# HYDRAULIC MODEL STUDY
# HARVARD GULCH FLOOD CONTROL PROJECT
# CONDUIT INTAKE

Wright – McLaughlin Engineers
Engineering Consultants
Denver, Colorado



Civil Engineering Department
Engineering Research Center
Colorado State University
Fort Collins, Colorado

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Final Report

of

# HARVARD GULCH FLOOD CONTROL PROJECT CONDUIT INTAKE

Prepared for

Wright-McLaughlin Engineers
Engineering Consultants
Denver, Colorado

by

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# PREFACE

The Engineering Research Center at Colorado State University is located between two lakes, Horsetooth Reservoir of the Colorado-Big Thompson project and College Lake. The laboratories of the Center are strategically located to utilize the high head, 250 feet, available from the reservoir and the storage capacity of the lake. The Center is the focal point for research and graduate education.

There are four principal parts to the Center: the offices for staff and graduate students, the hydraulics laboratory, the fluid dynamics laboratory and the outdoor hydraulics-hydrology laboratory. Included in the research activities of the Center are fluid mechanics, hydraulics, hydrology, groundwater, soil mechanics, hydrobiology, geomorphology and environmental engineering.

The Center includes well-equipped machine and woodwork shops. All research facilities of the Center are constructed on site and for this model study, necessary metal work and carpentry were done by personnel in the shops. The shop personnel are particularly well-experienced in the art and skill of model construction.

Grateful acknowledgment is hereby expressed by the writer to Dr. D. B. Simons, Professor and Associate Dean, College of Engineering, and Mr. S. Karaki, Associate Professor, Department of Civil Engineering for their administrative and technical assistance, to personnel in the shops for their contributions in solving model construction problems, and to others contributing to the model study and preparation of this report. The writer wishes to express his appreciation for the cooperation of Mr. Kenneth R. Wright of Wright-McLaughlin Engineers in providing assistance and helpful suggestions during the model tests.

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SUMMARY

This report describes a hydraulic model study of the intake to the 12-foot diameter conduit for the Harvard Gulch Flood Control Project. Design of an intake to provide a discharge of about 2100 cfs at an upstream water surface elevation of 128.7, to limit the flow at elevations above 128.7, and to accelerate the water to the uniform flow velocity in the conduit for the large discharges was the primary object of this study. A discharge rating curve for the intake is provided in Fig. 12.

Flow conditions through the transition were satisfactory for all discharges. An air vent should be provided in the conduit at a distance of 40 feet to 80 feet downstream from the transition. The exact location to be determined from the general location of the intake in relation to Logan Street. Velocity profiles in the conduit indicate that no unusual conditions prevail. The model construction tests and conclusions and recommendations are described in this report.

# INTRODUCTION

## General Description of Project

The Harvard Gulch Project is a proposed three-phase flood control project to be constructed in Southeast Denver. The general location of the project is shown in Fig. 1. The project will have a series of grassed channels, concrete channels, underground conduits, energy dissipators, culverts and some 23 bridges.

The project will be constructed in three phases, beginning at the downstream end at the South Platte River. Phase I will be the installation of 3700 feet of underground conduit along Wesley Avenue from the river to Grant Street. The conduit will pass under two mainline railroad tracks, two spur lines, and one state highway, as well as South Broadway. A stilling basin at the river will slow the 35 feet per second flows before they enter the river. The design capacity of the conduit at Grant Street is 2100 cfs at 75 percent depth. As the conduit goes to the west, the slope is increased gradually, allowing a further acceleration of the flood flows. At the same time, storm sewers and inlets will permit an additional 500 cfs to enter the conduit.

Phase II will extend the conduit to Logan Street where the flow limiting-acceleration intake will be constructed. It also includes a wide grassed channel upstream from the intake, a baffle chute, stilling basin, flood detention reservoir, side channel spillway, and 730 feet of underground 10-feet by 14-feet box culvert. Phase II extends from Grant Street to Downing.

Phase III extends two miles from Downing to Colorado Boulevard. From Downing to Race Street the channel will be concrete-lined and have design velocities of between 17 and 23 fps. At Race a chute will accelerate the slow flow from DeBoer Park lying between Race and York Streets. From Race to Colorado Boulevard the channel will be wide and grass-lined. The slow flows there will provide a degree of ponding in order to increase the time of concentration of the flood waters. Discharges above the design flow will tend to pool behind the numerous bridges crossing the channel.

All features are designed to carry the once in 25-year-flood under future fully sewered basin conditions. At Downing this is 2000 cfs. The reservoir will store the peak of the hydrograph over 1600 cfs. A tributary basin at Pearl Street will bring the total up to 2100 cfs at the Logan Street intake.

While the object of the project is flood protection, it is anticipated that the beautification of the area will help to improve the general assessed valuation of the neighborhoods through which the channel passes.

## Description of the Intake[1] and Transition

The intake tested in this model study is to be constructed at the Logan Street site. The mouth of the intake is 40 feet long and 4 feet high. The elevation of the crest is 124.0[2]. The chute has a 2:1 slope and intersects the stilling basin floor at elevation 105.5. The chute tapers from 40 feet wide at the crest to 12 feet wide at the stilling basin. Located on the chute are five rows of baffle blocks. The stilling basin floor is 10 feet long and a sill 2.9 feet high is located at the entrance to the transition. Details of the intake and stilling basin are shown in Fig. 2. The transition is 18 feet long. The transition changes the geometry of the conduit from a section 12 feet square at the beginning of the conduit to a 12-foot diameter circular section. Details of the transition are given in Fig. 3. The conduit slope initially is 0.0062. The slope increases gradually as it continues west.

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1 The intake is described as conceived in the initial design stages. Subsequent testing of the intake resulted in changes in some of the features described herein.

2 All elevations expressed in numbers in this report will be understood to have dimensions of feet whether or not it is explicitly stated. Elevations are referenced to the City of Denver Datum.

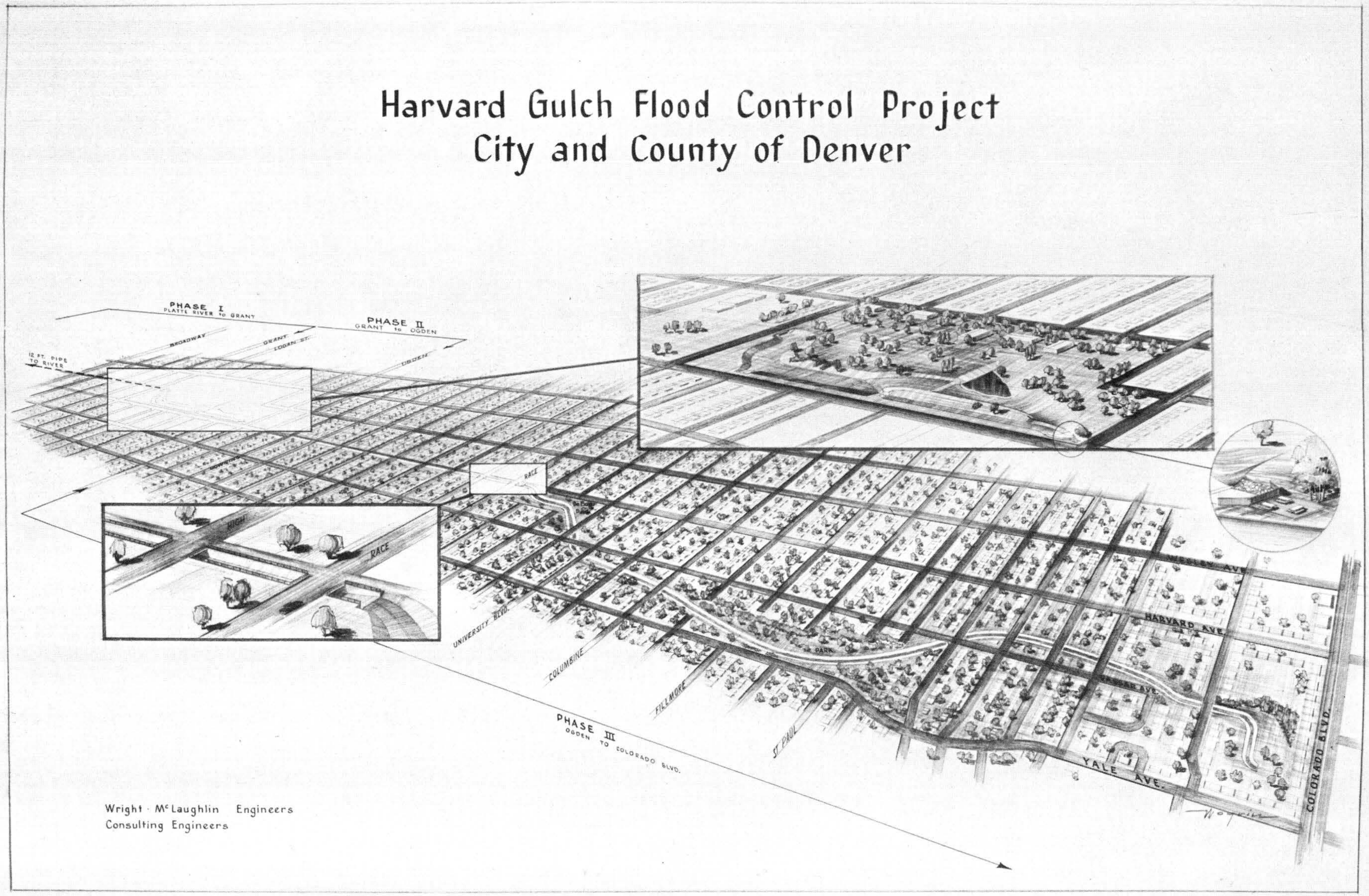



FIGURE I GENERAL LOCATION OF
HARVARD GULCH FLOOD CONTROL PROJECT

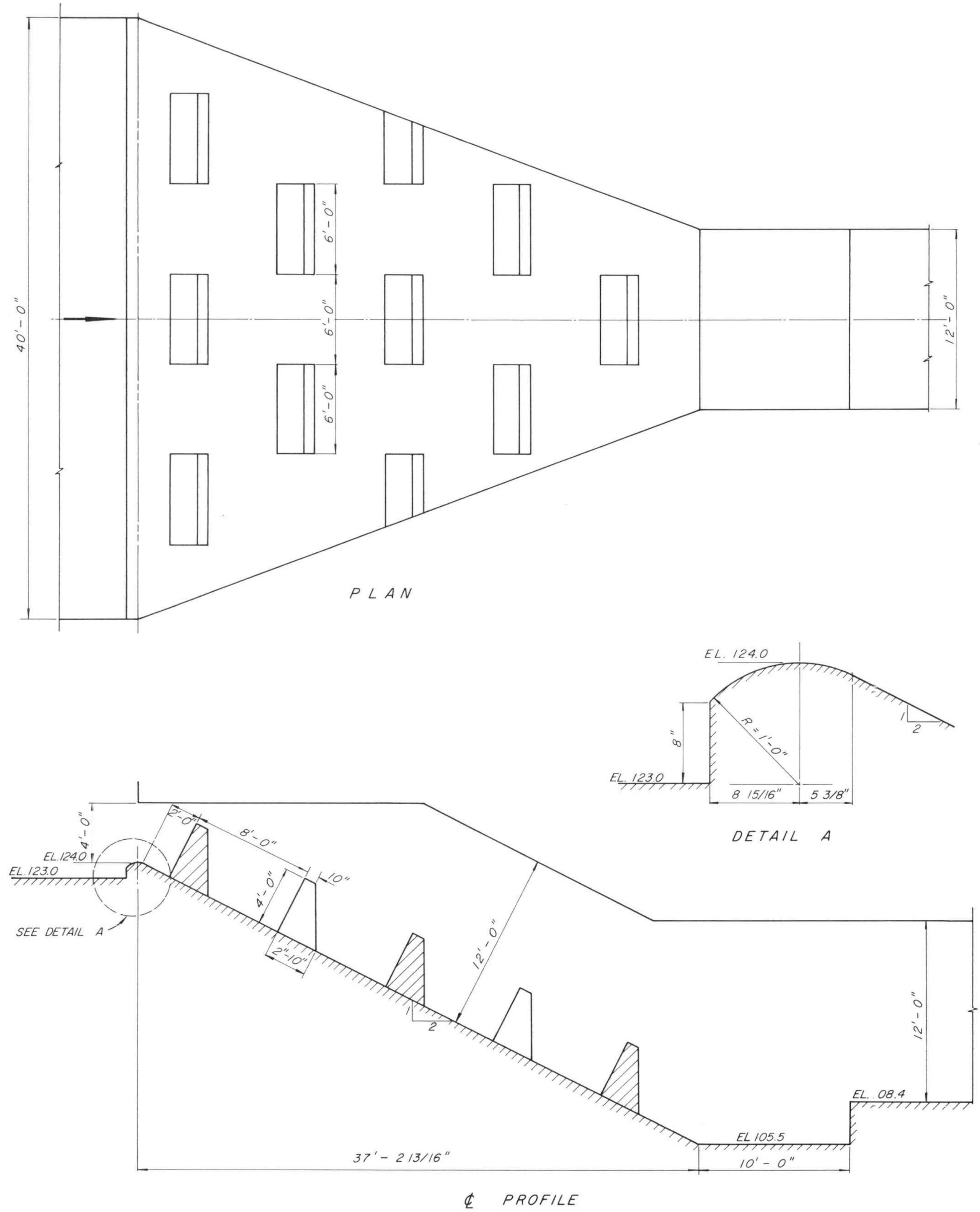



FIGURE 2 DETAIL OF THE INTAKE

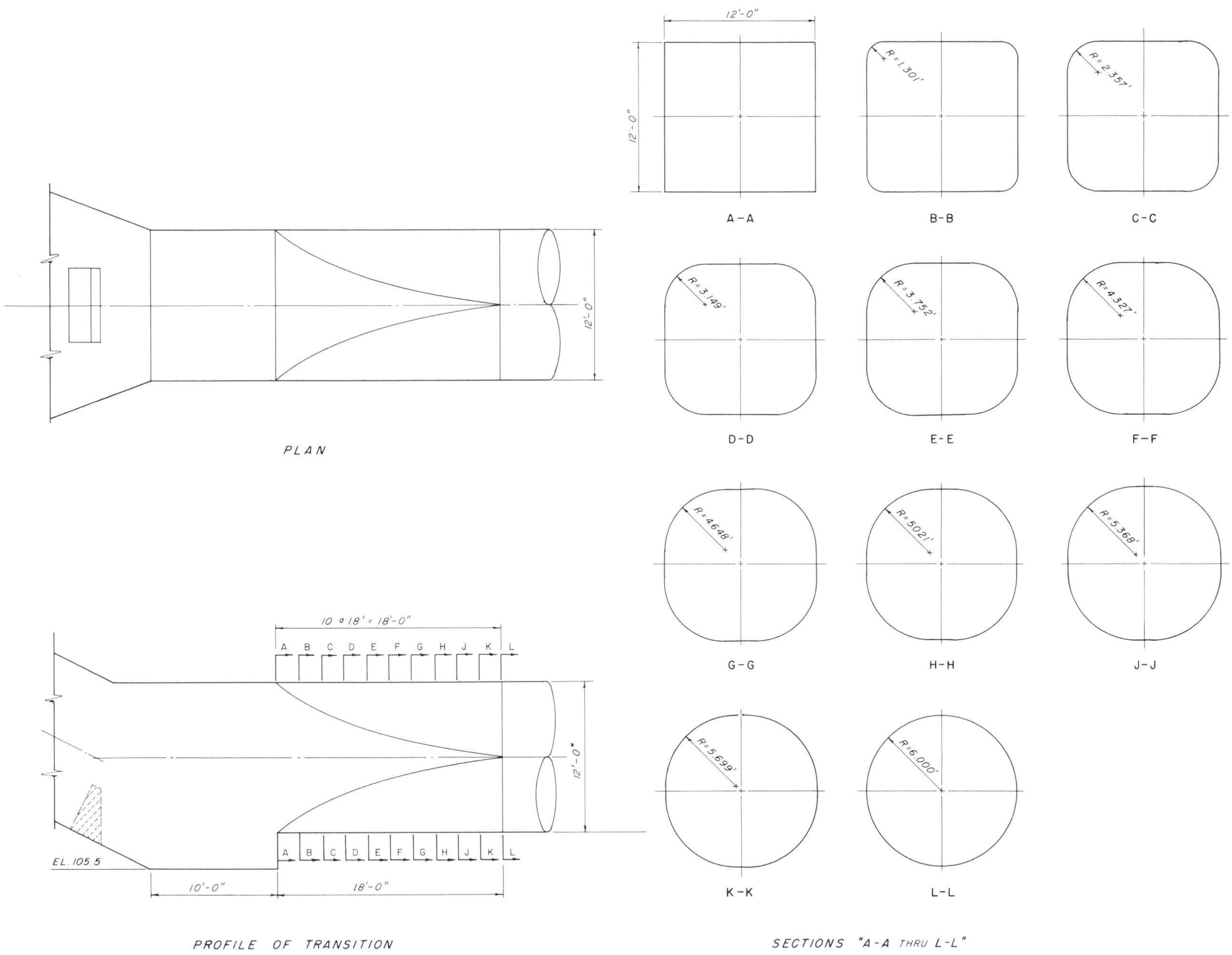



FIGURE 3 DETAILS OF THE TRANSITION

## Selection of Model Criteria and Scale

The conduit design at the initiation of the model study provided for either a 12-foot diameter conduit or a box culbert 14 feet wide by 9 feet high. The final design to be subject to the low bidder of the phase one project.[3] The decision to design the model for the 12-feet diameter conduit was made to provide a check of the hydraulic performance of the transition required between the intake and the circular conduit. The results of this model study could then be used to design the intake for either the circular conduit or box culvert.

The objective of the model is to develop flows dynamically and kinematically similar to the prototype. Geometric similarity must, therefore, be maintained. Dimensional analysis will show that the Froude number is important for the objectives of this study. For instance, the free overflow, orifice flow and open channel flow are dependent upon gravity predominantly, hence, the Froude criterion prevails and was chosen to determine the geometric scale.

A model-prototype relationship of 1:12 was determined to be the most feasible from our analysis of scale ratios based upon model size required for accurate representation of the flow conditions, available laboratory space and facilities, and economy of construction costs. Table I contains some characteristic ratios between model and prototype at the selected scale.

## Scope of the Model Study

The purpose of the model study is to design and investigate an intake to be constructed during phase two of the project at the Logan Street site. The intake is to provide control of the discharge entering the conduit. The specific objectives sought in the model study are listed below:

1. Determine the discharge rating curve for the intake.

2. Determine through visual observations, photographs, pressure data and velocity traverses the flow characteristics through the intake, transition, and conduit for all expected discharges.

3. Determine hydraulic dimensions for design purposes.

4. Determine the necessity of vents for the intake or release of air at the intake, transition or along the conduit.

TABLE I

MODEL PROTOTYPE SCALE RATIO

| Parameter | Scale Ratio: Function of the Length | Scale Ratio: Numerical Ratio | Absolute Magnitude: Prototype | Absolute Magnitude: Model |
|---|---|---|---|---|
| Length | $L_r$ | 1:12 | 1 ft | 1.00 in. |
| Area | $(L_r)^2$ | 1:144 | 100 ft$^2$ | 0.694 ft$^2$ |
| Velocity | $(L_r)^{1/2}$ | 1:3.465 | 1 fps | 0.288 fps |
| Discharge | $(L_r)^{5/2}$ | 1:498.831 | 1000 cfs | 2.004 cfs |
| Time | $(L_r)^{1/2}$ | 1:3.465 | 1 min | 17.316 sec |

[3] Decision to construct a box culvert during phase one was made after completion of these tests. The box culvert was approximately $150,000 less than the pipe.

## Model Construction

The general limits of the model are shown in Fig. 4. The dimensions of the model facilities and actual arrangement are given in Fig. 5 with a photograph of the completed model shown in Fig. 6.

The head box was constructed of plywood and waterproofed with a fiberglass lining. The head box was constructed to the size indicated in Fig. 5. The areal extent of the head box was considered sufficient to provide control of the head water level. Some topography was included in the head box to simulate the approach conditions to the intake. Figure 7 shows the topography being installed in the head box.

Water to the head box was supplied by a 14-inch turbine pump. The discharge was regulated by a valve in the pipe line. Discharge measurements were made with a calibrated orifice in the supply line.

The intake was constructed from fiberglass coated plywood and plexiglass. Plywood formed the chute, left wall, basin floor, and roof. Plexiglass was used for the right wall to facilitate visual observation of the flow conditions and water surface profile within the intake.

The transition was molded from plexiglass to facilitate visual flow observations. A 12-inch I. D. pipe was used for the circular conduit. Piezometers were installed in the conduit at the locations shown in Fig. 8. Horizontal and vertical velocity traverses were made at the locations shown in Fig. 8.

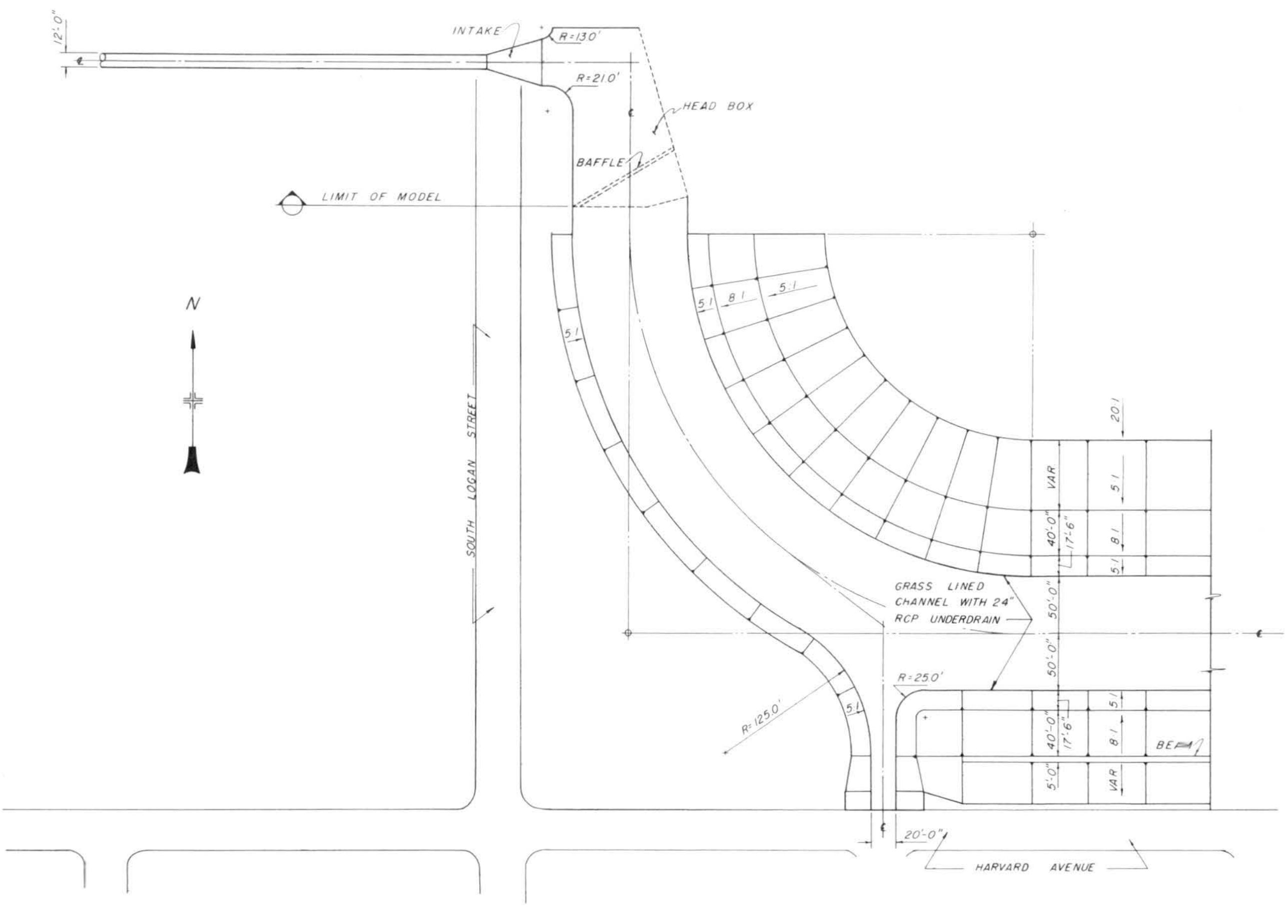



FIGURE 4 GENERAL LIMITS OF THE MODEL

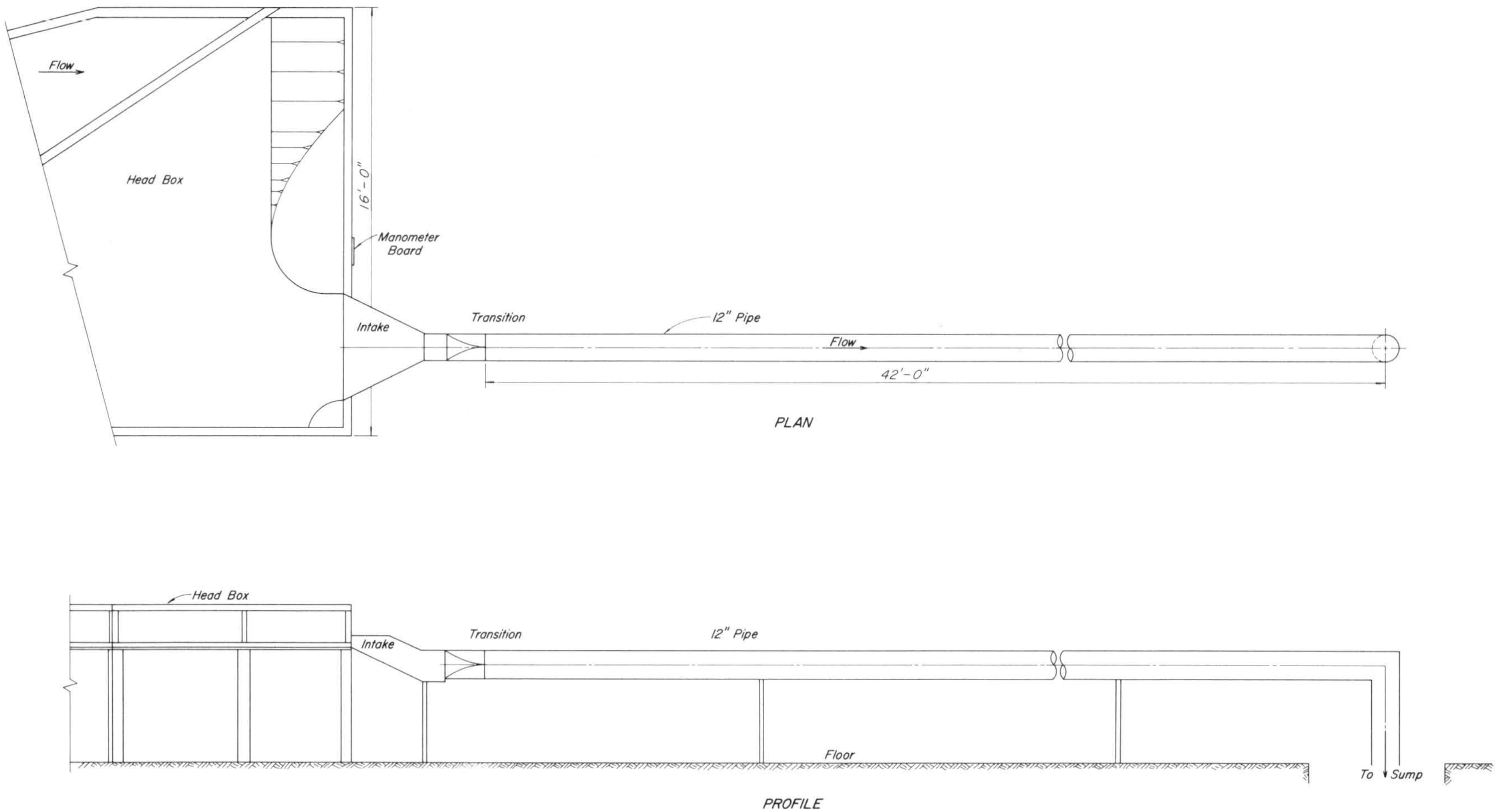



FIGURE 5 SCHEMATIC DRAWING OF THE MODEL

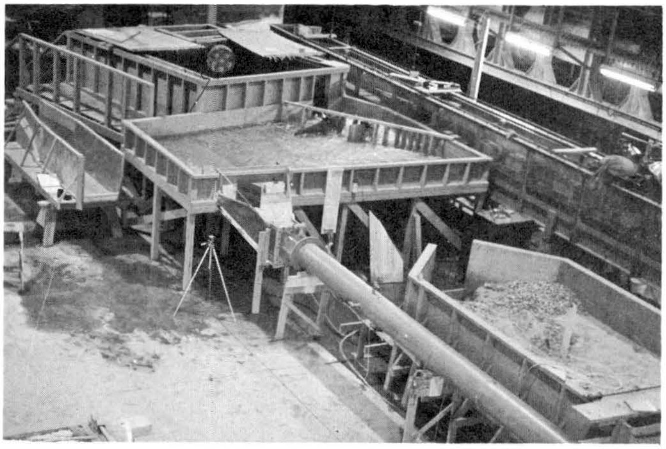


Figure 6. Photograph of completed model

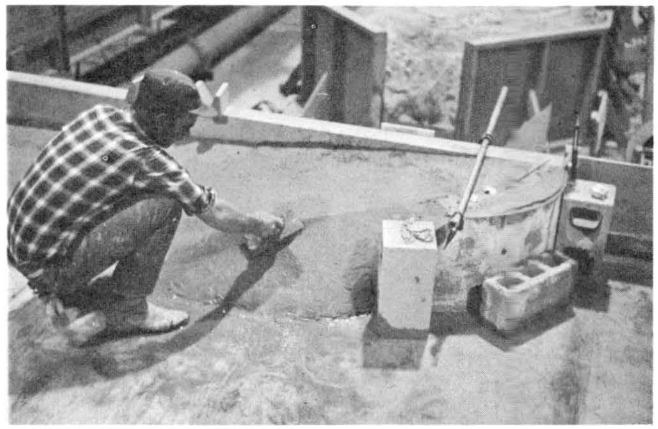
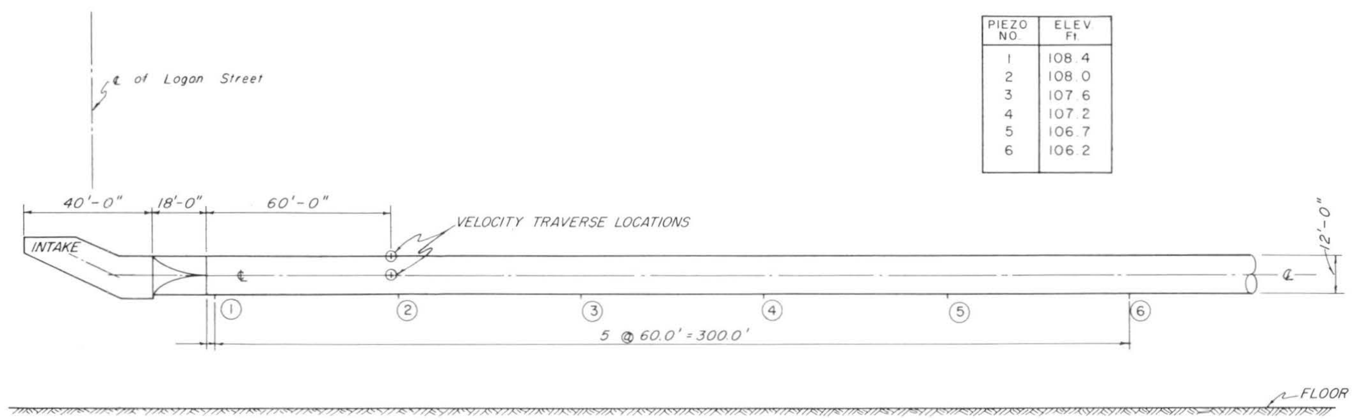


Figure 7. Topography being installed in the head box




PROFILE

FIGURE 8 CONDUIT PIEZOMETER LOCATIONS

## The Intake

The discharge rating curve for the model without modifications is shown in Fig. 9. The curve is included here so that the reader may relate discharge to upstream water surface elevation in the following discussion.

The permissible flow through the conduit should be about 2000 cfs to 2100 cfs at an upstream water surface elevation of 128.7 . Water will flow over Logan Street and reach the river via an overland route at elevations greater than 128.7 . A discharge of 900 cfs through the intake without modifications at elevation 128.7 is not sufficient.

The rows of baffle blocks were removed one row at a time in an attempt to increase the discharge. The row of blocks nearest the mouth was removed first. Continuing downstream, the baffle blocks were removed and a discharge rating curve was found after each subsequent row was removed. The discharge rating curves for the conditions described above are shown in Fig. 10. The baffle block rows are numbered from 1 to 5 starting with the upstream row. Removal of the baffle blocks result in an increase of the discharge from 900 cfs to 1450 cfs at elevation 128.7 but the discharge is not satisfactory.

To obtain a satisfactory discharge at elevation 128.7 , the intake was lowered two feet. The crest elevation was set at 122.0. The stilling basin floor was raised 1.5 feet to elevation 107.0. Details of the intake are shown in Fig. 11. Raising the basin floor did not affect the discharge rating curve for the lower crest and will provide some economy in construction costs. The end sill, 1.4 feet high insures that a hydraulic jump will form. The jump will dissipate some energy and reduce the velocity of the jet entering the conduit.

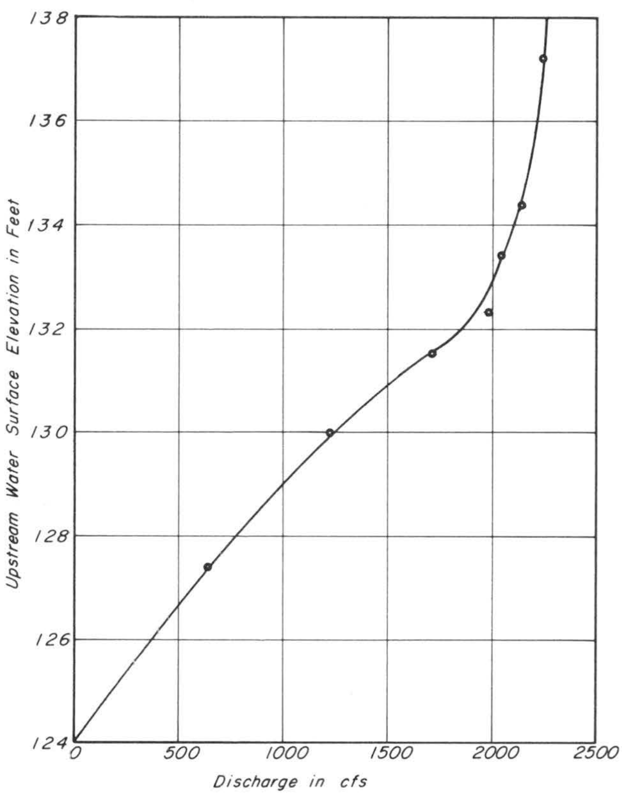



FIGURE 9 MODEL DISCHARGE RATING CURVE

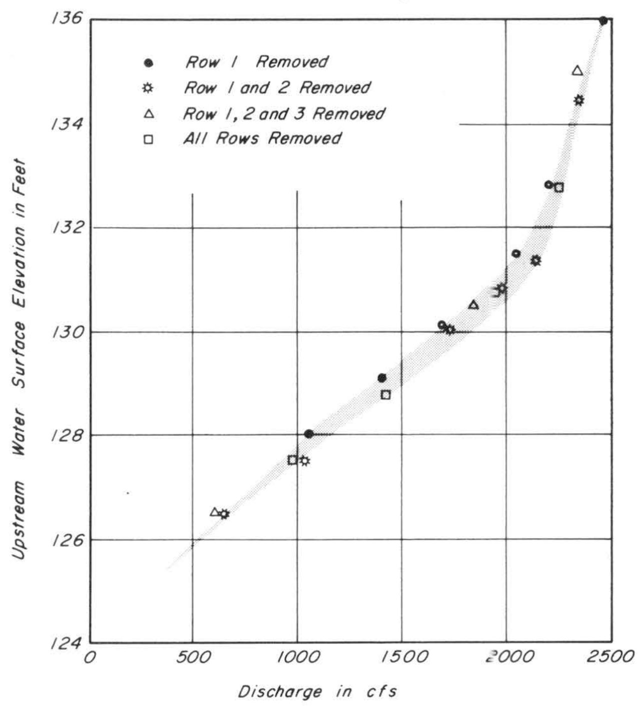



FIGURE 10. MODEL DISCHARGE RATING CURVE WITH BAFFLE BLOCK ROWS REMOVED

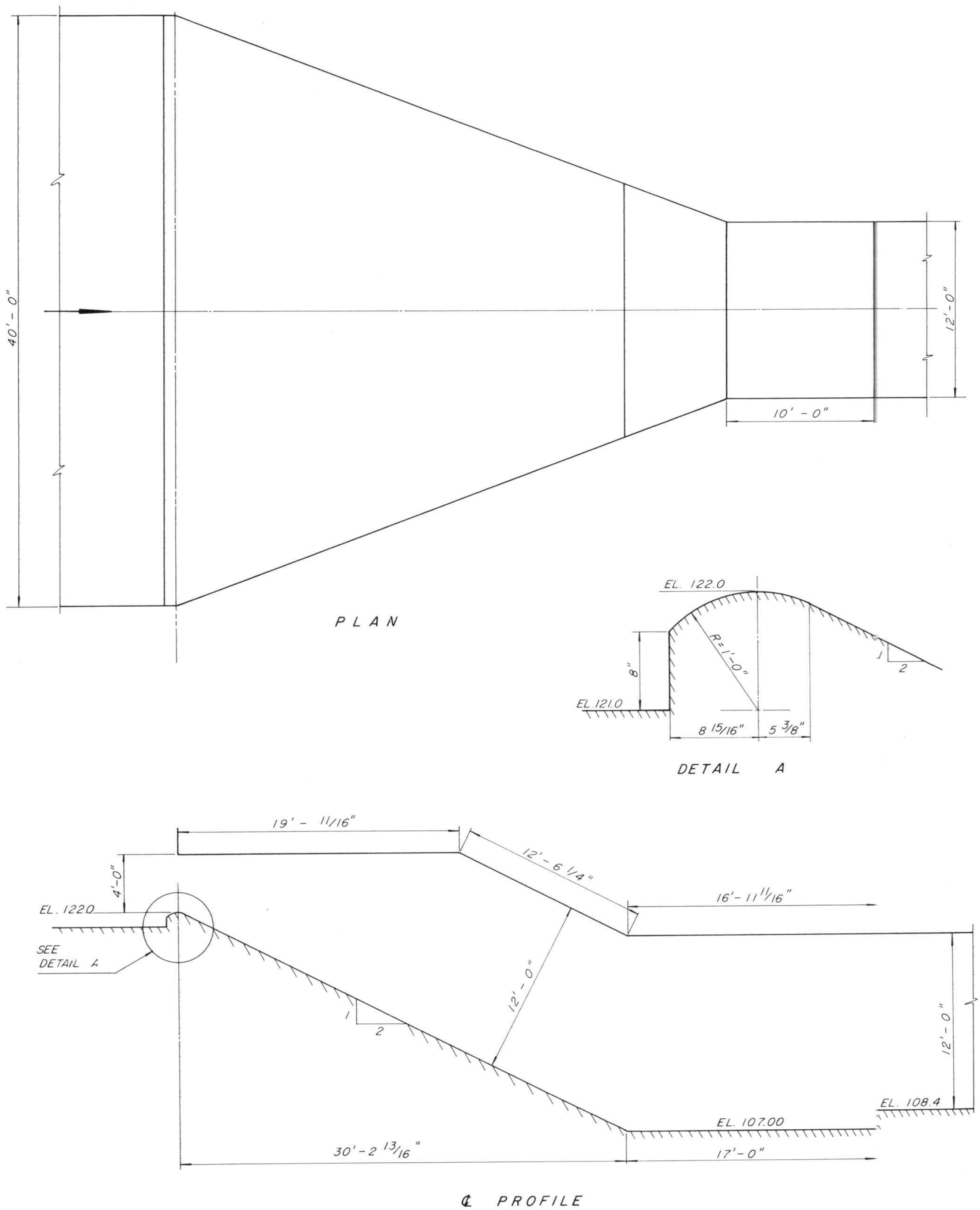



FIGURE II RECOMMENDED INTAKE

The discharge rating curve for the intake with modifications described above is shown in Fig. 12. Flow conditions through the intake, stilling basin and transition are satisfactory for all discharges. Pictorially, Fig. 13 shows the flow at the mouth of the intake and through the chute, stilling basin and transition for discharges of 930 cfs [4], 1500 cfs, and 2100 cfs.

The water surface profiles within the conduit for discharges between 930 cfs and 2100 cfs are shown in Fig. 14. The water surface elevations were determined from the piezometer readings. For discharges less than 2100 cfs the conduit flows with a free water surface downstream from the transition. For discharges greater than 2100 cfs, the conduit flows full for an undetermined distance before additional acceleration occurs and the character becomes open channel. The maximum pressure on the crown of the conduit was 2.9 feet of water, measured at piezometer No. 2, at a discharge of 2300 cfs. A pressure of 5 feet of water or less was considered satisfactory. Pressure data are given in the appendix.

Horizontal and vertical velocity traverses were made at a point located 60 feet downstream from the transition (see Fig. 8 for velocity traverse location). The velocity traverses were made with a calibrated pitot tube. A pressure transducer was used to measure the differential pressure of the pitot tube and convert the pressure to an electrical signal. The signal is passed through a square root amplifier and applied to one coordinate of an X-Y plotter. The other coordinate of the plotter plots the distance from the wall of the conduit by varying the voltage by means of a rotary potentiometer. With this arrangement, model velocity profiles were made at several discharges. Figure 15 shows velocity profiles in the conduit for discharges of 1900 cfs, 2100 cfs, and 2240 cfs. The velocity scale for the profiles in Fig. 15 is for the velocities observed in the model. The circled numbers indicate the prototype velocities in fps. From the velocity profile shown in Fig. 15, it can be seen that no unusual conditions prevail in the conduit.

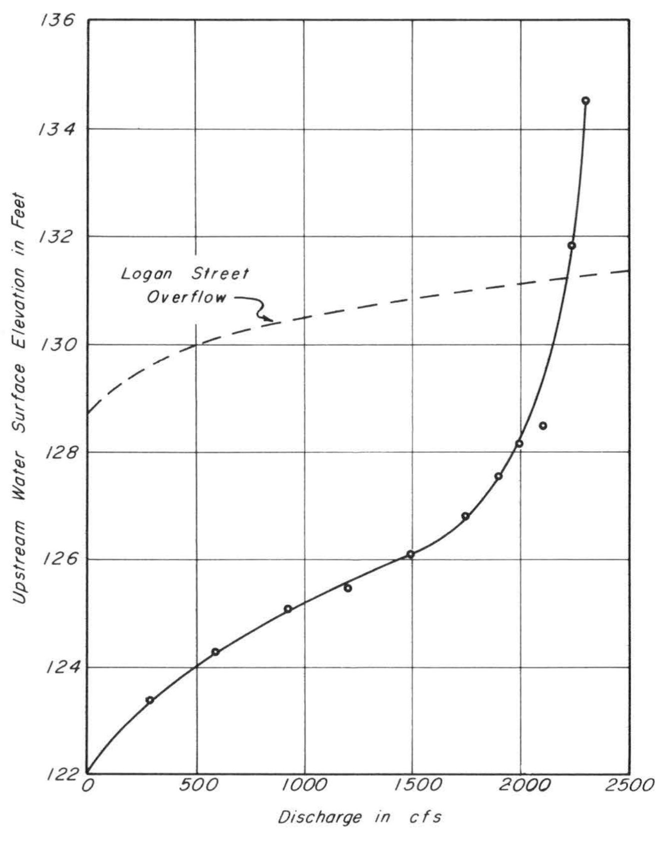



FIGURE 12 RECOMMENDED DISCHARGE RATING CURVE

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[4] Size of June, 1963 flood on Harvard Gulch

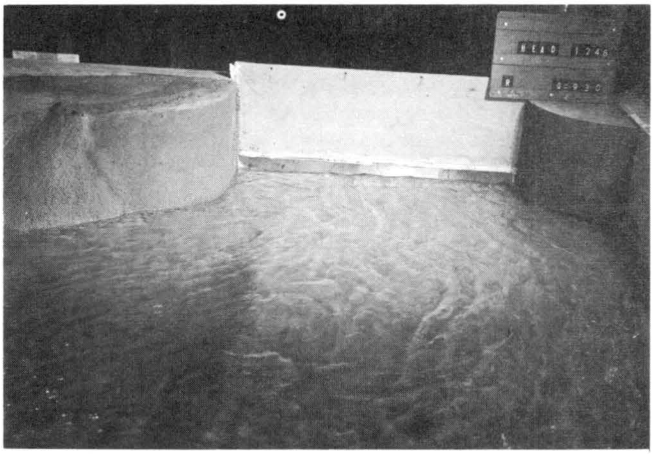

Figure 13 (a) Flow at mouth of intake Q = 930 cfs

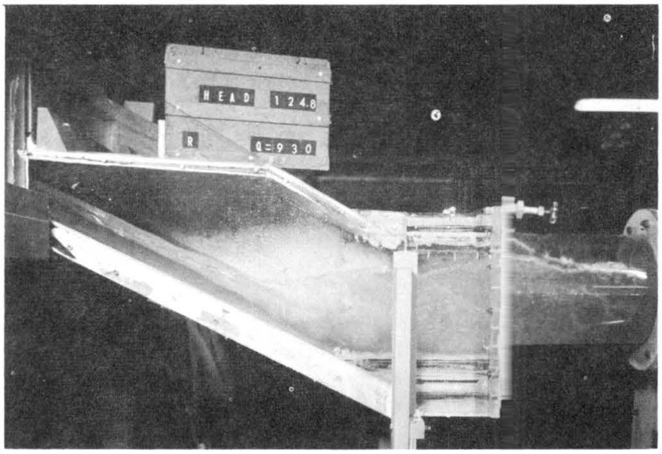


Figure 13 (b) Flow through chute, stilling basin, and transition Q = 930 cfs

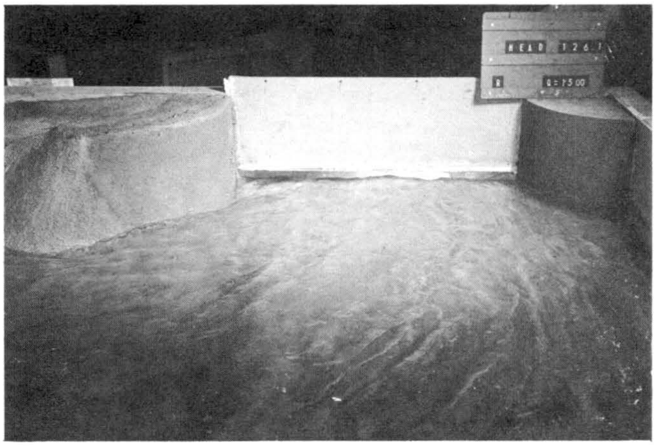

Figure 13 (c) Flow at mouth of intake Q = 1500 cfs

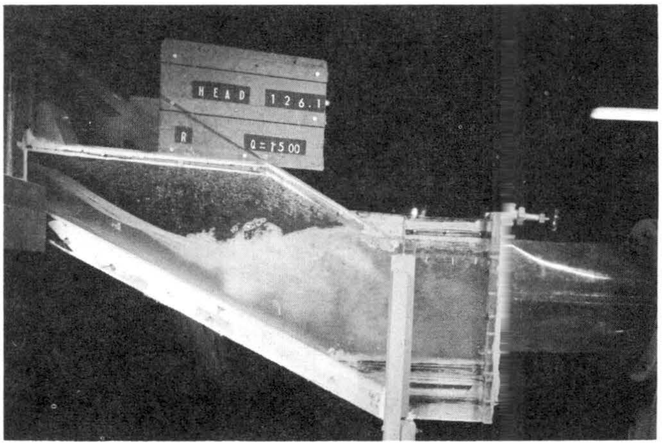


Figure 13 (d) Flow through chute, stilling basin, and transition Q = 1500 cfs

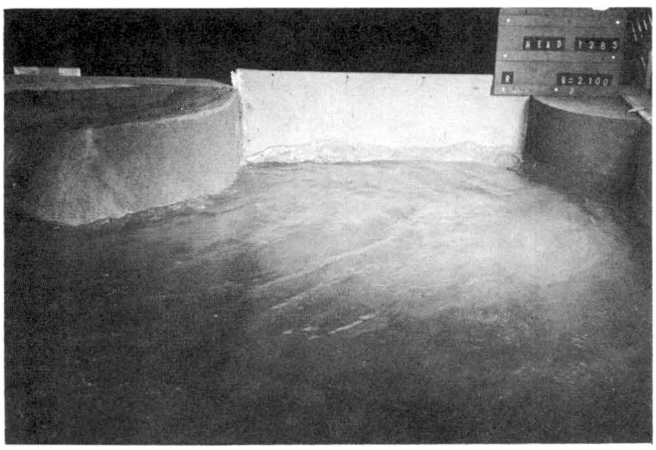

Figure 13 (e) Flow at mouth of intake Q = 2100 cfs

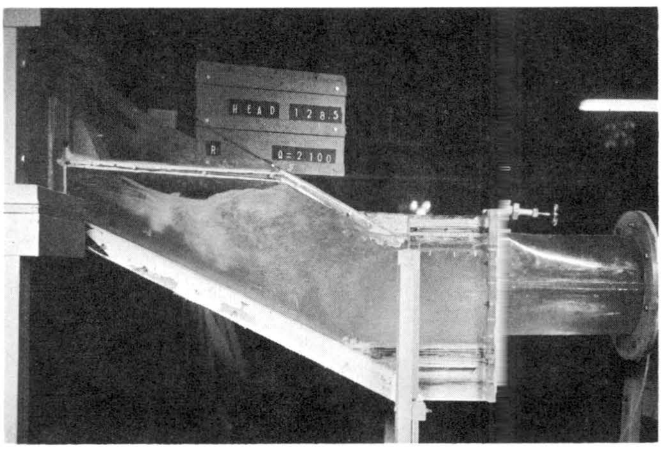


Figure 13 (f) Flow through chute, stilling basin, and transition Q = 2100

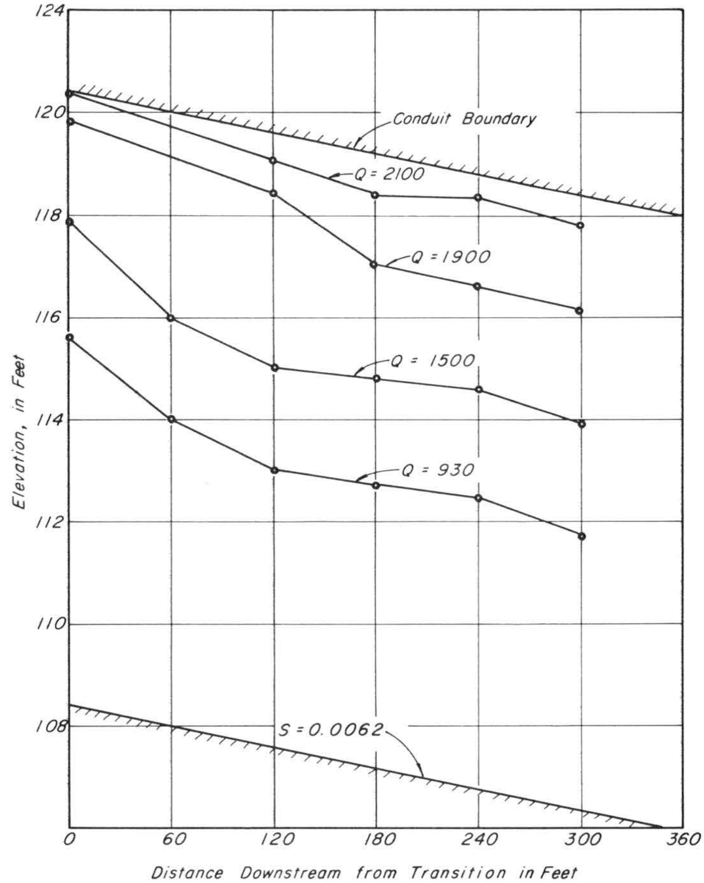


FIGURE 14 CONDUIT WATER SURFACE PROFILE

Note: Circled numbers indicate prototype velocities in fps.
H indicates horizontal velocity profile.
V indicates vertical velocity profile.

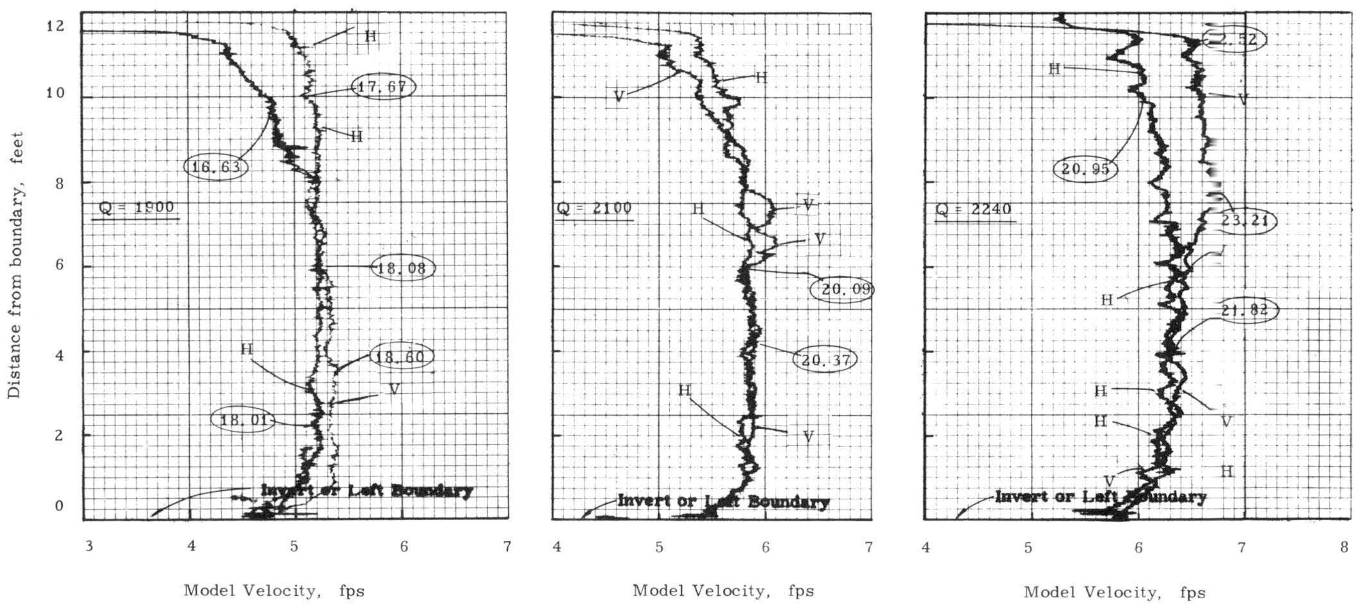


FIGURE 15 CONDUIT VELOCITY PROFILES

## Air Vents

The hydraulic jump which forms in the throat of the intake entrains a considerable amount of air. The air is supplied through the mouth of the intake until the mouth becomes submerged. After submergence of the intake some air enters at the vortices which are evident in an area just upstream from and near the corners of the mouth. Neither the vortices nor the entrained air create any adverse conditions within the intake.

Air vents were installed near the upstream end of the transition and in the conduit 60 feet downstream from the transition. The vent located in the transition was effective in the release of some air entrained by the hydraulic jump but did not appear to act as an air intake at any discharge. The amount of air released by this vent was neglibible. Hence the air vent in the transition was eliminated.

The air vent in the conduit is effective in providing both for release and intake of air For discharges to about 2000 cfs the hydraulic jump remains in the throat. The entrained air tends to rise to the water surface as it flows through the conduit. At discharges from about 1800 cfs to 2000 cfs the conduit is almost full in the vicinity of the vent and the air bubbles are released through the vent. For discharges from 2000 cfs, until the conduit flows full and under pressure,air is drawn into the conduit through this vent. For discharges above 2000 cfs, the intake is submerged. The throat is flowing full and very little air enters the conduit. The transition is full and the water is accelerating through the conduit. The flow tends to separate from the crown of the conduit. Aeration of the conduit through the vent located in the conduit permits a physical separation of the water from the crown and eliminates the possibility of local low pressure areas along the crown. An air vent in the conduit is recommended. The vent should be located at a distance from 40 feet to 80 feet downstream from the transition. The exact location of the vent to be determined with respect to the general location of the intake and Logan Street.[5]

[5] The consulting engineers have indicated that an opening in the conduit would be located in this general area. The opening would serve two purposes. It would act as an air vent when required and would be used to lower equipment for inspection and maintenance purposes.

# CONCLUSIONS AND RECOMMENDATIONS

## Intake

The crest of the intake should be set at elevation 122.0. The intake performs satisfactorily for all discharges up to 2300 cfs. For discharges up to about 2000 cfs the intake has a free overflow. For discharges larger than 2000 cfs the mouth is submerged and the intake performs as an orifice.

The floor of the stilling basin should be set at elevation 107.0. An end sill 1.4 feet high insures that a hydraulic jump will form at the lower discharges. Details of the recommended intake are shown in Fig. 11. The discharge rating curve is shown in Fig. 12.

## Transition

The transition performs satisfactorily for all discharges.

## Conduit

Flow conditions were satisfactory for all discharges up to 2300 cfs. The maximum pressure head on the crown of the conduit was 2.9 feet of water at a discharge of 2300 cfs. The velocity profiles indicate that no unusual flow conditions exist in the conduit.

## Air Vent

An air vent should be provided in the conduit at a distance from 40 feet to 80 feet downstream from the transition. This vent will allow both release and intake of air.

# APPENDIX

| Distance in cfs | Head Elevation in ft | Pressure head in feet of water at Piezometer No. | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 |
| 2300 | 134.5 | 14.6 | 14.9 | 14.0 | 13.5 | 13.6 | 13.2 |
| 2240 | 131.8 | 13.2 | 13.5 | 12.6 | 12.2 | 12.4 | 12.4 |
| 2100 | 128.5 | 12.0 | * | 11.5 | 11.2 | 11.6 | 11.4 |
| 2000 | 128.2 | 12.2 | 12.5 | 12.0 | 11.5 | 11.8 | 11.6 |
| 1900 | 127.6 | 11.4 | * | 10.8 | 10.2 | 10.2 | 9.8 |
| 1750 | 126.8 | 10.5 | 9.1 | 8.5 | 8.9 | 9.2 | 8.7 |
| 1500 | 126.1 | 9.5 | 8.0 | 7.4 | 7.6 | 7.9 | 7.7 |
| 1200 | 125.5 | 8.5 | 7.2 | 6.5 | 6.7 | 7.0 | 6.7 |
| 930 | 125.1 | 7.2 | 6.0 | 5.4 | 5.5 | 5.8 | 5.5 |
| 600 | 124.3 | 5.8 | 4.8 | 4.3 | 4.4 | 4.5 | 4.4 |
| 300 | 123.4 | 4.1 | 3.3 | 3.0 | 3.1 | 3.1 | 3.1 |

* Data not recorded.