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HYDRAULIC MODEL STUDIES YELLOWTAIL AFTERBAY DAM SLUICEWAY

July 1982
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A 1:24 scale model of Yellowtail Afterbay sluiceway was constructed to study the placement of flow deflectors designed to keep the water jets issuing from the sluiceway gates near the tailwater surface. Serious fish kills have occurred caused by gas supersaturation resulting from the plunging jets. Flow deflectors placed on the sluiceway curved invert will keep the major part of the flow near the tailwater surface, which lowers the pressure on gas bubbles and reduces the gas transfer, consequently, reduces resulting supersaturation.

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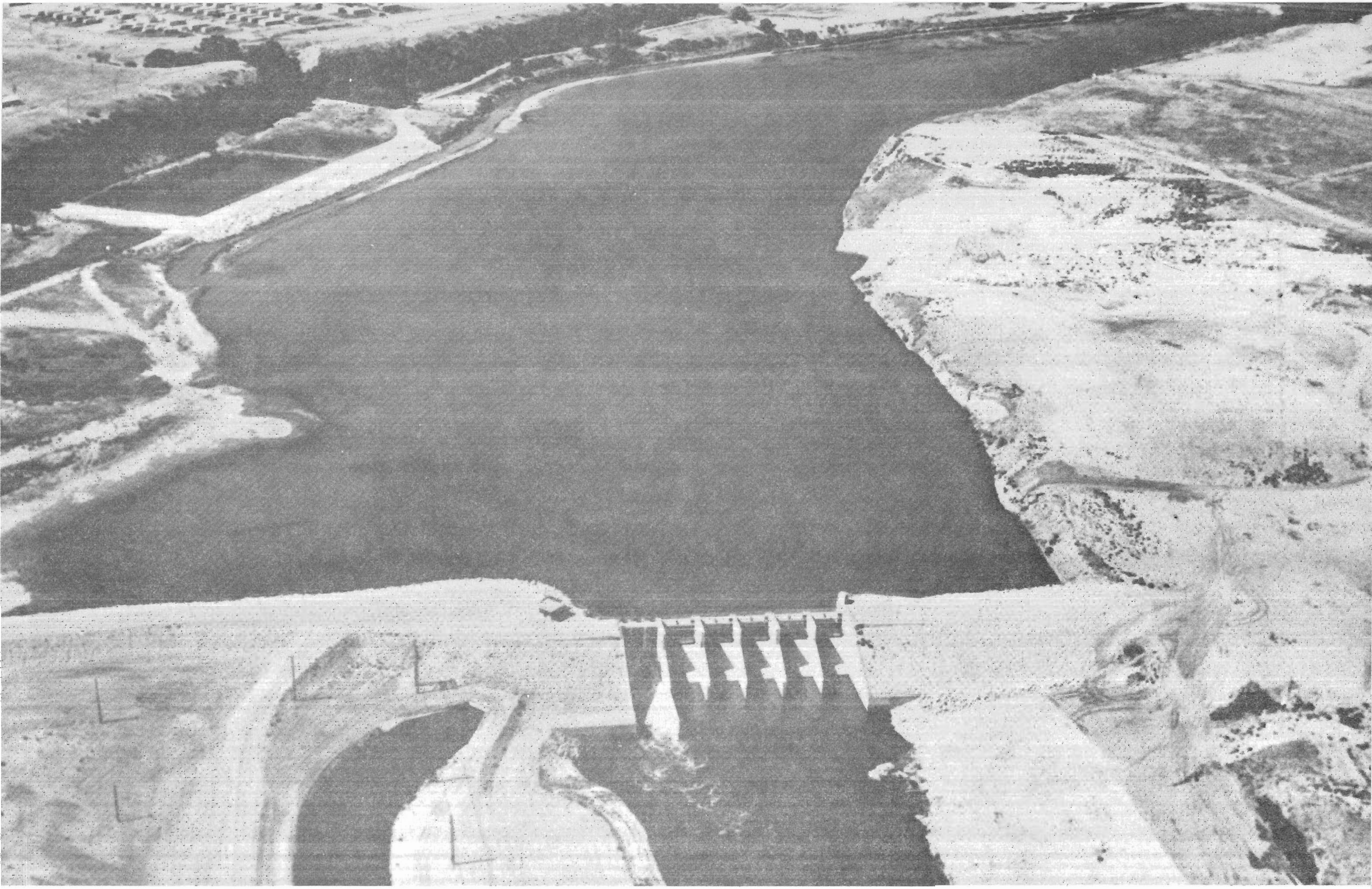

Frontispiece—Yellowtail Afterbay Dam and Reservoir. P801-D-79760

CONTENTS

TABLES

FIGURES

PURPOSE

The purpose of this study was to determine the best location for installing a flow deflector to reduce gas supersaturation below Yellowtail Afterbay Dam. Supersaturation occurs when entrained air in the hydraulic jump is carried to depth in the stilling basin resulting in excessive gas transfer. The pressure caused by the tailwater depth above the submerged jets increases gas transfer from the air bubbles and establishes the supersaturation condition.

CONCLUSIONS

1. Deflector plates installed on the curved invert of the sluiceway will reduce jet submergence—a cause of supersaturation.

2. Measurements show no subatmospheric pressures present on the flow deflector lips. The largest pressure measured was 1.83 m (6.0 ft).

3. Waves within the stilling basin will be larger with the deflectors in place than with the existing configuration, while waves outside of the basin will be the same size or smaller. Therefore, extensive erosion should not take place.

4. Velocity measurements taken at the end of the basin show that the existing configuration produces a velocity profile with highest values near the floor of the basin. This indicates the majority of the flow passes through the basin under the greatest pressure. With the flow deflectors in place, the largest velocities, and therefore the most flow, occur near the surface where the pressure is close to atmospheric. Although the velocities are low near the floor with the deflectors in place, they are high enough in a downstream direction to preclude material being drawn into the basin.

5. With the deflectors in place, material will not be brought back into the basin, although any material thrown into the basin will remain there.

INTRODUCTION

Yellowtail Afterbay Dam, completed in 1965, is on the Big Horn River 3.5 km (2.2 mi) below Yellowtail Dam and Powerplant. The dam and powerplant are features of the Yellowtail Unit, Lower Big Horn Division, Missouri River Basin Project, and are located 70 km (43 mi) southwest of Hardin, Montana (fig. 1). The afterbay dam is a concrete diversion dam having earthern dikes at each end and is 415 m (1360 ft) in length and 22 m (72 ft) in height. Releases from the afterbay dam are used to provide uniform daily flow in the Big Horn River, leveling the peaking power generation from Yellowtail Powerplant. The dam also diverts water to the Big Horn Canal which has a capacity of 21 m^3/s (750 ft^3/s). The river discharge below the afterbay dam remains fairly constant throughout the year with a mean discharge of 57 m^3/s (2000 ft^3/s).

The dam contains spillway, sluiceway, and canal diversion headworks structures. The spillway has an ogee crest controlled by five 9- by 4-m (30- by 13.5-ft) radial gates (fig. 2). The sluiceway consists of three bays and is controlled by three 3.1- by 2.4-m (10- by 8-ft) slide gates (fig. 3).

Gas Supersaturation

At times, gas supersaturation has occurred downstream from Yellowtail Afterbay Dam. Supersaturation occurs when more atmospheric gases are in solution than the water can hold stably. It can occur naturally below waterfalls, in lakes during heavy spring runoff and subsequent warming of the surface waters, and in pools containing excessive quantities of algae. It can also occur below dam spillways and sluiceways (as in this case) and below outfalls of thermal or nuclear-powered generating facilities.

There are two dangerous conditions that can be harmful to fish in supersaturated aquatic environments.

1. Because of the interactive nature of water and gases, water under high pressure and/or low temperature will hold more gas in solution than water under low pressure and/or high temperature. Fish often travel through deep, cool water that can hold large amounts of dissolved gas and then come up to shallower water either for feeding or because of the topography of the subaquatic terrain. When fish move into shallower or warmer water, dissolved gases that were absorbed into their blood under high pressure and cool temperature may then come out of solution and give rise to gas bubble disease. Gas bubble disease is similar to the bends experienced by some human divers who encounter comparable situations. The gas bubbles are released into the circulatory system which may damage organs or cause death.

2. Supersaturation conditions, which can injure or kill fish, may result when water with entrained air (as releases from sluiceway gates) passes with deep submergence through a stilling basin pool and then flows quietly downstream into shallower water. Under these conditions, large quantities of gas are dissolved into the water under high pressure in the deep pool. Supersaturation results when this flow passes to shallower, lower pressure regions. Usually, supersaturated, dissolved gases contained in water can be dissipated in a short perod of time through natural turbulence in the river. However, the river stretch below Yellowtail Afterbay Dam is tranquil, which interferes with this dissipation process, and the flow remains supersaturated for several kilometers downstream.

Dissolved gas concentrations may be measured as a percentage of the maximum quantity of gas that water can contain stably at the surface of a lake or river. Usually, 110 percent of this saturation level (110 percent supersaturation) is defined as the maximum point after which fish in the environment begin to be affected by the disease. The first effects are probably internal with bubbles in the bloodstream. External symptoms are bubbles under the skin, on the fins, and "pop eyes." With the saturation level at 115 percent over a prolonged period of time, dead fish appear in the river. Vulnerability varies with species and age group.

Fish can sometimes recover from gas bubble disease if they are in its early stages and are removed promptly from the supersaturated environment or if conditions which caused the supersaturation are changed. If symptoms are advanced, such as burst bubbles in the eye or body areas, the resulting infection can cause death or blindness.

In 1979, after a serious outbreak of gas bubble disease was discovered below Yellowtail Afterbay Dam, an operating procedure mixing sluiceway flow with spillway flow was introduced. The spillway does not cause as extensive a supersaturation problem as the sluiceway; therefore, when operated simultaneously, supersaturation is reduced to acceptable levels. However, the spillway crest is at elevation 969.11 m and the sluiceway crest is at 962.25 m (3179.50 and 3157.00 ft). Therefore, the afterbay reservoir elevation must be sufficiently above the spillway crest to discharge enough flow to lower the supersaturation from the sluiceway.

In 1973, 1974, and since 1979, saturation measurements have been made weekly using a saturometer. When saturation levels reach unacceptable values, the afterbay level is increased so that the spillway can also be used, diluting the sluiceway discharge.

Two problems are associated with this mode of operation. The most important problem is that the afterbay reservoir elevation should be at or above 972.16 m (3189.50 ft) because, at lower elevations, the head is not high enough above spillway crest to pass the required flow for sluiceway dilution. Therefore, if the sluiceway could be operated alone without causing a supersaturation problem, the afterbay elevation could drop to 967.75 m (3175.00 ft) (minimum operating pool) and still be able to pass the minimum stream requirement. The 4.4-m (14.5-ft) height of storage gained in the afterbay reservoir would provide more power generation at the Yellowtail Dam Powerplant. The other problem in using the spillway is that the spillway gates are not automated while the sluiceway gates are. When the spillway is operated, its radial gates must be opened manually. To adjust

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MODEL

Description

The model was built to a geometric scale of 1:24 and included:

- approach to the sluiceway
- one spillway entrance bay
- sluiceway crest and gate structure
- sluiceway stilling basin
- 30 m (100 ft) of downstream river channel (fig. 4)

One wall of the model box was constructed of clear plastic so that flow in the stilling basin could be viewed (figs. 5 and 6).

Water was supplied to the model through the laboratory piping system. Flows were measured by volumetrically calibrated Venturi meters installed in the system. After entering the model box, water passed through a rock baffle to quiet the turbulence.

Afterbay reservoir topography consisted of a wooden floor placed at elevation 961.6 m (3155 ft) which simulated the flat-bottomed approach channel. Topography downstream of the stilling basin was simulated by pea gravel. Armor rock, placed at the downstream end of the stilling basin in the prototype in 1970 to eliminate rock debris return into the stilling basin, also was represented in the model by 25-mm (1-in) rock. Sluiceway gates and piers were constructed of acrylic plastic and the crest and curved invert were of high density polyurethane foam (fig. 7). The stilling basin and endsill were made of wood (fig. 6).

The afterbay reservoir elevation was measured by a hook gage contained in a stilling well which was connected to the inside of the headbox reservoir.

Tailwater was controlled by an adjustable tailgate and measured by a staff gage located in the tailbox.

INVESTIGATION

Discharge Measurements

The first task involved in the model study was to verify the existing sluiceway discharge curve developed during the original model study completed in 1965.[1] The 1981 study indicates slightly less discharge for a given afterbay reservoir elevation than the earlier model. This difference can be attributed to the fact that the 1965 model did not represent as large an afterbay reservoir as the new model. Consequently, there was a higher approach velocity to the sluiceway in the early model and, therefore, greater discharge could be expected for a given reservoir head. Figure 8 curves accurately indicate reservoir head versus discharge for the full range of sluiceway gate openings.

[1] Arris, Wayne F., *Hydraulic Model Studies of the Sluiceway and Overflow Weir, Yellowtail Afterbay Dam*, Bur. Reclam. rep. Hyd-523, 21 pp., April 1965.

Analytical Model

There are two methods available to reduce supersaturation. The first method is to provide an artificial riffle downstream of the sluiceway in order to introduce turbulence into the flow so that the dissolved gas is released into the atmosphere. This could take the shape of a rockfill structure immediately downstream of the stilling basin which would both decrease the air uptake in the hydraulic jump by increasing the tailwater and would provide the needed turbulence. However, the added tailwater depth will increase supersaturation by the increased pressure acting on the gas; therefore, some trade-off is encountered. Insufficient research has been done in this area to predict accurately the amount of relief that could be expected from a river aeration structure. Also, because dissolved gas cannot be measured or represented in a hydraulic model, this alternative was not considered viable because of the uncertainties involved.

The other method that can be used to reduce supersaturation consists of keeping the flow from plunging to the floor of the stilling basin. By keeping the jet (the combined flow from each sluiceway gate) close to the tailwater surface, pressure on the entrained gas is lessened and the resulting supersaturation percentage is reduced. Three flow deflectors, one placed on the curved invert of each sluiceway gate bay, were evaluated in the hydraulic model study for Yellowtail Afterbay Dam. This same method was used for modification to the outlet works at Navajo Dam.[2] Advantages of using this method are that deflectors have proven effective in field use and that an analytical method exists for prediction of dissolved gas below hydraulic structures[3] when used in conjunction with findings from the hydraulic model.

A monitoring program was carried out in the early 1970's to evaluate the aeration capabilities of various types of outlet works and spillways. After completion of this

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[2] Johnson, P. L., *Hydraulic Model Studies of Navajo Dam Auxiliary Outlet Works and Hollow-jet Valve Bypass—Modifications to Reduce Dissolved Gas Supersaturation,* Bur. Reclam. rep. REC-ERC-76-5, 30 pp. April 1976.

[3] ______, *Prediction of Dissolved Gas at Hydraulic Structures,* Bur. Reclam. rep. GR-8-75, 67 pp., 1975.

survey, an analysis was initiated to develop a generalized predictive technique. The analysis is based on

- velocity head of the inflow jet at the tailwater surface
- angle of penetration of the jet into the tailwater
- jet dimensions
- basin length and depth
- water temperature
- barometric pressure
- initial dissolved gas levels in the reservoir

Accurate predictions have been made using existing data from Yellowtail Afterbay Dam. For this reason, an empirical approach, in conjunction with findings from the model, was used to select the elevation of the flow deflector.

Because it is known that 110 percent saturation is the highest limit of dissolved gas concentration that is acceptable for fish habitats, initially the "effective" tailwater depth or mean depth of jet submergence in the sluiceway stilling basin was adjusted so that this limit would not be exceeded. By using the worst operating conditions which could be encountered, a flow deflector elevation could be found so that the 110 percent value would never be surpassed. This assumes that the flow deflector would function as the stilling basin floor and that the jet would not penetrate below the deflector elevation. As the study progressed, this assumption proved to be untrue.

Figure 9 is a rather curious graph of percent saturation versus discharge obtained from field measurements of the unmodified Yellowtail Afterbay Dam sluiceway. Highest values of saturation occur at about 57 m^3/s (2000 ft^3/s) while higher discharges display smaller percentages of dissolved gas. This is true for various collections of data. Analytical computations do not indicate this high value at middle range discharges but instead show a nearly linear progression of saturation to the design discharge of 127 m^3/s (4500 ft^3/s). The saturation value for the maximum discharge is predicted accurately for all field data analyzed. The difference between the maximum saturation value and the value at the maximum discharge remains at about 5 percent for all data reviewed. For that reason, it was decided that 105 percent saturation in nitrogen would be the maximum saturation percentage allowed at the maximum discharge of 127 m^3/s which would allow for a value of 110 percent at the middle range discharges.

It is not fully understood why this anomaly occurs at the sluiceway. Possibly the turbulence at the maximum discharge might release more dissolved gas while, at middle range discharges, turbulence is not great enough to release as much gas to the atmosphere.

Flow Deflector Configuration

For maximum discharge and nitrogen saturation of 105 percent, analytical computations indicated that the flow deflectors should be placed at elevation 960.30 m (3150.6 ft). When this was done in the model (fig. 10), the jet was deflected upward by the tailwater. The jet then plunged toward the stilling basin floor downstream of the curved invert. The flow deflectors were too submerged by the tailwater to operate in a satisfactory manner hydraulically. The deflectors were placed at a relatively high elevation (fig. 11) where the flow velocity was not high enough to keep it horizontal; gravity influenced flow downward over the deflectors. Thus, it was discovered that there was a small range of elevations where the deflectors would operate satisfactorily. Optimum elevation for the flow deflectors was 961.43 m (3154.3 ft).

The next task was to determine optimum configuration for the deflectors. Many deflectors with differing angles of projection were tested. Downward and upward deflectors were tested as well as horizontal ones. Upward and horizontal flow deflectors worked well at keeping the sluiceway jet near the tailwater surface. The horizontal deflectors worked better than ones with a slightly upturned angle (adverse) at lower discharges (fig. 12). At 106 m^3/s (3750 ft^3/s), both alternatives worked equally well (fig. 13). At maximum discharge, the adverse slope worked extremely well compared to the horizontal one (fig. 14). There was less air entrained, and the waves in the basin were smaller.

Because both horizontal and adverse deflectors worked adequately at 57 m^3/s (2000 ft^3/s) and the adverse slope so much better at maximum discharge, the adverse slope configuration was recommended.

Various deflector lengths were tested. The shortest deflector worked as well as the longest; the shortest was selected for economic reasons. Testing also indicated that at least a 0.75-m (2.5-ft) depth of deflector was required to break the flow from the curved invert of the sluiceway. The location and configuration of the recommended design appear on figure 15.

Because the median river discharge throughout the year is 57 m^3/s (2000 ft^3/s), between a reservoir elevation of 967.75 and 972.92 m (3175.00 and 3192.00 ft), it is especially critical that the flow deflector work well at gate openings between 0.76 and 1.07 m (2.5 and 3.5 ft). Figure 16 shows how well the deflectors operate under these conditions.

Dye was introduced into the sluiceway flow at the gate to enhance flow patterns. The existing flow profile is the same for all discharges and is shown on figure 17. Flow was viewed passing over the deflector and into the stilling basin with the recommended modification installed. It was observed that there was interaction with the tailwater located below the elevation of the deflector lip. Flow depth varies with discharge, but is basically linear. The discharge profiles of 57 and 127 m^3/s (2000 and 4500 ft^3/s) with the modification in place are shown on figures 18 and 19.

Pressure Determination

When determining the pressure exerted on the gas bubbles and, consequently, the resulting supersaturation percentage, the average tailwater depth submerging the bubbles must be found.

With the existing configuration at the Yellowtail Afterbay Dam sluiceway, the entire jet plunges to the stilling basin floor at the upstream end of the basin, so the average depth of submergence is the *TW* (tailwater) depth and the resulting pressure is 0.67 *TW*. When the saturation concentration is found for that pressure, plus the atmospheric pressure, the equation can be written:

$$C_{s_{flow}} = [P + 0.67\, P_{TW}]\, C_{si}$$

where

$C_{s_{flow}}$ = saturation concentrations for flow in the structure under given tailwater conditions

P = atmospheric pressure

P_{TW} = pressure due to tailwater

C_{si} = saturation concentration at one atmosphere

However, in the recommended configuration, the average depth of tailwater submerging the jet with entrained air would be much less because of the triangular shape of the flow profile. The average depth at 57 m³/s (2000 ft³/s) would be approximately 0.5 *TW* and the resulting pressure 0.67 × 0.50 *TW* or 0.33 *TW*. At design discharge, the average depth would be 0.67 *TW* and the resulting pressure 0.67 × 0.67 *TW* or 0.45 *TW*. This reduces the supersaturation by about 6 to 7 percent. Because, at the present time, the structure operates at the borderline saturation value causing fish kills, the 6 to 7 percent reduction should eliminate the problem directly below the afterbay dam. However, any supersaturation caused by algae photosynthesis, in the many kilometers of river below Yellowtail Afterbay Dam, will be not lowered by the sluiceway modification.

Steel Deflector Plate

Originally, the flow deflectors were tested in the hydraulic model as solid blocks. After discussions with regional personnel, it was suggested that a steel plate placed at the appropriate angle with supports might be substituted for each solid concrete block deflector. This would lessen the time that the sluiceway and overflow spillway would be inoperable during modification. During the time the sluiceway and spillway are not operational, power generation at Yellowtail Dam Powerplant will have be curtailed to a maximum of 21 m³/s (750 ft³/s), the maximum capacity of Big Horn Canal, which in turn will supply the minimum stream requirements to the Big Horn River through a canal wasteway located downstream of the afterbay dam. Loss of generation capacity at the powerplant is costly and should be minimized. If solid deflectors were installed, downtime would be considerable due to concrete cure time. Steel deflectors would take only a few days to install.

The three flow deflector plates and supports were installed in the hydraulic model having the identical configuration of the solid deflectors to verify that no change in hydraulic flow conditions would occur. A piezometer tap was placed at the downstream tip of one of the deflector plates to measure pressures exerted on the plate by the water (fig. 20). The pressure measurements are shown in table 1. The maximum pressure measured was 1.83 m (6.00 ft) of water while the minimum pressure was just atmospheric (0.0 m of water). The deflector plates worked as well as the solid blocks in keeping the jet near the tailwater surface (fig. 21).

It is recommended that the plates be constructed of either stainless steel or coal-tar epoxy-coated structural steel; each plate could then be cinch-anchored in place.

If the plates are constructed of stainless steel, they should be of 304L stainless, welded with compatible weld rod (308L) to preclude weld corrosion. If the deflectors are made of structural steel, each plate must be sandblasted, coated with two coats of coal-tar epoxy, applied to a 0.4 mm dry film thickness, and cured for 5 days. Because of the cure time, it would be expedient to paint the structural steel before installation, being careful during installation not to damage the coating.

Velocity Profiles

Velocity profiles for both the existing and modified configurations are on figure 22. With flow from left to right, the profiles display average velocities across the width of the basin as a function of depth in the stilling basin. Velocity measurements were taken at the end of the stilling basin and indicate that a drastic velocity distribution change had occurred with the installation of the flow deflectors. Whereas, in the existing configuration, the major part of the discharge (highest velocity) is carried near the stilling basin floor, the modified configuration shows flow concentration near the tailwater surface. This results in less pressure on the entrained air and less supersaturation.

Wave Measurements

Wave measurements also were made in the model to assure that the flow deflectors would not cause adverse erosion downstream of the stilling basin. These wave measurements are shown in table 2. Capacitance-type wave probes (fig. 23) were installed in the model and connected to a recorder (fig. 24) that allowed both wave peaks and troughs to be seen. Measurements were made at the centerline of the stilling basin endsill, 18 m (60 ft) downstream, and near the shoreline. These data show that, although waves are larger in the stilling basin with the flow deflector installed, the waves are the same size or smaller at the endsill. This is due to the existing configuration where the sluiceway jet plunges to the stilling basin floor and surges upward at the endsill where large waves are generated and carried downstream. With the flow deflectors installed, the waves attenuate rapidly and are very small once they exit the stilling basin. The maximum wave height measured was 1.01 m (3.31 ft) at the stilling basin endsill for a discharge of 127 m^3/s (4500 ft^3/s) having a 2.44-m (8-ft) gate opening. Near the shoreline, the maximum height was 0.21 m (0.69 ft). Because the wave heights near the shoreline are so small, erosion of the riverbanks should not be a problem.

Debris Tests

Various tests were made to assure that, by installing the flow deflectors, material could not be brought into the stilling basin where it could abrade the concrete.

In early 1970, the sluiceway stilling basin at Yellowtail Afterbay Dam was dewatered to inspect the basin for concrete damage that might have occurred during operations up until that time. Rock material eroded from the channel bottom directly at the end of the stilling basin and migrated upstream into the basin where it damaged the concrete. The abraded concrete was replaced and 1-m (3-ft) diameter riprap was placed at the end of the stilling basin to preclude further damage.

The model was operated in its existing configuration without the armor rock installed to see if the prototype condition could be reproduced. At larger discharges, material moved up the endsill dentates before being swept back downstream. This situation occurred because of the upwelling of the sluiceway jet at the endsill. This upwelling formed a reverse roller outside the basin which swept material up the endsill. In the model, the sluiceway jet swept the material back downstream before it entered the basin showing the potential for debris to return in the prototype since the material mass was not modeled.

When this same test was run for flow with the deflectors in place, material was not returned to the stilling basin. There was no upwelling at the endsill and, consequently, no reverse roller.

It was noted, however, that any rock debris thrown into the stilling basin will remain there for all discharges. Debris will collect at the upstream end of the stilling basin where water is fairly calm.

Table 1.—*Pressure measurements on flow deflector*

Prototype discharge, m^3/s	Gate opening, m	Maximum pressure, m of H_2O	Minimum pressure, m of H_2O
127	2.44	1.65	0.73
	2.13	1.46	0.70
	1.83	1.40	0.00
106	2.44	1.52	1.13
	2.13	1.83	1.25
	1.83	1.83	0.98
	1.52	1.49	0.04
57	2.44 to 2.13 (free flow)	1.49	1.40
	1.83	1.46	1.34
	1.52	1.43	1.25
	1.22	1.13	1.04
	0.91	0.91	0.70

Table 2.—*Wave measurements*

Discharge, m³/s	Gate opening, m	Maximum wave heights, meters					
		Location 1, stilling basin endsill,		Location 2, 18 m downstream,		Location 3, near shoreline,	
		existing	modified	existing	modified	existing	modified
57	2.44 to 2.13 (free flow)	0.09	0.30	0.09	0.12	0.06	0.06
	1.83	0.21	0.18	0.06	0.15	0.06	0.03
	1.52	0.18	0.24	0.06	0.12	0.03	0.03
	1.22	0.18	0.27	0.09	0.15	0.03	0.06
	0.91	0.24	0.34	0.09	0.21	0.03	0.09
106	2.44	0.43	0.52	0.00	0.18	0.12	0.12
	2.13	0.55	0.88	0.09	0.37	0.09	0.09
	1.83	0.46	0.70	0.09	0.30	0.12	0.21
	1.52	0.64	0.58	0.09	0.37	0.12	0.09
127	2.44	1.01	0.76	0.37	0.18	0.15	0.18
	2.13	0.73	0.70	0.30	0.24	0.18	0.18
	1.83	0.91	0.67	0.21	0.24	0.12	0.09

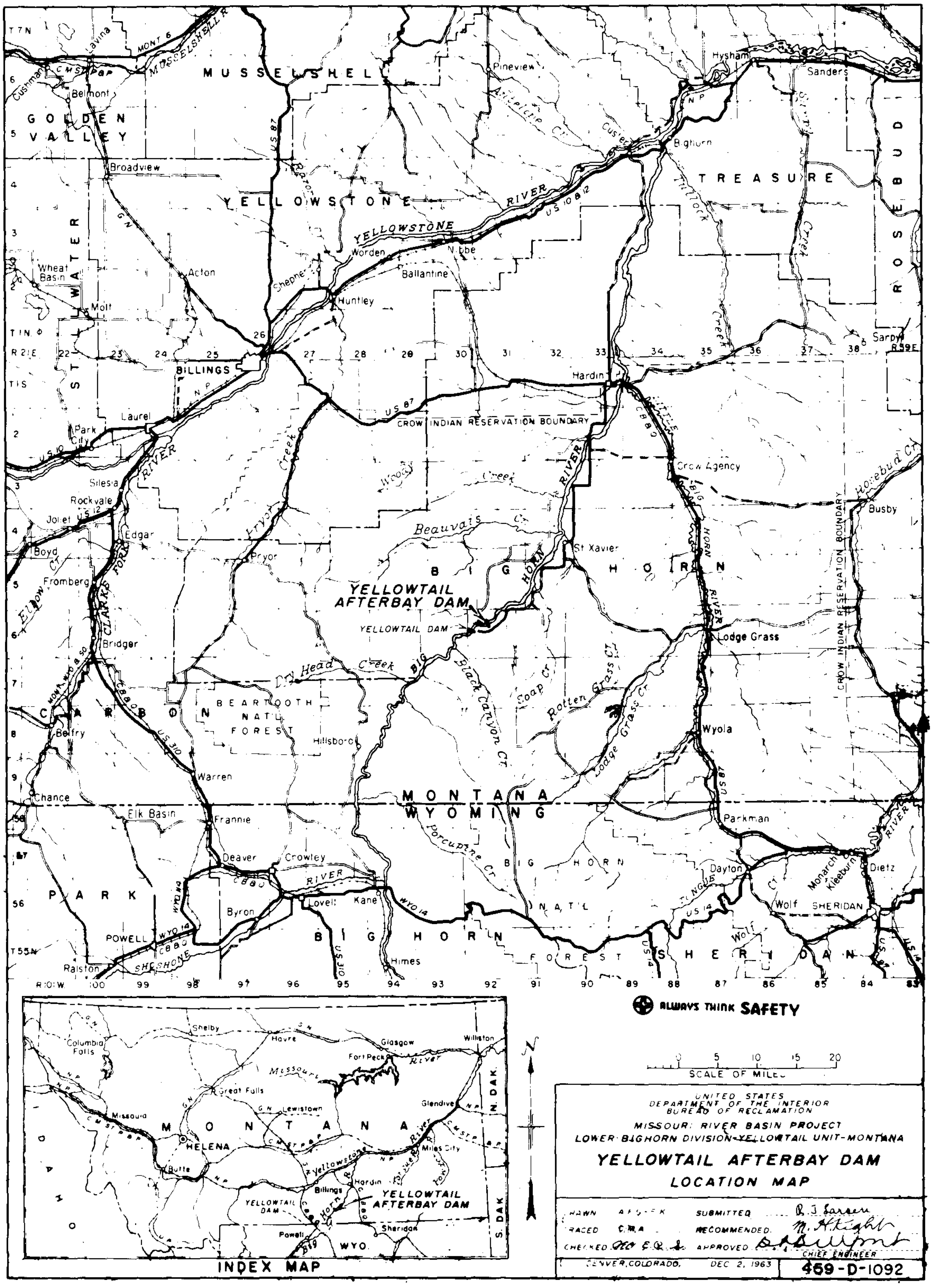


Figure 1.—Yellowtail Afterbay Dam—location map.

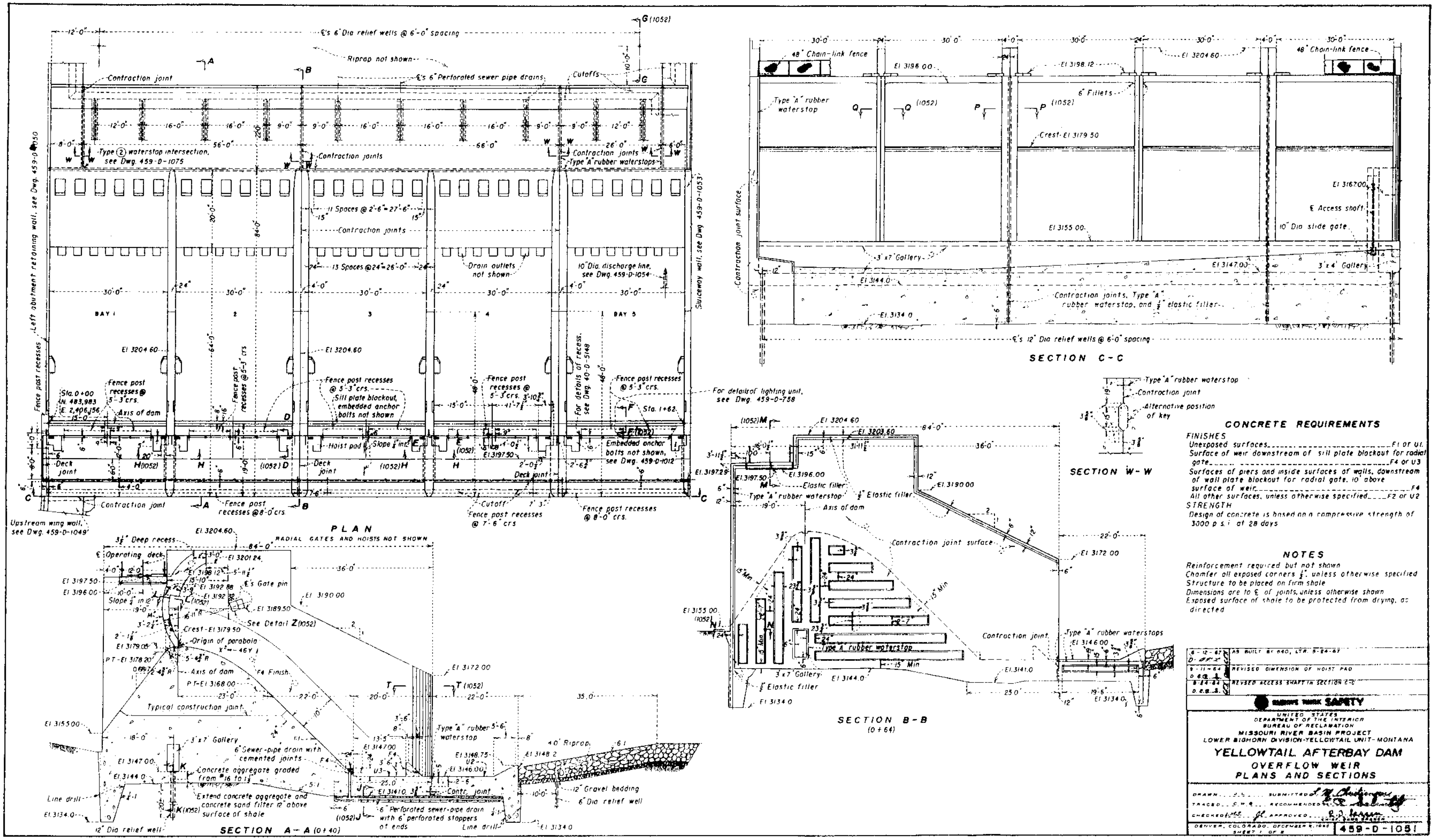


Figure 2.—Spillway overflow weir plan and sections.

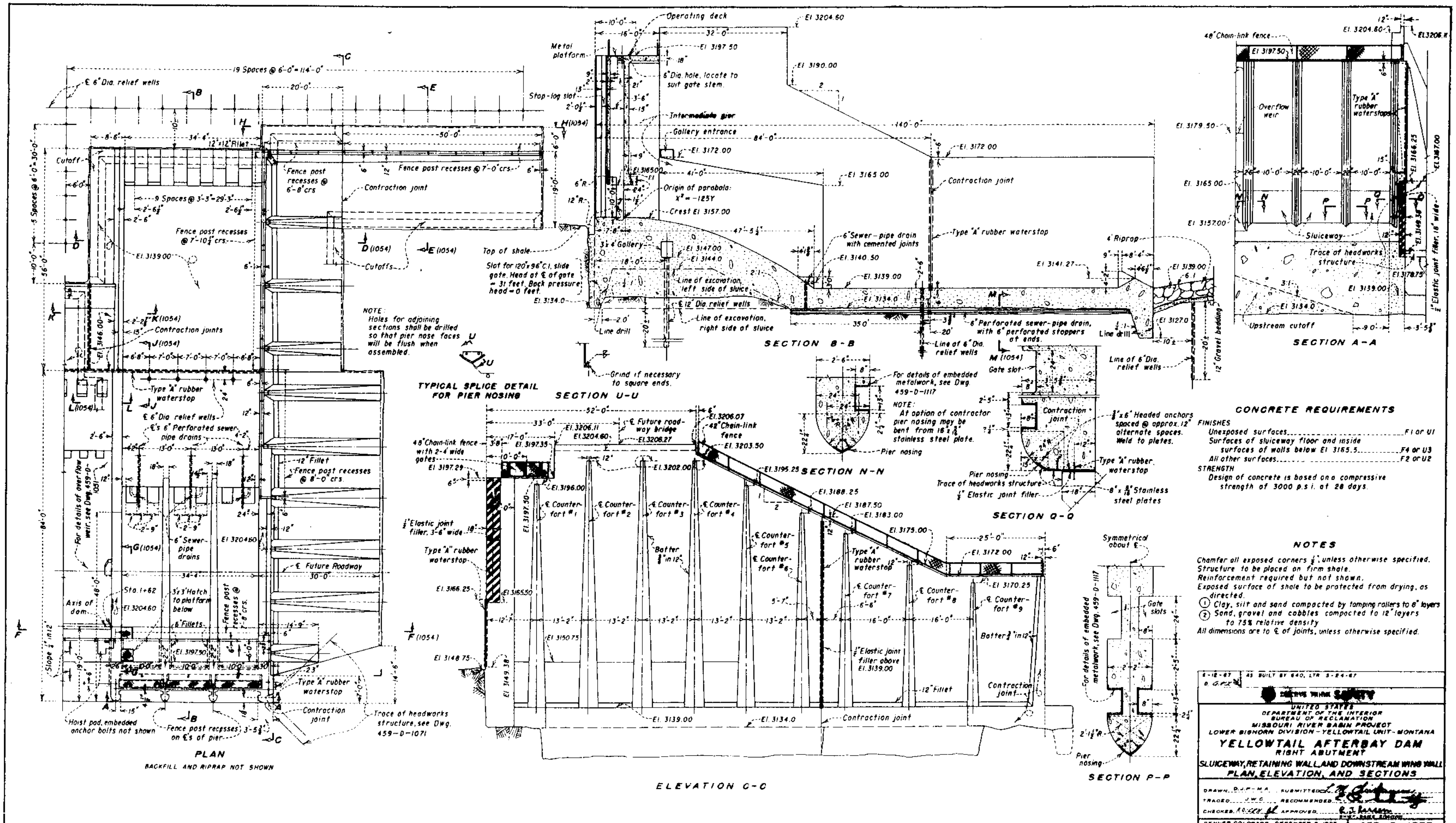


Figure 3.—Sluiceway plan and sections.

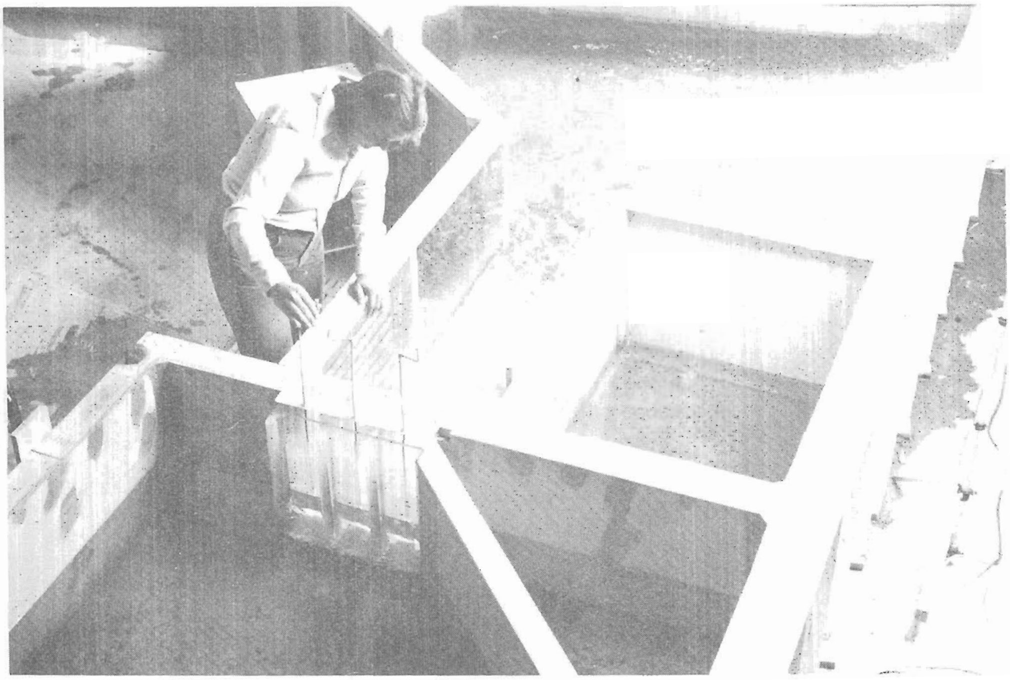


Figure 4.—Yellow Afterbay Dam sluiceway model in operation. Scale 1:24. P801-D-79761

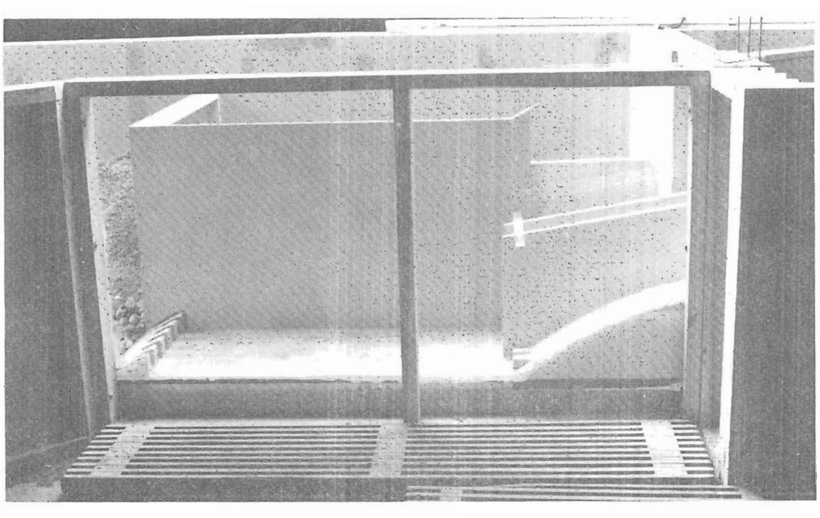


Figure 5.—Side view of hydraulic model. Yellowtail Afterbay Dam. P801-D-79762

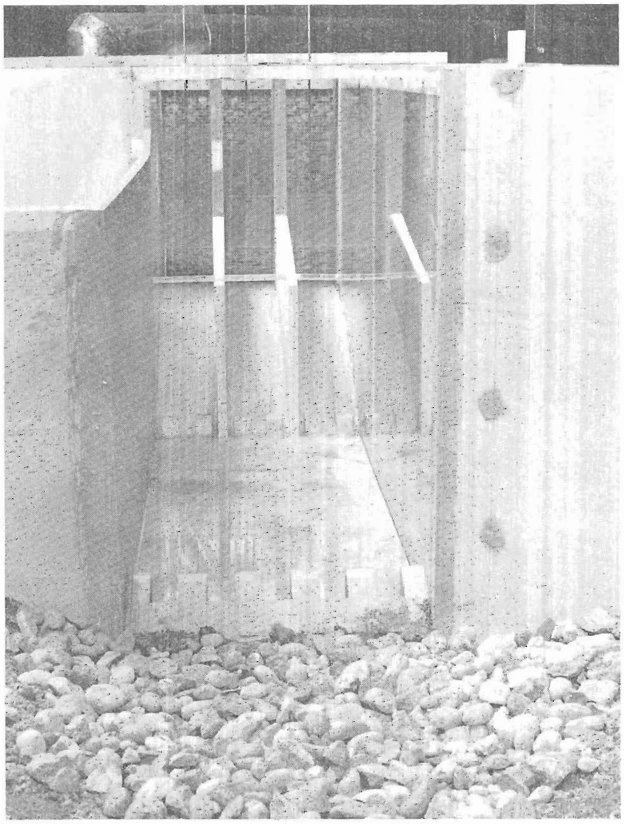


Figure 6.—Hydraulic model looking upstream into sluiceway stilling basin Yellowtail Afterbay Dam. P801-D-79763

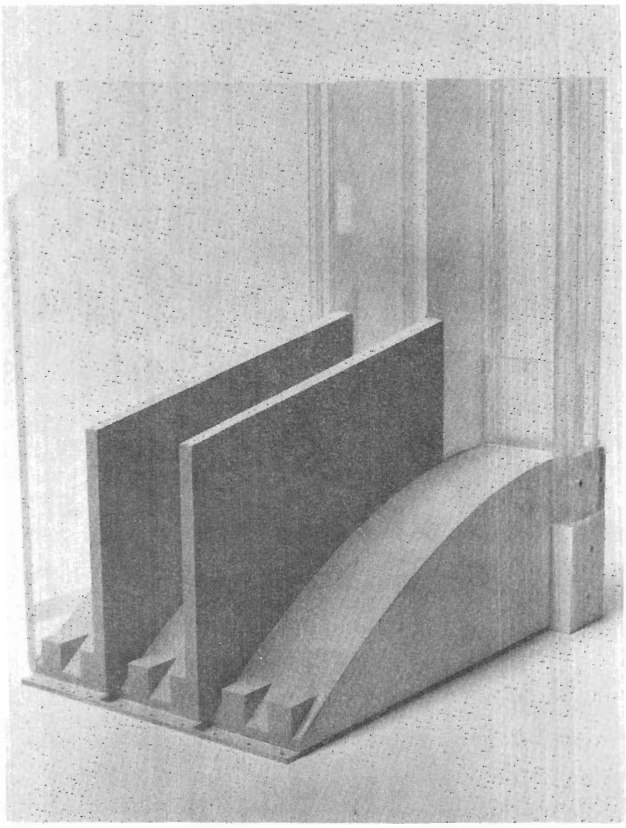


Figure 7.—Model sluiceway crest, gates, and piers. Yellowtail Afterbay Dam. P801-D-79764

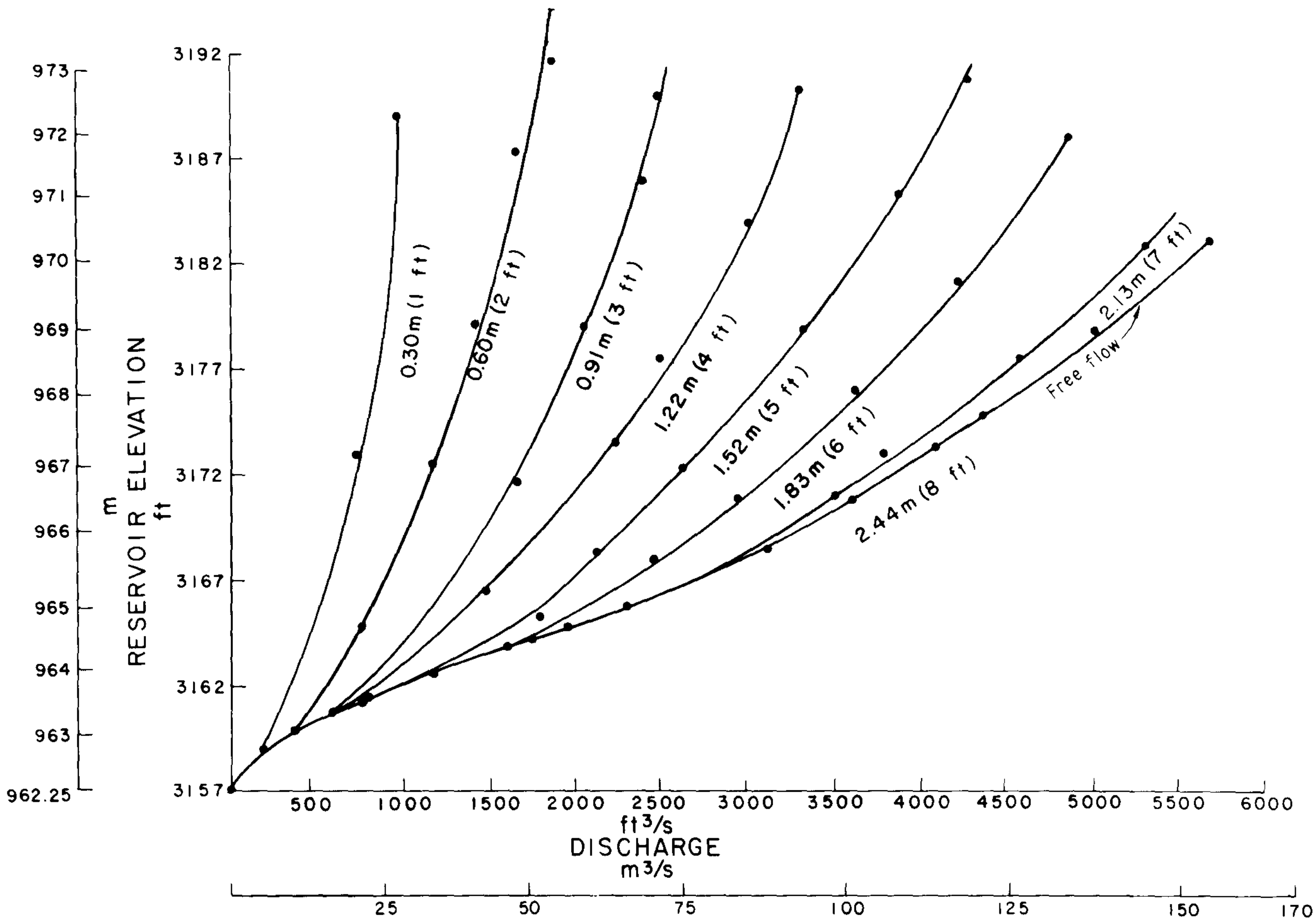


Figure 8.—Sluiceway discharge curve. Yellowtail Afterbay Dam.

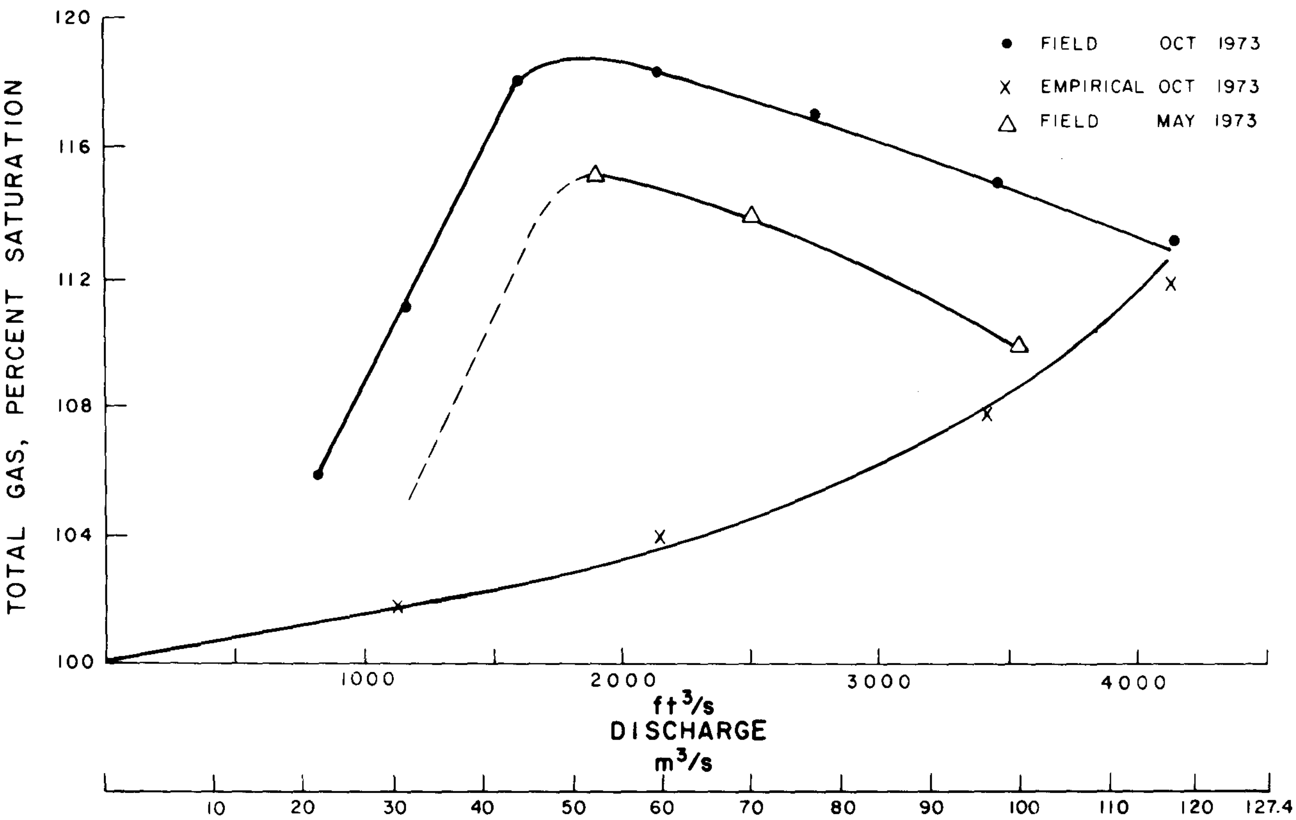


Figure 9.—Total gas saturation versus sluiceway discharge. Yellowtail Afterbay Dam.

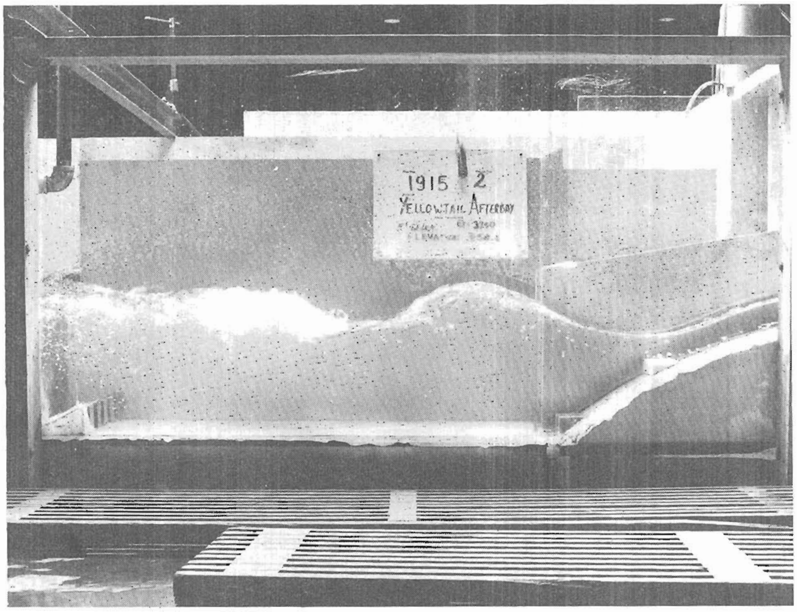


Figure 10.—First modification—deflectors EL 960.30 m (3150.6 ft). Gate opening = 2.44 m and Q = 106 m^3/s (8 ft & 3750 ft^3/s). Yellowtail Afterbay Dam. P801-D-79765

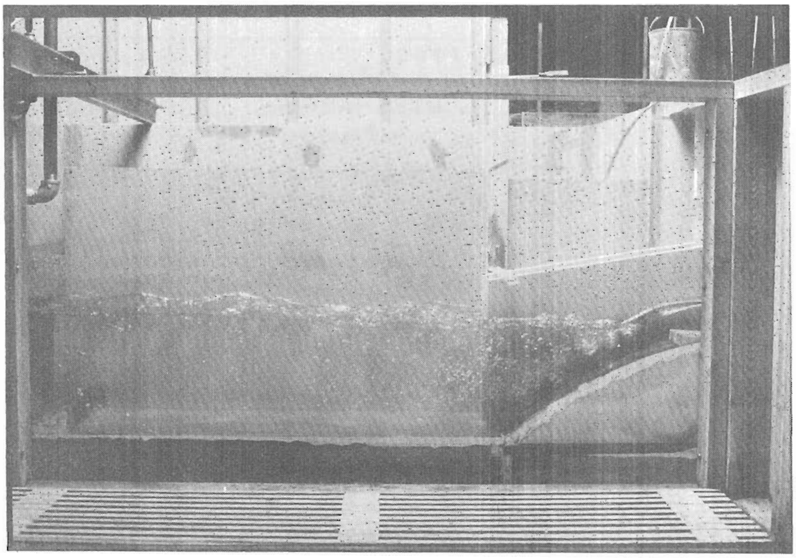
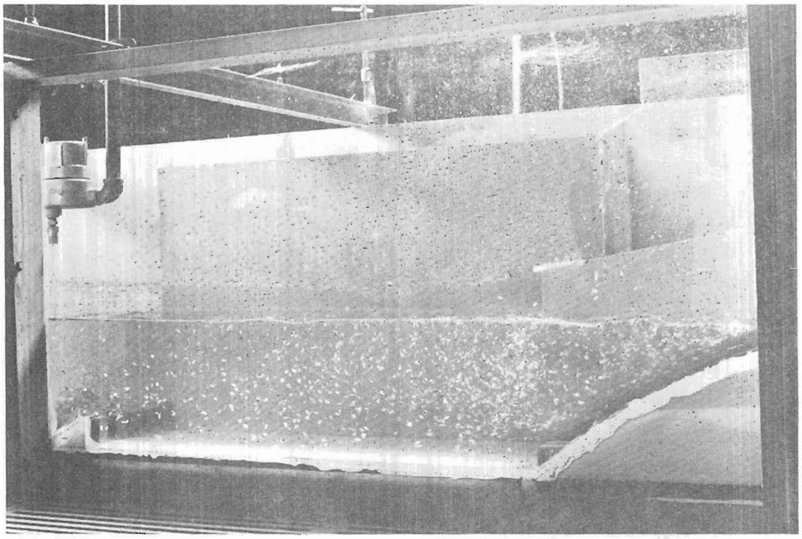
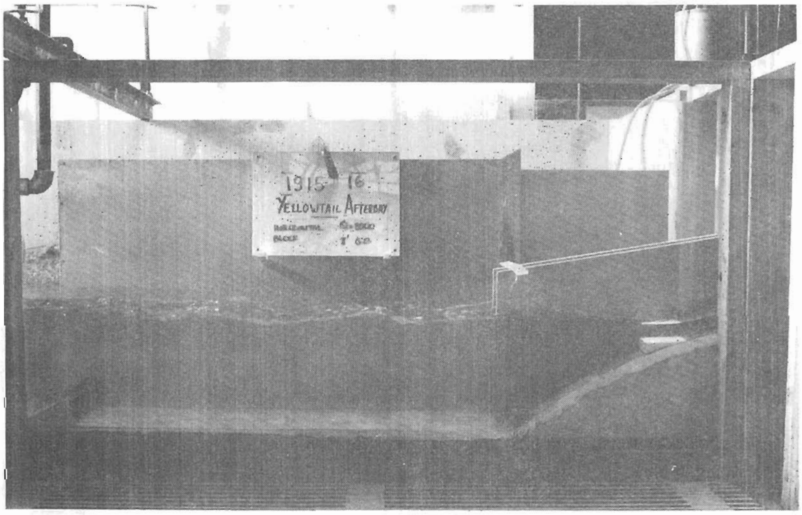


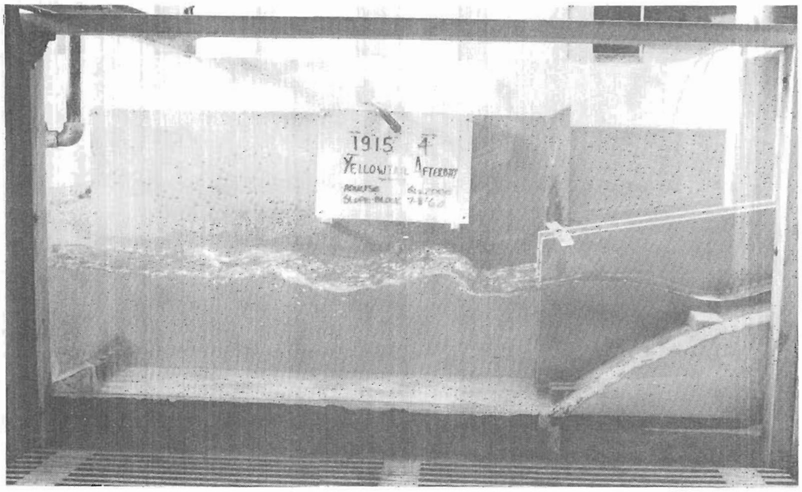
Figure 11.—Second modification—deflectors EL 962.25 m (3157.0 ft). Gate opening = 2.44 m and Q = 106 m^3/s (8 ft & 3750 ft^3/s). Yellowtail Afterbay Dam. P801-D-79766



a. Existing configuration.
P801-D-79767



b. Horizontal deflector.
P801-D-79768

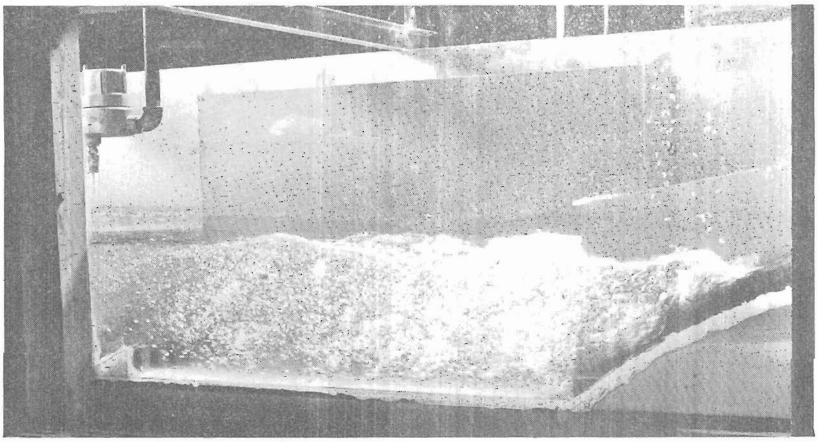


c. Adverse deflector.
P801-D-79769

Figure 12.—Model operating with flow deflector configuration. Gate opening = 2.44 m and Q = 57 m^3/s. (8 ft & 2000 ft^3/s). Yellowtail Afterbay Dam.

a. Existing configuration.
P801-D-79770

b. Horizontal deflector.
P801-D-79771



c. Adverse deflector.
P801-D-79772

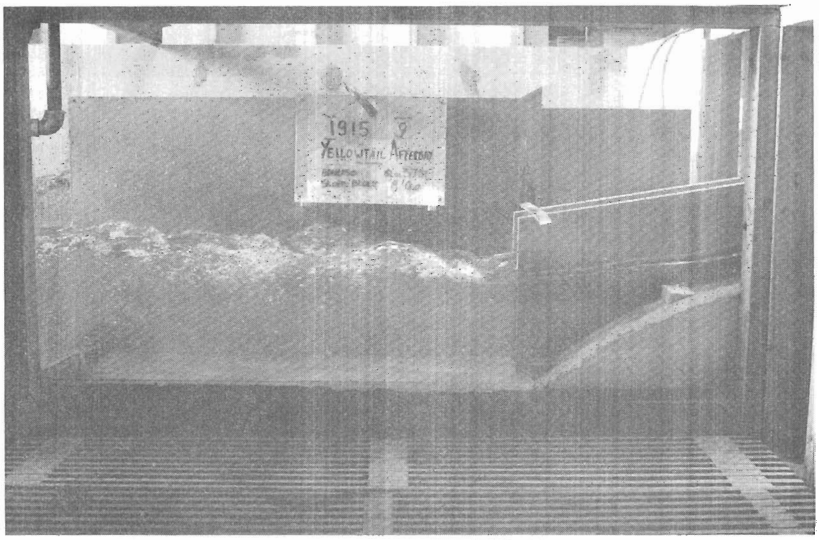
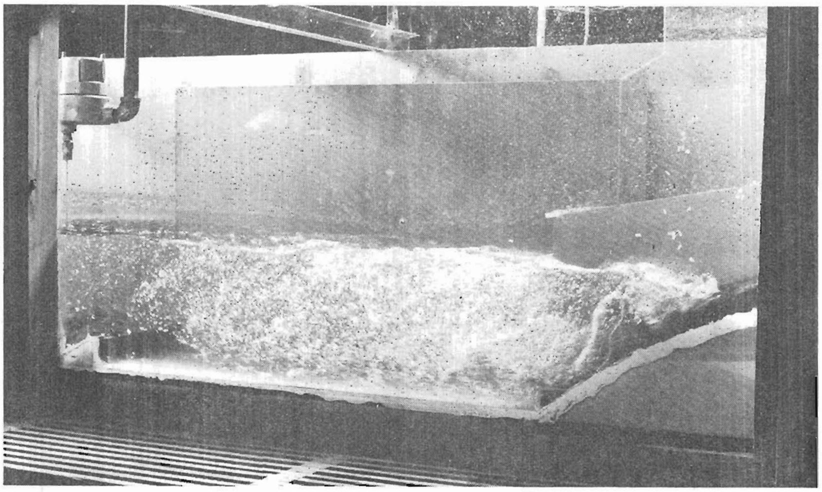
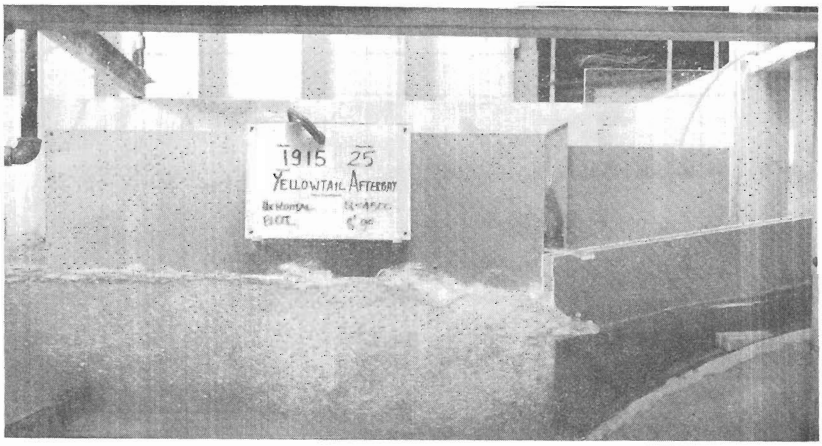


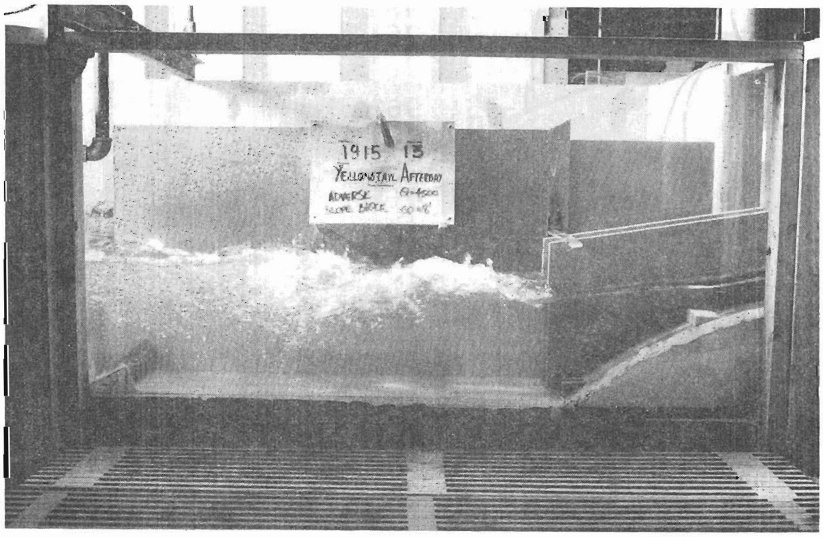
Figure 13.—Model operating with flow deflector configuration. Gate opening = 2.44 m and Q = 106 m^3/s. (8 ft & 3750 ft^3/s). Yellowtail Afterbay Dam.



a. Existing configuration.
P801-D-79773



b. Horizontal deflector.
P801-D-79774



c. Adverse deflector.
P801-D-79775

Figure 14.—Model operating with flow deflector configuration. Gate opening = 2.44 m and Q = 127 m^3/s. (8 ft & 4500 ft^3/s). Yellowtail Afterbay Dam.

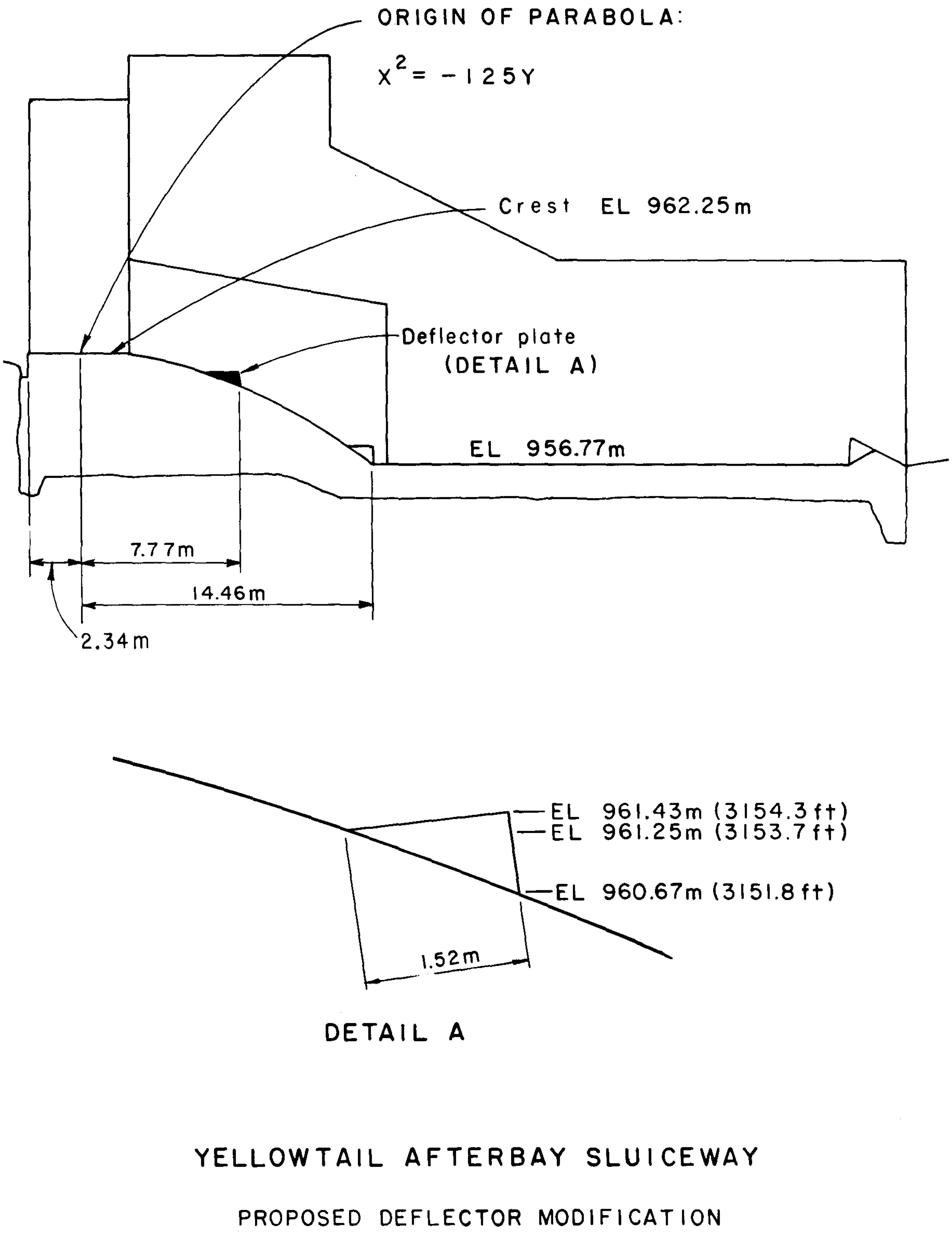


Figure 15.—Flow deflector, recommended design. Yellowtail Afterbay Dam.

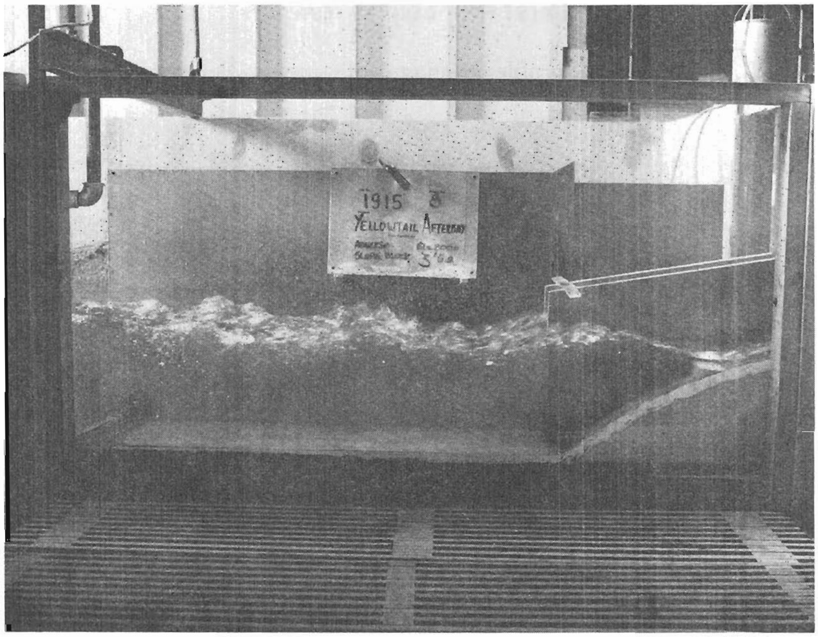


Figure 16.—Most frequent operating condition with flow deflectors installed. Gate opening = 0.91 m and Q = 57 m^3/s (3 ft and 2000 ft^3/s). Yellowtail Afterbay Dam. P801-D-79976

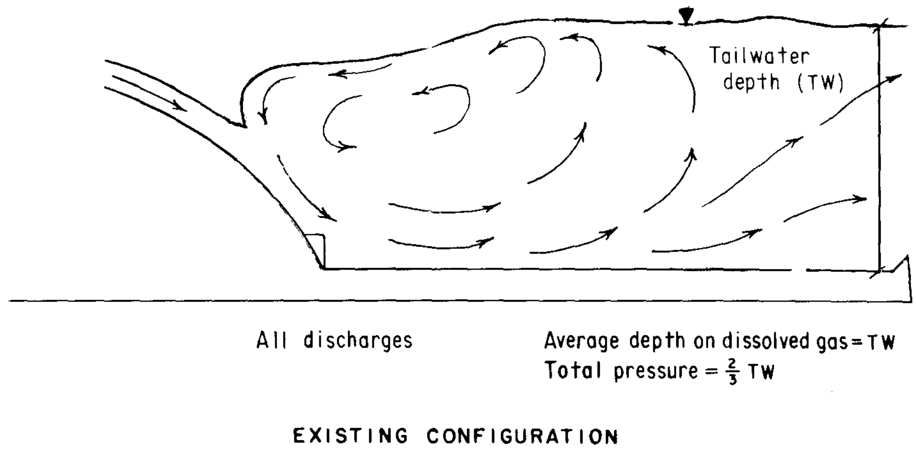


Figure 17.—Sluiceway jet profile, existing configuration. Yellowtail Afterbay Dam.

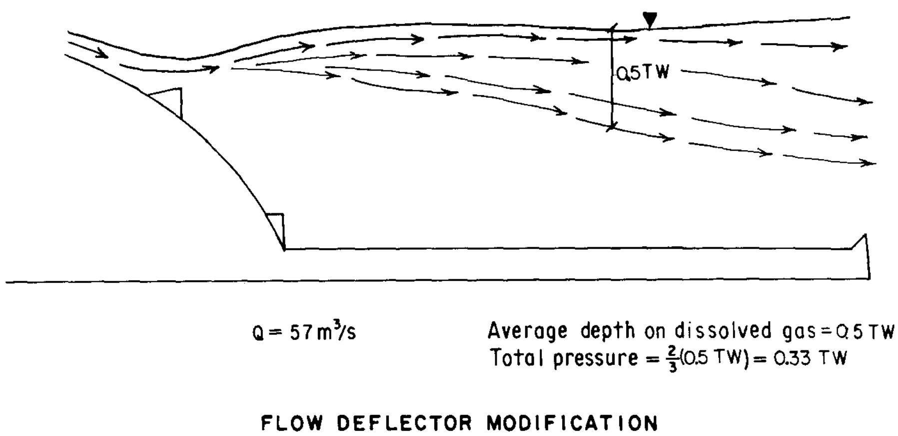


Figure 18.—Modified sluiceway jet profile, Q = 57 m^3/s (2000 ft^3/s). Flow deflector recommended design. Yellowtail Afterbay Dam.

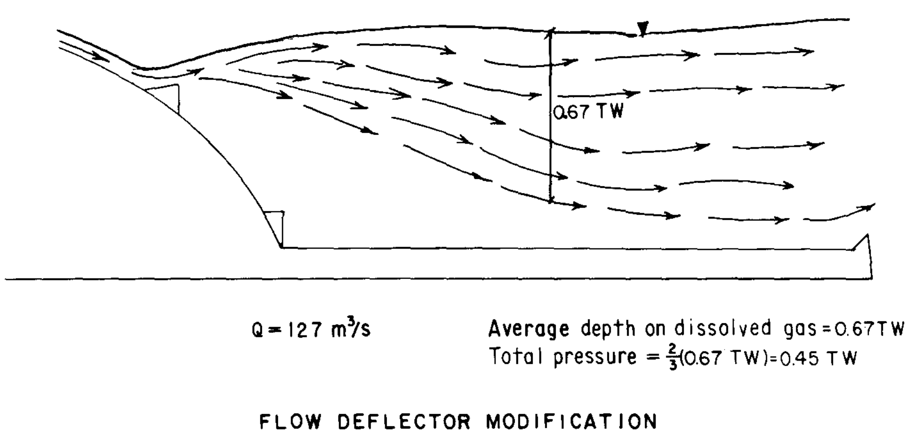


Figure 19.—Modified sluiceway jet profile, Q = 127 m^3/s (4500 ft^3/s). Flow deflector recommended design. Yellowtail Afterbay Dam.

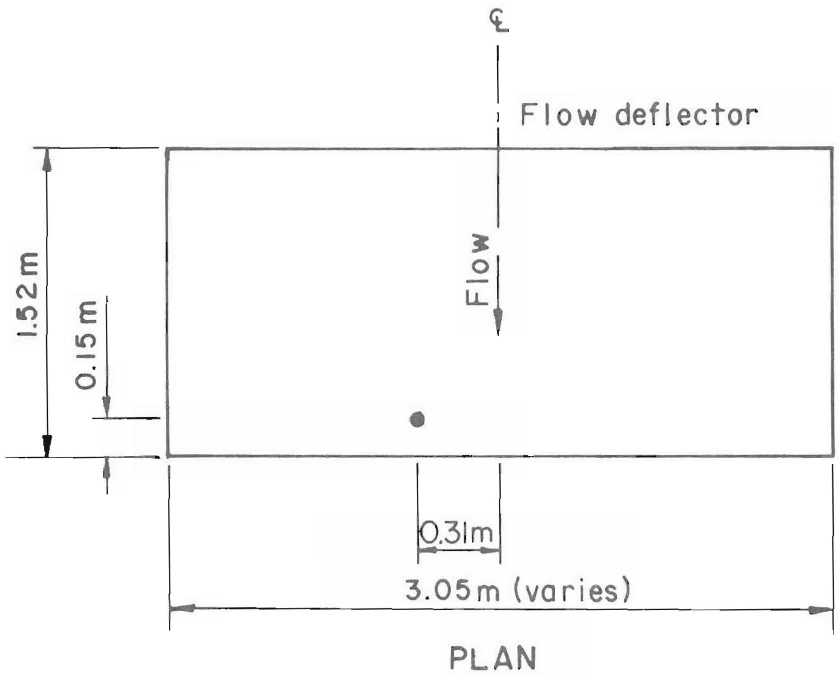


Figure 20.—Piezometer location on flow deflector. Yellowtail Afterbay Dam.

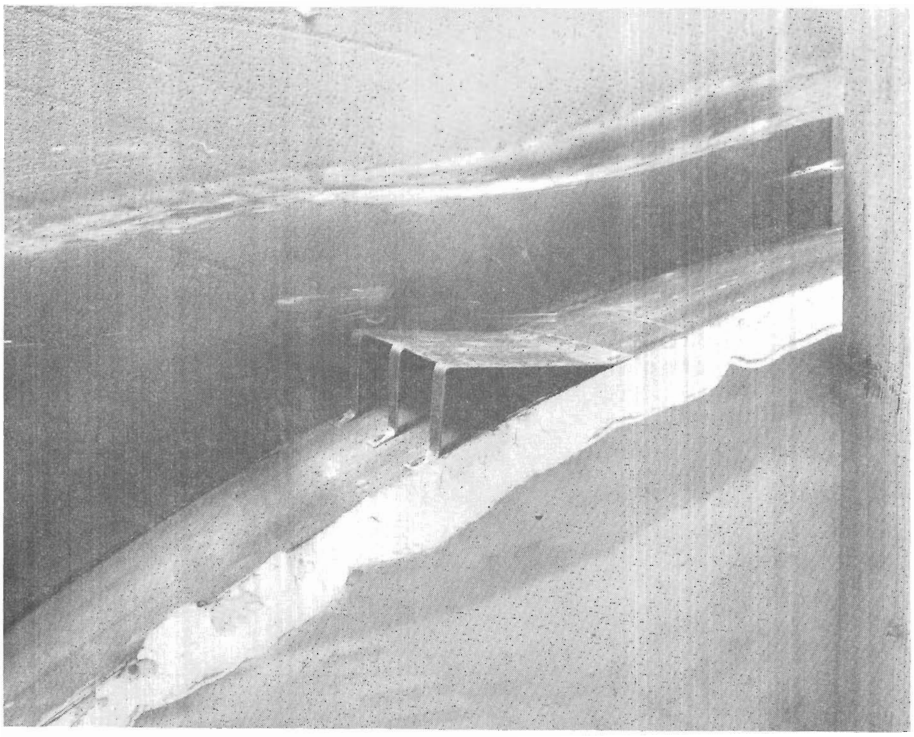


Figure 21.—Structural steel flow deflector installed in hydraulic model. Yellowtail Afterbay Dam. P801-D-79777

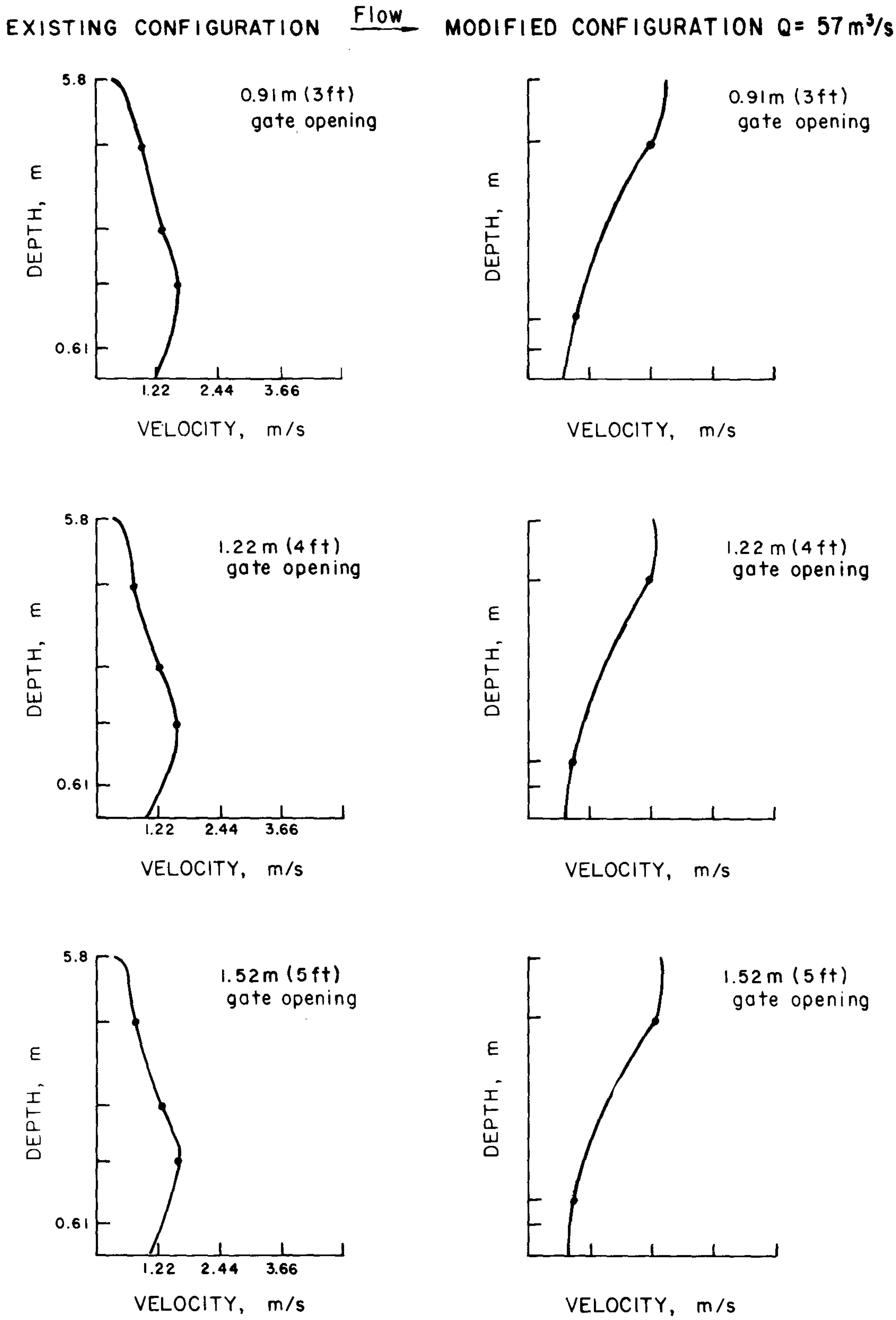


Figure 22.—Velocity profiles of existing and modified configurations. Yellowtail Afterbay Dam.

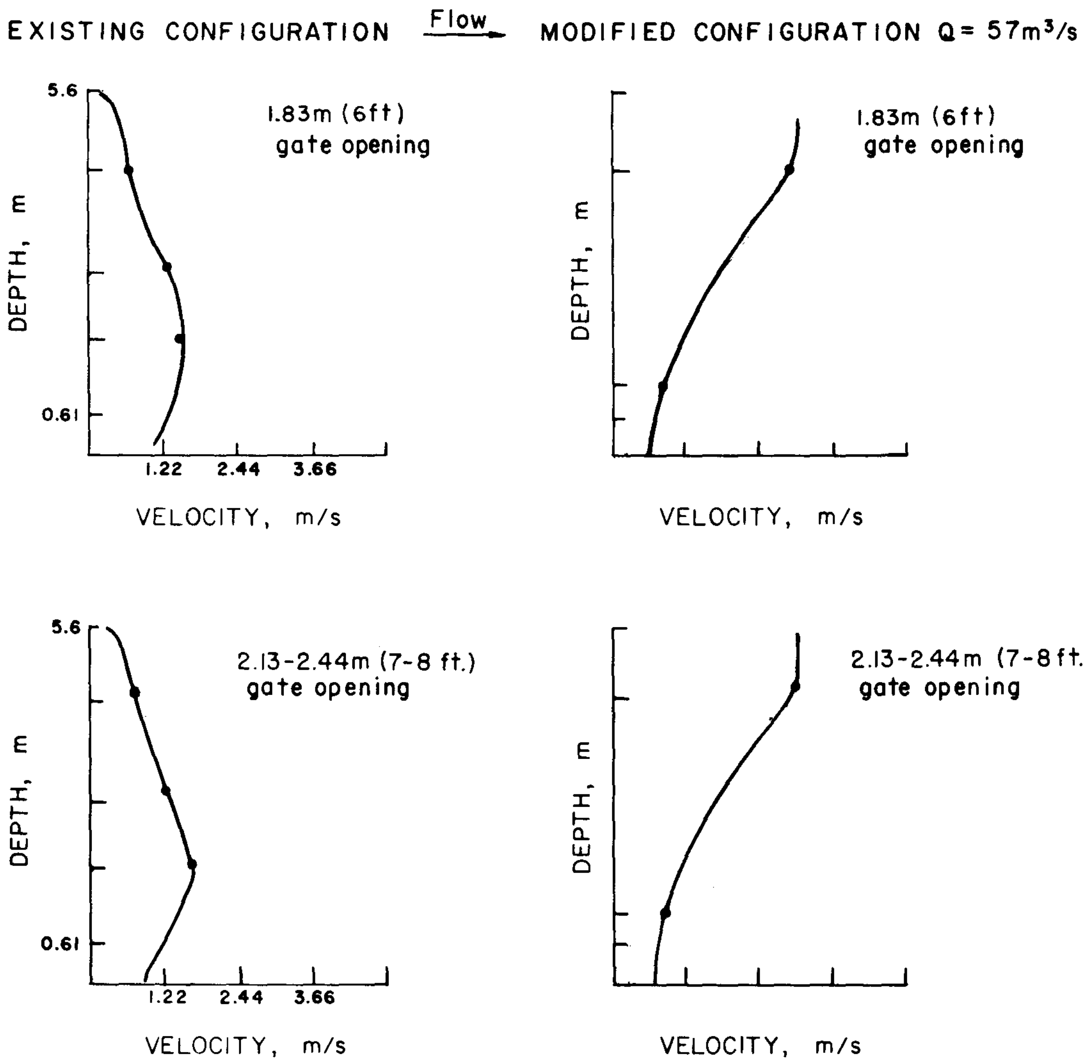


Figure 22.—Continued

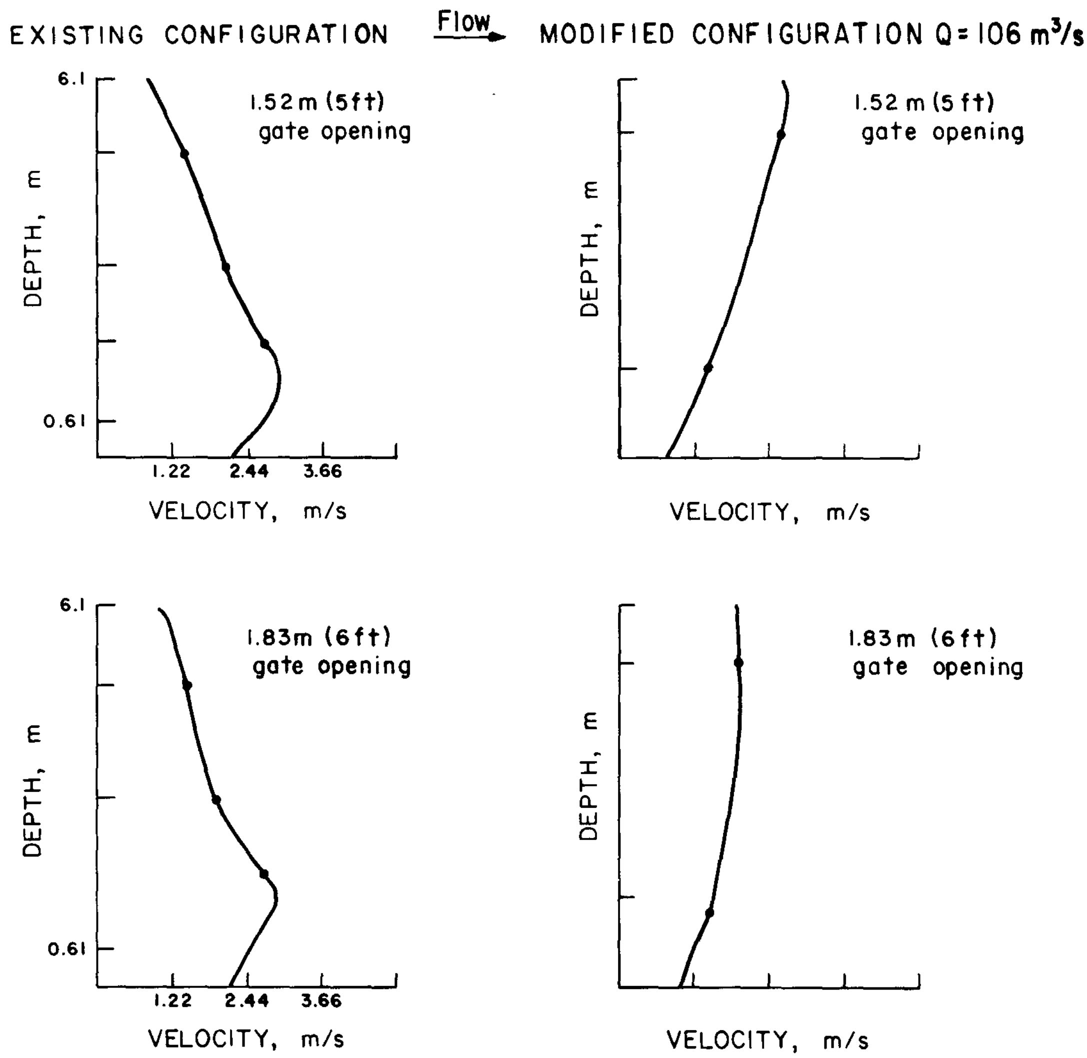


Figure 22.—Continued

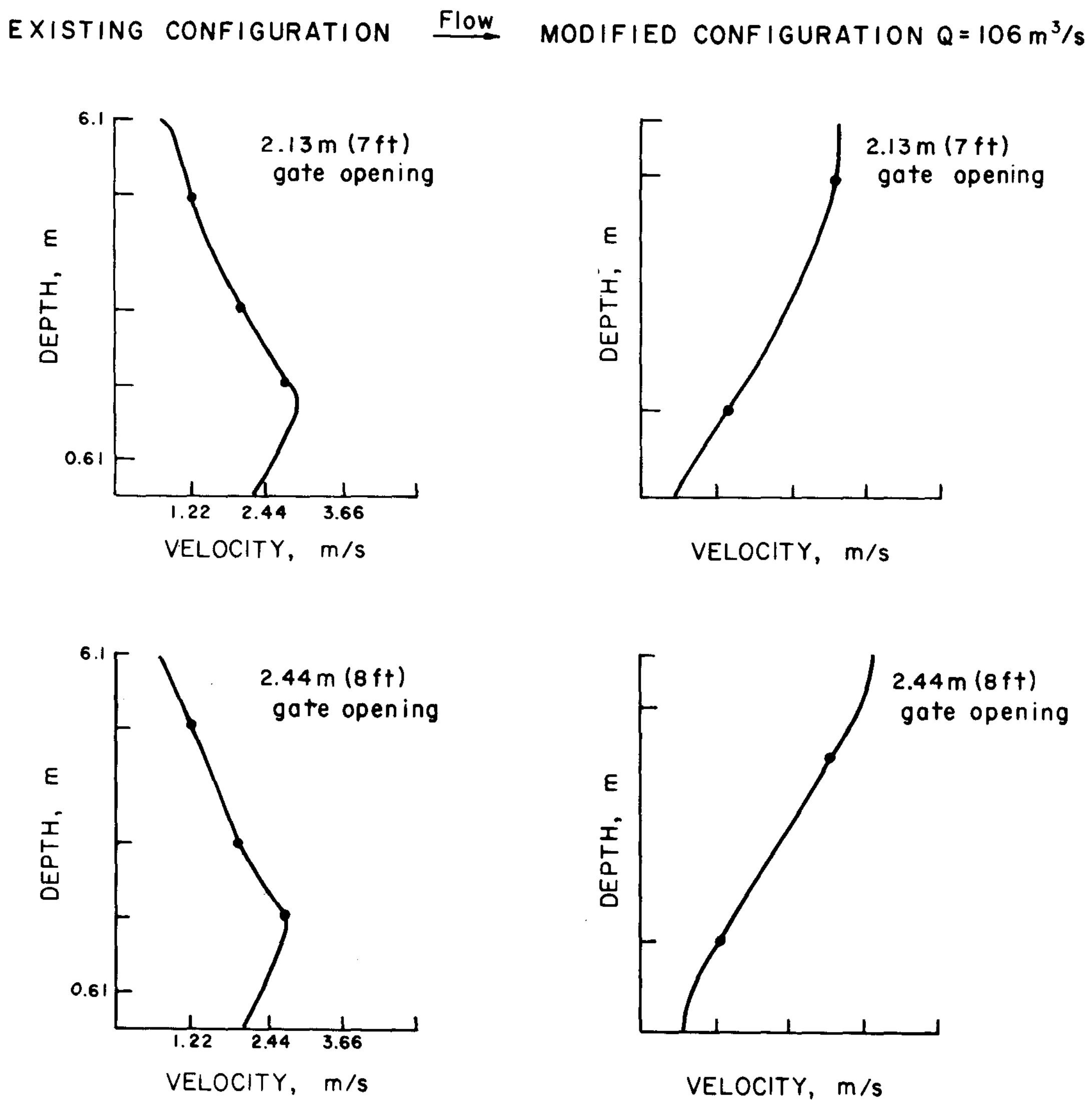


Figure 22.—Continued

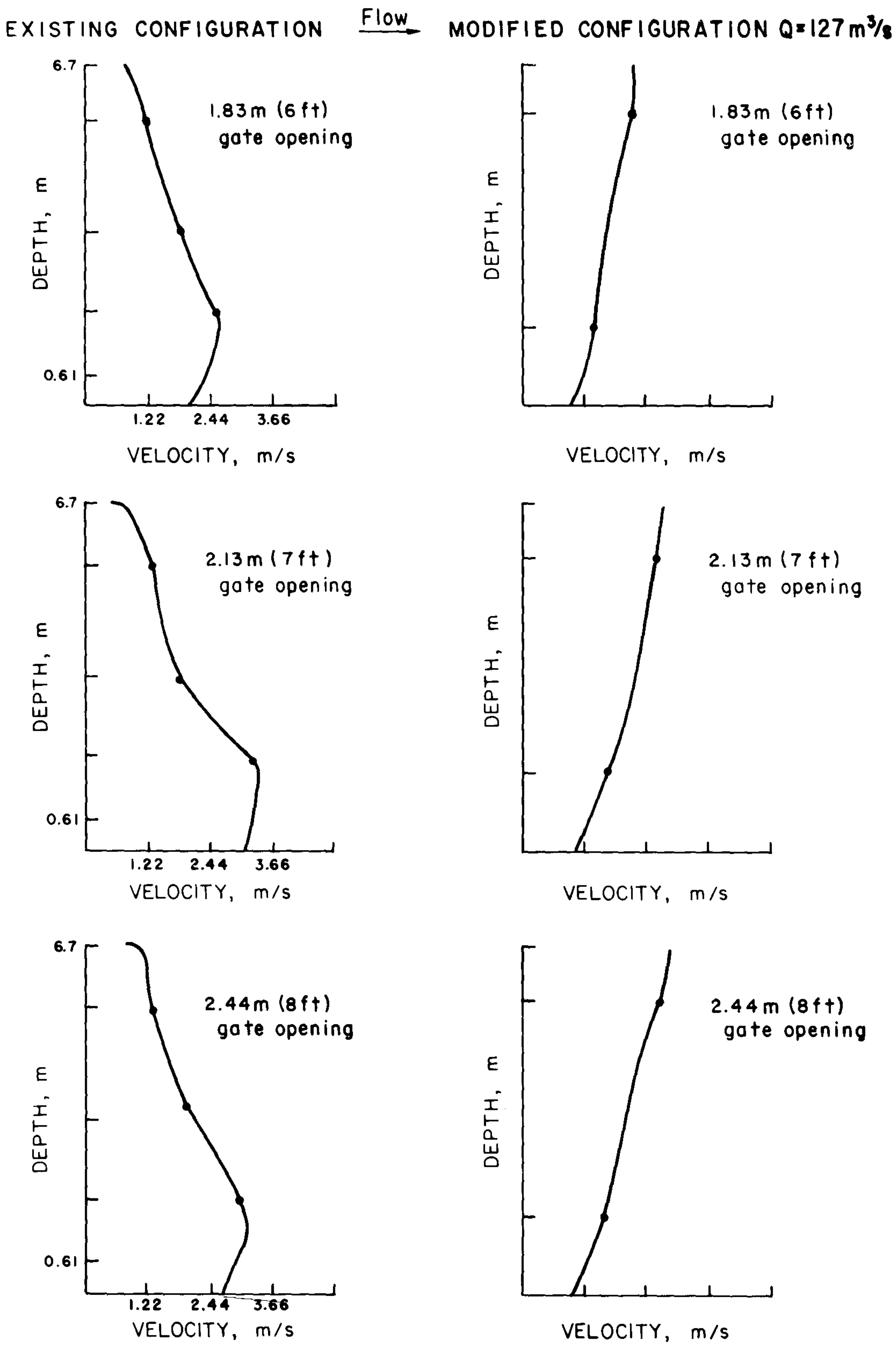


Figure 22.—Continued

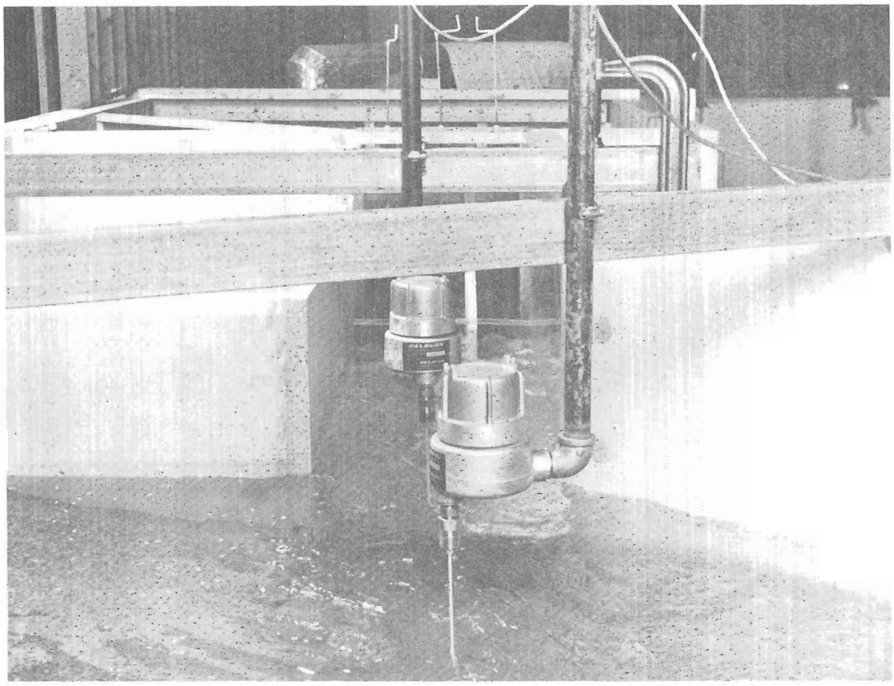


Figure 23.—Capacitance-type wave probes. P801-D-79778

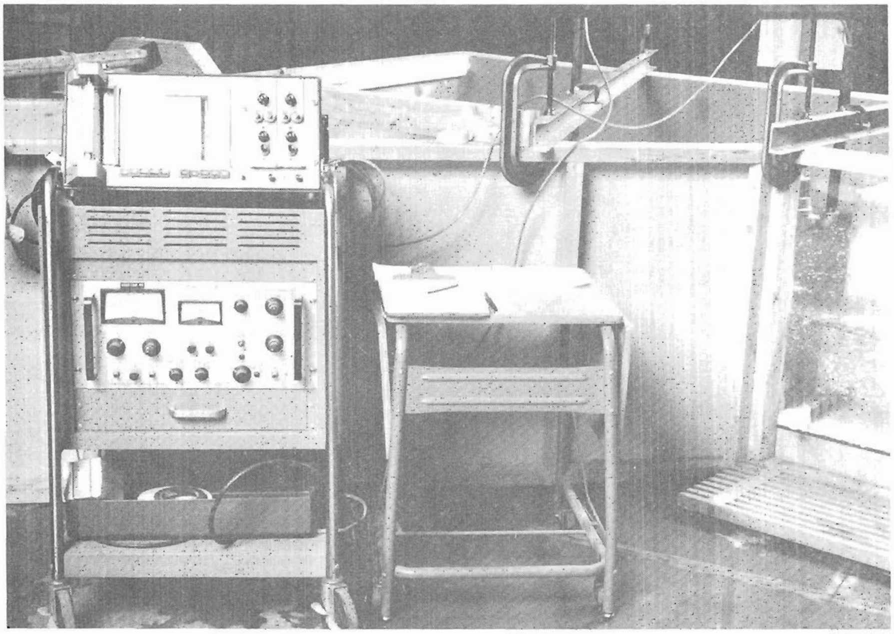


Figure 24.—Recorder for wave measurements. P801-D-79779

GPO 835-970

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled, "Publications for Sale". It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-922, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.