-0.07		
	45	4.41	-0.06	-0.36	-0.02	-0.10	-0.03	-0.17
	Front, Upper Section							
Fifth	46	1.60	16.41	14.41	1.64	1.44		
	47	2.36	13.43	12.53	1.98	1.85		
	48	3.11	16.84	14.94	3.27	2.90	6.89	6.19
	Front, Lower Section							
	49	2.28	22.90	20.30	3.26	2.89		
	50	1.78	22.70	21.30	2.52	2.37		
	51	1.60	27.76	22.70	2.77	2.27	8.55	7.53
	Sides, Lower Section							
	52	1.73	12.85	10.45	1.39	1.13		
	53	2.03	9.26	8.36	1.17	1.06		
	54	2.03	12.34	11.74	1.56	1.49		
	55	2.51	8.08	5.78	1.27	0.91		
	56	1.35	9.54	8.64	0.80	0.73		
	57	2.51	14.38	11.68	2.25	1.83	8.44	7.15
	Back, Upper Section							
	58	4.50	-0.59	-1.39	-0.17	-0.39	-0.17	-0.39
	Back, Lower Section							
	59	4.50	-0.37	-0.33	-0.10	-0.09		
	60	4.41	-0.77	-0.33	-0.21	-0.09	-0.31	-0.18

* Surface area affected by pressure at piezometer.

NOTES: 1. Baffle locations shown on plate A8.

2. Piezometer locations shown on plate A13.

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TABLE A10

TABLE A11

PRESSURE AND HYDRAULIC LOADS ON BAFFLES

Plan C Spillway

Pool Elev 2130, Discharge Per Bay 20,000 cfs

Baffle Row	Piezometer No.	Area* Sq Ft	Pressure Ft of Water		Hydraulic Load (Kips)		Total Hydraulic Load (Kips)	
			High	Low	High	Low	High	Low
	Front, Upper Section							
First	16	1.60	18.63	15.53	1.86	1.55		
	17	2.36	18.05	15.95	2.66	2.35		
	18	3.11	17.85	15.08	3.46	2.93	7.98	6.83
	Front, Lower Section							
	19	2.28	22.37	17.27	3.18	2.46		
	20	1.78	19.35	15.05	2.15	1.67		
	21	1.60	18.06	13.46	1.80	1.34	7.13	5.47
	Sides, Lower Section							
	22	1.73	13.20	11.20	1.42	1.21		
	23	2.03	12.01	10.21	1.52	1.29		
	24	2.03	15.28	12.78	1.94	1.62		
	25	2.51	10.55	7.45	1.65	1.17		
	26	1.35	12.39	10.89	1.04	0.92		
	27	2.51	14.96	11.06	2.34	1.73	9.91	7.94
	Back, Upper Section							
	28	4.50	-1.08	-3.18	-0.30	-0.89	-0.30	-0.89
	Back, Lower Section							
	29	4.50	4.11	1.91	1.15	0.54		

			Back, Upper Section					
	28	4.50	-1.08	-3.18	-0.30	-0.89	**-0.30**	-0.89
			Back, Lower Section					
	29	4.50	4.11	1.91	1.15	0.54		
	30	4.41	4.89	1.78	1.35	0.49	2.50	1.03
			Front, Upper Section					
Third	31	1.60	17.70	15.80	1.77	1.58		
	32	2.36	17.32	16.42	2.55	2.42		
	33	3.11	16.25	14.95	3.15	2.90	7.47	6.90
			Front, Lower Section					
	34	2.28	25.20	20.09	3.59	2.86		
	35	1.78	23.17	20.47	2.57	2.27		
	36	1.60	24.42	23.02	2.44	2.30	8.60	7.43
			Sides, Lower Section					
	37	1.73	14.14	11.34	1.53	1.22		
	38	2.03	10.39	9.29	1.32	1.18		
	39	2.03	14.65	13.55	1.86	1.72		
	40	2.51	11.11	8.11	1.74	1.27		
	41	1.35	10.82	9.62	0.91	0.81		
	42	2.51	17.02	13.82	2.67	2.16	10.03	8.36
			Back, Upper Section					
	43	4.50	-4.97	-7.27	-1.40	-2.04	-1.40	-2.04
			Back, Lower Section					
	44	4.50	0.96	-1.54	0.27	-0.43		
	45	4.41	2.14	-0.36	0.59	-0.10	0.86	-0.53
			Front, Upper Section					
Fifth	46	1.60	20.51	17.31	2.05	1.73		
	47	2.36	18.33	16.03	2.70	2.36		
	48	3.11	19.74	16.44	3.83	3.19	8.58	7.28
			Front, Lower Section					
	49	2.28	24.70	20.80	3.51	2.96		
	50	1.78	24.40	21.10	2.71	2.34		
	51	1.60	27.06	23.56	2.70	2.35	8.92	7.65
			Sides, Lower Section					
	52	1.73	15.05	11.75	1.62	1.27		
	53	2.03	10.96	9.76	1.39	1.24		
	54	2.03	15.44	14.24	1.96	1.80		

	38	2.03	10.39	9.29	[illegible]	1.18		
	39	2.03	14.65	13.55	1.86	1.72		
	40	2.51	11.11	8.11	1.74	1.27		
	41	1.35	10.82	9.62	0.91	0.81		
	42	2.51	17.02	13.82	2.67	2.16	10.03	8.36
	Back, Upper Section							
	43	4.50	-4.97	-7.27	-1.40	-2.04	-1.40	-2.04
	Back, Lower Section							
	44	4.50	0.96	-1.54	0.27	-0.43		
	45	4.41	2.14	-0.36	0.59	-0.10	0.86	-0.53
	Front, Upper Section							
Fifth	46	1.60	20.51	17.31	2.05	1.73		
	47	2.36	18.33	16.03	2.70	2.36		
	48	3.11	19.74	16.44	3.83	3.19	8.58	7.28
	Front, Lower Section							
	49	2.28	24.70	20.80	3.51	2.96		
	50	1.78	24.40	21.10	2.71	2.34		
	51	1.60	27.06	23.56	2.70	2.35	8.92	7.65
	Sides, Lower Section							
	52	1.73	15.05	11.75	1.62	1.27		
	53	2.03	10.96	9.76	1.39	1.24		
	54	2.03	15.44	14.24	1.96	1.80		
	55	2.51	9.48	6.98	1.48	1.09		
	56	1.35	11.54	9.64	0.97	0.81		
	57	2.51	16.38	12.58	2.57	1.97	9.99	8.18
	Back, Upper Section							
	58	4.50	-3.89	-6.49	-1.09	-1.82	-1.09	-1.82
	Back, Lower Section							
	59	4.50	0.97	-1.23	0.27	-0.35		
	60	4.41	1.87	-0.83	0.51	-0.23	0.78	-0.58

* Surface area affected by pressure at piezometer.

NOTES: 1. Baffle locations shown on plate A8.

2. Piezometer locations shown on plate A13.

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TABLE A12

PRESSURE AND HYDRAULIC LOADS ON BAFFLES

Plan C Spillway

Pool Elev 2130, Discharge Per Bav 30,000 cfs

Baffle Row	Piezometer No.	Area* Sq Ft	Pressure Ft of Water		Hydraulic Load (Kips)		Total Hydraulic Load (Kips)	
			High	Low	High	Low	High	Low
	Front, Upper Section							
First	16	1.60	21.93	21.33	2.19	2.13		
	17	2.36	20.55	19.75	3.03	2.91		
	18	3.11	20.06	18.80	3.89	3.65	9.11	8.69
	Front, Lower Section							
	19	2.28	27.57	25.07	3.92	3.57		
	20	1.78	23.75	21.75	2.64	2.42		
	21	1.60	23.96	20.46	2.39	2.04	8.95	8.03
	Sides, Lower Section							
	22	1.73	17.70	16.60	1.91	1.79		
	23	2.03	15.01	14.21	1.90	1.80		
	24	2.03	18.68	17.78	2.37	2.25		
	25	2.51	13.75	11.55	2.15	1.81		
	26	1.35	14.79	13.89	1.25	1.17		
	27	2.51	18.86	16.86	2.95	2.64	12.53	11.46
	Back, Upper Section							
	28	4.50	3.22	1.32	0.90	0.37	0.90	0.37
	Back, Lower Section							

			Back, Upper Section				
	28	4.50	3.22	1.32	0.90	0.37	0.90	0.37
			Back, Lower Section				
	29	4.50	5.81	4.71	1.63	1.32		
	30	4.41	6.39	5.19	1.76	1.43	3.39	2.75
			Front, Upper Section				
Third	31	1.60	23.90	22.00	2.39	2.20		
	32	2.36	22.02	20.92	3.24	3.08		
	33	3.11	20.55	18.65	3.99	3.62	9.62	8.90
			Front, Lower Section				
	34	2.28	29.49	25.09	4.20	3.57		
	35	1.78	27.97	25.07	3.11	2.78		
	36	1.60	29.12	27.72	2.91	2.77	10.22	9.12
			Sides, Lower Section				
	37	1.73	18.54	16.94	2.00	1.83		
	38	2.03	14.70	13.29	1.86	1.68		
	39	2.03	18.65	18.25	2.36	2.31		
	40	2.51	13.61	11.31	2.13	1.77		
	41	1.35	13.82	12.82	1.16	1.08		
	42	2.51	20.32	17.62	3.18	2.76	12.69	11.43
			Back, Upper Section				
	43	4.50	-2.47	-4.87	-0.69	-1.37	-0.69	-1.37
			Back, Lower Section				
	44	4.50	2.56	0.26	0.72	0.07		
	45	4.41	4.14	1.14	1.14	0.31	1.86	0.38
			Front, Upper Section				
Fifth	46	1.60	24.21	22.51	2.42	2.25		
	47	2.36	21.63	20.03	3.19	2.95		
	48	3.11	22.74	20.44	4.41	3.97	10.02	9.17
			Front, Lower Section				
	49	2.28	27.70	24.90	3.94	3.54		
	50	1.78	27.20	25.70	3.02	2.85		
	51	1.60	29.96	27.36	2.99	2.73	9.95	9.12
			Sides, Lower Section				
	52	1.73	18.85	17.25	2.03	1.86		

38	2.03	14.70	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	2.3[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]							
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] Section							
52	[illegible]	[illegible]	[illegible]	2.03	[illegible]		
53	[illegible]	[illegible]	[illegible]	1.90	[illegible]		
54	[illegible]	19.14	[illegible]	[illegible]	[illegible]		
55	[illegible]	[illegible]	12.08	[illegible]	1.89		
56	[illegible]	[illegible]	[illegible]	1.31	[illegible]		
57	1.51	20.28	17.28	3.18	[illegible]	[illegible]	12.06
Back, Upper Section							
58	4.50	-0.69	-2.89	0.19	0.81	0.19	0.81
Back, Lower Section							
59	4.50	5.77	3.47	1.62	0.97		
60	4.41	6.67	4.37	1.84	1.20	3.46	2.17

* Surface area affected by pressure at piezometer.

NOTES: 1. Baffle locations shown on plate A8.

2. Piezometer locations shown on plate A13.

TABLE A13

PRESSURE AND HYDRAULIC LOADS ON BAFFLES

Plan C Spillway

Pool Energy Grade Line Elev 2138.1, Discharge Per Bay 42,000 cfs

Baffle Row	Piezometer No.	Area* Sq Ft	Pressure Ft of Water		Hydraulic Load (Kips)		Total Hydraulic Load (Kips)	
			High	Low	High	Low	High	Low
			Front, Upper Section					
First	16	1.60	27.73	24.73	2.77	2.47		
	17	2.36	25.95	22.65	3.82	3.34		
	18	3.11	23.31	20.16	4.52	3.91	11.11	9.72
			Front, Lower Section					
	19	2.28	30.17	24.07	4.29	3.42		
	20	1.78	26.45	22.05	2.94	2.45		
	21	1.60	25.26	20.66	2.52	2.06	9.75	7.93
			Sides, Lower Section					
	22	1.73	19.30	17.90	2.08	1.93		
	23	2.03	17.91	17.41	2.27	2.21		
	24	2.03	21.38	19.48	2.71	2.47		
	25	2.51	17.65	14.25	2.76	2.23		
	26	1.35	19.89	17.39	1.68	1.46		
	27	2.51	22.76	18.86	3.56	2.95	15.06	13.25
			Back, Upper Section					
	28	4.50	6.52	3.32	1.83	0.93	1.83	0.93
			Back, Lower Section					
	29	4.50	10.51	[illegible]	[illegible]	[illegible]		

	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2.95	15.06	13.25
	Back, Upper Section							
	28	4.50	6.52	3.32	1.83	0.93	1.83	0.93
	Back, Lower Section							
	29	4.50	10.51	7.71	2.95	2.16		
	30	4.41	11.39	7.89	3.13	2.17	6.08	4.33
	Front, Upper Section							
Third	31	1.60	28.10	24.60	2.81	2.46		
	32	2.36	25.72	23.42	3.79	3.45		
	33	3.11	23.95	21.35	4.65	4.14	11.25	10.05
	Front, Lower Section							
	34	2.28	31.59	27.69	4.49	3.94		
	35	1.78	31.17	27.37	3.46	3.04		
	36	1.60	32.92	30.92	3.29	3.09	11.24	10.07
	Sides, Lower Section							
	37	1.73	24.14	22.04	2.61	2.38		
	38	2.03	19.39	18.49	2.46	2.34		
	39	2.03	23.95	23.05	3.03	2.92		
	40	2.51	18.21	13.31	2.85	2.08		
	41	1.35	18.72	17.42	1.58	1.47		
	42	2.51	24.12	19.02	3.78	2.98	16.31	14.17
	Back, Upper Section							
	43	4.50	3.43	1.53	0.96	0.43	0.96	0.43
	Back, Lower Section							
	44	4.50	9.16	6.26	2.57	1.76		
	45	4.41	10.64	6.64	2.93	1.83	5.50	3.59
	Front, Upper Section							
Fifth	46	1.60	29.61	27.21	2.96	2.72		
	47	2.36	27.13	24.43	4.00	3.60		
	48	3.11	25.63	23.13	4.97	4.49	11.93	10.81
	Front, Lower Section							
	49	2.28	32.80	29.50	4.67	4.20		
	50	1.78	32.00	29.30	3.55	3.25		
	51	1.60	34.76	31.76	3.47	3.17	11.69	10.62
	Sides, Lower Section							
	52	1.73	24.05	22.45	2.60	2.42		

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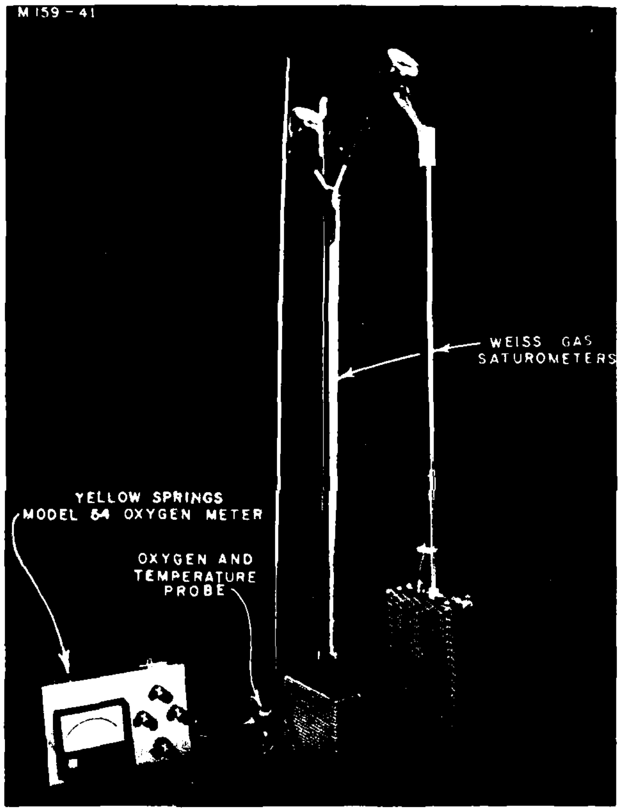
	39	2.03	23.95	23.05	[illegible]	2.92		
	40	2.51	18.21	13.31	2.85	2.08		
	41	1.35	18.72	17.42	1.58	1.47		
	42	2.51	24.12	19.02	3.78	2.98	16.31	14.17
			Back, Upper Section					
	43	4.50	3.43	1.53	0.96	0.43	0.96	0.43
			Back, Lower Section					
	44	4.50	9.16	6.26	2.57	1.76		
	45	4.41	10.64	6.64	2.93	1.83	5.50	3.59
			Front, Upper Section					
Fifth	46	1.60	29.61	27.21	2.96	2.72		
	47	2.36	27.13	24.43	4.00	3.60		
	48	3.11	25.63	23.13	4.97	4.49	11.93	10.81
			Front, Lower Section					
	49	2.28	32.80	29.50	4.67	4.20		
	50	1.78	32.00	29.30	3.55	3.25		
	51	1.60	34.76	31.76	3.47	3.17	11.69	10.62
			Sides, Lower Section					
	52	1.73	24.05	22.45	2.60	2.42		
	53	2.03	20.46	19.46	2.59	2.47		
	54	2.03	24.44	24.04	3.10	3.05		
	55	2.51	18.88	16.28	2.96	2.55		
	56	1.35	21.04	19.44	1.77	1.64		
	57	2.51	25.48	22.28	3.99	3.49	17.01	15.62
			Back, Upper Section					
	58	4.50	5.21	2.81	1.46	0.79	1.46	0.79
			Back, Lower Section					
	59	4.50	11.27	8.97	3.16	2.52		
	60	4.41	12.47	9.27	3.43	2.55	6.59	5.07

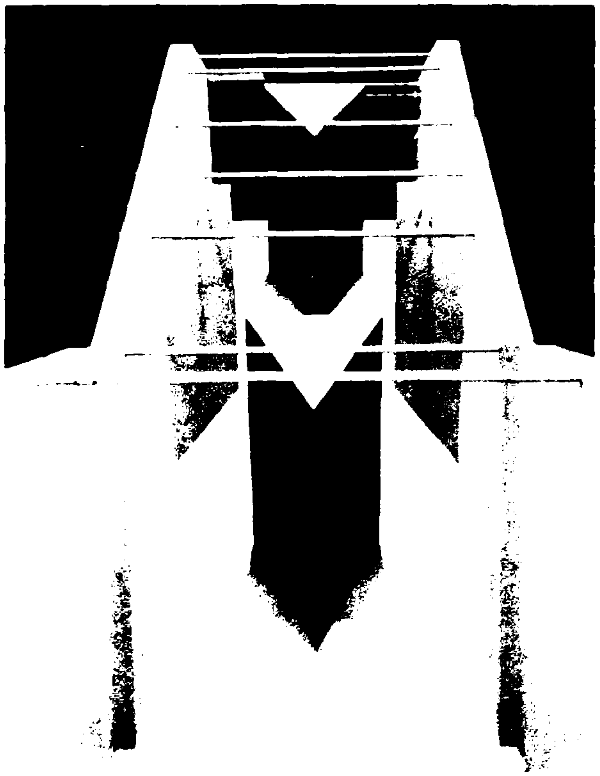
* Surface area affected by pressure at piezometer.

NOTES: 1. Baffle locations shown on plate A8.

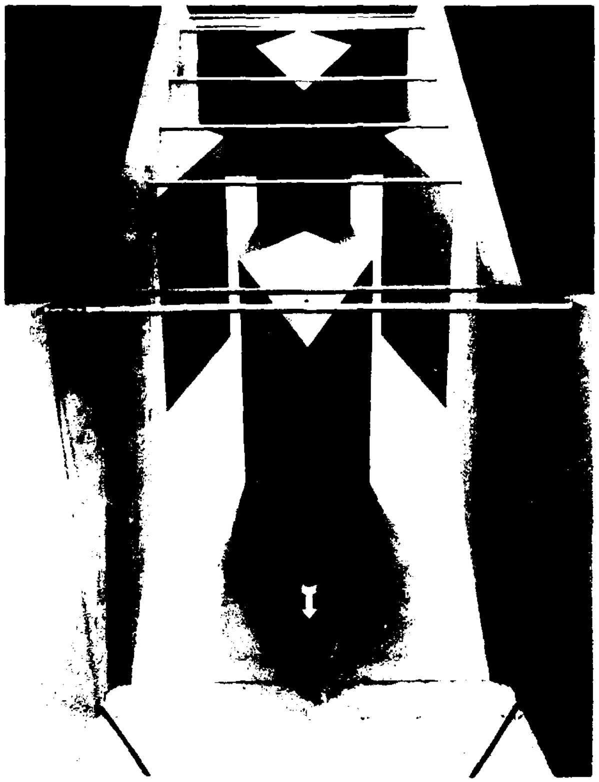
2. Piezometer locations shown on plate A13.



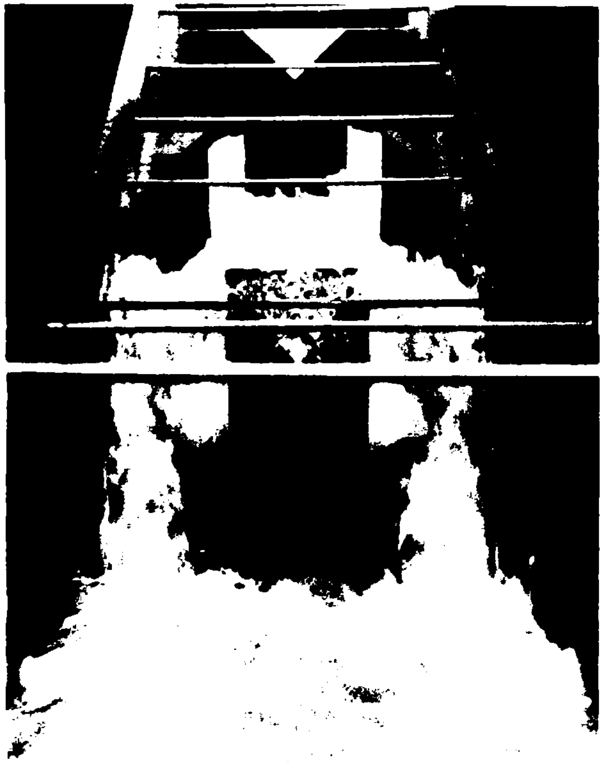
Photograph A1. Oxygen meter and gas saturometer



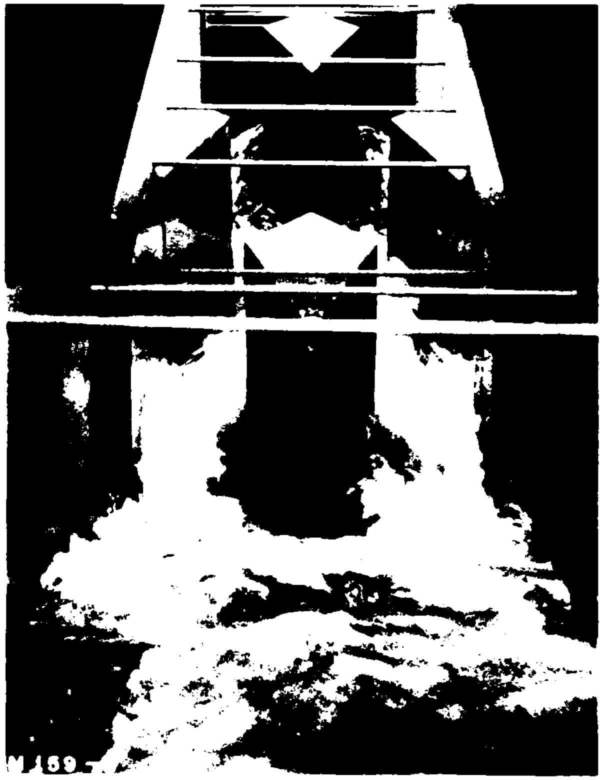
Photograph A2. Type A baffle



Photograph A3. Type B baffle

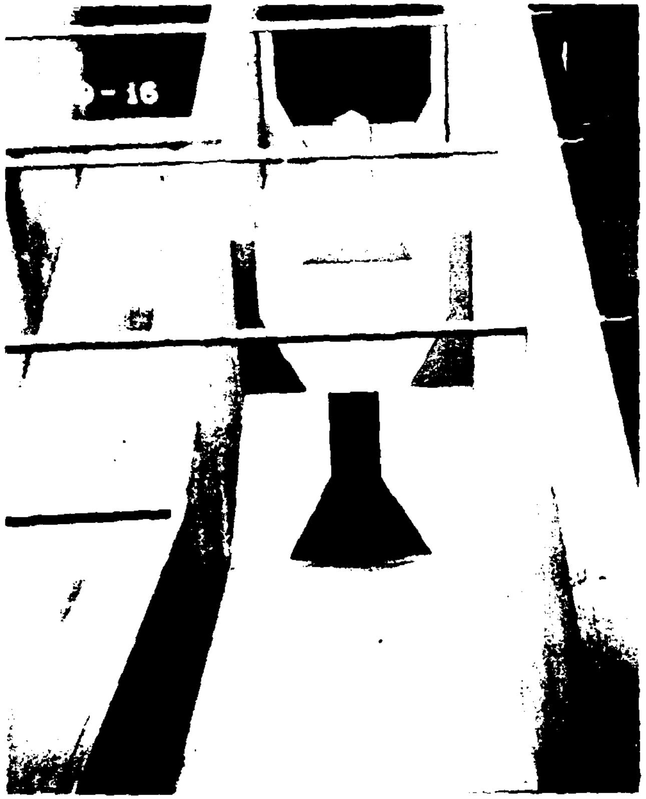


Photograph A4. Type A baffle

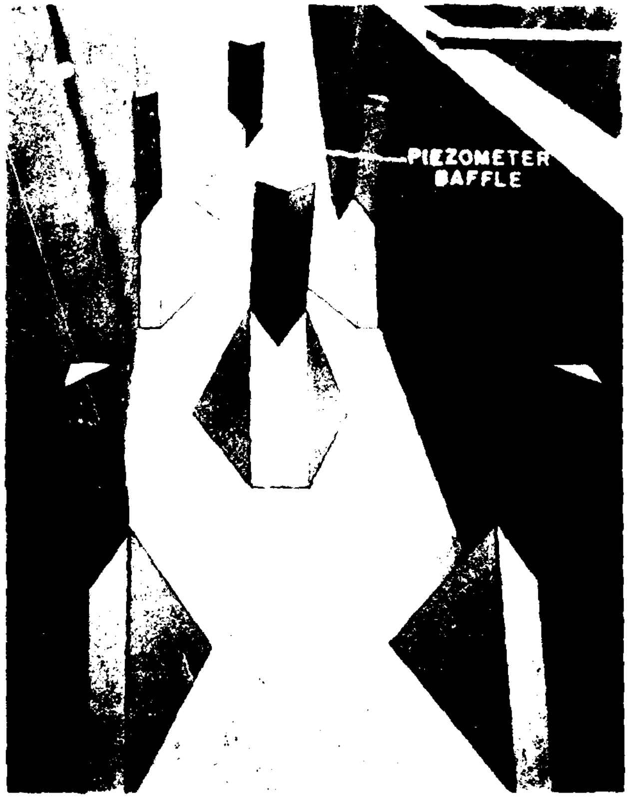


Photograph A5. Type B baffle

Flow condition around baffles; discharge 9 cfs

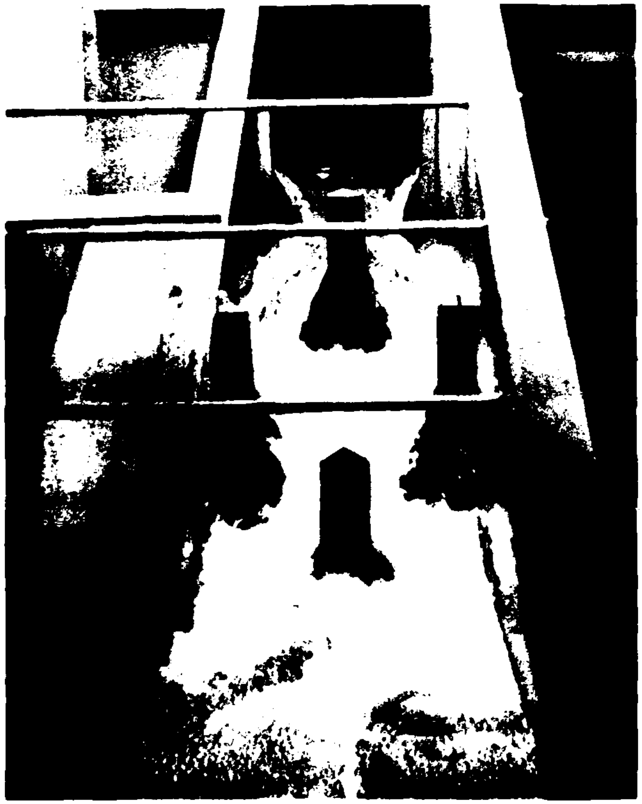


Photograph A6. Upstream view



Photograph A7. Downstream view

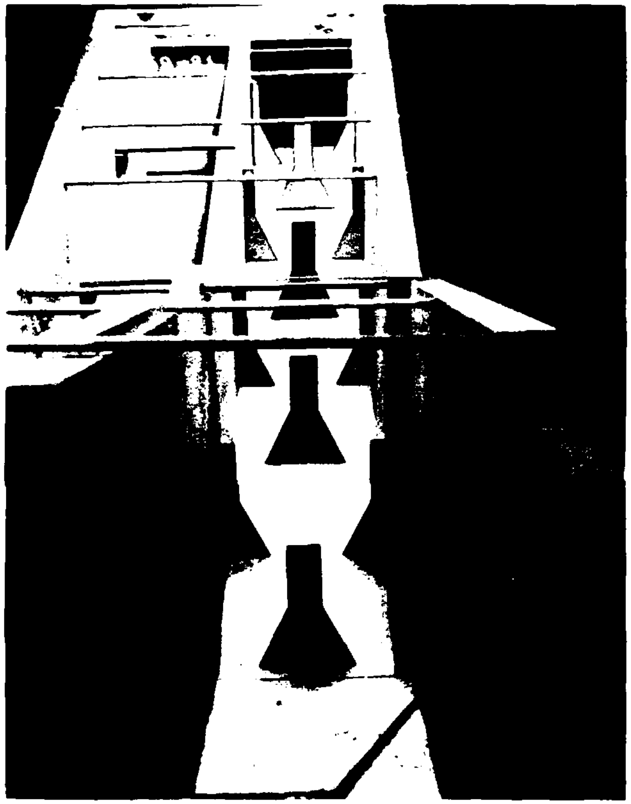
Type C baffle in Plan C-1 layout; dry bed



Photograph A8. Upstream view

Photograph A9. Downstream view

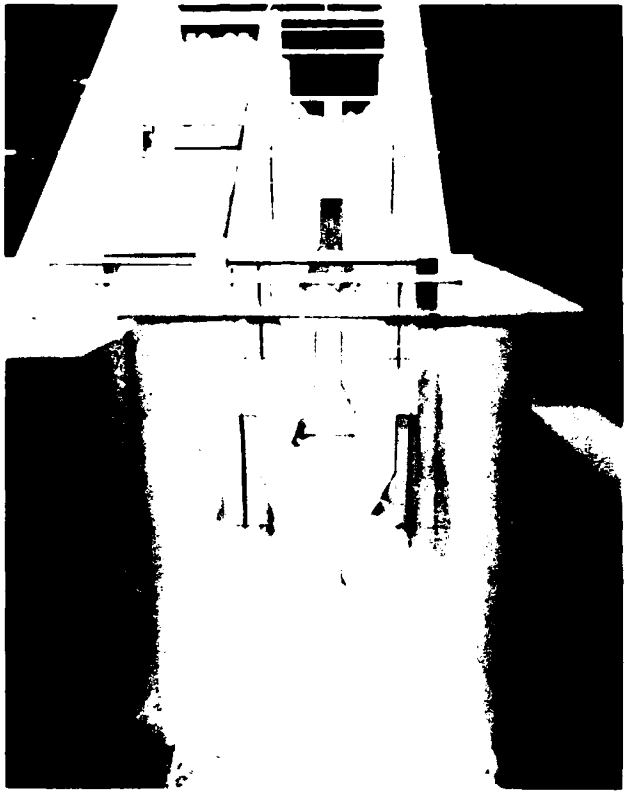
Type C baffle in Plan C-1 layout; discharge 1.9 cfs



Photograph A10. Upstream view

Photograph A11. Downstream view

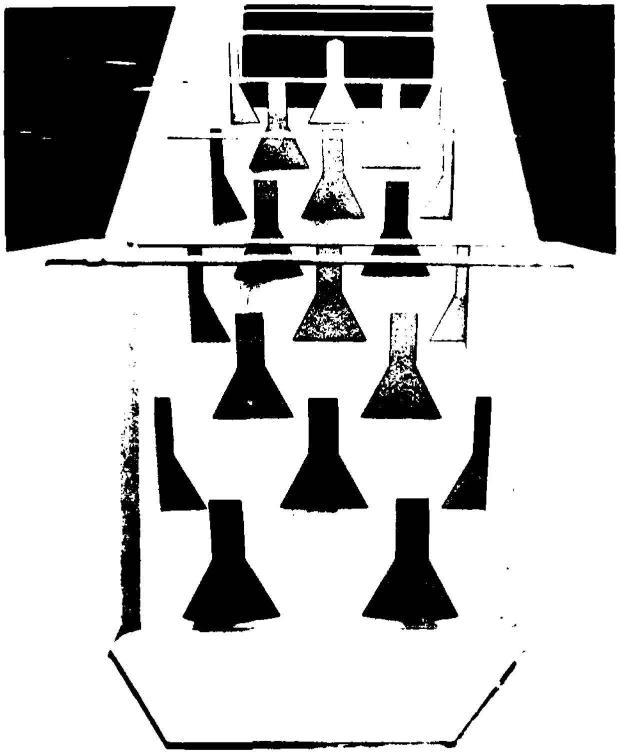
Type C baffle in Plan C-2 layout; dry bed



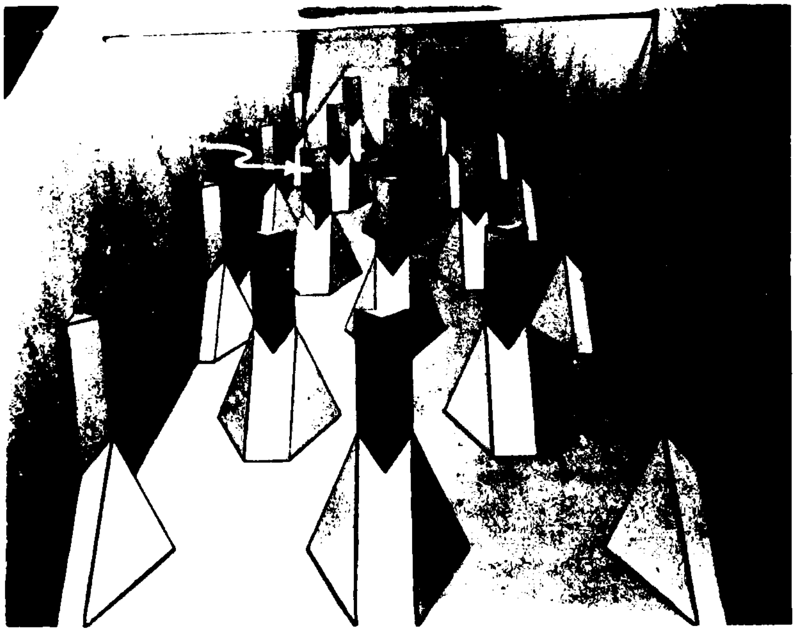
Photograph A12. Upstream view

Photograph A13. Downstream view

Type C baffle in Plan C-2 layout; discharge 1.9 cfs

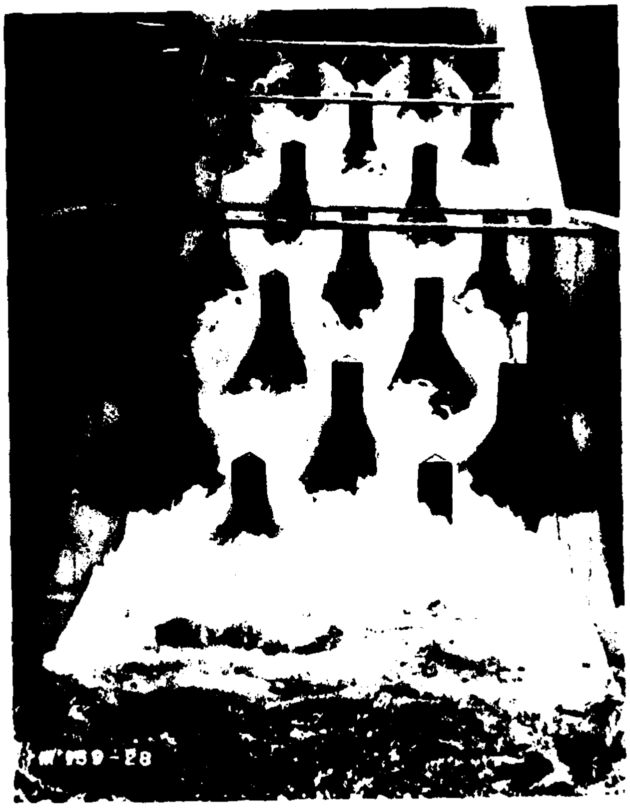


Photograph A14. Upstream view



Photograph A15. Downstream view

Type C baffle in Plan C-3 layout; dry bed

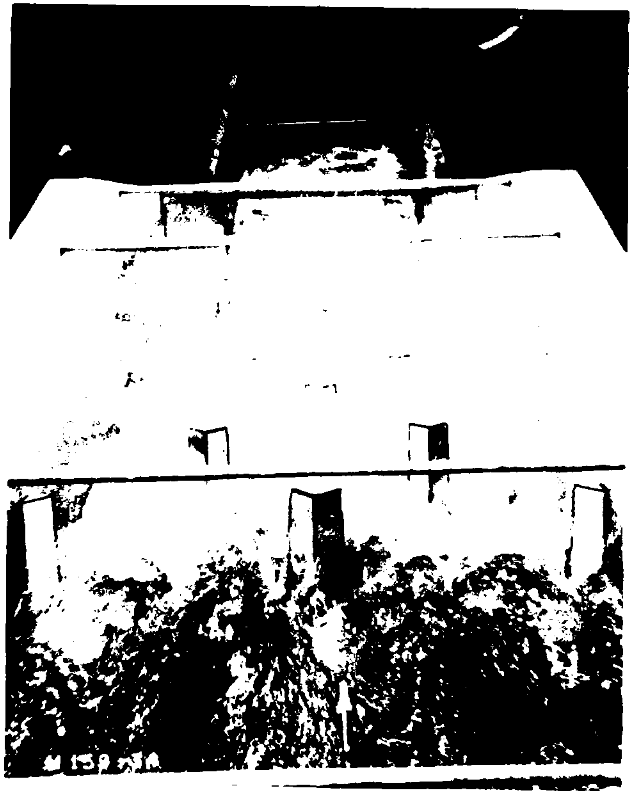


Photograph A16. Upstream view

Photograph A17. Downstream view

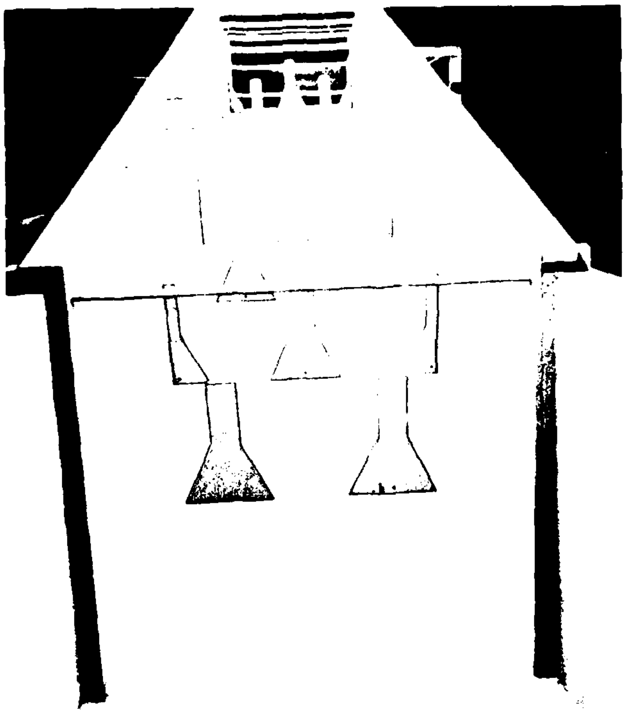
Type C baffle in Plan C-3 layout; discharge 3.9 cfs

Photograph A18. Upstream view

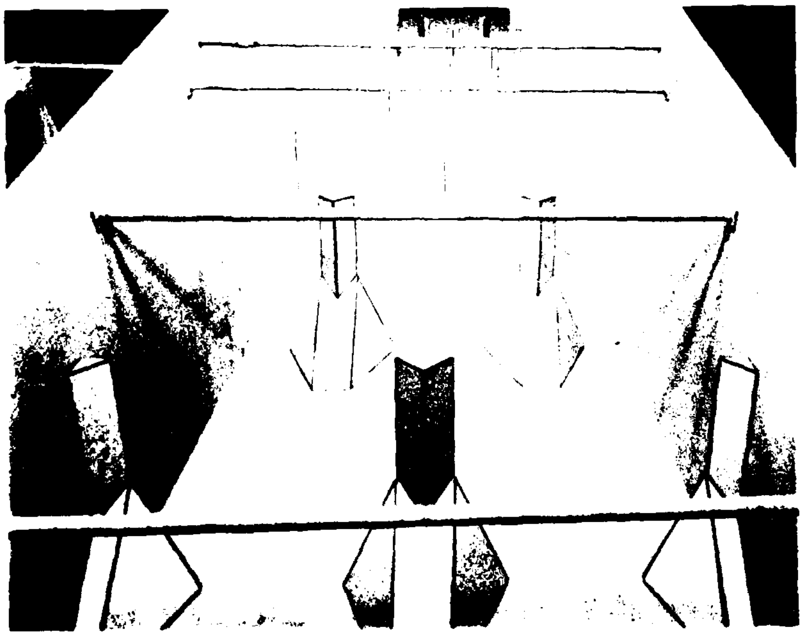


Photograph A19. Downstream view

Type C baffle in Plan C-3 layout; discharge 11.5 cfs

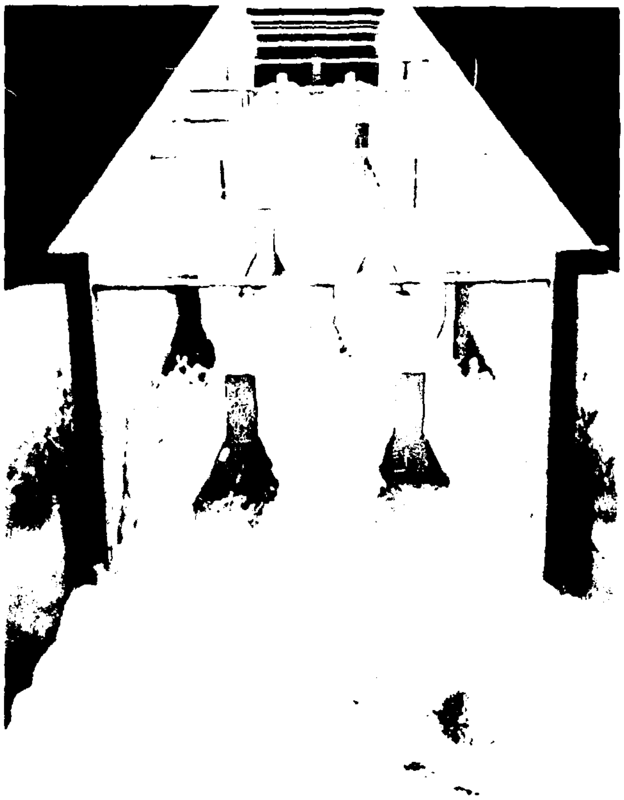


Photograph A20. Upstream view

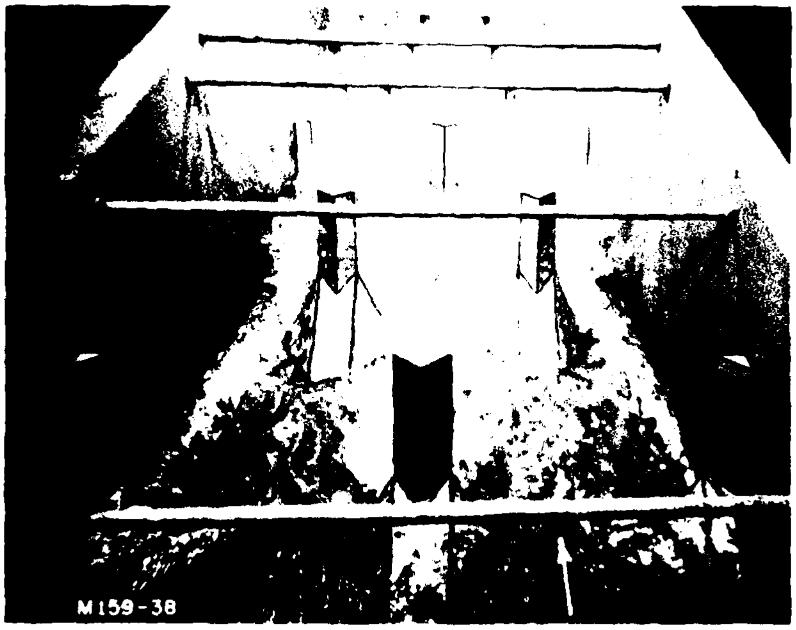


Photograph A21. Downstrem view

Type C baffle in Plan D layout; dry bed



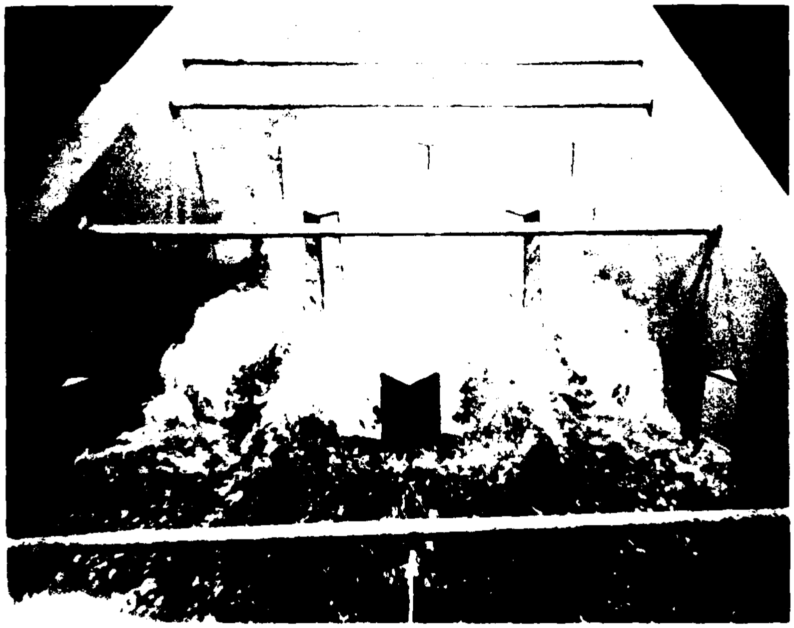
Photograph A22. Upstream view



Photograph A23. Downstream view

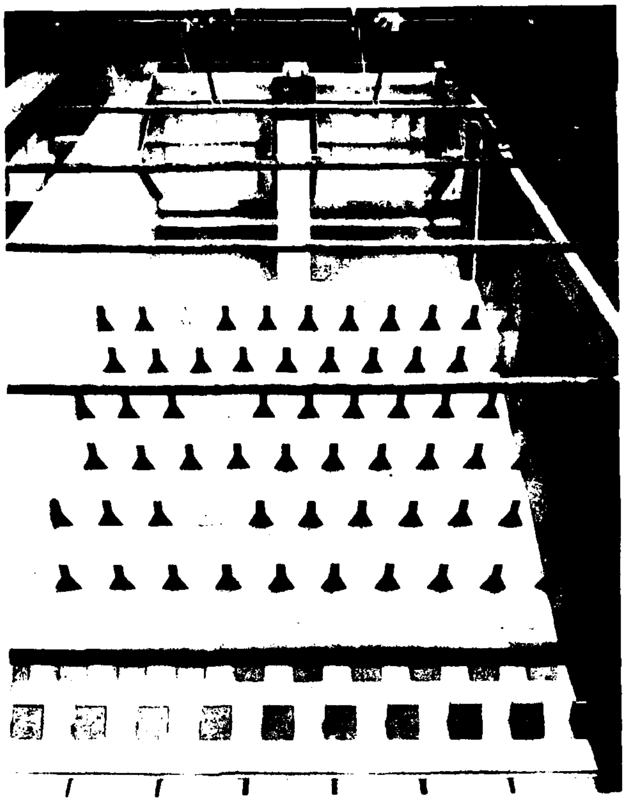
Type C baffle in Plan D layout; discharge 3.9 cfs

Photograph A24. Upstream view



Photograph A25. Downstream view

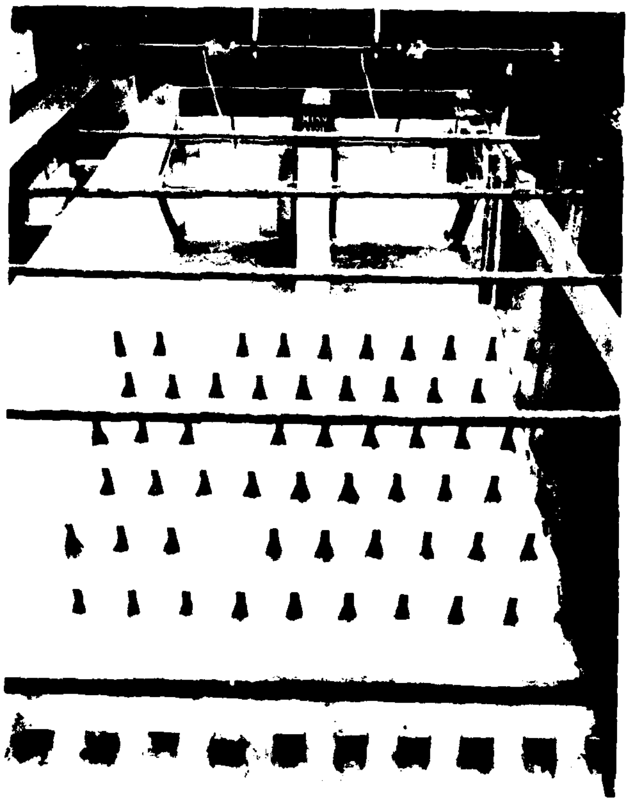
Type C baffle in Plan D layout; discharge 11.5 cfs



Photograph A26. Upstream view

Photograph A27. Side view

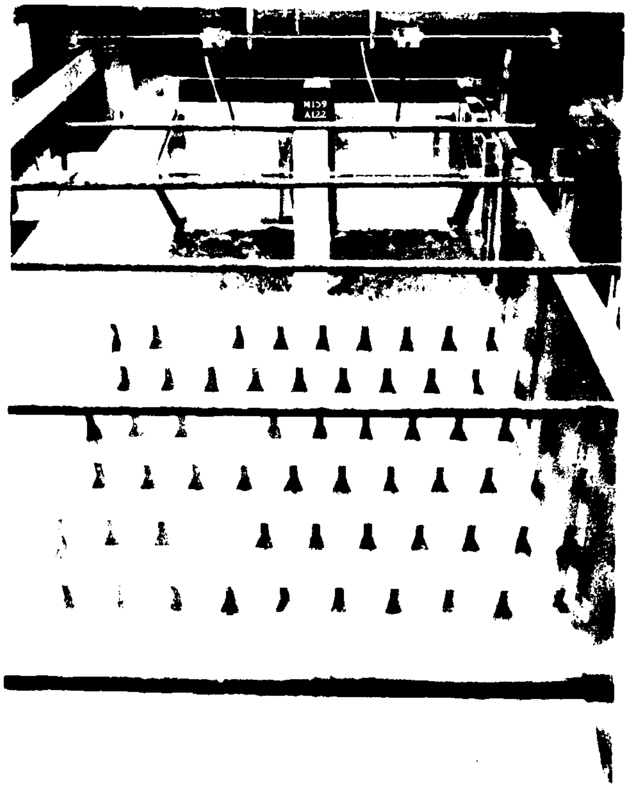
Final (Plan C) design spillway; dry bed



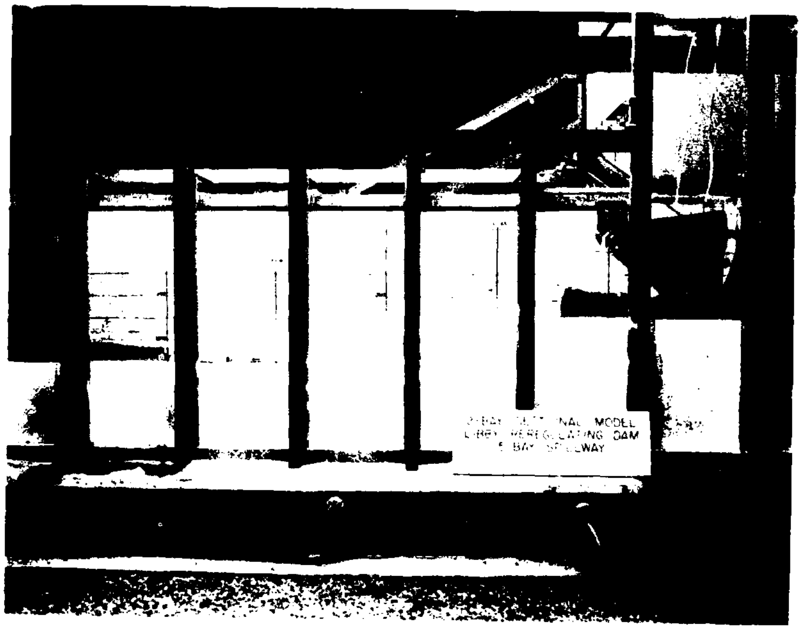
Photograph A28. Upstream view

Photograph A29. Side view

Final (Plan C) design spillway, 5,000 cfs (21.5 cfs/foot); gate controlled flow with pool elevation 2130

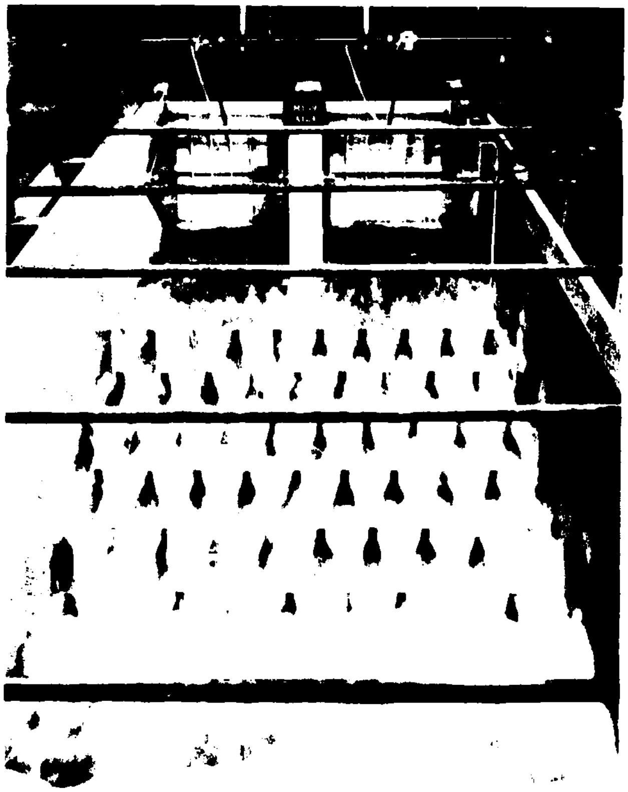


Photograph A30. Upstream view

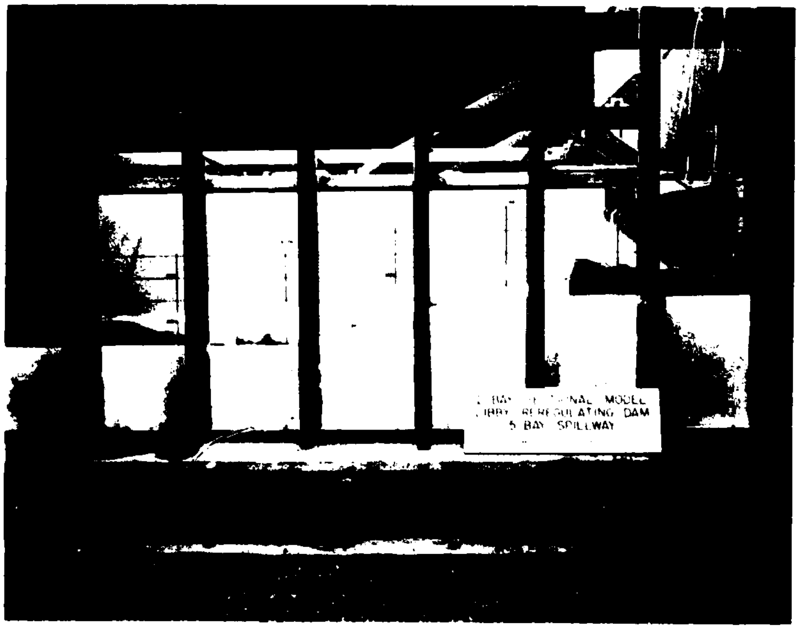


Photograph A31. Side view

Final (Plan C) design spillway, 15,000 cfs (64.5 cfs/foot);
gate controlled flow with pool elevation 2130

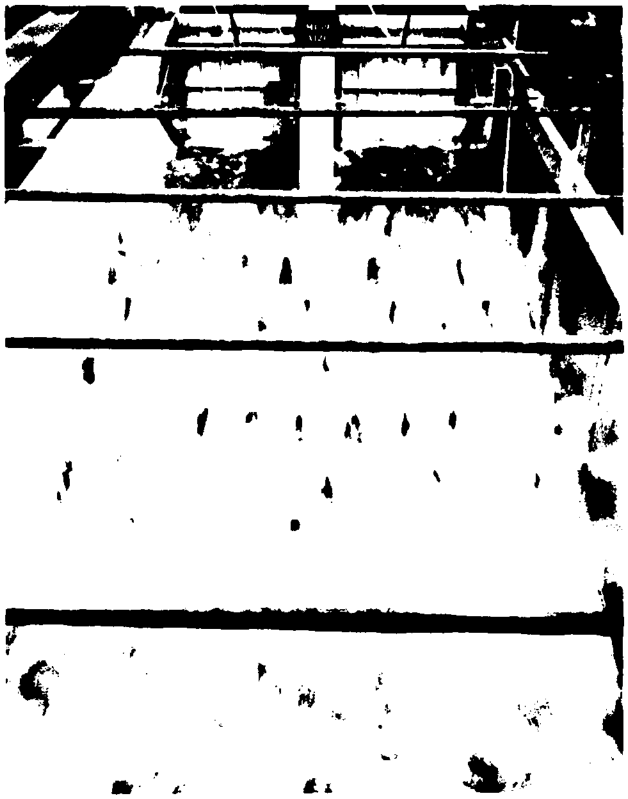


Photograph A32. Upstream view

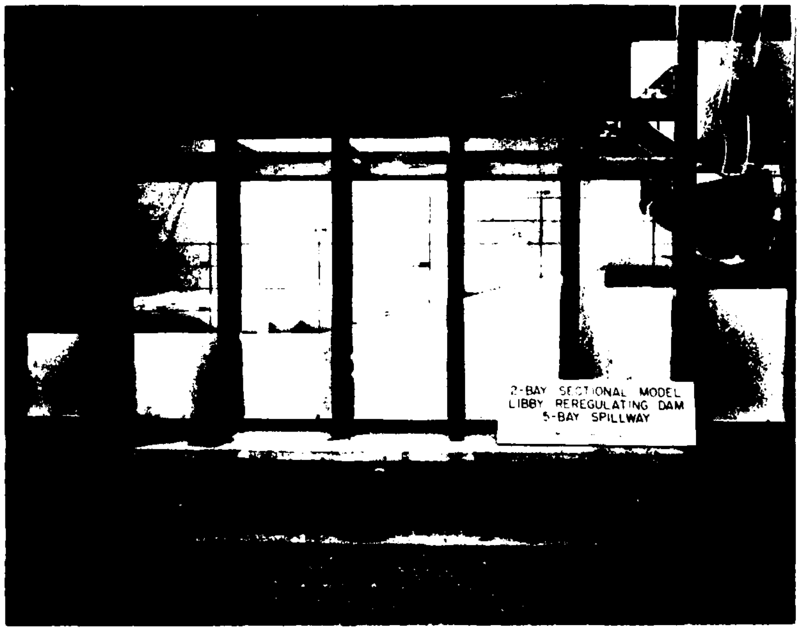


Photograph A33. Side view

Final (Plan) design spillway, 25,000 cfs (107.5 cfs/foot);
gate controlled flow with pool elevation 2130

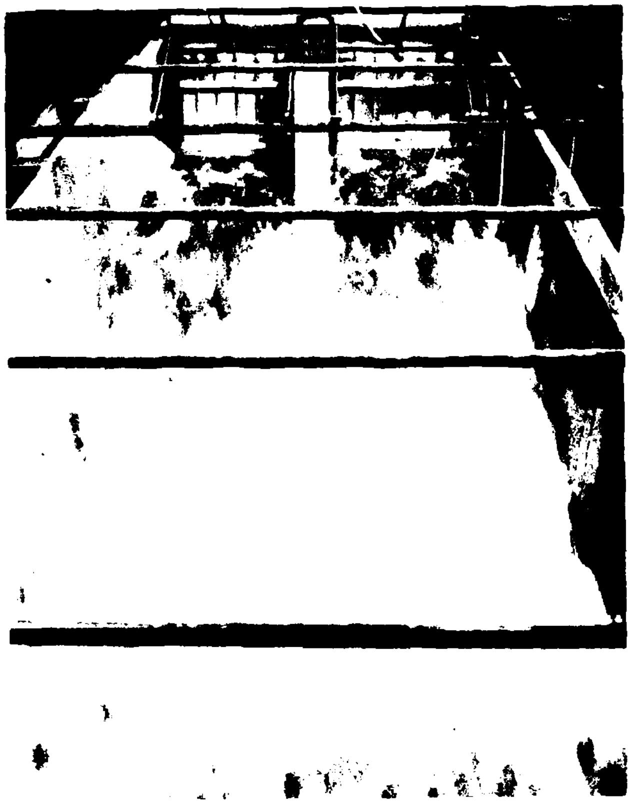


Photograph A34. Upstream view

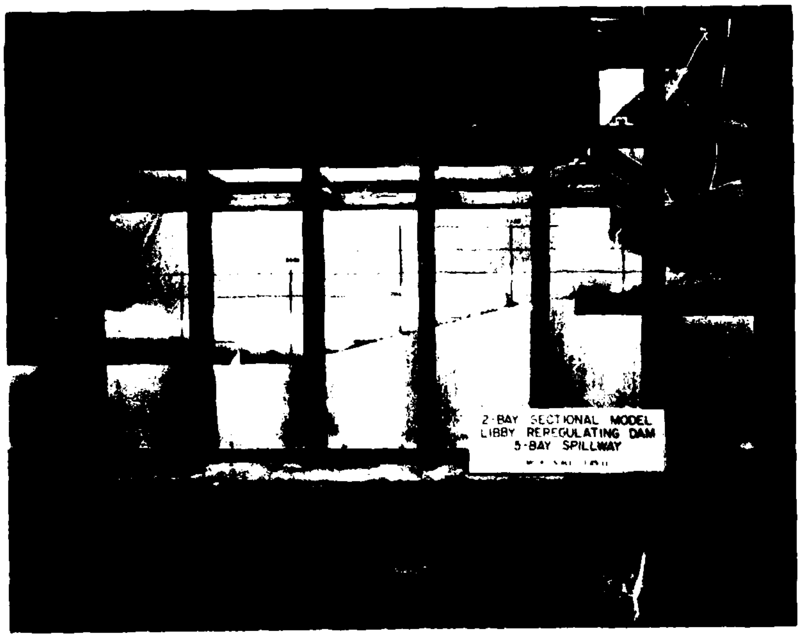


Photograph A35. Side view

Final (Plan C) design spillway, 42,000 cfs (181 cfs/foot); gate controlled flow with pool elevation 2130

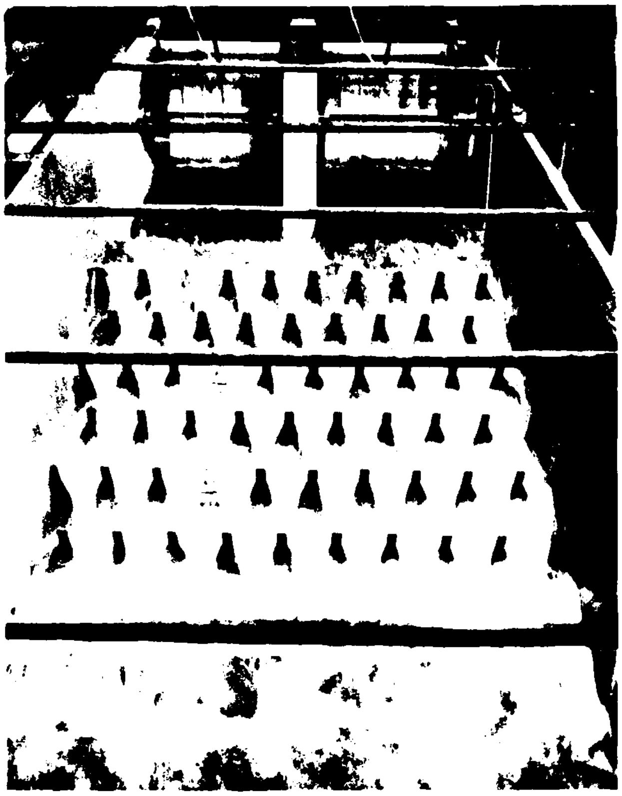


Photograph A36. Upstream view



Photograph A37. Side view

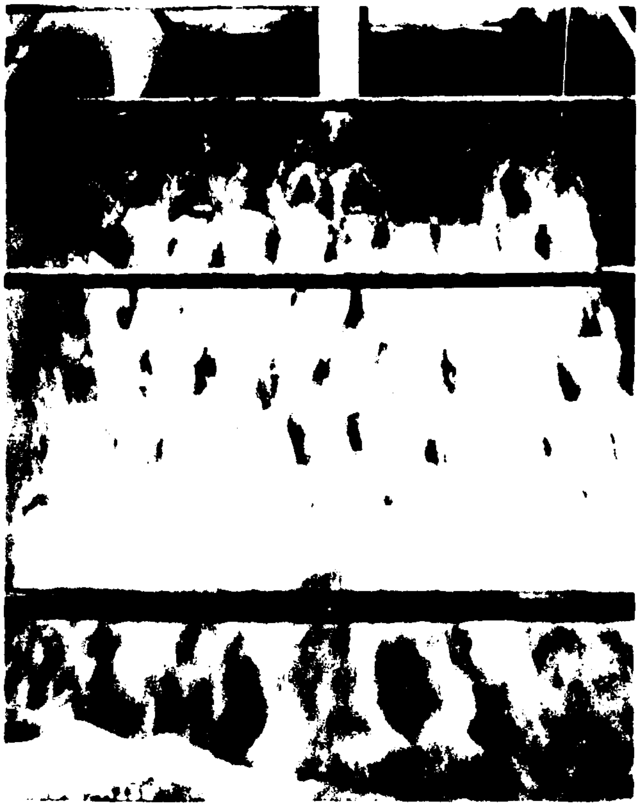
Final (Plan C) design spillway, 75,000 cfs (322 cfs/foot); gate controlled flow with pool elevation 2130



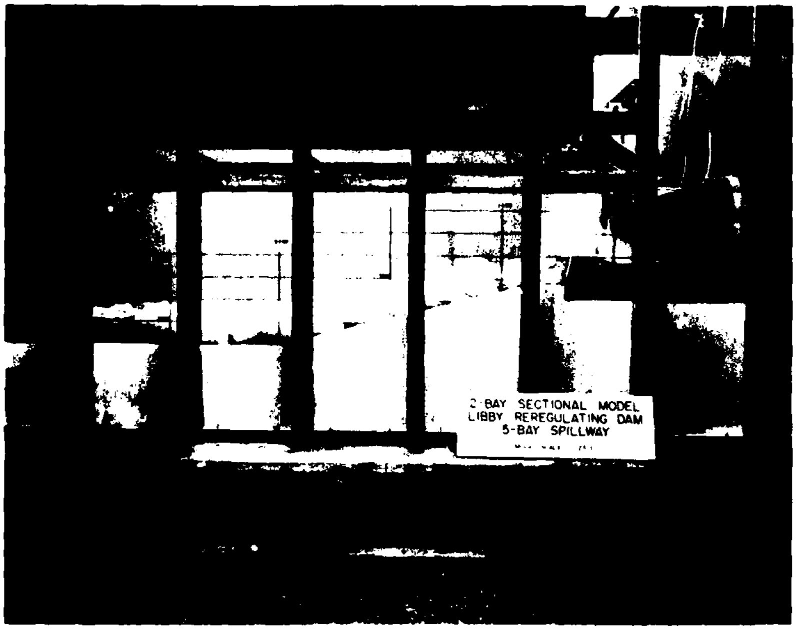
Photograph A38. Upstream view

Photograph A39. Side view

Final (Plan C) design spillway, 15,000 cfs (64.5 cfs/foot): gate controlled flow with pool elevation 2120

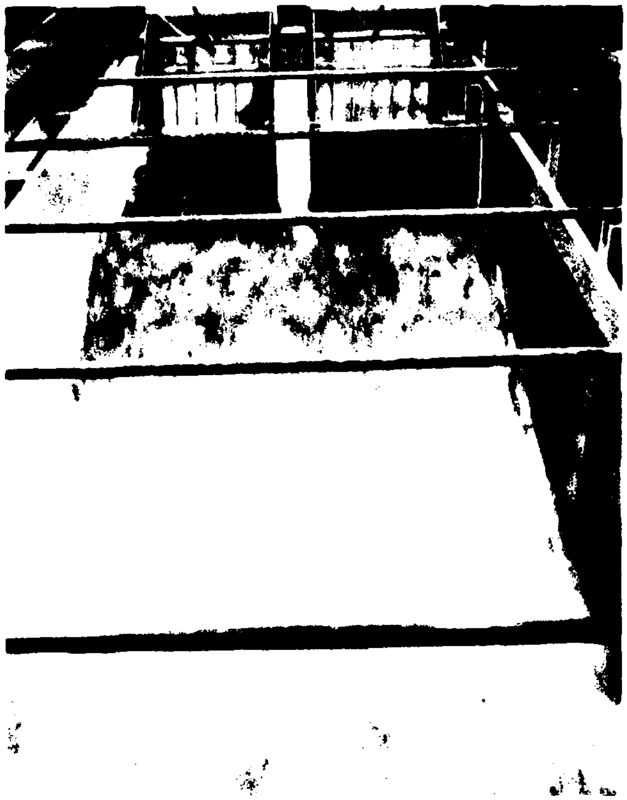


Photograph A40. Upstream view

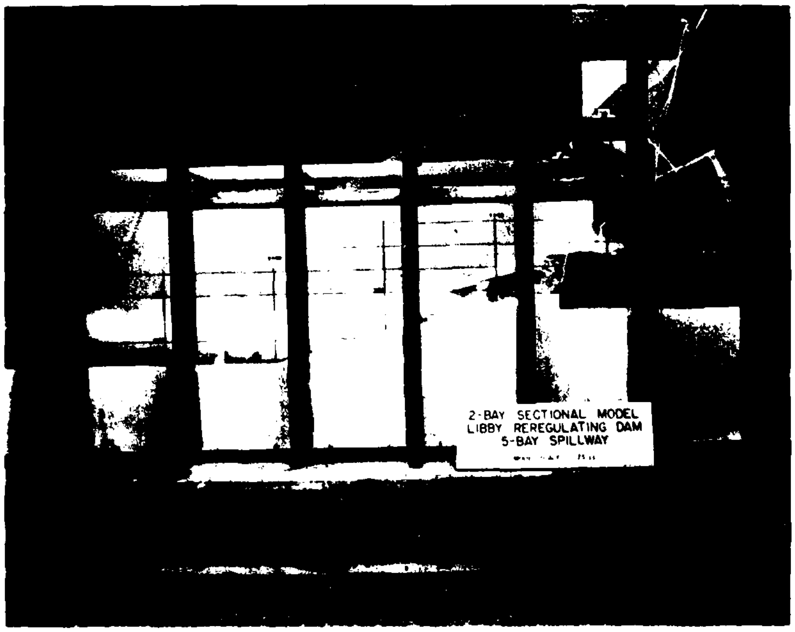


Photograph A41. Side view

Final (Plan C) design spillway, 42,000 cfs (181 cfs/foot); gate controlled flow with pool elevation 2120

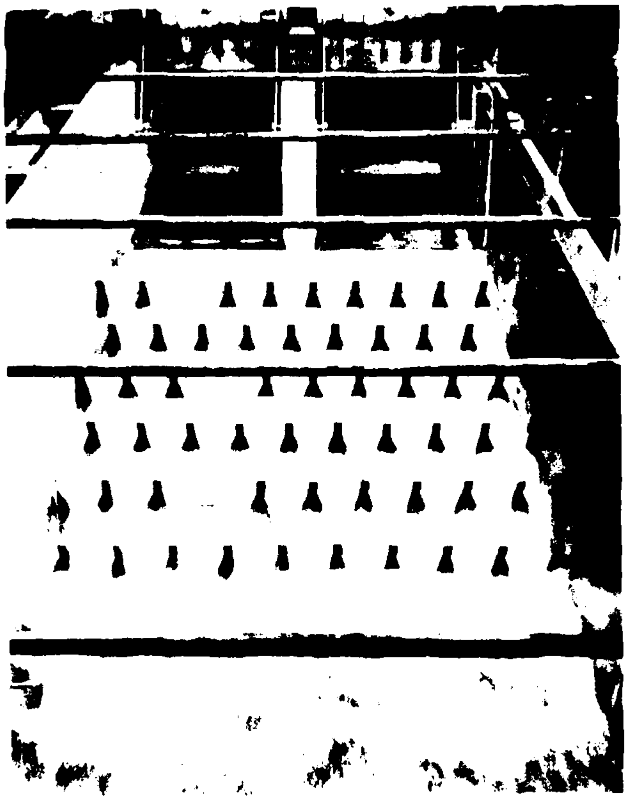


Photograph A42. Upstream view



Photograph A43. Side view

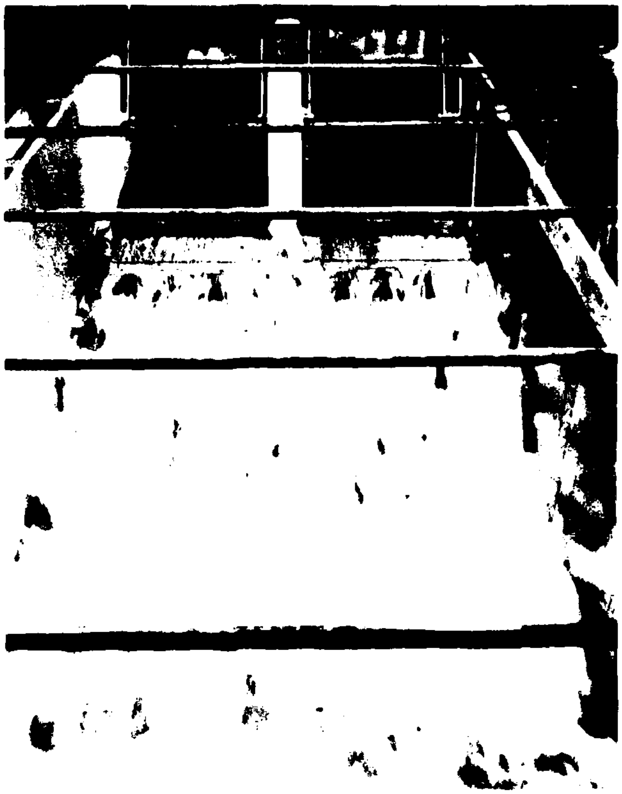
Final (Plan C) design spillway, 75,000 cfs (322 cfs/foot);
gate controlled flow with pool elevation 2120



Photograph A44. Upstream view

Photograph A45. Side view

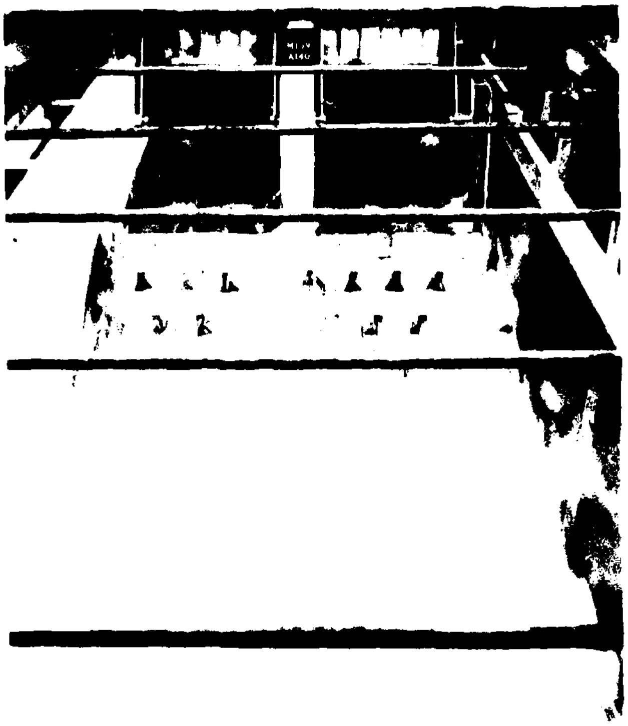
Final (Plan C) design spillway, 15,000 cfs (64.5 cfs/foot); free flow with pool EGL elevation 2105.4



Photograph A46. Upstream view

Photograph A47. Side view

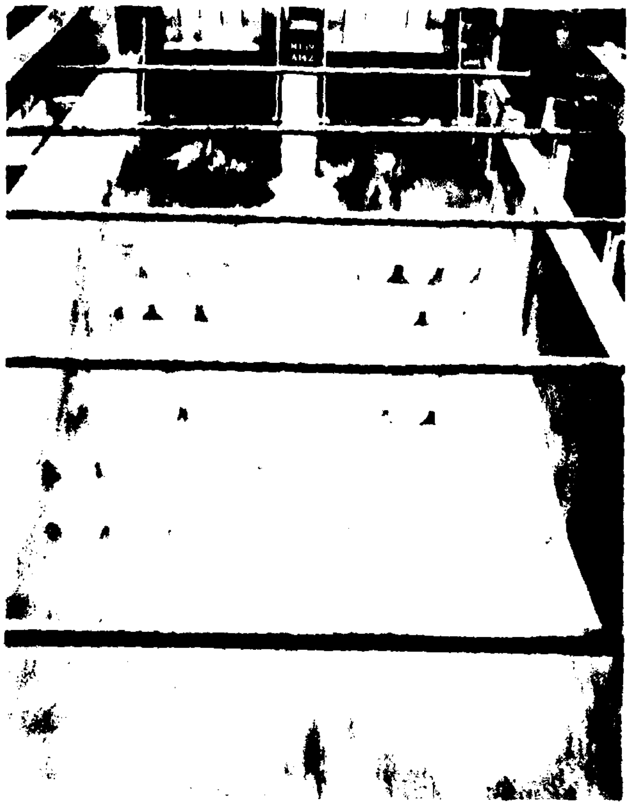
Final (Plan C) design spillway, 42,000 cfs (181 cfs/ foot);
free flow with pool EGL elevation 2112.5



Photograph A48. Upstream view

Photograph A49. Side view

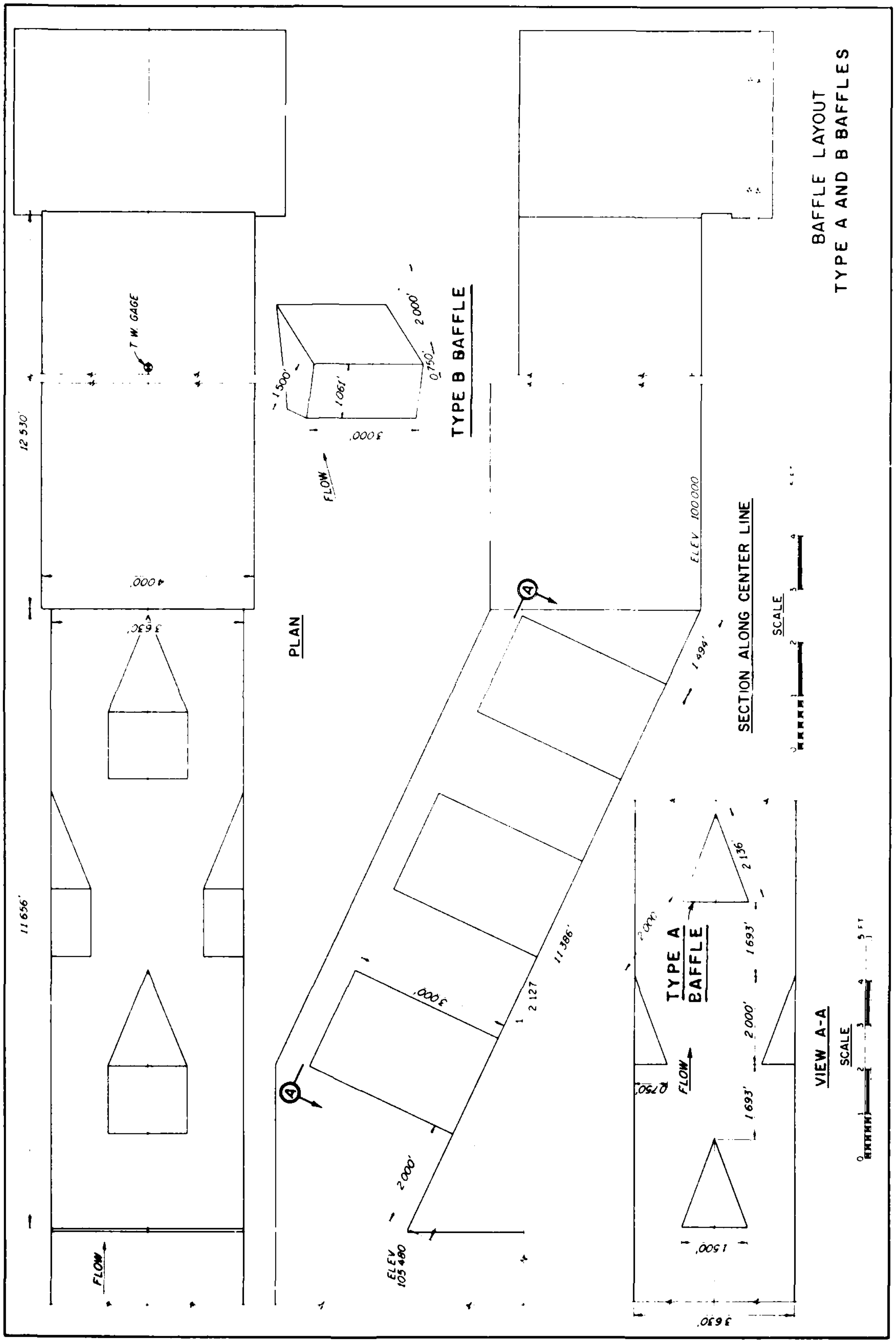
Final (Plan C) design spillway, 75,000 cfs (322 cfs/foot);
free flow with pool EGL elevation 2119



Photograph A50. Upstream view

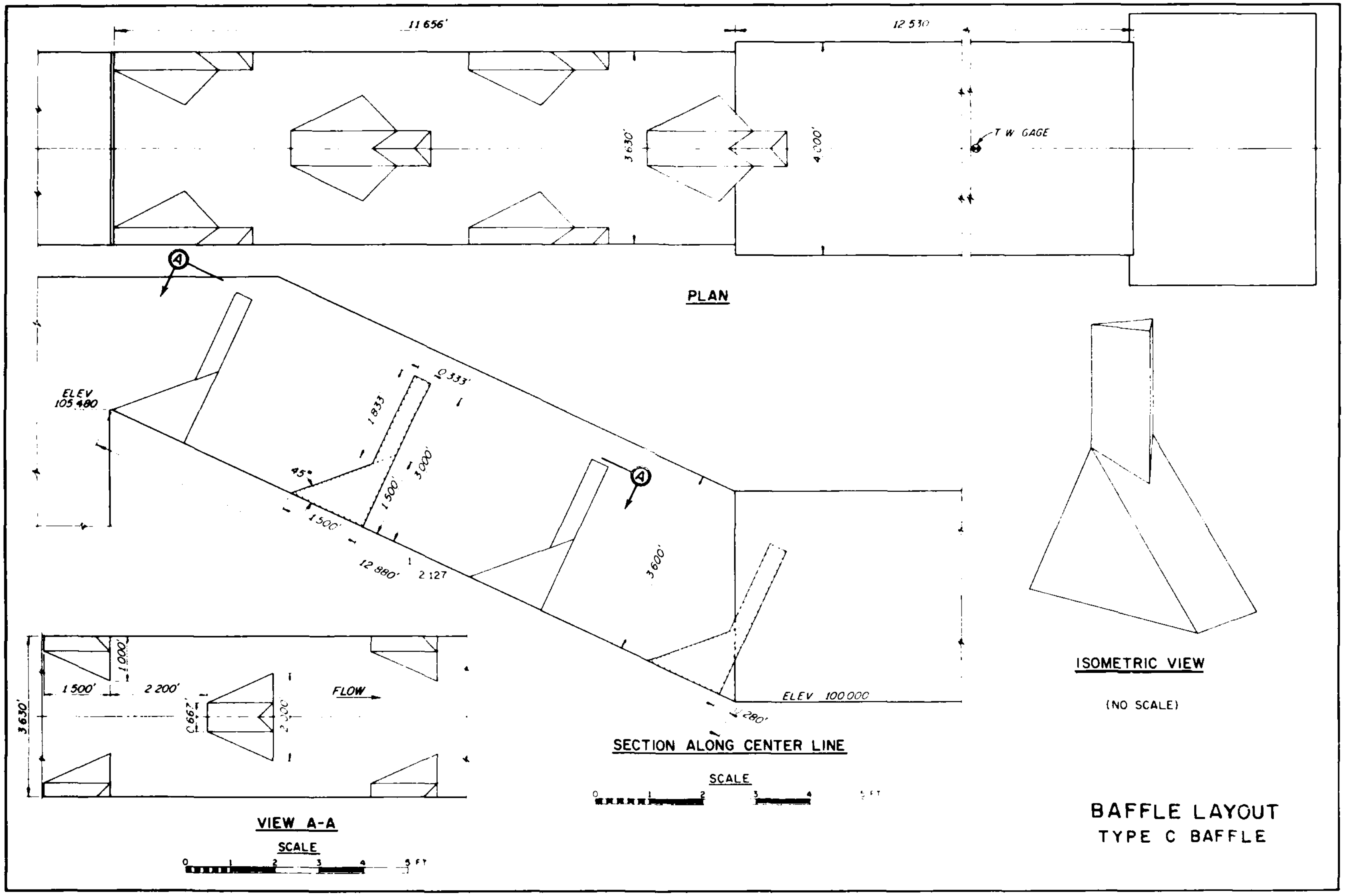
Photograph A51. Side view

Final (Plan C) design spillway, PMF discharge 210,000 cfs
(903 cfs/foot); free flow pool EGL elevation 2138.1



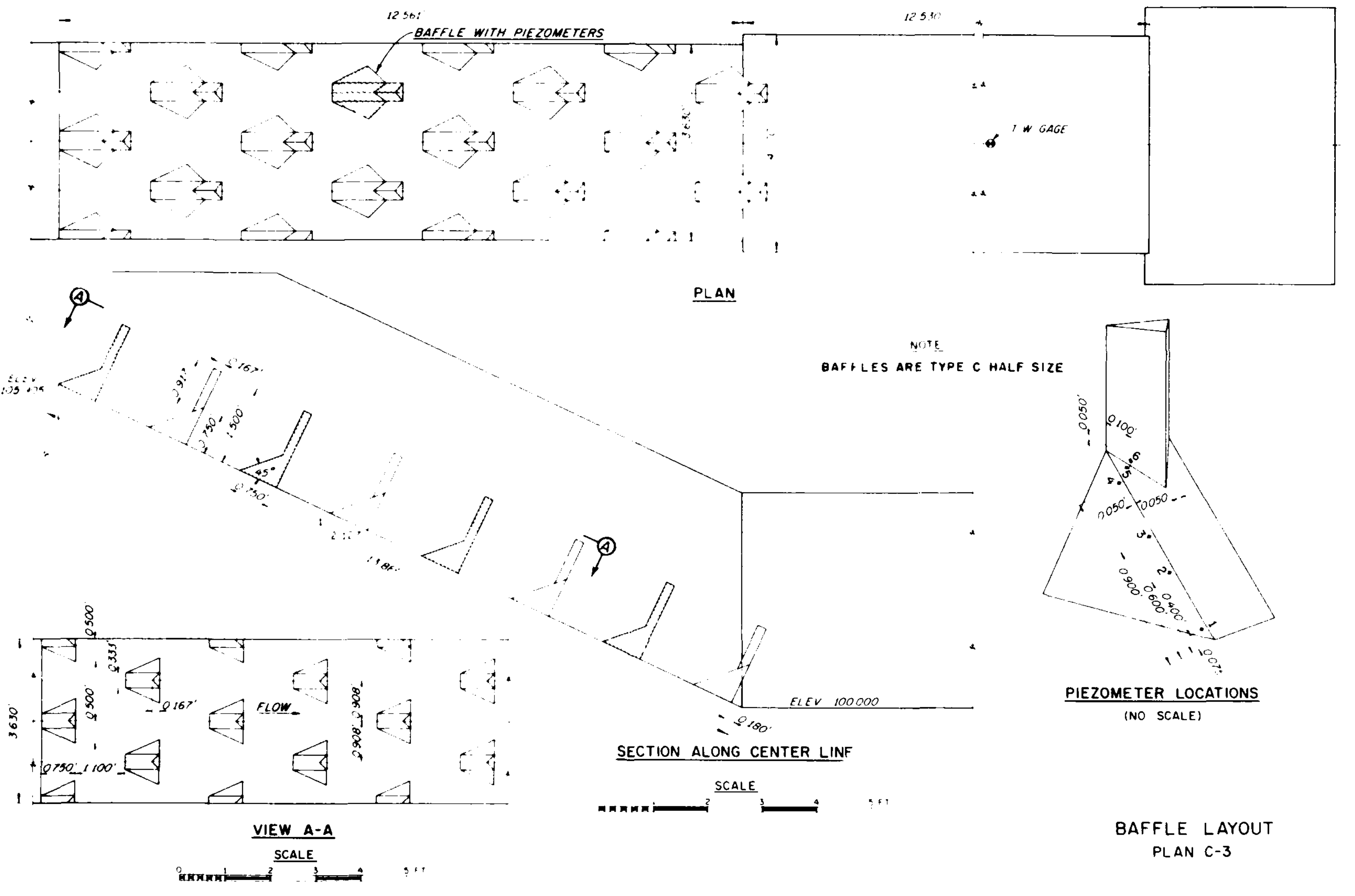
BAFFLE LAYOUT
TYPE A AND B BAFFLES

PLATE A I



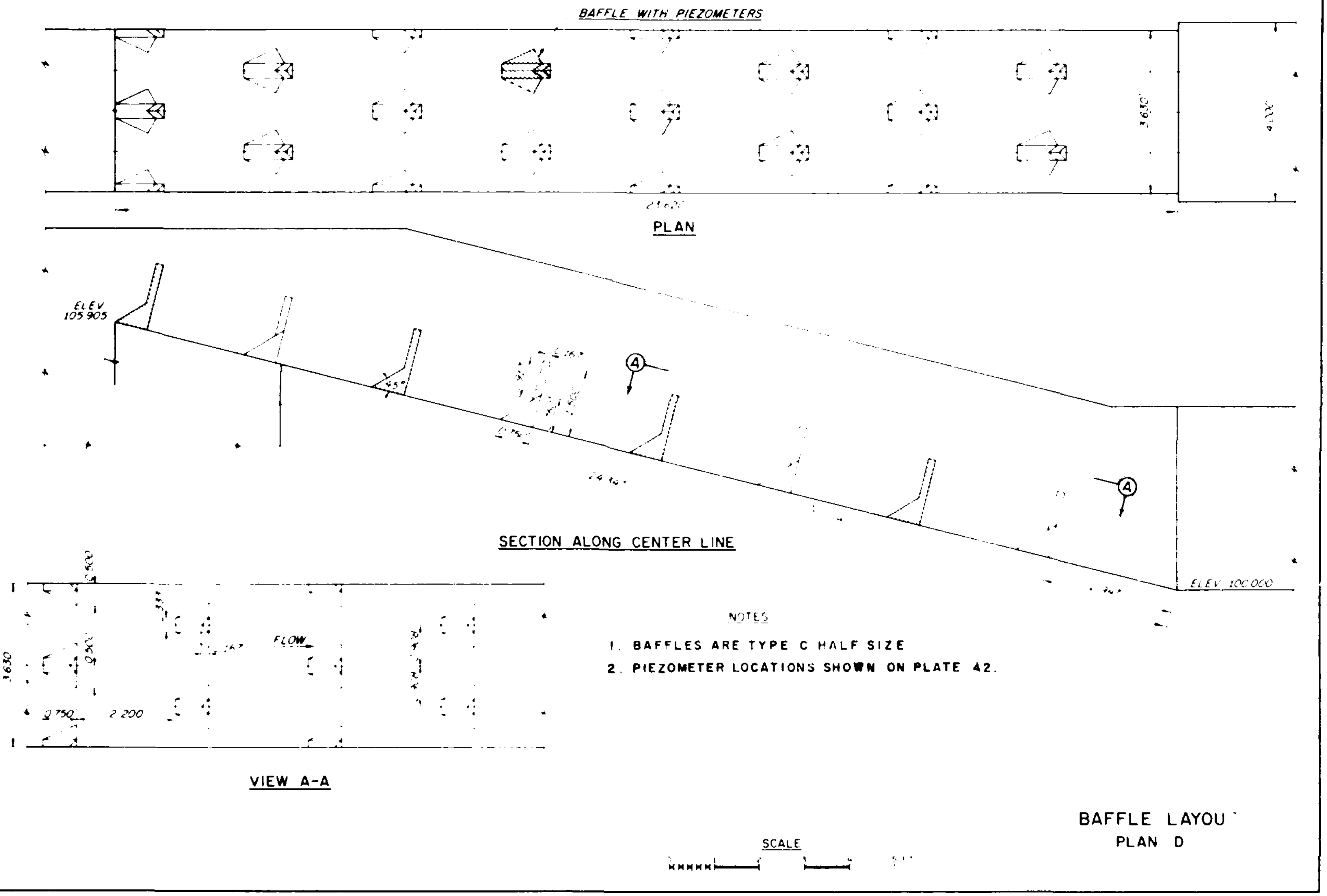
BAFFLE LAYOUT
TYPE C BAFFLE

PLATE A 2



BAFFLE LAYOUT
PLAN C-3

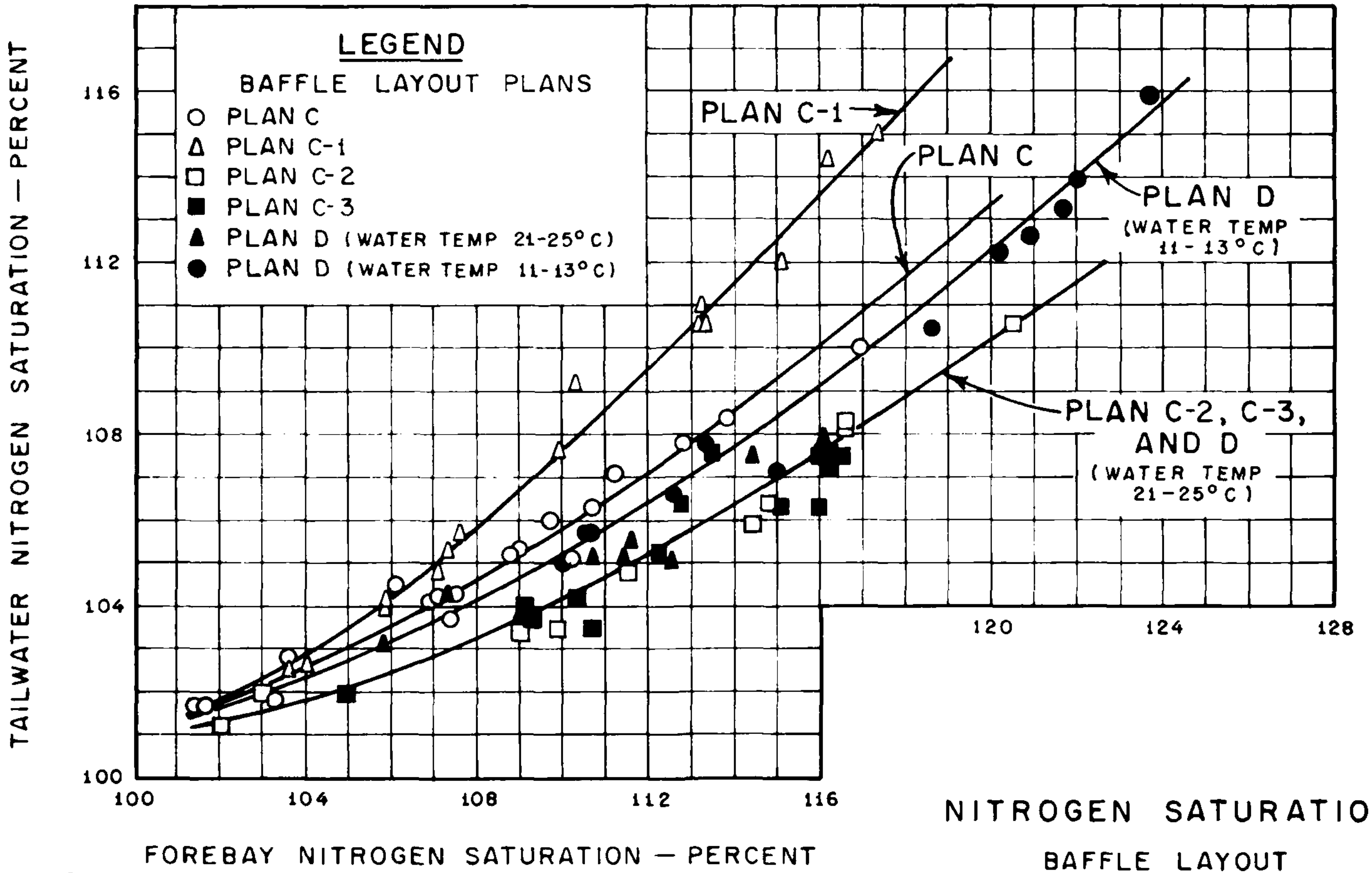
PLATE A 3



NOTES

1. BAFFLES ARE TYPE C HALF SIZE
2. PIEZOMETER LOCATIONS SHOWN ON PLATE 42.

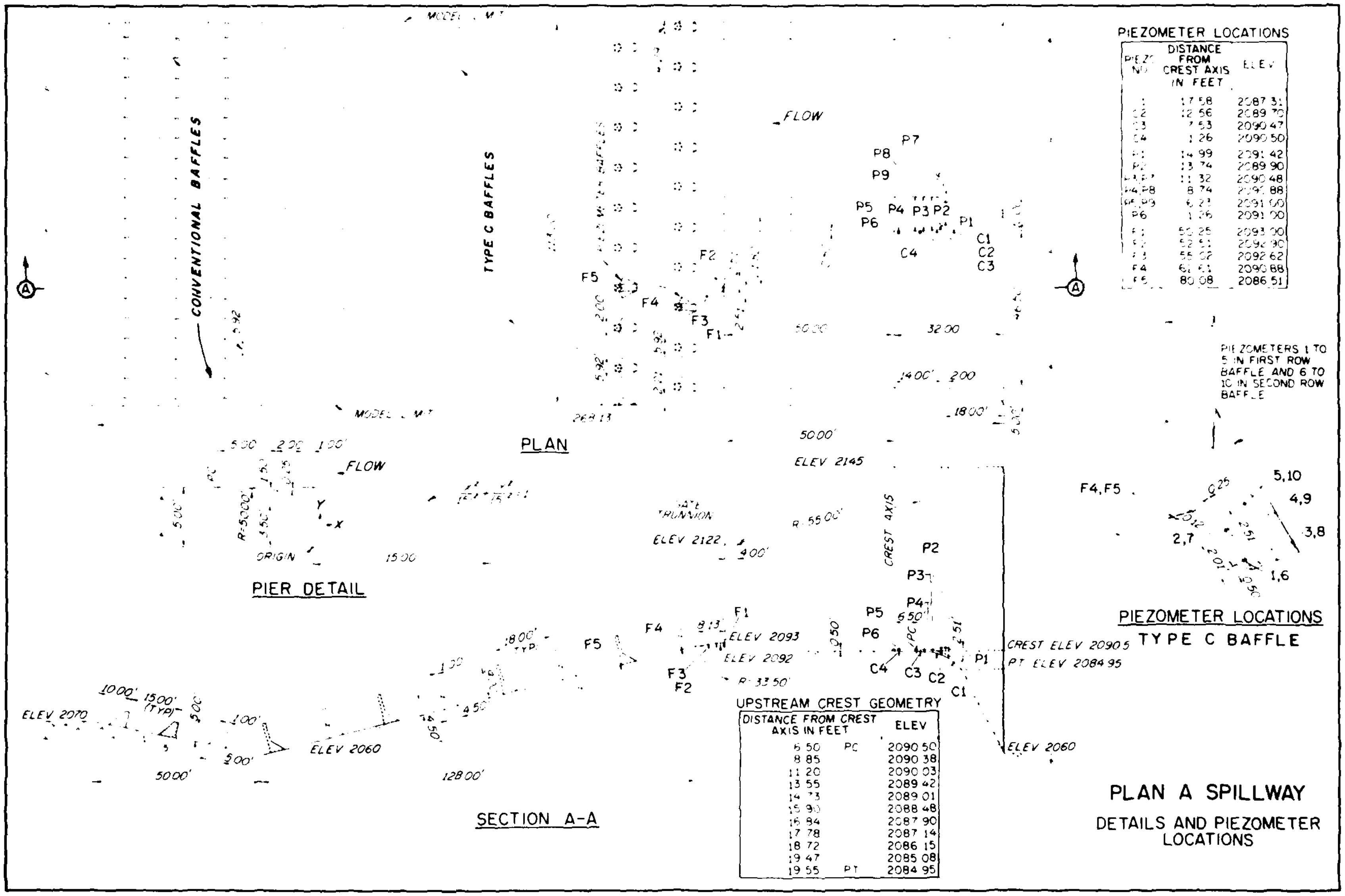
BAFFLE LAYOU
PLAN D



NOTES
1 DATA TABULATED IN TABLES A1 AND A2.
2. TYPE C BAFFLE.

NITROGEN SATURATION

BAFFLE LAYOUT
PLANS C, C-1 TO C-3, AND D



PIEZOMETER LOCATIONS

PIEZO NO	DISTANCE FROM CREST AXIS IN FEET	ELEV
C1	17.58	2087.31
C2	12.56	2089.70
C3	7.53	2090.47
C4	1.26	2090.50
P1	14.99	2091.42
P2	13.74	2089.90
P3,P7	11.32	2090.48
P4,P8	8.74	2091.88
P5,P9	6.23	2091.00
P6	1.26	2091.00
F1	50.25	2093.00
F2	52.51	2092.90
F3	55.02	2092.62
F4	61.61	2090.88
F5	80.08	2086.51

PIEZOMETERS 1 TO 5 IN FIRST ROW BAFFLE AND 6 TO 10 IN SECOND ROW BAFFLE

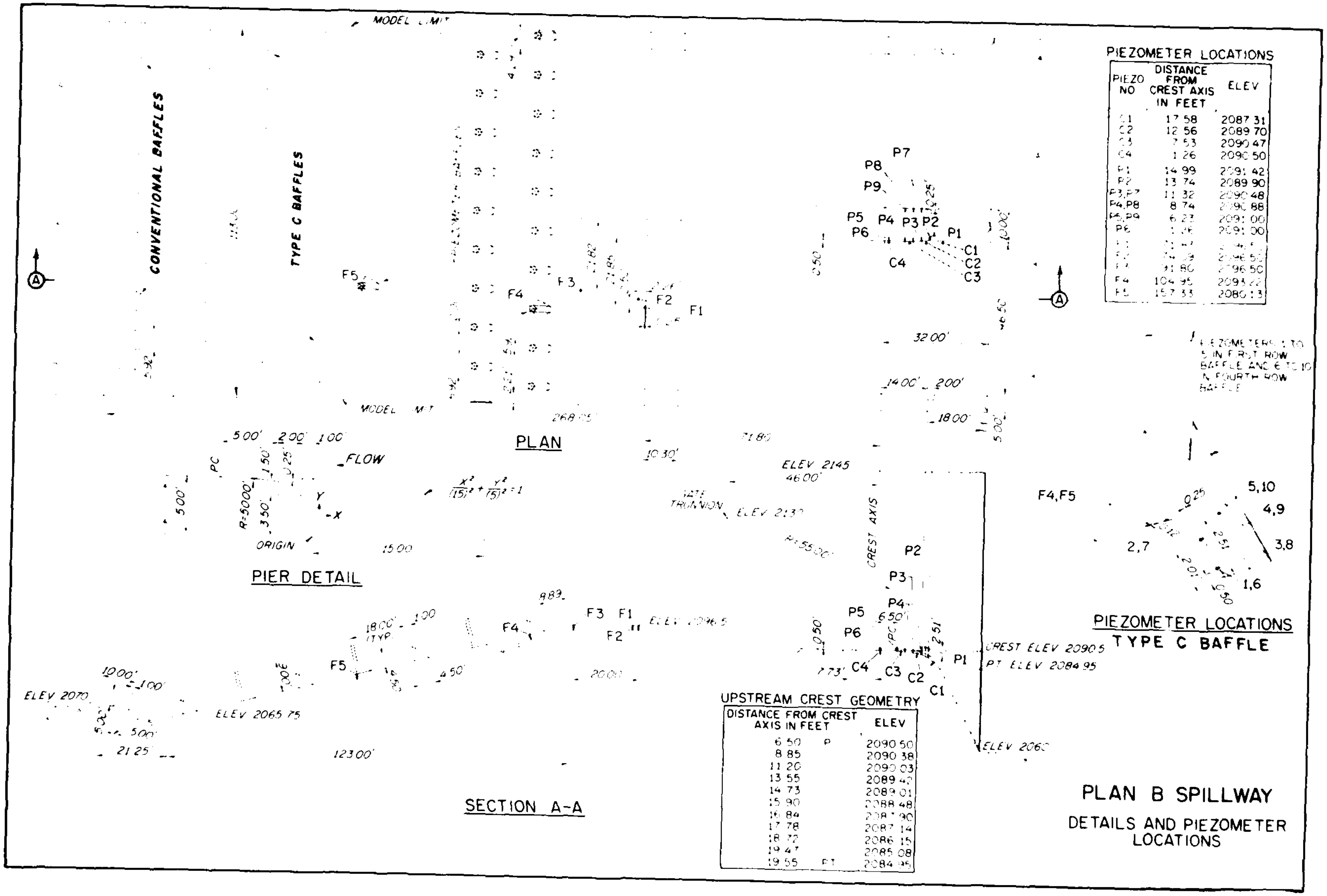
UPSTREAM CREST GEOMETRY

DISTANCE FROM CREST AXIS IN FEET		ELEV
6.50	PC	2090.50
8.85		2090.38
11.20		2090.03
13.55		2089.42
14.73		2089.01
15.90		2088.48
16.84		2087.90
17.78		2087.14
18.72		2086.15
19.47		2085.08
19.55	PT	2084.95

PLAN A SPILLWAY

DETAILS AND PIEZOMETER LOCATIONS

PLATE A 6



PIEZOMETER LOCATIONS

PIEZO NO	DISTANCE FROM CREST AXIS IN FEET	ELEV
C1	17 58	2087 31
C2	12 56	2089 70
C3	7 53	2090 47
C4	1 26	2090 50
P1	14 99	2091 42
P2	13 74	2089 90
P3,P7	11 32	2090 48
P4,P8	8 74	2090 88
P5,P9	6 23	2091 00
P6	1 26	2091 00
F1	[illegible]	[illegible]
F2	[illegible]	2096 50
F3	91 80	2096 50
F4	104 95	2093 22
F5	157 33	2080 13

PIEZOMETERS 1 TO 5 IN FIRST ROW BAFFLE AND 6 TO 10 IN FOURTH ROW BAFFLE

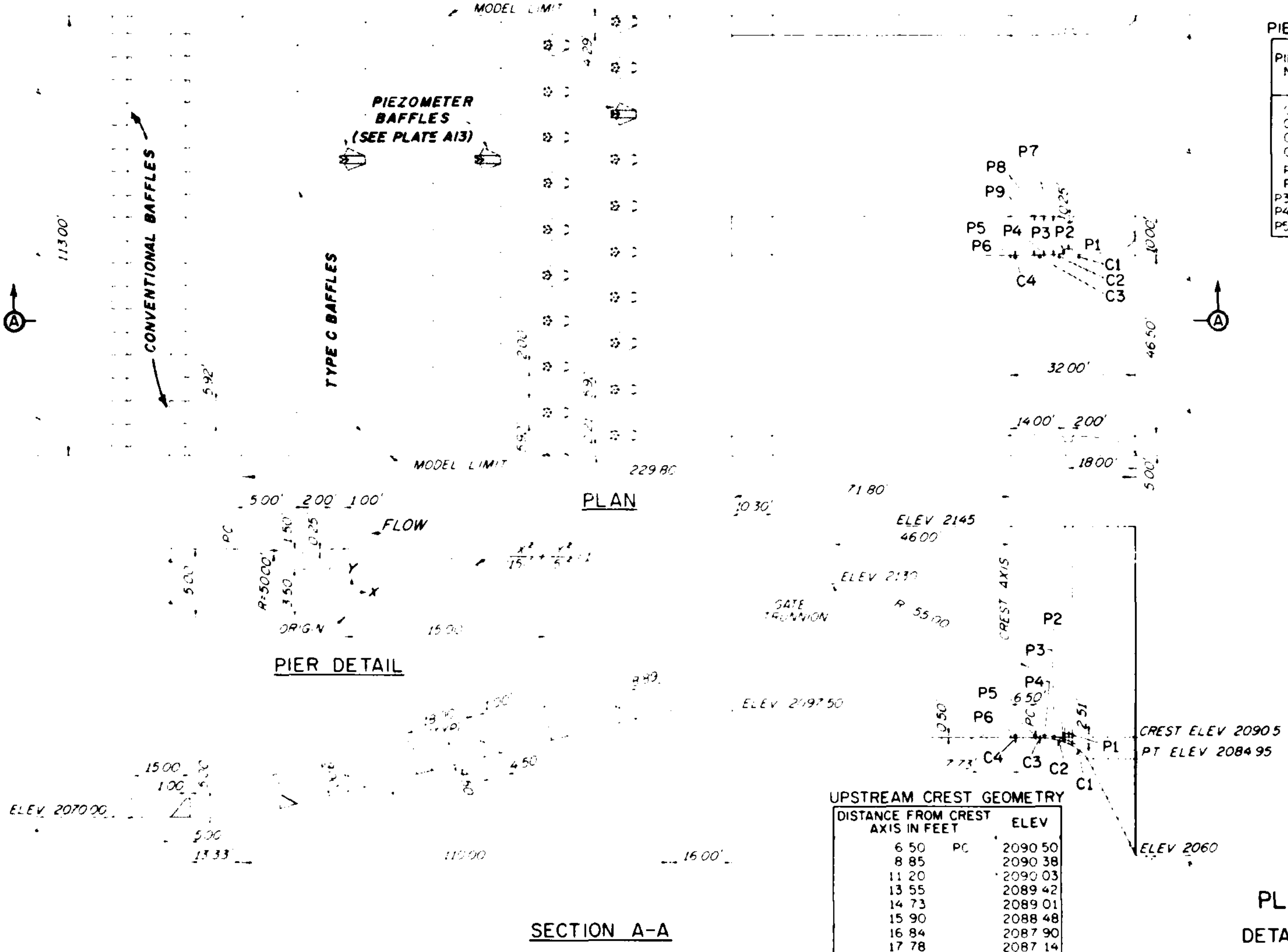
UPSTREAM CREST GEOMETRY

DISTANCE FROM CREST AXIS IN FEET		ELEV
6 50	P	2090 50
8 85		2090 38
11 20		2090 03
13 55		2089 42
14 73		2089 01
15 90		2088 48
16 84		2087 90
17 78		2087 14
18 72		2086 15
19 47		2085 08
19 55	PT	2084 95

PLAN B SPILLWAY

DETAILS AND PIEZOMETER LOCATIONS

PLATE A 7



PLAN

PIER DETAIL

SECTION A-A

PIEZOMETER LOCATIONS

PIEZO NO	DISTANCE FROM CREST AXIS IN FEET	ELEV
C1	17 58	2087 31
C2	12 56	2089 70
C3	7 53	2090 47
C4	1 26	2090 50
P1	14 99	2091 42
P2	13 74	2089 90
P3,P7	11 32	2090 48
P4,P8	8 74	2090 88
P5,P9	6 23	2091 00

UPSTREAM CREST GEOMETRY

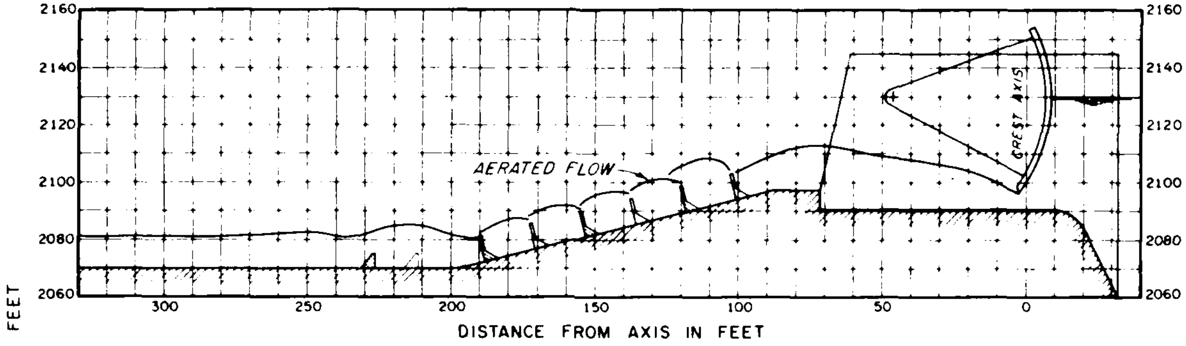
DISTANCE FROM CREST AXIS IN FEET		ELEV
6 50	PC	2090 50
8 85		2090 38
11 20		2090 03
13 55		2089 42
14 73		2089 01
15 90		2088 48
16 84		2087 90
17 78		2087 14
18 72		2086 15
19 47		2085 08
19 55	PT	2084 95

PLAN C SPILLWAY

DETAILS AND PIEZOMETER LOCATIONS

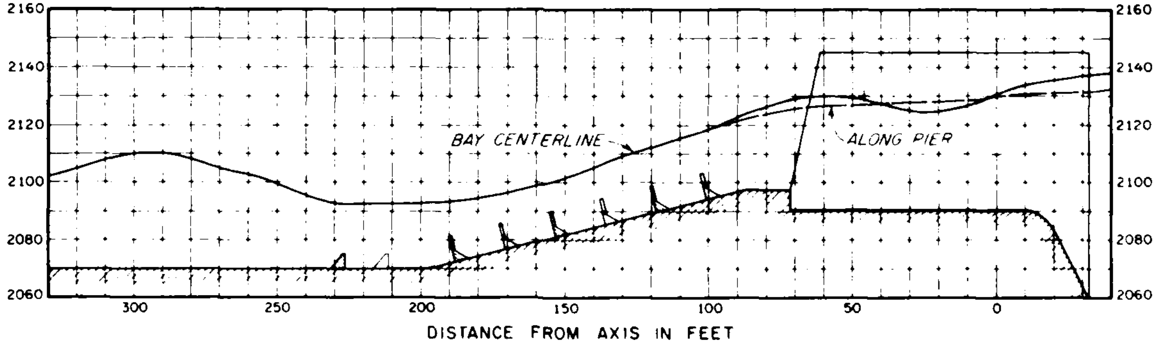
MAXIMUM WATER-SURFACE PROFILES

PLAN C SPILLWAY



GATED FLOW

DISCHARGE PER BAY	8400 CFS
RIVER DISCHARGE	42000 CFS
POOL	ELEV 2130.0
TAILWATER	ELEV 2082.0

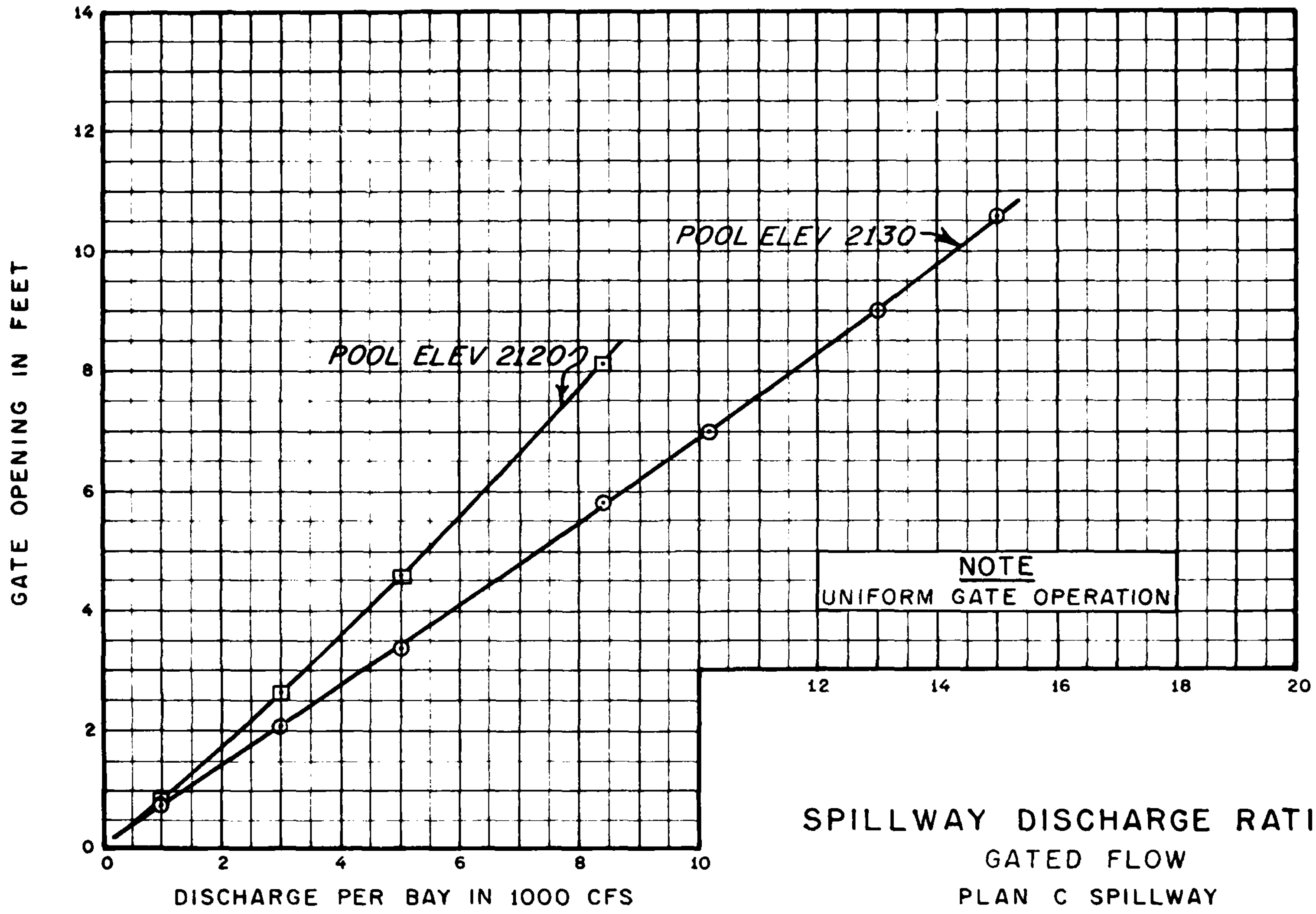


FREE FLOW

DISCHARGE PER BAY	42000 CFS
RIVER DISCHARGE	210000 CFS
POOL ENERGY GRADE LINE	ELEV 2138.1
TAILWATER	ELEV 2099.5

NOTES

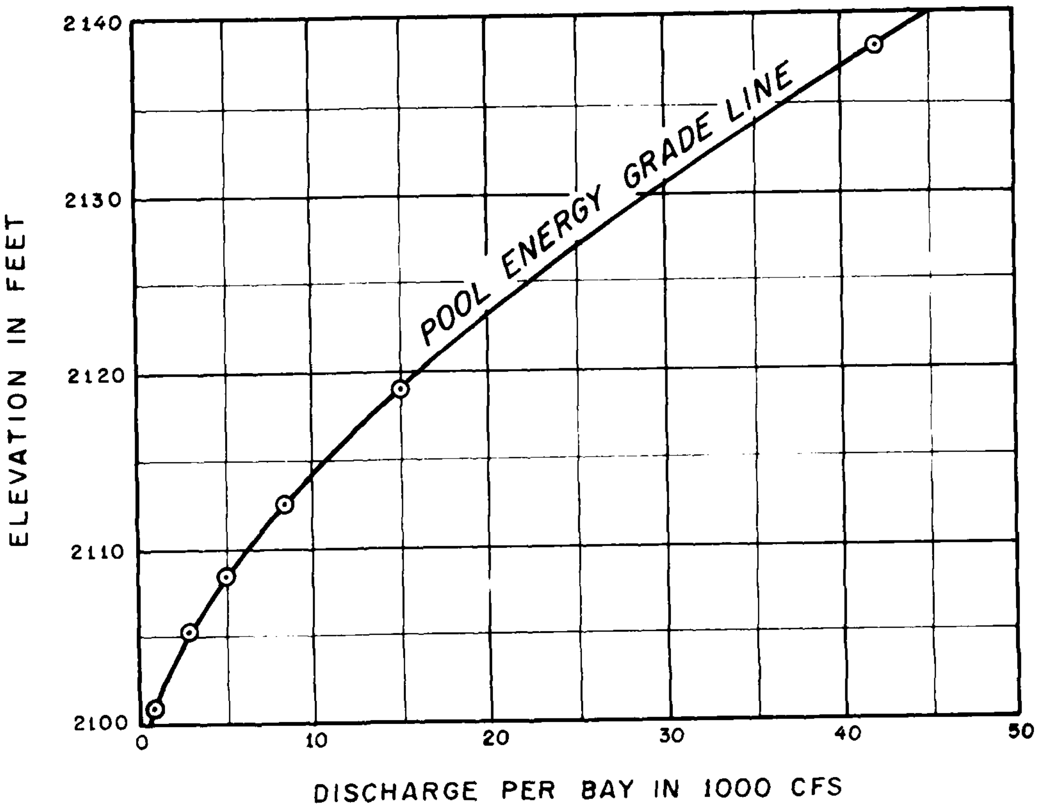
1. POOL ELEVATION AND ENERGY GRADE LINE MEASURED 231 FT UPSTREAM FROM CREST AXIS
2. TAILWATER GAGE LOCATED 522 FT DOWNSTREAM FROM CREST AXIS



SPILLWAY DISCHARGE RATING

GATED FLOW

PLAN C SPILLWAY



NOTE

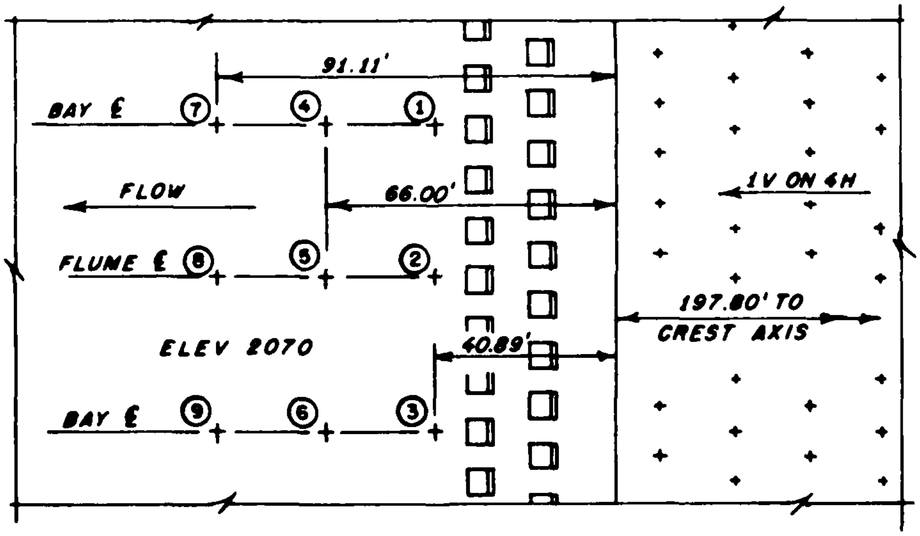
ENERGY GRADE LINE MEASURED
231 FT UPSTREAM FROM CREST AXIS.

SPILLWAY DISCHARGE RATING
FREE FLOW
PLAN C SPILLWAY

Location	Spill per Bay in CFS	
	8,400	42,000
	Tailwater Elevation in Feet	
	2082.0	2099.5
	Velocity in FPS	
1	1	11
2	1	10
3	1	12
4	3	16
5	2	10
6	1	11
7	2	10
8	2	11
9	2	9

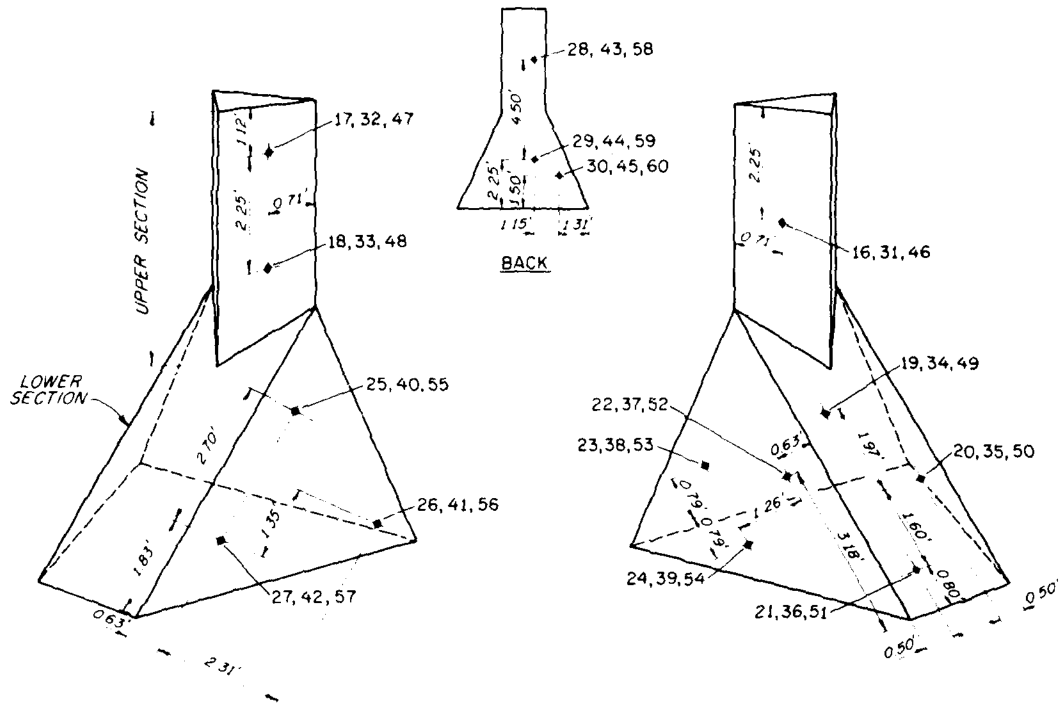
NOTE: Velocities measured 2.5 ft above bottom.

Velocity Measurement Locations



SPILLWAY VELOCITIES

PLAN C SPILLWAY



RIGHT FRONT

LEFT FRONT

ISOMETRIC VIEWS
(NO SCALE)

NOTES

1. BAFFLE LOCATIONS SHOWN ON **PLATE A8.**
2. PIEZOMETERS 16 TO 30 IN FIRST ROW BAFFLE, 31 TO 45 IN THIRD ROW BAFFLE, AND 46 TO 60 IN FIFTH ROW BAFFLE

PIEZOMETER LOCATIONS
PLAN C SPILLWAY
TYPE C BAFFLE

PLATE A13