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COLORADO RIVER FRONT WORK AND LEVEE SYSTEM - HYDRAULIC MODEL STUDIES FOR DEVELOPMENT OF MIXING AND RATING STRUCTURES DELIVERY OF WATER TO MEXICO

A Feasibility Investigation

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Engineering and Research Center
Bureau of Reclamation

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16. ABSTRACT

The discharge rating curve for the Colorado River at the Northern International Boundary with Mexico is variable because of the shifting bed. Lack of mixing in the channel results in a nonuniform distribution of salinity and pollutants, requiring frequent and expensive sampling procedures to obtain reliable data. Hydraulic model studies were performed to determine the feasibility of an improved, permanent rating structure and devices to promote mixing of the water in the river. Structures are suggested for an unimproved and an improved channel configuration.

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by

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Hydraulics Branch
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UNITED STATES DEPARTMENT OF THE INTERIOR * BUREAU OF RECLAMATION
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Commissioner

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CONTENTS

LIST OF FIGURES

CONTENTS--Continued


COLORADO RIVER FRONT WORK
AND LEVEE SYSTEM
MEASURING FLUME
& FLOW MIXER STRUCTURES

PURPOSE

The purpose of these studies was to determine the feasibility of (1) a permanent rating structure for measurement of discharges crossing the Northern International Boundary between the United States and Mexico, and (2) structures to promote mixing of segments of the stream which contain varying kinds and amounts of pollutants and provide more accurate and simpler measurement of water quality at the Boundary.

PROCEDURE

1. A 1:24 scale model simulating a reach approximately from the Rockwood weir to the Northern International Boundary cableway was used to study several configurations of mixing baffles without a rating structure in the model.

2. A trial rating structure was placed in the 1:24 model. The structure extended across the cableway. Effects of placing mixing baffles within the structure were determined.

3. A 1:36 model was constructed within the test facility to simulate a short section of channel immediately below Main Outlet Drain Extension No. 2, to determine the feasibility and desirability of placing mixing baffles in that area.

4. A 1:60 model was built to simulate the reach from immediately upstream from the Main Outlet Drain Extension No. 2 to about 800 feet downstream from the Northern International Boundary cableway. Mixing baffles and a rating structure, spanning the Northern International Boundary cableway, were developed.

5. Effects of channel modifications were determined in the 1:60 model.

6. The rating structure was relocated upstream from the Boundary, entirely within the United States, as part of a feasibility design, and final tests were made in the 1:60 model.

CONCLUSIONS

1. The hydraulic model studies verified that lack of mixing is due to deficiency in transverse shear forces across the width of the channel and natural coves along the channel banks. Effects of density stratification are negligible.

2. Two sets of baffles were developed to promote mixing within the channel. The general configurations of the baffles are shown in Figure 22.

An alternate configuration of the downstream baffles, based on an assumed channel modification, is shown in Figure 39.

These baffles and the rating structure shown in Figure 29 were developed under the assumption that the quality and discharge would be measured at the Northern International Boundary (NIB) cableway, as under the existing procedure. It was further assumed that a single-path acoustic velocity meter would be installed within the rating structure. The resulting structure would be 400 feet (121.9 m) long and 300 feet (91.4 m) wide with 6-foot (1.8-m) high sidewalls and floor elevation 103.

3. Later in the study, it was decided that the rating structure, if constructed, should be located entirely within the United States. To minimize the length of the structure, it was divided into four 75-foot-wide bays. Installation of four pairs of acoustic transducers would also reduce the acoustic path length and increase the accuracy and reliability of the velocity measurement. This rating structure is shown in Figure 41. The downstream mixing baffles, also Figure 41, were revised in location and configuration as a result of modifying the rating structure. Figure 43 shows the locations of the recommended rating structure and mixing baffles with and without channel modification. Water quality would be measured within the rating structure.

4. The studies indicated that with the mixing baffles the average concentration can be determined to within ±10 percent of the true value by withdrawing a single sample at the transverse midpoint of the rating section, or to within ±3 percent by taking samples at the one-fourth and three-fourths points. Because of timewise variations in concentration, a continuous sample should be withdrawn over a period of about 15 minutes, or an average of five individual samples taken at 3-minute intervals should be obtained. The continuous sample would be best. The final sampling procedure could easily be determined in the prototype.

5. Velocities through the rating section will be high enough that sediment will not be deposited within the section. Deposition will probably occur in the decelerating zone downstream from the structure. Riprap protection will be necessary on the banks and bottom immediately upstream and downstream of the

structure to withstand velocities up to approximately 5 fps (1.5 m/sec) as determined by measurement in the model.

6. Riprap protection on the riverbank to withstand velocities of about 10 fps (3.0 m/sec) would be required. However, the literature and observations of local scour around piers indicate that riprap on the bed would serve little use unless buried to the depth of maximum scour. It has been suggested that the riprap should be deleted and the baffles designed for maximum scour. Deposition of sediment should be expected immediately upstream and downstream from the baffles.

7. The combined backwater effects of the rating structure and baffles, as compared with the existing channel with no structures, resulted in a negligible increase in flow depth at the upper Rockwood gage, for a discharge of 6,000 cfs (169.8 cu m/sec). Maximum depth increase was 1.3 feet (0.4 m) at a discharge of 1,000 cfs (28.3 cu m/sec). (The increase in depth decreased with an increase in discharge.) Water surface elevation at the gage about the Rockwood weir was 106.5 for a discharge of 4,000 cfs (Figure 30), as compared with an allowable elevation of 108.2 specified as the governing criterion.

8. Channel modification had no effect on operation of the rating structure and negligible effect on the backwater at the upper Rockwood gage.

9. The studies showed that without baffles the unmodified channel is more efficient than the modified channel in natural mixing of pollutants. However with baffles the mixing characteristics were about equal.

APPLICATIONS

The location and size of mixing baffles and rating section determined in this study are applicable only to the reach of the Colorado River at the Northern International Boundary. Rating sections and methods of accomplishing mixing will vary depending on the configuration and composition of the specific channel under consideration.

INTRODUCTION

In 1944 an international agreement was signed with Mexico, which specified an annual delivery of 1.5 million acre-feet (1.85×10^9 m^3) of water from the Colorado River. As a result of the entry of drainage water from irrigated land into the river, the salinity rose to such a level that Mexico registered a formal complaint in late 1961. Additional agreements resulted in construction of an extension to the drainage channel, which allows conveyance of the drainage water to the Colorado River either upstream or downstream of the Mexican diversion structure. The river reach between the upstream inflow point named Main Outlet Drain Extension No. 2 (MODE 2), and the Northern Internationl Boundary (NIB) is the study area covered in this report.

Increasing demands on the Colorado River have amplified the importance of accurate discharge measurement. When this study began, the riverflow was metered daily at the NIB; the Mexican Section of the International Boundary and Water Commission (IBWC) made current meter measurements 3 days each week and the American Section measured the remaining 4 days. Revisions of the rating curve based on these daily flow measurements severely complicated river operations. The rating curve is now modified only when the velocity measurements show a definite shift in the bed. The rating curve has been found to be somewhat variable with 15 percent of a large number of previous measurements differing from the average by 3 to 5 percent. Ten percent of the measurements differ from the average by more than 5 percent.

Salinity of the river water is determined with several samples taken daily across the river by IBWC from which conductivity measurements are made. In addition, total dissolved solids (TDS) are determined once a week in a laboratory. The Federal Water Quality Administration (FWQA) is also taking samples at the Boundary for determination of salinity and other water quality parameters.

Lack of mixing in the channel causes the saline flow from MODE 2 to remain near the left bank. Pollutants from sources farther upstream behave similarly. Figure 1 shows a typical distribution of TDS at the NIB.

The nonuniformity of salinity and pollutants results in complicated and expensive procedures of sampling and laboratory analysis, which may nevertheless fail to yield reliable results.

Figure 2 is an aerial view of the Colorado River in the area of interest. Other minor inflows occur upstream of the area shown in this photograph. The primary source of salinity is at MODE 2. Mixing of this inflow with the main channel flow is retarded by the low, nearly uniform velocity in the main channel. The main source of flow in the main channel upstream from MODE 2 is the Pilot Knob Powerplant and Wasteway which discharges relatively high quality water into the right side of the stream. The Yuma sewer outfall presently discharges domestic sewage into the left side of the stream. The only appreciable turbulence that might induce mixing occurs at the Rockwood weir, which is a low, submerged structure formed with dumped stone. A supplementary water-stage recorder immediately upstream from this structure measures the river stage for determining water passing the NIB. Photographs of some of these features are shown in Figure 3.

This study assumed approximately 300 cfs (8.5 cu m/sec) discharging at MODE 2. Discharge at the NIB ranged from 750 (21.2) to 6,000 cfs (169.8 cu m/sec), leaving 450 (12.7) to 5,700 cfs (161.3 cu m/sec) to originate upstream from MODE 2. Most of this flow enters the river at Pilot Knob Powerplant and Wasteway during the summer and at the California Wasteway in Yuma during the winter. The higher riverflows normally occur during early spring and summer and lower flows occur in fall and early winter.

Dispersion in natural streams is influenced by several parameters, the most important being the variation in velocity across the stream. Theoretically then, mixing should be induced by variations in depth, sinuousity, etc. This reach of the Colorado River contains these features; however, the stream is so wide and tranquil that velocities are relatively uniform and very little natural mixing occurs. The problem is increased by islands which limit lateral movement of the water and by coves which tend to retard the flow.

Dye tests by FWQA[1 2] (formerly FWPCA) conducted in March and September of 1969 defined the natural mixing characteristics of the stream. The studies verified that the saline inflow from MODE 2 and the relatively high-quality inflow from Pilot Knob were primarily responsible for the sharply skewed distribution of salinity and pollutants at the NIB. Figure 4 shows the distribution of Rhodamine WT dye at the NIB, measured with a fluorometer. The dye was injected continuously in the MODE 2 channel immediately upstream from the inflow point.

The data suggest that the skewness of the dye distribution increases with increasing discharge. The original fluorometer records also show fluctuations in concentration at a given point over a period of time. The FWQA tests helped verify the applicability of the hydraulic models.

THE LABORATORY INVESTIGATION

The 1:24 Model

General.—Figure 5 shows the configuration of the 1:24 model. The three structures shown in the photograph are trial mixing baffles.

Cross sections obtained in the field in August 1968, and aerial photographs were used to form the sand bed. The model represented the portion of the prototype channel between a point immediately upstream from Rockwood weir and a point approximately 50 feet (15 m) downstream from the NIB cableway. Thus, the MODE 2 inflow was not included and the distribution of pollutants at the Rockwood weir was assumed.

The model water supply was recirculated through the laboratory system. Discharge was measured with volumetrically calibrated venturi meters, which are permanently installed in the laboratory. Water surface elevations were measured with staff gages and/or point gages and velocities were measured with a miniature propeller meter, Figure 6A.

Pontacyl Brilliant Pink dye was used to represent the saline inflow. Dye concentrations at several points across the channel at or near the NIB cableway were measured with a Turner Model 111 fluorometer, Figure 6B. Samples were pumped from the channel and passed continuously through the fluorometer. The transverse profile of dye concentration was recorded on a strip-chart recorder. The resulting data were used to evaluate the performance of the several trial mixing structures.

A computer program was developed for reduction of the data and automatic machine plotting. Concentration at each sampling point was determined from the chart record. The average concentration was then computed and the ratio of point concentration to average concentration at each sampling point was determined. This ratio was plotted by machine against the ratio of distance from the left bank to total channel width.

[1] *"Flow Pattern Studies in the Colorado River in the Vicinity of the Northerly International Boundary,"* FWPCA, Colorado River–Bonneville Basins Office, Denver, Colorado, May 1969.
[2] *"Flow Pattern Studies in the Colorado River in the Vicinity of the Northerly International Boundary, II,"* FWPCA, Colorado River–Bonneville Basins Office, Denver Colorado, December 1969.

Mixing Characteristics of the Stream.—Distribution of dye at the NIB cableway, resulting from various methods of dye injection at the upstream end of the model, was determined for a discharge of 4,000 cfs (113.2 cu m/sec). The results are shown in Figure 7.

Curve 1 represents the most severe condition, with injection on the left bank, immediately upstream from the Rockwood weir. Most of the dye is confined to the left one-half of the channel at the NIB cableway. Curve 2 resulted from injection in the deep part of the channel, about 100 feet (30 m) from the left bank. The distribution is somewhat improved, but remains sharply skewed to the left. Curve 3 shows the amount of mixing at the NIB cableway when dye was injected over the right one-third of the channel, with dye flow increasing with distance from the bank. The data show some mixing across the channel with most of the dye confined to the right half. The blocking effect of the island along the right side of the channel is also evident.

Curve 4 shows the "completely mixed" distribution resulting from uniform injection of dye across the full width of the channel. Note that some nonuniformity remains. A distribution similar to this was the goal for developing artificial mixing structures.

Development of Rating Structure and Mixing Baffles.—Several configurations of mixing baffles were tried, including those shown in Figure 5, tapered weirs, spur dikes extending from the left bank, and various size solid baffles in several locations and configurations, without a rating section. None of these trials gave satisfactory results.

A tentative rating section was installed in the model so that the effects of mixing baffles placed in the section could be determined. The section was 600 feet (182.9 m) long, 300 feet (91.4 m) wide, and 6 feet (1.83 m) deep, with a bottom elevation of 102, Figure 8. The downstream end of the section was an average of about 65 feet (20 m) downstream from the NIB cableway. The rating section was approximately sized to accommodate an acoustic velocity meter installation. The length was sufficient for a 45° acoustic signal path with 150 feet additional length on each end.

Figure 9 shows one of the more efficient configurations of mixing baffles in the rating section with a discharge of 6,000 cfs (169.8 cu m/sec). Figure 10 gives the dye concentration profile at the NIB cableway resulting from this baffle arrangement. Each baffle was 100 feet (30.5 m) long and extended above the maximum water surface (prototype baffles should extend to the maximum water surface). The baffles were placed within the rating section to eliminate scour which would occur in the natural channel. The arrangement caused a drawdown on the downstream side of the midchannel baffle. A "jet" resulted which forced a flow pattern from the left to the right side of the section. The dye concentration profile was fairly symmetrical except on the far right side. The rating section alone without baffles had no important effect on mixing.

Figure 11 shows the velocity distributions at the NIB cableway for seven test discharges, without mixing baffles in the rating structure. For discharges of 5,000 (141.5) and 6,000 cfs (169.8 cu m/sec), the backwater from Morelos Dam affects the depth and thus the velocity in the rating section.

Figure 12 shows velocity distributions at the NIB cableway for three test discharges, with the mixing baffles of Figure 9. The effect of the mixing baffles is readily apparent. Model velocities corresponding to prototype velocities less than 2 fps (0.6 m/sec) were too small to measure, hence the curves are cut off at 2 fps. For 6,000 cfs (169.8 cu m/sec) a definite upstream current was observed along the left wall. These data indicated that baffles should not be placed in the rating section because of their effect on the velocity distribution, which would probably result in deposition of sediment.

Figure 13 gives backwater profiles through the test reach for discharges of 6,000 (169.8), 3,000 (84.9), and 1,000 cfs (28.3 cu m/sec) demonstrating the effects of the rating section and mixing baffles of Figure 9. Water surface profiles without the rating section and baffles were measured in the model. Deviations from the profiles measured in the prototype (solid lines on Figure 13) were applied as corrections to the model data recorded with the rating section and baffles, resulting in the broken lines on Figure 13. Further investigation of backwater effects is discussed later in this report.

1:36 Scale Tests.—A short section of the channel immediately below MODE 2 was simulated at a 1:36 scale, to investigate the feasibility and desirability of installing mixing baffles in that area. Because of the undesirable effects of placing baffles in the rating section, accomplishing some mixing as far upstream as possible seemed appropriate. The section shown in Figure 14 (looking upstream) is a mirror image of the prototype. Dye was injected on the side of the channel where the baffles are located. The resulting dye concentration profile is shown on Figure 15, which indicates considerable mixing. Construction of another model to represent the entire problem reach thus appeared to be justified.

The 1:60 Model

General.—A 1:60 scale model, Figure 16, representing a longer reach of the river, was constructed to further develop and evaluate the rating structure and mixing baffles. The model represented the channel from MODE 2 to a point about 800 feet (244 m) downstream from the NIB cableway. Thus, the mixing characteristics of the prototype could be more accurately simulated by including in the model the inflow at MODE 2, and the Rockwood weir. The bed was formed in concrete, using the survey cross sections and information obtained from an aerial photograph.

The riverflow originating upstream from MODE 2 was measured with a contracted rectangular weir, Figure 17, which was calibrated with a permanent laboratory orifice meter. Discharges below 2,000 cfs (56.6 cu m/sec) could only be estimated because the nappe clung to the downstream face of the weir. The MODE 2 flow, also Figure 17, was supplied from a hose which was calibrated by weighing the discharge.

The Turner fluorometer was used as described earlier to measure the profile of dye concentration at or near the NIB cableway. A precision differential water manometer, Figure 18, was used to accurately measure water surface elevation differences, and small staff gages attached to the channel bottom were used for approximate measurements.

Mixing Characteristics of the Stream.—Figure 19 shows the dye concentration profile at the NIB cableway for several discharges (the rating section referred to is described later). Injection and sampling locations varied. Curves 4 and 5 compare the results of FWQA prototype measurements with model results for dye injection in MODE 2. The data show that the model did not duplicate the mixing characteristics of the prototype stream; therefore, some runs were made with dye injection at a point near the left bank to ensure the most severe conditions possible for the model tests. It will be shown later that the point of dye injection had little effect on the efficiency of the mixing baffles.

The penetration of the MODE 2 flow into the channel is shown in Figure 20A. The flow penetrates one-half to two-thirds of the channel width, then is turned back towards the left bank, as shown in Figure 20B. Figure 21 shows the position of the dye cloud through the length of the channel. By the time the dye reaches Rockwood weir, it is confined to about the left one-third of the channel. Upon reaching the NIB, the dye is visible over less than one-half of the channel width. This condition corresponds to Curve 6 in Figure 19.

Development of the Mixing Baffles.—After several trials, the baffle sizes, configurations, and locations shown in Figure 22 were determined to be optimum. The upstream set consisted of two solid baffles, each 75 feet long, located near Station 42+50 or about 350 feet (107 m) downstream from the MODE 2 exit channel. The downstream set consisted of two 50-foot (15.2-m) long solid baffles, located near Station 10+00, or about 850 feet (259 m) upstream from the NIB cableway. The baffle heights extend above the maximum water surface.

Figure 23 shows the action of the upstream set of baffles. The staggered arrangement of the baffles caused a jet to form which directed the dye toward the right side of the channel. Also, the jet oscillated from side to side, which generated local turbulence and induced mixing. Figure 24 shows the resulting distribution of dye in the channel. It was noted that clear water, indicating no mixing, remained on the right side just downstream from the abrupt change in alinement. Thus, a downstream set of baffles, which is just beyond the range of this photograph, is necessary to redirect the flow toward the right bank and complete the mixing.

Figure 25 shows the dye concentration profile at the NIB cableway with both baffle sets in place, with dye injection in MODE 2 or near the left bank. Note from Curves 5 and 6 that the baffle efficiency of mixing is not sensitive to the difference in location of dye injection. Curve 1 shows that the baffles are inadequate for the minimum discharge of 750 cfs. However, injection of dye on the left bank probably represents an unduly severe initial condition in this particular case. In reality, initial mixing which would be expected to occur in the channel near MODE 2, should result in a very uniform distribution at the NIB cableway with the baffles in place. Curves 8 and 9 on Figure 25 show the variation of the distribution with time.

Figure 26 shows the surface and bottom patterns of flow around the upstream set of baffles. Upstream currents were observed along the left bank upstream from the baffles. Figure 27 shows the surface flow pattern for the downstream set of baffles. Figure 28 gives measured average velocities in the vicinity of the baffles for Q = 6,000 cfs (169.8 cu m/sec) (the velocities were highest for this discharge). Maximum local velocities up to approximately 10 fps (3 m/sec) might be expected.

The Rating Structure.--Figure 29 shows a possible configuration for the rating structure (assuming discharge measurement at the NIB cableway), which is 300 feet (91.4 m) wide, 400 feet (121.9 m) long, and 6 feet (1.83 m) deep. The structure was sized according to the available channel width and to accommodate an acoustic velocity meter with the transducers mounted for one signal path of 45^{o}. The length of the structure allowed 50 feet upstream and downstream from the signal path. This distance was considered to be adequate. The bottom of the structure is horizontal at elevation 103. The downstream end of the section is located an average of approximately 65 feet (19.8 m) downstream from the NIB cableway. The transition shapes shown upstream and downstream from the section were determined arbitrarily for the model tests. These transitions would be either solid structures or riprap protected slopes. The structure is placed as close as possible to the left bank of the channel, in case some skewness in the salinity distribution remains.

Figure 30 shows the water surface profiles with the rating structure and baffles, to determine the backwater effect of these appurtenances. Approximate elevations were determined from staff gages and verified with a precision manometer. The governing criterion was that the water surface elevation at the gage upstream from Rockwood weir should not exceed elevation 108.2 at a discharge of 4,000 cfs (121.9 cu m/sec). Figure 30 shows this water surface elevation to be 106.5, which is well within this limit. By comparing the water surface elevation on Figures 13 and 30, it will be noted that the backwater effect of the rating structure and baffles actually decreased with increasing discharge; so that water surface elevations with and without the baffles and rating structure for the maximum discharge of 6,000 cfs (169.8 cu m/sec) were nearly identical; for 3,000 cfs (84.9 cu m/sec) the baffles and rating structure raised the water surface 0.4 foot (0.12 m) above that for the natural channel without structures; and for 1,000 cfs (28.3 cu m/sec) about 1.3 feet (0.40 m). Also, comparison with Figure 13 shows that the Figure 9 configuration caused more backwater than the configuration described in this section. Figure 30 also shows that for several discharges, a slight increase in water surface elevation occurred as the flow passed across the Rockwood weir. This reflects the controlling effect of the channel geometry between the rating section and the Rockwood weir.

Figure 31 shows velocities in or near the rating structure with and without the downstream set of baffles. Velocity measurements at the NIB for discharges of 4,000 (113.2) and 6,000 cfs (169.8 cu m/sec) show no effect from the baffles. Measurements taken immediately upstream from the rating structure, for the 4,000 cfs discharge, indicate the effect of the baffles and also show the smoothing effect of the rating structure either with or without the baffles. The data for the 2,000 cfs (56.6 cu m/sec) discharge showed that nonuniformity existed both upstream and downstream from the rating structure, whether or not the baffles were in use. Measurement of velocity at the NIB cableway was not possible because of the shallow depth with 2,000 cfs.

Figure 32 shows the movement of confetti through the rating structure, with the baffles in place. The downstream end of the eddy produced by the baffles can be seen at the right edge of the photograph in Figure 32.

Figure 33 shows water surface profiles measured within the rating structure for discharges of 6,000 (169.8), 4,000 (113.2), and 750 cfs (21.2 cu m/sec). The flow accelerates through the structure and, as indicated by the data for 4,000 and 750 cfs, the depth is greater on the left side than on the right at the NIB cableway. These observations must be considered when designing the acoustic velocity meter installation. The data for 750 cfs, measured at the NIB cableway appears to be in error, as far as the absolute value of the depth is concerned.

For discharges less than 4,000 cfs, the flow passes through critical depth at the downstream end of the rating structure. The maximum drop is 1.3 feet at 750 cfs. The water surface disturbance at the downstream end of the structure in Figure 32 shows that the drawdown curve is barely submerged at Q = 4,000 cfs.

The model also showed a slight drop in the water surface and accompanying surface disturbance at the upstream end of the structure for discharges less than 4,000 cfs. The maximum drop was approximately 0.2 foot at 750 cfs.

Without the single-path acoustic velocity meter, the rating structure could be shortened considerably and used as a stabilized section for current meter measurements and as a control for determining the stage discharge relationship. A family of curves, however, would be necessary because of the variable backwater from Morelos Dam.

First Channel Modification.—To determine the effects of channel improvement, the model was modified by filling in the cove on the left side of the channel near Station 15+50 and removing the point on the opposite bank. The modification extended from Station 9+87 to Station 23+00. The banks between these two stations were straight and the bottom was essentially planar.

Figure 34A shows the movement of dye in the modified channel without mixing baffles. The dye appeared to occupy a greater portion of the river than it did with the unmodified channel, Figure 21. However, this was true only in the portion of the channel upstream from the Rockwood weir; downstream from that point, the dye was again confined to a narrow strip near the left bank. The previously developed baffles, appeared to be as efficient as before, Figure 34B.

Figure 35 shows the distribution of dye at the NIB cableway with the rating structure for discharges of 3,000 (84.9), 3,510 (99.3), and 4,000 cfs (113.2 cu m/sec), with and without both sets of baffles. These data indicate that the baffles were slightly less efficient for this channel modification than for the unmodified channel, Figure 25. Apparently, the wide area in the channel between Stations 27+00 and 39+00 (approximately) and the reduction of channel curvature makes the velocity distribution more uniform. Thus, the transverse shear is reduced and less mixing takes place.

This modification had no effect on the rating structure and negligible effect on the water surface profiles in the channel.

Second Channel Modification.—The model was further modified by blocking off the wide area to the left of the upstream island with a sand dike. Figure 36A shows the distribution of dye without mixing baffles in the channel. The dye appeared to be mixed less than that observed with the first modification, probably because of the lack of a deceleration zone. The upstream set of mixing baffles performed as before, Figure 36B.

The configuration of the downstream baffles was changed and the baffles were moved about 850 feet upstream; the new configuration was similar to that of the upstream baffles and each baffle was 50 feet long. This change was made to attempt to overcome some of the mixing efficiency lost by modifying the channel shape.

Figures 37 and 38 show dye distributions at the NIB cableway for the full range of test discharges with and without the mixing baffles. The data indicate that this baffle arrangement works well for the modified channel. Again, the exception is for the minimum discharge of 750 cfs (21.2 cu m/sec), for which the initial mixing at MODE 2 could not be determined.

The water surface profiles in the channel remained unchanged. Because the downstream baffles were moved to a location farther upstream, the rating structure was completely unaffected by the baffles.

Figure 39 shows the pattern of surface circulation around the downstream baffles for a discharge of 4,000 cfs (113.2 cu m/sec).

Small plastic chips, with a specific gravity slightly greater than that of water, were placed in the stream to determine qualitatively the areas where deposition of sediment might be expected to occur. Figure 40 shows several areas of deposition after 4 hours of model operation at a discharge of 4,000 cfs (113.2 cu m/sec). Similar deposits in the vicinity of the baffles would be expected for the unmodified channel.

Sampling Procedure

The studies indicated that with the recommended mixing baffles and no channel improvements, a single sample withdrawn at the midpoint of the rating structure at the NIB cableway would result in an approximate deviation of ±10 percent from the average concentration. Two samples, withdrawn at the one-fourth and three-fourths points, would reduce this deviation to approximately ±3 percent. These estimates are based on the distributions shown in Figure 25.

Variation of measured dye concentration at the midsection sampling point, under steady conditions, ranged from ±16 to ±45 percent of the average concentration (± 45 for 6,000 cfs (169.8 cu m/sec) only) over a time interval of 10 to 15 minutes (prototype). A suggested procedure would be to withdraw a continuous sample over a period of 15 minutes. An alternative procedure, though less accurate, would be to average five samples taken at 3-minute intervals. The final sampling procedure could easily be determined in the prototype.

Feasibility Design

Following completion of the tests described thus far in this report, the decision was made that any rating structure would be constructed entirely within the United States. The suggested structure described above was located under the assumption that the quality and discharge would be measured at the Northern

International Boundary cableway, as under the presently existing procedure. Locating the structure farther upstream would also require moving the downstream set of mixing baffles for the unmodified channel configuration.

The Hydraulic Structures Branch, Division of Design, prepared a feasibility design for the purpose of estimating the cost of construction. An artist's conception of the structures is the frontispiece to this report. To minimize the length of the structure and the path length of acoustic signals for velocity measurement, three intermediate longitudinal walls were added. The rating structure thus designed includes a 100-foot-long horizontal concrete floor at elevation 103. The horizontal section is 300 feet wide with the three vertical walls dividing the structure into four 75-foot-wide bays. The three interior walls extend to elevation 110. The tops of the sidewalls are at elevation 112. Concrete transitions 35 and 50 feet long with warped sidewalls are included upstream and downstream, respectively, of the horizontal section, with 50 feet of riprap beyond each transition. The downstream end of the downstream riprap is at the NIB. Thus the upstream end of the rating structure is approximately 250 feet upstream from the location assumed during the model study.

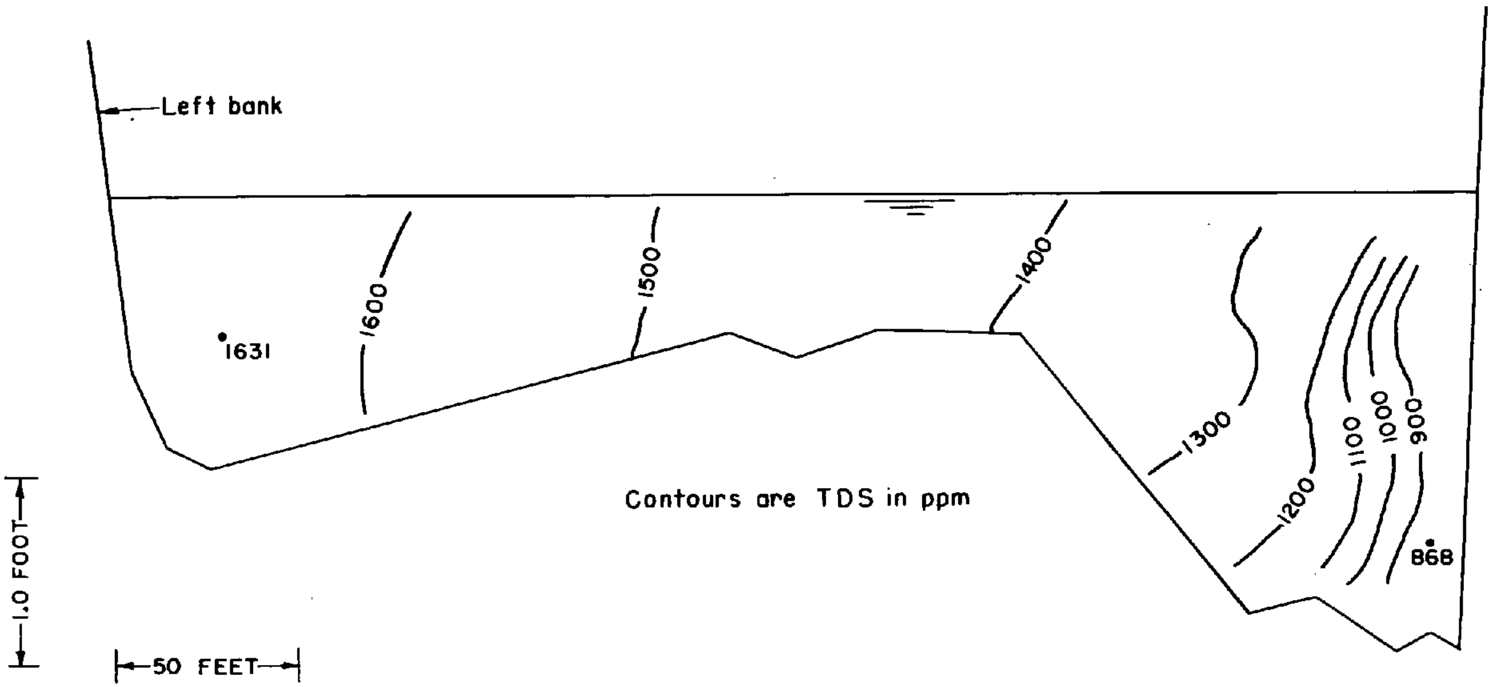
Additional tests were performed on the 1:60 model of the unmodified channel to optimize the location and configuration of the downstream mixing baffles with the rating structure just described.

Mixing was evaluated by sampling the dye distribution immediately upstream from the rating structure with the fluorometer. The configuration of the downstream baffles developed earlier was shown to be unsatisfactory when the baffles were moved about 200 feet upstream from their original location. The island in the right portion of the channel, immediately opposite the baffles, apparently blocked the spreading of the dye.

The model was operated for total river discharges at the NIB of 1,000, 2,000, 3,000, 4,000, 5,000, and 6,000 cfs. Dye was injected at MODE 2 with just enough water to carry the dye into the channel with minimal initial mixing. The upstream baffles remained as developed during the earlier part of the model study. After several trials, downstream baffles were developed which improved the dye distribution, Figure 41. The downstream baffles are 50 feet long in a configuration similar to the upstream baffles and are located at Station 11+94, approximately 400 feet upstream from the concrete floor of the rating structure. The downstream baffles and rating structure in the model are shown in Figure 42.

Some nonuniformity remains, particularly for discharges of 2,000 and 3,000 cfs. Removal of the island mentioned above would be beneficial.

Figure 43 shows suggested locations and configurations for the mixing baffles and rating structure, for a modified or unmodified river channel.



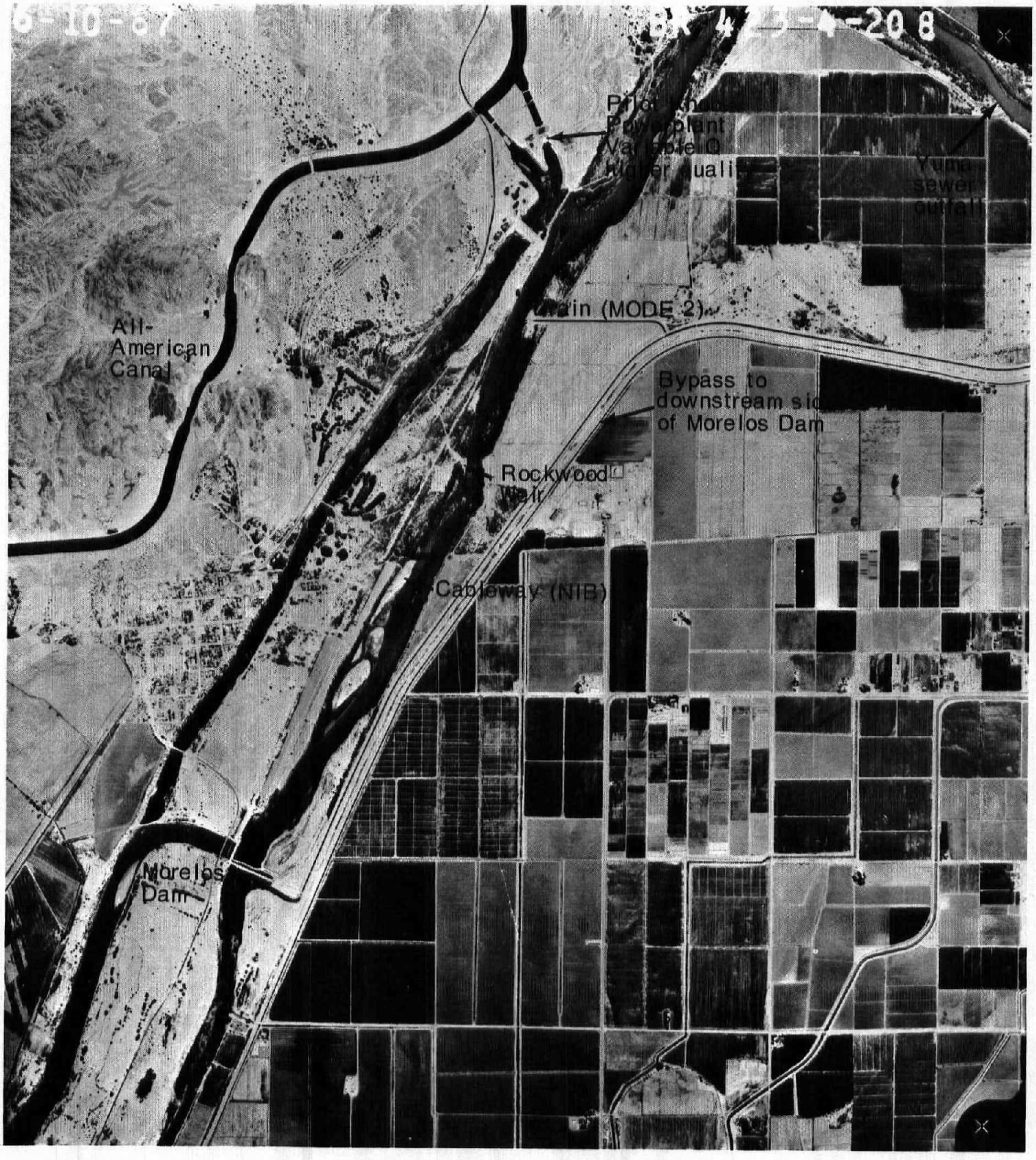
COLORADO RIVER STUDY

WATER QUALITY AT THE NORTHERN INTERNATIONAL BOUNDARY ON JULY 10, 1968

DISCHARGE = 2098 CFS

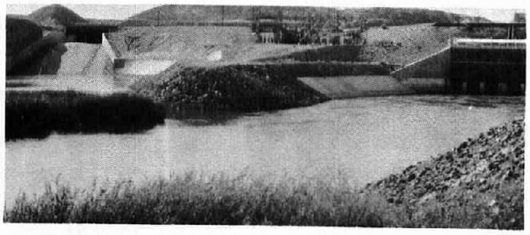
FIGURE 1

FIGURE 2



COLORADO RIVER STUDY

Aerial View of Study Reach

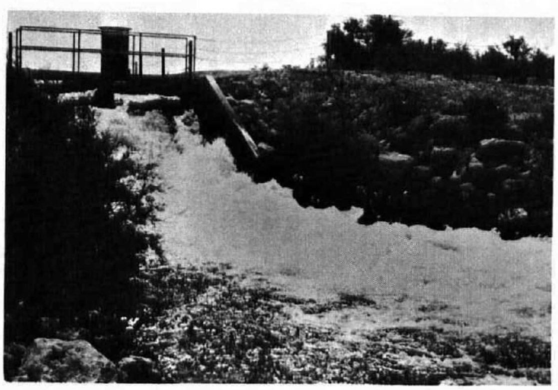


A. Pilot Knob Powerplant and wasteway. Photo PX-D-66010

B. Problem reach looking upstream from NIB cableway. Photo PX-D-66011

C. Old Rockwood weir, looking upstream across left side of weir. Photo PX-D-66012

D. Cove and old piling, looking downstream from near Rockwood weir. Photo PX-D-66013

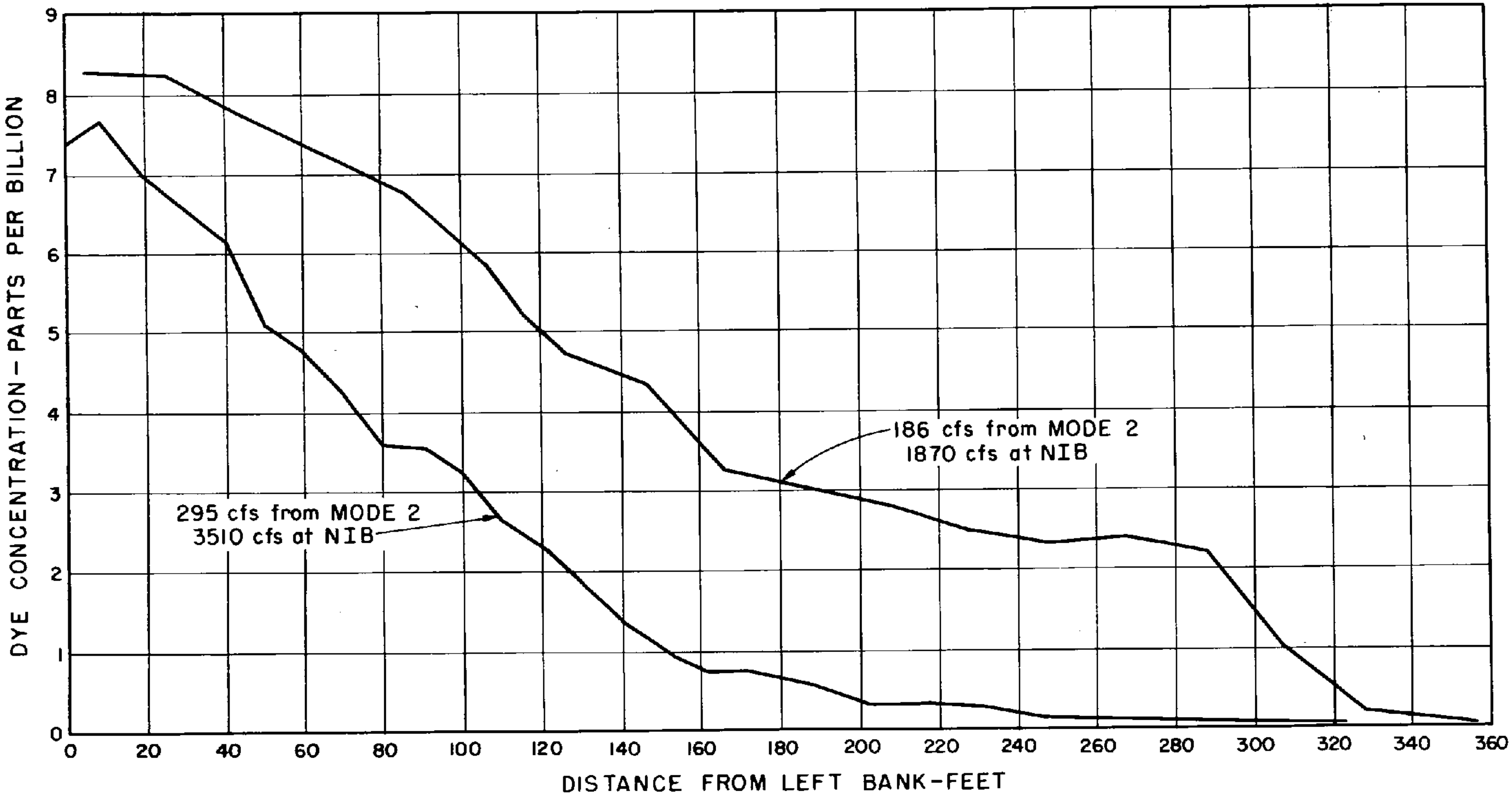


E. Baffled drop at MODE 2. Photo PX-D-66014

COLORADO RIVER STUDY

Important Channel Features

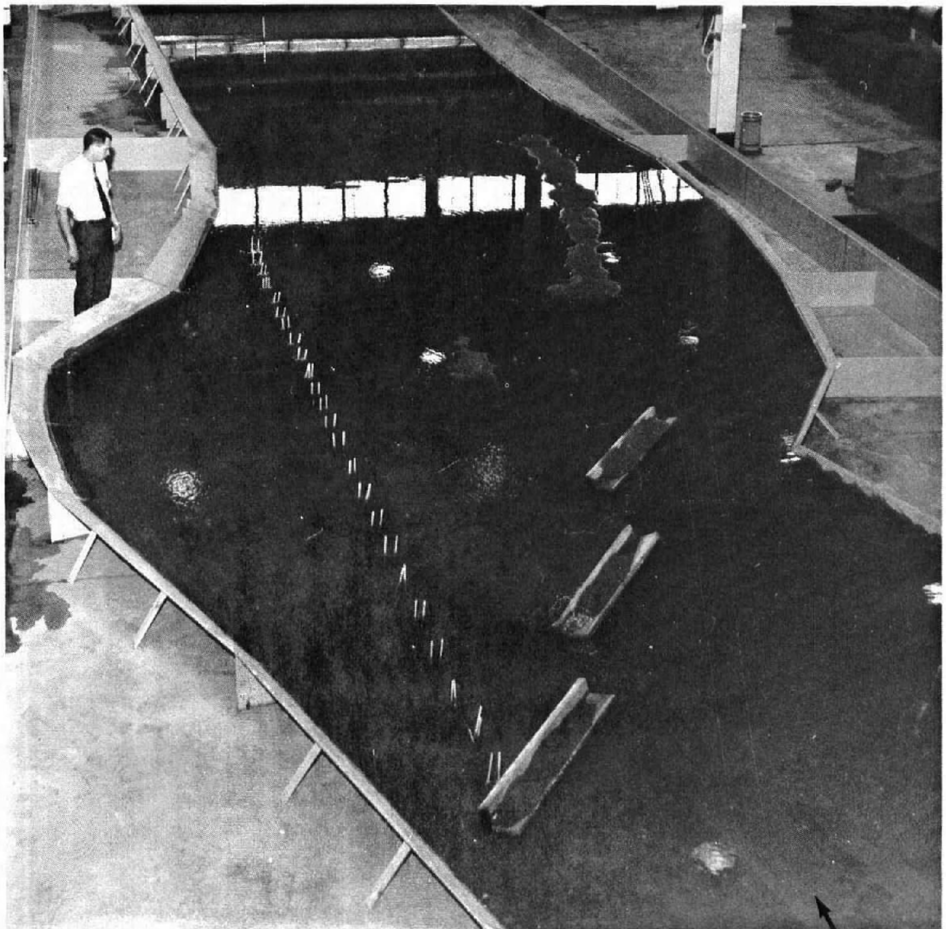
FIGURE 4



COLORADO RIVER STUDY

FWQA PROTOTYPE DYE TESTS

FIGURE 5

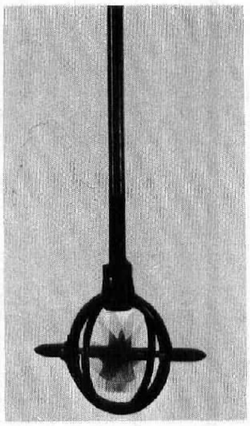


FLOW

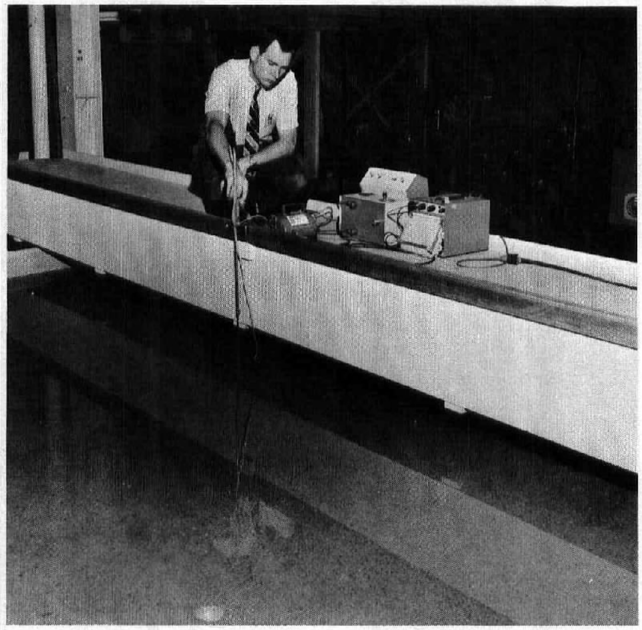
COLORADO RIVER STUDY

Configuration of 1:24 Model
Photo PX-D-66015

FIGURE 6



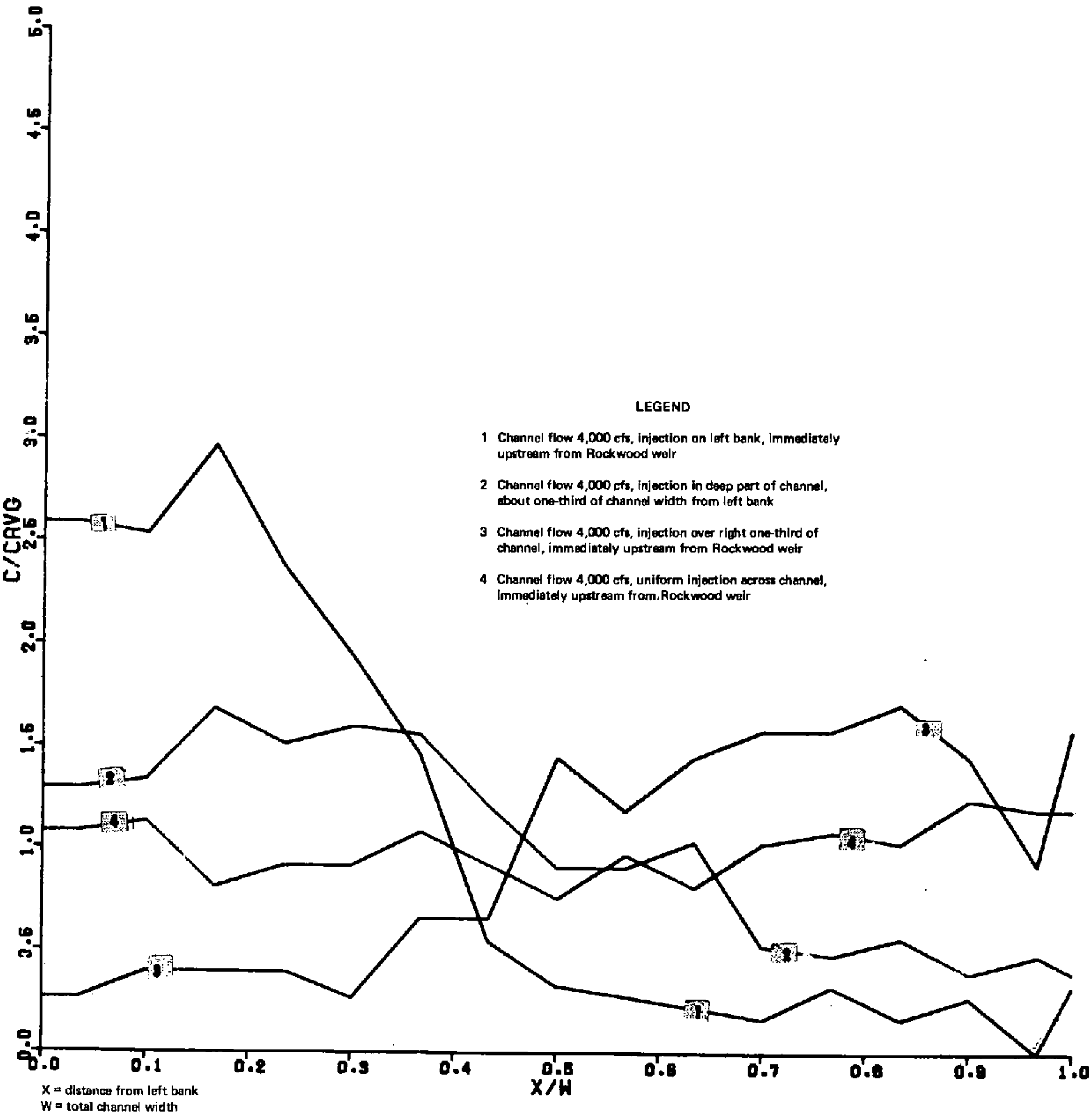
A. Miniature propeller meter for velocity measurement. Photo PX-D-63971



B. Instrumentation for dye sampling. Photo PX-D-63965

COLORADO RIVER STUDY

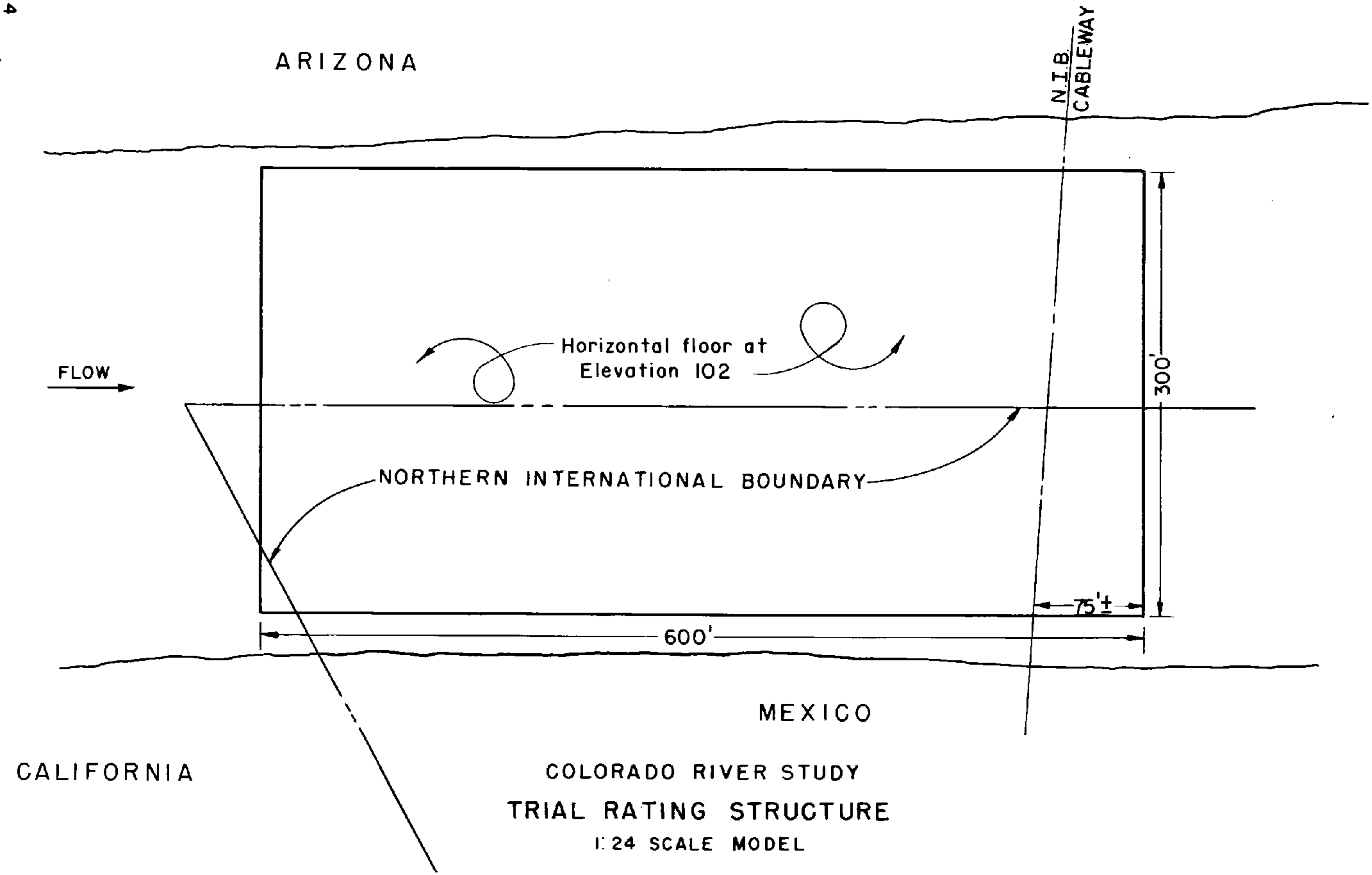
Instrumentation



COLORADO RIVER STUDY

1:24 Scale Model
Natural Mixing at NIB Cableway in Model Channel

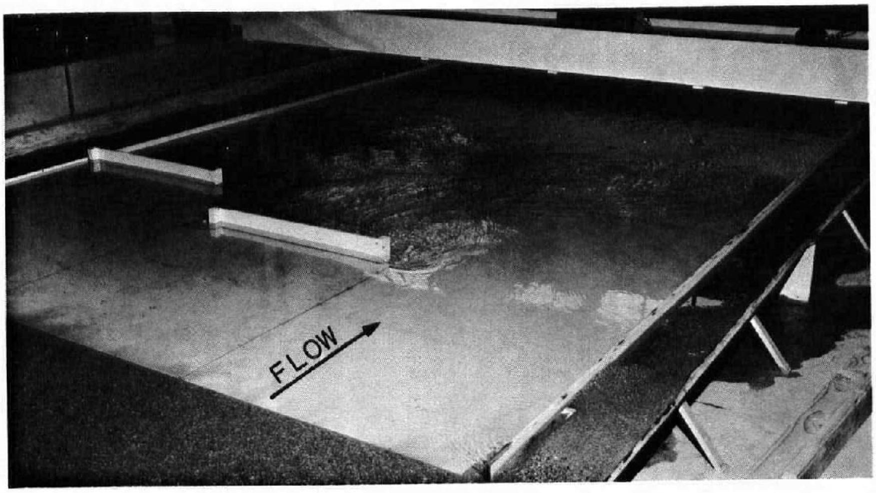
FIGURE 8



COLORADO RIVER STUDY

TRIAL RATING STRUCTURE

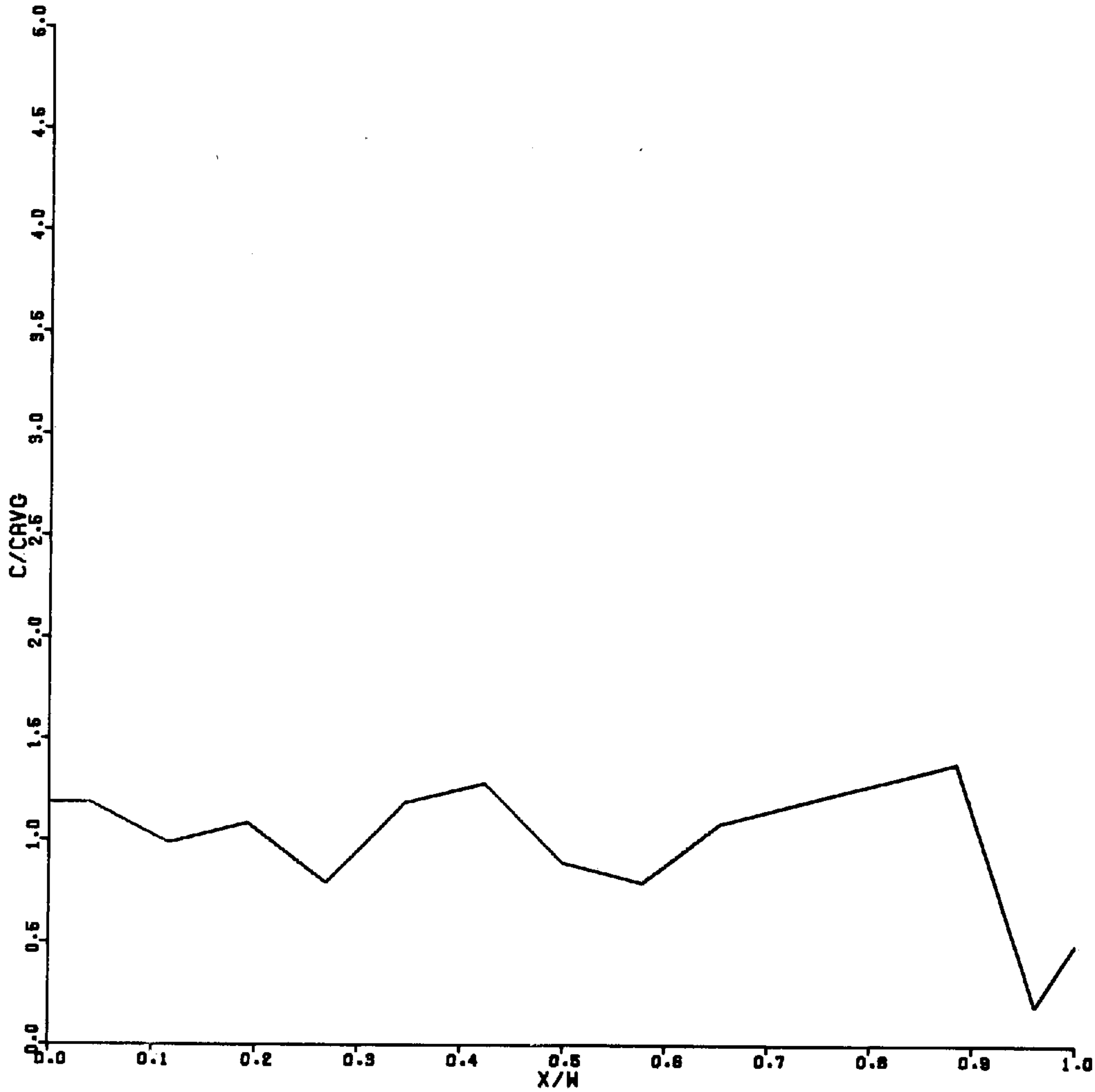
1:24 SCALE MODEL



COLORADO RIVER STUDY

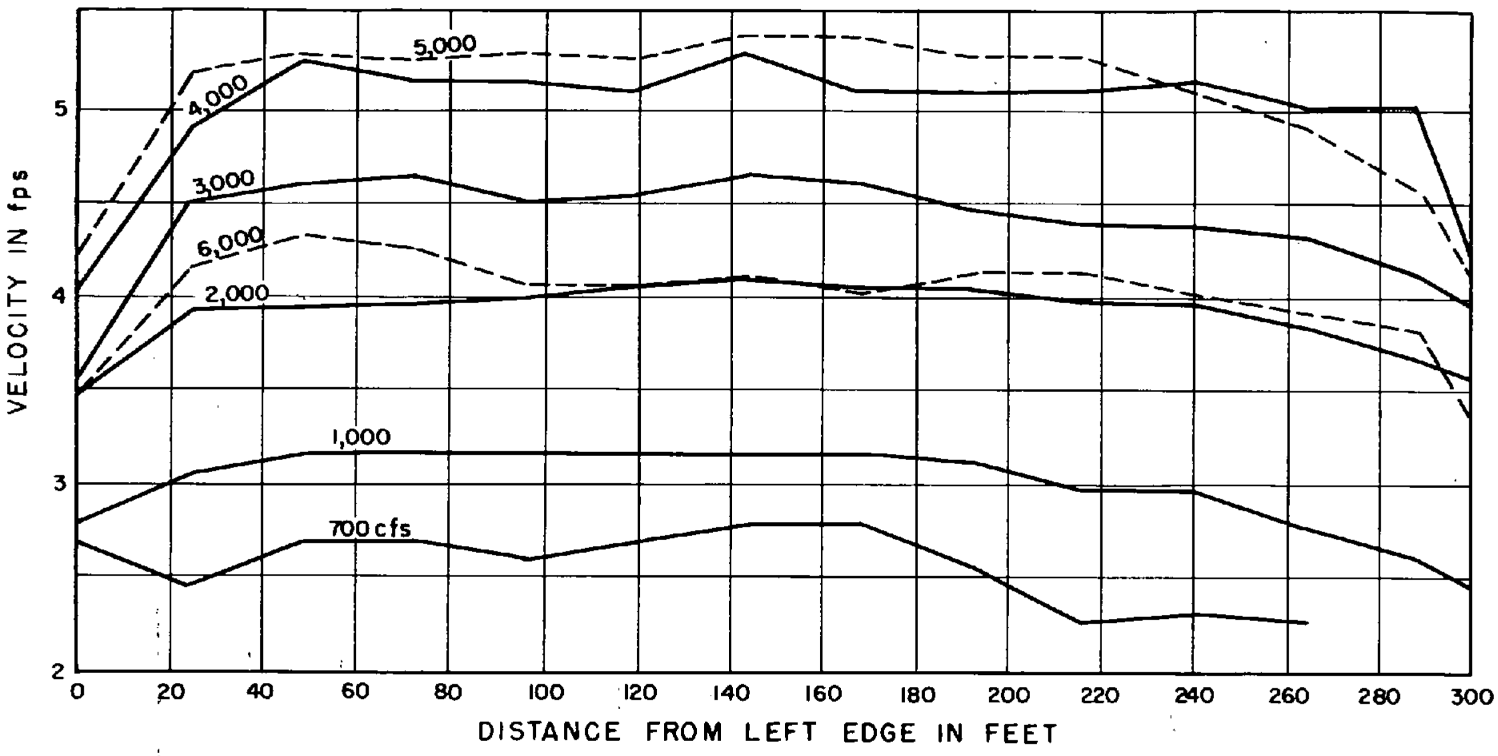
1:24 Scale Model
Mixing Baffles in Rating Structure Q = 6,000 cfs
Photo PX-D-66016

FIGURE 10



COLORADO RIVER STUDY

1:24 Scale Model
Mixing Effect of Baffles in Rating Structure, Q = 6,000 cfs



COLORADO RIVER STUDY

VELOCITY DISTRIBUTION AT N. I. B. CABLEWAY

300 FT. WIDE RATING SECTION

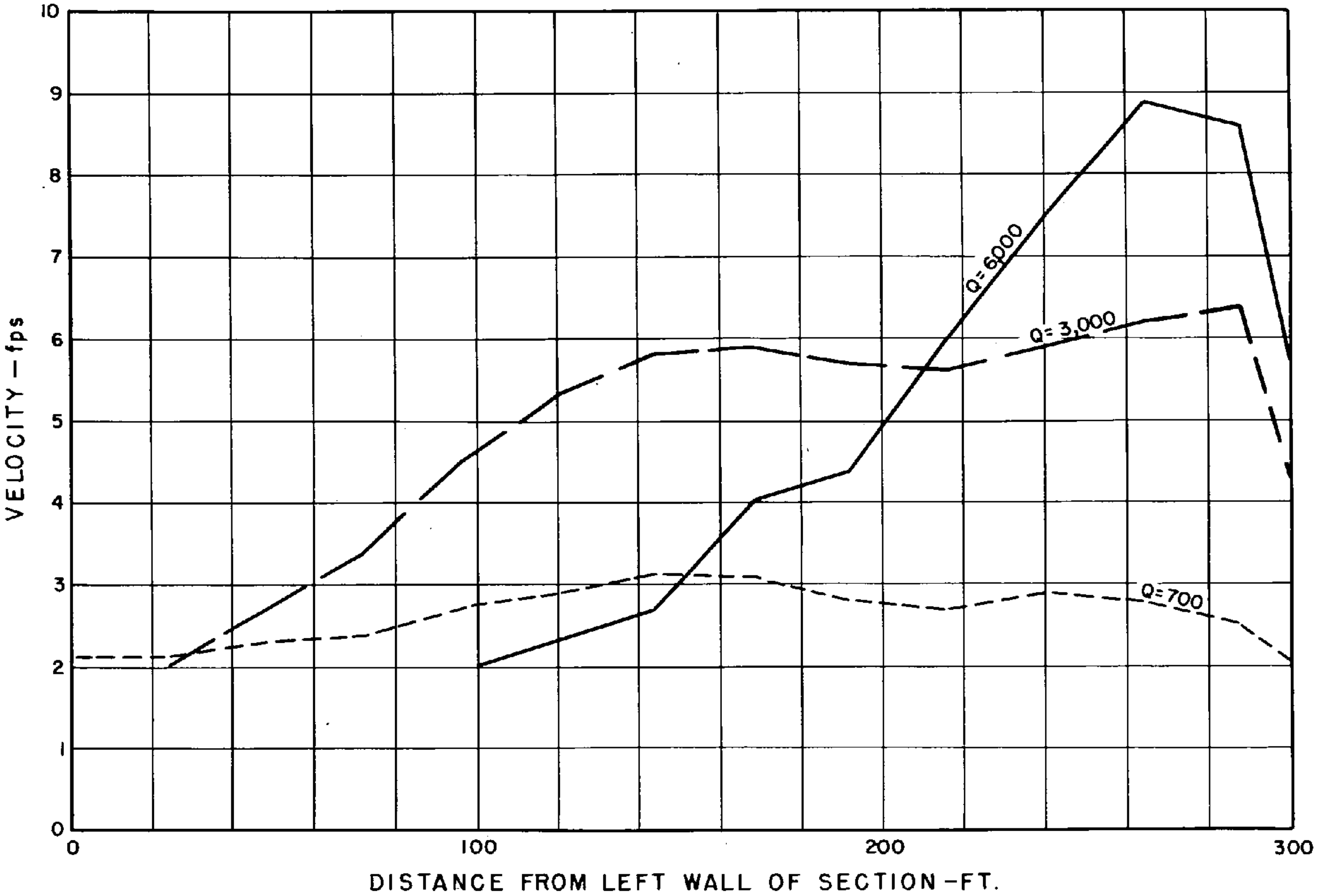
NO BAFFLES

1:24 SCALE MODEL

FIGURE 11

744

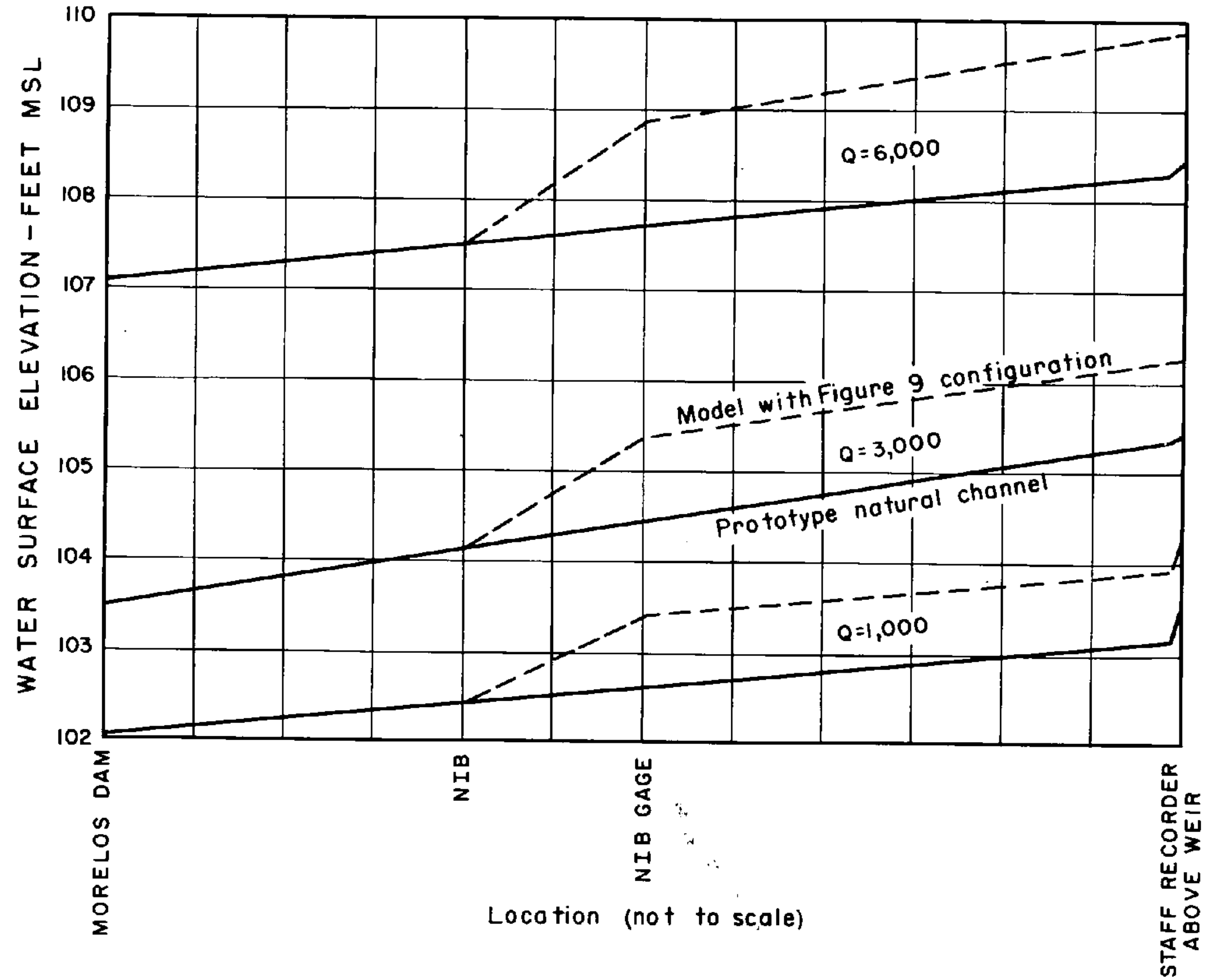
FIGURE 12



COLORADO RIVER STUDY

VELOCITIES IN RATING STRUCTURE WITH BAFFLES

1:24 SCALE MODEL



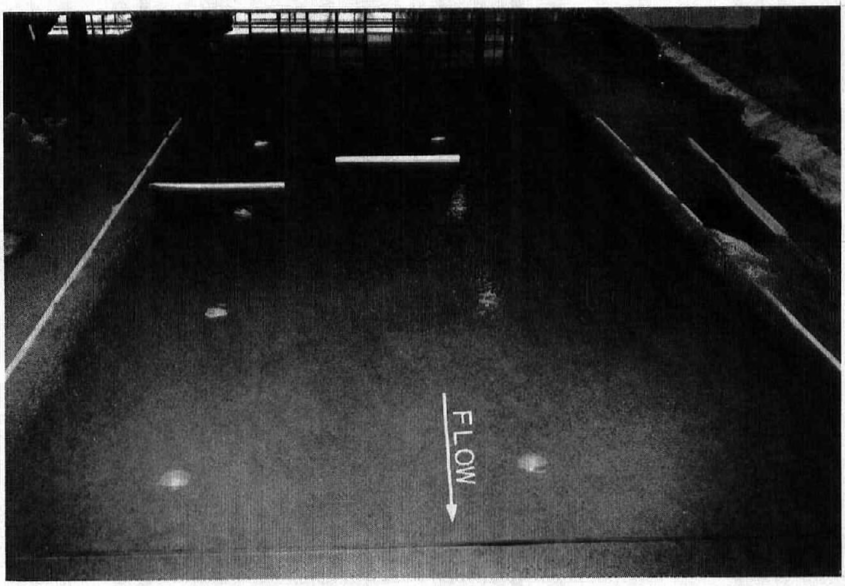
COLORADO RIVER STUDY

BACKWATER PROFILES WITH RATING STRUCTURE AND MIXING BAFFLES OF FIGURE 9

1:24 SCALE MODEL

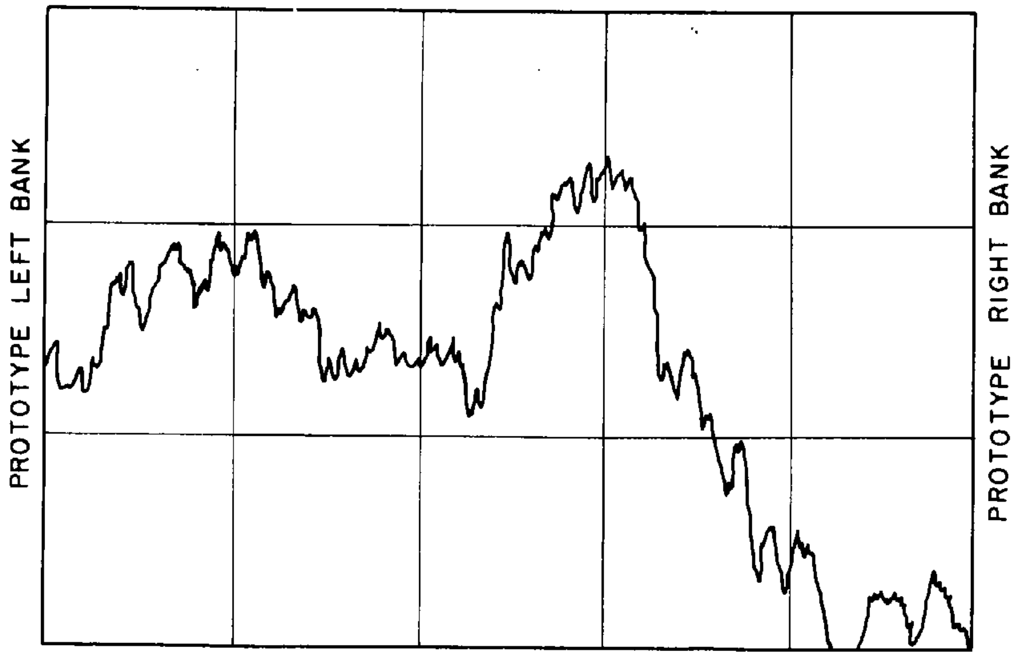
FIGURE 13

FIGURE 14



COLORADO RIVER STUDY

1:36 Scale Model
Mixing Baffles Immediately Downstream from MODE 2.
Photo PX-D-66017



COLORADO RIVER STUDY

MIXING EFFECT OF BAFFLES SHOWN IN FIGURE 14

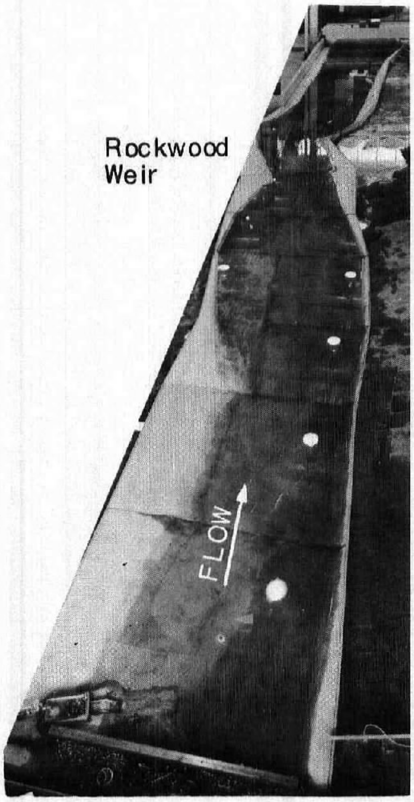
1:36 SCALE MODEL

744

FIGURE 16

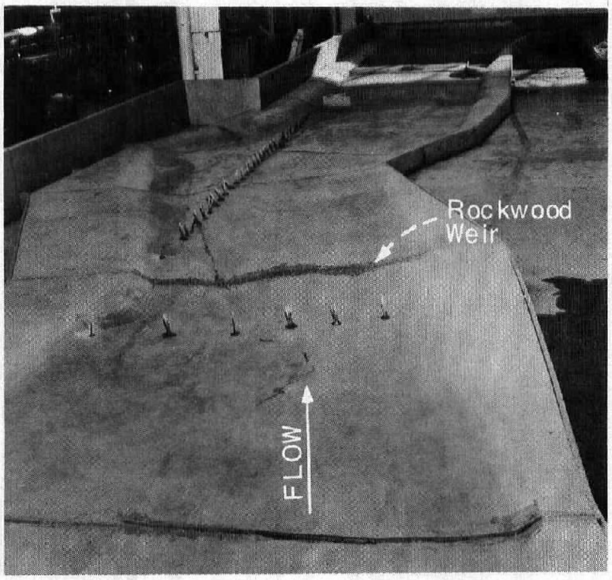
NIB

Rockwood
Weir



MODE 2

A. Overall view of 1:60 model. Photo PX-D-66018

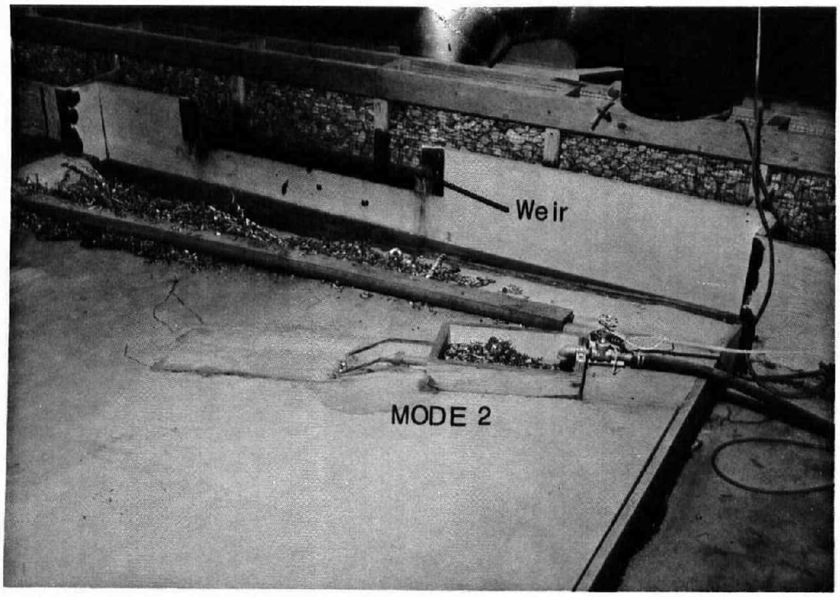


B. Rockwood weir and cove area. Photo PX-D-66019

COLORADO RIVER STUDY

1:60 Scale Model
Model Configuration

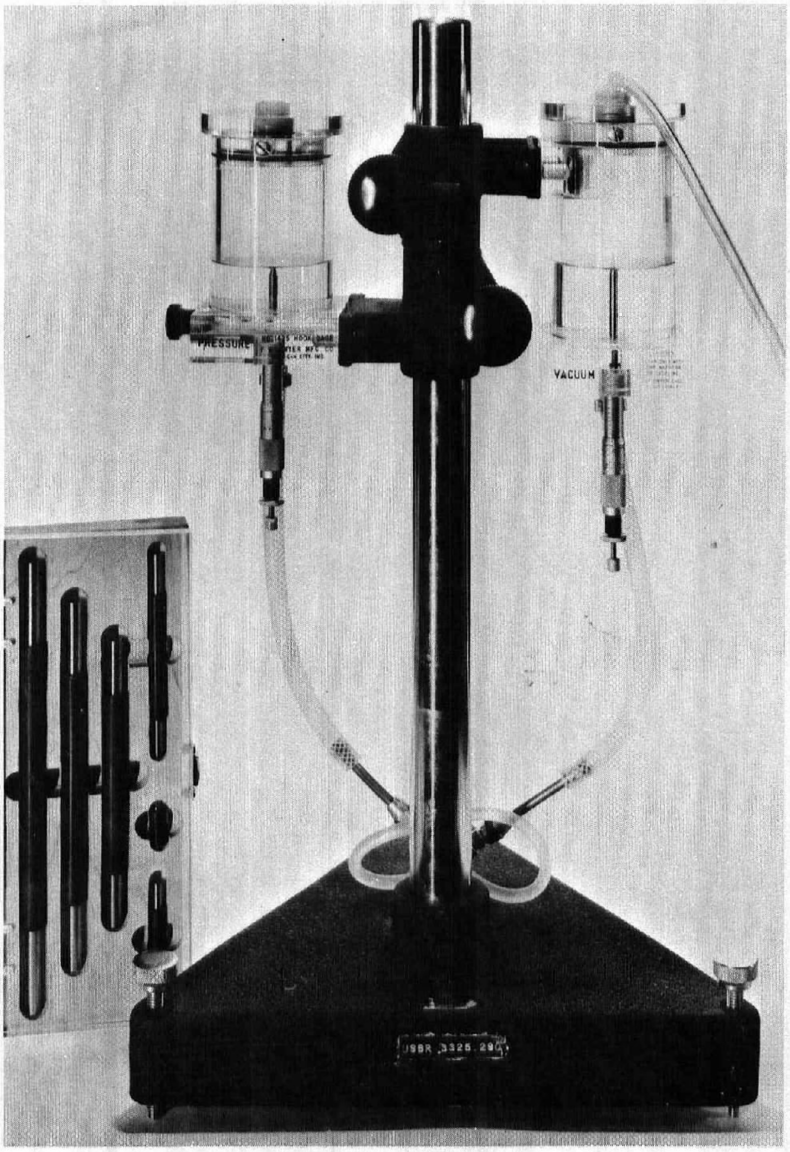
FIGURE 17



COLORADO RIVER STUDY

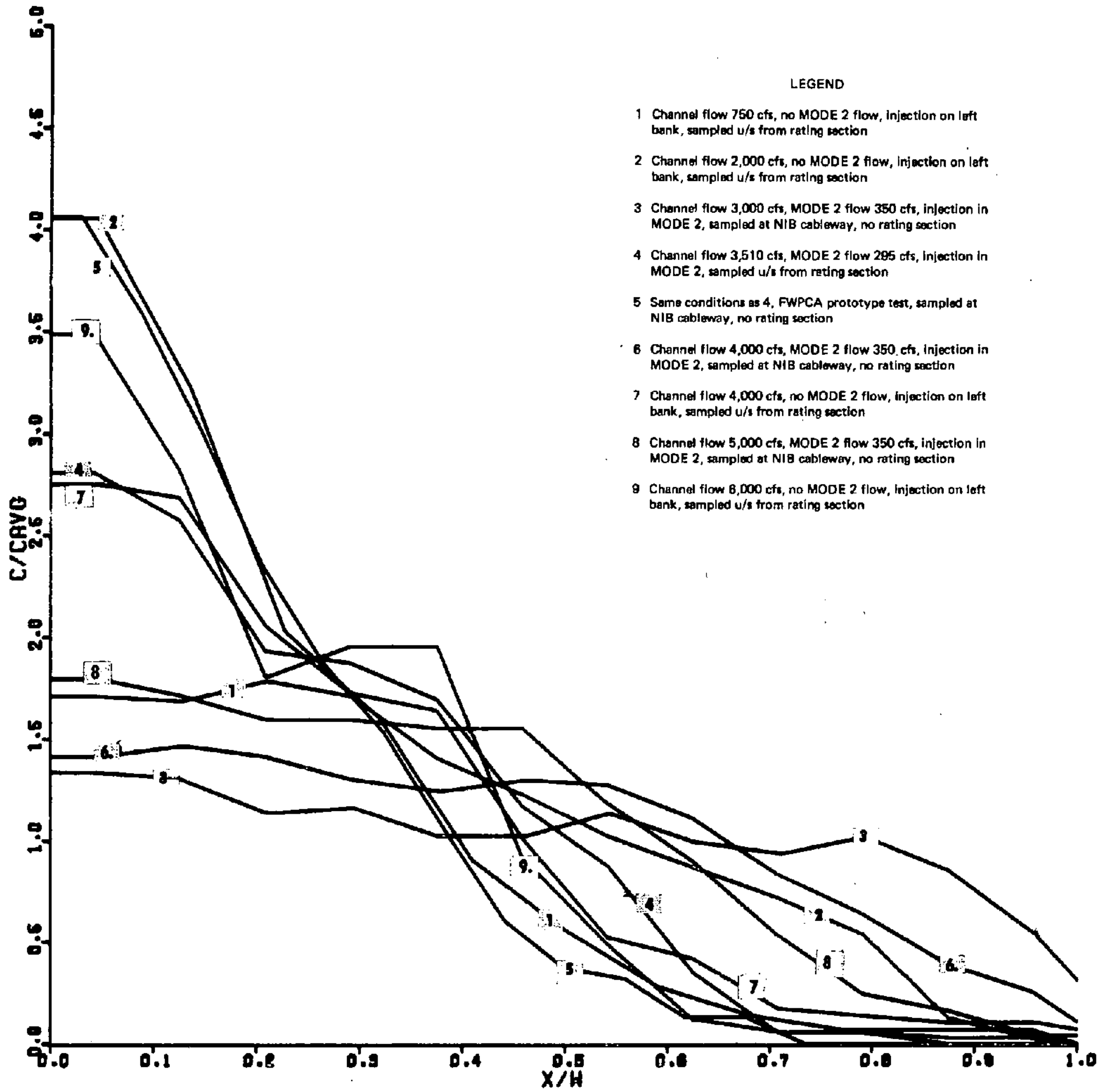
1:60 Scale Model
Water Supplies and Weir for Discharge Measurement
Photo PX-D-66020

FIGURE 18



COLORADO RIVER STUDY

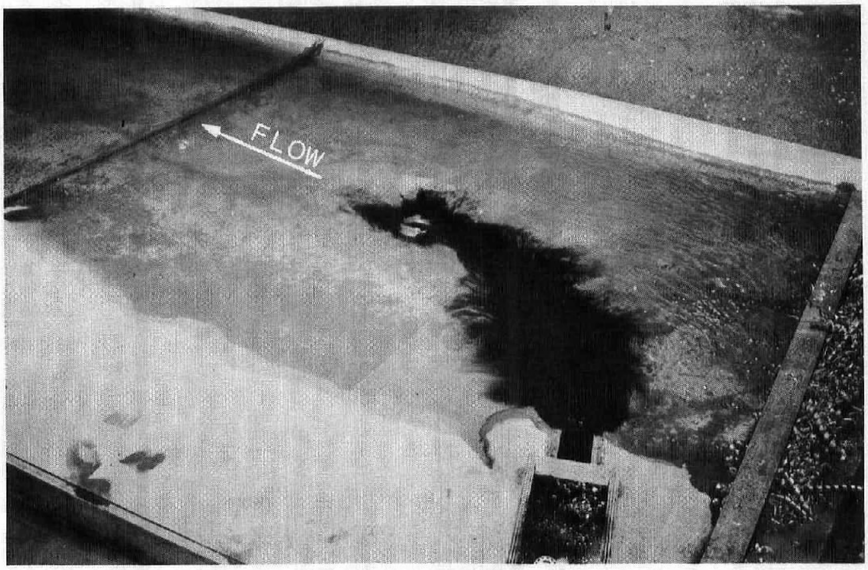
1:60 Scale Model
Precision Differential Water Manometer
Photo PX-D-66021



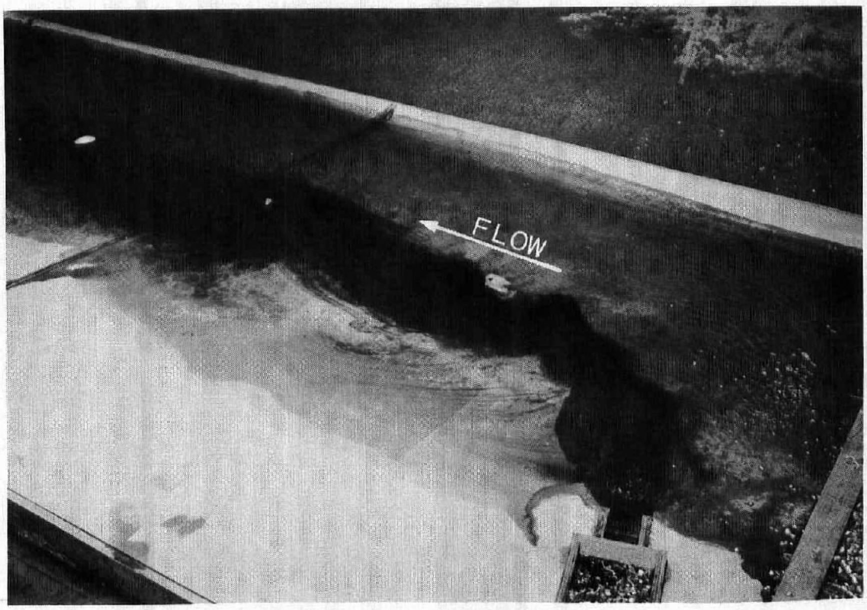
COLORADO RIVER STUDY

1:60 Scale Model
Natural Mixing in Model Channel

FIGURE 20



A. Initial penetration. Photo PX-D-66022



B. Distribution after several seconds. Photo PX-D-66023

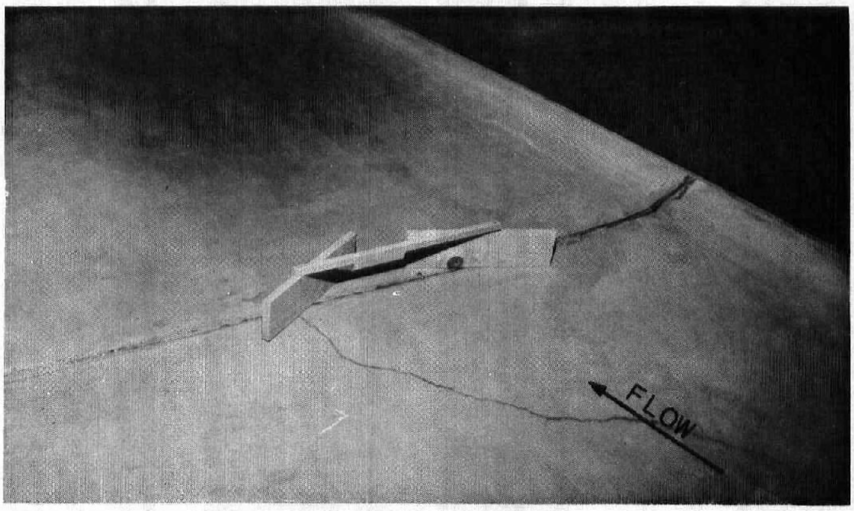
COLORADO RIVER STUDY

1:60 Scale Model
Natural Mixing in Model Channel, MODE 2
Q = 350 cfs, Total River Q = 4,000 cfs

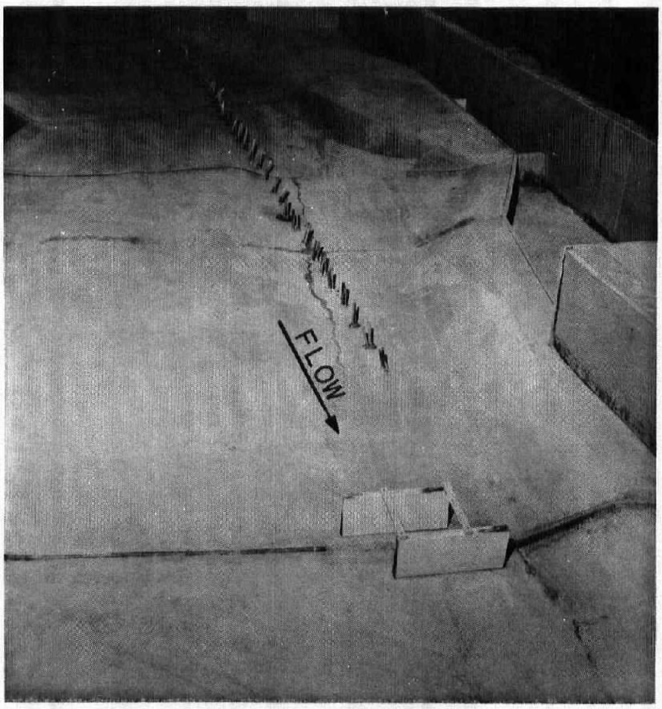
COLORADO RIVER STUDY

1:60 Scale Model
Natural Mixing in Model Channel, MODE 2
Q = 350 cfs, Total River Q = 4,000 cfs
Photo PX-D-66024

FIGURE 22



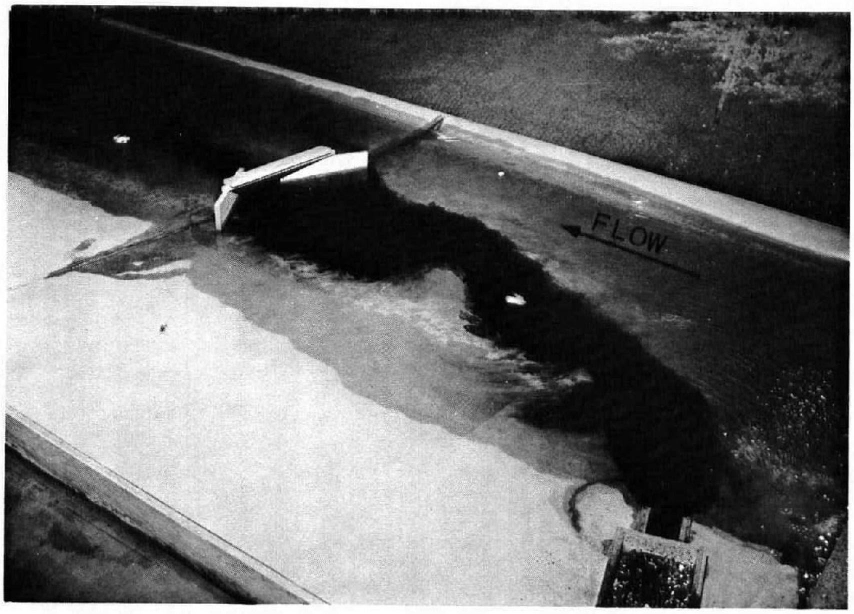
A. Upstream set. Photo PX-D-66026



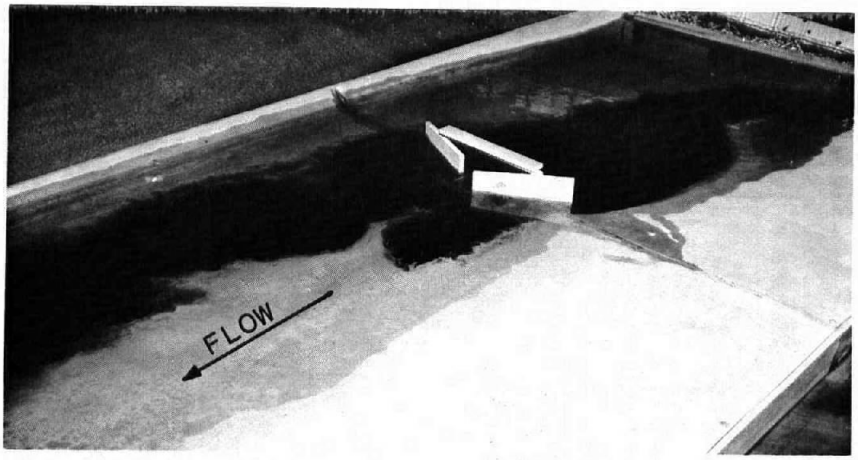
B. Downstream set. Photo PX-D-66025

COLORADO RIVER STUDY

1:60 Scale Model
Configurations of Mixing Baffles



A. Looking downstream from left bank. Photo PX-D-66028

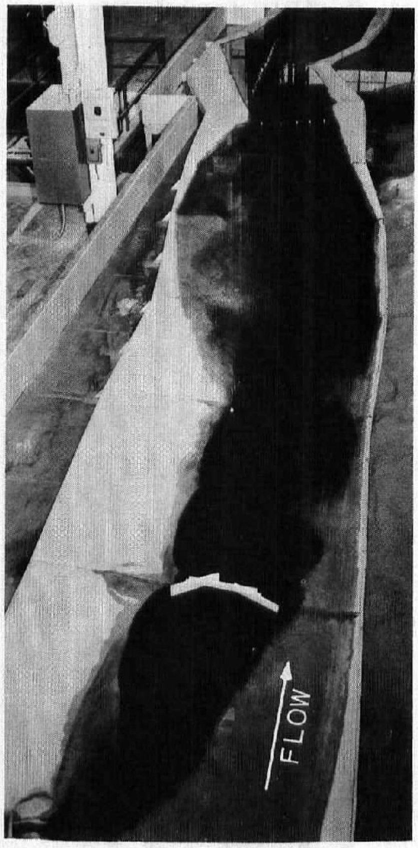


B: Looking upstream from left bank. Photo PX-D-66027

COLORADO RIVER STUDY

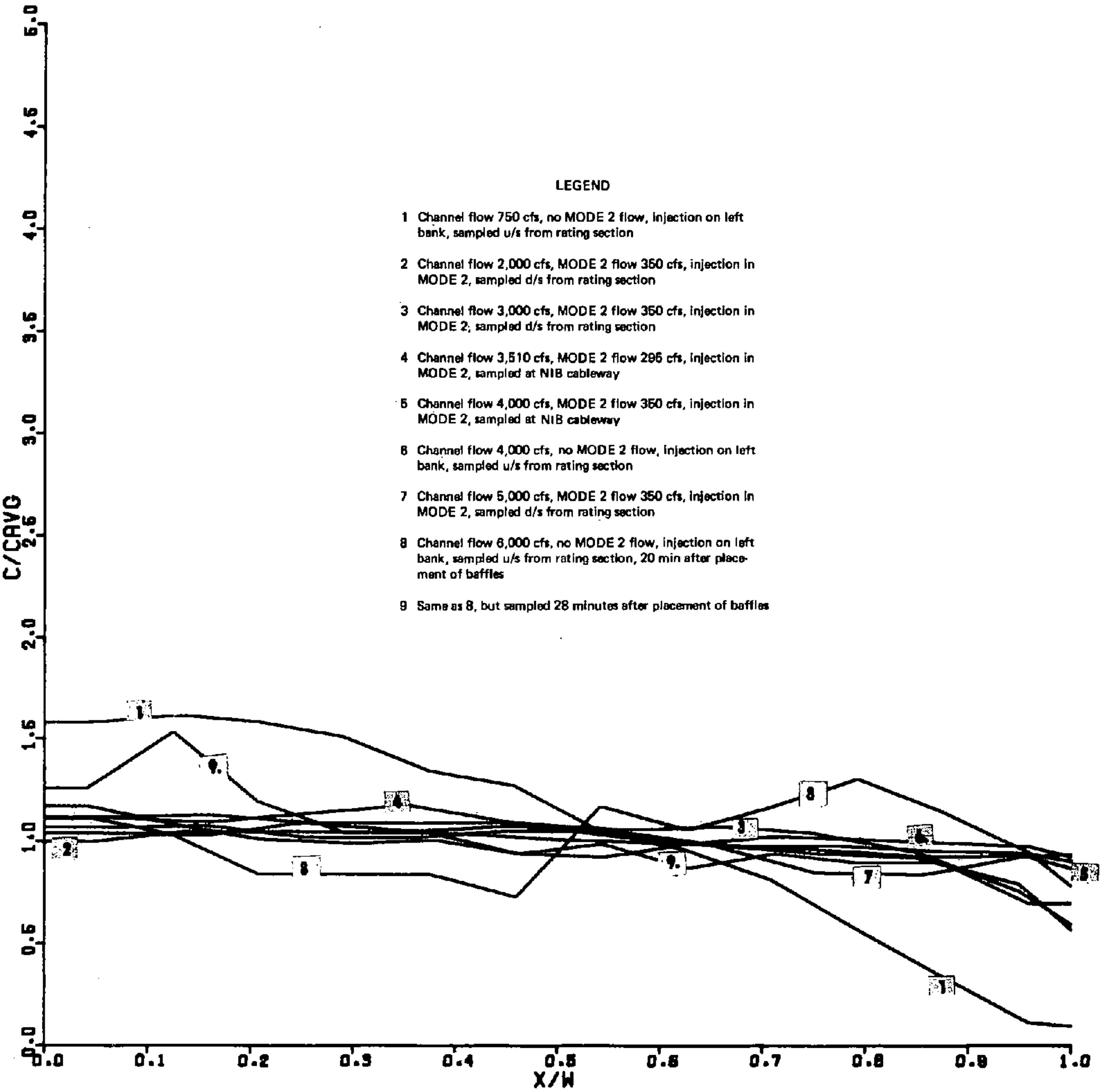
1:60 Scale Model
Performance of Upstream Mixing Baffles MODE 2
Q = 350 cfs, Total River Q = 4,000 cfs

FIGURE 24



COLORADO RIVER STUDY

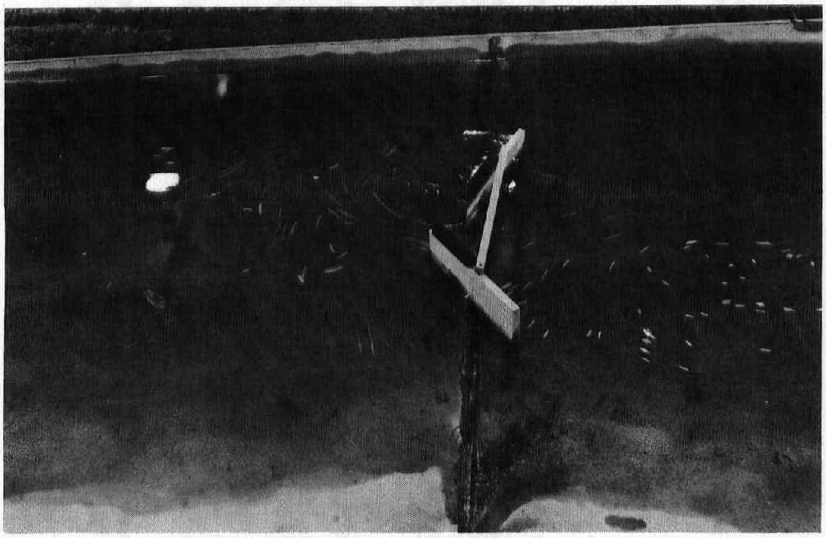
1:60 Scale Model
Performance of Upstream Mixing Baffles MODE 2
Q = 350 cfs, Total River Q = 4,000 cfs
Photo PX-D-66029



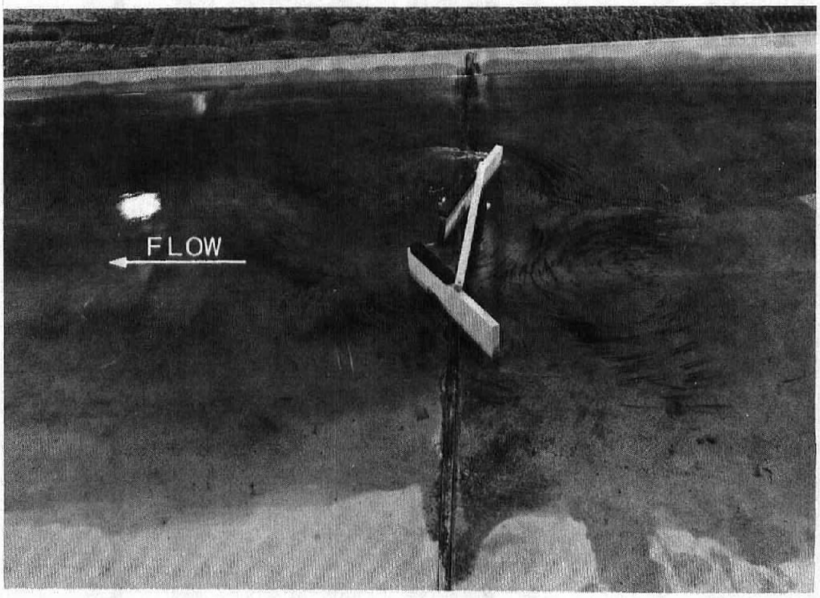
COLORADO RIVER STUDY

1:60 Scale Model
Mixing Effect of Baffles

FIGURE 26



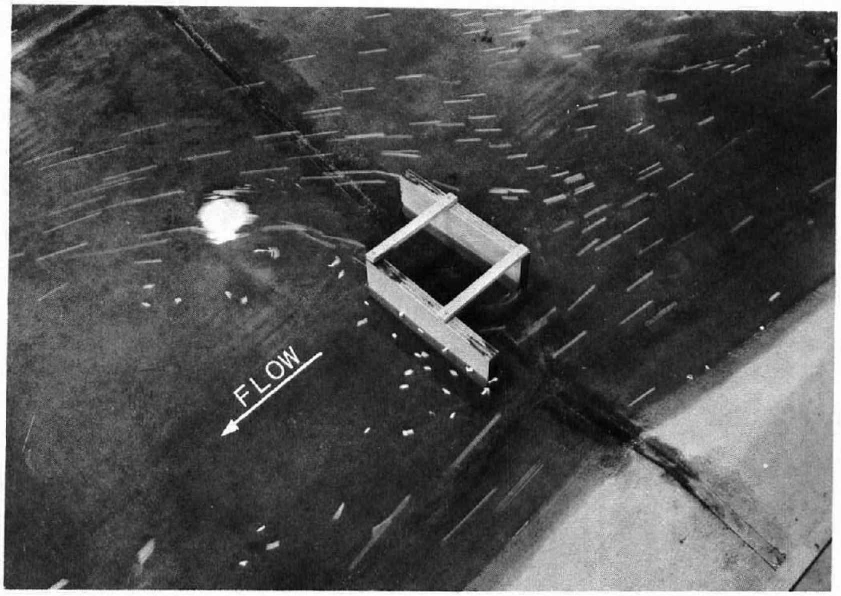
A. Surface flow pattern. Photo PX-D-66030



B. Bottom flow pattern. Photo PX-D-66031

COLORADO RIVER STUDY

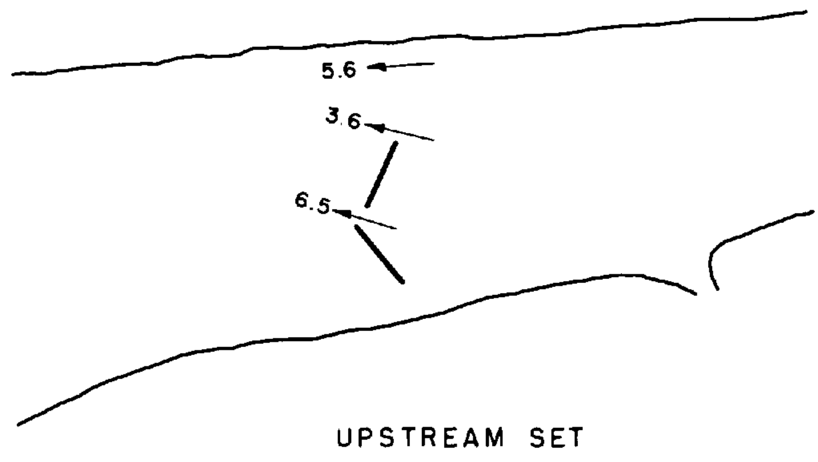
1:60 Scale Model
Flow Patterns Around Upstream Baffles
Q = 4,000 cfs

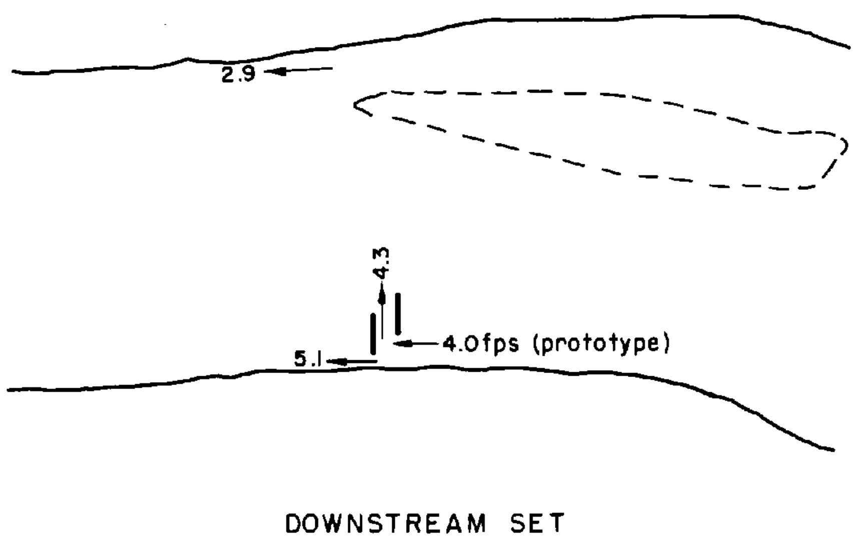


COLORADO RIVER STUDY

1:60 Scale Model
Surface Flow Pattern Around Downstream Baffles
Q = 4,000 cfs

FIGURE 28



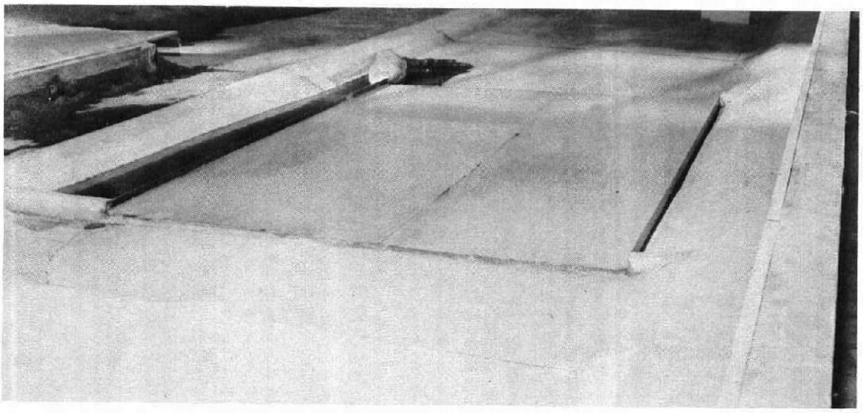


COLORADO RIVER STUDY

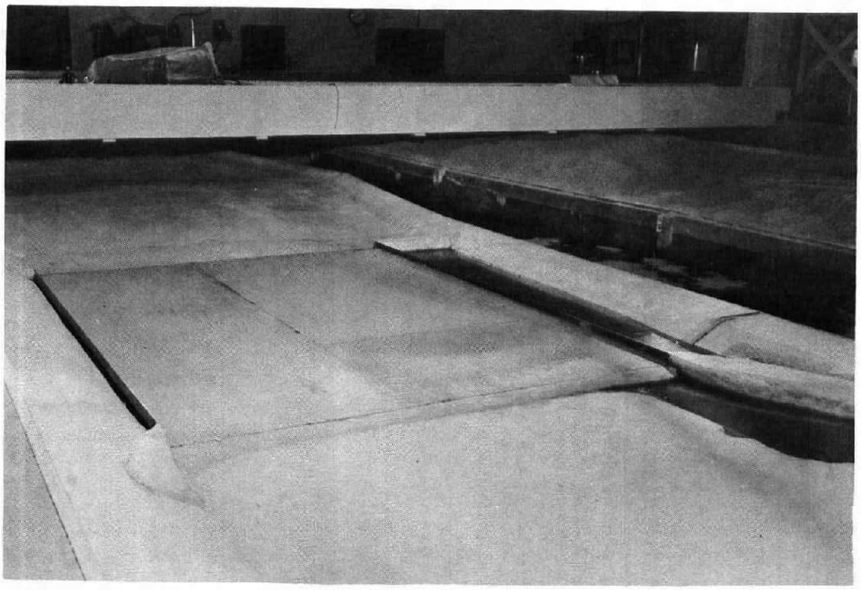
AVERAGE VELOCITIES AROUND THE BAFFLES, Q = 6,000 CFS

1:60 SCALE MODEL

744



A. Looking upstream. Photo PX-D-66033

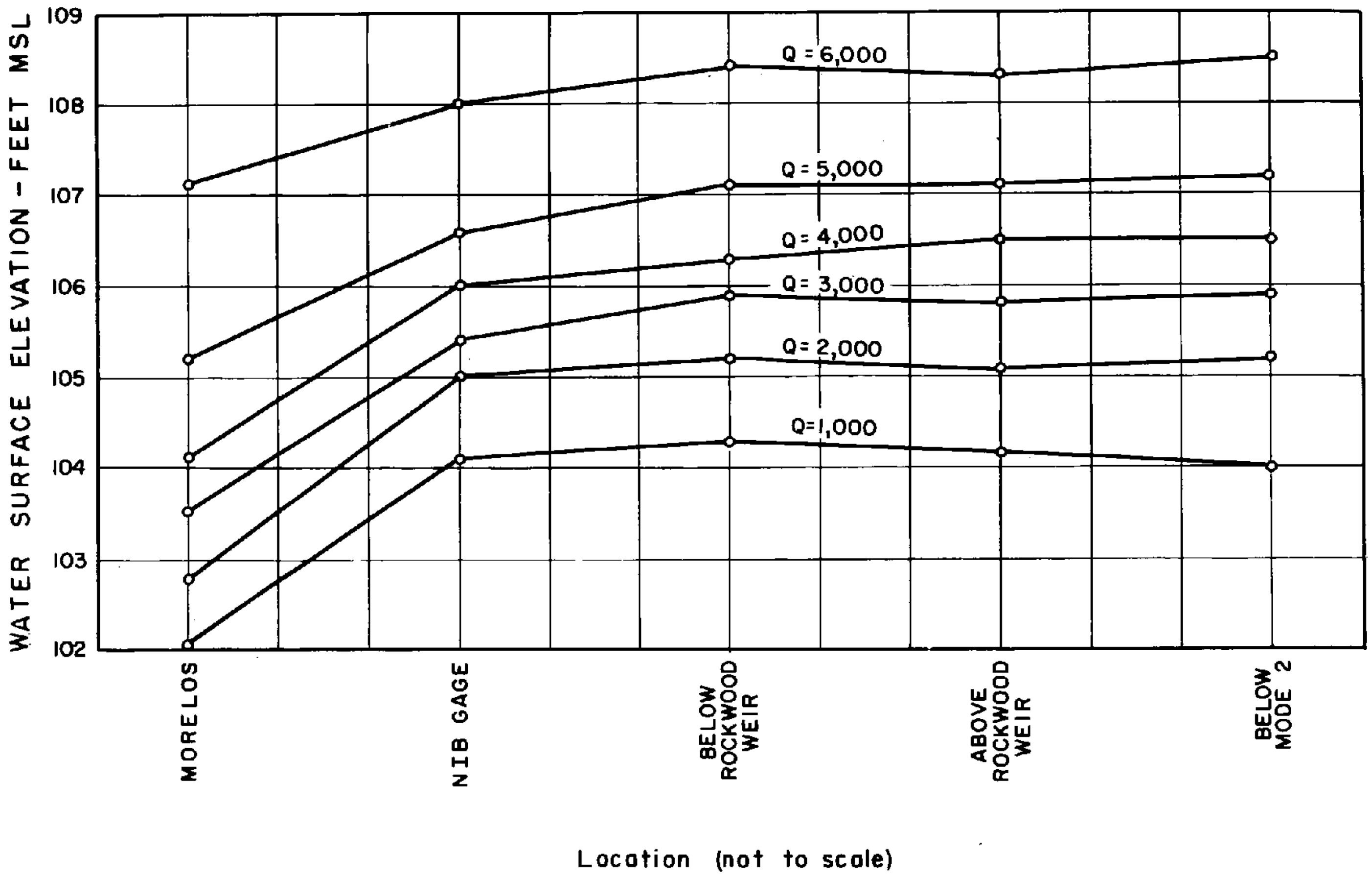


B. Looking downstream. Photo PX-D-66034

COLORADO RIVER STUDY

1:60 Scale Model
Configuration of Suggested Rating Structure

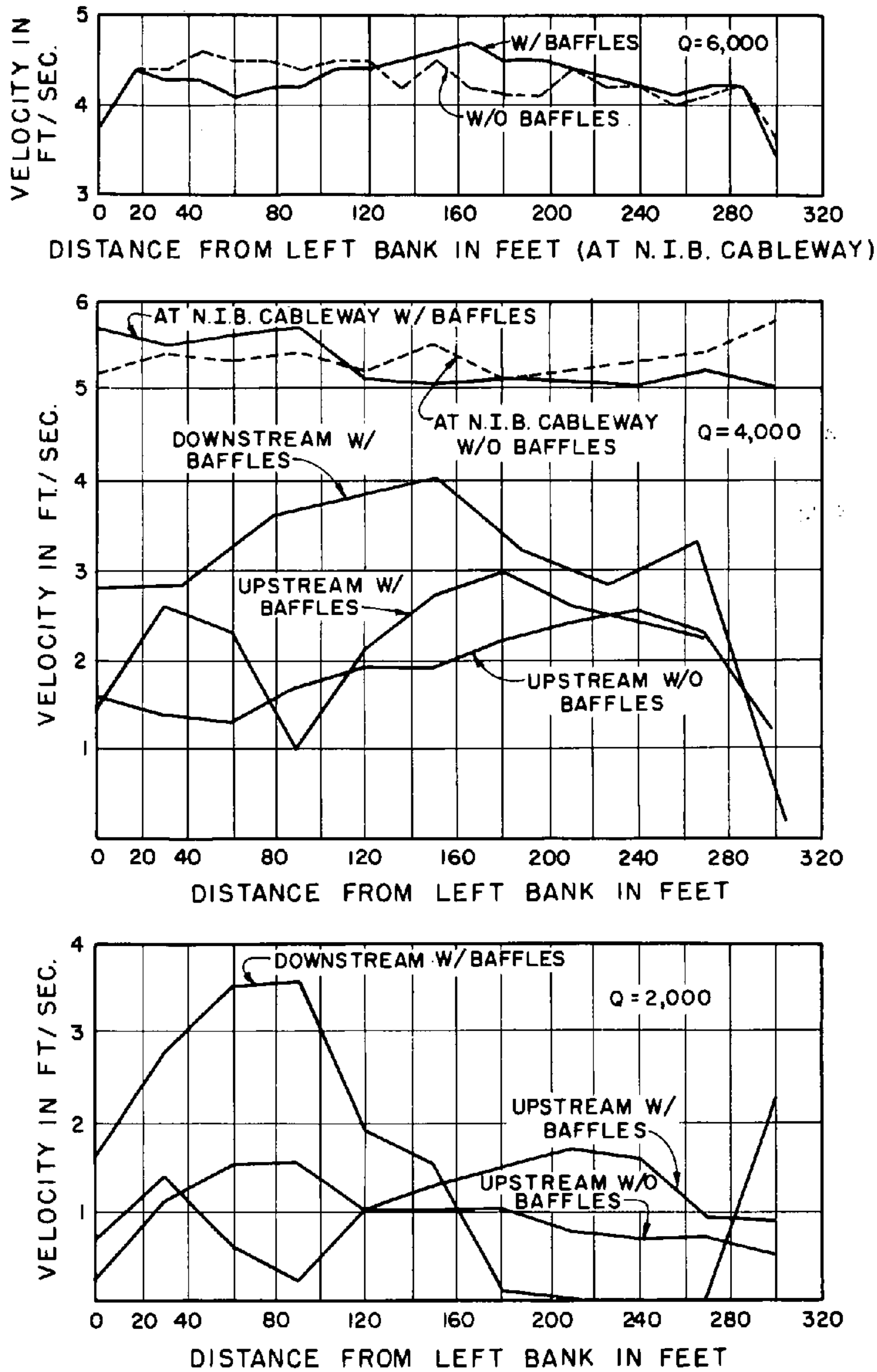
FIGURE 30



COLORADO RIVER STUDY

BACKWATER PROFILES WITH RATING STRUCTURE AND MIXING BAFFLES

1:60 SCALE MODEL



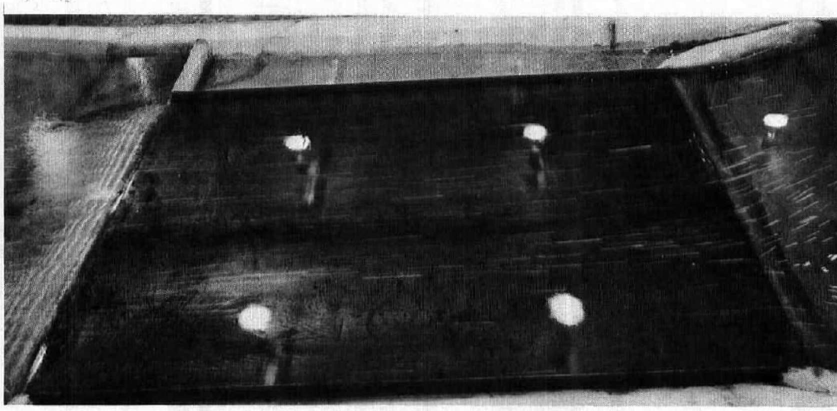
COLORADO RIVER STUDY

VELOCITY AT N.I.B. CABLEWAY, UPSTREAM, AND DOWNSTREAM FROM PROPOSED RATING STRUCTURE, WITH AND WITHOUT DOWNSTREAM BAFFLES

1:60 SCALE MODEL

744

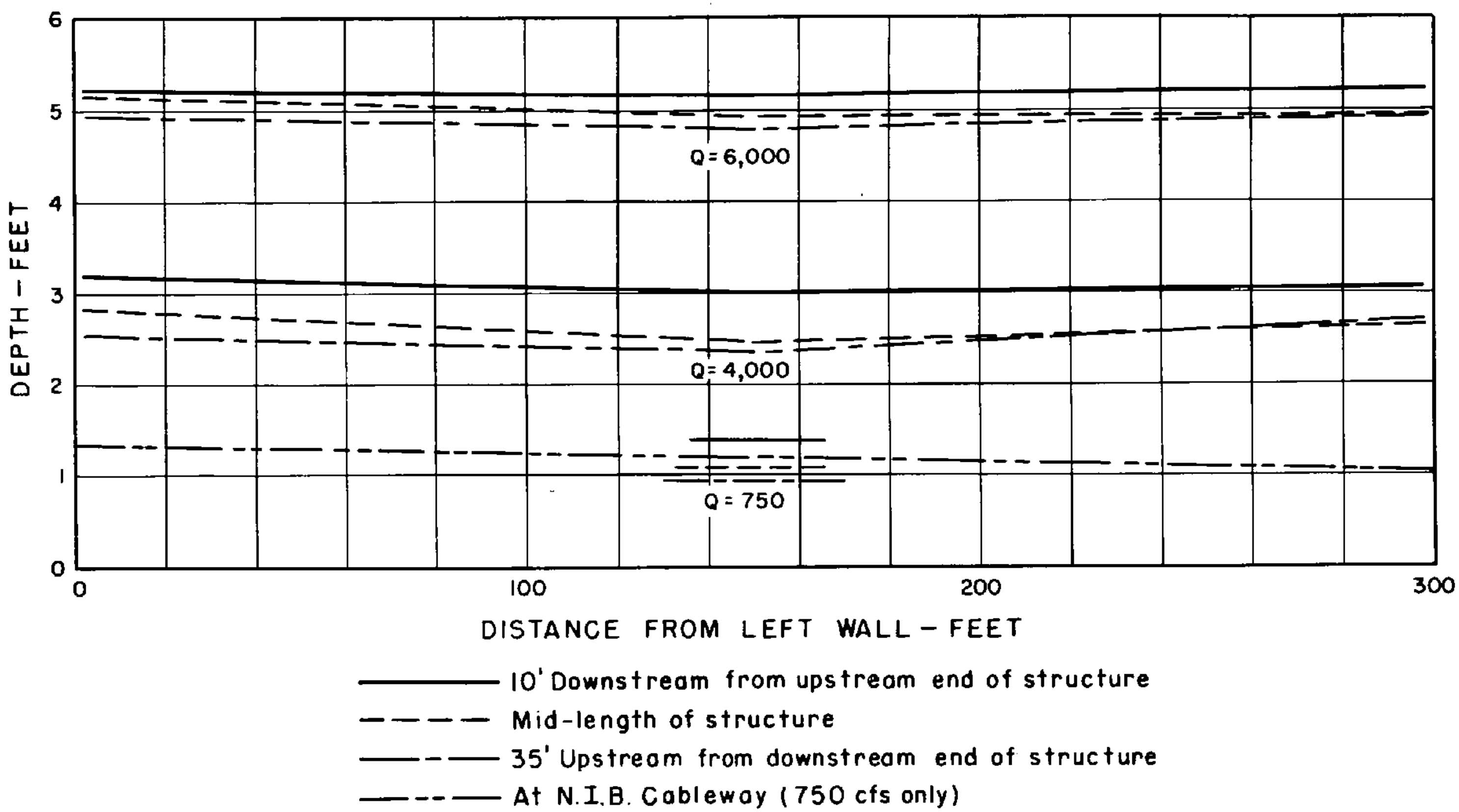
FIGURE 32



FLOW

COLORADO RIVER STUDY

1:60 Scale Model
Surface Flow Pattern in Rating Structure Q = 4,000 cfs
Photo PX-D-66035



COLORADO RIVER STUDY

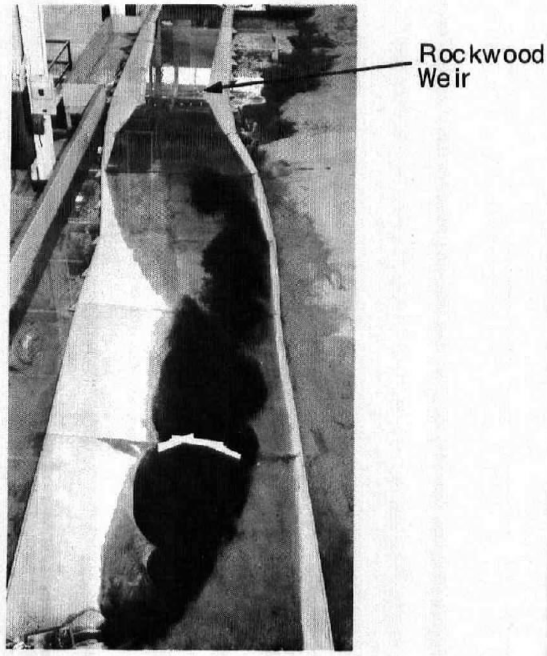
WATER SURFACE PROFILES IN THE RATING STRUCTURE

1:60 SCALE MODEL

FIGURE 33

FIGURE 34

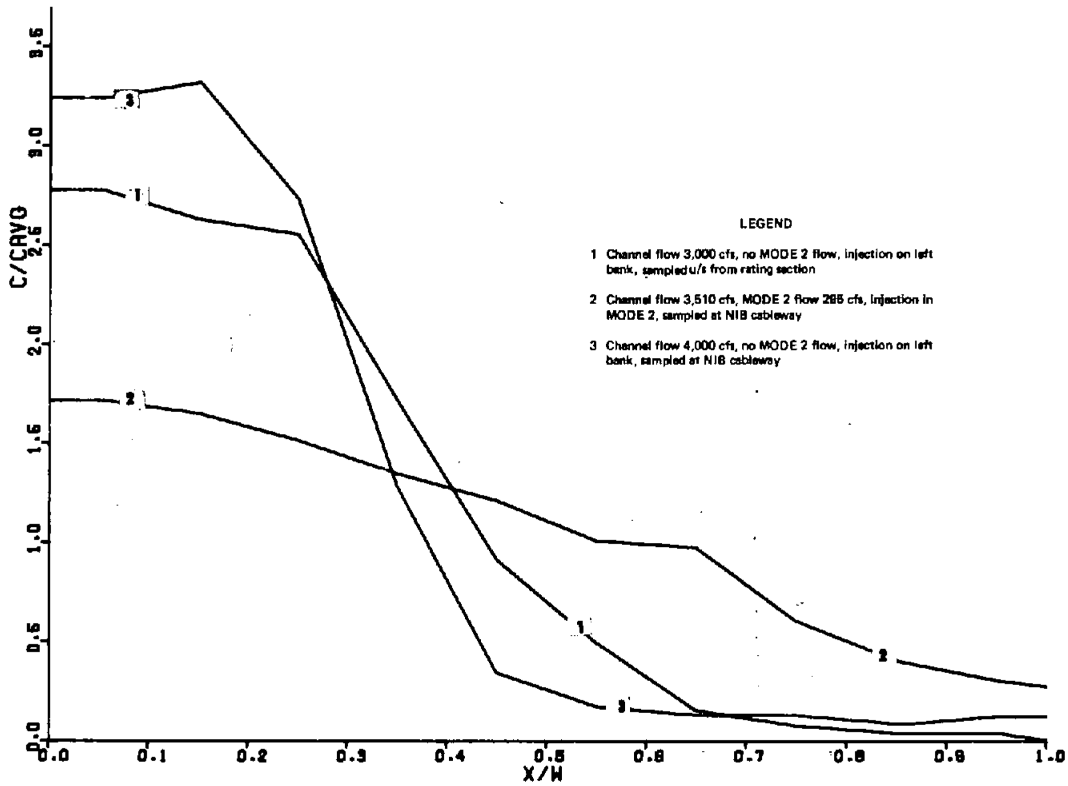
A. Without baffles.
Photo PX-D-66036



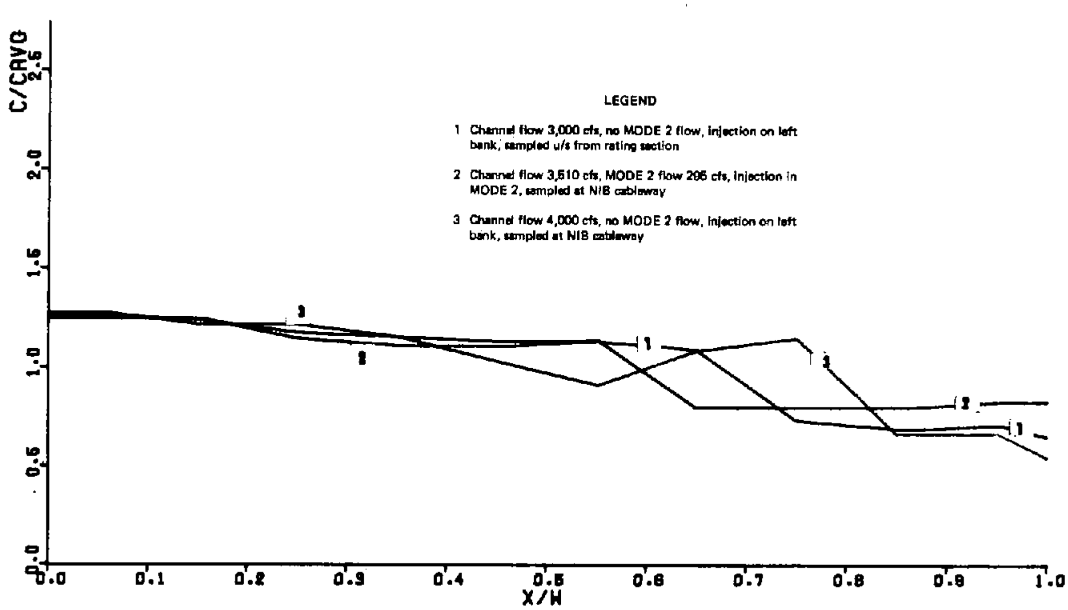
B. With baffles.
Photo PX-D-66037

COLORADO RIVER STUDY

1:60 Scale Model
First Channel Modification
Dye Distribution With and Without Mixing Baffles



Without baffles.



With baffles.

COLORADO RIVER STUDY

1:60 Scale Model
First Channel Modification
Fluorometer Records

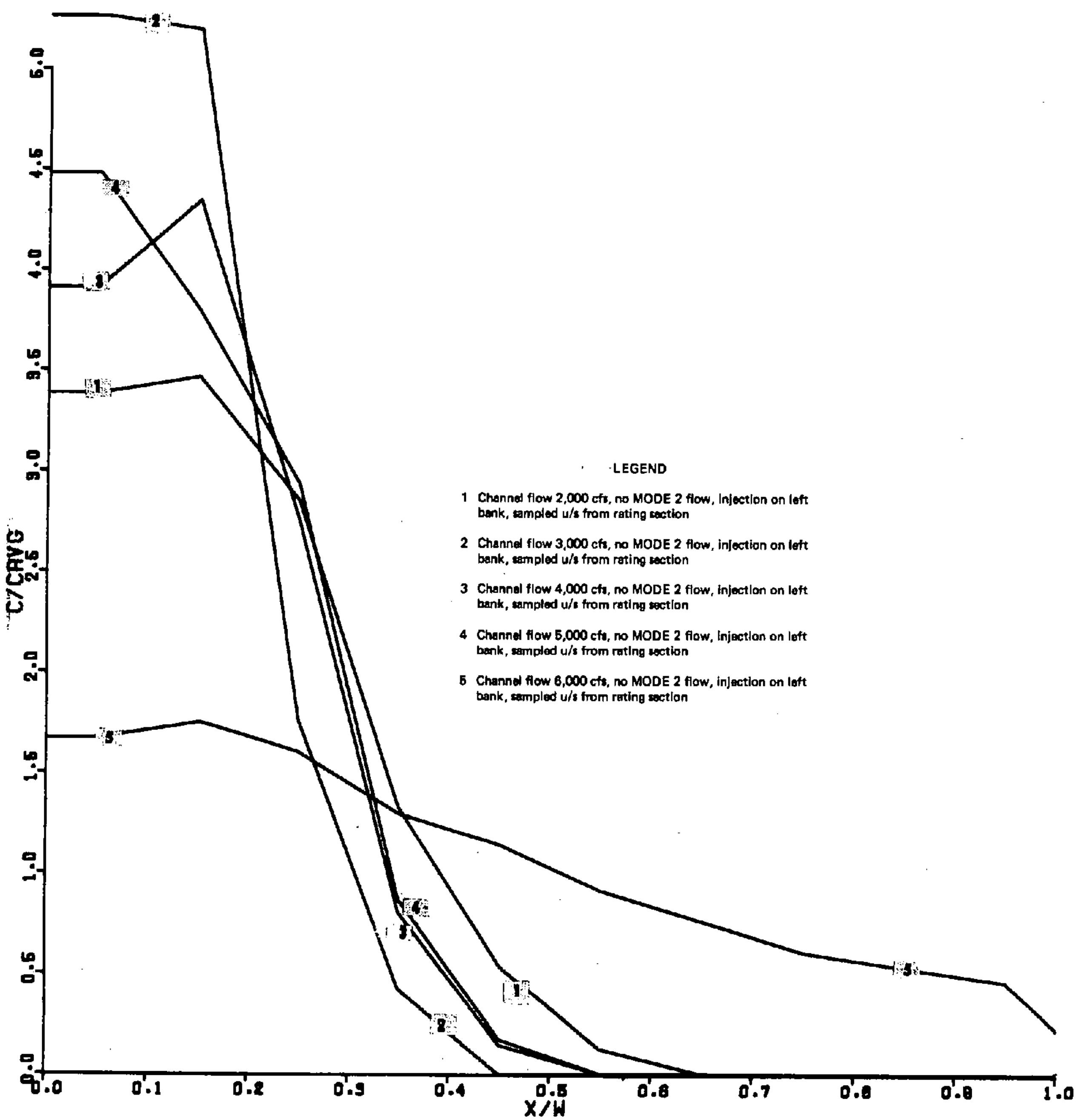
FIGURE 36

A. Without baffles. Photo PX-D-66038

B. With baffles. Photo PX-D-66039

COLORADO RIVER STUDY

1:60 Scale Model
Second Channel Modification
Dye Distribution With and Without Mixing Baffles

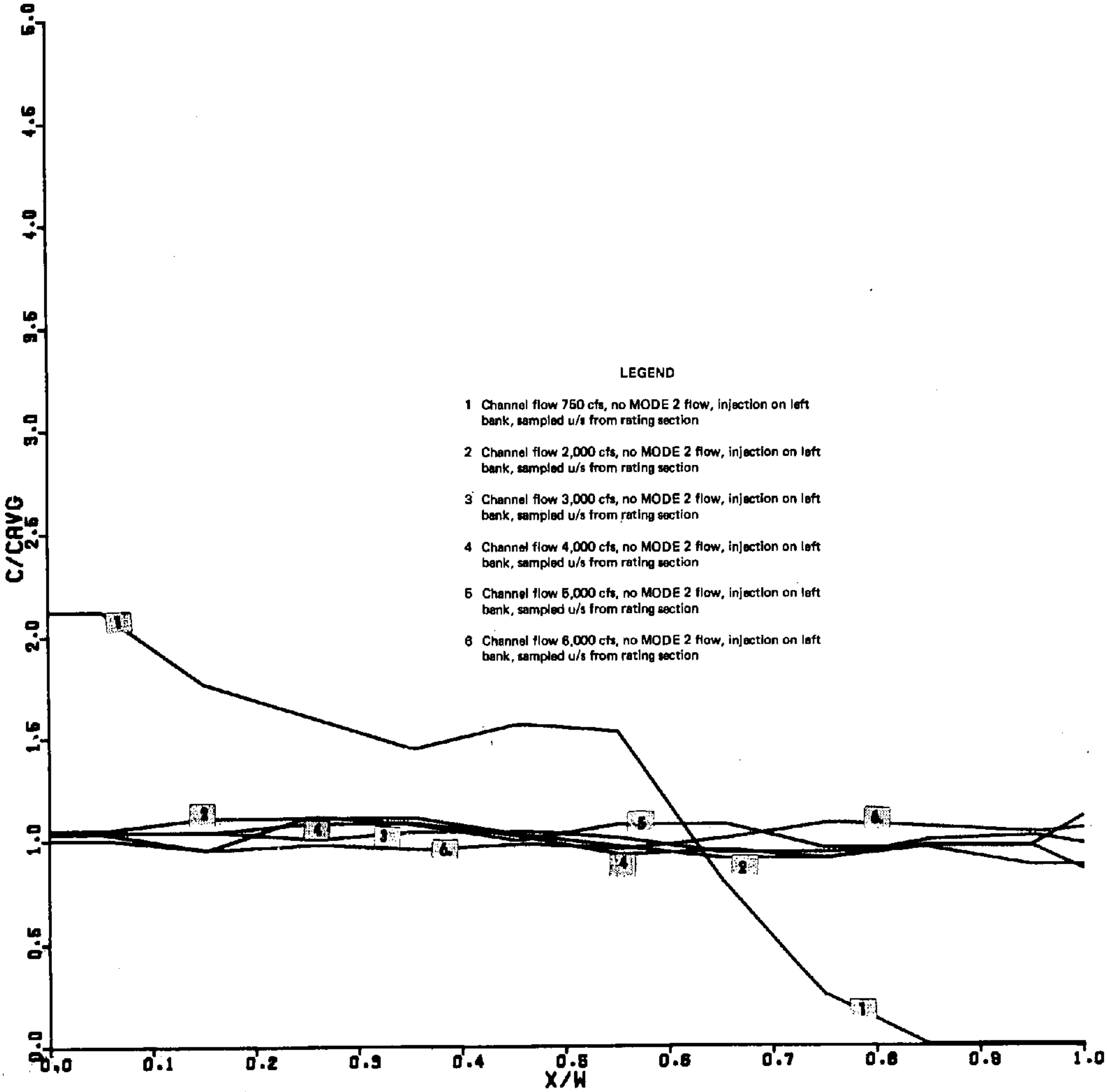


Without baffles.

COLORADO RIVER STUDY

1:60 Scale Model
Second Channel Modification
Fluorometer Records
Sheet 1 of 2

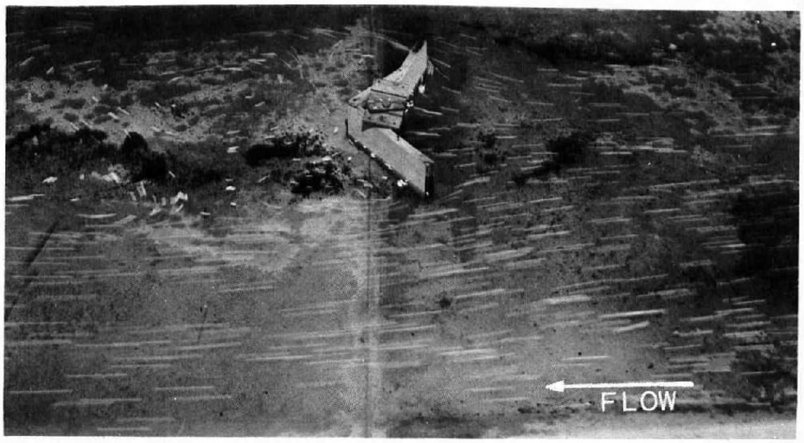
FIGURE 38



With baffles.

COLORADO RIVER STUDY

1:60 Scale Model
Second Channel Modification
Fluorometer Records
Sheet 2 of 2



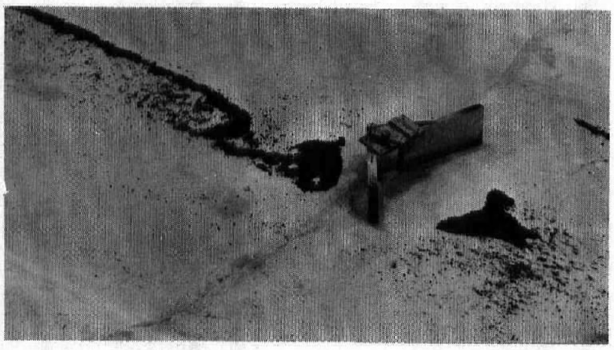
COLORADO RIVER STUDY

1:60 Scale Model
Second Channel Modification
Surface Flow Pattern Around Downstream Baffles
Q = 4,000 cfs
Photo PX-D-66040

FIGURE 40

B. Deposition of sand just downstream from rating structure. Photo PX-D-66042

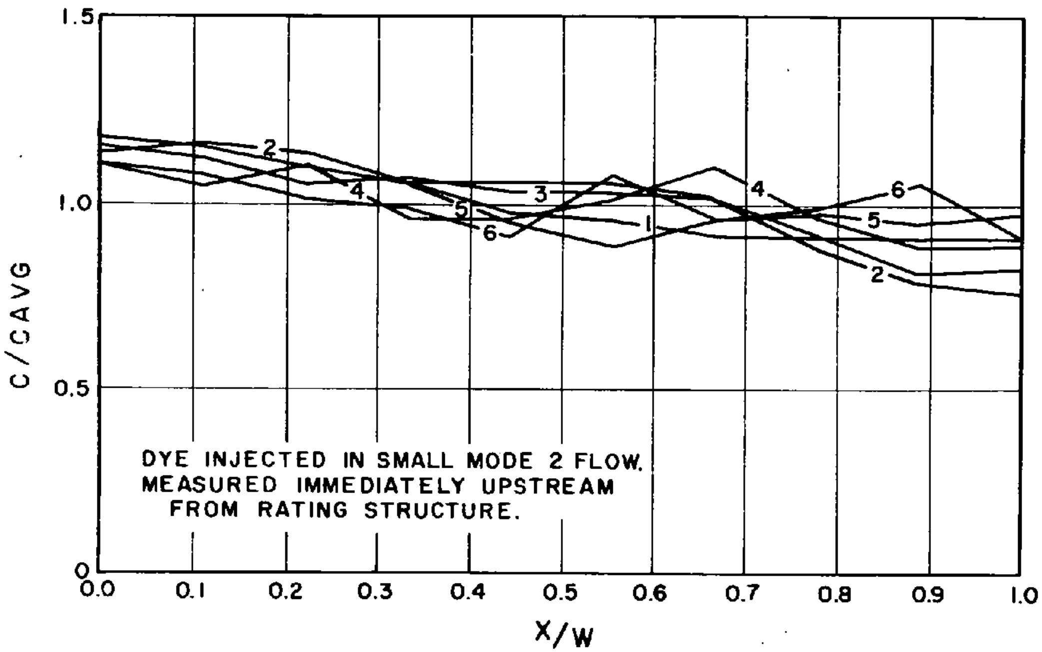
A. Deposition of plastic chips throughout length of channel. Photo PX-D-66041



C. Deposition of plastic chips in vicinity of downstream set of baffles. Photo PX-D-66043

COLORADO RIVER STUDY

1:60 Scale Model
Second Channel Modification
Deposition of Sediment, After 4 Hours' Operation at Q = 4,000 cfs



LEGEND

1.- 1,000cfs	4. - 4,000cfs
2.- 2,000cfs	5. - 5,000cfs
3.- 3,000cfs	6. - 6,000cfs

COLORADO RIVER STUDY

FLUOROMETER RECORDS

FEASIBILITY DESIGN
1:60 SCALE MODEL

FIGURE 41

FIGURE 42

COLORADO RIVER STUDY

1:60 Scale Model
Configuration of Downstream Baffles and Rating Structure, Feasibility Design
Photo PX-D-68044

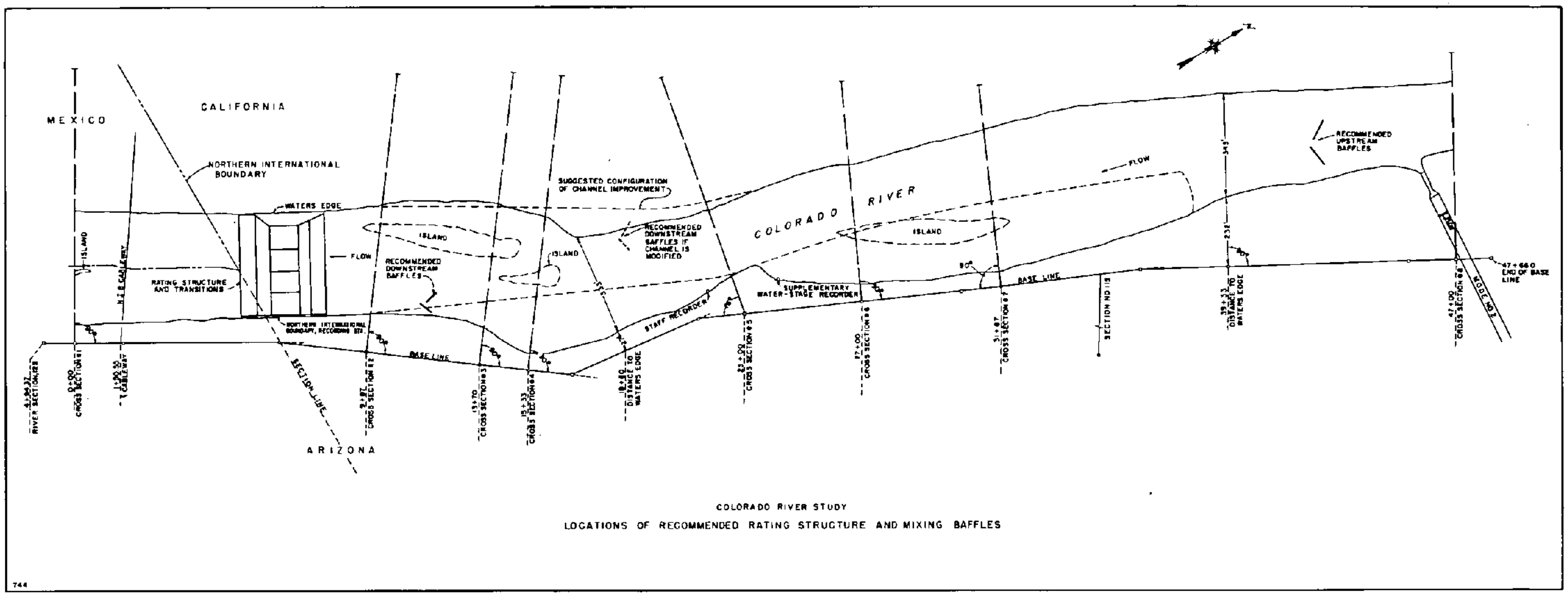


Figure 43. Colorado River Study—Locations of recommended rating structure and mixing baffles.

CONVERSION FACTORS--BRITISH TO METRIC UNITS OF MEASUREMENT

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

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

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

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

Table I

QUANTITIES AND UNITS OF SPACE

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

Table II

QUANTITIES AND UNITS OF MECHANICS

Multiply	By	To obtain
MASS		
Grains (1/7,000 lb)	64.79891 (exactly)	Milligrams
Troy ounces (480 grains)	31.1035	Grams
Ounces (avdp)	28.3495	Grams
Pounds (avdp)	0.45359237 (exactly)	Kilograms
Short tons (2,000 lb)	907.185	Kilograms
	0.907185	Metric tons
Long tons (2,240 lb)	1,016.05	Kilograms
FORCE/AREA		
Pounds per square inch	0.070307	Kilograms per square centimeter
	0.689476	Newtons per square centimeter
Pounds per square foot	4.88243	Kilograms per square meter
	47.8803	Newtons per square meter
MASS/VOLUME (DENSITY)		
Ounces per cubic inch	1.72999	Grams per cubic centimeter
Pounds per cubic foot	16.0185	Kilograms per cubic meter
	0.0160185	Grams per cubic centimeter
Tons (long) per cubic yard	1.32894	Grams per cubic centimeter
MASS/CAPACITY		
Ounces per gallon (U.S.)	7.4893	Grams per liter
Ounces per gallon (U.K.)	6.2362	Grams per liter
Pounds per gallon (U.S.)	119.829	Grams per liter
Pounds per gallon (U.K.)	99.779	Grams per liter
BENDING MOMENT OR TORQUE		
Inch-pounds	0.011521	Meter-kilograms
	1.12985×10^6	Centimeter-dynes
Foot-pounds	0.138255	Meter-kilograms
	1.35582×10^7	Centimeter-dynes
Foot-pounds per inch	5.4431	Centimeter-kilograms per centimeter
Ounce-inches	72.008	Gram-centimeters
VELOCITY		
Feet per second	30.48 (exactly)	Centimeters per second
	0.3048 (exactly)*	Meters per second
Feet per year	0.965873×10^{-6}*	Centimeters per second
Miles per hour	1.609344 (exactly)	Kilometers per hour
	0.44704 (exactly)	Meters per second
ACCELERATION*		
Feet per second^2	0.3048*	Meters per second^2
FLOW		
Cubic feet per second (second-feet)	0.028317*	Cubic meters per second
Cubic feet per minute	0.4719	Liters per second
Gallons (U.S.) per minute	0.06309	Liters per second
FORCE*		
Pounds	0.453592*	Kilograms
	4.4482*	Newtons
	4.4482×10^{-5}*	Dynes
WORK AND ENERGY*		
British thermal units (Btu)	0.252*	Kilogram calories
	1,055.06	Joules
Btu per pound	2.326 (exactly)	Joules per gram
Foot-pounds	1.35582*	Joules
POWER		
Horsepower	745.700	Watts
Btu per hour	0.293071	Watts
Foot-pounds per second	1.35582	Watts
HEAT TRANSFER		
Btu in./hr ft^2 deg F (k, thermal conductivity)	1.442	Milliwatts/cm deg C
	0.1240	Kg cal/hr m deg C
Btu ft/hr ft^2 deg F	1.4880*	Kg cal m/hr m^2 deg C
Btu/hr ft^2 deg F (C, thermal conductance)	0.568	Milliwatts/cm^2 deg C
	4.882	Kg cal/hr m^2 deg C
Deg F hr ft^2/Btu (R, thermal resistance)	1.761	Deg C cm^2/milliwatt
Btu/lb deg F (c, heat capacity)	4.1868	J/g deg C
Btu/lb deg F	1.000*	Cal/gram deg C
Ft^2/hr (thermal diffusivity)	0.2581	Cm^2/sec
	0.09290*	M^2/hr
WATER VAPOR TRANSMISSION		
Grains/hr ft^2 (water vapor transmission)	16.7	Grams/24 hr m^2
Perms (permeance)	0.659	Metric perms
Perm-inches (permeability)	1.67	Metric perm-centimeters

Table III

OTHER QUANTITIES AND UNITS

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

GPO 832-018

ABSTRACT

The discharge rating curve for the Colorado River at the Northern International Boundary with Mexico is variable because of the shifting bed. Lack of mixing in the channel results in a nonuniform distribution of salinity and pollutants, requiring frequent and expensive sampling procedures to obtain reliable data. Hydraulic model studies were performed to determine the feasibility of an improved, permanent rating structure and devices to promote mixing of the water in the river. Structures are suggested for an unimproved and an improved channel configuration.

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REC-OCE-70-8
King, D L
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Bur Reclam Rep REC-OCE-70-8, Div Gen Res. Oct 1970. Bureau of Reclamation, Denver, 50 p, 41 fig, 3 tab, 2 ref

DESCRIPTORS--/ *salinity/ *design data/ appurtenances/ stream pollution/ hydraulic structures/ backwater/ channels/ *discharge measurement/ river currents/ *model tests/ hydraulics/ open channel flow/ sampling/ channel improvement/ laboratory equipment/ velocity meters/ water quality/ water analysis/ water sampling/ *mixing
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