UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

FIELD AND LABORATORY TESTS TO DEVELOP THE DESIGN OF A FISH SCREEN STRUCTURE DELTA-MENDOTA CANAL HEADWORKS CENTRAL VALLEY PROJECT, CALIFORNIA

Hydraulic Laboratory Report No. Hyd-401

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
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Subject: Field and laboratory tests to develop the design of a fish screen structure--Delta-Mendota Canal headworks--Central Valley Project, California

PURPOSE

The purpose of this report is to describe field and laboratory investigations leading to the design of a structure to conserve the fish at the headworks for the Delta-Mendota Canal of the Central Valley Project in California. The first part of the report pertains to the field investigations, while the detailed results of the laboratory studies are contained in Part II.

SUMMARY

Field Tests

The problem consists of preventing the entrance of fish into the Tracy Pumping Plant near the headworks of the Delta-Mendota Canal. The solution consists of trapping the fish in holding ponds until a sufficient number are accumulated for economical transportation to a point sufficiently far downstream to permit the fish to continue migration to the ocean.

Information to design a suitable structure was nonexistent, hence, a pilot structure was provided near the headworks to enable the performance of field studies leading to the design of a permanent fish screen structure. This pilot structure also permitted the conservation of a large number of fish during the testing period.

Although several schemes were tested, this report is limited to the activities during the 1954 season. It is presumed that the Fish and Wildlife Service, who assisted in the studies, will prepare a report describing the comprehensive testing program.

One of the schemes tested employed traveling screens equipped with cups to elevate the fish to a small horseshoe-shaped trough leading

to holding ponds from which the fish were transported by truck to a point approximately 40 miles nearer the ocean.

The scheme adopted for the permanent structure employs a line of louvers rather than traveling screens. Briefly, the line of louvers consists of a row of vertical steel plates extending diagonally across the channel with bypasses to conduct the fish to holding ponds.

One of the major problems is to remove peat moss from the water in the holding ponds. The screening process has been solved for an installation involving traveling screens, but the problem is greatly aggravated by a louver system involving a considerably greater quantity of water.

Laboratory studies are currently being made to assist in the design of the final louver structure. The studies involve a composite model to develop proper flow conditions in the approach channel to the line of louvers and a second hydraulic model to develop bypasses with the required flow pattern. The results of these studies will be reported upon completion.

Laboratory Studies

The laboratory studies were performed to correct (1) the excessive erosion of the channel banks upstream and downstream from the fish screen structure, (2) the severe erosion of the channel bed downstream from the fish screen structure, and (3) to investigate and improve the flow conditions at the louver installation in one bay of the fish screen structure.

CONCLUSIONS

Field Studies

Mortality tests performed in connection with the trapping of fish (striped bass) with traveling screens are somewhat misleading inasmuch as the natural mortality is unknown. Other factors also existed to reflect doubt on the accuracy of the percentage of mortality.

Possibly the mortality of the fish trapped by traveling screens would be greater than in the case of louvers, but information has not been acquired to evaluate any difference since mortality tests were not performed in connection with louvers comparable to those for the traveling screens.

Many of the questions pertaining to the effectiveness of traveling screens were not pursued in view of the decision to employ a line of louvers.

The initial cost of the permanent structure employing louvers has been estimated to be practically the same as that for an installation of traveling screens, but the operating cost of the former will be greater due to the necessity of pumping the return flow from the bypasses. The maintenance cost for traveling screens would probably be higher than for the louver installation.

The efficiency of the louver installation, based on tests in a bay of the pilot structure and in a nearby flume, will be from approximately 75 to 95 percent depending on the size of fish, time of day, and velocity of flow, which varies in accordance with the tide, and the operation of the Tracy Pumping Plant. The efficiency of the traveling screens would be near 100 percent except for a relatively short time when some of the striped bass (less than 25 mm in length) would pass through the screens.

The disadvantages of the proposed louver installation would largely disappear at a location where the flow through the bypasses together with the fish could be diverted back to the river by gravity flow.

Laboratory Studies

As a result of the model investigations, it was found that the excessive erosion of the channel banks was caused by the alinement of the pilot canal. The severe floor erosion downstream from the fish screen structures was found to have been caused by the sluicing action of the high velocity flow under a partially raised fish screen with the action accentuated by the method of raising the screens during the cleaning operation.

The model investigation of the louver installation showed that the poor flow conditions through the louvers were the result of the inability of the flow to pass through the louvers without an excessive head loss. The head loss was greatly reduced by placing flow straighteners on the downstream side of the louver installation. With the reduction in head loss other unsatisfactory flow conditions were also eliminated.

Further tests were made on the model of the louver installation to determine the relation between head loss and the angle of the line of louvers with the direction of flow and of the angle of the louver slat with direction of flow. These tests indicated that the angle between the line of louvers and line of flow should not be greater than 30°, and the angle between the louver slat and line of flow should be less than 90°.

RECOMMENDATIONS

Field Studies

The following design criteria were established by the Fish Advisory Council, composed of representatives of the Bureau of

Reclamation, the Fish and Wildlife Service, and the California Department of Fish and Game:

1. Angle of line of louvers with direction of flow to be 11 to 15°.

2. Louver slat spacing to be 1 inch, clear.

3. Louver slats to be 90° to the direction of flow.

4. Distance of 75 feet, maximum, between bypasses measured along the line of louvers.

5. Bypass width of 6 inches.

6. Maximum velocity of approach (average) to be 5.3 ft/sec.

7. A minimum distance of 25 feet between trashrack and start of line of louvers.

8. Smooth flow pattern between trashrack and start of line of louvers.

9. A 2-inch, clear, spacing between trashrack bars.

10. No provision for medication with salt of the fish in the holding ponds.

11. Although recognized that preditors might stay in the bypass channels or ahead of the trashrack to prey upon the small fish, no preventive action to be taken.

Additional recommendations worthy of consideration during design are:

1. Protective coating for all metal in contact with the water.

2. Provision to remove sections of the line of louvers for cleaning and maintenance.

3. Facilities for raking and disposal of debris from the trashracks.

Laboratory Studies

From the laboratory studies the following corrective measures were recommended:

1. The channel both upstream and downstream from the fish screen structure should be widened and straightened.

2. A layer of riprap should be placed on the channel floor on the downstream side of the structure.

3. An end sill should be placed on the concrete apron under the fish screens.

4. The method of raising and lowering the fish screens for cleaning should be modified.

5. Flow straightening vanes should be placed on the downstream side of the louvered fish screens.

6. The angle between the line of louvers and line of flow should not be greater than 30°, and the angle of louver slat with line of flow should be less than 90°.

ACKNOWLEDGMENT

The authors wish to acknowledge the cooperation and assistance extended by the Regional Engineer and his staff in Sacramento, California. In connection with the field studies, special recognition is due to the Construction Engineer and his Field Engineer, who was responsible for the actual performance of the tests. A great amount of credit is extended to representatives of the U. S. Fish and Wildlife Service who actively participated in the entire field testing program and were responsible for many of the final decisions. The California Department of Fish and Game also materially contributed to the successful conclusion of the program.

The entire program was conducted in cooperation with the Canals and Headworks Section of the Canals Branch in the Office of the Assistant Commissioner and Chief Engineer.

PART I

FIELD TESTS TO DEVELOP THE DESIGN OF A FISH SCREEN STRUCTURE DELTA-MENDOTA CANAL HEADWORKS CENTRAL VALLEY PROJECT, CALIFORNIA

INTRODUCTION

To permit a grasp of the magnitude and complexity of the problem being discussed, a brief description is warranted. Basically, the problem consists of conserving fish by providing a structure suitable for preventing their entrance into the Tracy Pumping Plant near the headworks of the Delta-Mendota Canal in the Central Valley Project of California, Figure 1. Only small fish are involved as the large ones are capable of averting the pumping plant. Furthermore, although 20 species of fish are encountered at the site, the only ones of importance to both commercial and sportsman's interests are striped bass, salmon, catfish, and shad. The annual commercial catch for the area has been estimated at 5,600,000 pounds of salmon and 1,460,000 pounds of shad, while the annual sports catch has been estimated at 60,000 pounds of salmon and 6,000,000 pounds of striped bass. The catfish are of interest to sportsman only and no estimate of the annual catch has been made. In addition, large commercial interests are involved through the sale of fishing and boating equipment.

The total number of fish which may be affected by operations of the Tracy Pumping Plant has been estimated at 4,000,000 per year. Ten to fifteen percent of the striped bass in the upper delta may be affected by the Tracy Pumping Plant, but no estimate has been made of the percentage of other species affected.

Approximately 8 years ago when the problem was recognized, the Bureau of Reclamation requested assistance from the U. S. Fish and Wildlife Service. However, insufficient information was available to design a suitable fish screen device. Accordingly, at the headworks, a pilot channel was excavated of sufficient capacity to permit operation of the Tracy Pumping Plant at two-thirds capacity and a temporary structure, known as the pilot fish screen structure, was constructed in 1951 to accomplish two objectives: (1) to enable the conduct of studies leading to the design of the ultimate fish screening device and (2) to conserve as many fish as possible during the interim period between the design and construction. A larger pilot canal was not necessary as the ultimate fish screen structure is to be constructed before full capacity of the pumping plant will be needed. Figure 2 shows the location of the pilot canal and the temporary structure, while the ultimate structure is to be located to the left in the area labeled for borrow material.

The research program inaugurated to develop a satisfactory screening device was indeed comprehensive. No attempt will be made in this report to describe the details of the entire program. Only that portion having a direct relationship to the final structure will be described.

It is presumed that the Fish and Wildlife Service will issue a detailed report of the entire study for future reference. The papers which have been written together with pertinent references are identified in the Bibliography. Suffice it to say here that the investigation has involved fish trapping systems known as ports and risers, sloping screens, traveling screens, electric screens, sound barriers, air bubbles, light screens, and line of louvers. The final solution utilizes the line of louvers.

The comprehensive program has involved a survey to ascertain the number of fish in the delta area, the number possibly affected by Tracy Pumping Plant, mortality studies, effect of temperature and salinity, and modes of transporting fish. The entire study was in cooperation with members of the Fish and Wildlife Service.

The studies have been conducted in the pilot canal, and were augmented by observations in a nearby test flume constructed in the early part of 1952, Figure 3. The new test flume, Figure 4, was not completed until near the end of the current season, and only a very few tests were performed during the presence of the writer.

THE PILOT FISH SCREEN STRUCTURE

Description

The pilot structure consists of 12 bays, each 10 feet in width. Bay No. 1 has been reserved for the testing of special devices, such as sloping screens, louvers, etc. When testing is not in progress this bay is closed by means of a wooden bulkhead. Six of the bays (Nos. 2, 3, 4, 5, 6, and 7) are equipped with traveling screens normally used to remove debris but modified to trap fish. Bays No. 8 to 12, inclusive, are equipped with stationary screens to provide a passage for water but not fish. The stationary screens are periodically washed by high pressure jets as each screen is raised and lowered. A second screen, known as a wash screen, is temporarily placed in front of a screen before washing, hence, at no time does an opening exist to permit the passage of fish. It has been necessary, however, in a few instances to remove all or a number of the stationary screens for short periods of time to minimize the differential head across the structure.

One occasion for decreasing the head on the structure was due to erosion at the downstream side caused by failure of the stationary screens to completely lower into position after washing, and although not realized at the time, the partially raised screens caused a jet of water to deflect downward at the toe of the structure resulting in severe erosion. The cause of the failure and remedial measures were developed in a hydraulic model described in full in Part II.

Operation

In operation of the pilot structure small fish, unable to swim against the approach velocity or in their natural migration toward the ocean, come in contact with the traveling screens and are raised by means of the horizontal members forming the frames of the screen sections. A modification permits washing the fish from these members with jets of water which operate at a time when the horizontal members are immediately above a continuous horseshoe-shaped trough leading to holding ponds. On some of the screens, the members have been equipped with cups to facilitate raising the fish in water. In a further attempt to minimize any injury which might occur to the fish, one of the screens was equipped with rubber troughs which were folded outward at the proper time by water jets, thus dumping the fish into the trough. Figure 5 shows the hydraulic action of a screen equipped with jets discharging against the front of the screen while Figure 6 shows similar action by jets from the back side of the screen. This latter one, however, is not equipped with the cups. Obviously, the front jets are less desirable as the water tends to impinge the fish against the screen.

Holding Pond

Once the fish are in the trough, they are carried by gravity flow to a 12-inch diameter rotating drum screen, Figure 7. The water flows through this rotating screen into a holding pond, with an overflow returning to the pilot channel while the fish are flipped by the drum into the holding pond. By experiment it was determined that the screen must rotate 102 rpm to flip small striped bass into the holding pond. With larger fish the speed may be reduced to a minimum of 25 rpm. In the event it is desirable to increase the salinity of the water in the pond for medication of the fish, an arrangement exists whereby all the flow passing through the rotating screen may be diverted back to the channel without passing through the holding pond. The purpose of the rotating screen is to remove peat moss which, if allowed to collect in the pond, will become sufficiently concentrated to suffocate the fish. The peat moss is washed from the outside of the rotating screen by water jets and returned to the channel by gravity flow. Other debris, such as small sticks, are flipped by the rotating screen into the holding pond and removed by a trash conveyor belt.

Transportation

The water in the holding pond is maintained in constant motion by a small circulating pump. After a sufficient number of fish have been collected in the pond they are transported by truck to a point sufficiently far downstream to permit the fish to continue migration toward the ocean and not be drawn back into the screen structure. The truck is equipped with a pump to circulate and aerate the water, and ice is added to maintain the proper temperature. Earlier experiments utilized a specially constructed barge to transport the fish but high operation cost forced abandonment of this method in favor of tank trucks.

The fish are transferred from the pond to the truck by gravity through a specially designed valve to prevent damage to the fish. This valve, Figure 8, located in the center of the holding pond consists of a vertical stand pipe to maintain the proper depth of water in the pond while fish are being collected from the traveling screens. The overflow into the stand pipe passes through the outer portion of the opening leading to the channel while the fish are retained by four vertical screens. Immediately prior to discharging the fish into the truck, the vertical stand pipe is decreased in height by removing sections to obtain a volume of water equal to the capacity of the tank truck. The opening to the waste pipe is closed by means of the circular plate, standing behind the valve in the figure, the screens are removed, and the center plug is lifted by means of the vertical pipe handle allowing a clear passage for the fish and water into the tank truck below the holding pond.

Two identical holding ponds are provided so that one may be in service while the other is being emptied. Each pond consists of a circular steel tank 18 inches deep at the periphery, 20 feet in diameter, with the bottom sloping toward the discharge valve in the center to facilitate the removal of fish.

Traveling Screens

At one time it was thought that traveling screens would be utilized in the ultimate structure. The scheme was to provide 12 such screens, resulting in a maximum approach velocity of approximately 2 feet per second, or 24 screens with an approach velocity of 1 foot per second. One thought was that the low velocity of approach should be maintained to prevent severe impingement of fish against the traveling screens. Another thought was that the low approach velocity resulted in fish avoiding the screens as long as physically possible; hence, the fish were in a weakened condition due to exhaustion upon arrival in the holding pond. Sufficient tests were not conducted to permit a decision as to the proper approach velocity, which would, in turn, determine the number of traveling screens.

Objections to traveling screens were: (1) high maintenance costs and (2) a considerable number of the very small fish (less than 25 mm in length) passed through the screens. Use of a smaller mesh screen to prevent passage of these small fish was not considered practicable. The maintenance cost could unquestionably be reduced by proper operational procedures and simplification of design combined with the use of materials more suitable than the standard catalog models. The number of fish under 25 mm in length was relatively insignificant, in fact, the consensus was that these could be ignored. Several unanswered questions pertaining to the use of traveling screens were not pursued in view of the decision to employ a system of louvers.

MORTALITY STUDIES

Mortality studies were performed for striped bass by observing the number of live and dead fish in a holding pond immediately prior to discharging the live ones into the truck for transporting to a distant point in the river. The holding pond mortality, Figure 9, included that from natural causes together with any adverse effects of the traveling screens, collecting trough, demossing wheel, or any other factor introduced by the collecting system. Also included are any fish which were dead upon arrival at the pilot structure and picked up by the traveling screens. Hence, it is not possible to state the portion of the loss of fish due to the method of trapping. But certainly the traveling screens cannot be charged with entire mortality. Mr. Heckman 1/ stated that not more than 12 percent of the mortality could be attributed to the traveling screens. Even this 12 percent did not reflect such important items as natural mortality, damage which may have occurred due to previous contact with the stationary screens, effect of improving the operation of traveling screens through changing the speed of travel, or improving the method of jetting the fish from the screens.

It is reasonable to assume that utilization of the louver principle whereby the fish do not come in contact with traveling screens may result in lower mortality, but it is not known if any advantage in mortality is realistic as facilities did not exist to perform similar studies in connection with the louver installation during a comparable period when the striped bass were very small.

Salt Treatment

In an effort to decrease the mortality, salt was introduced into the holding pond for medication of the fish. Figure 9 reveals this treatment to be very effective, particularly during the early part of the season when the fish were quite small. At the close of the season in August, the salt treatment was still noticeably effective though materially less than earlier due to the increased size of the fish.

Although not shown graphically, the mortality was unaffected by the length of time the fish were kept in a holding pond up to 24 hours.

When the fish were returned to the river they were placed in a tank fitted with a screen and held for 24 hours after which a mortality count was obtained. The mortality during the 24 hours in the river may be obtained from Figure 9 by taking the difference between the total mortality and that for the holding pond. The river mortality includes any loss due to transportation, physical damage to the fish in loading and unloading, together with any natural mortality. The loss during transit could conceivably be high due to the chunks of ice used to maintain the proper temperature of the water. These chunks were free to move around in the tank and could possibly crush the fish.

Number of Fish

A concept of the number of fish involved in this series of tests may be had from Figure 10 which reveals the total number of live fish transported from the holding ponds to the river some distance downstream from the structure. The largest daily count occured on July 5 when 36,300 striped bass, 480 shad, 360 catfish, and 200 salmon were hauled. It is desirable to mention that a summation from this plot will not give the total number of fish expected from the ultimate fish screen structure as the Tracy Pumping Plant was only operating at two-thirds capacity. The notations on July 9, 10, and 11, relative to removal of screens and trashracks, pertain to one of the instances when it was necessary to decrease the differential head on the structure for safety reasons. Hence, during the period from July 9 to August 13, when the stationary screens were removed, a considerable number of fish were allowed to pass through to the Tracy Pumping Plant.

The results of any mortality tests which may have been performed on species other than striped bass are not known except in the case of shad where the mortality has been nearly 100 percent. A biologist of the California Department of Fish and Game stated that this particular species apparently could not breathe except when the velocity of flow is relatively high; hence, a 100 percent loss is to be expected in a holding pond. This fact tends to minimize the importance of attempting to save shad.

Temperatures

Figure 11 shows water temperatures in the river at the pilot structure, point of release of the fish, in the holding pond, and tank truck. The temperatures increased to a maximum in the latter part of July. However, the variations in temperature apparently were insufficient to affect mortality as no relationship seems to exist between mortality and water temperature.

Fish Length

The length of the striped bass employed in the mortality tests is shown in Figure 12. It will be noticed that two sets of measurements were taken, those in connection with the holding pond mortality studies and those pertaining to the tests in Bay No. 1, to be described later. It was desirable to show the two sets of measurements as they were made by different individuals. However, for all practical purposes, the results were the same. The average length of striped bass varied from 23.2 mm on June 19 to 53 mm on August 27. One of the disadvantages listed for the traveling screens indicated that a portion of the fish smaller than 25 mm in length passed through the screens, but Figure 12 shows that the average fish length was greater than 25 mm after July 1 or 22 days after the start of the striped bass migration; hence, this disadvantage is relatively unimportant.

LINE OF LOUVERS

The system of screening fish by means of louvers involves a series of closely spaced vertical steel plates forming a diagonal line across the stream, with bypasses at regular intervals to allow the fish to pass into small channels and eventually into holding ponds. For the installation being considered, the overflow from the holding ponds must then be pumped back to the river. Conceivably, with suitable topography, the return flow could also be by gravity thus tremendously decreasing initial and maintenance costs. In the present case, the initial cost for an installation with louvers has been estimated to be approximately the same as for a structure employing traveling screens, but the operating cost for the former will be greater than the other design due to operation of the pumps required to return the flow from the bypasses to the river channel. It is true that pumps are required in the case of traveling screens to remove debris and to flush fish into the channel leading to the holding ponds, but this quantity of water is insignificant compared to that which must be pumped in a louver installation.

Principle of Louvers

To understand the principle of a line of louvers to divert fish into a bypass, one must realize the natural swimming habits of migratory fish. The fish always swim into the current but move downstream at a velocity representing the difference between the swimming speed and the velocity of flow. Upon approaching a line of louvers, the fish feel the disturbance (one opinion is that the disturbance is heard by the fish) and do one of three things (1) increase the swimming speed to move away from the disturbance for later return, (2) move diagonally upstream and away from the line of louvers in a step pattern, or (3) orient at an angle approaching the normal to the line of louvers, illustrated on Figure 13, for eventual entrance into the bypass. Probably the greatest number of fish follow the third pattern.

If all fish reacted in the manner described above, the efficiency of the louvers would be 100 percent. As will be shown later, the efficiency is decreased because some of the fish pass through the louvers due to chance, exhaustion, schooling effect, or perhaps inquisitiveness.

The tests performed during the 1954 season were performed in Bay No. 1, Figure 14. The louvers did not extend the full depth of the channel, but the ultimate structure will be equipped with louvers extending the entire depth of approximately 22 feet.

Measurements

Three different louver spacings were tested, identified as the initial, second, and third setups. The field observations included:

a. Head loss measurements.

b. Velocity determinations.

c. Effectiveness to screen fish, referred to as efficiency.

Head Loss

The head loss measurements were obtained by observing the depth of flow 4 feet upstream from the start of the line of louvers and 4 feet downstream from the end of the line of louvers. These particular points were chosen to correspond to measurements made previously in the Hydraulic Laboratory in Denver. The model study was performed to improve the flow pattern through a line of louvers and to minimize the head loss. As a result of the study, straightening vanes were provided on the downstream side of the louvers. Without these vanes, the flow concentrated along the right side of the louver slats deflecting the flow at right angles for a considerable distance before it turned to the original flow direction. In order to turn the flow from each louver space, the water surface in the adjacent upstream space must be slightly higher. This backwater buildup progressed upstream from space to space along the line of louvers until, at the upstream end, it allowed very little flow through the louvers and created an uneven flow pattern with high loss in head. Theoretically, a straightening vane for each louver would be most desirable but, practically, the tests showed that satisfactory conditions prevailed with straightening vanes eight louver spaces apart. The effectiveness of the flow straighteners was also evaluated by determining the velocity increase along the upstream side of the louvers. The flow straighteners resulted in 40 percent decrease in head loss. There was some concern relative to the restricted area for the louver space immediately downstream from the louver slat fastened to the straightening vane. Although the restricted area did not affect the flow pattern, it might become clogged with debris. Accordingly, a test was conducted on the model by installing the flow straighteners farther downstream allowing 2 inches between the louver slat and the upstream end of the vane. This change did not affect the flow distribution. To facilitate construction the appropriate louver slat could be extended to intersect the vane without interfering with the flow pattern. The straightening vanes should be at least 9-1/2 inches long, measured parallel to the line of flow. The laboratory studies, comprising both an hydraulic and an air model, were based on a louver spacing of 1 inch.

Figure 15 shows the results from both the field study and the hydraulic laboratory model. Results are also shown for the second and third setups in the pilot structure. For the ultimate structure, which will correspond to the initial setup, the head loss across the line of louvers will be 0.4 foot at the maximum velocity of 4 feet per second. Actually, due to the addition of structural members, this head loss may be somewhat greater. The accumulation of any trash will also increase the head loss, and for this reason provision should be made in the ultimate structure to remove the louvers by sections for cleaning. Trash is not expected to become a major problem of the louvers since only debris which can pass through the 2-inch spaces between the trashrack bars at the upper end of the structure will be present.

Velocity

Velocity determinations in connection with the head loss studies were performed in the section at the upper end of the line of louvers, as shown on Figure 14. The measurements were made with a Price Type-A current meter utilizing the 0.6 depth method. This method was necessary to minimize the time required to make the measurements, thereby avoiding appreciable change in stage due to tide.

The velocity measurements performed in connection with tests to determine the ability of the louvers to screen fish were taken with the same current meter at five points along a line midway between the line of louvers and the right wall of the bay, as indicated by A, B, C, D, and E on Figure 14. These points were chosen to coincide with similar measurements taken in the test flume at Tracy. The velocity of approach, as related to the fish studies, was considered to be the average of these five readings at 0.6 depth. Velocity readings were taken at a time which would reflect average water stage during a particular test, or in some instances, they were obtained at the beginning and the end of the test, with the final result being an average of the two sets of readings.

Efficiency

The effectiveness of a line of louvers to screen fish was evaluated by placing a net at the downstream end of the bypass to trap fish passing through this section. Another net spanned the downstream end of the bay between the bypass and the left wall of the bay. At the completion of a test, usually lasting for 1 hour, the nets were raised and the fish counted. Netting and subsequent counting of the fish resulted in their destruction, therefore, mortality due to other causes could not be quantitatively determined. The efficiency was then computed by dividing the total number of fish in both nets into the number in the bypass net. For example, if 80 fish were obtained from the bypass net and 20 from the other net, representing those which passed through the line of louvers, then the efficiency would be $\frac{80}{80 + 20} \times 100 = 80$ percent.

Figure 16 shows a graph of louver efficiency versus velocity of flow for the initial louver setup in Bay No. 1. The scatter of the points is apparent, but a definite pattern does exist in that the efficiency decreases with increasing velocity, particularly above 3 feet per second. It will be noticed that no efficiency greater than 90 percent was obtained with a velocity above 2.8 feet per second. There was considerable feeling that the behavior of the fish varied by night and day; hence, the plot makes this distinction and, unmistakably, the average daytime efficiency is lower than that at night. One may argue that the day hours should be something different than between 8 a.m. and 4 p.m., as shown on the plot, but the fact cannot be altered that the efficiency is lower during that daylight period. Actually, these hours were chosen with the thought that detritus in the water resulted in simulated night conditions except during the period of greatest light intensity.

Some feeling existed that the fish were excited after passing through the trashrack and, hence, more susceptible to passing through the louvers. Accordingly, tests were run with and without the trashrack but, as may be seen on Figure 16, efficiency versus velocity follows the same pattern; hence, it is concluded that presence of the trashrack has little, if any, effect on efficiency of the louvers.

During tests of the initial louver setup, the average fish length increased from 22 to 30 mm. To ascertain whether the increased size of the fish was reflected in the efficiency, a plot was made showing date versus efficiency, Figure 17. It is indicated that the efficiency is greater near the end of the test period for the initial louver setup, but Figure 18 reveals that the velocity of flow was low during the same period and, therefore, the relationship of efficiency versus approach velocity of flow was not affected by the date or fish size.

Because the depth of flow varied with the tide, efficiency could conceivably vary with depth but Figure 19 shows no relationship between depth and efficiency. In this regard, it is desirable to point out that maximum flow depth was 5 feet, while the ultimate structure will have a maximum depth of approximately 22 feet. It is not known whether a relationship exists between efficiency and depth when the latter is greater than 5 feet. Tests made prior to the writer's introduction to the problem revealed that the upper 5 feet of water carried the greatest number of fish; hence, a material change in efficiency is not anticipated due to greater flow depth.

One other factor which could possibly affect the efficiency is the water temperature. If the temperature became sufficiently high the fish would be weakened with a resulting loss of efficiency for the line of louvers. Figure 11 shows the temperature increase in the river at the pilot structure to be from 71.6° to 75.7° F during tests of the initial setup. Although not included in this report, a plot of temperature versus efficiency revealed the two variables to be independent of each other over this temperature range.

As may be seen from Figure 14, the line of louvers was divided into four sections by extending three of the straightening vanes to the end of the bay. The net which caught the fish which passed through the line of louvers was similarly divided into four sections, enabling a determination of the number of fish which passed through each of the four sections. It was reasoned that if the number of fish passing through any one section was consistently higher than any other section, then a criterion would have been established by which the desirable length of a line of louvers between bypasses could be set. However, the tests revealed no pattern, that is, more fish might pass through the uppermost section during one test and another test might reflect a greater number of fish in the second section, hence, it may be concluded that the 40-foot-long line of louvers was not sufficient to affect the efficiency.

Flume Studies

An opinion was expressed that the turbulence of flow approaching the line of louvers in Bay No. 1 caused a decrease in efficiency. Some turbulence did exist, but the velocity distribution at the gaging station at the start of the line of louvers disclosed a relatively uniform approach velocity. The ultimate structure will have less turbulence than existed in Bay No. 1, but any hope for an increased efficiency is doubtful after considering that the studies in the flume at Tracy resulted in comparable efficiencies over practically the same range as observed in Bay No. 1. Figure 20 shows efficiencies from the flume tests in 1953 to vary from 64 to 100 percent with a fish length somewhat greater than during the measurements in Bay No. 1. Figure 21 shows similar results for the flume tests in 1954 when efficiencies varied from 72 to 100 percent with fish approximately twice as long as those in the tests in Bay No. 1. In the 1954 flume tests the louvers were spaced farther apart than in the initial setup in Bay No. 1, but the fact remains that the efficiency tests in the flume and in the pilot structure gave comparable results and since there were smooth flow conditions in the flume, it is therefore reasonable to expect that the turbulence in Bay No. 1 was insufficient to affect the efficiency.

It is worthy of mention that the results shown for the flume tests in 1954 were performed in unfiltered water pumped direct from the pilot canal, whereas all other tests in the flume were performed with clean water obtained with a filtering process. The need for using clear water to permit visual study of the reaction of fish to a line of louvers is obvious, however, a possibility existed that the behavior of the fish was influenced by the degree of turbidity. But since the efficiency in 1954 with unfiltered channel water was essentially the same as in 1953 with clear water, it may be concluded that the fish behavior is unaffected by clearness of water. During performance of tests using clear water care was taken not to frighten the fish. All flume tests described were performed during regular working hours, hence, any day or night influence has not been determined for the flume.

Statistical Analysis

In an effort to simplify test results from the initial setup in Bay No. 1, Figure 22 was prepared to show the relation of efficiency to velocity by utilizing the moving average method. This figure shows the same results as Figure 16 but in a simplified manner. A strict interpretation of the simplified graphs reveals that efficiency for night tests is somewhat greater with the trashrack removed and similarly for the day tests, but the daytime efficiency is less than that for the night tests. However, the difference indicated by presence of the trashrack is not sufficient to conclude that efficiency is affected after considering the exceptionally wide spread of the basic data due to dealing with animated objects.

An opinion was voiced that efficiency should be weighted by some method in accordance with the number of fish in a particular test.

If such were true, then a plot of efficiency against number of fish in a test would show a varying efficiency as the number of fish changed. Obviously, any such study should not be undertaken without considering other variables, such as velocity, time of day, and fish size. Accordingly, the tests were grouped into units with velocities of flow from 1.5 to 2.0 feet per second, 2.0 to 2.5 feet per second, etc., and furthermore, the tests were grouped in accordance with the length of time and whether day or night. Many plots were made but only one, Figure 23, is included for illustration. The results reveal that efficiency is independent of the number of fish in the test.

A further study was made to reflect the possibility of a correlation by the analysis of variance. 2/ This analysis indicated the degree of correlation between efficiency and velocity of flow to be approximately 0.5, while a true correlation would be 1.0; in other words, there are factors other than stream flow which affect the variability of louver efficiency, such as the element of chance. Other statistical analyses may be applied but the number of fish in a particular test becomes insignificant. Probably the most important conclusion is that any analysis which ignores velocity of flow, fish size, or time of day is grossly in error.

Results of tests in Bay No. 1 of the pilot structure for the second and third setups will not be described in detail since the final structure will correspond to the initial setup. However, pertinent information for the second setup may be obtained from Figures 12, 14, 15, 17, 18, 24, and 25, and Figures 14, 15, 17, 18, 26, and 27 for the third setup.

Louver Spacing

The only difference between the setups was the difference in louver spacing. It is not possible, however, to draw definite conclusions pertaining to relative efficiencies for the three sets of tests since the fish size increased materially over that existing at the time of tests for the initial installation. It is possible to definitely state that efficiency increased with fish size, but the actual effect of wider louver spacing cannot be obtained without tests of various spacings with the same fish size. Facilities for simultaneously testing the three setups, thereby using fish of the same size, did not exist. The problem is not acute since any advantage in wider louver slat spacing would be minor.

Bypass Channel

In the ultimate structure the invert of the bypasses will be approximately 22 feet below the water surface. Installation of the holding ponds at this same elevation would be quite costly due to the required excavation and inherent ground water problems. Locating the holding ponds at a higher elevation would require a gradual increase in invert elevation of the conveyance connecting the bypasses to the ponds.

To determine the effect of the increase in elevation of the connecting channel, a few tests were performed in the louver installation in Bay No. 1 by inclining the bypass floor. The efficiency of the louvers was diminished by the inclined floor but this test is not considered conclusive as the bypass channel was only 5 feet in length causing the increase in elevation of the floor to be very rapid. If the rise of the bypass channel were started at a greater distance downstream and with a more gradual slope, there is no reason to believe that such a scheme would affect the efficiency of the louvers. A materially cheaper installation of the holding ponds would result.

Catfish

All the previous discussion has pertained to striped bass only but as previously stated, catfish, shad, and salmon are also important. Results of efficiency tests for catfish are shown on Figure 28 which shows 100 percent efficiency for the initial setup, while for the other two sets of tests the efficiency varied from 0 to 100 percent. However, the catfish were large during the initial test period and it was practically impossible for them to pass through the louvers. Again, it is not possible to evaluate the effect of various louver spacings since tests could not be made with comparable fish size.

Shad

The statements made relative to catfish apply equally to shad, as shown graphically on Figure 29.

Salmon

No tests were performed with salmon during the 1954 season in Bay No. 1 since the louver installation was not completed until after the salmon run had subsided. Tests performed the previous season with salmon as well as other species are not comparable with the 1954 tests since the louver slats were not 90° to flow but rather were at such an angle as to make it virtually impossible for fish to pass through the line of louvers. Furthermore, a high head loss was created.

The reaction of salmon to a louver installation can, however, be obtained from a series of tests conducted by the California Department of Fish and Game on their installation in the South Stanford Vina Diversion Canal on Deer Creek in Tehama County, approximately 15 miles north of Chico, California. 3/ This installation was identical to that in Bay No. 1 except the depth of flow was approximately 3 feet. The angle of the line of louvers was varied from 11° 32' to 12° 45' and no straightening vanes were provided. The velocity of flow was in the same range as that in Bay No. 1 of the pilot structure. Three sets of tests were performed with bypass widths of 6, 12, and 18 inches. The average length of the salmon was 50.68 mm. The relation between efficiency, velocity of flow, number of fish in test, and bypass width is shown in the following tabulation:

Bypass width (in)	Efficiency (%)	Velocity (ft/sec)	Number of fish in test
6	85	3.08	492
6	87	2.91	32
12	88	2.65	135
18	97	2.06-2.91	116

These results are based on a limited number of tests which are insufficient to be a basis to conclude definitely that efficiency increases with the width of the bypass. However, the efficiencies are comparable to those determined at Tracy with striped bass.

Mathematical Approach

As previously stated, one factor which could not be evaluated in the test installation was the effect of the length of the line of louvers on efficiency. Obviously, if the line of louvers was of sufficient length to cause the fish to become exhausted, they would be forced through the louvers with a resulting decrease in efficiency. There is, however, an engineering approach to the problem. 4/

Referring to Figure 13, let the swimming ability of the fish be V_s, the approach velocity of flow V_a, and the resulting motion of the fish V, with α representing the angle of the line of louvers with the direction of flow. The maximum approach velocity for the ultimate structure has been established at 4.0 ft/sec and the line of louvers at an angle of 15° with the direction of flow. The line of louvers will be approximately 325 feet in length.

Then

$$\text{Sin } 15^\circ = \frac{V_s}{4}$$

or

$$V_s = 4(0.259) = 1.04 \text{ ft/sec, swimming speed}$$

$$\text{Cos } 15^\circ = \frac{V}{4}$$

or

$$V = 4(0.966) = 3.86 \text{ ft/sec, resulting motion of fish}$$

$$T = \frac{325}{3.86} = 84.2 \text{ seconds or } 1.4 \text{ minutes}$$

Hence, it would take 1.4 minutes for the fish to pass the entire length of the line of louvers of 325 feet. Thus, the fish would be required to swim for a period of 1.4 minutes at a velocity of 1.04 ft/sec in an approach velocity of 4.0 ft/sec. From observations during the testing program, a swimming speed of 1.04 ft/sec for a period of 1.4 minutes is very conservative. Accordingly, no bypass would be required for the ultimate structure except at the end of the 325-foot long line of louvers. Figure 30 gives a conception of the swimming ability of the fish.

However, all members of the Fish Advisory Council were not willing to accept this mathematical approach to the problem due to the uniqueness of the design.

Laboratory Approach

Accordingly, an attempt was made to simulate a considerable length of a line of louvers in the Hydraulic Laboratory by means of a circular device illustrated on Figure 31. This device consisted of a circular set of louvers 20 inches in diameter around a center aperture. All louver slats were set at the same angle with respect to the tangents. The water was admitted radially by means of vanes fastened to the perforated plate baffle. The flow pattern was a spiral vortex. It was reasoned that fish introduced into the model would properly orient themselves, in accordance with observations made at Tracy, and the number of times any particular fish passed around the 20-inch diameter louver installation would be a measure of the allowable length of the line of louvers between bypasses.

Small trout and bass (1-1/2 to 2 inches in length obtained from the Colorado Game and Fish Department) were employed in the model with a flow velocity of approximately 1 foot per second. The fish properly oriented himself, but after a very short time (1 to 6 revolutions around the louvers) he would move out to a region of fairly low velocity and rest for a time before again venturing near the line of louvers. In the prototype structure the fish could not get into low velocities. Hence, the model study yielded no usable information due to the velocity gradient. Any attempt to confine the fish to the region of high velocity near the louvers would result in an improper flow pattern. It was, therefore, not possible to demonstrate the permissible length of the line of louvers between bypasses.

Design Criteria

To establish criteria necessary to proceed with design of the ultimate structure, a meeting of the Fish Advisory Council, established several years ago, was held in Sacramento on November 18, 1954. This meeting was attended by representatives of the Bureau of Reclamation, Fish and Wildlife Service, and the California Department of Fish and Game. The following criteria were agreed upon by those present:

1. Angle of line of louvers, 11^{o} to 15^{o}, depending on design requirements.

2. Louver slat spacing, 1 inch clear.

3. Louver slats, 90^{o} to flow.

4. Distance between bypasses, 75 feet maximum.

5. Bypass width, 6 inches.

6. Maximum velocity of approach (average) 5.3 feet per second.

7. Distance between trashrack and start of line of louvers, 25 feet minimum.

8. Smooth flow pattern between trashrack and start of line of louvers.

9. Trashrack bar spacing, 2 inches clear.

10. No provision for medication with salt of the fish in the holding ponds.

11. Although recognized that preditors might stay in the bypass channels or ahead of the trashrack to prey upon the small fish, no preventive action is to be taken.

The limitation of 75 feet between bypasses will materially increase the cost of the structure. In an attempt to minimize the cost, a proposal was made to provide only one bypass in the original installation with provision to activate intermediate bypasses if found necessary. However, the Fish and Wildlife Service insisted that all bypasses be made operative initially and that some could be taken out of service if found unnecessary.

PART II

HYDRAULIC MODEL STUDIES OF THE PILOT CANAL AND PILOT FISH SCREEN STRUCTURE

INTRODUCTION

The pilot canal and pilot fish screen structure are located at the headworks of the Delta-Mendota Canal, Central Valley Project, California. The pilot canal is used as a temporary channel to provide passage of water from Old River to the Tracy Pumping Plant until such a time as the headworks of the main canal are finished, Figure 1.

The fish screen structure, located at about the midpoint in the pilot canal, is for the purpose of aiding in the conservation of the small fish in the area by preventing their access to the canal. The structure is set at an angle to the center line of the pilot channel in order to keep the velocities low through the structure by providing a large area for the flow passage. The structure consists of a bridge work frame used to contain the fish screens and trashracks as well as the necessary apparatus for removing and cleaning the screens and holding the screened fish. The presence of peat moss and trash in the water makes it necessary to clean the screens several times each day.

The laboratory was requested to make model studies on the pilot canal and pilot fish screen structure when the channel began to show signs of excessive erosion along the banks, and soundings taken on the channel floor downstream from the structure showed that the footings of the structure were being undermined.

The louver type fish screen was considered for installation in the fish screen structure when investigation by project personnel showed that it had great potential in fish screening efficiency as well as requiring very little maintenance since the peat moss could pass through the louvers without clogging the openings. However, their investigations indicated that there were some adverse hydraulic characteristics that could best be corrected by a hydraulic model study.

THE MODELS

The studies were performed with four models. A 1:15 scale model was used to determine the channel realinement for the pilot canal and also for the overall pattern of the channel bed erosion. A 1:10 scale sectional model of one bay of the fish screen structure was used to study the channel bed erosion downstream from the structure. The model studies of the louver installation were performed on two models. One was a hydraulic model of a 16-foot length of the line of louvers built to a scale of 1:4 to give an overall picture of the flow pattern. In the other, a section of the louvers 6 inches high and 4 feet long with prototype dimensions for width and spacing was tested in air instead of water.

The pilot canal was formed in the 1:15 scale model from sand to conform to drawings from Specifications No. 20C-1015, Figure 2. The fish screen structure was constructed of wood from drawings in the same specifications. The 1:15 model layout is shown by Figure 32. The 1:10 scale sectional model was installed in an existing narrow flume which had a glass panel for one wall.

The model discharge, water surface elevations, extent of erosion, and other important measurements were determined by standard laboratory methods.

INVESTIGATION OF THE PILOT CANAL AND PILOT CANAL STRUCTURE

The investigation on the pilot canal and pilot fish screen structure was performed in two phases; the first, using the 1:15 scale model, was the investigation to determine the channel realinement. The second phase, using the 1:10 scale model, was the determination of methods to prevent the severe channel bed erosion downstream from the fish screen structure. After recommendations had been determined from these two investigations, they were combined and incorporated in the 1:15 scale model and a final test made to show the overall effectiveness. The effectiveness was determined by visual comparisons of the flow conditions and amount of erosion. Photographs were obtained of these two features both upstream and downstream from the fish screen structure.

Pilot Canal Tests

Test No. 1. In the initial test the existing channel alinement was formed in the model, Figures 33 and 34A, and the model operated at 3,800 cfs (5-pump operation at high tide). This test was performed in order to duplicate the existing flow conditions and extent of erosion and also to have a basis for comparing the effectiveness of a modification.

The flow in the channel formed an eddy along the left bank on the upstream side of the fish screen structure and showed definite indications of eroding the right bank downstream from the structure. The extent of the erosion both upstream and downstream from the structure, as shown in Figure 35, indicated that the channel was too narrow for 5-pump operation. The erosion pattern also showed the points where the channel should be widened.

Test No. 2. The first channel revision followed recommendations made by the project office. Figures 34B and 36A show the outline of this revision; the upstream section of the channel was widened about 60 feet by excavating along the left bank. The right bank of the downstream section was moved back so as to eliminate all of the projecting curve and thus permit nearly a straight approach to the main canal.

The revised channel was tested at 6-pump discharge at high tide, 4,600 cfs. It was felt that since this was a possible operating condition it would provide a more severe test. The eddy in front of the sloping screen bay was not as severe as in the previous test and would probably disappear if there were flow through the sloping screen bay, Figure 37A. In the downstream section the only sign of an adverse flow condition was the slight eddy along the left bank; this also was probably due to the lack of flow through the sloping screen bay and in any case was not damaging to the channel banks.

The channel appearance after 4 hours of 6-pump operation showed only a slight amount of erosion of the banks, indicating that the channel was sufficiently wide. In the upstream section the floor of the channel near the entrance from Old River showed signs of bed movement; this was probably due to the slope of the channel floor rather than because of channel alinement.

Test No. 3. The smooth flow conditions and lack of bank erosion indicated that it might be possible to make the channel narrower and thereby considerably reduce the amount of excavation necessary in the large channel. Accordingly, the upstream channel width was reduced from 92 to 62 feet. The downstream section was re-formed so as to form a channel about halfway between the original channel and the one tested in Test No. 2. Figures 36B and 38A show the channel investigated in Test No. 3.

This test was also made at 6-pump operation; however, the upstream water surface elevation was lowered to correspond to low tide since the resulting increased velocity would tend to cause more severe erosion. Figure 37B shows the flow appearance for this channel alinement. In the upstream section the flow near the structure was very smooth; a slight eddy in front of the sloping screen bay was still noticeable but did no harm. The flow in the downstream section was very smooth through most of the channel; however, there was a slight water surface roughness along the right bank that indicated the bank protruded too far into the channel. The extent of the erosion showed that the channel was adequately wide but that the approach curve along the right bank would benefit by being streamlined.

Test No. 4--Recommended channel. From the above three tests the recommended channel alinement was derived, Figure 38B. For the recommended channel the upstream section remained 62 feet in width and the right side approach was not further streamlined. The downstream section was widened so that it was a compromise between the channels of Test No. 2 and Test No. 3. The changes in the downstream section also included a modification of the downstream end of the left bank. It had been noticed in the previous tests that the left bank had a tendency to erode in this vicinity. Although in each individual test the amount of erosion was slight, collectively after several tests it had accumulated to a significant amount that indicated the bank should be moved back about 10 feet at the junction with the main canal. From the appearance of the flow and the condition of the channel banks after 4 hours operation the channel alinement was judged to be satisfactory for the prototype installation.

Pilot Fish Screen Structure Tests

During the tests to determine the channel realinement of the pilot canal, the fish screens of the pilot fish screen structure were in place and the head loss across the screens corresponded to about 1-1/2 feet difference in elevation between the upstream and downstream sides. It had been noticed that when the screens were raised a small amount the flow under the screen caused severe erosion of the channel bed just downstream from the structure.

Information received from the prototype structure also showed that there had been severe bed erosion downstream from the structure, Figure 39. It was not practical to try to correct this erosion by using the large model; therefore, a sectional model of one bay of the structure was constructed to a scale of 1:10 and installed in a glass sided flume, Figure 40.

The testing procedure closely followed information received on the prototype operation. The discharge was equivalent to 5-pump, high tide, operation through 11 bays with about 1-1/2-foot head loss across the screen. The screen was operated to duplicate the prototype screen cleaning procedures. The cleaning was accomplished by slowly raising and lowering the screen while playing a jet of water over it to remove the debris. Before raising the dirty screen a clean screen was temporarily lowered in front of it. When the cleaned screen was being returned, the workmen were often unable to fully lower it, and it was allowed to remain in a partially raised position for 2 or 3 hours. The model testing procedure duplicated this by slowly raising the screen for 2 or 3 feet and allowing the model to operate while observing the action through the glass panel.

Test No. 1. For the first test the existing prototype setup was modeled, Figure 40A. When the screen was first raised the sluicing action of the flow under the gate caused the bed to erode very rapidly. Figure 40B shows the channel floor after only 10 minutes of operation.

It was apparent that the sluicing action of the flow under the screen was the cause of the prototype erosion. Figure 39 shows the extent of prototype erosion. The lack of erosion downstream from the first three bays can be explained by the fact that there was no flow through the sloping screen bay and the next two bays were equipped with self cleaning traveling screens which did not need to be raised for cleaning. The remaining eight bays had to be raised in order to clean them.

Since it was not practical to install the moving screens in all the bays, further tests were made to determine other methods of preventing the erosion.

Test No. 2. For Test No. 2 the channel bed was modified by placing a protective layer of riprap downstream from the structure. The layer was 1 foot thick and consisted of 2-1/2- to 4-inch prototype size and extended 10 feet downstream.

The erosion was negligible after 10 minutes operation so the amount of screen opening was altered to find a more severe operating condition. Starting with the screen raised 5 feet, it was lowered by 1 foot increments. At 1 foot open the bed movement was greatest so the model was allowed to operate at this opening for 20 minutes, Figure 41A shows the amount of bed movement at the end of this period. The riprap reduced the amount of erosion; however, it was thought that the structure would receive better protection if some type of deflector or end sill were placed on the concrete apron under the screens.

Tests No. 3, 4, 5, and 6, end sills. Four types of end sills were investigated and all were found to be effective in reducing the erosion. The tests are summarized below:

Test No. 3. End sill 6 inches high, sloped upstream face, Figure 42A. At the 2-foot screen opening the erosion was very slight. Though the screen was raised and lowered to find the opening that produced the greatest bed movement, the 2-foot opening was selected for erosion time trials. Figure 41B shows the amount of erosion at the end of 30 minutes operation. The erosion pattern was not extensive and the sill had tended to cause a protective bar to be formed at the end of the apron.

Test No. 4. End sill 1 foot high, 2:1 slope on upstream face, riprap also used, Figure 42B. The greatest bed movement occurred with the screen raised 3 feet. Figure 43A shows the extent of erosion after 4 hours. The eroded area has moved several feet downstream and some of the eroded material has moved upstream toward the apron.

Test No. 5. A 7-1/2-inch angle iron placed on the apron as an end sill, no riprap, Figure 42C. Figure 43B shows the extent of erosion after 2 hours operation with the screen raised 2 feet. The eroded area is about 20 feet downstream from the apron, the eroded material has moved upstream and formed a sand bar to the same elevation as the top of the sill and extending for about 4 feet downstream.

Any of the end sills that were investigated would protect the structure from excessive erosion but since the installation of a sill would have to be done under 20 feet of water, the angle iron end sill was recommended as it would be the easiest for prototype installation. It was also recommended that a 1 foot thick layer of 2-1/2- to 4-inch riprap be installed for 10 feet downstream from the structure.

Overall investigation. Two tests were performed on the 1:15 scale model to determine the effectiveness of the end sill when it was installed in all twelve bays of the structure. The tests were made with the channel alinement as recommended, 6-pump operation and with the upstream water surface elevation representing mean low tide.

In the first test the screens were raised 2 feet, no end sills or riprap was used and the head loss across the screens varied from about 3/4 foot at the start of the test to about 1-3/4 feet near the end of the test. At the end of 3 hours' operation the model was unwatered and the extent of erosion determined. Figure 44A shows the extent of erosion at the end of the test. The erosion was between 4 and 6 feet deep with the deepest part of the eroded area about 11 feet downstream from the apron and the end of the apron was undermined in all bays.

For the second test the 7-1/2-inch angle iron end sills were installed in all bays; the other operating data were the same as in the previous test. Figure 44B shows the extent of erosion at the end of 3 hours operation. The erosion was between 1 and 4 feet deep with the lowest point about 15 feet downstream from the apron. The end of the apron was not undermined in any of the bays; however, between Bays No. 5 and 6 and between Bays No. 7 and 8 the end of the apron was exposed but the addition of the protective layer of riprap would probably eliminate this.

Screen raising studies. As previously discussed, the screen raising methods during cleaning operations seemed to have a definite bearing on the cause of the prototype erosion. A test was made on the 1:10 scale model to show that a simple change in the prevailing methods would benefit the structure as much as the end sill and riprap would benefit it. The discharge and water surface elevation were the same as were used for the other tests, and no end sill or riprap was used to protect the channel bed. Two screens were used, one was the same as in the previous tests and this is referred to as the dirty screen; the second screen had less than 1/4 foot head loss through it and is referred to as the clean screen.

For the first test the prototype procedure was followed: this was to lower the clean screen on the upstream side of the dirty screen and then to raise the dirty screen. When this procedure was followed, the erosive action downstream from the screen was extremely violent and in a very few minutes a large amount of material eroded from the channel bed, Figure 45A.

In the second test the position of the screens were reversed, which put the clean screen on the downstream side of the dirty screen. When the dirty screen was raised there was little erosive action of the channel bed. Figure 45B shows the condition of the channel bed after 30 minutes operation with the screen raised 2 feet.

INVESTIGATION OF THE LOUVER INSTALLATION

The investigation was directed at correcting an existing poor flow condition and to obtain a constant velocity in the approach channel with a uniform distribution through the louvers. For the initial tests the existing design was installed in both models and the poor flow condition duplicated in order to determine the cause. The poor flow condition was quite apparent in the models. Figure 46A shows the flow lines through the louver as traced by confetti. The concentration of flow lines along the right side shows that part of the flow is deflected parallel to the line of louvers, causing the water velocity to increase about 2-1/2 times from the upstream end of the louver to the downstream end. This is caused by the condition on the downstream side of the louver where the flow lines show that the flow is normal to the line of louvers for a considerable distance before it turns to the original flow direction. In order to turn the flow from each louver space, the water surface in the adjacent space (upstream) must be slightly higher. This backwater build up progresses upstream from space to space along the line of louvers until at the upper end it allows very little flow through the louver. This is indicated by the absence of flow lines in this area. The buildup is also reflected downstream by an increased flow velocity along the left wall.

The investigation of this design in the air model showed practically the same conditions. Figure 46B shows the flow lines traced by smoke streamers induced into low velocity flow on the upstream side of the louvers. The deflected flow is indicated by the distance the smoke travels along the upstream face of the louver before it passes through. On the downstream side, the distance the smoke travels normal to the louver before it turns is also quite apparent. The preliminary tests indicated that if each unit of the louver would take its proportionate share of the flow, the flow would not be deflected and even flow distribution and a constant approach velocity would be attained.

Flow Straighteners

The upstream side of the louvers could not be altered since it was thought that the fish repelling characteristics might be changed; therefore, the modifications were developed on the basis that they had to be placed on the downstream side. Preliminary tests showed that if the flow emerging from the louvers were forcibly turned so that it flowed in the proper direction the backwater buildup was minimized and good approach flow resulted. Good outflow conditions might also be accomplished by downstream channel realinement but obviously would be very expensive, so all further tests were made to determine the length and spacing of flow straighteners placed on the downstream side of the louvers. The length of the flow straighteners would depend on their spacing since in order to completely turn the flow the straighteners must overlap. The flow had to be turned about 70° which set the minimum spacing as one vane for every two louver spaces.

Flow distribution. Two flow straighteners were investigated in the air model; the first had a vane for every two louver spaces, Figure 47, and the second a vane for every eight louver spaces, Figure 48. The flow patterns were traced by the smoke streamers and the results photographed. Figure 49 shows the pattern through the two flow straighteners. In both cases the smoke entered the louver more directly than it had in the case of the louver without the straighteners; it was also apparent that the stream was turned and flowed downstream with a fairly uniform distribution. Of the two flow straighteners tested, the closer spacing provided the better flow distribution. For comparison, the flow lines in the 1:i model when the flow straightener is used are shown in

Figure 50B; both the upstream and downstream distribution is more uniform than that shown in Figure 46A.

Velocity increase. Another method of determining the effectiveness of flow straighteners was to determine the velocity increase along the upstream side of the louver. The ratio of the increase in velocity versus the spacing of the straightening vanes has been plotted on Figure 51. The velocities were measured at the upstream end of the line of louvers, V_1, and at the downstream end, V_2. The spacing was measured normal to the flow lines. For this test both models were used. In the air model, tests were made with the two flow straighteners previously described; in the water model two tests were made, one with the louvers alone and one with a flow straightener patterned after the wider of the two tested in the air model.

Flow in the air model without a flow straightener can also be considered as flow with a straightener every 15 inches with the upper and lower model boundaries being the straighteners. Data were obtained from the models for five different spacings; in addition, data were used from information available on tests that had been performed in the test flume at the Delta-Mendota Canal headworks. From the curve on Figure 51 it is possible for the designer to determine the best spacing in keeping with the desired flow efficiency and construction economy. The curve shows that any spacing up to 6 inches will provide good velocity distribution.

Head loss. The head loss across a system of louvers with or without the flow straightener was also obtained from the models. In the 1:4 model the head loss was determined from a point about 4 feet (prototype) upstream from the start of the line of louvers to a point about 4 feet (prototype) downstream from the end of the line of louvers. The test showed that the head loss for the louver without the flow straightener was about 0.24 foot; when the flow straightener was added, the head loss was reduced to about 0.14 foot, a reduction of about 40 percent. Similar measurements taken in the air model also showed the flow straightener reduced the head loss with the closer spacing being more effective than the wider spacing.

With a flow straightener vane fastened directly to a louver slat, the flow area for the louver space immediately downstream is constricted. Although this does not reduce the flow, the possibility that it might become clogged with trash necessitated a test to determine the effect of separating the flow straighteners from the louvers. Figure 50A shows the flow pattern with the flow straighteners about 2 inches from the louvers. There was very little change in the flow pattern and the effectiveness of the flow straighteners was not impaired. Although tests were not made, it is thought that if the louver slat is extended to intersect the displaced flow straightener vane its effectiveness would not change.

INVESTIGATION OF ANGLE BETWEEN LINE OF FLOW AND LINE OF LOUVERS AND BETWEEN LINE OF FLOW AND LOUVER SLAT

The specific purpose of the tests was to determine the head loss across the louver system for different values of the angle between the line of louvers and the direction of flow and of the angle between the louver slat and the direction of flow, Figure 52. The angle of the line of louvers with the direction of flow was measured in a clockwise direction and will be referred to as the angle α . The angle of the louver slats with the direction of flow was measured in a counterclockwise direction and will be referred to as the angle ϕ. The head loss is expressed in terms of the velocity head based on the average velocity about 5 feet upstream from the line of louvers.

In making the head loss measurements a predetermined discharge was turned into the test flume and the flow depth adjusted with a tail gate so that the depth at the upstream measuring station was 17.75 inches, which was slightly less than the height of the model louvers. The elevation of the water surface at the downstream measuring station was then obtained. The upstream measuring station was located at a point corresponding to 5 feet upstream from the start of the line of louvers; similarly, the downstream station corresponded to a point 5 feet downstream from the end of the line of louvers. A louver system was next placed in the flume and the upstream water surface adjusted until it was at the same elevation as before; the elevation of the downstream water surface was then determined. The difference or change in elevation was recorded as the head loss for the louver system being investigated. This method of determining the magnitude of the loss, which eliminates channel loss, was the same for all of the louver installations.

The results of the tests have been plotted on Figure 52 as the head loss in velocity heads versus the angle ϕ for four values of angle α . The curves show that when α is less than 30° the head loss is a function only of angle ϕ. However, as the angle increases above 30°, the loss for any particular value of angle ϕ increases very rapidly. As an example take a value for angle ϕ of 90° where the head loss at angle α of 20° and 30° was about 6.3 velocity heads, when angle α was increased to 40° the loss becomes 8.2 velocity and with α equal to 45° the loss was 10 velocity heads.

The greatly increased loss when angle α becomes greater than 30° was thought to be a function of the relative position of adjacent louver slats, Figure 53. The head loss seemed to vary inversely with the ratio B/A, where "B" is the length of slat that is overlapped by the adjacent slat upstream, dimension "B" on Figure 53, and "A" is that portion of the slat that is directly exposed to the flow, dimension "A" on Figure 53. The line of louvers that was used for $\phi = 90°$ and $\alpha = 40°$ had a ratio B/A equal to 1.71 and a head loss of 8.2 velocity heads, when this line of louvers was modified so that the ratio was 2.65 the head loss dropped to 6.5 velocity heads, which compared favorably with the head loss when angle α was less than 30°, Figure 53.

For expediency in the model construction and testing all of the above tests were made without flow straighteners on the downstream side of the louvers. In order to substantiate value of the flow straighteners another series of tests were performed with flow straighteners on the line of louvers at α 's of 20° and 45°. The flow straightener used at α = 20° consisted of a straightening vane for every eight louver spaces, the flow straightener for α = 45° also consisted of a vane for every eight louver spaces. The results of these tests indicated that the head loss was reduced approximately 40 percent, Figure 52. Although no investigation was made on the use of a flow straightener at α = 30° the fact that the loss curves for α = 20° and 30° are identical for the louvers without flow straighteners suggests that they would also be the same after the straightener is added.

In the above tests only one flow depth upstream from the line of louvers was used, providing approximately the same velocity for all tests. In order to compare the model tests with similar prototype investigations, the model was operated with variable upstream and downstream depths and the head loss in velocity heads related to a head loss depth ratio, Figure 54. For the tests a louver setup with ϕ = 90° and α = 30° and a flow straightener for every eight louver spaces was used. This test indicated that the head loss varied from 2 to 4 velocity heads for most head loss depth ratios.

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2. :atistical Methods for Research Workers, by R. A. Fisher

3. Report on Experimental Louver Fish Screen--South Stanford Vino Canal--1954, by George H. Warner of the California Department of Fish and Game

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5. Studies of the Delta-Mendota Canal Fish Protective Facilities, 1951-1952, U. S. Department of the Interior, Region II, Delta District, Tracy, California, Solano Construction Division

6. A Report of Preliminary Shock Studies on Striped Bass (Roccus Saxatilis, Walbaum) and King Salmon (Concarhynchus Tschawytscha), by Bertram D. Lift, Fishery Management Biologist, U. S. Bureau of Reclamation

7. Compilation of Pilot Fish Screen Structure Test and Appurtenant Data, U. S. Department of the Interior, Bureau of Reclamation, R. O. II, Delta District, Tracy District, Tracy, California, Fish and Wildlife Service, July 1[illegible], 1952

8. Review and Appraisal of the Fish Protection Problem Associated with the Diversion of Water at the Tracy Pumping Plant, Central Valley Project, California, by Joseph T. Barnaby, Scott H. Bair, and Gerald B. Collins, Fish and Wildlife Service, Region I, Portland, Oregon, June 1953

9. Sacramento-San Joaquin Delta Fishery Resources: Effects at Tracy Pumping Plant and Delta Bass Channel, Special Scientific Report, Fisheries No. 56, Fish and Wildlife Service

10. Report of Invention for the Screening of Fine Debris from Water used in the Collection and Holding of Fish, by Russell Vinsonhaler

11. Report of Invention for the Lifting and Salvage of Fish, Flexible Fish Salvage Cups, by Russell Vinsonhaler and Arthur C. Birdzell

12. Invention Report of Russell Vinsonhaler, Daniel W. Bates, and George O. Black, for "Fish Diversion Louver System."

Interior - Reclamation - Denver, Colo.

FIGURE 1
REPORT HYD. 401

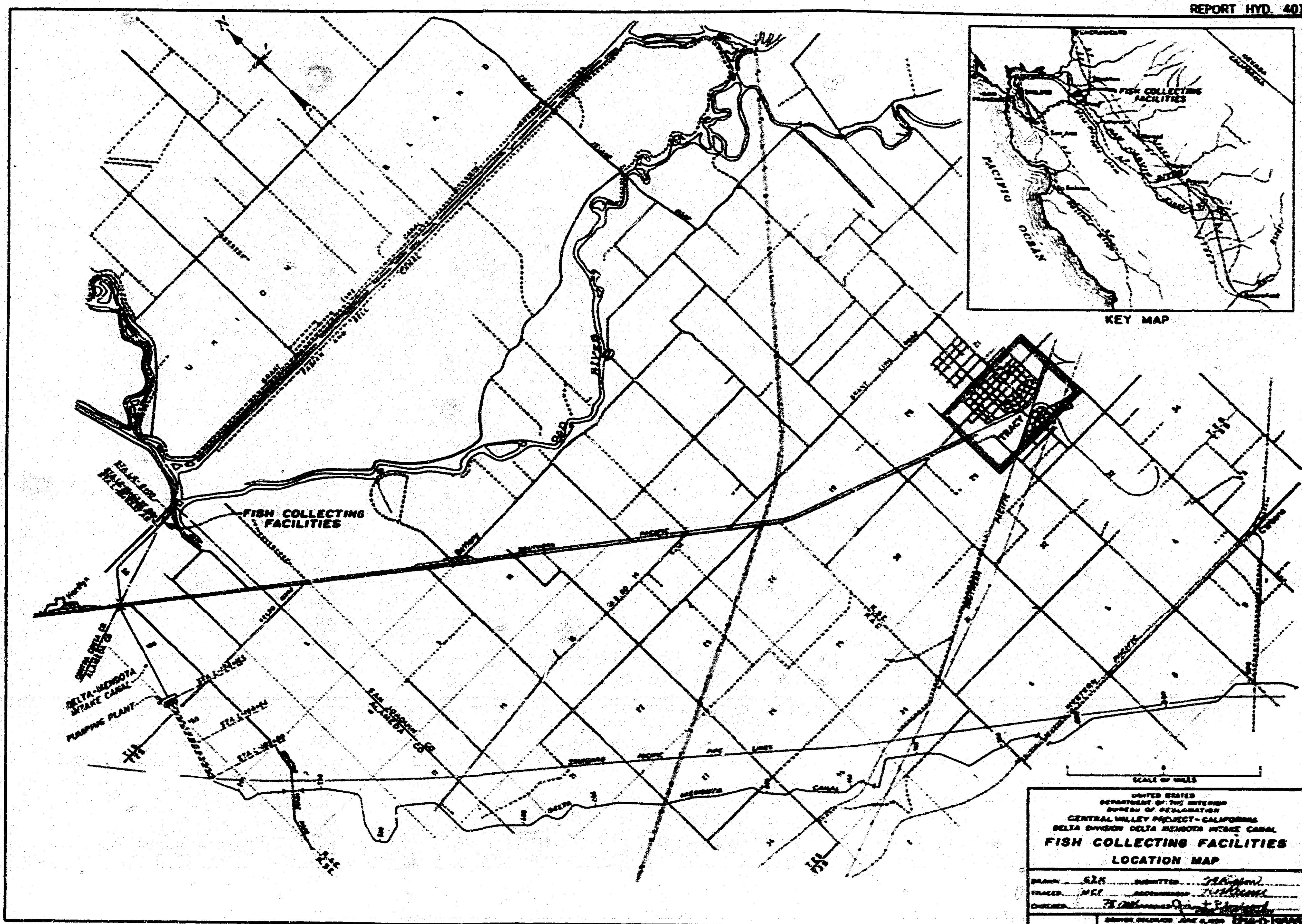


FIGURE 2
REPORT HYD. 401

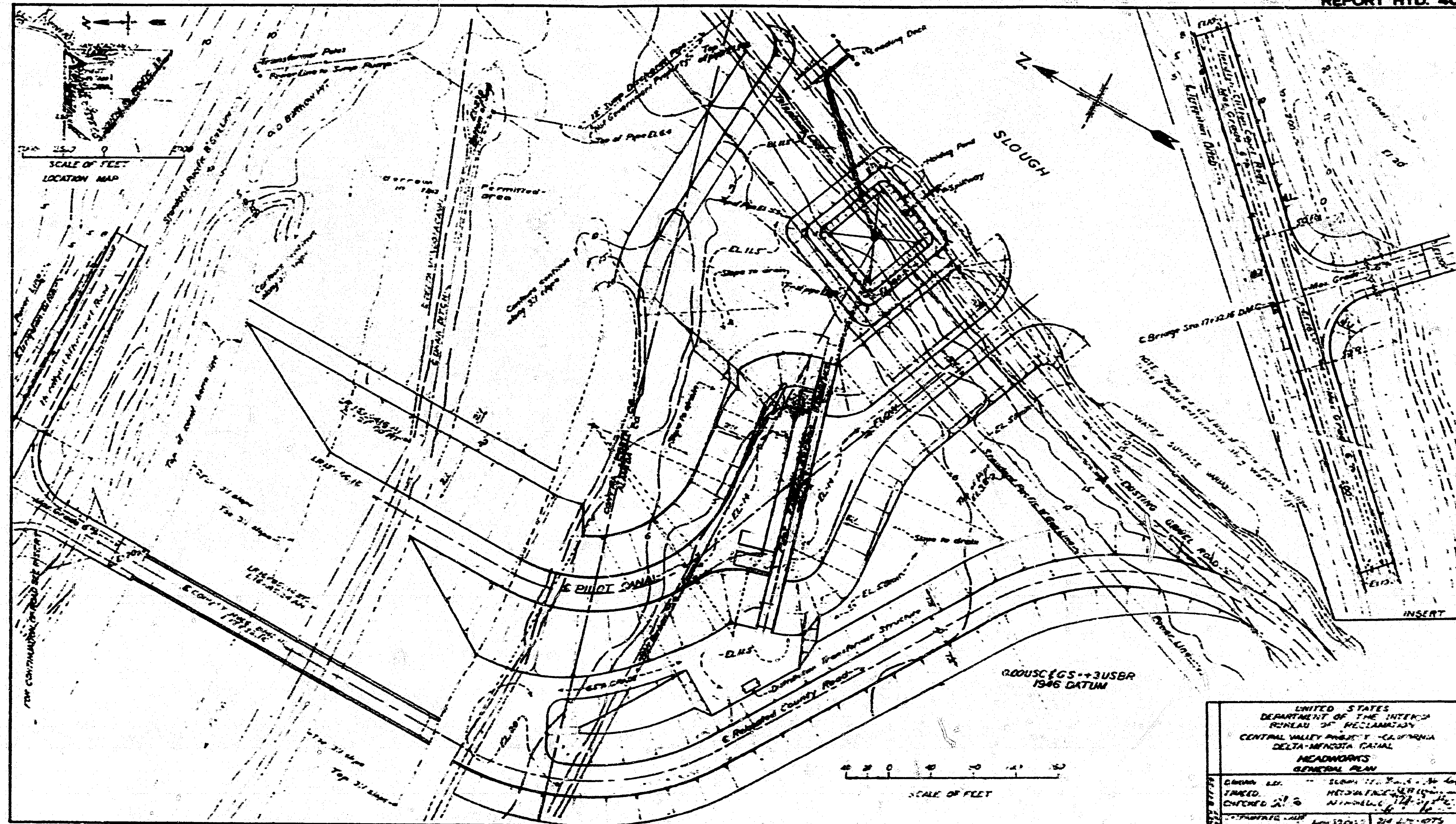
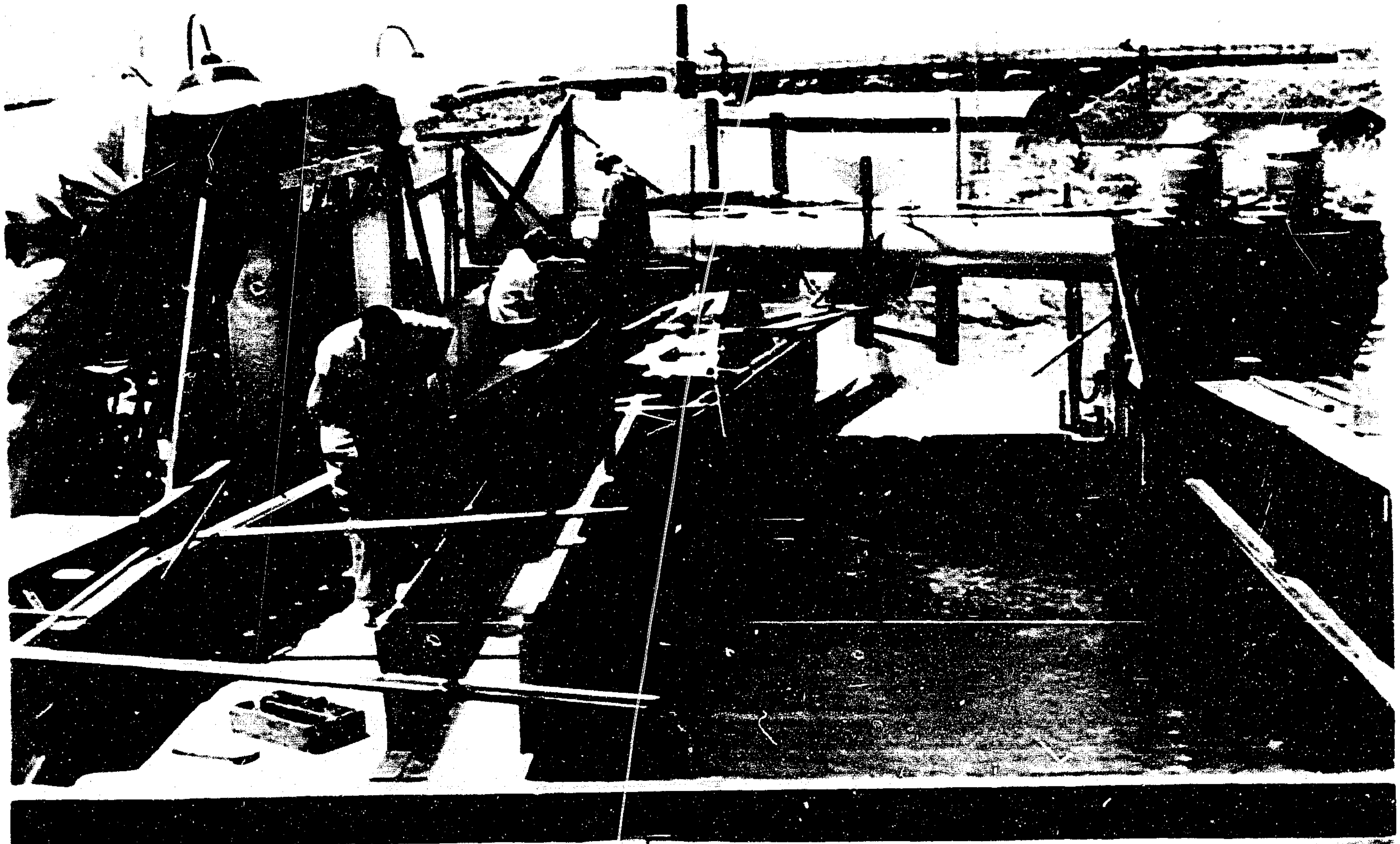
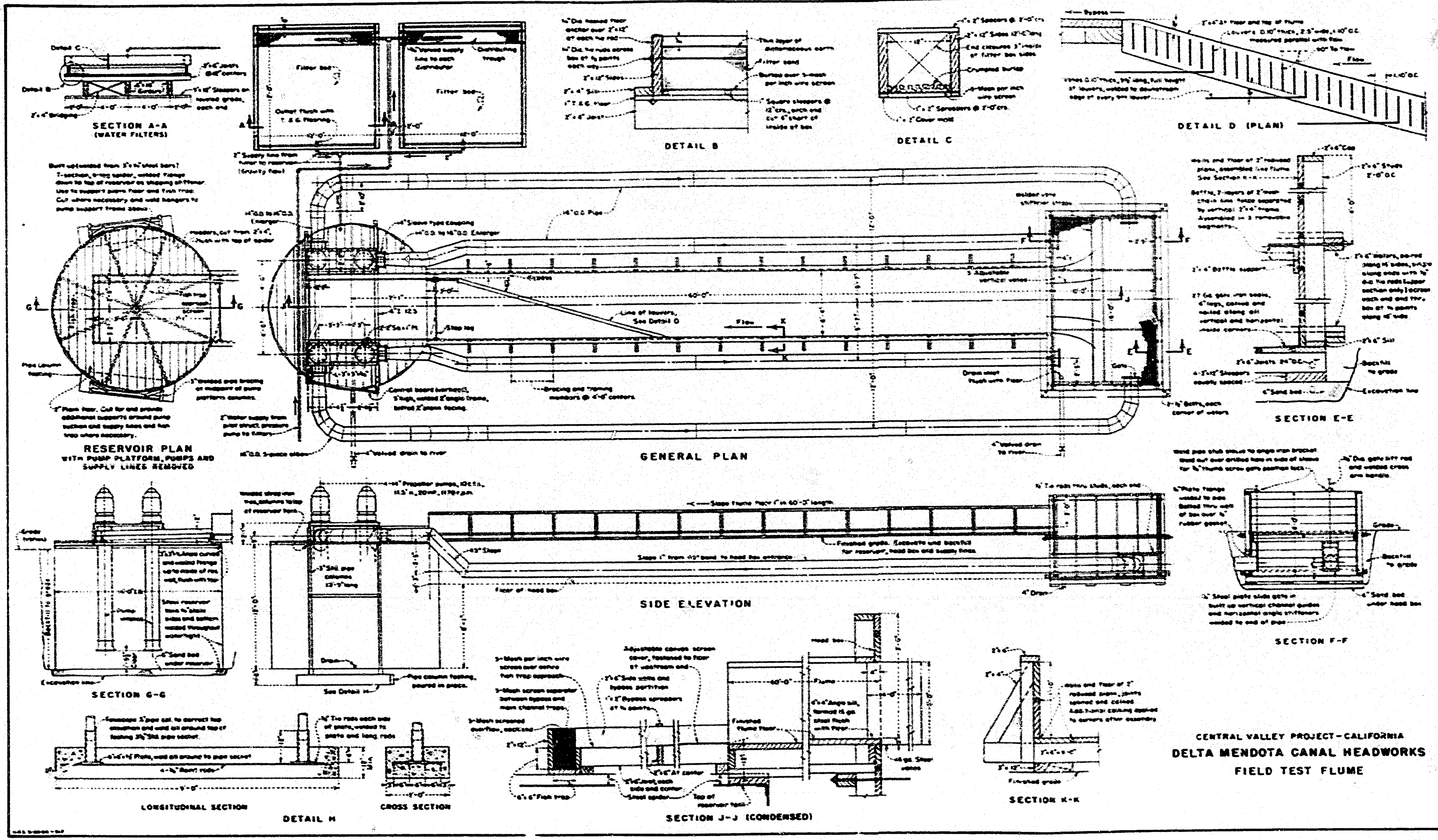


Figure 3
Report Hyd. 401



Old Test Flume. Delta-Mendota Canal Headworks.



CENTRAL VALLEY PROJECT—CALIFORNIA
DELTA MENDOTA CANAL HEADWORKS
FIELD TEST FLUME

Jetting Fish From Traveling Screen. Delta-Mendota Canal Headworks.

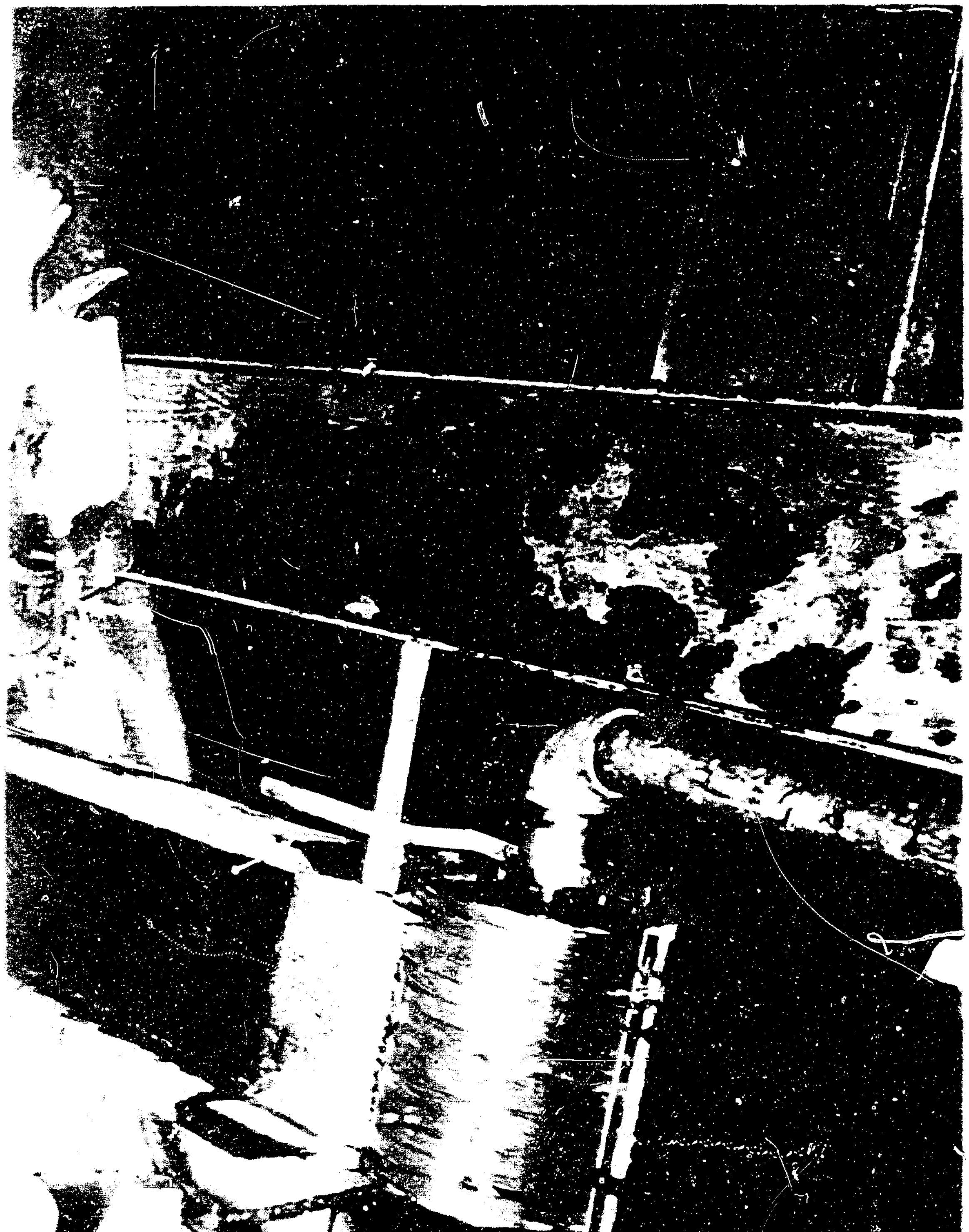
Figure 5
Report Hyd. 401

Jetting Fish From Traveling Screen, Delta-Mendota Canal Headworks.

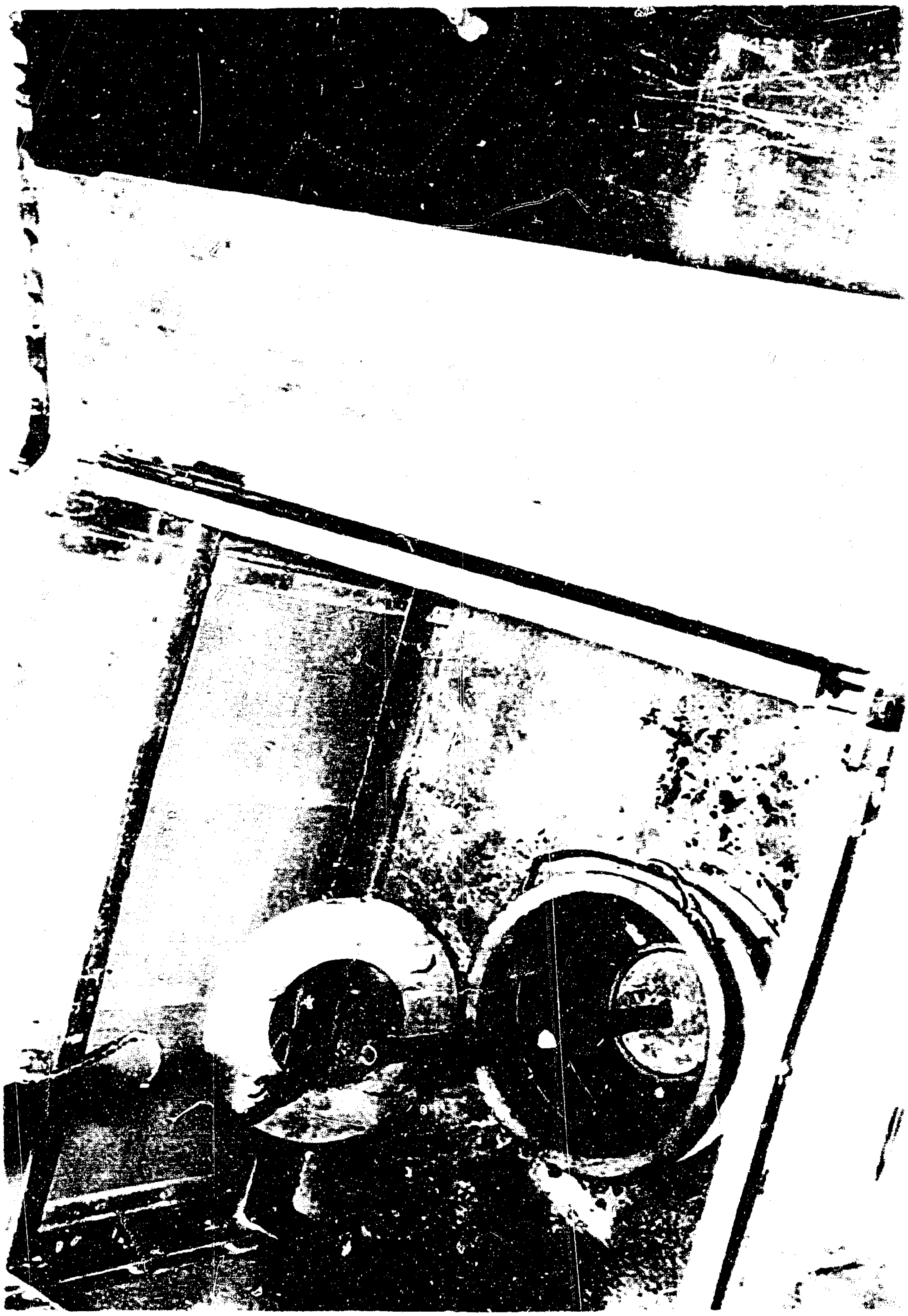
Figure 5
Report Hyd-401

Jetting Fish From Traveling Screen. Delta-Mendota Canal Headworks.

Figure 7
Report Hyd. 461



Dewatering Wheel - Delta-Mendota Canal Headworks



Special Valve to Discharge Fish From Holding Pond
Delta-Mendota Canal Headworks

FIGURE 9
REPORT HYD. 401

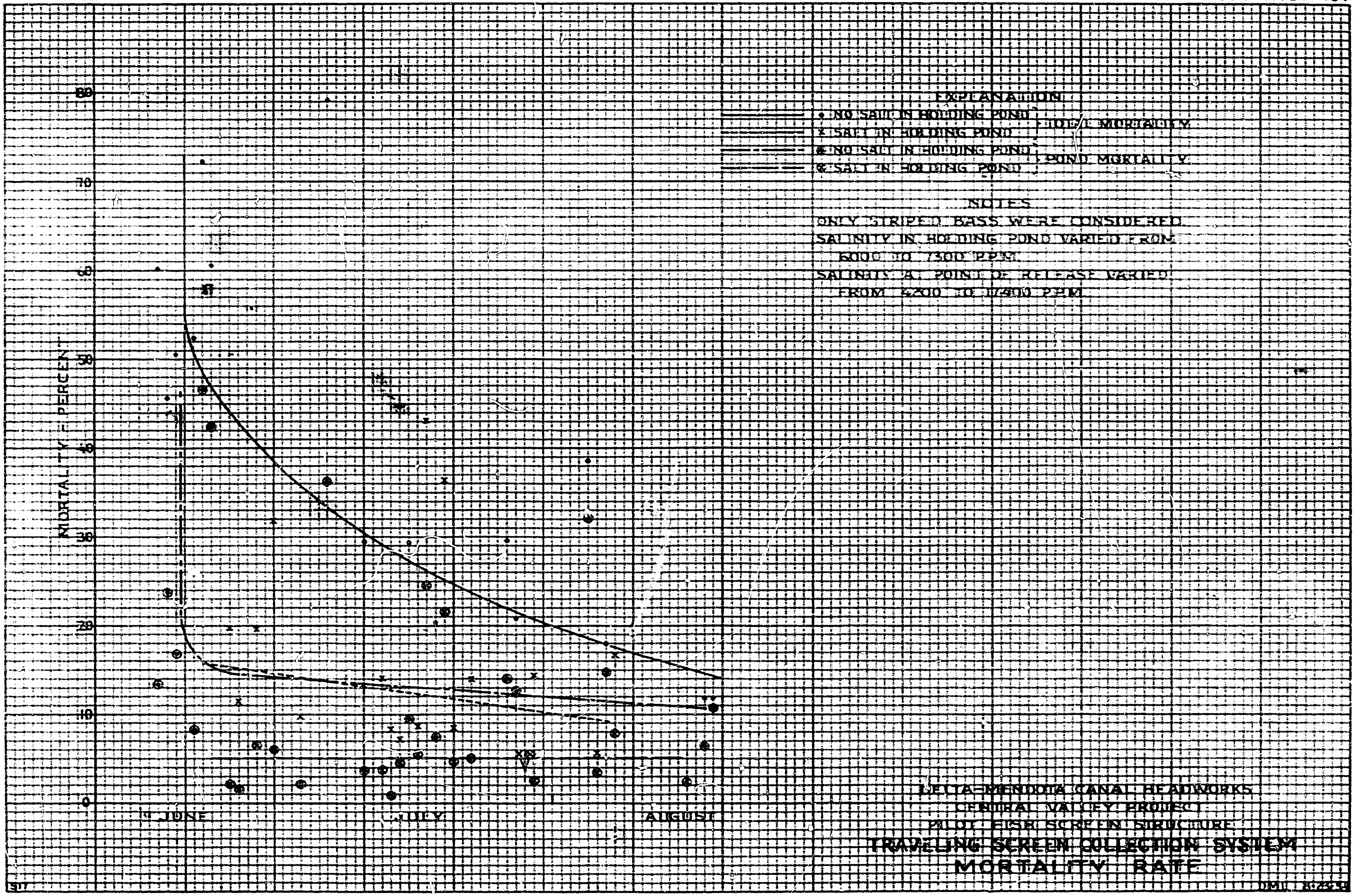
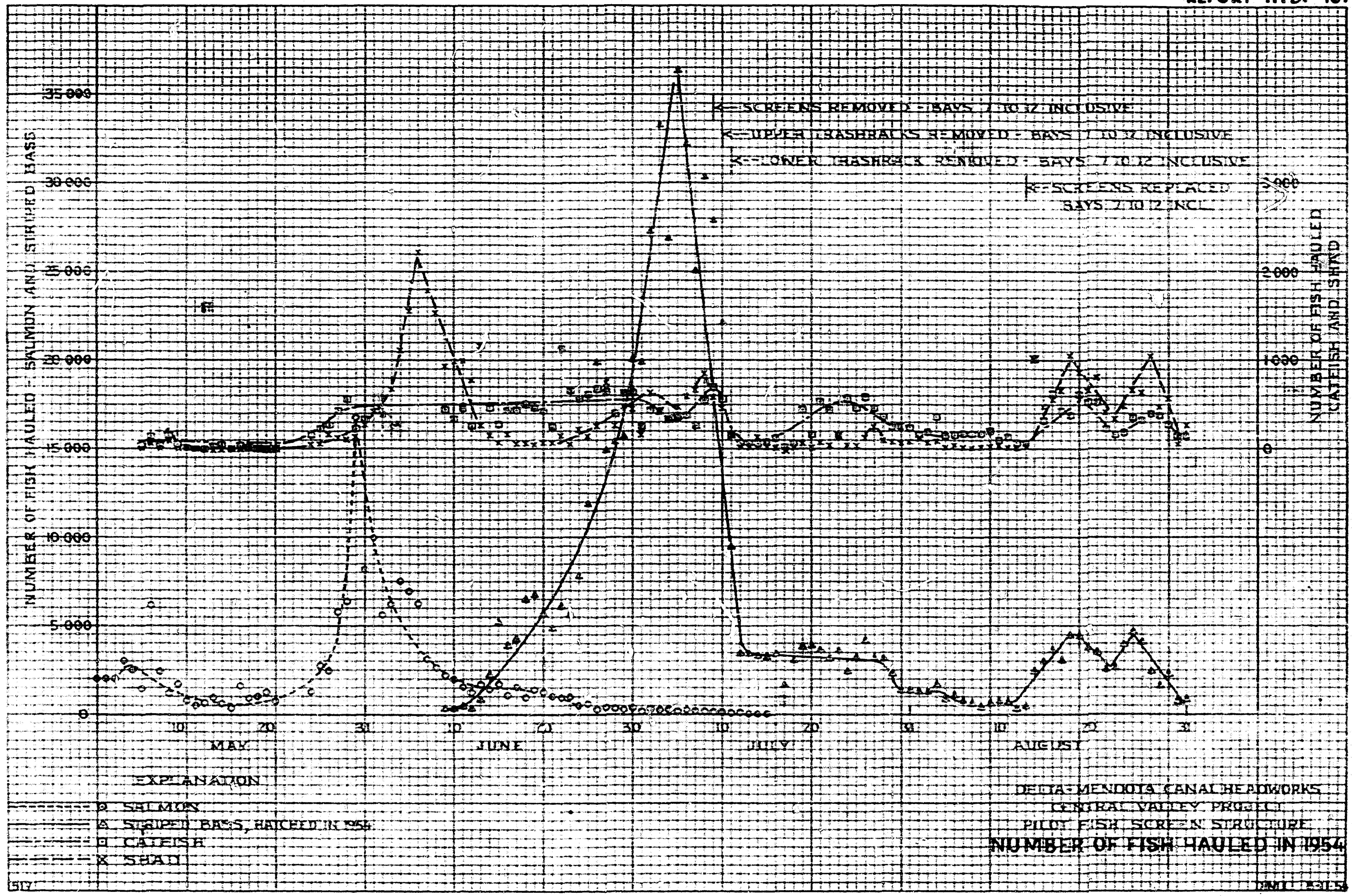
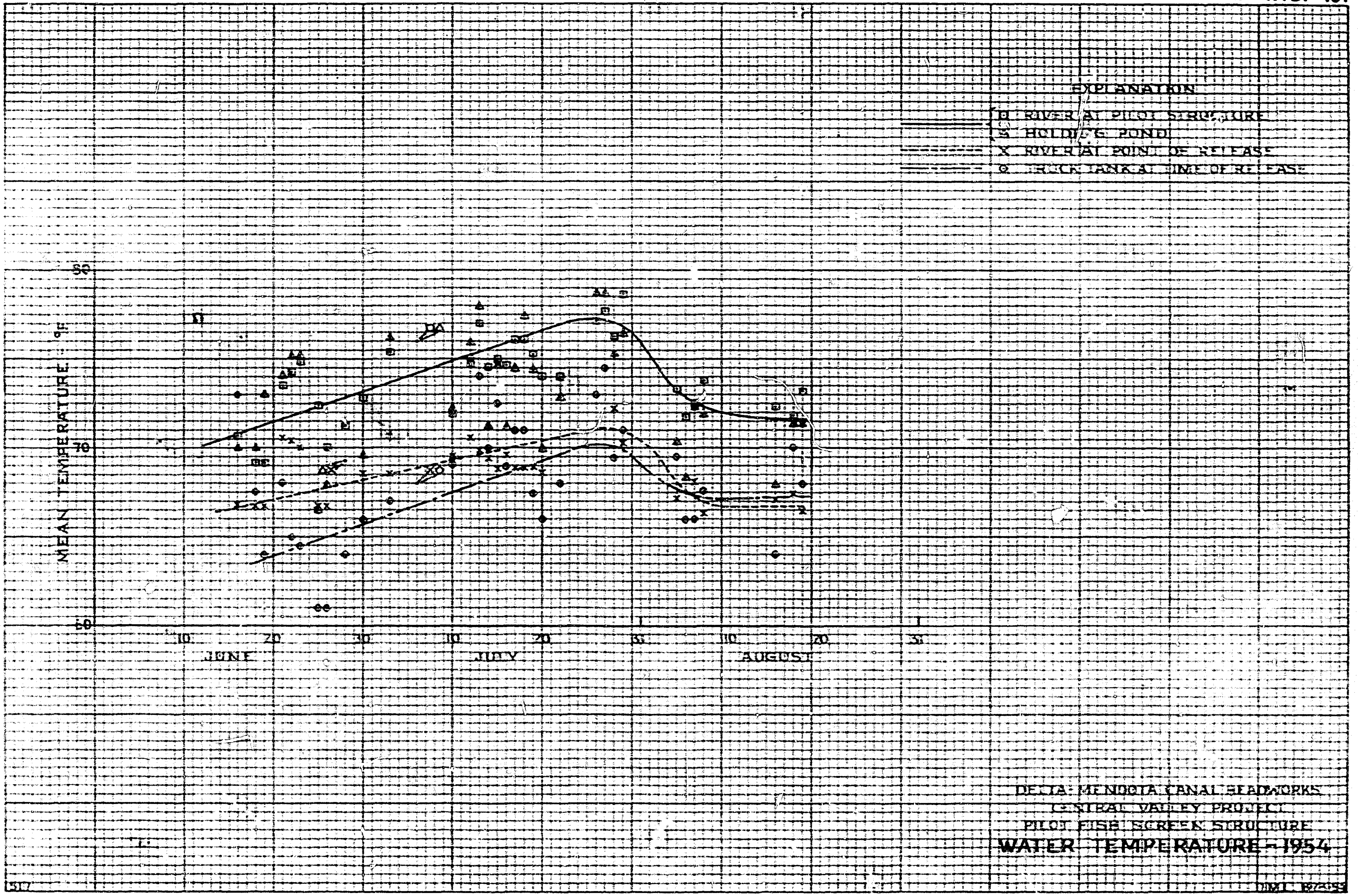


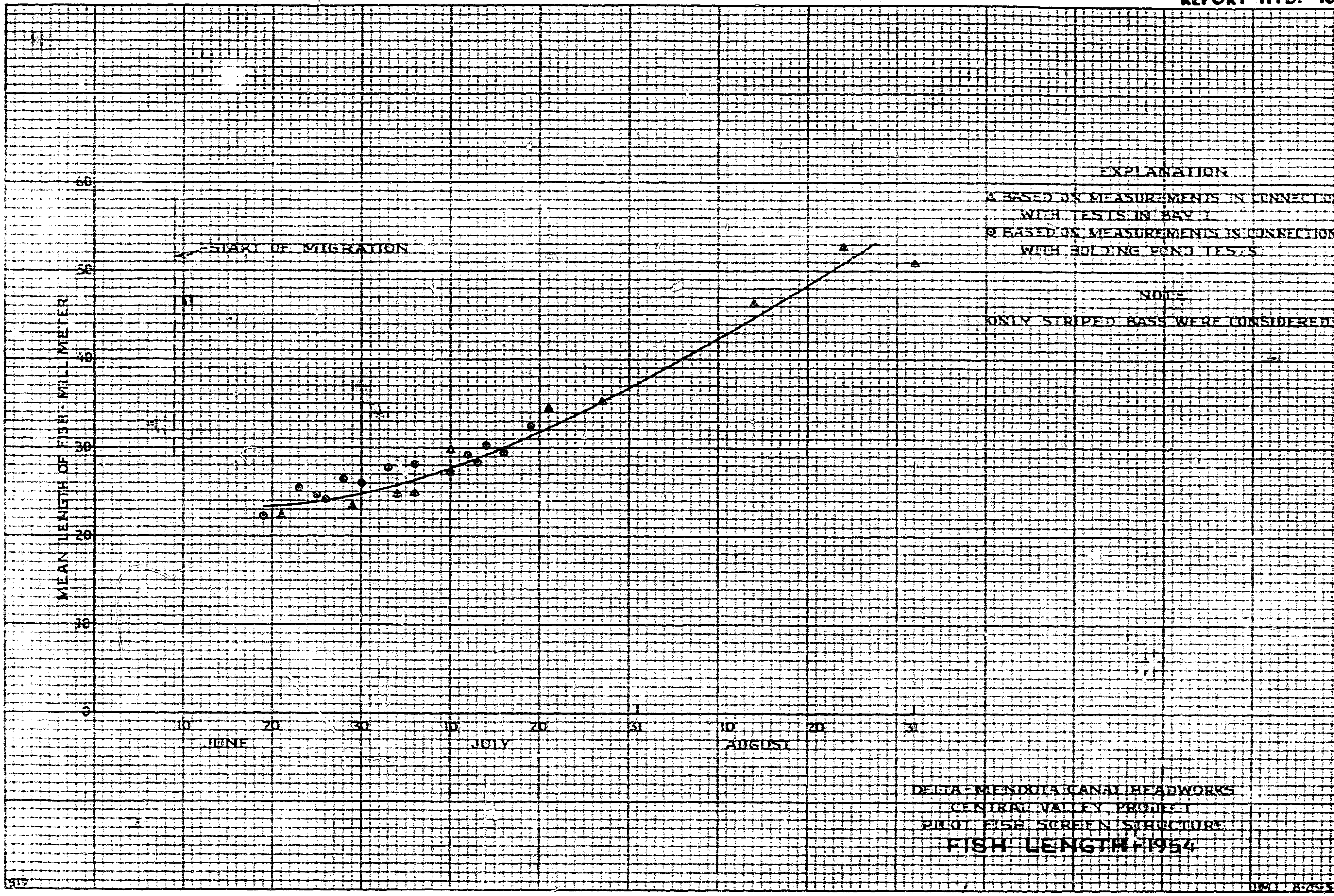
FIGURE 10
REPORT HYD. 401

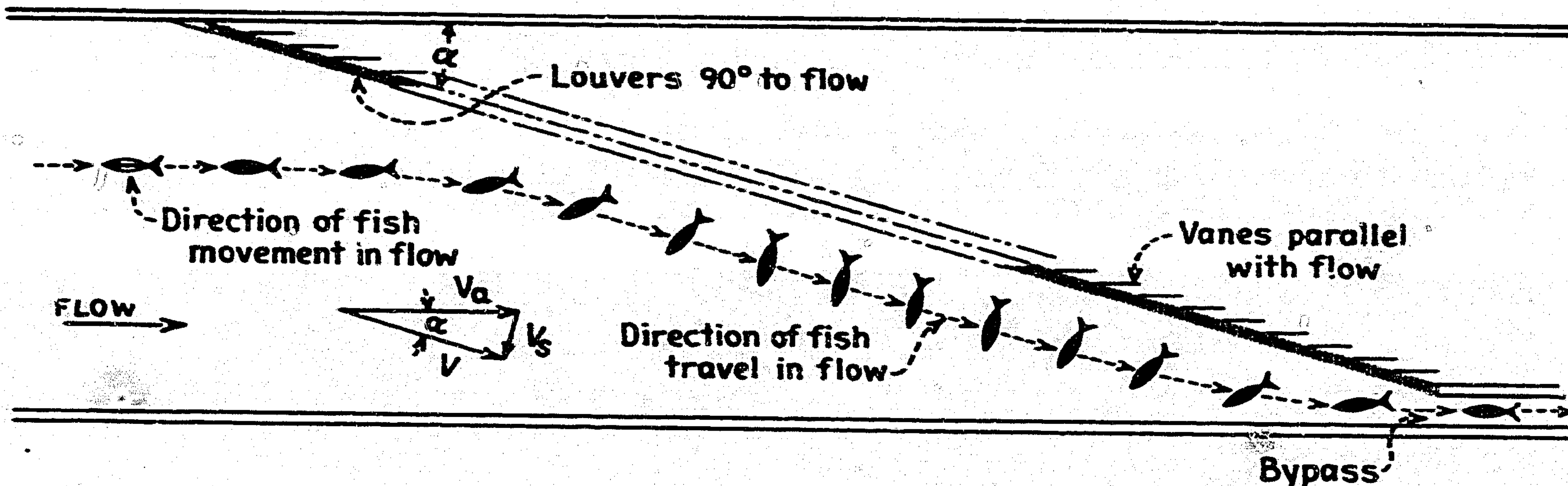


DELTA-MENDOTA CANAL HEADWORKS
CENTRAL VALLEY PROJECT
PILOT FISH SCREEN STRUCTURE
NUMBER OF FISH HAULED IN 1954

FIGURE 11
REPORT HYD. 401




MEAN LENGTH OF FISH-MILLIMETERS
0
10
20
30
40
50
60
START OF MIGRATION
10
20
30
JUNE
10
20
31
JULY
10
20
31
AUGUST
EXPLANATION
▲ BASED ON MEASUREMENTS IN CONNECTION WITH TESTS IN BAY 1
⊙ BASED ON MEASUREMENTS IN CONNECTION WITH HOLDING POND TESTS
NOTE
ONLY STRIPED BASS WERE CONSIDERED
DELTA-MENDOTA CANAL HEADWORKS
CENTRAL VALLEY PROJECT
PILOT FISH SCREEN STRUCTURE
FISH LENGTH-1954

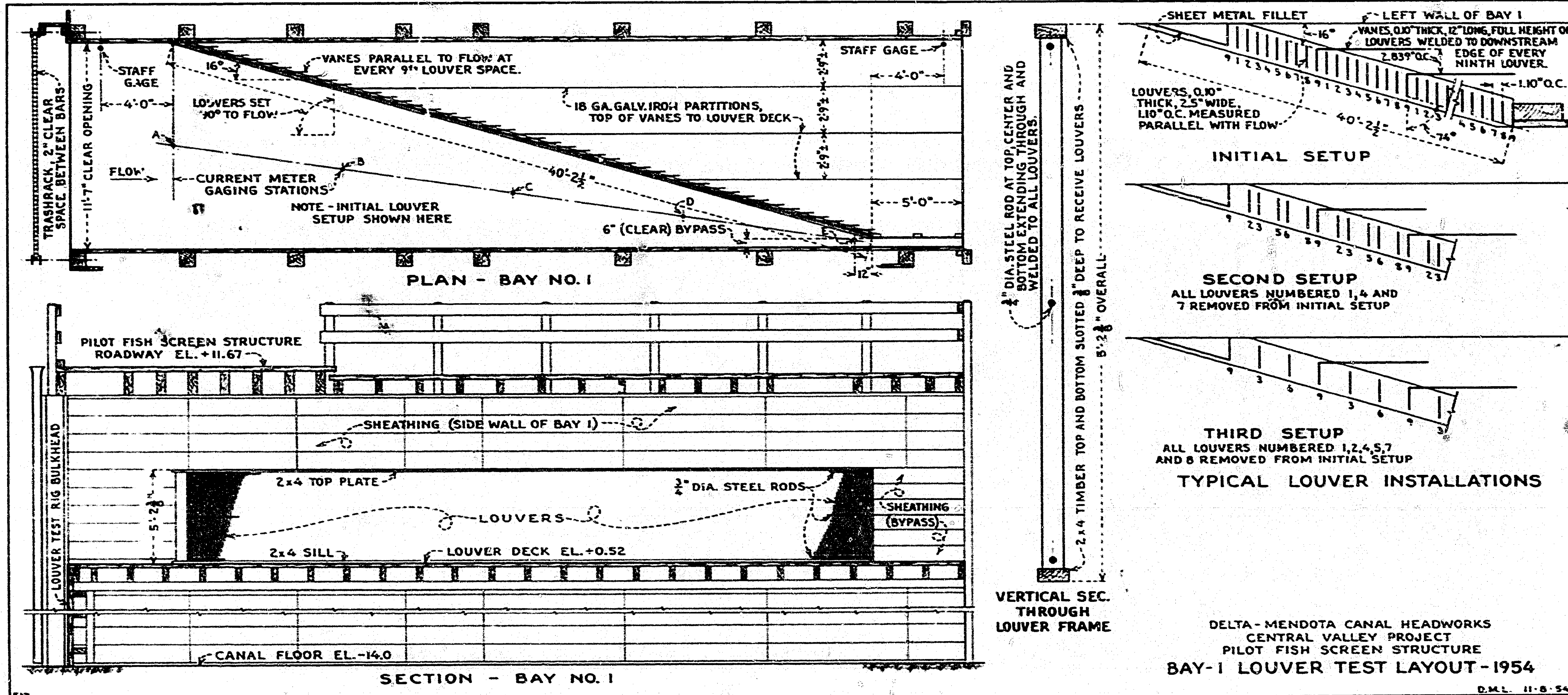


DELTA-MENDOTA CANAL HEADWORKS
CENTRAL VALLEY PROJECT
PILOT FISH SCREEN STRUCTURE-1954
REACTION OF FISH TO LINE OF LOUVERS

517

D.M.L.

FIGURE 13
REPORT HYD. 401



DELTA-MENDOTA CANAL HEADWORKS
CENTRAL VALLEY PROJECT
PILOT FISH SCREEN STRUCTURE

BAY-1 LOUVER TEST LAYOUT-1954

D.M.L. 11-8-54

FIGURE 15
REPORT HYD. 401

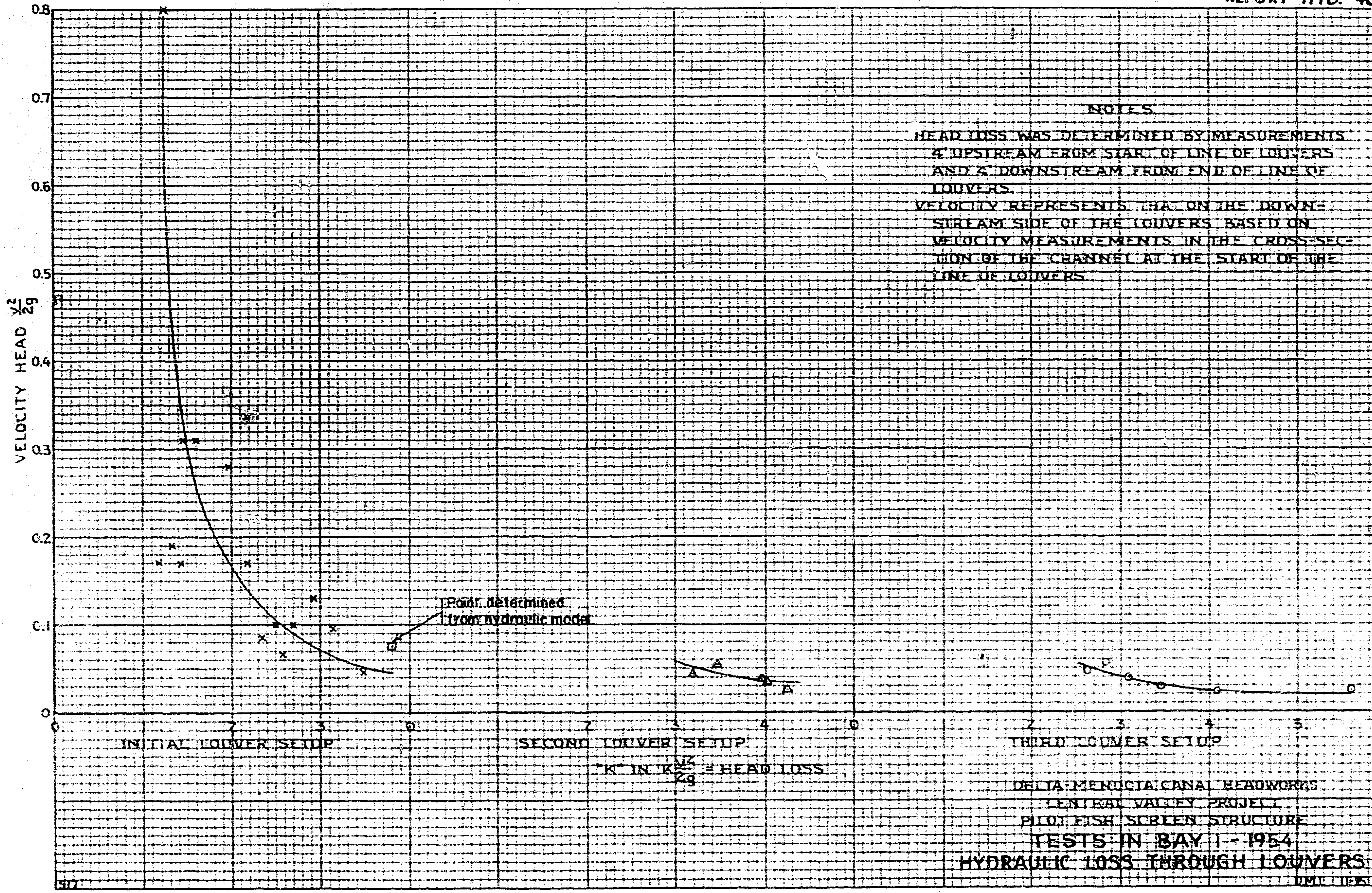
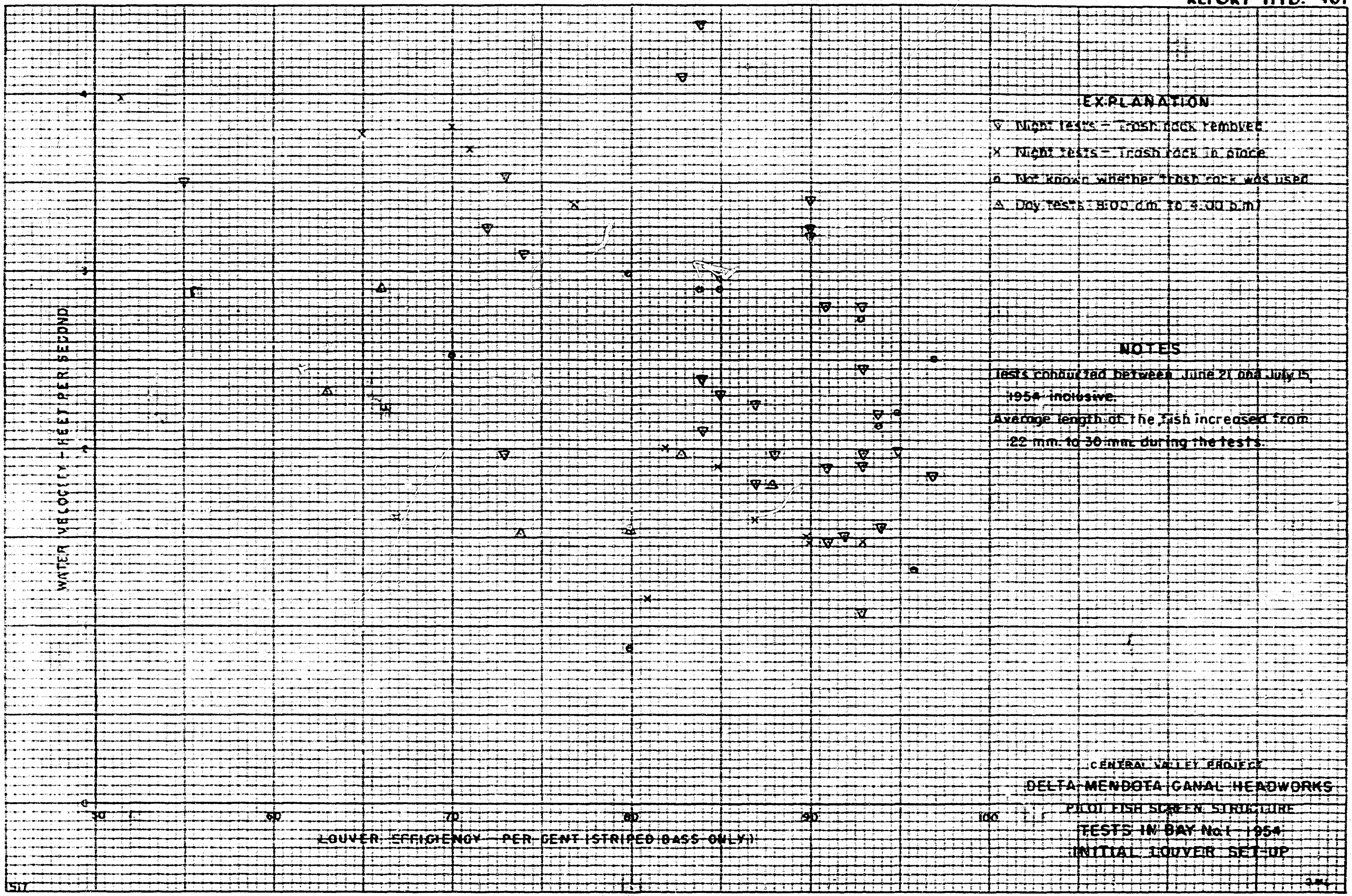
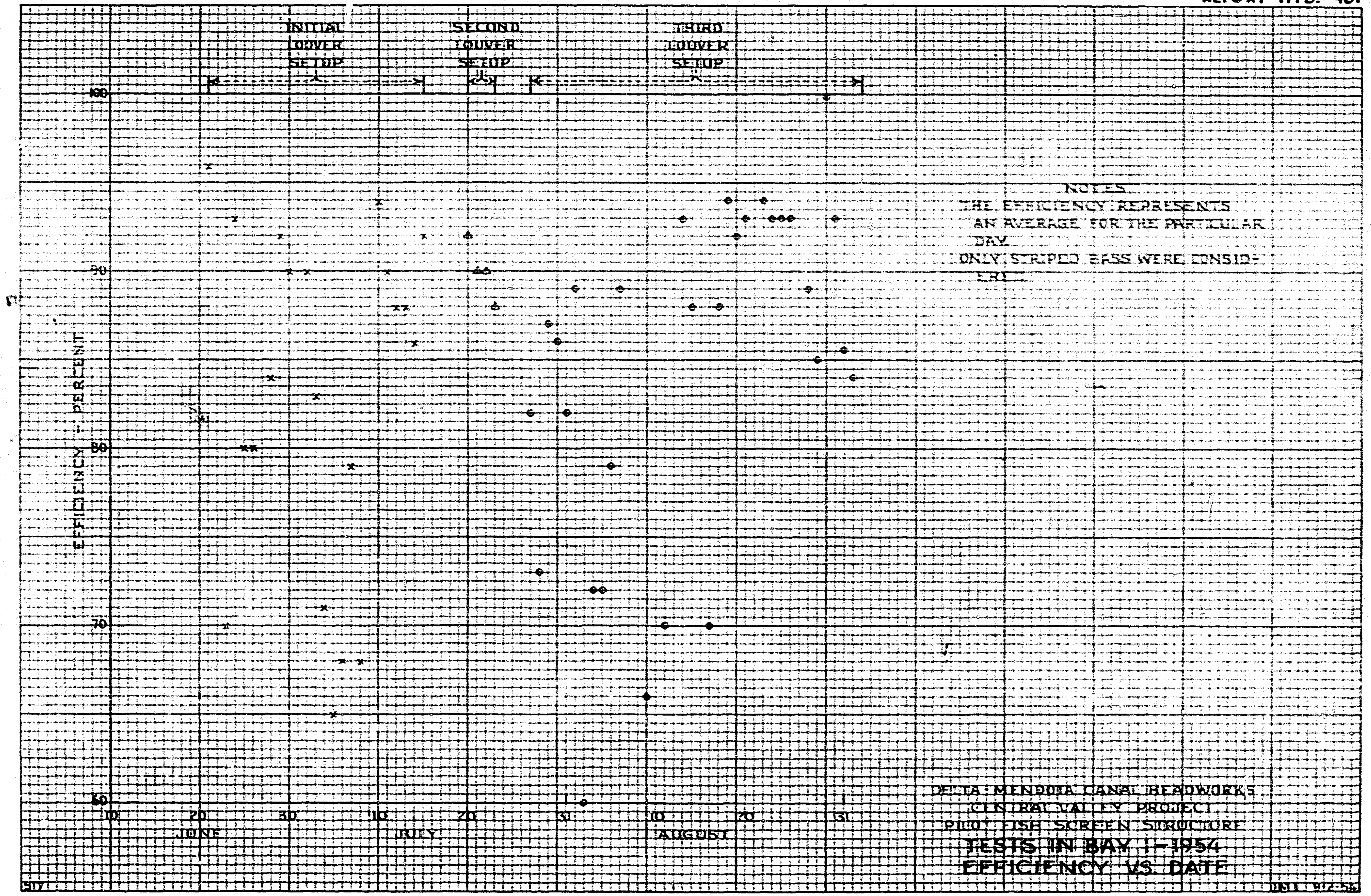
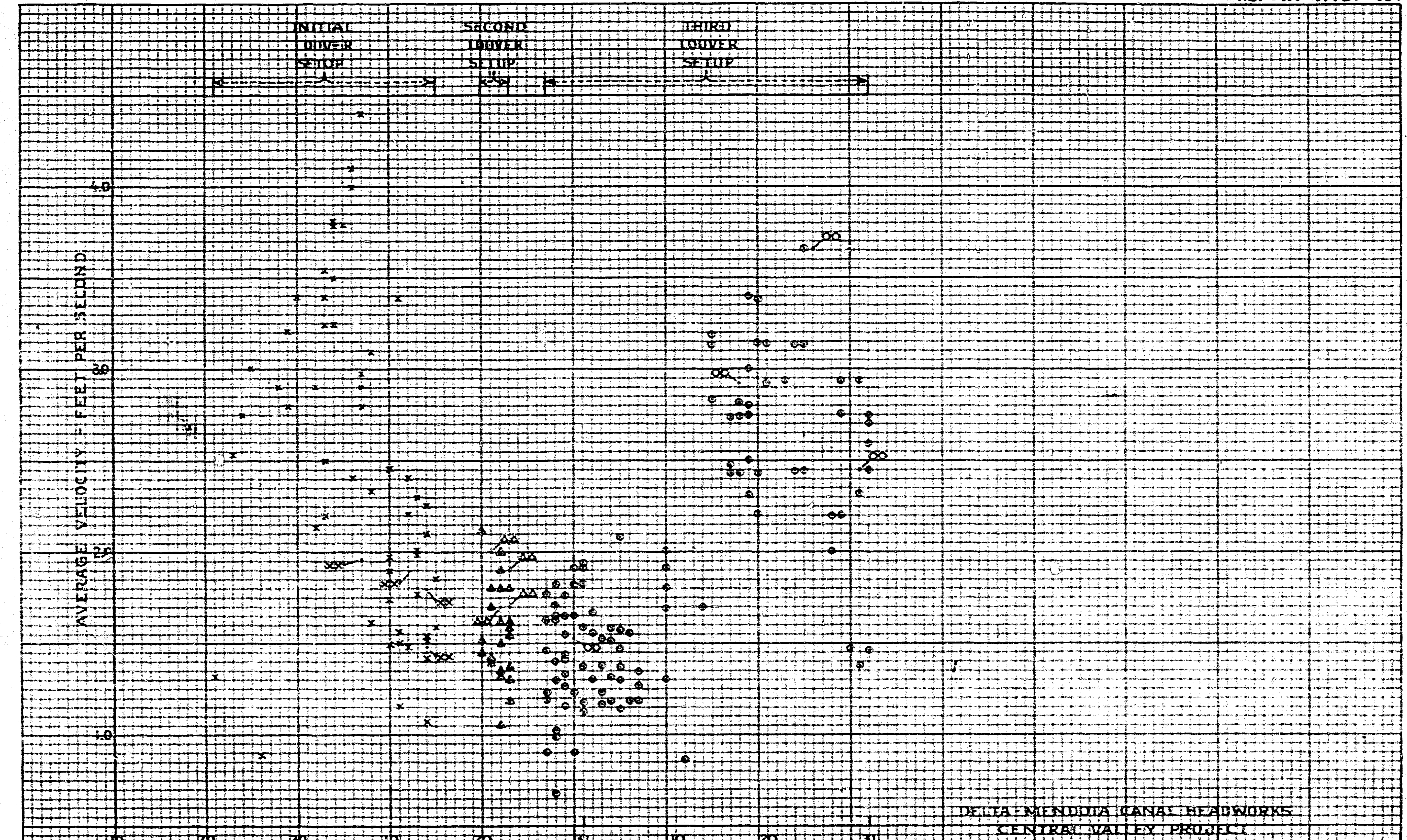


FIGURE 16
REPORT HYD. 401

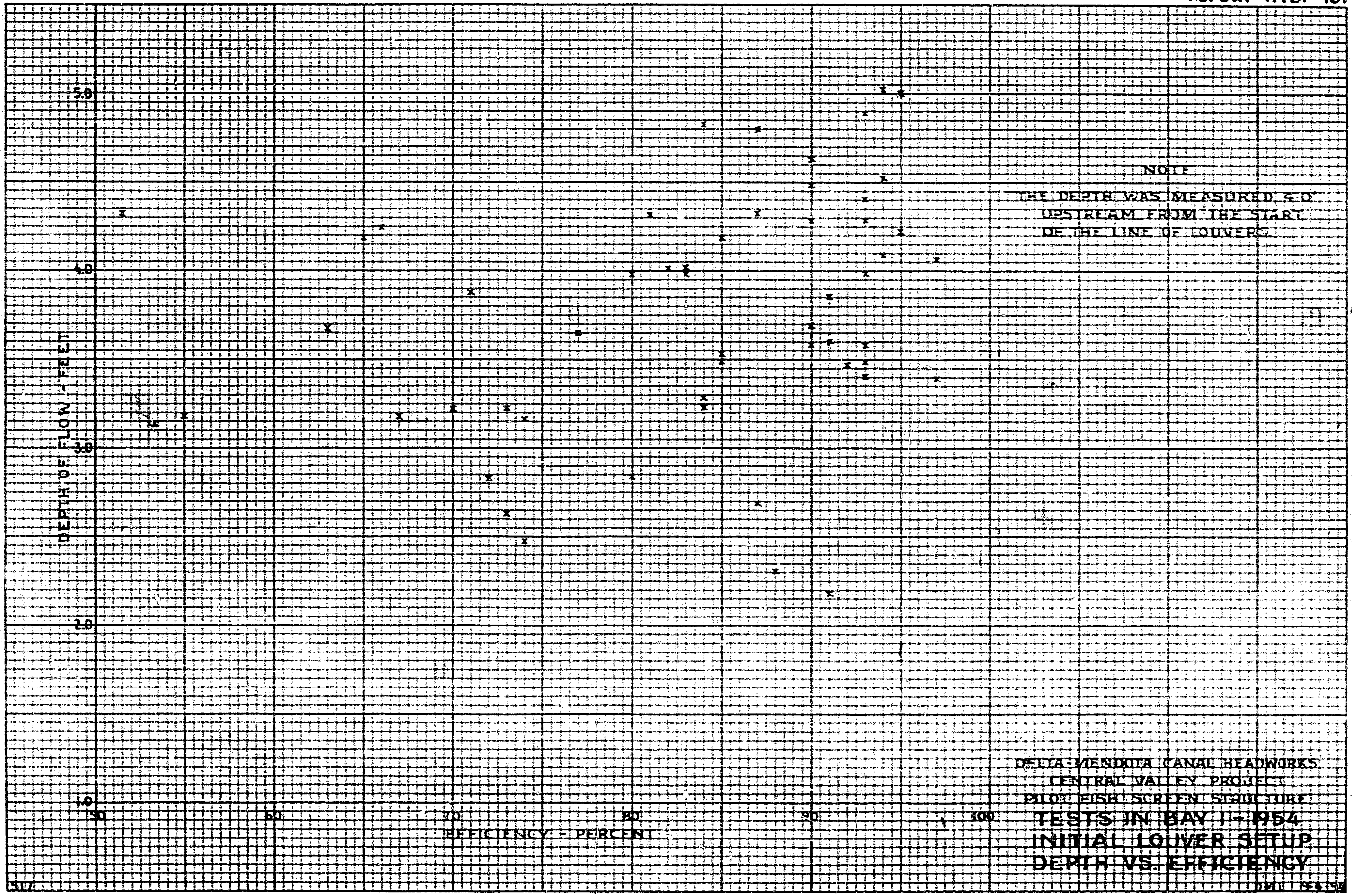


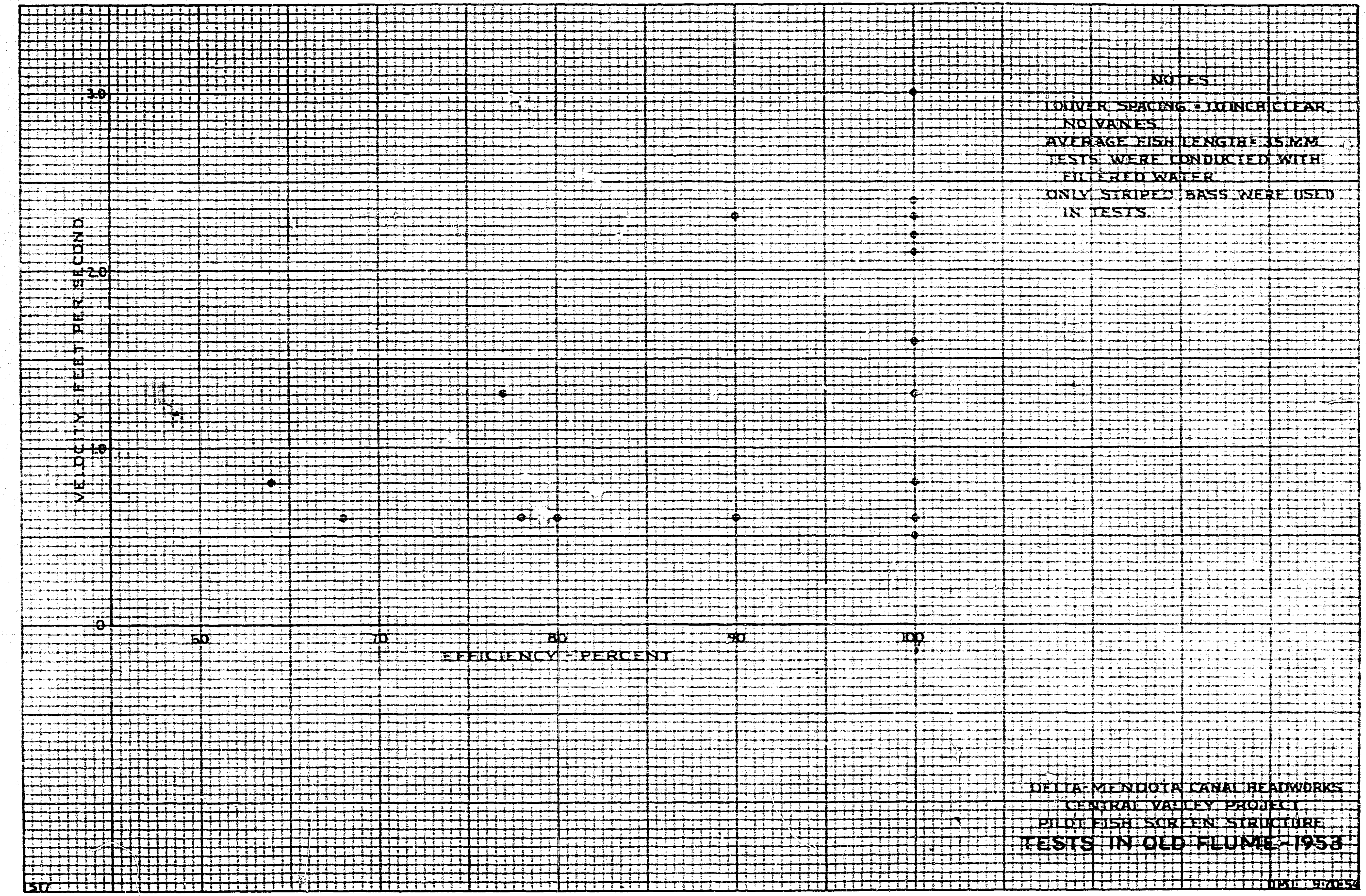
CENTRAL VALLEY PROJECT
DELTA-MENDOTA CANAL HEADWORKS
PILOT FISH SCREEN STRUCTURE
TESTS IN BAY No. 1 - 1954
INITIAL LOUVER SET-UP

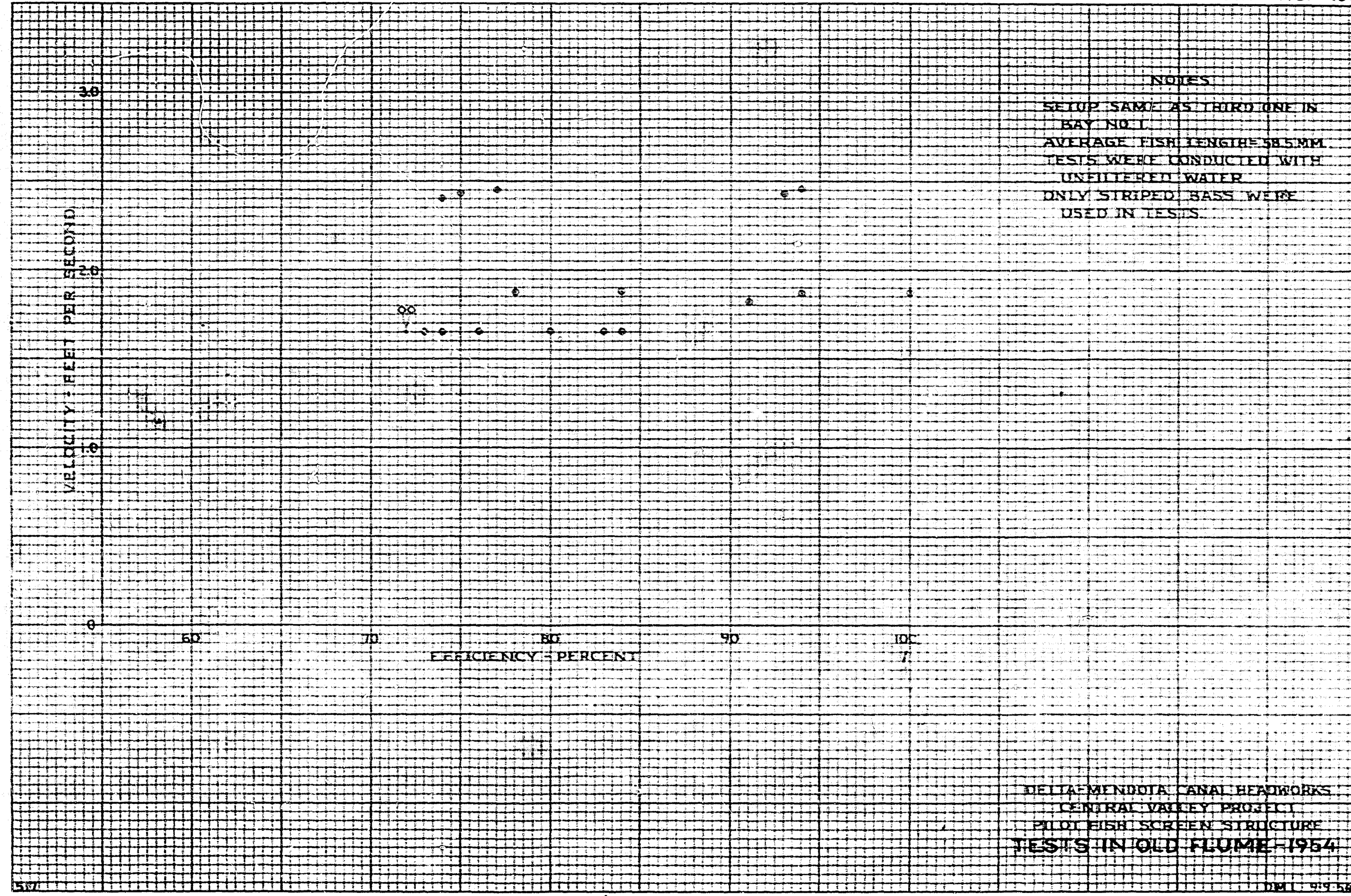

INITIAL LOUVER SETUP
SECOND LOUVER SETUP
THIRD LOUVER SETUP
100
90
80
70
60
EFFICIENCY - PERCENT
10
20
30
10
20
31
10
20
31
JUNE
JULY
AUGUST
NOTES
THE EFFICIENCY REPRESENTS AN AVERAGE FOR THE PARTICULAR DAY.
ONLY STRIPED BASS WERE CONSIDERED.
DELTA-MENDOTA CANAL HEADWORKS
CENTRAL VALLEY PROJECT
PILOT FISH SCREEN STRUCTURE
TESTS IN BAY 1-1954
EFFICIENCY VS. DATE



DELTA-MENDOTA CANAL HEADWORKS
CENTRAL VALLEY PROJECT
PILOT FISH SCREEN STRUCTURE
TESTS IN BAY 1 - 1954
VELOCITY VS. DATE


DEPTH OF FLOW - FEET
5.0
4.0
3.0
2.0
1.0
50
60
70
80
90
100
EFFICIENCY - PERCENT
NOTE
THE DEPTH WAS MEASURED 4'-0"
UPSTREAM FROM THE START
OF THE LINE OF LOUVERS
DELTA-MENDOTA CANAL HEADWORKS
CENTRAL VALLEY PROJECT
PILOT FISH SCREEN STRUCTURE
TESTS IN BAY 1 - 1954
INITIAL LOUVER SETUP
DEPTH VS. EFFICIENCY


NOTES
LOUVER SPACING = 1.0 INCH CLEAR, NO VANES
AVERAGE FISH LENGTH = 35 MM.
TESTS WERE CONDUCTED WITH FILTERED WATER.
ONLY STRIPED BASS WERE USED IN TESTS.
VELOCITY - FEET PER SECOND
3.0
2.0
1.0
0
60
70
80
90
100
EFFICIENCY - PERCENT
DELTA-MENDOTA CANAL HEADWORKS
CENTRAL VALLEY PROJECT
PILOT FISH SCREEN STRUCTURE
TESTS IN OLD FLUME - 1953



DELTA-MENDOTA CANAL HEADWORKS
CENTRAL VALLEY PROJECT
PILOT FISH SCREEN STRUCTURE
TESTS IN OLD FLUME-1954

FIGURE 22
REPORT HYD. 401

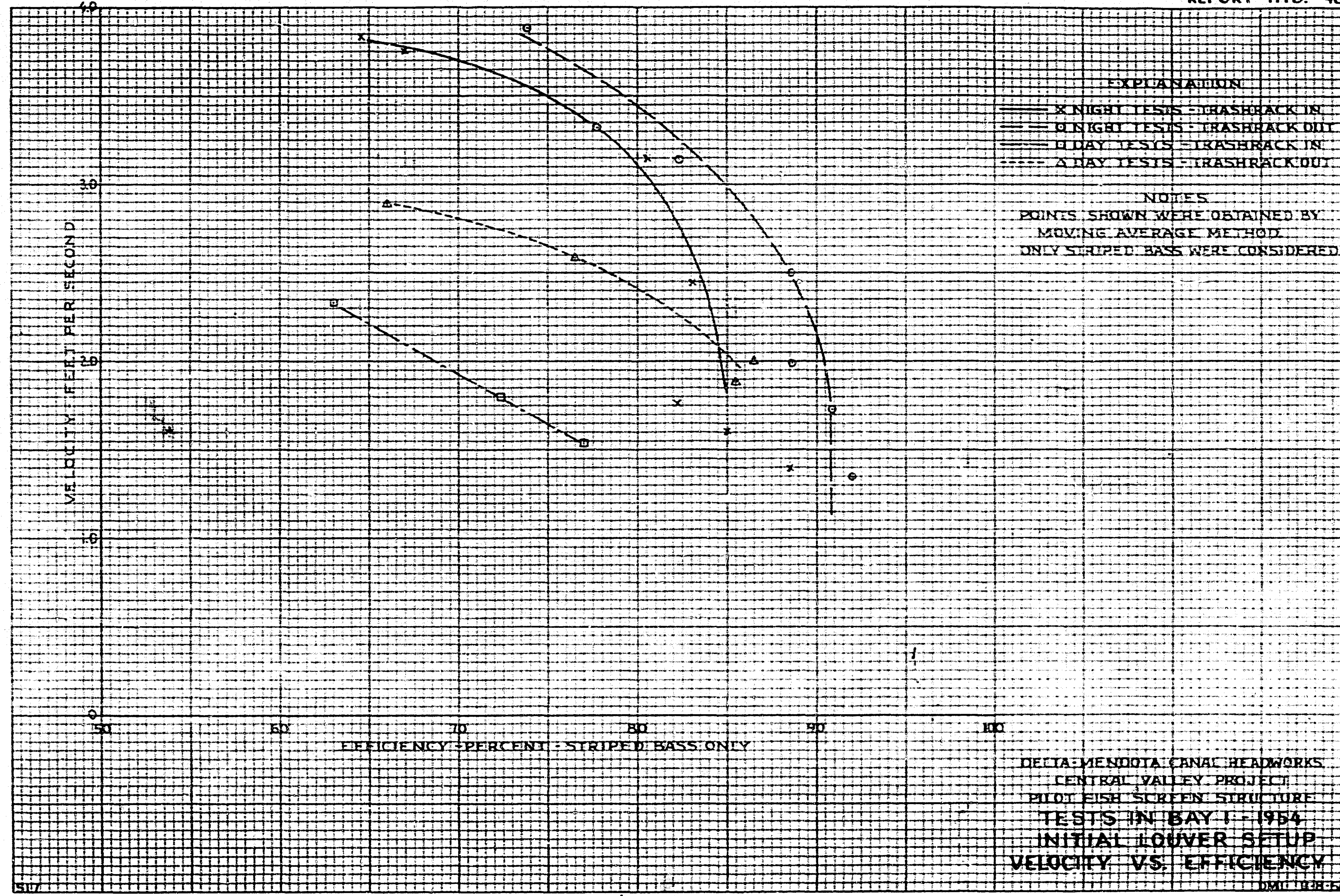


FIGURE 23
REPORT HYD. 401

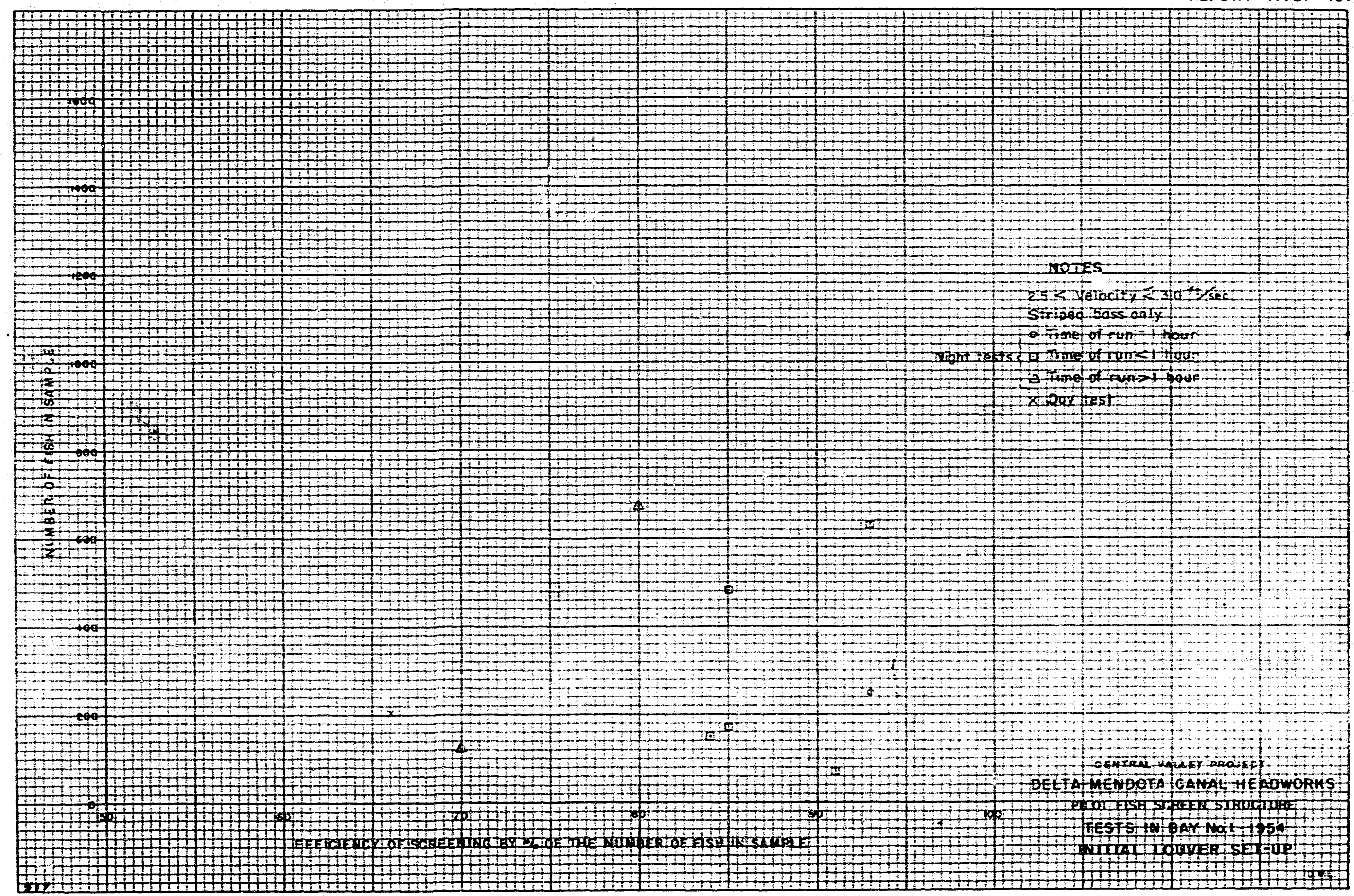
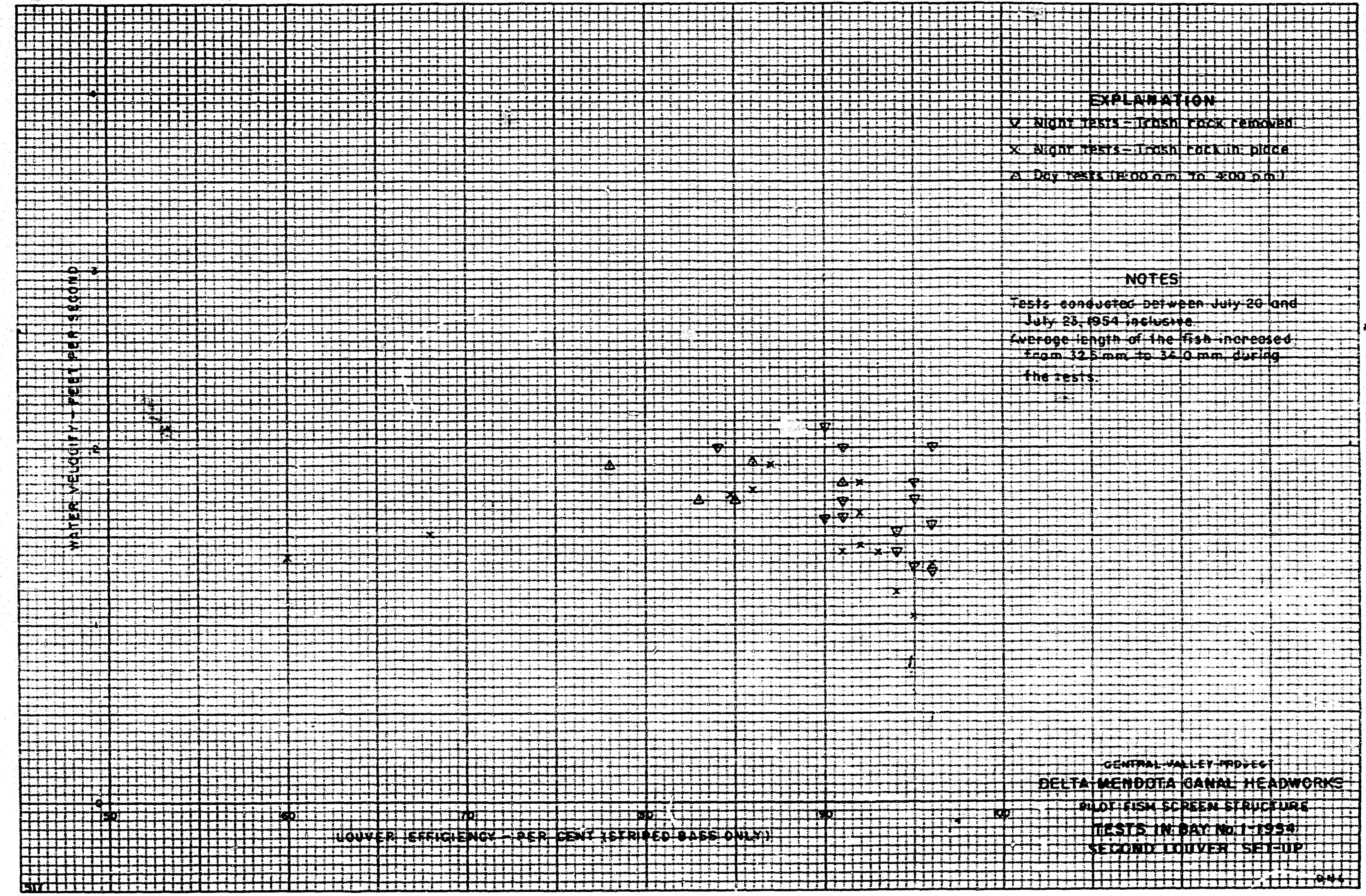
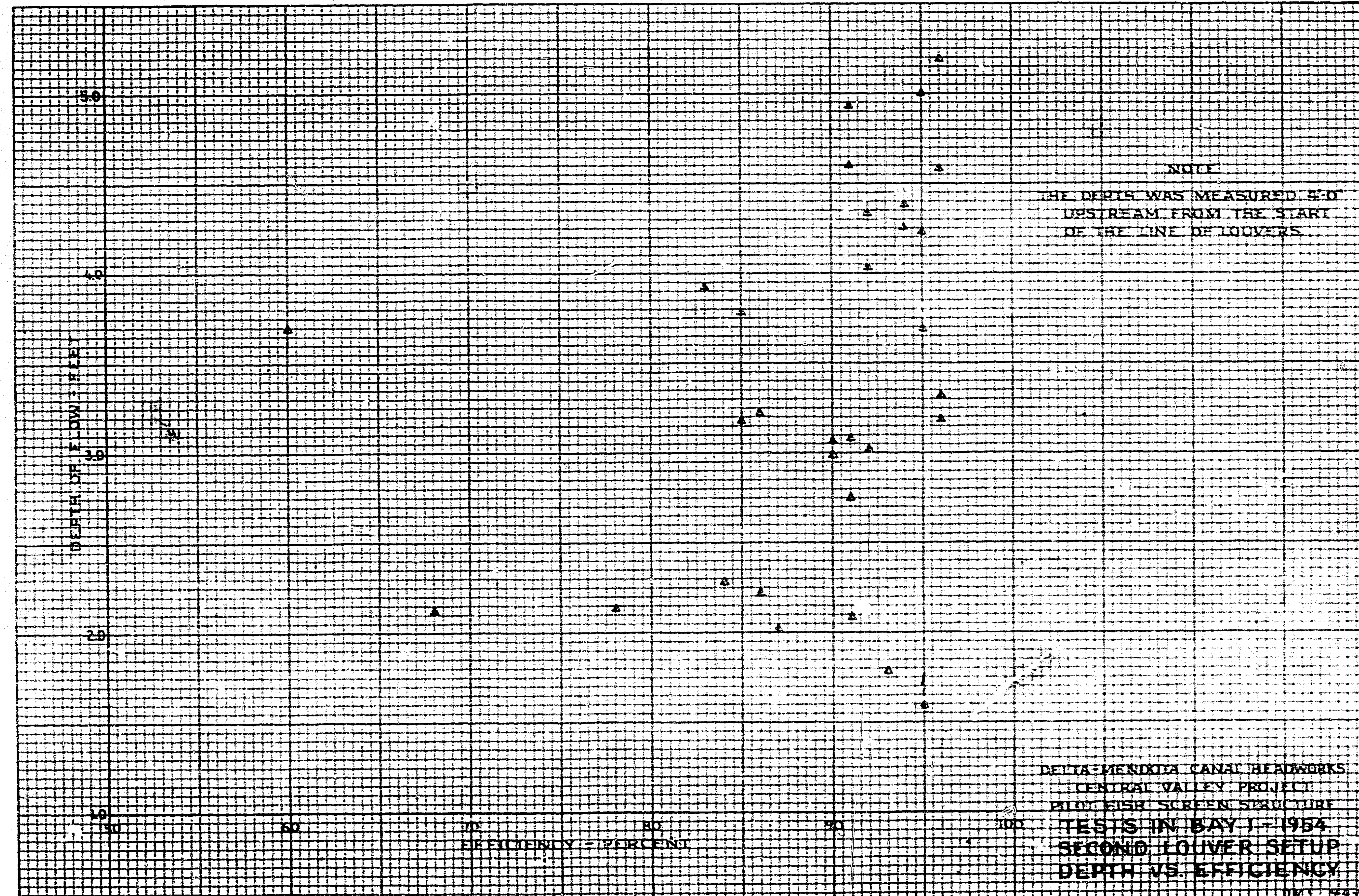


FIGURE 24
REPORT HYD. 401





DELTA-MENDOTA CANAL HEADWORKS
CENTRAL VALLEY PROJECT
PILOT FISH SCREEN STRUCTURE
TESTS IN BAY I - 1954
SECOND LOUVER SETUP
DEPTH VS. EFFICIENCY

FIGURE 26
REPORT HYD. 401

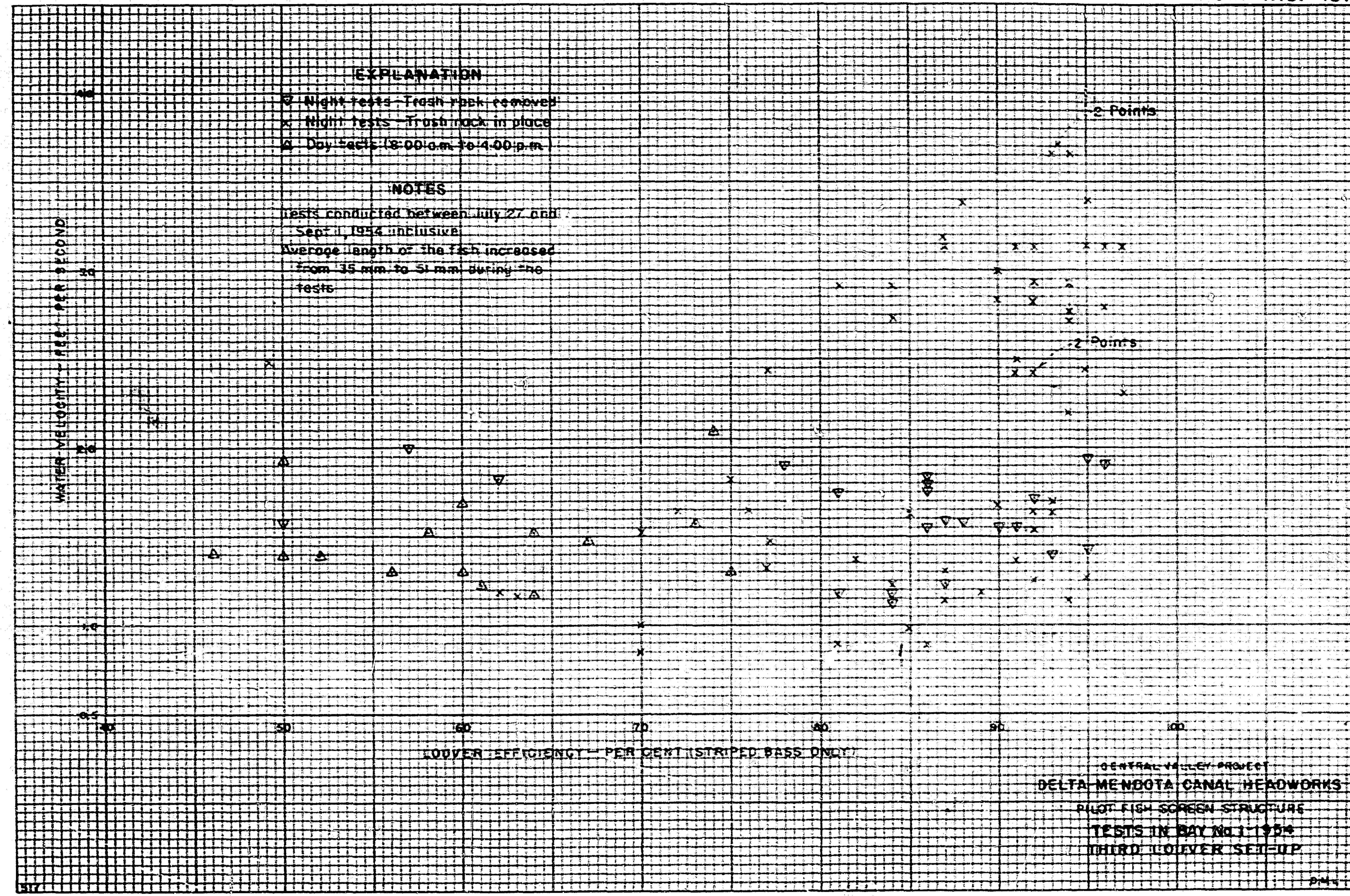
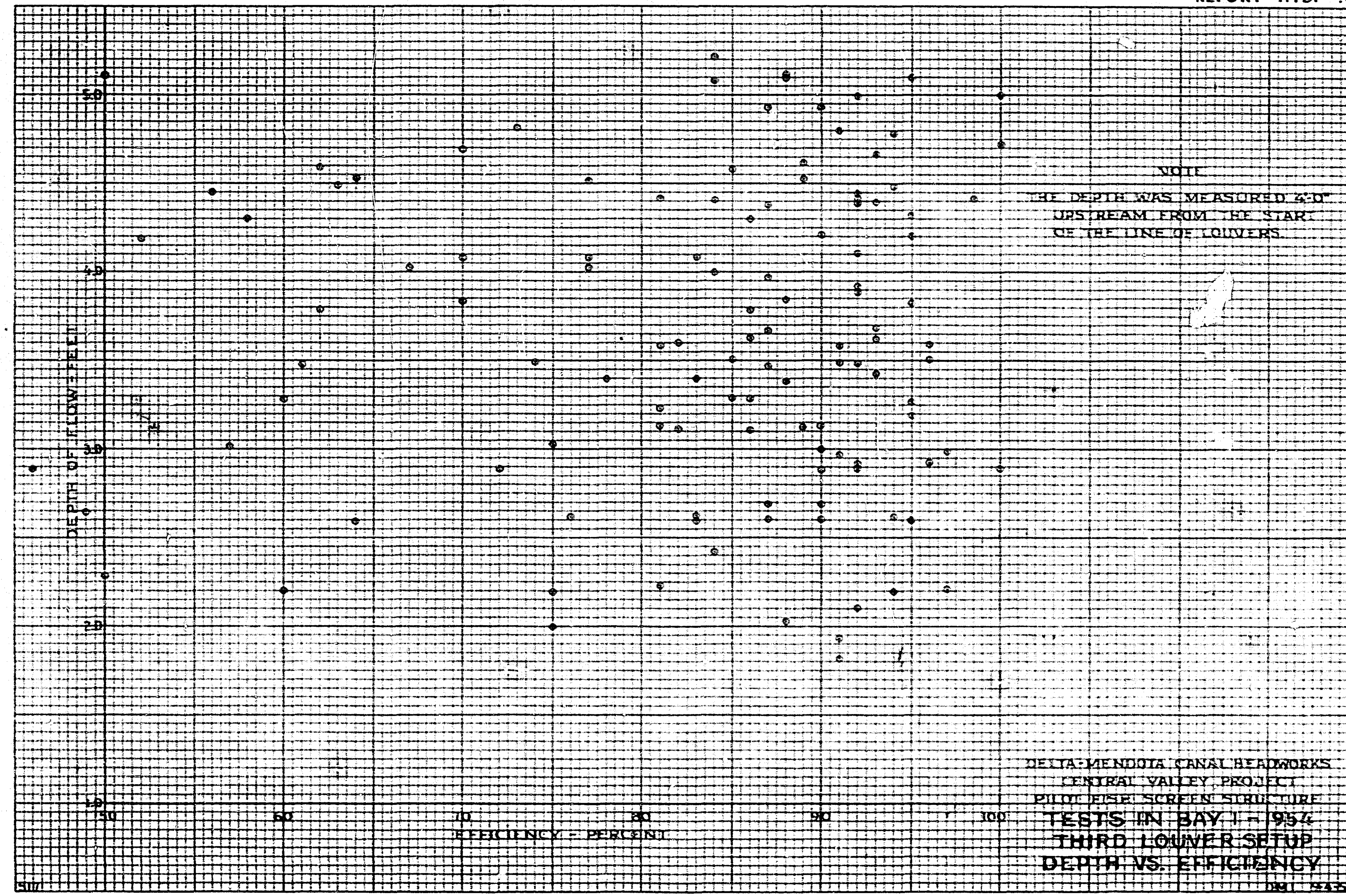
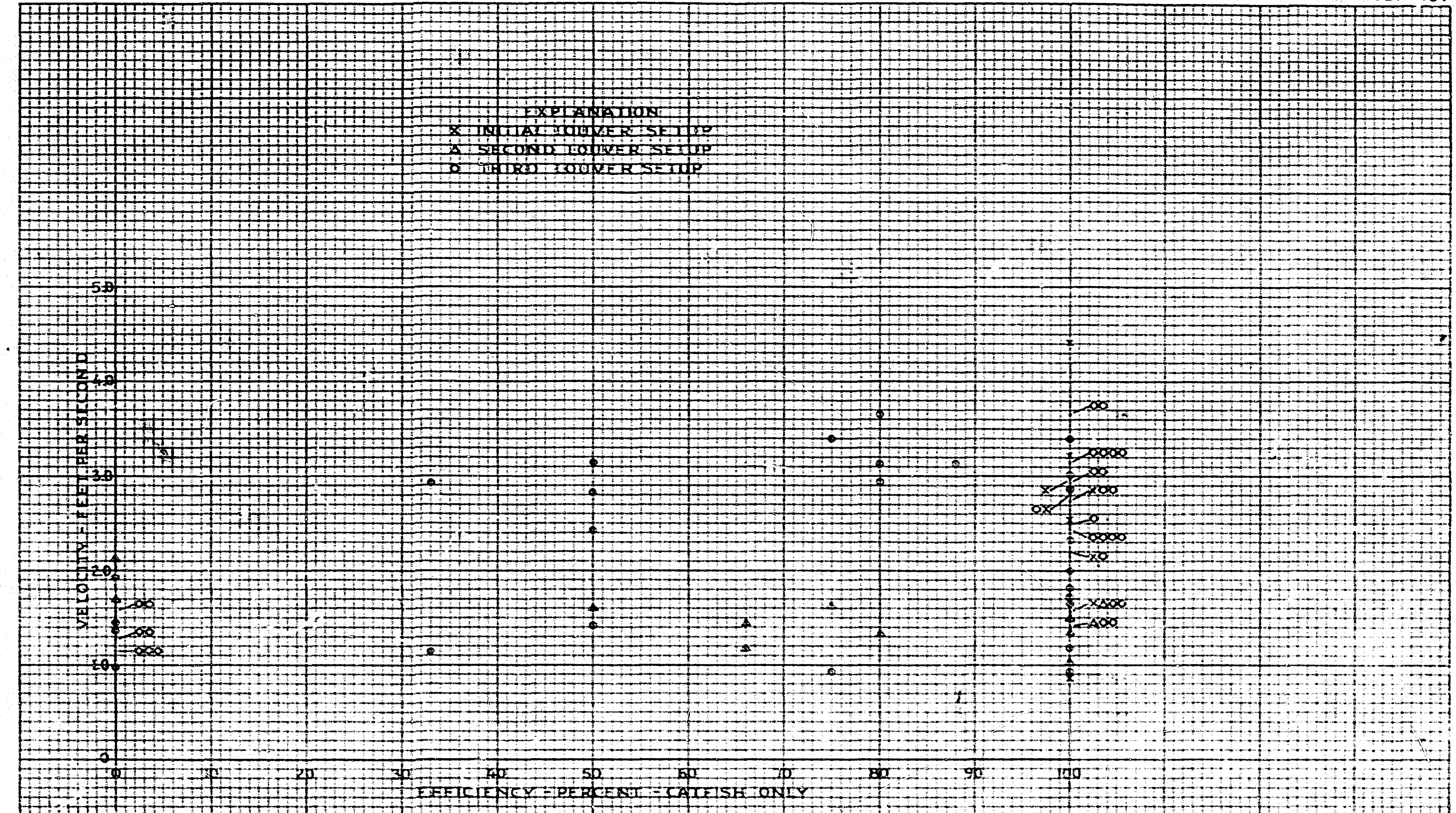
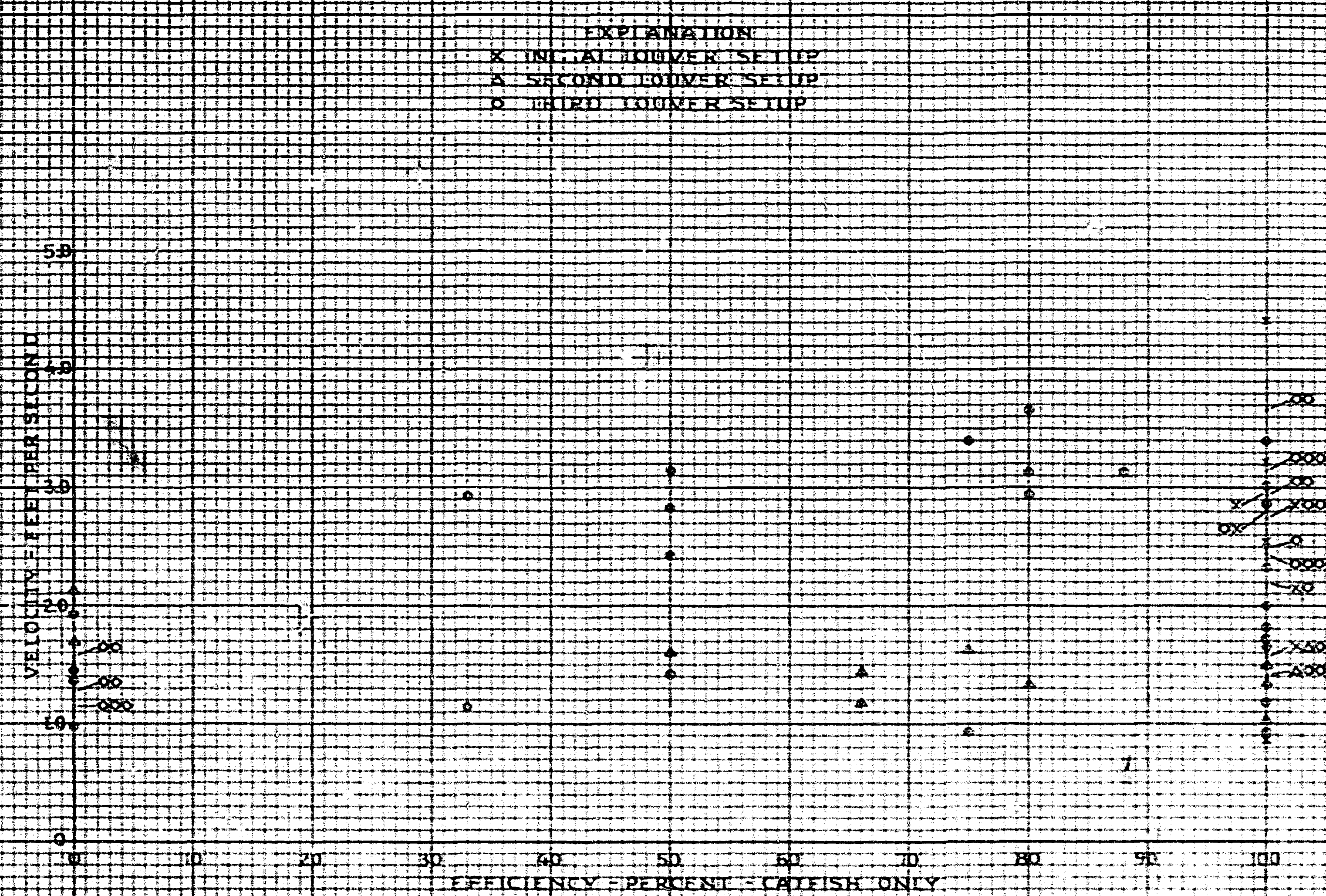


FIGURE 27
REPORT HYD. 401

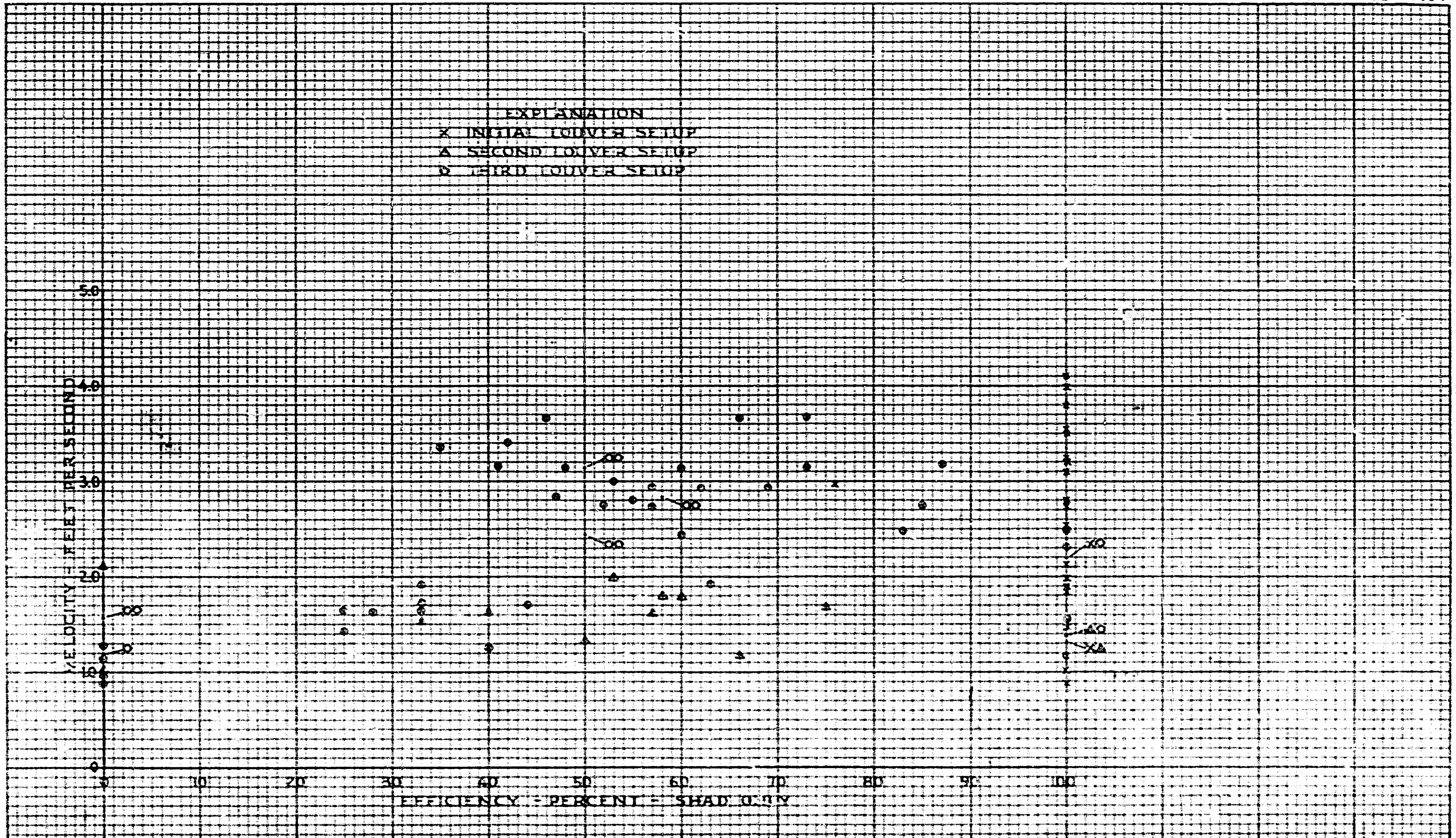




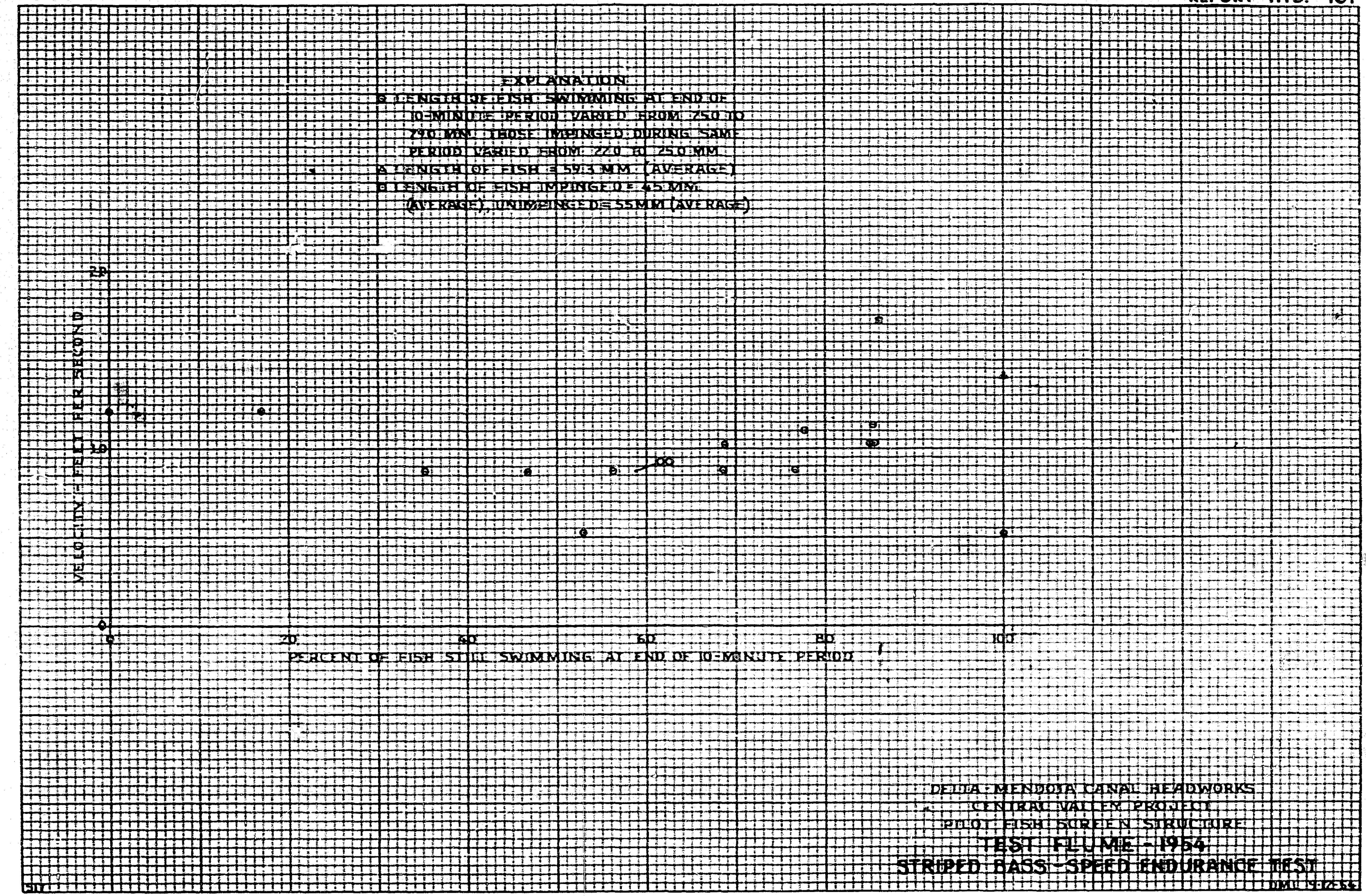
DELTA-MENDOTA CANAL HEADWORKS
CENTRAL VALLEY PROJECT
PILOT FISH SCREEN STRUCTURE
TESTS IN BAY 1 - 1954
LOUVER EFFICIENCY FOR CATFISH

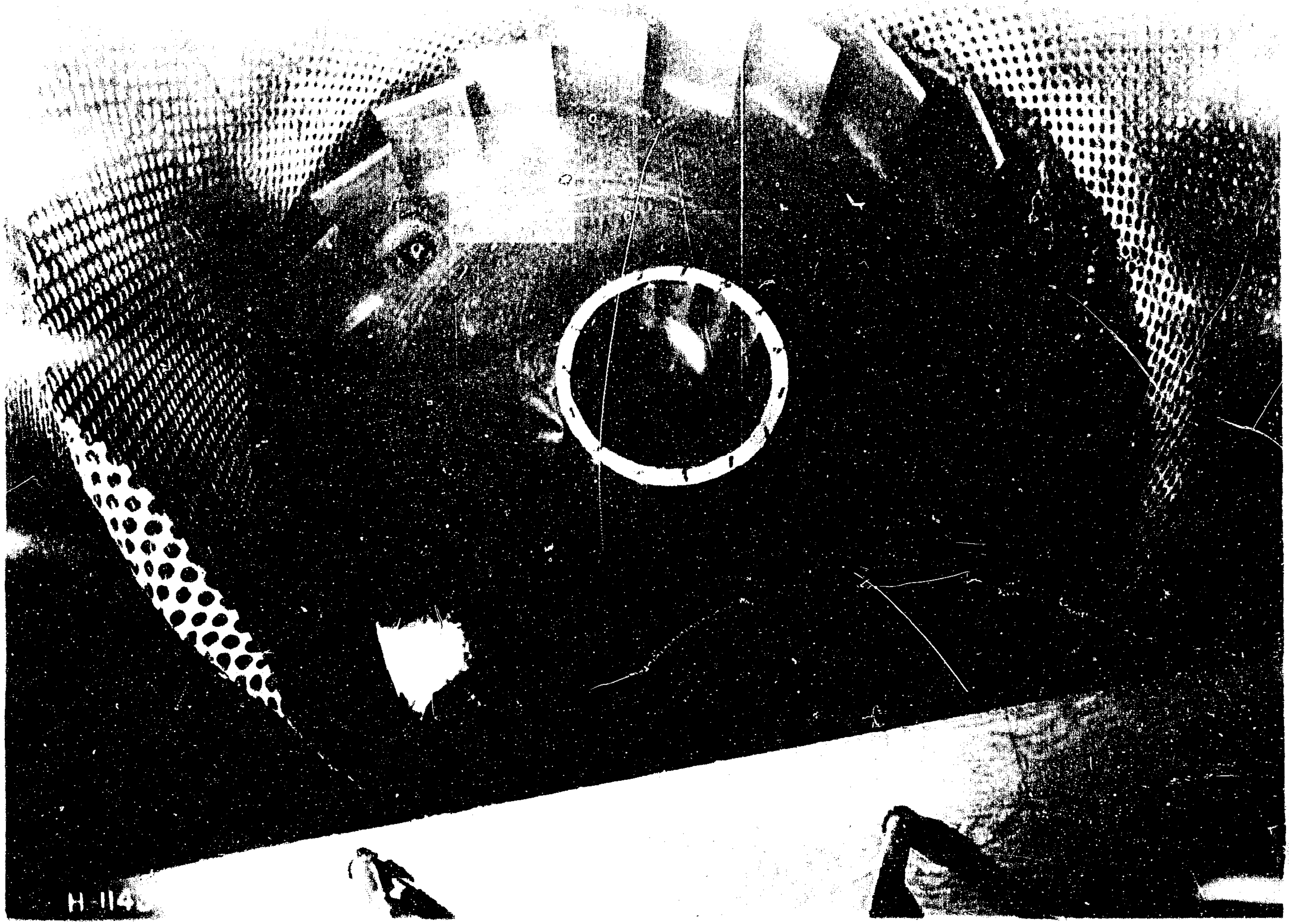


DELTA-MENDOTA CANAL HEADWORKS
CENTRAL VALLEY PROJECT
PILOT FISH SCREEN STRUCTURE
TESTS IN BAY 1 - 1954
LOUVER EFFICIENCY FOR CATFISH



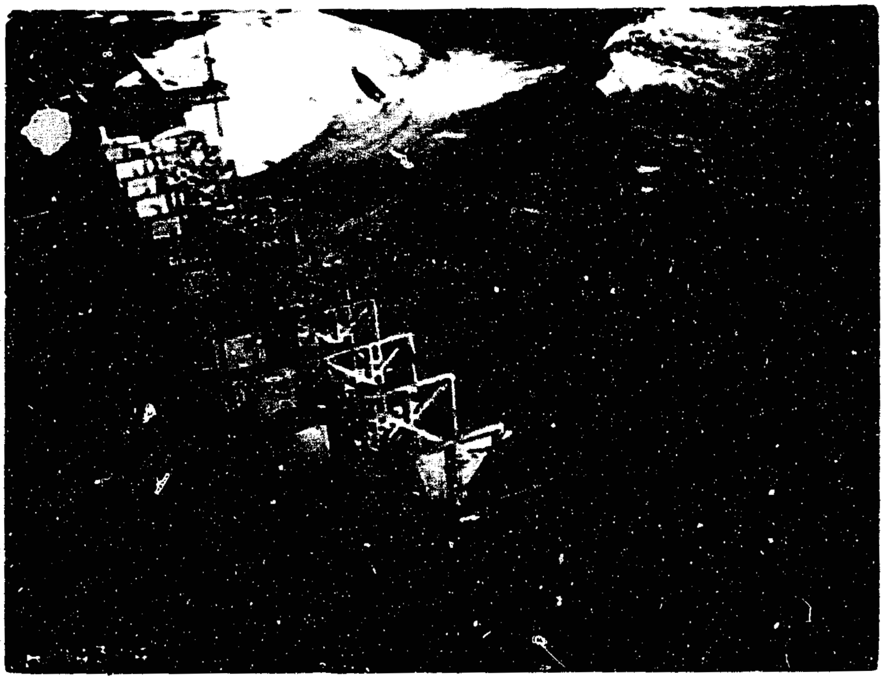
DELTA-MENDOTA CANAL HEADWORKS
CENTRAL VALLEY PROJECT
PILOT FISH SCREEN STRUCTURE
TESTS IN BAY 1 - 1954
LOUVER EFFICIENCY FOR SHAD


EXPLANATION
LENGTH OF FISH SWIMMING AT END OF 10-MINUTE PERIOD VARIED FROM 250 TO 290 MM. THOSE IMPINGED DURING SAME PERIOD VARIED FROM 220 TO 250 MM.
LENGTH OF FISH = 59.3 MM (AVERAGE)
LENGTH OF FISH IMPINGED = 45 MM. (AVERAGE), UNIMPINGED = 55 MM (AVERAGE)
2.0
1.0
VELOCITY - FEET PER SECOND
0
20
40
60
80
100
PERCENT OF FISH STILL SWIMMING AT END OF 10-MINUTE PERIOD
DELTA-MENDOTA CANAL HEADWORKS
CENTRAL VALLEY PROJECT
PILOT FISH SCREEN STRUCTURE
TEST FLUME - 1954
STRIPED BASS - SPEED ENDURANCE TEST

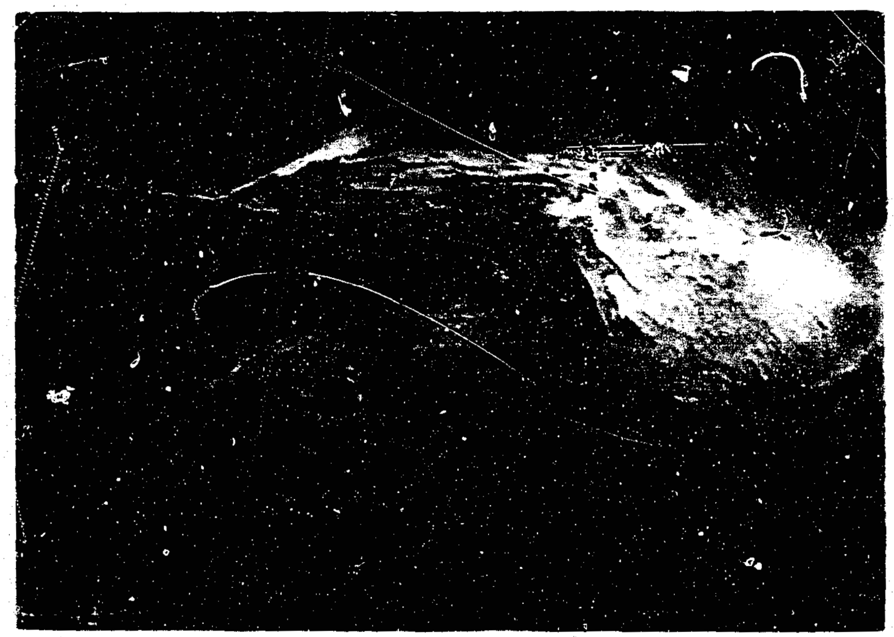


Circular Device to Simulate Line-of-Louvers
Delta-Mendota Canal Headworks

1:15 Scale Model - Pilot Canal and Pilot Fish Screen Structure, Delta-Mendota Canal Headworks.

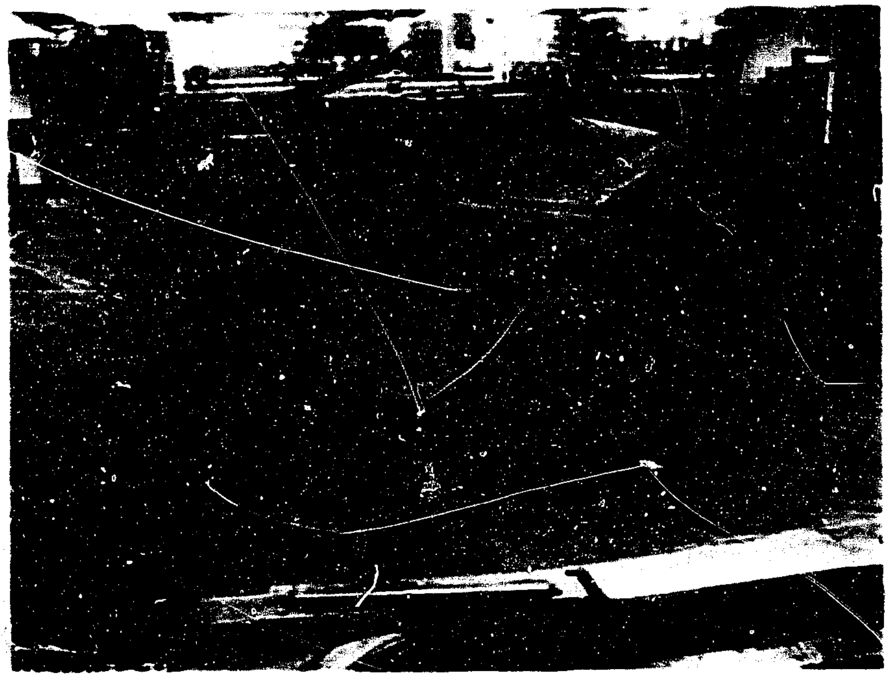


Erosion on Upstream Side of Pilot Fish Screen Structure after One Hour Operation at 3,800 cfs.



Erosion Along Right Bank Downstream From Fish Screen Structure After One Hour Operation at 3,800 cfs.

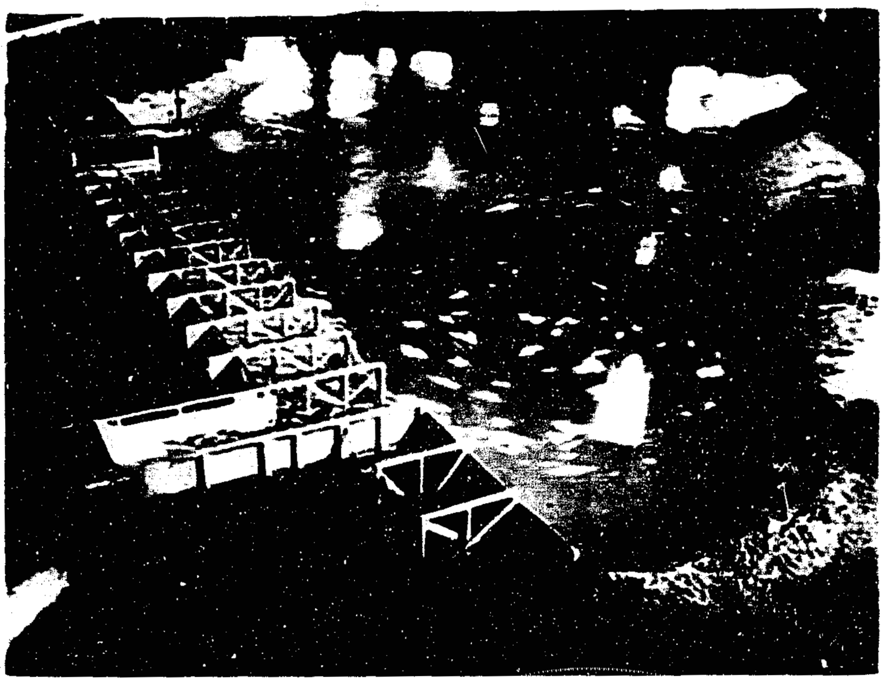
DELTA-MENDOTA CANAL HEADWORKS
PILOT FISH SCREEN STUDIES
CHANNEL REALIGNMENT
EXISTING CHANNEL



A - CHANNEL REVISION NO. 1.
White Cord Shows Outline of Existing Channel.

B - CHANNEL REVISION NO. 2.

DELTA-MENDOTA CANAL HEADWORKS
PILOT FISH SCREEN STUDIES
CHANNEL REALIGNMENT

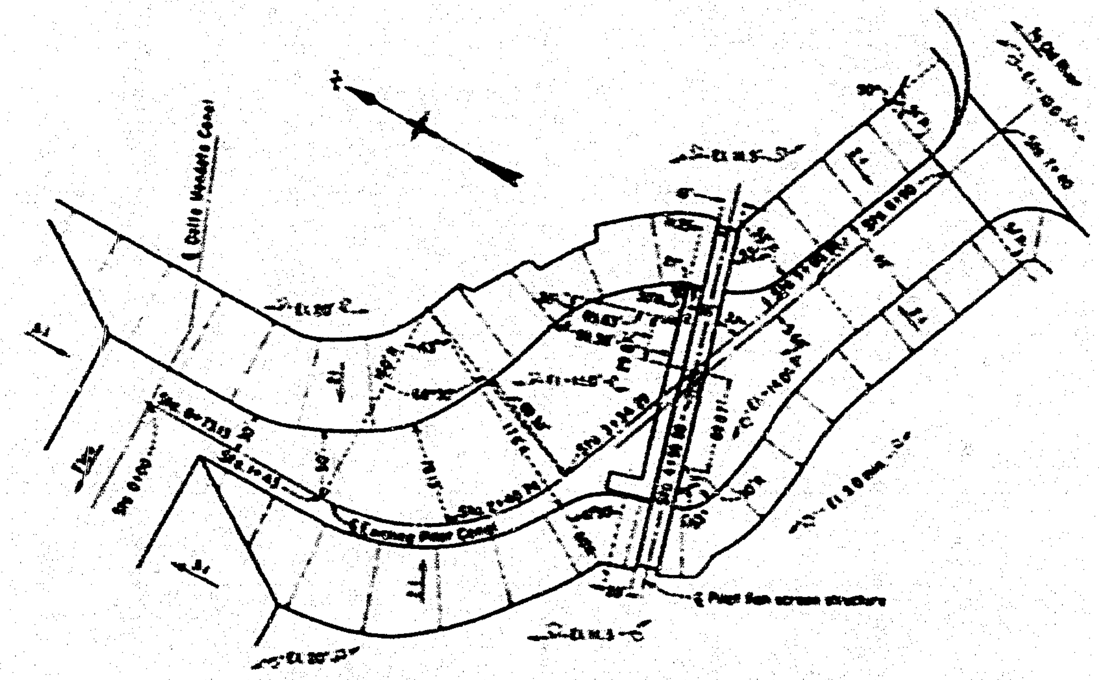


A - Flow Appearance Upstream from Fish Screen Structure - Channel Modification No. 1. Discharge - 4,600 cfs at Mean Tide.

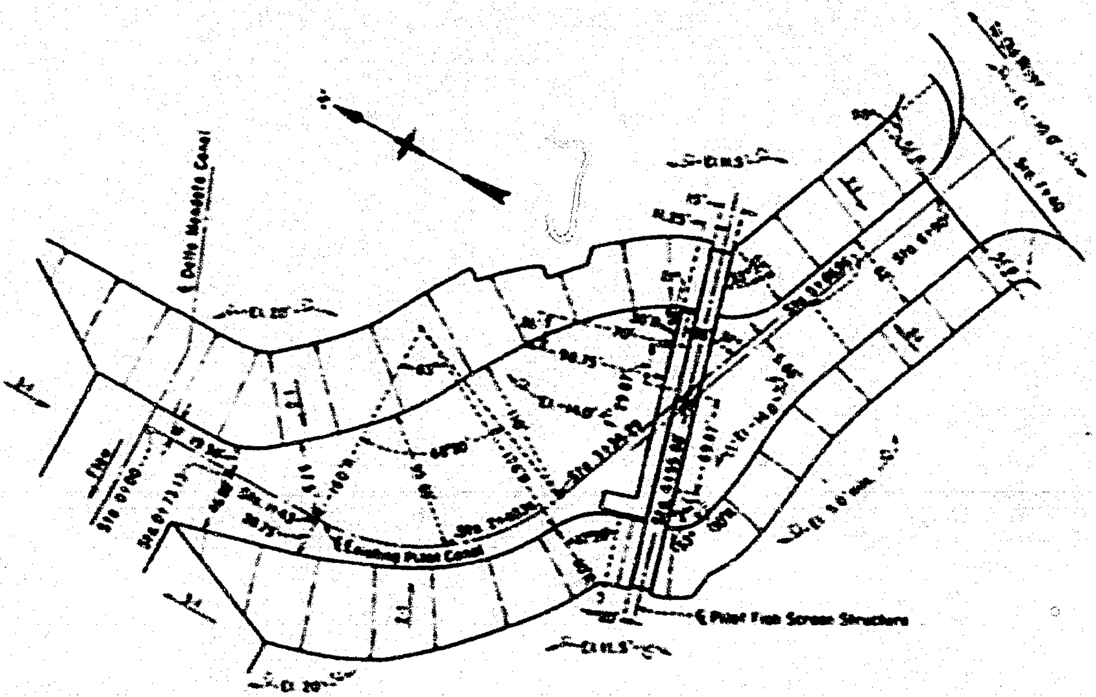
B - Flow Appearance Upstream From Fish Screen Structure for Channel Modification No. 2. Discharge = 4,600 cfs at Low Tide.

DELTA-MENDOTA CANAL HEADWORKS
PILOT FISH SCREEN STUDIES
CHANNEL REALIGNMENT STUDIES

FIGURE 38
REPORT HYD. 401



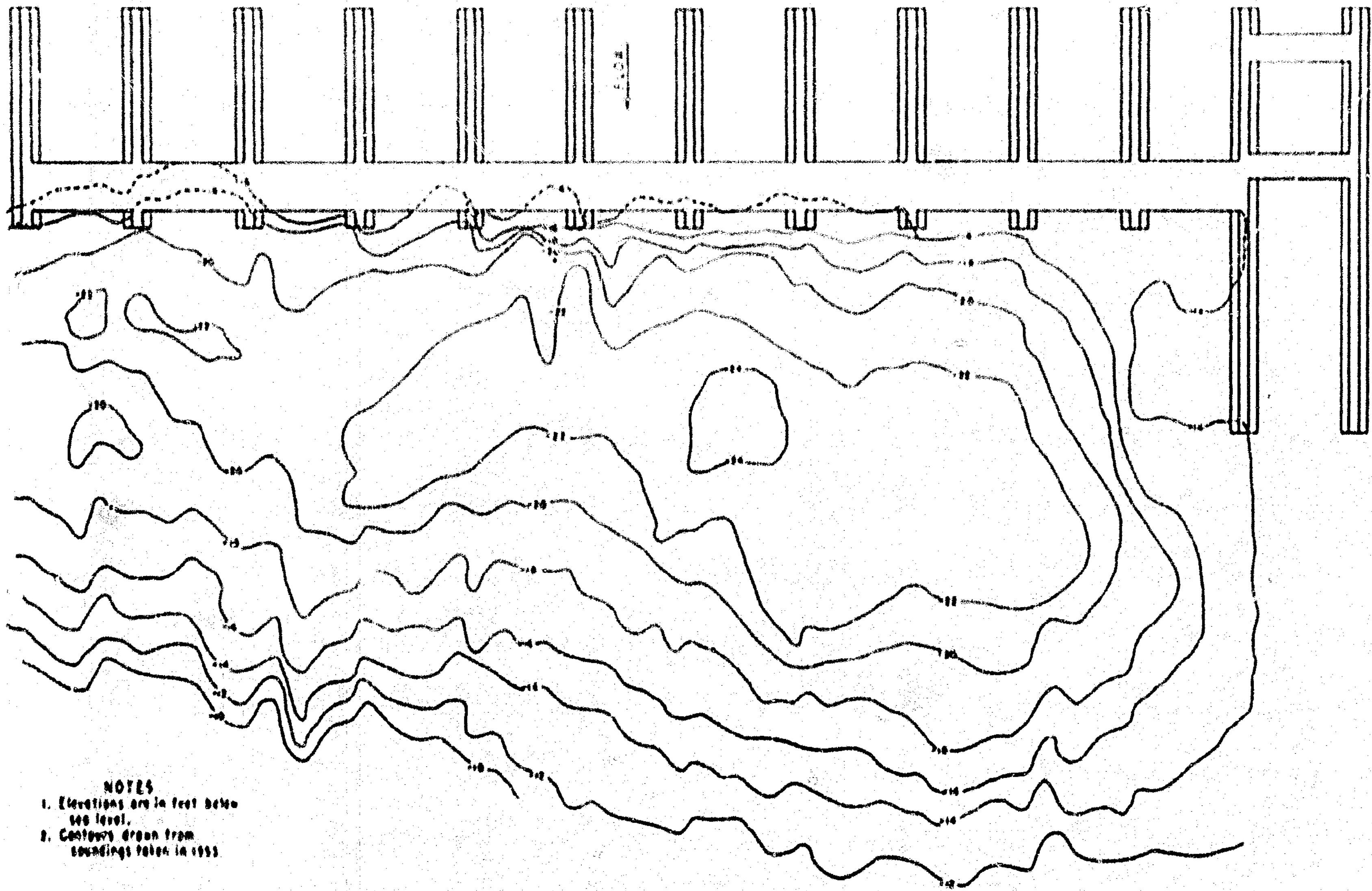
A. CHANNEL MODIFICATION No. 2



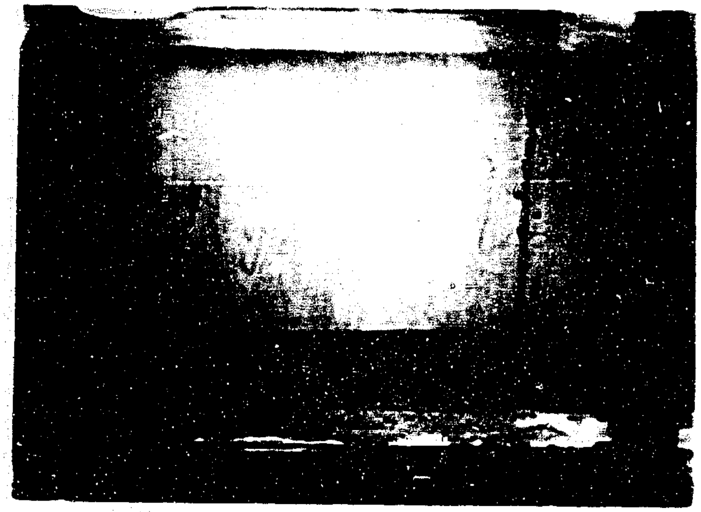
B. CHANNEL MODIFICATION No. 3, RECOMMENDED

DELTA MENDOTA CANAL HEADWORKS
PILOT FISH SCREEN STRUCTURE
CHANNEL REALIGNMENT STUDIES

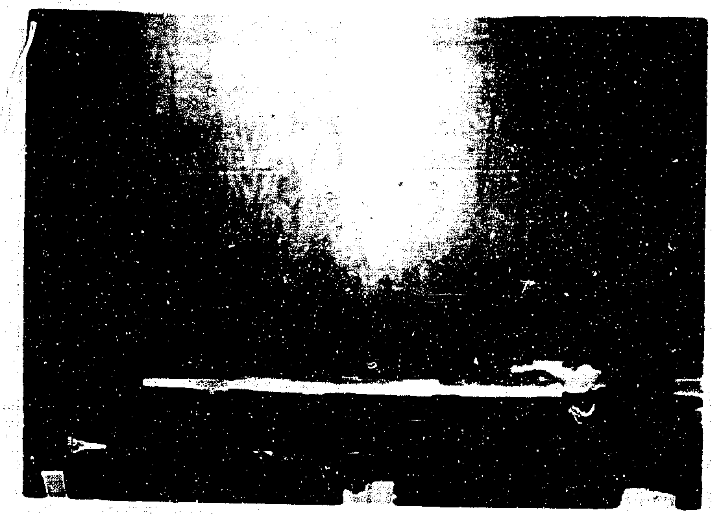
FIGURE 39
REPORT HYD 431



DELTA MENDOTA CANAL HEADWORKS
PILOT FISH SCREEN STRUCTURE
CHANNEL BED PROTECTION STUDIES
EROSION ON DOWNSTREAM SIDE OF FISH SCREEN STRUCTURE



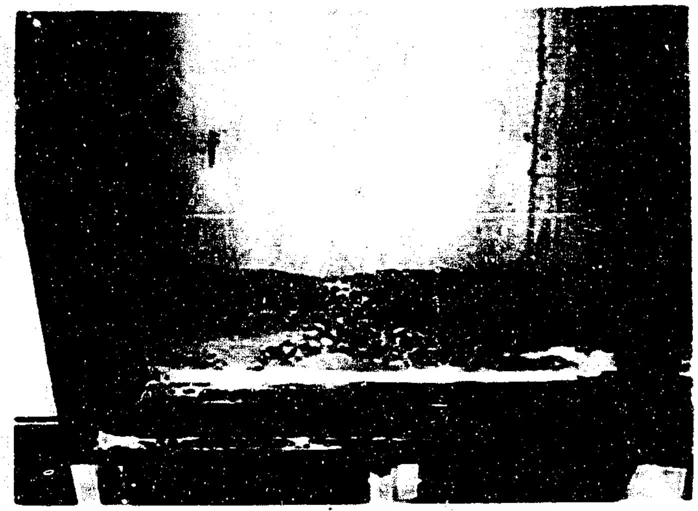
A - Sand Bed Downstream From Fish Screen
Before Operation Flow From Right to Left.



B - Sand Bed Downstream From Fish Screen
After Ten Minutes Operation.

DELTA-MENDOTA CANAL HEADWORKS
PILOT FISH SCREEN STRUCTURE
CHANNEL PROTECTION STUDIES

EXISTING DESIGN, TEST NO. 1.

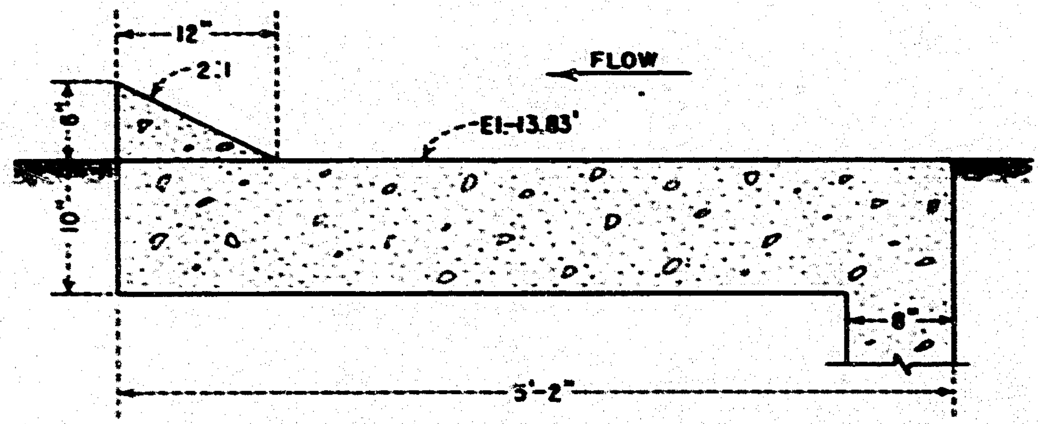


A - Riprap Placed Downstream From Apron - Erosion After 20 Minutes Operation.

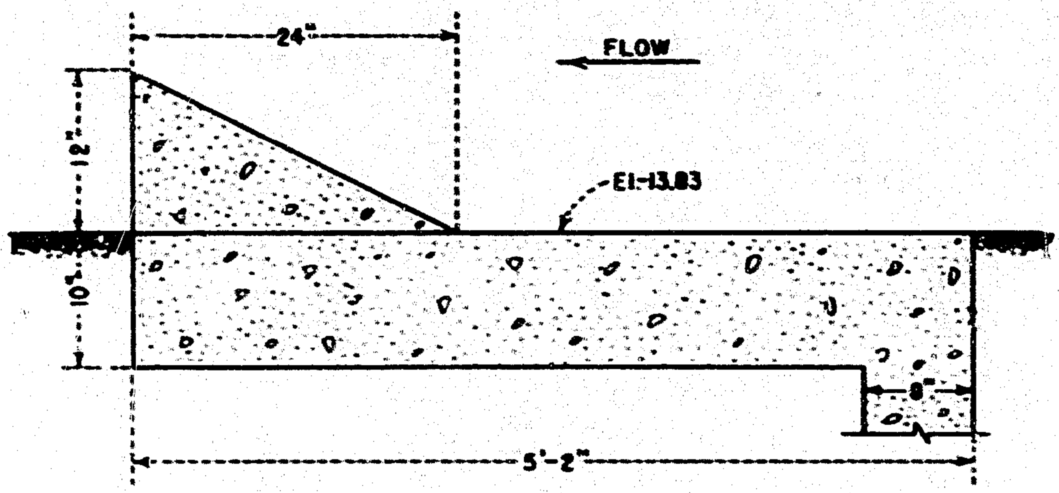
B - 6-Inch High End Sill and Riprap - Erosion After 30 Minutes Operation.

DELTA-MENDOTA CANAL HEADWORKS
PILOT FISH SCREEN STRUCTURE
CHANNEL PROTECTION STUDIES

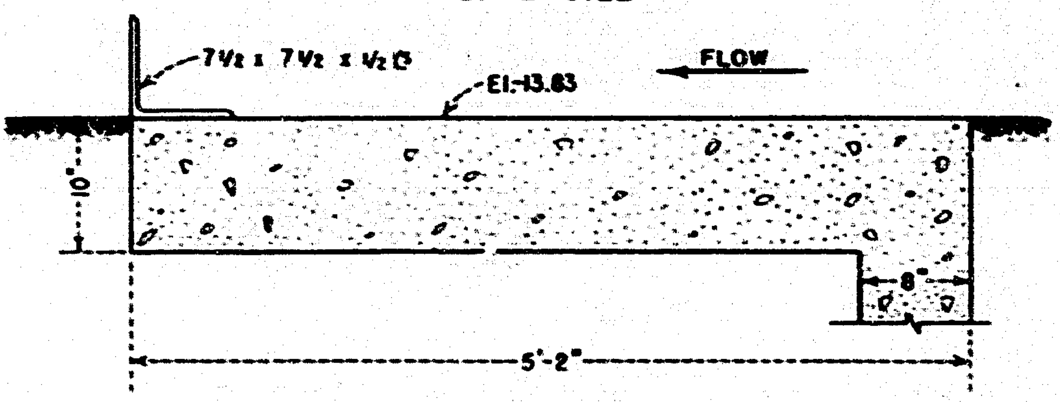
TESTS NOS. 2 AND 3



A. 6" SILL



B. 12" SILL



C. 7½" ANGLE IRON SILL

DELTA MENDOTA CANAL HEADWORKS
PILOT FISH SCREEN STRUCTURE
CHANNEL BED PROTECTION STUDIES
END SILLS

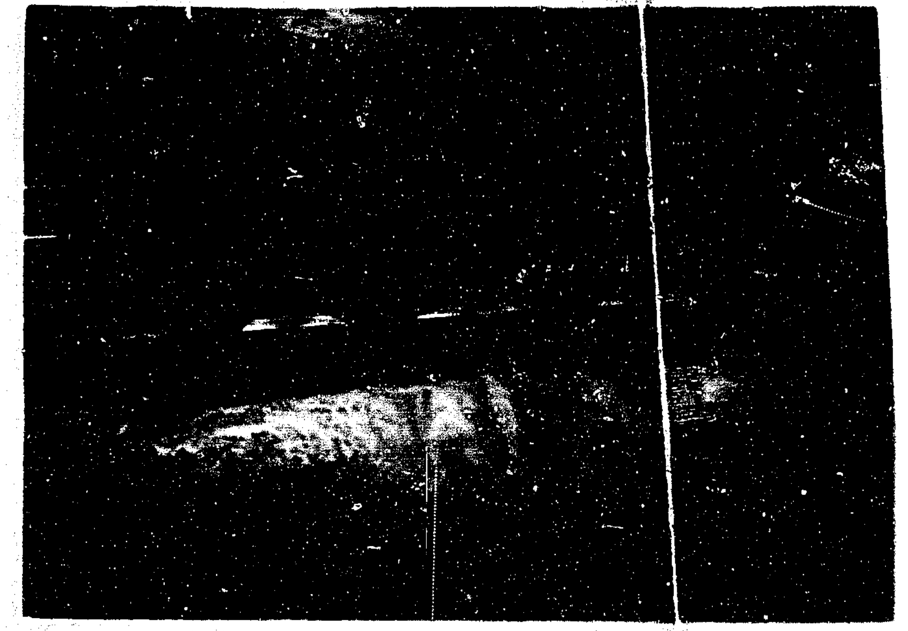
A - 12-Inch High End Sill - Test No. 4
Erosion After 4 Hours Operation.

B - Test No. 5. 7½ Inch End Sill Placed On Apron - Erosion After 2 Hours Operation.

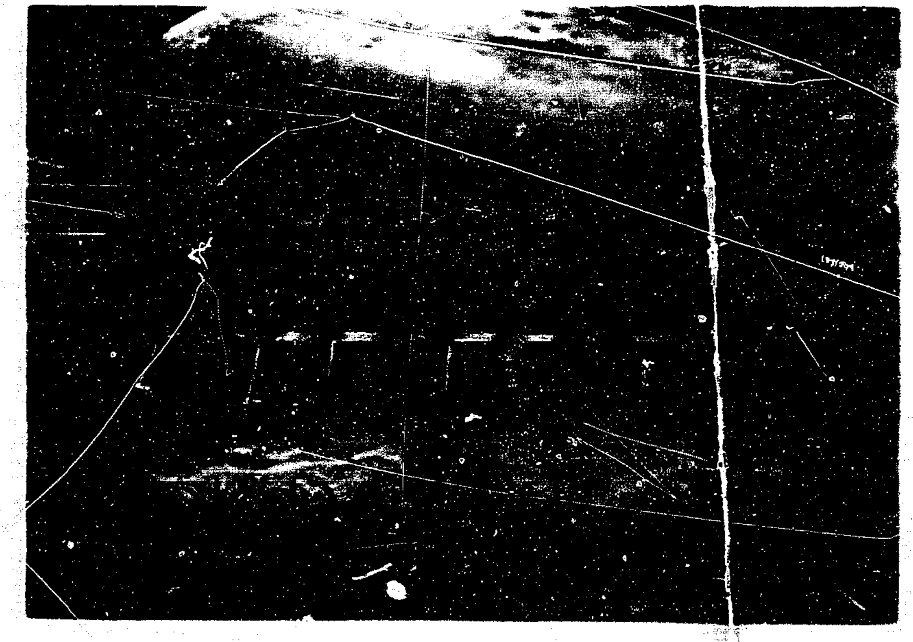
DELTA-MENDOTA CANAL HEADWORKS
PILOT FISH SCREEN STRUCTURE
CHANNEL BED PROTECTION STUDIES

TESTS NOS. 4 AND 5

Figure 44
Report Hyd. 401



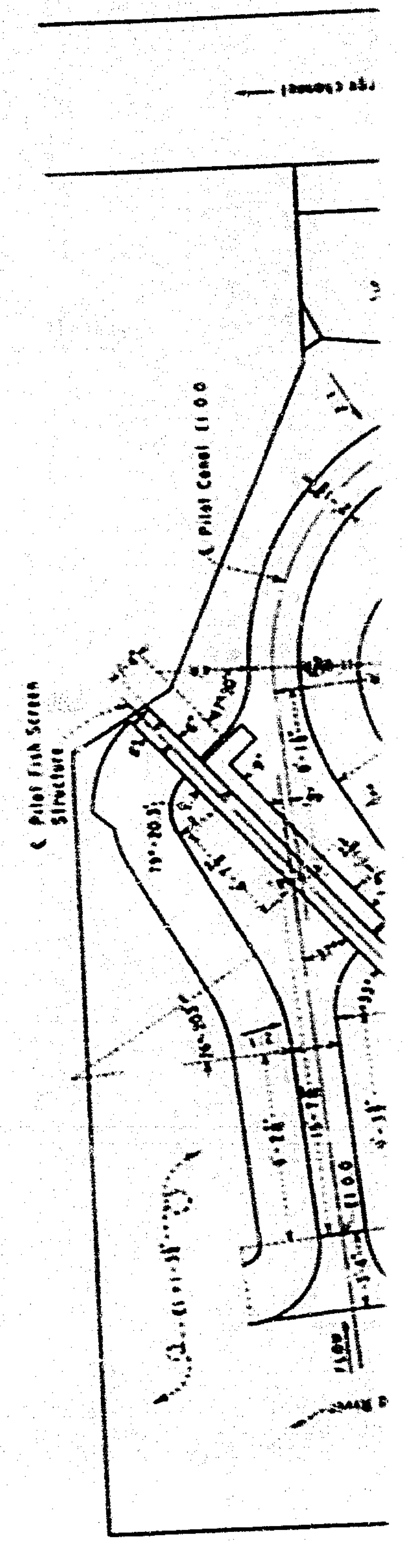
A - Over-All View of Erosion Downstream From Structure - Original Design



B - Over-All View of Downstream Erosion, 7½ Inch Angle-Iron End Sills on Apron.

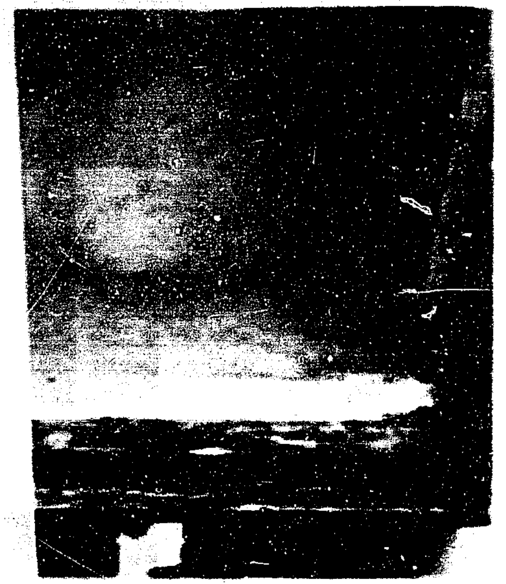
DELTA-MENDOTA CANAL HEADWORKS
PILOT FISH SCREEN STRUCTURE
CHANNEL BED PROTECTION STUDIES

OVER-ALL INVESTIGATION



DELTA MENDOTA CAN/
PILOT FISH SCREEN
MODEL LAYO
EXISTING ALIGN

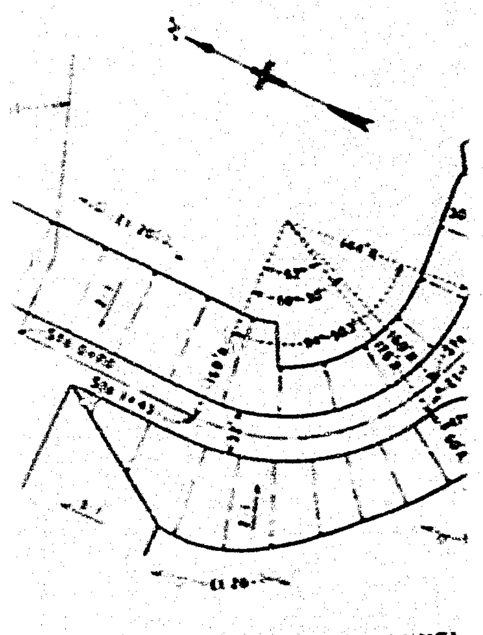
That Occurred During
...creen Raising Procedures.



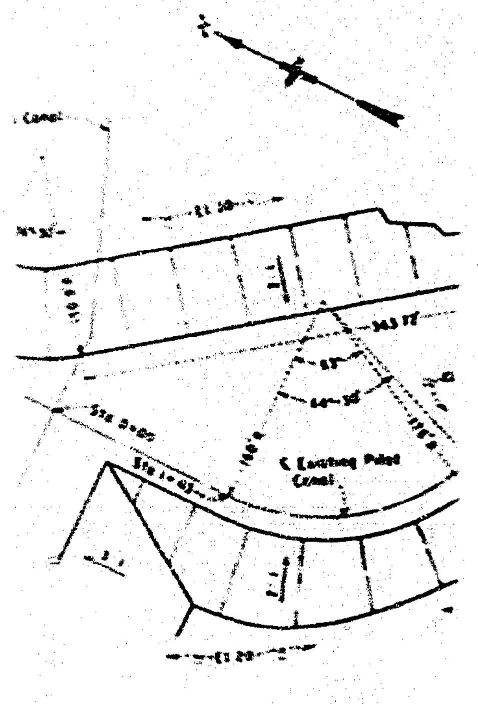
...t Occurred When Screen
...cedures Were Modified.

...TA CANAL HEADWORKS
...SCREEN STRUCTURE
...PROTECTION STUDIES

...SCREEN RAISING PROCEDURES



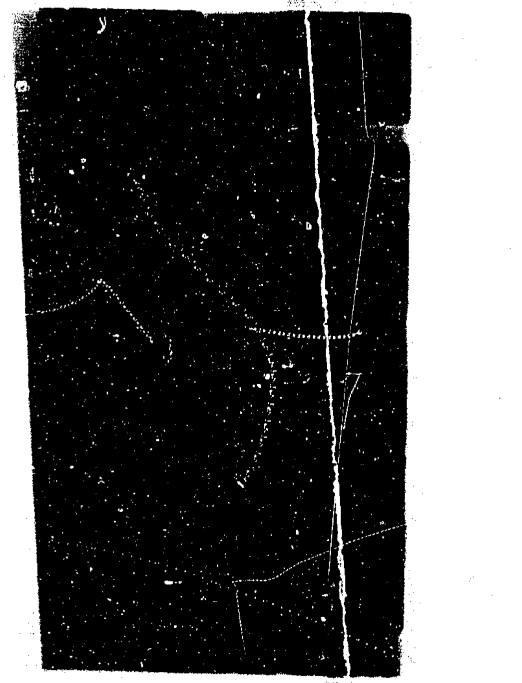
A. EXISTING CHANNEL



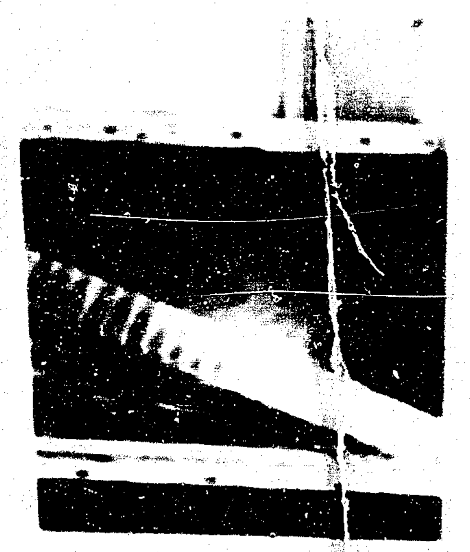
B. CHANNEL MO...

DELTA MENDOTA ...
PILOT FISH SC...
CHANNEL REALI...

Figure 46
Report Hyd. 401



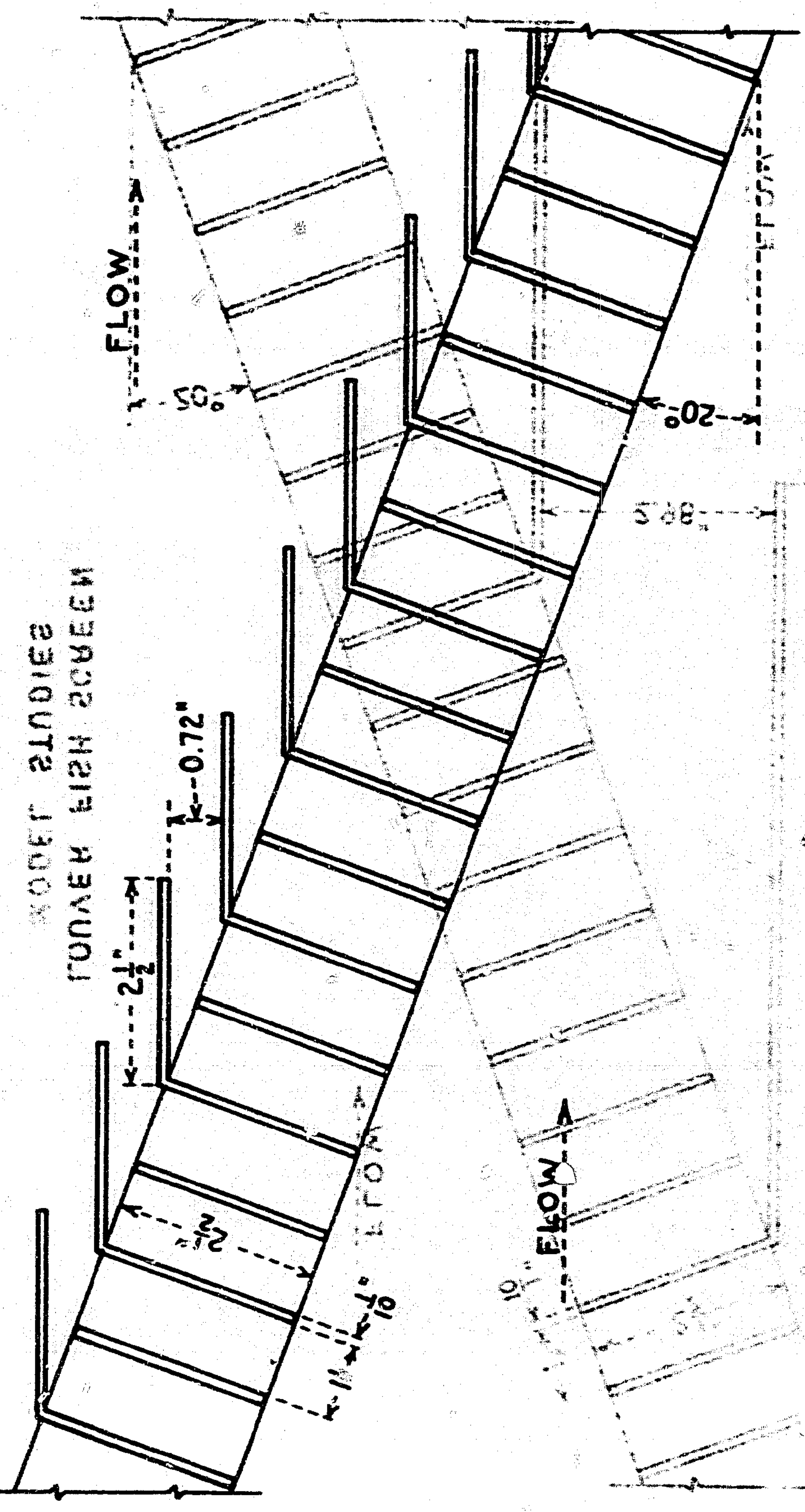
... 1:4 Scale Model



... Louvers in Full-Size

...AL HEADWORKS
...N STRUCTURE

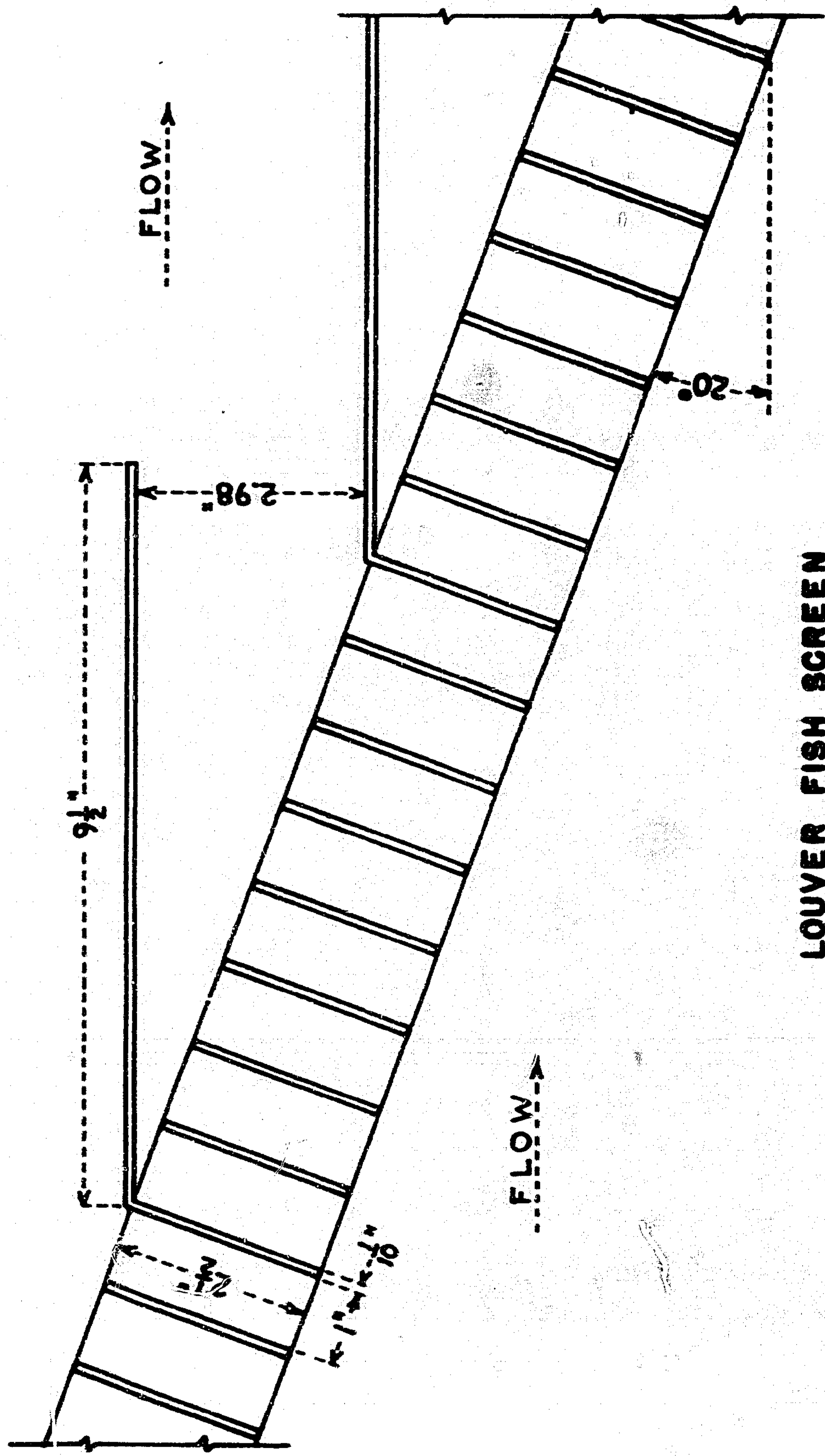
MODEL AND IN ... MODEL



LOUVER FISH SCREEN
MODEL STUDIES

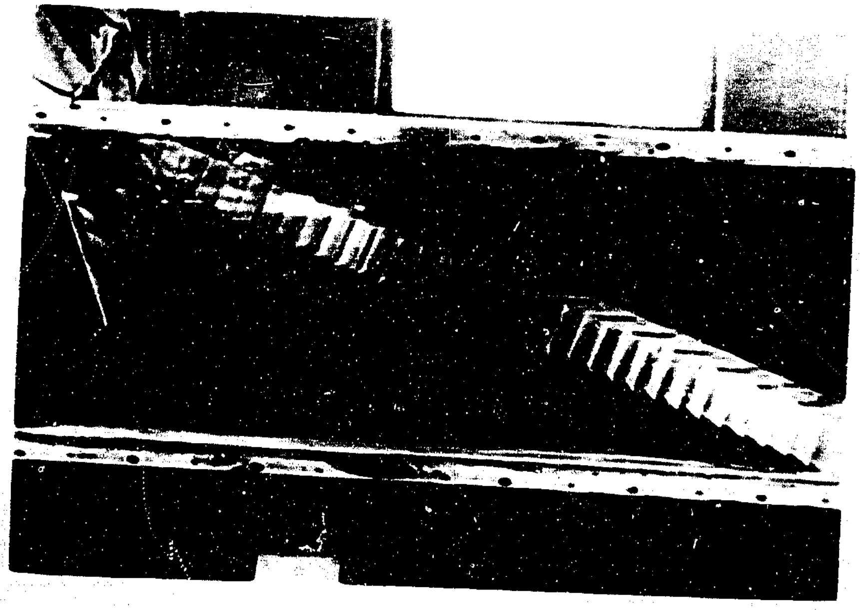
FLOW STRAIGHTENERS

FIGURE 48
REPORT HYD. 401

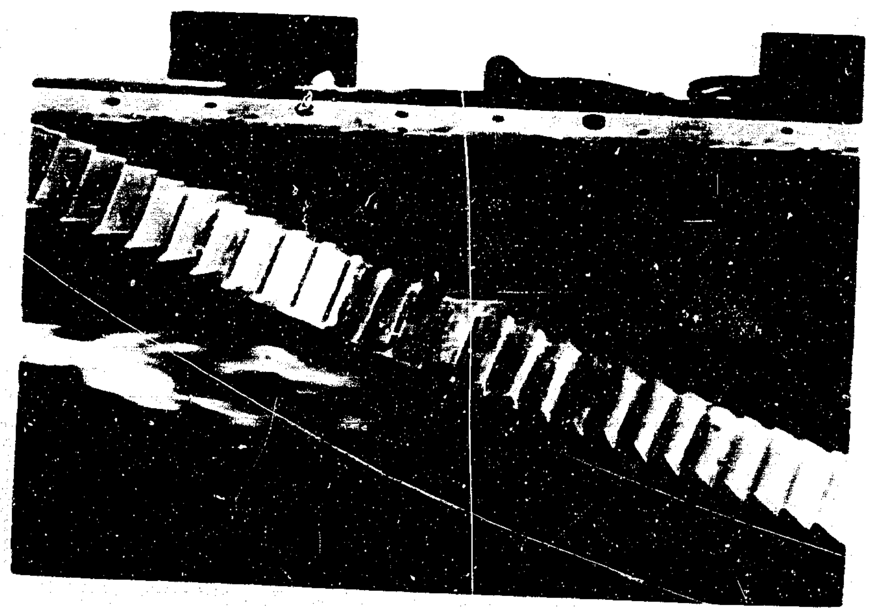


LOUVER FISH SCREEN
MODEL STUDIES

FLOW STRAIGHTENERS



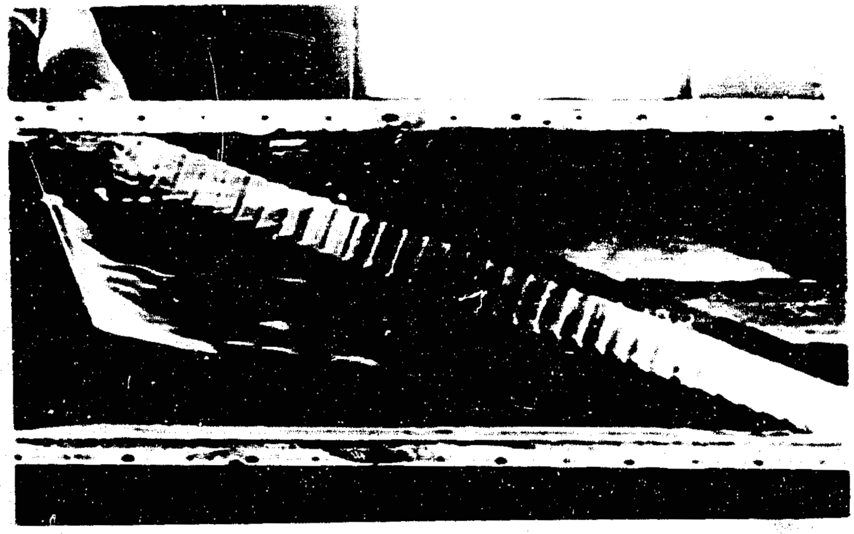
A - Flow Lines Through Louvers - Close-Spaced Flow Straighteners in Place.



B - Flow Lines Through Louvers - Wide-Spaced Flow Straightener in Place.

DELTA-MENDOTA CANAL HEADWORKS
PILOT FISH SCREEN STRUCTURE

FLOW PATTERN WITH FLOW STRAIGHTENERS

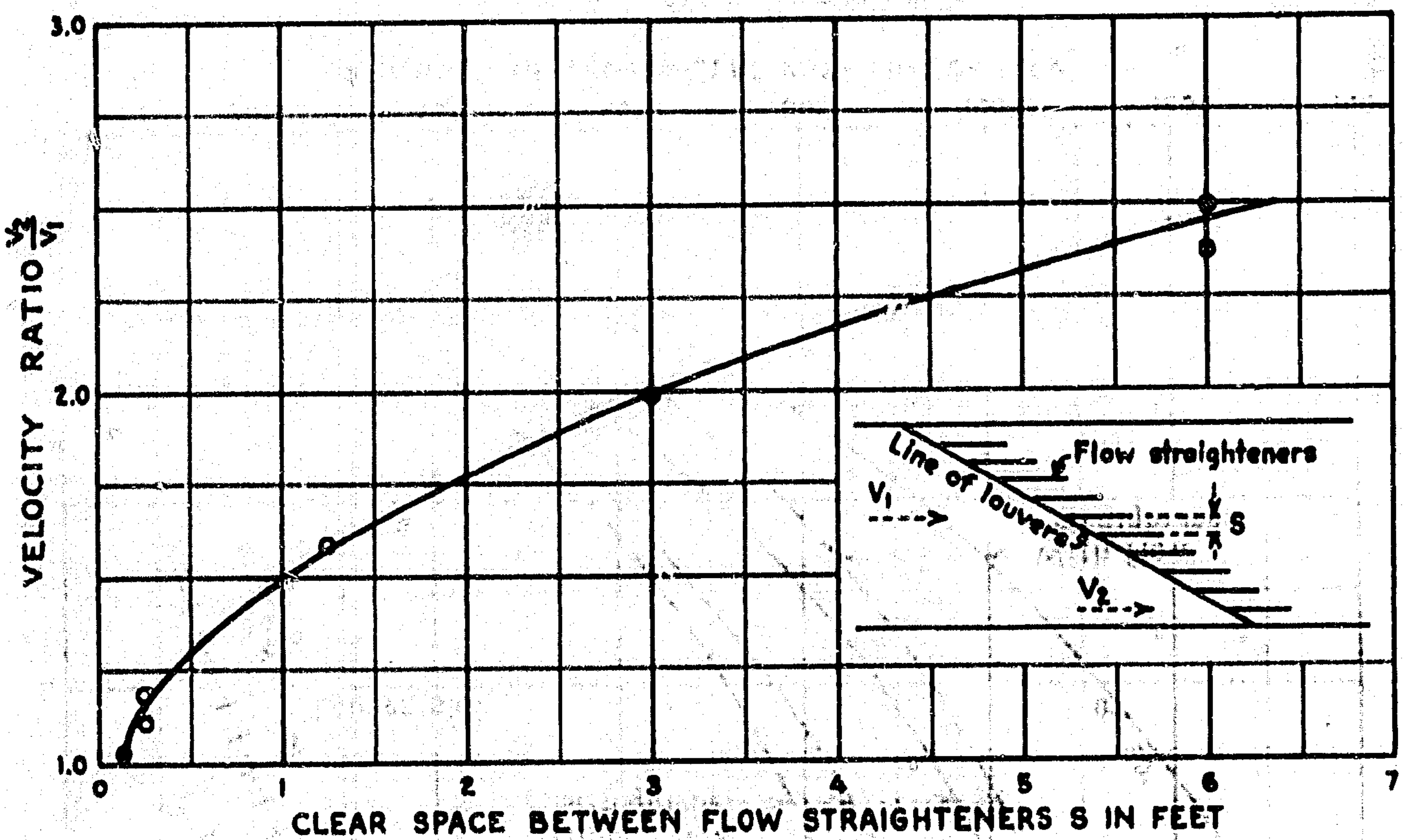


A - Flow Lines Through Louvers - Wide-Spaced Flow Straightener Separated From Louvers by About 2 Inches.

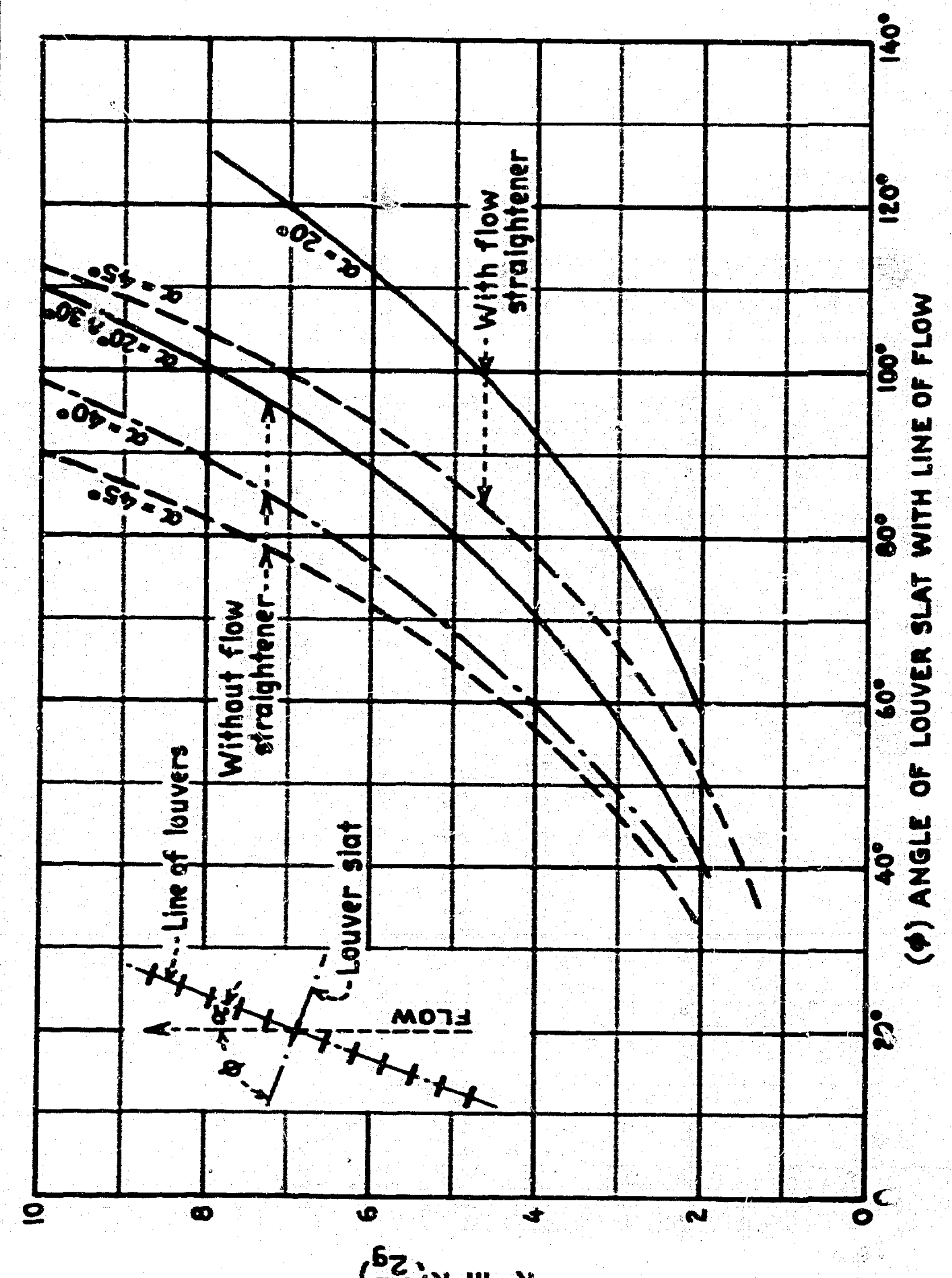
B - Flow Lines in 1:4 Scale Model With Flow Straightener in Place.

DELTA-MENDOTA CANAL HEADWORKS
PILOT FISH SCREEN STRUCTURE

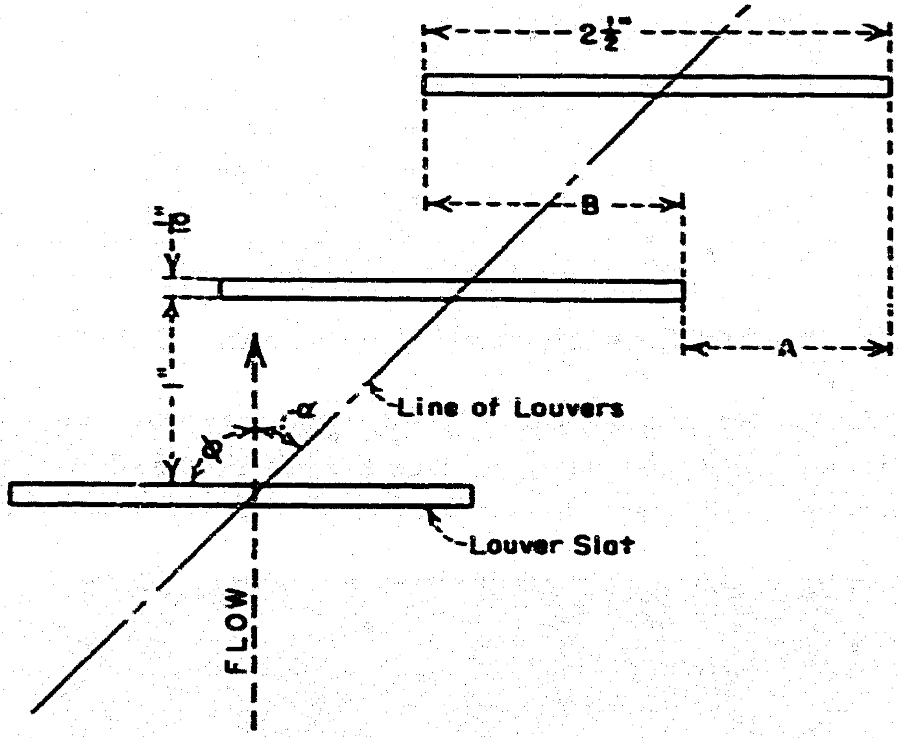
FLOW PATTERN WITH FLOW STRAIGHTENERS
1:4 SCALE MODEL AND AIR MODEL



RELATION OF FLOW STRAIGHTENER SPACING
TO VELOCITY INCREASE ALONG UPSTREAM SIDE OF LOUVERS



LOUVER FISH SCREEN
HEAD LOSS STUDIES

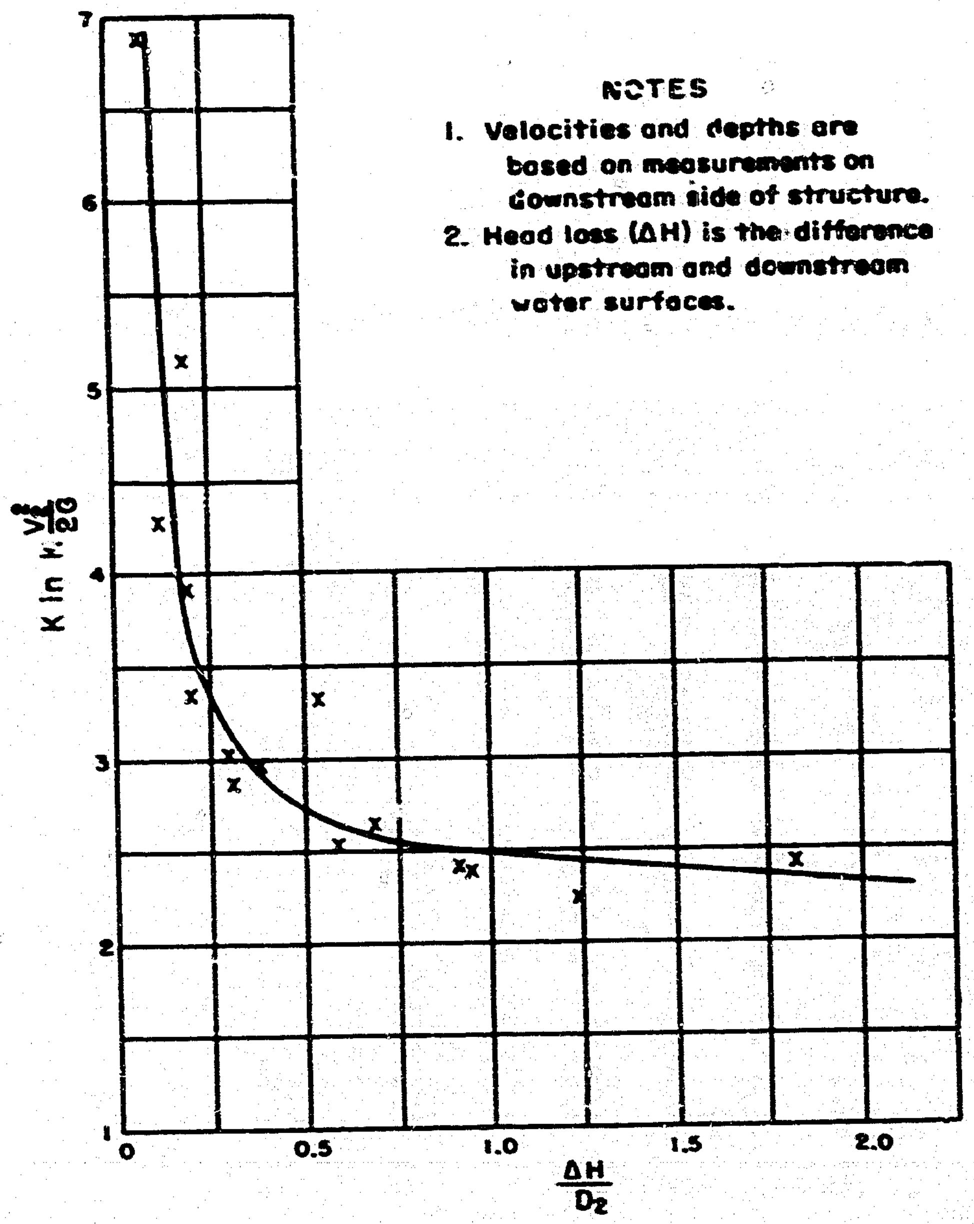


φ	α	A	B	B/A	HEAD LOSS
90°	20°	0.40"	2.10"	5.25	$6.3\frac{V^2}{2G}$
90°	30°	0.64"	1.86"	2.93	$6.3\frac{V^2}{2G}$
90°	40°	0.92"	1.58"	1.71	$8.2\frac{V^2}{2G}$
90°	45°	1.10"	1.40"	1.26	$10.0\frac{V^2}{2G}$
90°	40°*	0.92"	2.58"	2.65	$6.5\frac{V^2}{2G}$

*Slot length increased to 3½".

DELTA MENDOTA CANAL HEADWORKS
PILOT FISH SCREEN STRUCTURE
LOUVER FISH SCREEN
HEAD LOSS STUDIES

FIGURE 54
REPORT HYD. 401



DELTA MENDOTA CANAL HEADWORKS
PILOT FISH SCREEN STRUCTURE
LOUVER STUDIES
HEAD LOSS — DEPTH — VELOCITY RELATION

Interior - Reclamation - Denver, Colo.