UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

HYDRAULIC MODEL STUDIES OF THE SECONDARY LOUVER STRUCTURE--FISH PROTECTIVE FACILITIES--TRACY PUMPING PLANT CENTRAL VALLEY PROJECT, CALIFORNIA

Hydraulic Laboratory Report No. Hyd-480

DIVISION OF ENGINEERING LABORATORIES

OFFICE OF ASSISTANT COMMISSIONER AND CHIEF ENGINEER
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Office of Assistant Commissioner and Chief Engineer
Division of Engineering Laboratories
Hydraulic Laboratory Branch
Hydraulic Structures and Equipment Section
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Laboratory Report No. Hyd-480
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Subject: Hydraulic model studies of the secondary louver structure--Fish protective facilities--Tracy Pumping Plant--Central Valley Project, California

PURPOSE

Studies were made to determine modifications needed on the existing secondary fish screen structure to eliminate eddying and reverse flow conditions in which fish were disoriented, exhausted, and eventually killed.

CONCLUSIONS

1. The 1:6.316 scale model of the existing structure reproduced the eddying flow, rollback, and turbulent conditions found in the upstream end of the prototype (Figures 5 and 7).

2. Substantial differences in flow rates among the four pipelines affected the flow pattern in the structure to a limited degree, but unbalanced flows were not the principal cause of the poor conditions.

3. Removal of the gate wall from the upstream end of the structure produced only slight improvement in the flow.

4. Expanding closed-conduit transitions in the pipelines immediately upstream from the structure provided slower flow velocities into the structure. The lower velocities decreased the intensities of the eddies but did not change the basic flow pattern.

5. Good flow was obtained by providing nearly continuous, slowly expanding closed-conduit passages through the upstream part of the structure and into the narrowed part near the first line of louvers (Figures 11, 12, and 13). These passages were obtained by using expanding transitions in the pipelines and by adding dividing piers, straight walls, and a cover inside the structure.

6. The closed-conduit-type design was insensitive to moderate unbalances of flow rates in the pipelines but severely unbalanced flow rates produced undesirable conditions. Therefore, appreciable flow should be maintained through each line (Figure 15).

7. The head loss through the structure was reduced from 1.055 times the velocity head difference in the pipelines and the louver structure for the initial (existing) structure, to a value of 0.290 Δh_v for the closed-conduit design (Figure 16).

RECOMMENDATION

Operate the structure with uniform or nearly uniform distribution of flow among all four pipelines. If appreciable unbalance of flow becomes necessary, attempt to maintain the minimum rate of flow in any line to at least 50 percent of that in the maximum flow line.

INTRODUCTION

Tracy Pumping Plant is a principal feature of the Central Valley Project in California and lifts a maximum of 5,400 cubic feet per second of water about 190 feet into the Delta-Mendota Canal (Figure 1). The plant is located 9 miles northwest of Tracy, California, and draws water from the combined flows of the Sacramento, the San Joaquin, and other streams entering the delta area at the head of San Francisco Bay.

Tremendous numbers of fish hatch each year in the maze of sloughs and channels in the delta area. The most important spawning and rearing area on the Pacific Coast for striped bass and shad lies in this region. Young king salmon in huge numbers migrate through the channels to the sea each spring and the annual commercial catch of grown salmon is 5,600,000 pounds. About 1,460,000 pounds of shad are taken. The annual catch by sportsmen is about 60,000 pounds of salmon and 6,000,000 pounds of striped bass. Catfish and other species are also taken in large quantities. In general, fish and fishing represent a valuable economic and recreational resource to the people in the area.

Within a few weeks after they hatch, the young fish start migrating by following natural flows in the channels. When the pumping plant operates, the large water drafts cause some of the tributary flows near the plant to reverse. This flow reversal induces fish to move toward the plant where many would be killed and many others would be pumped into the Delta-Mendota Canal to die later of starvation. Only fish less than 3 inches in length are of concern because larger fish avoid the plant by their own efforts. As a means of protecting these smaller fish and maintaining the populations in the delta area, a structure was needed to prevent the entrance of tiny fish to the plant.

The search for an economical and practicable structure that would pass moss and other inert debris and still be capable of deflecting or diverting tiny fish is described in Laboratory Report No. Hyd-401. 1/ The design adopted consisted of venetian-blind-like louvers placed in a line running diagonally across the pumping plant intake channel (Figure 2). The louver slats were placed vertically and oriented so that the sides were normal to the flow and to the structure centerline (Figure 3). Fish, when approaching the louvers, detect the presence of these obstacles and orient and exert themselves to avoid them. Thus, they drift diagonally downstream with the flow along the line of louvers. At intervals along the line four bypasses are provided where the accumulated fish, together with considerable quantities of water, are pumped from the intake channel.

The pumped water and fish are led into a secondary louver structure to further concentrate the fish and remove much of the water that transported them to the structure (Figure 4). From the secondary structure, the fish and a limited quantity of channel water, plus a quantity of screened water, are placed in holding tanks. Here the fish recover from their unaccustomed experiences and regain their strength. Then they are placed in trucks and transported to a point beyond the unnatural influence of the pumping plant and reintroduced into the channels.

Experience has shown that the primary and secondary louver structures are remarkably efficient. 2/ In spite of this excellent overall record, an undesirable flow condition within the upstream portion of the secondary louver structure has caused unnecessary fish mortalities. Several field attempts have been made to overcome this poor flow condition by modifying the structure. However, restrictions on time available to make structural changes, the unwieldy size of the structure, and the costs of prototype changes precluded a thorough investigation. Model studies were made in the Hydraulic Laboratory of the Denver Office and a satisfactory solution was evolved. This report discusses the model studies and the evolution and performance of the recommended design.

ACKNOWLEDGMENT

The results in this test program were attained through close cooperation between staff members of the Canals Branch and the Hydraulic Laboratory Branch of the Denver Office and the Regional office in California.

1/ "Field and Laboratory Tests to Develop the Design of a Fish Screen Structure--Delta-Mendota Canal Headworks--Central Valley Project, California" by D. M. Lancaster and T. J. Rhone.

2/ "Efficiency Evaluation, Tracy Fish Collecting Facility." Bureau of Commercial Fisheries, Pacific Region, U. S. Fish and Wildlife Service, Seattle, Washington; and Bureau of Reclamation, Region 2, Sacramento, California; October 1960, by D. W. Bates, Orren Logan, and E. A. Pesonen.

THE MODEL

A model about one-sixth the size of the prototype structure provided sufficiently large dimensions for accurate tests and a convenient size for construction and operation. The opportunity of using existing sections of 5.70-inch-diameter transparent plastic pipe to represent the 36-inch-diameter prototype conduits established the final scale ratio at 1:6.316.

The model consisted of a head box, four 5.70-inch-diameter conduits, and the major portion of the secondary louver structure (Figures 5 and 6). Water entered the upstream end of the head box and passed through a 6-inch-thick, gravelfilled baffle to smoothly approach the entrances of the four conduits. A short distance downstream from the entrances a sheet-metal slide gate was provided in each line so the flows could be adjusted. Water entered the secondary louver structure from these lines, passed through a short compartmented space and then through square openings in the gate wall to enter the large, open, upstream end of the structure. A tailgate at the downstream end of the structure permitted control of the water depth.

Water was supplied by a 5-inch vertical turbine pump driven by a 10-horsepower motor. The rate of flow was measured by a laboratory orifice-Venturi meter using a 2.375-inch-diameter orifice plate. The heads in the pipelines and in the secondary structure were measured by single-leg water manometers so loss determinations could be made.

INVESTIGATION

Existing Design

The initial tests were made with equal and nearly equal flows in all four lines and with flow rates equivalent to 120 and 135 cubic feet per second. Undesirable flow conditions were immediately apparent. Considerable turbulence occurred in the lower part of the compartments between the structure headwall and the gate wall. This turbulence decreased rapidly in the water above the pipeline openings. The water surface in the compartments was quiet. Bits of paper placed in the water moved about but remained trapped in the compartment.

In the wide portion of the structure just downstream from the gate wall, part of the flow recirculated in a large, slow-moving eddy or rollback. Dye clouds of potassium permanganate showed that the water from the two center conduits moved straight downstream into the narrow section. However, flows from the outer conduits struck the converging walls of the structure and water was deflected upward to form a roller along each side with flows at the surface moving toward the centerline. Some of the water in the rollers moved downstream to enter the narrow part of the structure. The remainder moved upstream along the surface to produce the relatively slow-moving transverse eddy or rollback of water in the wide part of the structure. Dyes or pieces of water-soaked paper remained in the eddy zone of the model for considerable lengths of time.

The surface flow pattern within the structure was made visible by sprinkling confetti on the water and taking time-exposure photographs (Figures 7, 8, and 9). These photographs clearly show the surface movement toward the structure centerline and the transition zone between flows moving upstream and downstream.

Changing the flows in individual lines to produce unbalanced conditions affected the symmetry of the flow in the structure but did not change the general pattern. Similarly, changes in water depth had no appreciable effect on the general pattern.

Removal of the gate wall eliminated the compartment-like traps from the flow system but did not significantly alter the flow pattern (Figure 8).

Expanding Pipeline Transitions

The effect of lower entering velocities upon the eddy action was determined by replacing the circular pipelines just upstream from the headwall with expanding transitions (Figure 10A). These 19-foot-long (prototype) transitions were 36 inches in diameter at the inlet and 52 inches wide by 60 inches high at the outlet. Thus, the area of the transition outlets was 3.07 times larger than the inlet area, producing exit velocities about one-third of the velocity in the circular pipelines. The overall rate of expansion equalled that of a 6.8° (total included angle) cone. This represented a nearly maximum rate of expansion without severe separation. The gate wall was not included within the model structure in these studies.

Tests showed that the expected reduction in intensity of eddying was achieved by the lower entrance velocities, but that the basic eddying pattern was not changed (Figure 9). It was evident that more positive control was needed.

Cover Within the Structure

A short cover, or roof, was placed inside the upstream part of the structure to confine the flow to a given path and eliminate the deadwater space above the conduit outlet (Figure 10B). The 19-foot long cover started at the top of the pipeline transition outlets and rose to elevation +9.0. The sides of the structure were modified to converge in straight lines and become tangent to the existing curves at the narrowed section. A more controlled and expanding flow path was thus provided for the water, and large areas where eddying could occur were eliminated.

Good results were obtained with this exploratory design. The flow moved directly through the structure with only local tendencies for eddying. These small eddies occurred between and downstream from the conduit exits, at the small step in the floor at the structure entrance, and in the tops of the expanding pipeline transitions near the exits.

Recommended Design

The area curve of the flow passage through the exploratory design showed regions of undesirable change and excessive expansion (Figure 11A). A new design was developed representing a compromise between an ideal straight line area curve and a structure easy and economical to build (Figures 11B, 11C, 12, and 13). The conduit transitions were shortened to fit within the 13-foot long space between the end of the last bend in Conduit No. 4 and the structure headwall. The existing step in the floor was eliminated by sloping the transition inverts upward to the elevation of the structure floor. Tapered piers were placed downstream from the headwall to fill the spaces between the conduits. The cover was sloped slightly upward to the end of these piers, and then more sharply upward to terminate at elevation +9.0 in the parallel narrow part of the structure.

Tests made over a wide range of equal flows in the four discharge lines and with several water surface elevations showed smooth, steady, eddy-less flow (Figure 14). No areas of possible fish holdup or disorientation were found.

Tests made with grossly distorted flow distributions among the pipelines showed acceptable to good flow conditions (Figure 15). If the flow through a conduit was completely shutoff, the area just downstream from that conduit became a deadwater area where fish could seek refuge. As soon as flow started through the line the deadwater was eliminated. At 25 percent or larger openings, the flow was established strongly enough to produce reasonably good distribution. Dye clouds placed in a model conduit were cleared in about 7 minutes with a 25-percent gate opening, 1 minute with a 50-percent opening, and 10 seconds with a 75-percent opening. These tests were made with the rest of the conduits 100 percent open.

On the basis of the above data, and considering that all field operation will be with nearly symmetrical distribution of flow among the conduits, the performance of the structure is expected to be excellent. It is, therefore, recommended for use on the prototype structure. An important corollary operation recommendation is that the minimum flow in any line be at least 50 percent of that in the maximum flow line. This will maintain satisfactory flow through all areas of the structure.

Head Loss

Measurements were made of the head loss sustained by symmetrical flows in passing from Station 11+24.0 in the circular pipelines to Station 11+91.5 in the louver structure (Figure 16). The computed velocity head in the circular pipelines was added to the average piezometric head in the lines to obtain the upstream total head. The downstream total head was determined similarly in the narrow part of the structure. The difference between the upstream and downstream total heads was taken as the loss. The loss at a flow of 120 cubic feet per second for the existing (initial) structure was 0.26 feet prototype, or 1.055 times the difference in velocity head in the circular pipelines and the narrow part of the channel. Removal of the gate wall reduced the loss to 0.23 feet and the loss factor to 0.915. The loss in the recommended design was further reduced to 0.07 feet, or a loss factor of 0.290. Thus, a reduction in pumping costs will be realized due to the improved hydraulic performance of this part of the system.

FIGURE I
REPORT HYD. 480

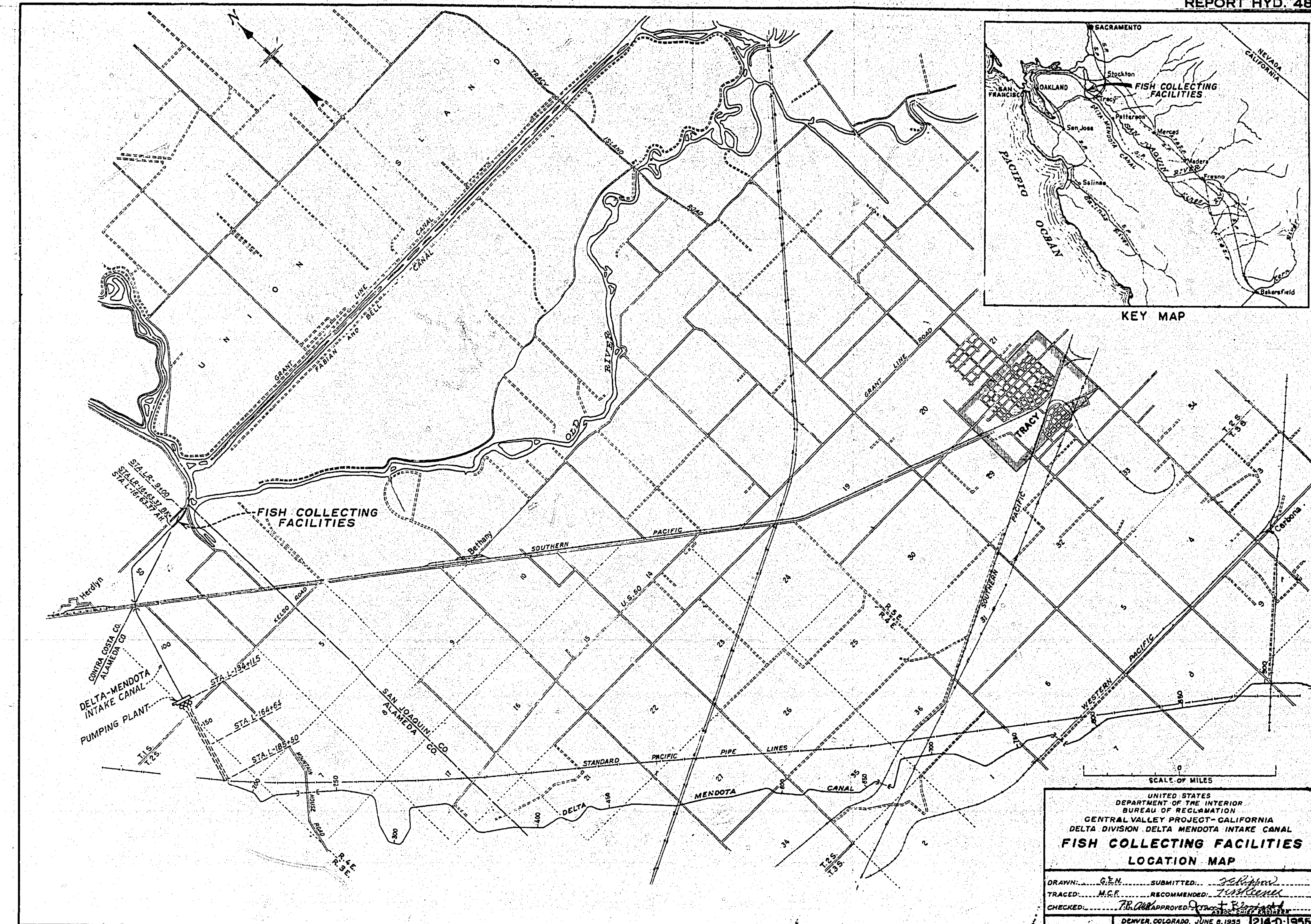


FIGURE 2
REPORT HYD. 480

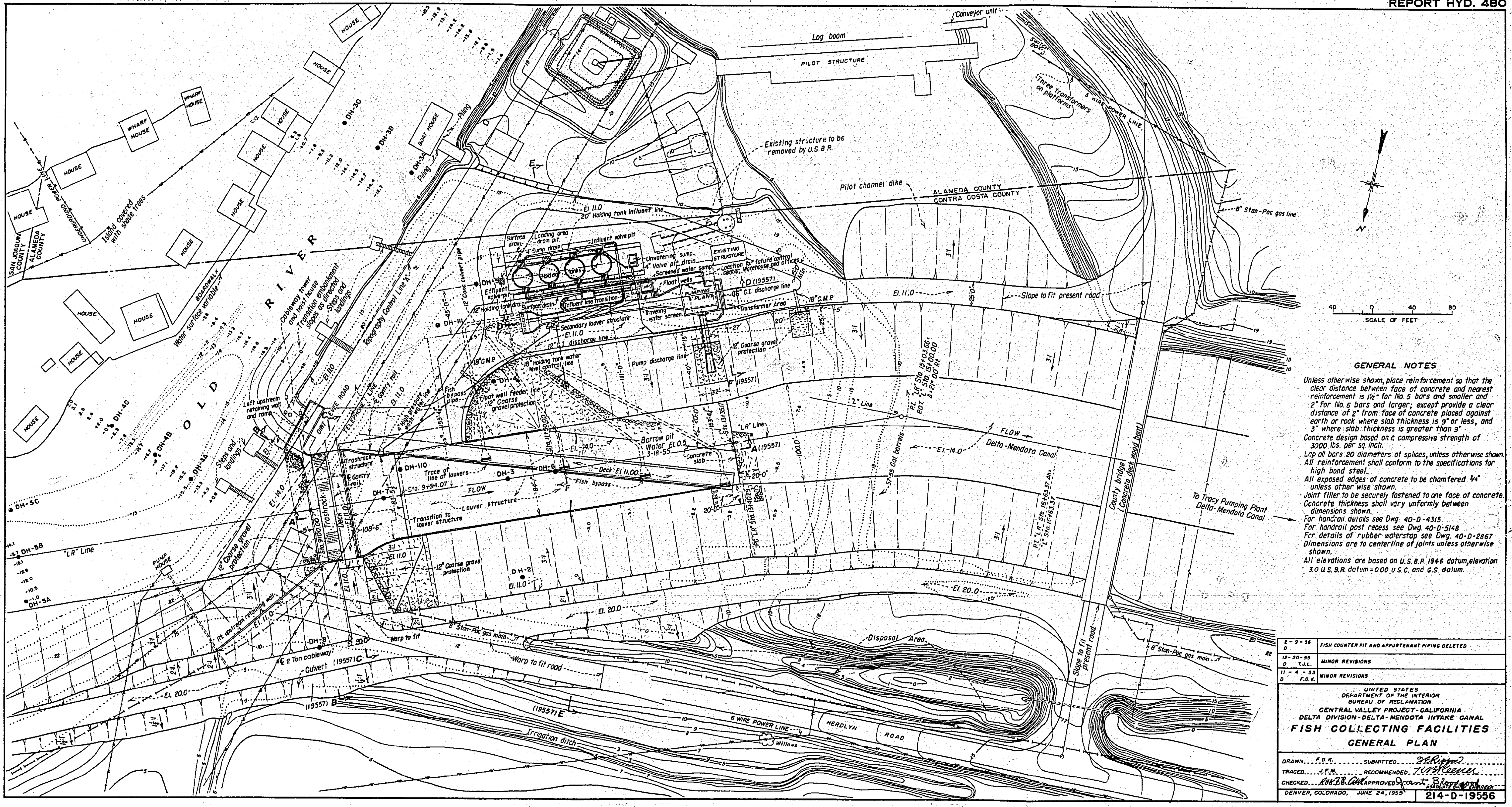


FIGURE 3
REPORT HYD. 480

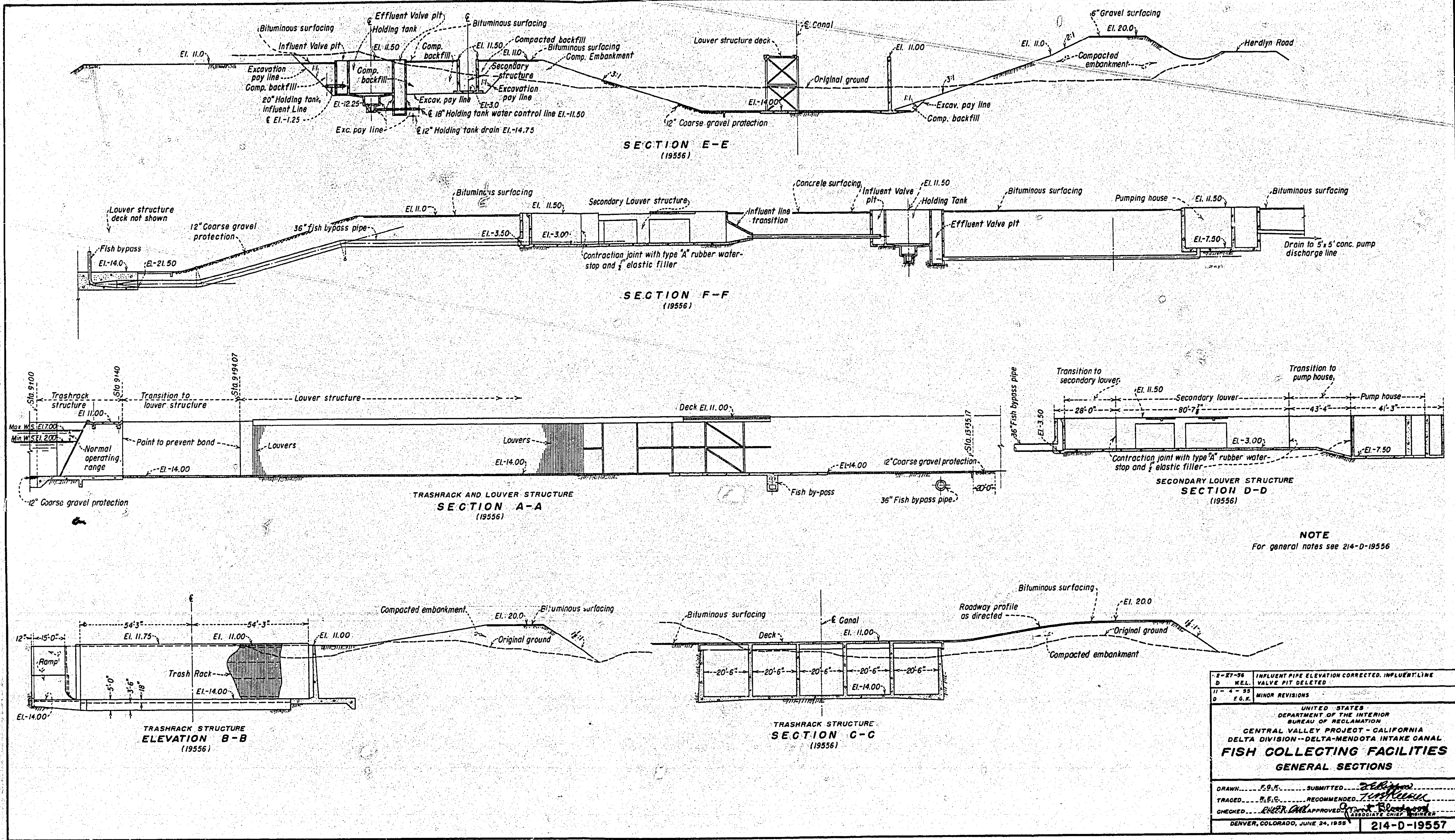


FIGURE 4
REPORT HYD. 480

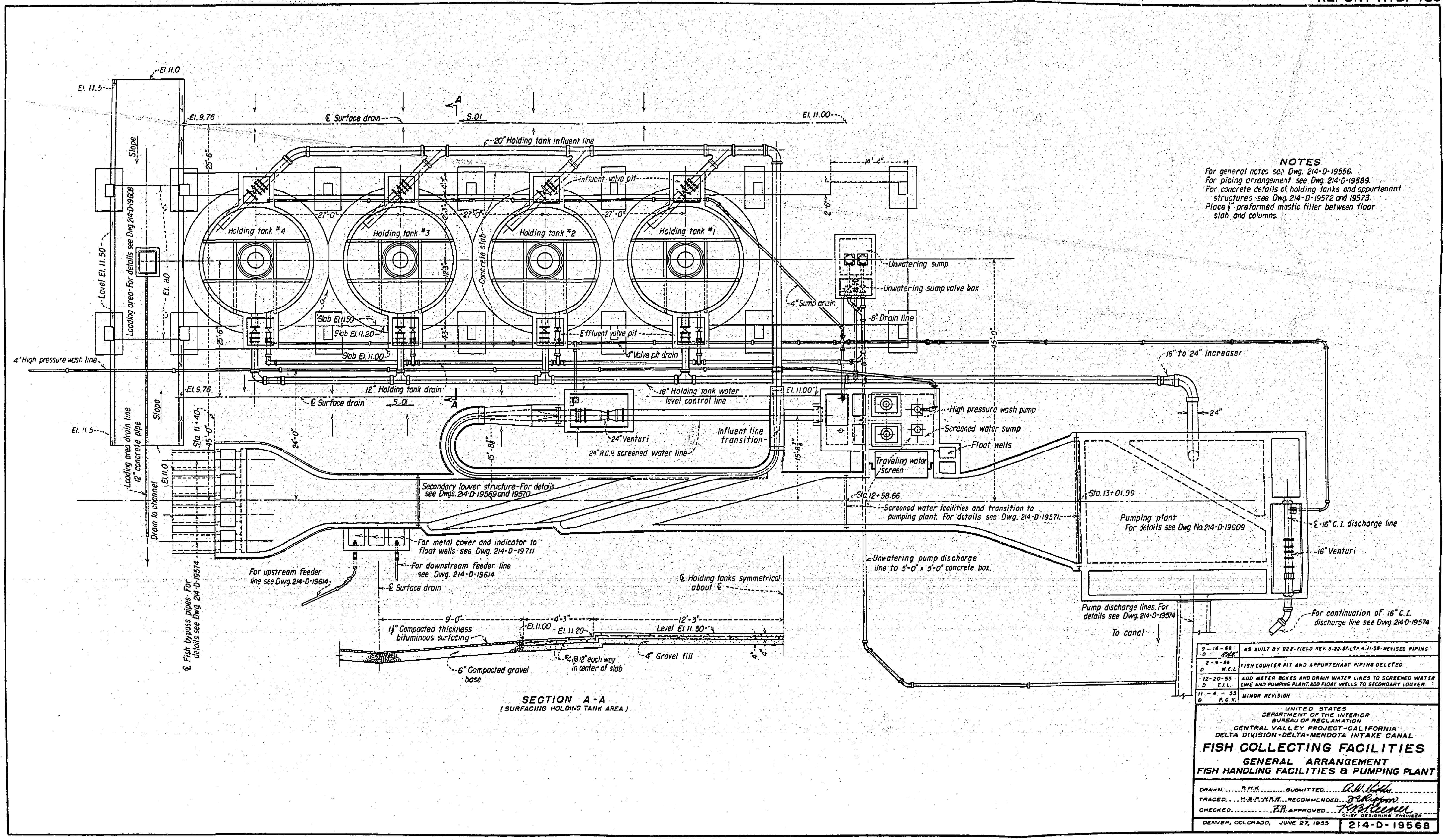
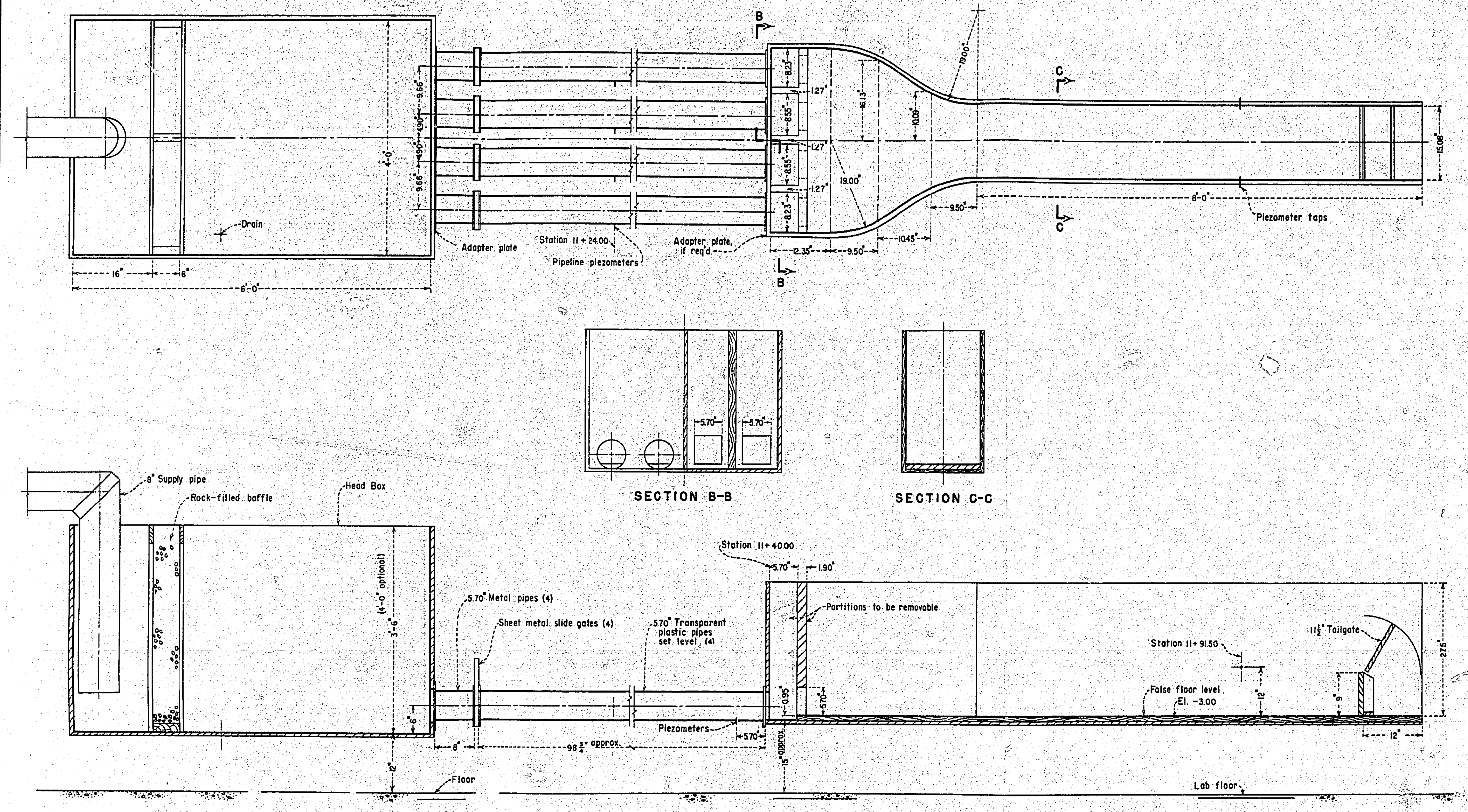


FIGURE 5
REPORT HYD 480

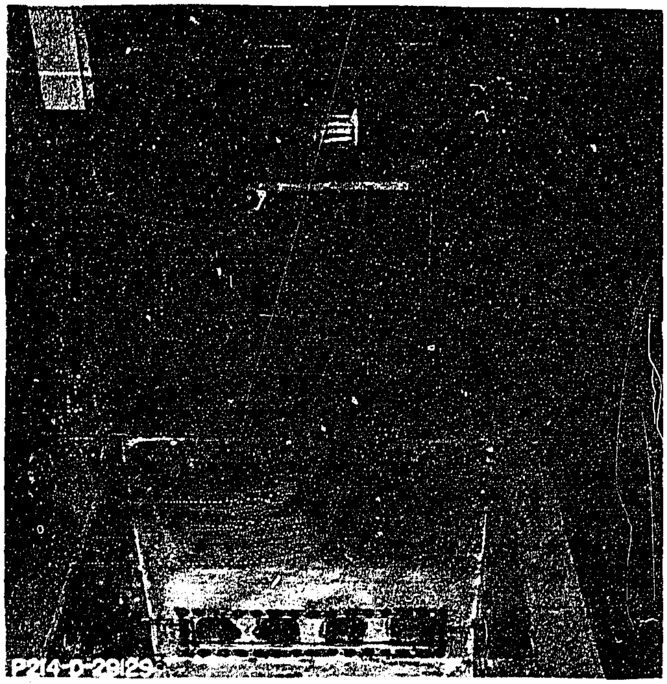


SECONDARY LOUVER STRUCTURE

TRACY PUMPING PLANT FISH SCREENS

1:6.316 MODEL OF SECONDARY LOUVER STRUCTURE

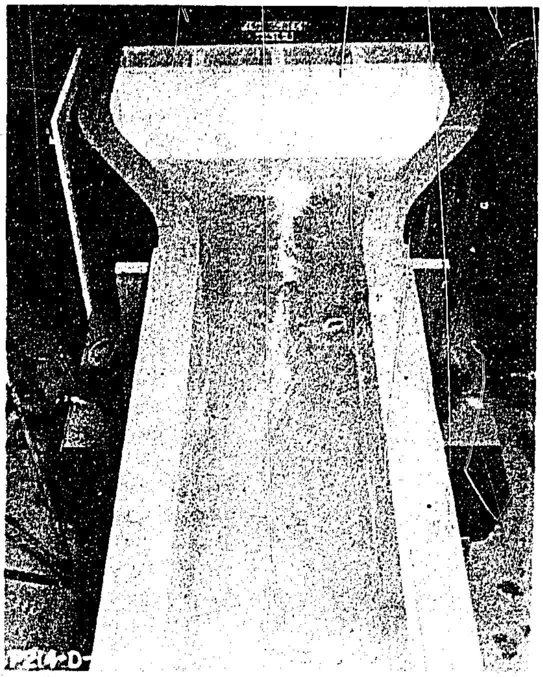
536



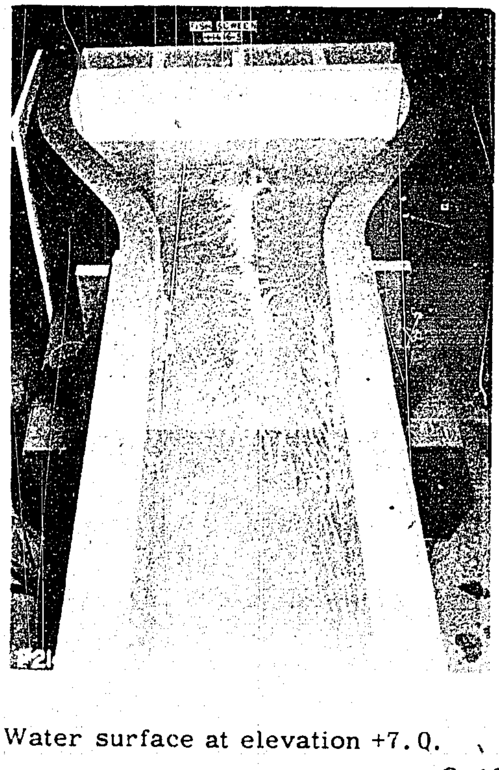
A. View looking downstream from headbox.

B. View looking upstream into structure.

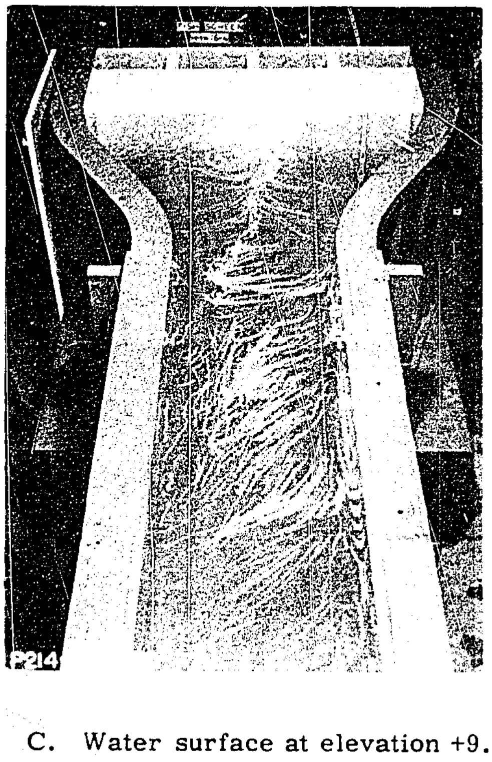
SECONDARY LOUVER STRUCTURE
TRACY PUMPING PLANT FISH SCREENS
1:6.316 Model of Existing Design



A. Water surface at elevation +5.0.



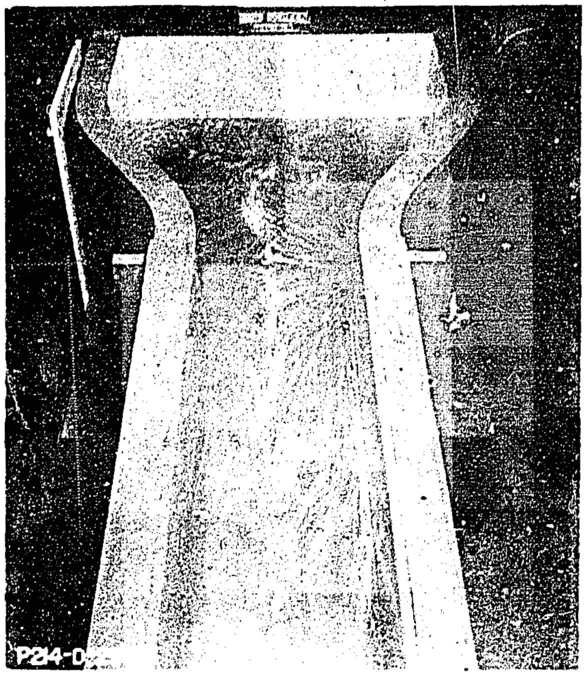
B. Water surface at elevation +7.0.



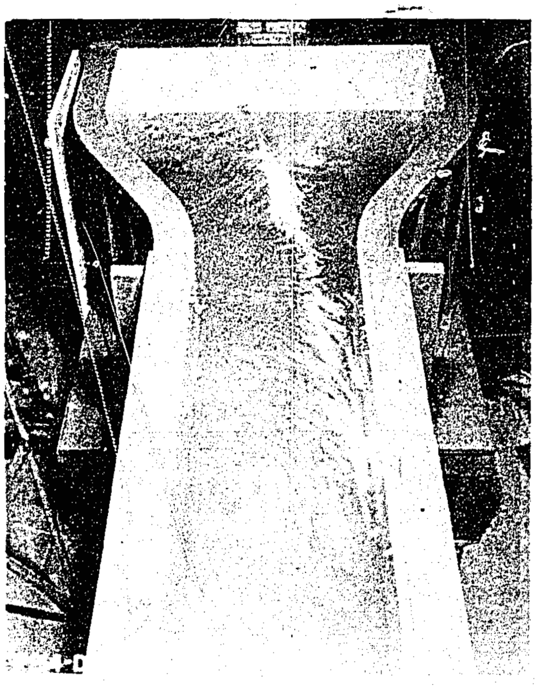
C. Water surface at elevation +9.0.

Q=130 cfs, prototype

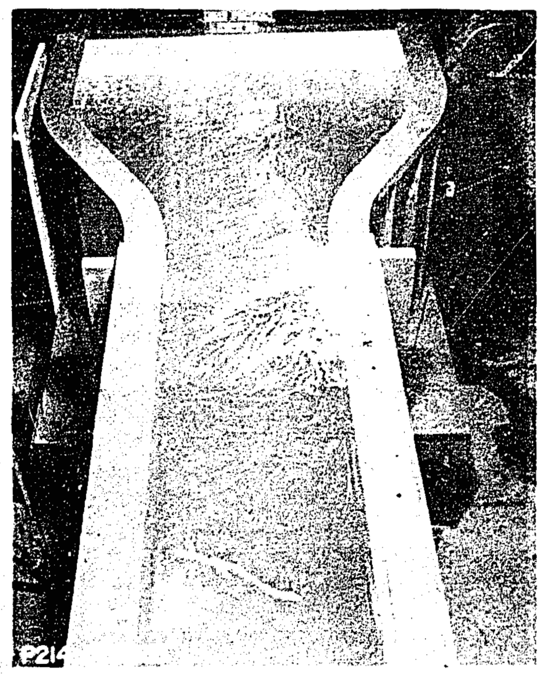
SECONDARY LOUVER STRUCTURE
TRACY PUMPING PLANT FISH SCREENS
Surface Flow Patterns in Existing Design
Equal Flow in Four Conduits
Exposure 1/2 Second



A. Water surface at elevation +5.0.



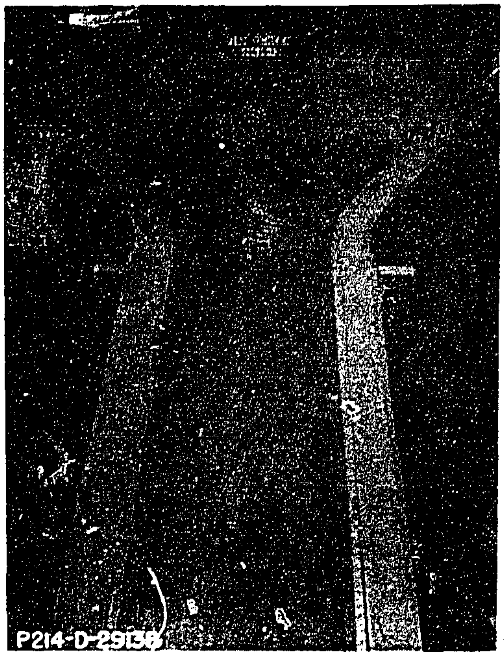
B. Water surface at elevation +7.0.



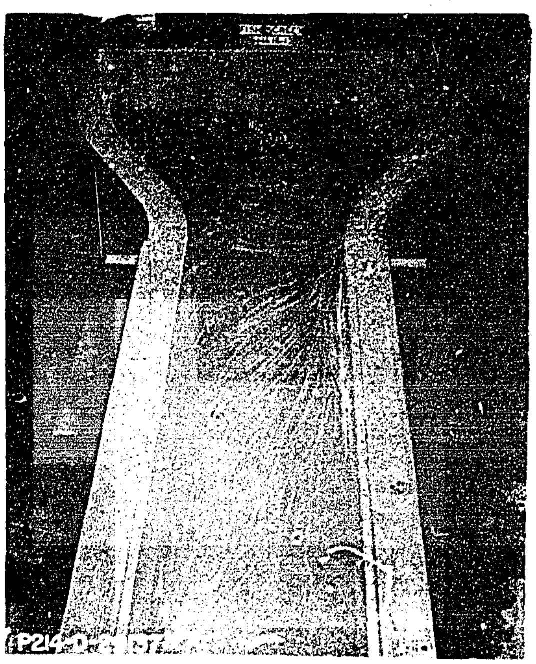
C. Water surface at elevation +9.0.

Q=130 cfs, prototype

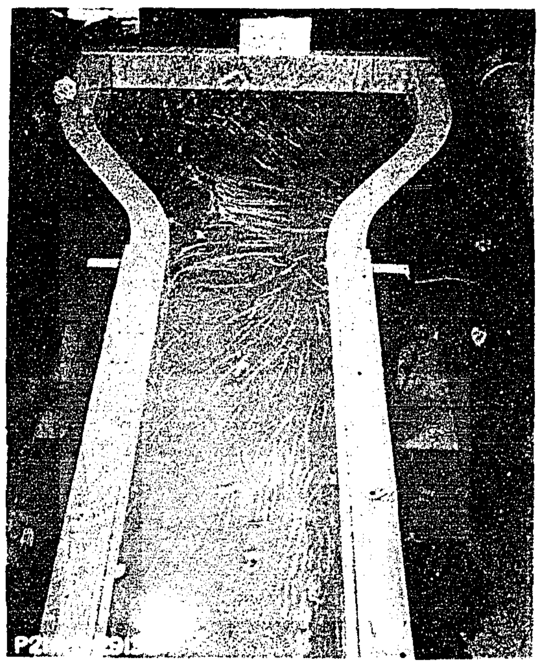
SECONDARY LOUVER STRUCTURE
TRACY PUMPING PLANT FISH SCREENS
Surface Flow Pattern With Gate Wall Removed From Existing Structure
Equal Flow in Four Conduits
Exposure 1/2 Second



A. Water surface at elevation +5.0.



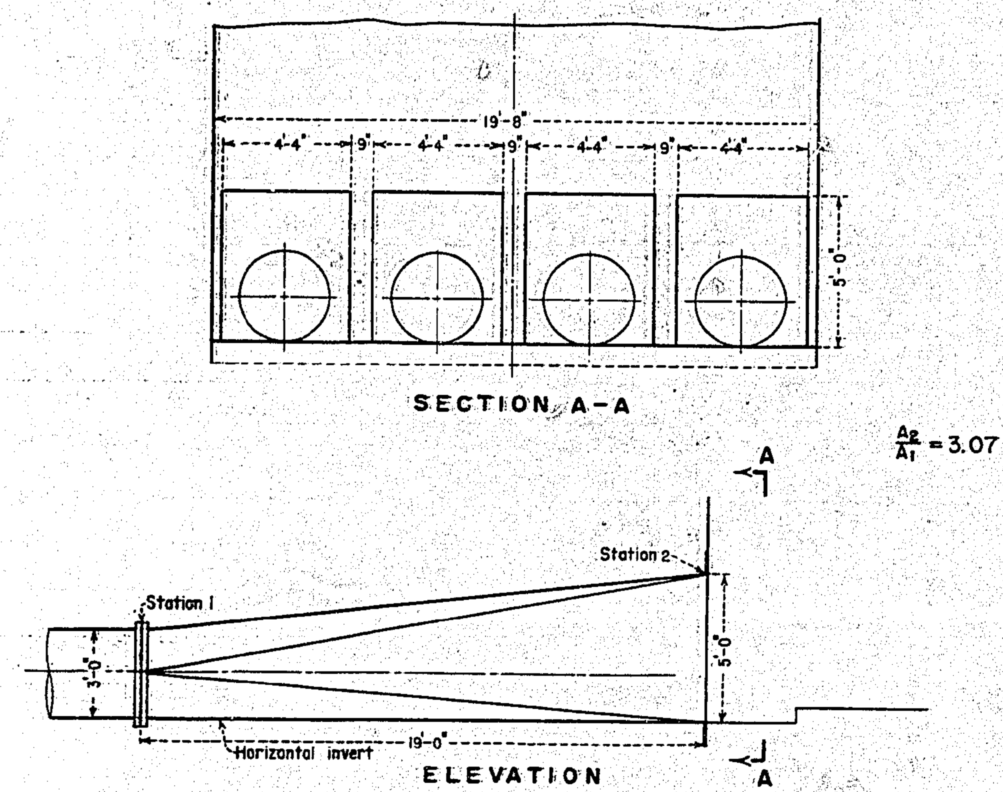
B. Water surface at elevation +7.0.



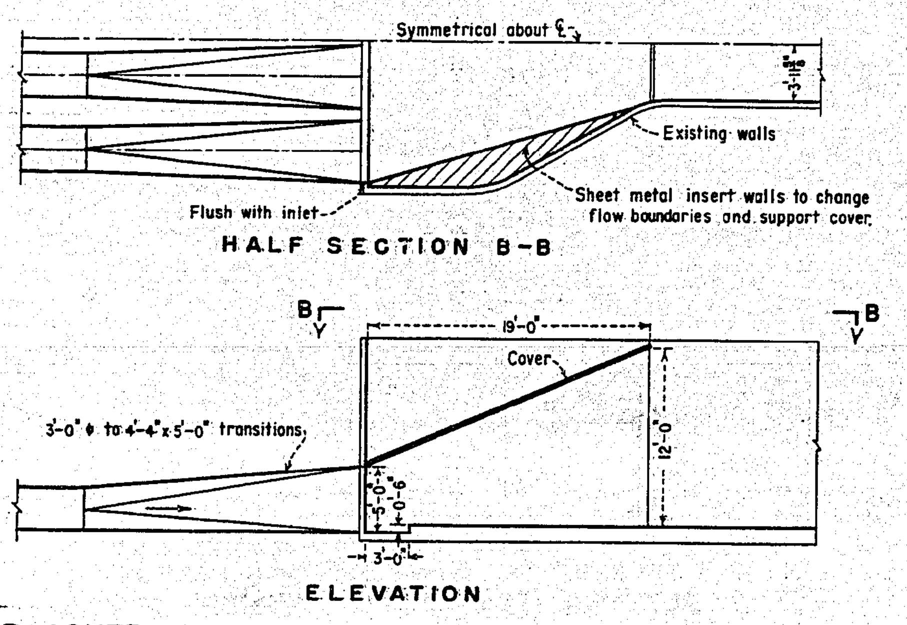
C. Water surface at elevation +9.0.

Q=130 cfs, prototype

SECONDARY LOUVER STRUCTURE
TRACY PUMPING PLANT FISH SCREENS
Surface Flow Pattern With 19 Foot Long Expanding
Transitions--Equal Flow in Four Conduits
Exposure 1/2 Second



A. PRELIMINARY EXPANDING PIPELINE TRANSITIONS



B. COVER AND STRAIGHTENED SIDES IN STRUCTURE

Note: dimensions given in feet, prototype

SECONDARY LOUVER STRUCTURE
TRACY PUMPING PLANT FISH SCREENS
PRELIMINARY EXPANDING TRANSITIONS AND COVER WITH STRAIGHT SIDEWALLS 1:6.316 MODEL

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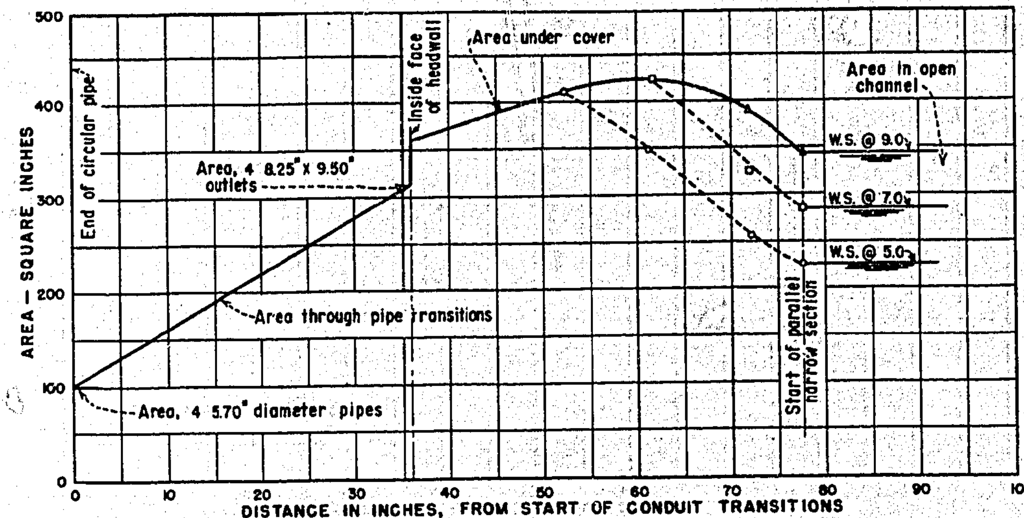
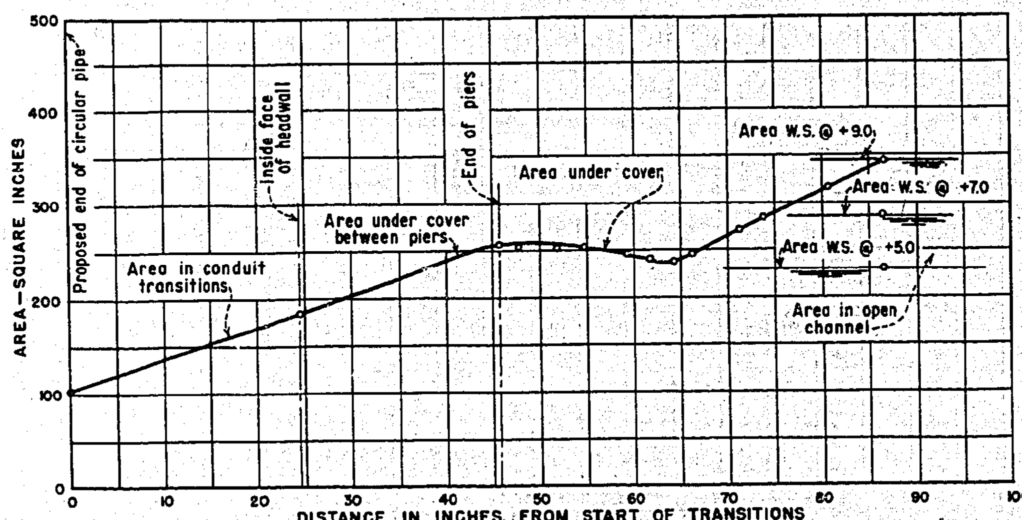
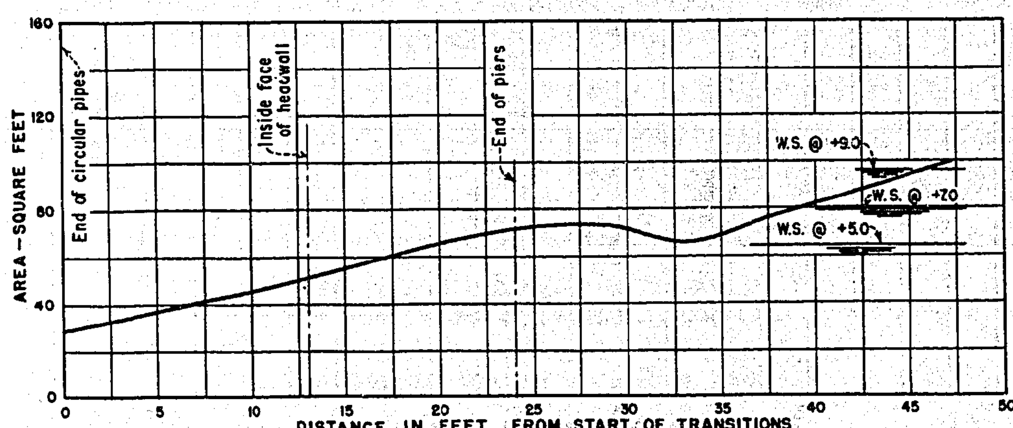


A. EXPLORATORY DESIGN–PRELIMINARY TRANSITIONS AND SHORT COVER

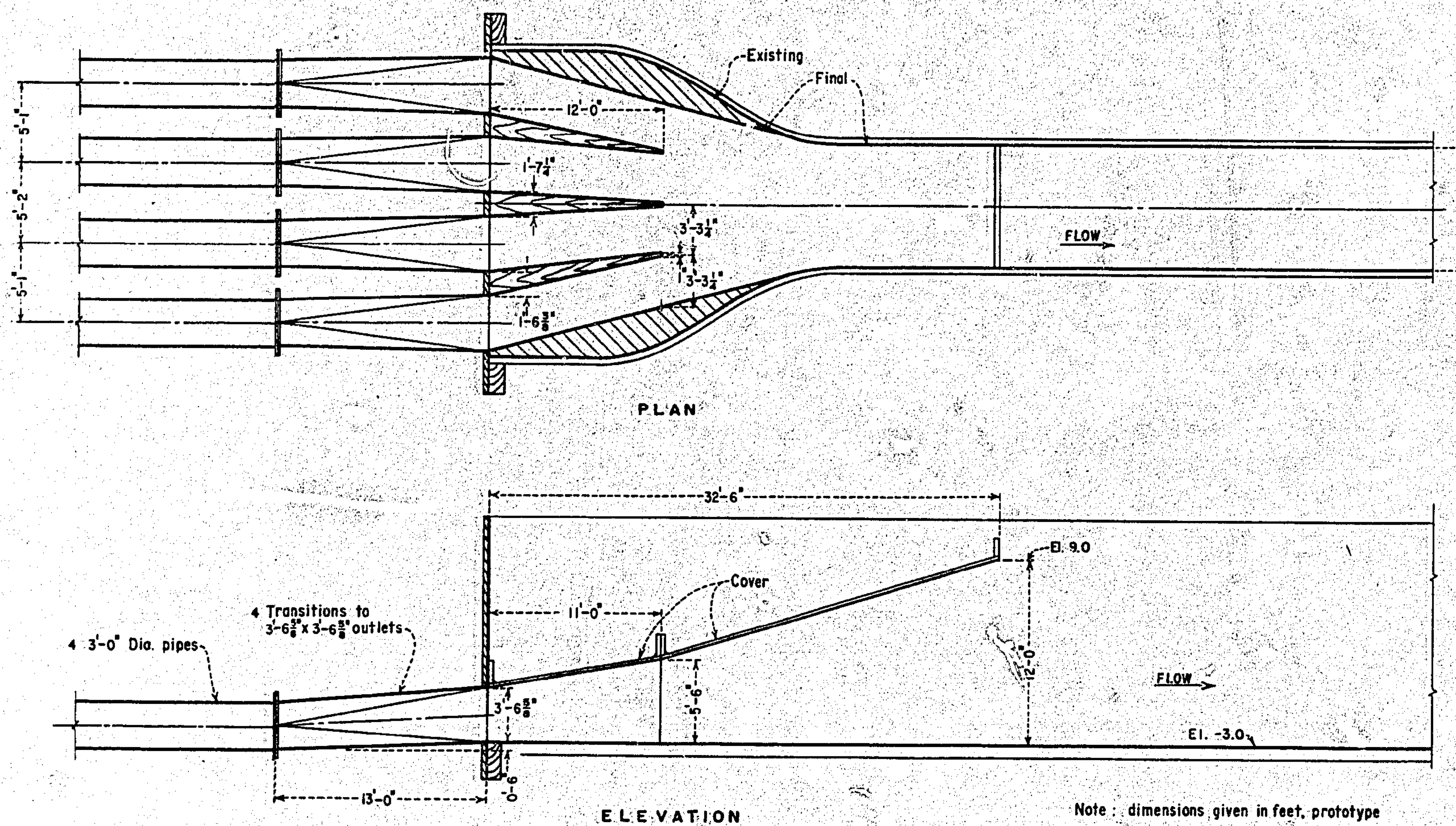


B. RECOMMENDED DESIGN–MODEL



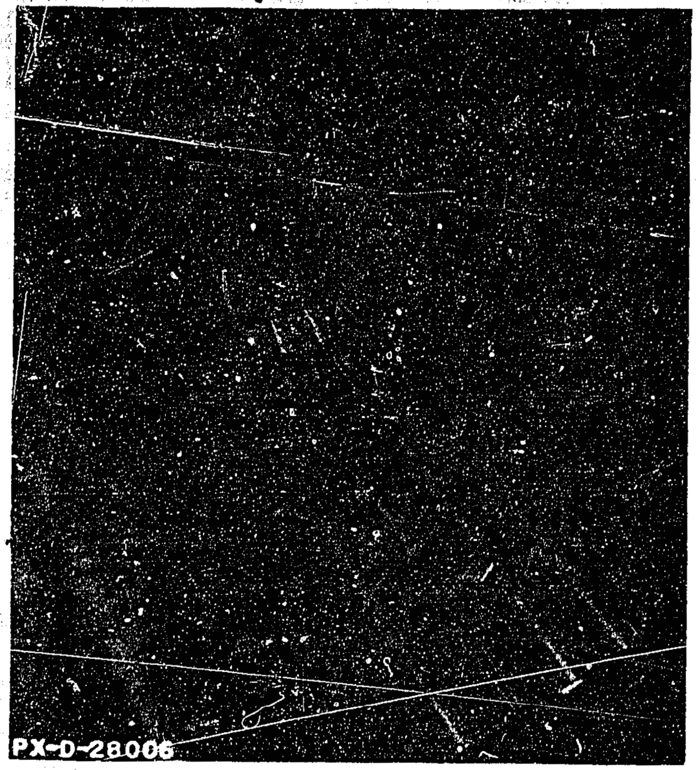
C. RECOMMENDED DESIGN–PROTOTYPE

SECONDARY LOUVER STRUCTURE
TRACY PUMPING PLANT FISH SCREENS
FLOW AREA CURVES IN MODELS AND IN RECOMMENDED PROTOTYPE STRUCTURES

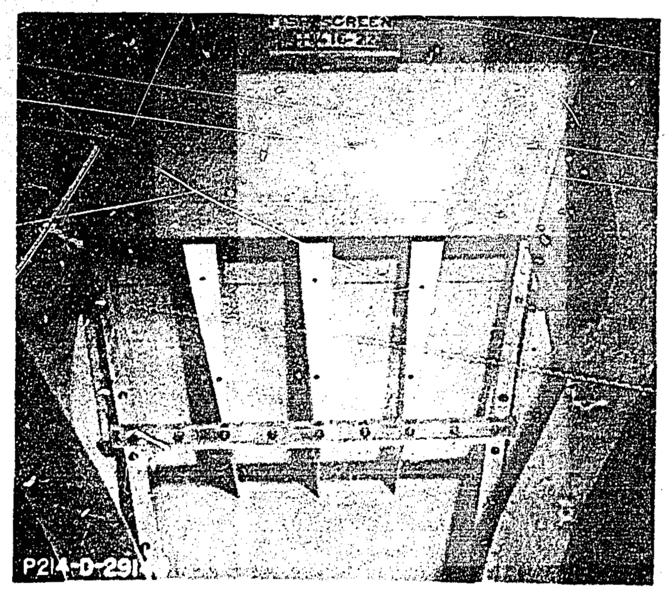


SECONDARY LOUVER STRUCTURE
TRACY PUMPING PLANT FISH SCREENS
RECOMMENDED DESIGN 1:6.316 MODEL

FIGURE 12
REPORT HYD 480



View looking downstream.

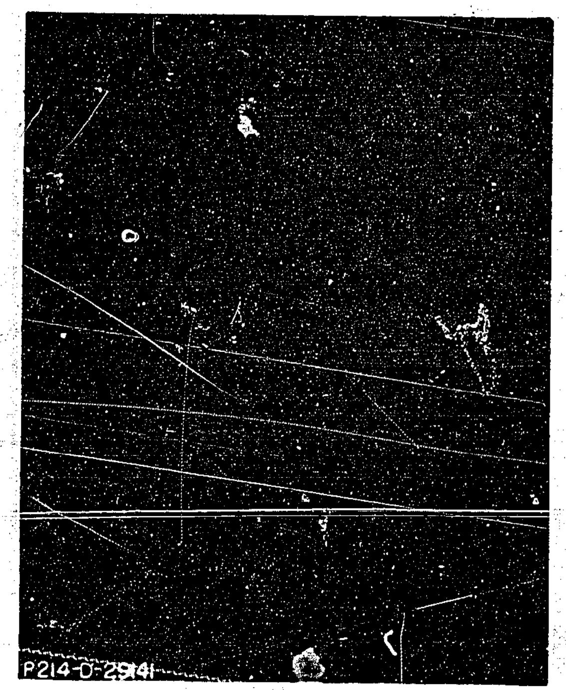


View looking upstream.

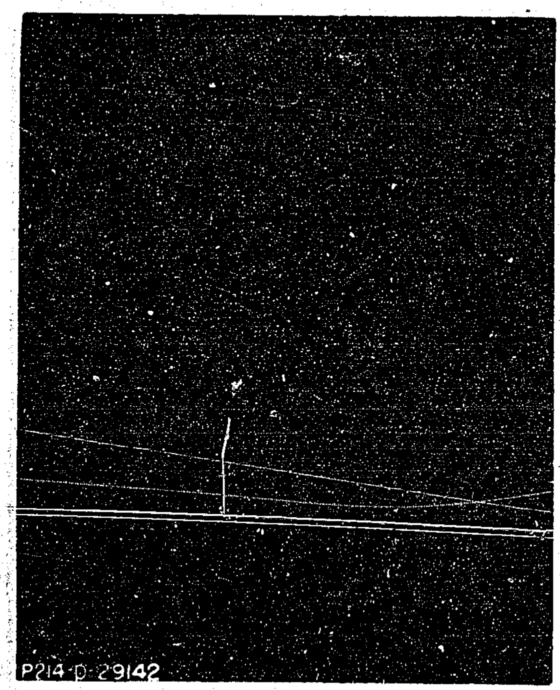
Upstream view inside structure.

SECONDARY LOUVER STRUCTURE
TRACY PUMPING PLANT FISH SCREENS
1:6.316 Model of Recommended Design

A. Water surface at elevation +5.0.



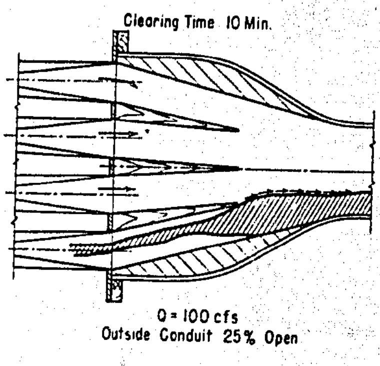
B. Water surface at elevation +7.0.



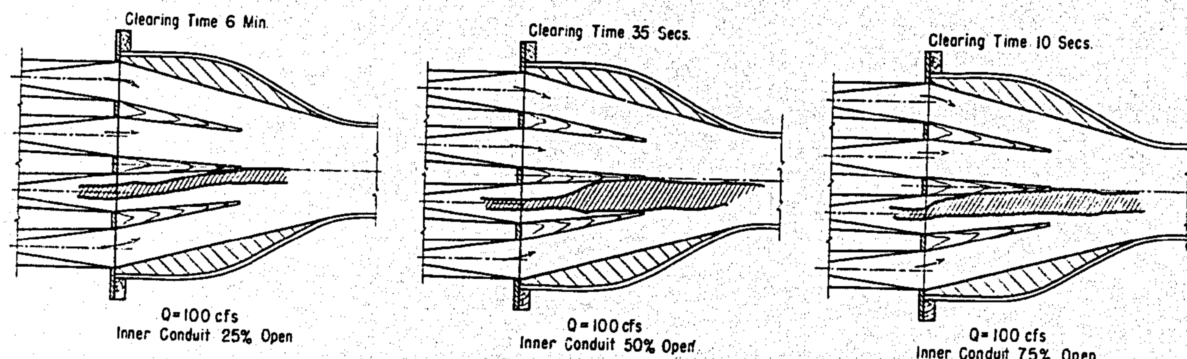
C. Water surface at elevation +9.0.

Q=130 cfs, prototype

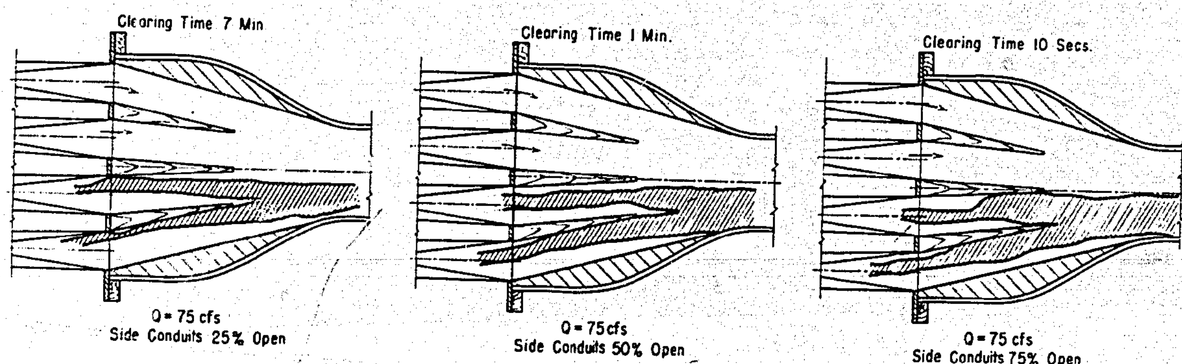
SECONDARY LOUVER STRUCTURE
TRACY PUMPING PLANT FISH SCREENS
Flow Patterns in Recommended Design
Equal Flow in Four Conduits
Exposure 1/2 Second



A. 3 CONDUITS OPEN, OUTSIDE CONDUIT THROTTLED



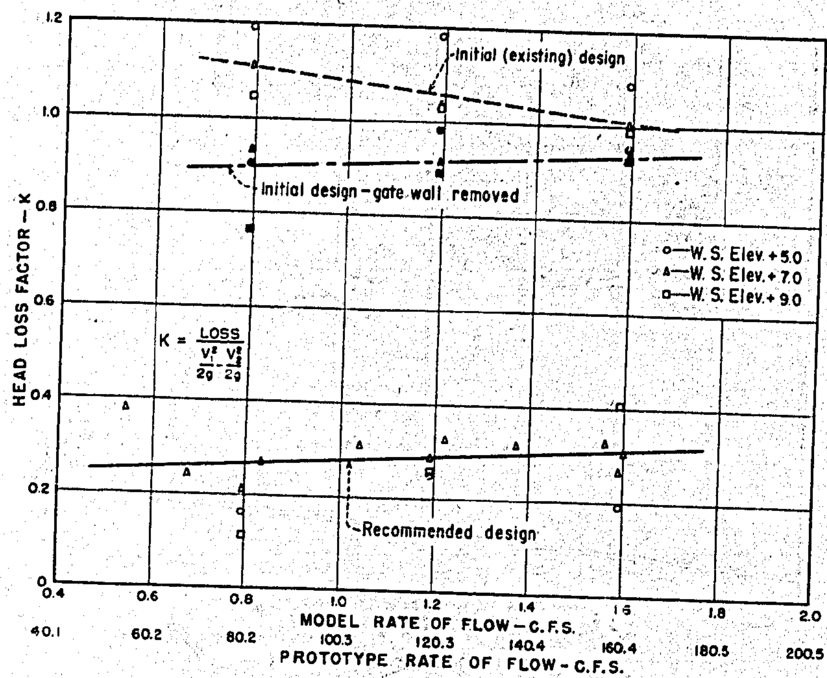
B. 3 CONDUITS OPEN, INNER CONDUIT THROTTLED



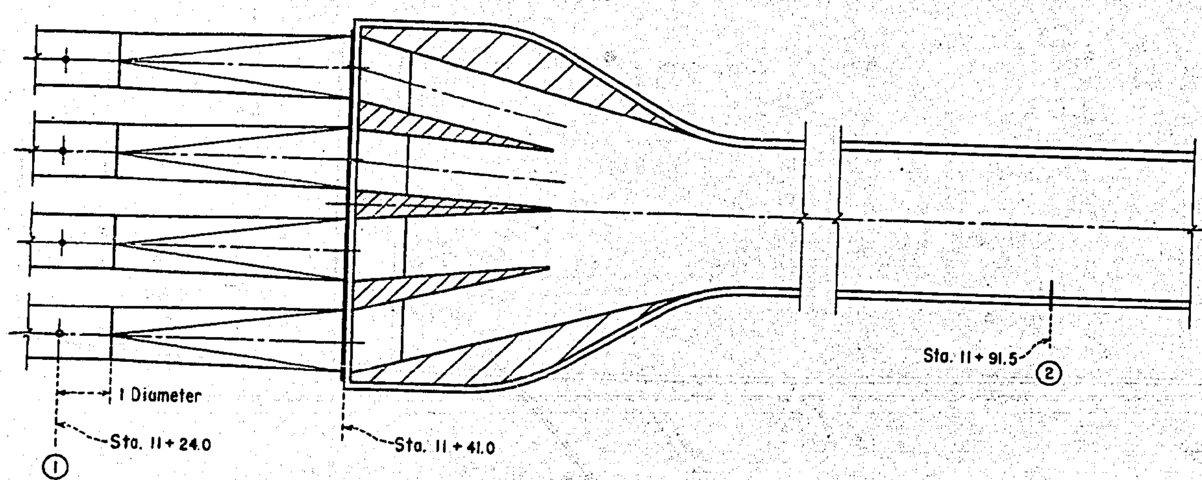
C. 2 CONDUITS OPEN, 2 SIDE CONDUITS THROTTLED

Shaded Areas Show Flow Paths As Indicated By Dye Clouds.
Times Given Are For Dye Clouds To Completely Clear.

SECONDARY LOUVER STRUCTURE
TRACY PUMPING PLANT FISH SCREENS
FLOW CONDITIONS IN RECOMMENDED STRUCTURE WITH VERY UNSYMMETRICAL FLOWS. WATER SURFACE ELEV. +7.0
DATA FROM 1:6.316 SCALE MODEL



A. RATE OF FLOW VS. HEAD LOSS FACTOR



B. PLAN - RECOMMENDED LOUVER STRUCTURE

SECONDARY LOUVER STRUCTURE
TRACY PUMPING PLANT FISH SCREENS
HEAD LOSSES FOR INITIAL AND RECOMMENDED STRUCTURES
DATA FROM 1:6.316 MODEL