University of Minnesota
St. Anthony Falls Hydraulic Laboratory

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PERFORMANCE STUDIES OF THE UNOCAL PUMP SUMP HYDRAULIC MODEL

by

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I. INTRODUCTION

Stone and Webster Engineering Corporation has prepared a preliminary hydraulic design of the Colorado River Water Supply Project for the UNOCAL Corporation. Of particular concern was the area extending from a proposed pumping station to a proposed grit basin on the Colorado River near Grand Valley. The grit basin is used as a settling pond to remove the sediment carried by the river.

Two vertical turbine, mixed flow, wet–pit pumps are proposed, and the sump is designed for installation of dual flow traveling screens in the future. The flow entering the sump from two 48–inch pipes connecting the station and the intake at the river is very complex, and hydraulic model studies were deemed necessary to evaluate the performance of the sump design. Of particular interest was the desire to achieve a relatively uniform flow–through velocity with a magnitude of about 0.5 fps at the face of the traveling screens. More specifically, the following items were to be addressed:

1. Investigate the existence and magnitude of potential problems related to the screens and pumps.

2. Investigate the flow pattern (magnitude and direction of the velocity) at the screens and pumps.

3. Investigate the dimensions of the baffle block in front of the pipe discharge, such as the height, opening of the orifice, the space from sump side wall and the loads at the baffle block.

4. Develop design changes and additions to correct any potential performance problems, with such changes being both compatible, in design and construction, to the sump constraints.

II. DESCRIPTION OF MODEL

A 1 to 8 undistorted scale model which included the two 48–inch diameter inlet pipes and the pump sump was constructed in accordance with the preliminary design as shown in Fig. 1. The internal components of the sump consisted of a baffle plate, the dual–traveling screens, and the two pump intakes. As the basin was symmetrical, only one of the pump intakes and vertical columns were operable. The model was incorporated into a recirculating loop using city water.

The sump itself was constructed of transparent plastic to permit flow visualization. The bottom of the sump was made larger than required so that one side wall could be moved if the width of the sump in the preliminary design was inadequate. As seen in Photo 1 the water was supplied to the sump through two 6–inch diameter PVC pipes, each fitted with a control valve and a calibrated orifice meter. The orifice calibrations are included in the Appendix. A carriage running on leveled racks was installed on the top of the sump. This carriage was used to allow movement of the velocity measuring equipment to the various measuring stations.

The pump columns were also modeled using 6–inch PVC pipe. The pumps themselves were not modeled; this is customary practice in such studies. Since the particular pumps were not selected at the time of the tests, the shape of the bellmouth intake was not available. Therefore, a generic shape was chosen with an outside diameter of 9 inches. The outside of the bellmouth was machined to a straight taper, and the inside consisted of a circular arc with a radius of 1.5 inches. This bellmouth was machined from transparent plastic (Photo 2). As only one pump intake was to be used in the model studies, the intake in the other column was made of a solid piece of wood to the same outside dimensions.

As is recommended practice in the modeling of such facilities, the screens themselves were not modeled. Installation of the screens in the prototype will typically provide a more uniform velocity distribution than found in the model.

The model was operated in accordance with the Froude law of similarity. This assures that the ratio of the inertia to gravity forces is the same in the model as in full scale. The pertinent scaling ratios between model and full scale parameters are listed below:

Length	L_r	1:8
Velocity	V_r	1:2.828
Discharge	Q_r	1:181
Time	T_r	1:2.828

Thus, if the full scale velocity is 0.5 fps, the velocity in the model is 0.18 fps.

The test variables specified for the model study are given in the following table:

Table 1. Test Variables

1. With dual–flow traveling screens:

Pumping Rate (cfs)	Sump Water Level (ft)	No. of Pipes Discharging
123.5	5066.1	2
92.6	5063.4	1
137.2	5076.5	2

2. With stationary screens:

Pumping Rate (cfs)	Sump Water Level (ft)	No. of Pipes Discharging
123.5	5066.1	2
92.6	5063.4	1
137.2	5076.5	2

III. MODEL OBSERVATIONS

Several criteria were chosen to be indicative of overall pump sump performance. Items of particular interest included the baffle plate, both the dual flow traveling screen, and the stationary screen designs, as well as the bellmouth region.

The modeling program required that testing and modification of the dual flow traveling screen design be completed prior to testing the stationary screen design. Sump performance was evaluated under four different flow conditions:

Flow Condition	Pumping Rate (cfs)	Sump Water Surface Elevation (ft)	No. of Pipes Discharging
1	123.5	5066.1	2
2 and 4	92.6	5063.4	1
3	137.2	5076.5	2

Flow condition 1 is a condition which is anticipated to be periodically encountered during prototype operation and also the condition most likely to cause detrimental operational problems. As such, condition 1 was deemed the "critical" test condition and was used to test many developmental design modifications.

Flow condition 2 is known as the "flushing" case during which water is drawn into the sump using only one intake pipe. Using a single intake pipe will provide higher than normal velocities causing the intake pipe to be flushed of any accumulated sediment. As the flushing is anticipated to be an infrequent occurrence, this condition was tested and documented for the final design configurations only. Due to the flow asymmetry to the sump being provided by one pipe for all incoming water, this condition was tested for water discharging from either the right or the left inlet pipe; hence, the fourth different flow condition.

Flow condition 3 is a typical prototype operating condition with a slight increase in flow over condition 1. The increase in sump water surface elevation of over ten feet from flow condition 1 greatly increased the cross-sectional area of the screen and the bellmouth submergence. As these two conditions should enhance sump performance as compared to flow condition 1, flow condition 3 was tested only for the final dual flow traveling screen and the stationary screen designs.

Flow patterns near the baffle plate were observed in a qualitative manner to verify that the intake pipe discharge was evenly distributed throughout the sump, thereby balancing flow between the right and left screens.

Velocity normal to the screen faces was measured using a Marsh–McBirney, Inc. Model 523, two–component magnetic velocity meter for both the dual flow traveling screen and stationary screens. The instrumentation setup is seen in Photo 3. For each face, a measurement grid consisting of a 2 ft horizontal by 2.2 ft to 3.0 ft vertical spacing (prototype) was used to define the velocity distribution at the screen face. Flow near the bellmouth was observed qualitatively, and to an extent quantitatively, to ascertain the overall flow entering the bellmouth. The region was observed for both submerged and surface vortex formation using dye. Yarn angles under the bellmouth were measured to determine the magnitude of the non–radial flow component. In addition, velocity profiles were taken just upstream of the bellmouth to check the approach flow pattern. Initially the flow meter information was manually recorded from the indicating needles. This generally worked quite well; however, to avoid any possible skewing of the data caused by visual observation and manual recording, the meter signal was computer recorded beginning with configuration T, run 3F.

IV. DISCUSSION OF RESULTS

A. Dual Flow Traveling Screens

1. Model Modifications

Formal testing commenced on April 26, 1989, and continued until early August 1989. Most of the testing centered on the internal sump modifications necessary to create reasonably uniform conditions. Additionally, the stationary screens were tested with all proposed modifications for the dual flow traveling screens intact and also with only the revised baffle installed.

Modifications were confined to two areas: the baffle near the sump inlet pipes and the installation (and subsequent testing and modification) of additional flow distribution devices near the dual flow traveling screens. Due to the vast quantity of data taken during the testing program, only the test results for the final design have been included in this report. All data taken are stored in SAFHL archives and are available to the client at their request. A summary listing data availability is provided in Table 2.

To avoid confusion, all directions are given looking downstream from the intake pipes.

During the course of the model studies, a large number of revisions to the baffle and the structure in the vicinity of the dual–traveling screens were necessary. Each of these revisions were denoted alphabetically, starting with the preliminary design, Configuration A. The list of modifications is presented in Table 2. The following text describes the modifications in an additive manner, each building on the previous modification. Configuration B was a revision of configuration A solely to correct for a minor miscommunication in the model design. Configuration B was modified to configuration C by adding a rectangular flow obstruction to each sidewall, midway between the baffle plate and the upstream end of the dual flow traveling screens. Changing from C to D involved modifying the baffle plate by removing the central support effectively creating a single orifice.

Configuration E, involved removal of the sidewall flow obstruction. Configuration F was created by installing triangular flow obstruction wedges where the rectangular ones were earlier. Configuration G was comprised of the triangular wedges and the original baffle plate. Configuration H tested replacement of the left sidewall triangular wedge with a rectangular wedge. Configuration I incorporated dual symmetrical 9 ft, 6 inch high by 7 ft, 0 inch wide inlet baffles and removal of the sidewall wedges. Configuration J reduced the spacing between each baffle and the sidewall from the 33 inch spacing in "I" to 26 inches in "J." The baffle to side wall spacing was returned to 33 inches in Configuration K, which involved the installation of a flow directing wedge with a protruding plate extending upstream a short distance, midway between the upstream ends of the right and left dual flow traveling screens. Configuration L increased the distance to the downstream end of flow wedge as measured from the upstream end of the screen faces, from the 18 inches in "K" to 20 inches. Configuration M further increased this to 24 inches. Configuration N eliminated the plate protruding upstream from the nose and increased the distance measured from the upstream end of the screens to the downstream edge of the wedge to 27 inches. Changing from configuration N to P involved insertion of two sidewall wedges in the same plane as the central wedge while also increasing the height of the upstream baffles to 13 ft, 9 inches, and decreasing the width 1 inch. In Configuration Q, the baffles were returned to 9 ft, 6 inches in height but the baffle was extended for its top 2 ft to encompass the entire width of the basin, in effect creating three orifices. Configuration R again tested the 13 ft, 9 inches high baffle with the sidewall wedges moved slightly. Configuration S tested the 9 ft, 6 inches baffle with the revised wedge placement. The testing of the dual flow traveling screen was culminated with configuration T.

Configuration T, as shown in Fig. 2, is the final revision tested for the dual flow traveling screen design and involves several modifications to the sump from the preliminary design of Fig. 1. The initial design resulted in high velocity wall jets along both outside walls of the sump, which led to high velocities along the downstream edge of the outboard screen faces. To reduce these velocities, the baffle plate was modified from the original design of a symmetrical single 9.5 ft high x 14.5 ft wide baffle with two 3.5 ft high x 4.25 ft wide orifices to two symmetrical 13.75 ft high x 7.00 ft wide baffles with a 3.33 ft spacing between them. Additional modification involved the installation of two 1.83 ft x 5.5 ft side wall triangular wedges and a central wedge 3.79 ft x 5.5 ft which extends to the top of the sump. The splitter wall, between the two pump columns, was modified from the proposed design by blocking the 1.5 ft wide opening along the back part of the wall's lower half.

Table 2. Configurations tested:

Configuration	Sump water Elevation ft	Data available		
		Screen Velocities	Bell-mouth Velocities	Yarn angles
A	5066.1	Y	N	N
B	5066.1	Y	N	N
C	5066.1	Y	N	N
D	5066.1	Y	N	N
E	5066.1	Y	N	N
F	5066.1	Y	N	N
G	5066.1	Y	N	N
H	5066.1	Y	N	N
I	5066.1	Y	N	N
J	5066.1	Y	N	N
K	5066.1	Y	N	N
L	5066.1	Y	N	N
M	5066.1	Y	N	N
N	5066.1	Y	N	N
0	5066.1	Y	N	N
P	5066.1	not complete	N	N
Q	5066.1	not complete	N	N
R	5066.1	Y	N	N
S	5066.1	Y	N	N
T	5066.1	Y	Y	Y
T	5063.4	Y	Y	Y
T	5076.5	Y	Y	Y
U	5066.1	Y	Y	N
U	5063.4	Y	Y	N
U	5076.5	Y	Y	N
V	5066.1	N	N	Y

2. Velocity Distributions

Qualitatively, as seen in Photo 4, the flow in the baffle plate region was noticeably improved with configuration T, wall jets were substantially reduced, and the flow redistributed in a more uniform manner. The results can be quantitatively seen in Figures 3 through 18 showing that reasonably uniform velocities were obtained during final configuration testing of the dual flow screens. Note that for all figures related to the dual flow traveling screens, x is measured from the downstream edge of the upstream screen frames and z is measured down from the water surface. A summary of the results can also be seen in Table 3. Figures 3 through 6 pertain to the relatively low water surface elevation case denoted as flow condition 1 earlier in this report. The final testing runs were labeled using the following notation. Runs 3F, 4F and 5F represent testing at a water surface elevation of 5066.1 ft and a sump inflow of 61.7 cfs from each inlet pipe. Runs 1R, 2R and 1L, 2L represent testing at water surface elevation 5063.4 ft and a sump inflow of 92.6 cfs through the right or left pipe, respectively. Testing at water surface elevation 5076.5 with an evenly distributed sump inflow of 68.6 cfs per inlet pipe is represented in runs High 1,2,3.

As seen from Figures 3 through 6, flow is distributed fairly uniformly between the right and left screen. Additionally, the flow is quite well balanced between the port and starboard sides of each screen. Within each screen face the flow is as uniform as can be reasonably expected for such a facility. Flow velocities are generally somewhat higher near the bottom center of each screen face. Higher than average velocities are also seen at the top center of the left screen, screen faces and at the downstream edge of the left starboard screen. Low inflow velocities are noted along the upstream end of the screen faces both near the water surface and the sump bottom. Low velocities are also noted at the lower elevations of the downstream edge of each screen face. As noted earlier, twenty design variations were tested with configuration T found to provide good overall flow conditions and reasonably uniform screen face velocities. A statistical analysis of the velocities obtained during the testing of configuration T will follow later in this section.

Testing for the water surface elevation of 5076.5 (denoted by the word high on the data sheets) proved uneventful as was expected. The inflow was well distributed between the right and left screens. Both screens exhibited flow 15 to 20 percent higher on the outboard screen face than the inboard screenface. However, within the measurement accuracy of the tests, all screen faces show generally uniform velocities well below the 0.31 ft/s chosen as the "critical" velocity. The velocity of 0.31 was chosen based on a general criteria of 0.5 fps through–screen velocity and a screen porosity of 62%. As in the previous test, the extreme corners of the screen faces, particularly along the upstream edge, have reduced velocity.

Testing of the flushing cases (Flow conditions 2 and 4) where all inflow was provided through either the right or left intake (denoted by R or L on the data sheets) showed highly variable, yet symmetrical, velocity distributions. If one flips the figures symmetrically, i.e. right starboard

Runs 1L and 2L to left port for runs 1R and 2R, etc., the similarity of the velocity distribution is startling. While this flow condition will occur very infrequently and is not of consequence in general operation of the facility, these results do indicate a generally good design (i.e. symmetrical flow patterns) and reliable model test. As in the previous tests, flow distribution between the screens is relatively balanced; however, in excess of 2/3 of the water enters each screen through outboard screen face.

Table 3. FLOW DISTRIBUTION SUMMARY
DUAL FLOW TRAVELING SCREENS*

Run		Left Port	Left Star	Left Total	Right Port	Right Star	Right Total	Total
3F,4F,5F	Flow	30.0	32.9	62.9	29.0	27.7	56.7	119.6 cfs
	Percentage	25.1	27.5	52.6	24.2	23.2	47.4	
1R, 2R	Flow	34.4	18.2	52.6	12.2	35.2	47.4	100.0 cfs
	Percentage	34.4	18.2	52.6	12.2	35.2	47.4	
1L,2L	Flow	31.2	14.8	46.0	11.8	38.8	50.6	96.6 cfs
	Percentage	32.3	15.3	47.6	12.2	40.2	52.4	
High 1,2,3	Flow	38.2	30.8	69.0	34.6	40.5	75.1	144.1 cfs
	Percentage	26.5	21.4	47.9	24.0	28.1	52.1	

* All values shown are an average of the runs listed.

3. Pump Intake

The sump performance in the bellmouth region appeared to be quite good. The yarn angles under the bellmouth varied less than 10 degrees from radial for typical operating conditions. A weak floor vortex was noted under the center of the bellmouth. Infrequent formation of small dye core vortices was noted in the back right and left corners of the sump. Of Photos 5, 6, and 7 only Photo 7 shows any rotational tendency while photos 5 and 6 just show generalized turbulence. However, such vortex formation can be very specific to the particular bellmouth design. As the pump manufacturer was not known at the time of the model study, it was only possible to model a typical design anticipated to be installed in the prototype; therefore, little can be said as to the exact prototype performance other than minimal vortex formation is expected if the bellmouth closely resembles the model. Further information on bellmouth performance can be seen in the SAFHL video produced as a supplement to this report.

B. Sensitivity Analysis

As part of the test program, the Laboratory reviewed magnetic flow meter performance for the UNOCAL project. The isolated higher values of velocity recorded during testing can be explained as several possible combinations of occurrences. The sensitivity analysis was done for data collected at the right starboard screen; however, results of the analysis apply generally to all data taken.

First, for the measurement locations along the downstream edge of the right starboard screen, SAFHL probed several and found that a localized velocity gradient existed very near the downstream wall. The effect of incorrectly placing a meter in this location by as little as 1/2" (model) can cause over a 40% variation in the observed velocity. It is probable that this velocity gradient would be apparent in most designs and is believed to be caused by the downstream screen framing. It should be emphasized that the region affected is quite small, and the discrepancy is only apparent when measuring very near the downstream edge of the screen.

However, it does explain the higher than expected readings sometimes observed at these locations. In addition, metering factors 2a–2d described below can also affect these readings.

With regard to the location at the bottom center of the screen, 5 ft downstream of the upstream end of the screen, 9.8 ft below the water surface, the Laboratory checked numerous potential factors which are summarized as follows:

1. Effect of meter positioning was not critical.

2. The Laboratory took 171 readings over a three–day period at this location. These data shown in Figures 19 and 20 indicate the mean to be approximately 0.35 ft/s. This basically agrees with the values obtained during runs 1F and 3F of 0.37 and 0.35 ft/s; run 2F indicated a value of 0.14 ft/s. Note that Runs 1F and 2F were taken manually, not by computer and therefore were not included in the overall data analysis of Figures 3 through 18.

   It is believed that a mean value for this location of 0.35 ft/s is an accurate representation. The values obtained during runs 5F(a) and 5Fb of 0.441 and 0.46 ft/s, respectively, when added to all other points obtained at this location, have the probability of exceedence of approximately 1 percent for 0.46 ft/s and 13 percent for 0.41 ft/s. However, it is very possible these readings were affected by any, or a combination, of the following.

   a. A noticeable effect of temperature on the meter was apparent. The testing procedure of taking zeros immediately prior to and after testing a screen face should minimize this effect. However, a small potential for error can exist.

   b. Due to signal amplification, an RMS electronic noise of ± .085 ft/s prototype may be apparent.

   c. The resolution of the meter is 0.03 ft/s. This relates to ± 0.085 ft/s prototype.

d. The azimuth accuracy of the meter, due to flow in the vertical direction in testing of the UNOCAL sump model, can be as high as ± 0.05 ft/s (± 0.14 ft/s prototype). The vertical flow component in the model is likely quite small. Therefore, while this may be noticed in certain locations, its effect should be less than 0.14 ft/s.

In summary, the velocity profiles obtained during testing of the UNOCAL sump study appear reasonably uniform. The higher than expected values for runs 5F(a) and 5F(b) are most likely due to a combination of factors 2a, 2b, 2c, and 2d. In addition meter positioning was found to be critical near the downstream edge of the screen. The bottom central region of the screen (position 5, 9.8) appears to have a mean value of 0.35 ft/s. This value ± 10 percent (0.32 to 0.38 ft/s) contains approximately 70 percent of all readings. If one includes the single effect of any factor, 2b, 2c, or 2d, even an observed velocity of 0.46 ft/s falls within this range. It is reasonable that flow fluctuations on the order of ± 10 percent are possible in the model at any one time, and readings significantly above 0.35 ft/s are most likely due to a combination of factors 2a, 2b, 2c and 2d.

C. Stationary Screens

1. Velocity Distributions

Upon completion of the testing of configuration T, the dual flow traveling screen framing was removed and framing for the stationary screens installed (configuration U, Fig. 21). Testing was done without removing the triangular wedges upstream of the screens. It is our understanding that the wedges will be installed only if the dual flow traveling screens are installed. Removal of the wedges would likely lead to more uniform overall velocity profiles at the screen faces.

Labeling of the testing runs for the stationary screens followed a format similar to that used for the dual flow traveling screens. Runs S–a,b,c, represents testing at water surface elevation 5066.1 and a sump inflow of 61.7 cfs from each inlet pipe. Runs S–R, and S–L represent testing of the two flushing cases and run S–H represents testing water surface elevation 5076.5 and a sump inflow of 68.6 cfs per pipe.

The test results of configuration U, Figs. 22 to 29, indicate reasonable general flow uniformity for flow condition 1, with somewhat lower velocities near the outboard edge of both screen faces. To some extent this may be due to the deflection of the wall jet by the outboard wedges. Testing of flow condition 3 shown in Photo 8 exhibited a slight wandering effect, possibly caused by the low velocities which may explain the lack of symmetry in the data taken near the outboard edge of the screens; however, general flow patterns appear quite good. Test conditions 2 and 4 showed that during flushing most, if not all, of the water can be expected to go through the screen opposite of that being flushed. Photo 9 shows the general flow pattern and Photo 10, dye testing for vortices under test condition 2.

2. Pump Intake

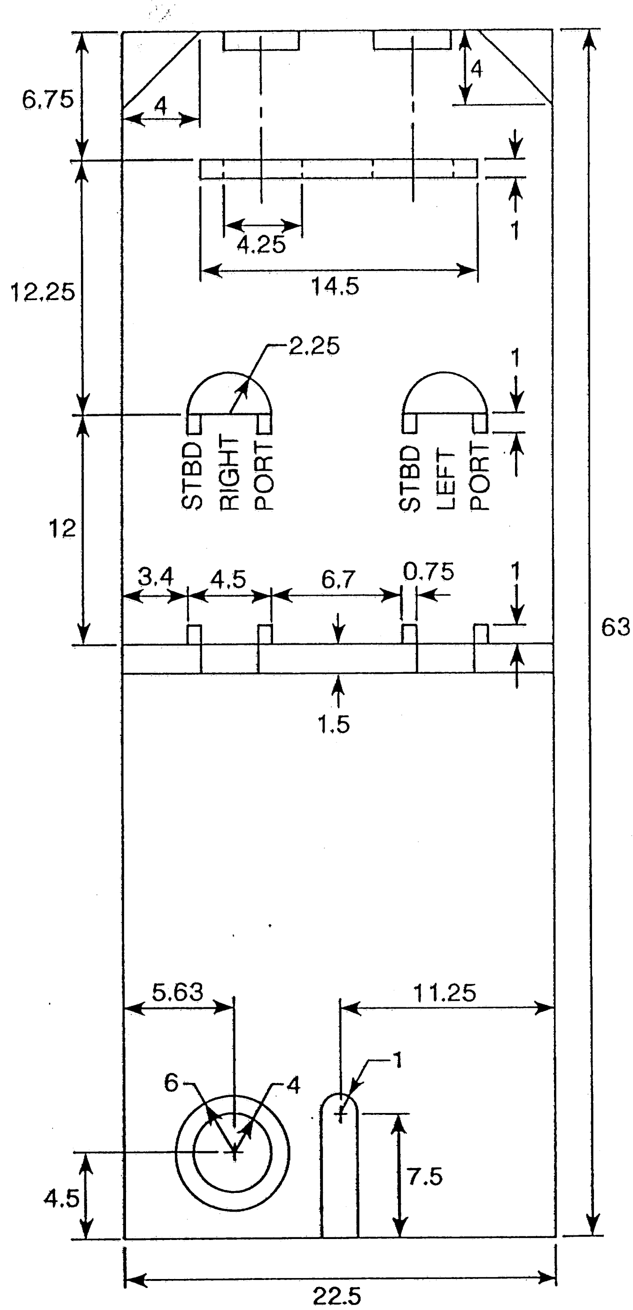
For configuration U the velocities just upstream of the bellmouth were taken for flow conditions 1 and 3, and one flushing case at the request of Stone & Webster Engineering Corporation. These data are included in the Appendix and showed expected results with the velocity much higher near the bottom of the bellmouth. As in configuration T, weak floor vortices were apparent underneath the center of the bellmouth (Photo 11). A few weak surface vortices were noted with a general rotation seen in the back right corner. This can be observed in the videotape.

The flow patterns in the bellmouth region were also reviewed for configuration V, Fig. 30, which simply was configuration U with all wedges removed. Testing of configuration V revealed the occasional formation of a very narrow surface vortex of dye core strength in the near left–hand corner of the pump column. This vortex formation was infrequent and may be very dependent upon the particular bellmouth design.

After completion of the testing program it was brought to SAFHL's attention by Stone & Webster that it would be advantageous to construct the stationary screens 5.17 ft further upstream from bellmouth. While it is difficult to state for certain what effects will be noted, it is our opinion that the modification will not be detrimental to flow in the bellmouth region.

V. CONCLUSIONS

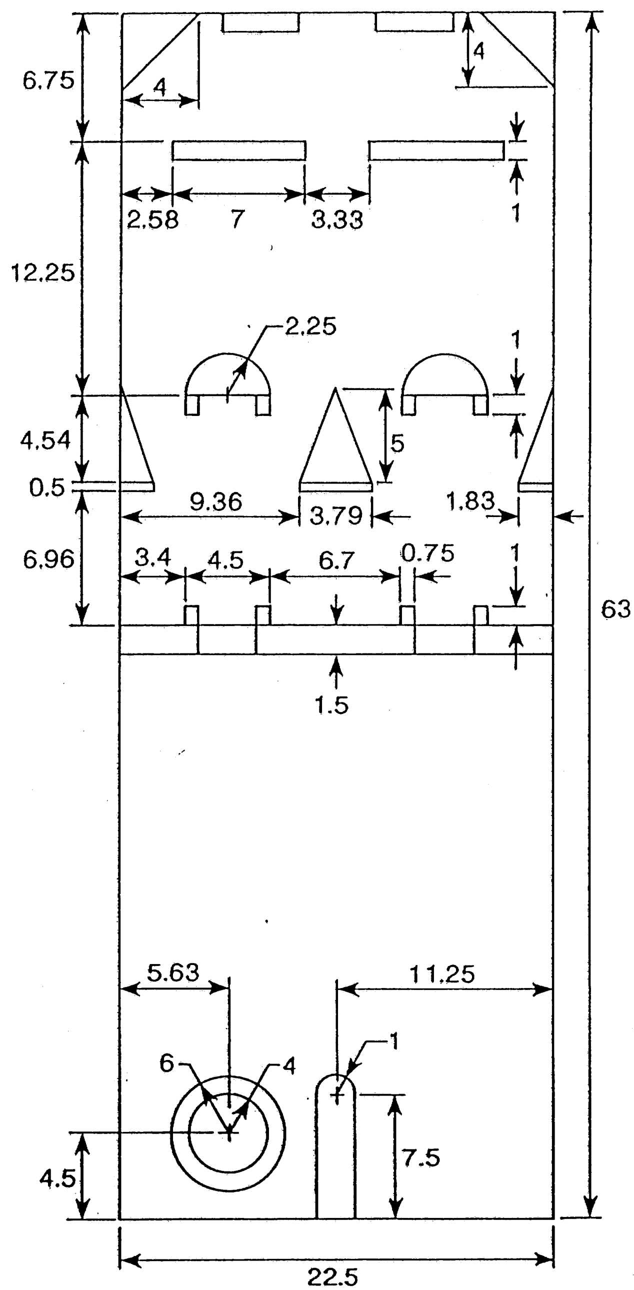
The UNOCAL pump sump as modified performs quite well. The final baffle block design shown in Fig. 2 of configuration T, effectively dissipates incoming energy and provides good flow distribution. Velocity patterns in the vicinity of the dual flow traveling screens are relatively uniform. Prototype screen face porosity adjusted values averaged 0.37 ft/s for flow condition 1, and 0.25 ft/s for flow condition 3 well below the suggested limit of 0.5 ft/s. The test data taken ascertaining the through screen velocity are as uniform as can reasonably be expected. The sensitivity analysis shows that in isolated regions of higher velocity the percentage of exceedence is typically quite low. In other cases isolated readings higher than anticipated may be, wholly or in part, due to several metering factors themselves and may not actually be occurring. As is recommended practice in the modeling of such facilities, the screens themselves were not modeled. Installation of the screens should act to reduce any velocity variations seen in the model. Velocity distribution near the bellmouth is generally well balanced and only occasionally a few weak surface vortices were apparent. It is recommended that the overall sump dimensions remain unchanged with only those interior modifications shown in configuration T and stated in the report being incorporated into the design.



INITIAL CONFIGURATION
ALL DIMENSIONS IN FEET

Figure 1.

BAFFLE HEIGHT 9.5 FT



CONFIGURATION T (PROTOTYPE)
ALL DIMENSIONS IN FEET

Figure 2.

BAFFLE HEIGHT 13.75 FT

Figure 3. VELOCITY DISTRIBUTION

Config. T
Run No: 3F,4F,5Fa,b

Location: Right Starboard
W.S. Elev. 5066.1
Discharge: L = 61.7, R = 61.7 cfs

Z	1.0	3.0	5.0	7.0	9.0
1.0	x –0.06	x 0.18	x 0.23	x 0.20	x 0.19
3.2	x 0.06	x 0.27	x 0.28	x 0.20	x 0.31
5.4	x 0.28	x 0.30	x 0.23	x 0.09	x 0.31
7.6	x 0.29	x 0.30	x 0.25	x 0.18	x 0.33
9.8	x –0.02	x 0.27	x 0.41	x 0.29	x 0.28
12.0	x –0.07	x 0.20	x 0.33	x 0.21	x –0.07

$\overline{V}$ = 0.21 ft/sec
Q = 27.73 cfs

Figure 4. VELOCITY DISTRIBUTION

Config. T
Run No: 3F,4F,5F

Location: Right Port
W.S. Elev. 5066.1
Discharge: L = 61.7, R = 61.7 cfs

	1.0	3.0	5.0	7.0	9.0
1.0	x –0.06	x 0.19	x 0.31	x 0.34	x 0.31
3.2	x 0.06	x 0.28	x 0.28	x 0.20	x 0.32
5.4	x 0.35	x 0.30	x 0.14	x 0.20	x 0.31
7.6	x 0.33	x 0.33	x 0.22	x 0.20	x 0.16
9.8	x 0.07	x 0.27	x 0.30	x 0.25	x 0.11
12.0	x 0.04	x 0.24	x 0.32	x 0.27	x 0.0
Z					

$\overline{V}$ = 0.22 ft/sec
Q = 28.99 cfs

Figure 5. VELOCITY DISTRIBUTION

Config. T
Run No: 3F,4F,5F

Location: Left Starboard
W.S. Elev. 5066.1
Discharge: L = 61.7, R = 61.7 cfs

Z	1.0	3.0	5.0	7.0	9.0
1.0	x 0.01	x 0.21	x 0.36	x 0.30	x 0.28
3.2	x 0.07	x 0.34	x 0.33	x 0.19	x 0.31
5.4	x 0.30	x 0.29	x 0.20	x 0.09	x 0.46
7.6	x 0.27	x 0.35	x 0.23	x 0.21	x 0.45
9.8	x 0.10	x 0.36	x 0.39	x 0.23	x 0.27
12.0	x 0.00	x 0.28	x 0.42	x 0.27	x –0.03

$\overline{V}$ = 0.25 ft/sec
Q = 32.92 cfs

Figure 6. VELOCITY DISTRIBUTION

Config. T
Run No: 3F,4F,5F

Location: Left Port
W.S. Elev. 5066.1
Discharge: L = 61.7, R = 61.7 cfs

Z	1.0	3.0	5.0	7.0	9.0
1.0	x 0.01	x 0.29	x 0.43	x 0.34	x 0.30
3.2	x 0.12	x 0.32	x 0.37	x 0.30	x 0.23
5.4	x 0.25	x 0.25	x 0.20	x 0.15	x 0.19
7.6	x 0.35	x 0.25	0.15	x 0.01	x 0.10
9.8	x 0.22	x 0.28	x 0.38	x 0.21	x 0.17
12.0	x 0.10	x 0.31	x 0.38	x 0.27	x –0.07

$\overline{V}$ = 0.23 ft/sec
Q = 29.96 cfs

Figure 7. VELOCITY DISTRIBUTION

Config. T
Run No: 1R, 2R

Location: Right Starboard
W.S. Elev. : 5063.4
Discharge: L = 0, R= 92.6 cfs

Z	1.0	3.0	5.0	7.0	9.0
1.3	x 0.11	x 0.45	x 0.69	x 0.61	x 0.39
3.9	x 0.18	x 0.57	x 0.78	x 0.51	x 0.39
6.5	x 0.16	x 0.53	x 0.70	x 0.33	x 0.16
9.1	x 0.34	x 0.33	x 0.28	x –0.23	x –0.52

$\overline{V}$ = 0.34 ft/sec
Q = 35.15 cfs

Figure 8. VELOCITY DISTRIBUTION

Config. T
Run No: 1R,2R

Location: Right Port
W.S. Elev. 5063.4
Discharge: L = 0, R= 92.6 cfs

Z	1.0	3.0	5.0	7.0	9.0
1.3	x 0.10	x –.09	x –0.36	x –0.40	x 0.96
3.9	x –0.04	x –0.01	x –0.48	x –0.31	x 1.30
6.5	x –0.19	x –0.30	x –0.57	x –0.19	x 1.42
9.1	x –0.12	x 0.21	x –0.05	x 0.27	x 1.19

$\overline{V}$ = 0.12 ft/sec
Q = 12.17 cfs

Figure 9. VELOCITY DISTRIBUTION

Config. T
Run No: 1R,2R

Location: Left Starboard
W.S. Elev. 5063.4
Discharge: L= 61.7, R= 61.7 cfs

Z	1.0	3.0	5.0	7.0	9.0
1.3	x –0.16	x 0.37	x 0.06	x –0.14	x –0.01
3.9	x 0.24	x 0.57	x 0.24	x –0.02	x 0.11
6.5	x 0.21	x 0.67	x 0.41	x 0.15	x 0.16
9.1	x 0.04	x 0.39	x 0.45	x –0.04	x –0.19

$\overline{V}$ = 0.18 ft/sec
Q = 18.25 cfs

Figure 10. VELOCITY DISTRIBUTION

Config. T
Run No: 1R,2R

Location: Left Port
W.S. Elev. 5063.4
Discharge: L= 0, R= 92.6 cfs

Z	1.0	3.0	5.0	7.0	9.0
1.3	x 0.12	x 0.52	x 0.51	x 0.44	x 0.40
3.9	x 0.24	x 0.77	x 0.61	x 0.26	x 0.22
6.5	x 0.20	x 0.61	x 0.53	x 0.19	x 0.10
9.1	x 0.20	x 0.44	x 0.38	x 0.14	x –0.27

$\overline{V}$ = 0.33 ft/sec
Q = 34.37 cfs

Figure 11. VELOCITY DISTRIBUTION

Config. T
Run No: 1L,2L

Location: Right Starboard
W.S. Elev. 5063.4
Discharge: L = 92.6, R = 0 cfs

Z	1.0	3.0	5.0	7.0	9.0
1.3	x 0.23	x 0.53	x 0.38	x 0.33	x 0.52
3.9	x 0.30	x 0.73	x 0.55	x 0.33	x 0.39
6.5	x 0.12	x 0.59	x 0.56	x 0.23	x 0.29
9.1	x 0.13	x 0.61	x 0.56	x 0.23	x –0.14

$\overline{V}$ = 0.37 ft/sec
Q = 38.84 cfs

Figure 12. VELOCITY DISTRIBUTION

Config. T
Run No: 1L,2L

Location: Right Port
W.S. Elev. 5063.4
Discharge: L = 92.6, R = 0 cfs

	1.0	3.0	5.0	7.0	9.0
1.3	x –0.20	x 0.24	x 0.05	x –0.15	x –0.02
3.9	x 0.15	x 0.43	x 0.18	x –0.02	x 0.17
6.5	x 0.20	x 0.55	x 0.33	x 0.04	x 0.13
9.1	x 0.02	x 0.27	x 0.10	x –0.02	x –0.19
Z					

$\overline{V} = 0.11$ ft/sec
Q = 11.75 cfs

Figure 13. VELOCITY DISTRIBUTION

Config. T
Run No: 1L,2L

Location: Left Starboard
W.S. Elev. 5063.4
Discharge: L = 92.6, R = 0 cfs

Z	1.0	3.0	5.0	7.0	9.0
1.3	x –.06	x –0.04	x –0.22	x –0.35	x 0.90
3.9	x 0.03	x –0.08	x –0.38	x –0.27	x 1.00
6.5	x –0.01	x –0.13	x –0.49	x –0.14	x 1.50
9.1	x 0.05	x –0.02	x –0.04	x 0.29	x 1.31

$\overline{V}$ = 0.14 ft/sec
Q = 14.82 cfs

Figure 14. VELOCITY DISTRIBUTION

Config. T
Run No: 1L,2L

Location: Left Port
W.S. Elev. 5063.4
Discharge: L = 92.6, R = 0 cfs

Z	1.0	3.0	5.0	7.0	9.0
1.3	x 0.01	x 0.49	x 0.72	x 0.50	x 0.38
3.9	x 0.32	x 0.57	x 0.66	x 0.39	x 0.32
6.5	x 0.26	x 0.55	x 0.57	x 0.23	x –0.11
9.1	x 0.37	x 0.33	x 0.11	x –0.10	x –0.58

$\overline{V}$ = 0.30 ft/sec
Q = 31.15 cfs

Figure 15. VELOCITY DISTRIBUTION

Config. T
Run No: High 1,2,3

Location: Right Starboard
W.S. Elev. 5076.5
Discharge: L = 68.6, R = 68.6 cfs

Z	1.0	3.0	5.0	7.0	9.0
1.5	x –0.05	x 0.18	x 0.29	x 0.22	x 0.17
4.5	x –0.1	x 0.21	x 0.24	x 0.21	x 0.19
7.5	x 0.04	x 0.21	x 0.23	x 0.17	x 0.24
10.5	x 0.17	x 0.13	x 0.19	x 0.12	x 0.16
13.5	x 0.21	x 0.26	x 0.14	x 0.13	x 0.20
16.5	x 0.15	x 0.26	x 0.27	x 0.20	x 0.21
19.5	x 0.03	x 0.21	x 0.31	x 0.23	x 0.15
22.5	x 0.01	x 0.12	x 0.26	x 0.23	x 0.01

$\overline{V}$ = 0.17 ft/sec
Q = 40.54 cfs

Figure 16. VELOCITY DISTRIBUTION

Config. T
Run No: High 1,2,3

Location: Right Port
W.S. Elev. 5076.5
Discharge: L = 68.6, R = 68.6 cfs

Z	1.0	3.0	5.0	7.0	9.0
1.5	x 0.02	x 0.17	x 0.29	x 0.18	x 0.14
4.5	x 0.07	x 0.20	x 0.26	x 0.09	x 0.11
7.5	x 0.12	x 0.21	x 0.11	x 0.02	x 0.10
10.5	x 0.20	x 0.12	x 0.10	x –0.02	x 0.13
13.5	x 0.08	x 0.14	x 0.09	x 0.03	x 0.06
16.5	x 0.23	x 0.18	x 0.25	x 0.16	x 0.12
19.5	x 0.10	x 0.23	x 0.24	x 0.27	x 0.10
22.5	x 0.05	x 0.40	x 0.31	x 0.20	x 0.03

$\overline{V}$ = 0.15 ft/sec
Q = 34.60 cfs

Figure 17. VELOCITY DISTRIBUTION

Config. T
Run No: High 1,2,3

Location: Left Starboard
W.S. Elev. 5076.5
Discharge: L = 68.6, R = 68.6 cfs

Z	1.0	3.0	5.0	7.0	9.0
1.5	x –0.02	x 0.17	x 0.32	x 0.15	x 0.12
4.5	x 0.00	x 0.21	x 0.18	x 0.12	x 0.16
7.5	x 0.03	x 0.18	x 0.14	x 0.05	x 0.21
10.5	x 0.04	x 0.15	x 0.10	x 0.03	x 0.22
13.5	x 0.01	x 0.02	x 0.04	x 0.07	x 0.21
16.5	x 0.10	x 0.14	x 0.05	x 0.05	x 0.20
19.5	x 0.0	x 0.21	x 0.20	x 0.24	x 0.17
22.5	x 0.03	x 0.26	x 0.32	x 0.24	x 0.12

$\overline{V}$ = 0.13 ft/sec
Q = 30.79 cfs

Figure 18. VELOCITY DISTRIBUTION

Config. T
Run No: High 1,2,3

Location: Left Port
W.S. Elev. 5076.5
Discharge: L = 68.6, R = 68.6 cfs

Z	1.0	3.0	5.0	7.0	9.0
1.5	x 0.01	x 0.16	x 0.27	x 0.17	x 0.09
4.5	x –0.01	x 0.21	x 0.31	x 0.16	x 0.11
7.5	x 0.07	x 0.20	x 0.29	x 0.16	x 0.13
10.5	x 0.12	x 0.16	x 0.20	x 0.08	x 0.09
13.5	x 0.13	x 0.20	x 0.18	x 0.06	x 0.12
16.5	x 0.31	x 0.30	x 0.24	x 0.14	x 0.12
19.5	x 0.12	x 0.23	x 0.31	x 0.20	x 0.13
22.5	x 0.07	x 0.23	x 0.30	x 0.16	x –0.02

$\overline{V}$ = 0.16 ft/sec
Q = 38.25 cfs

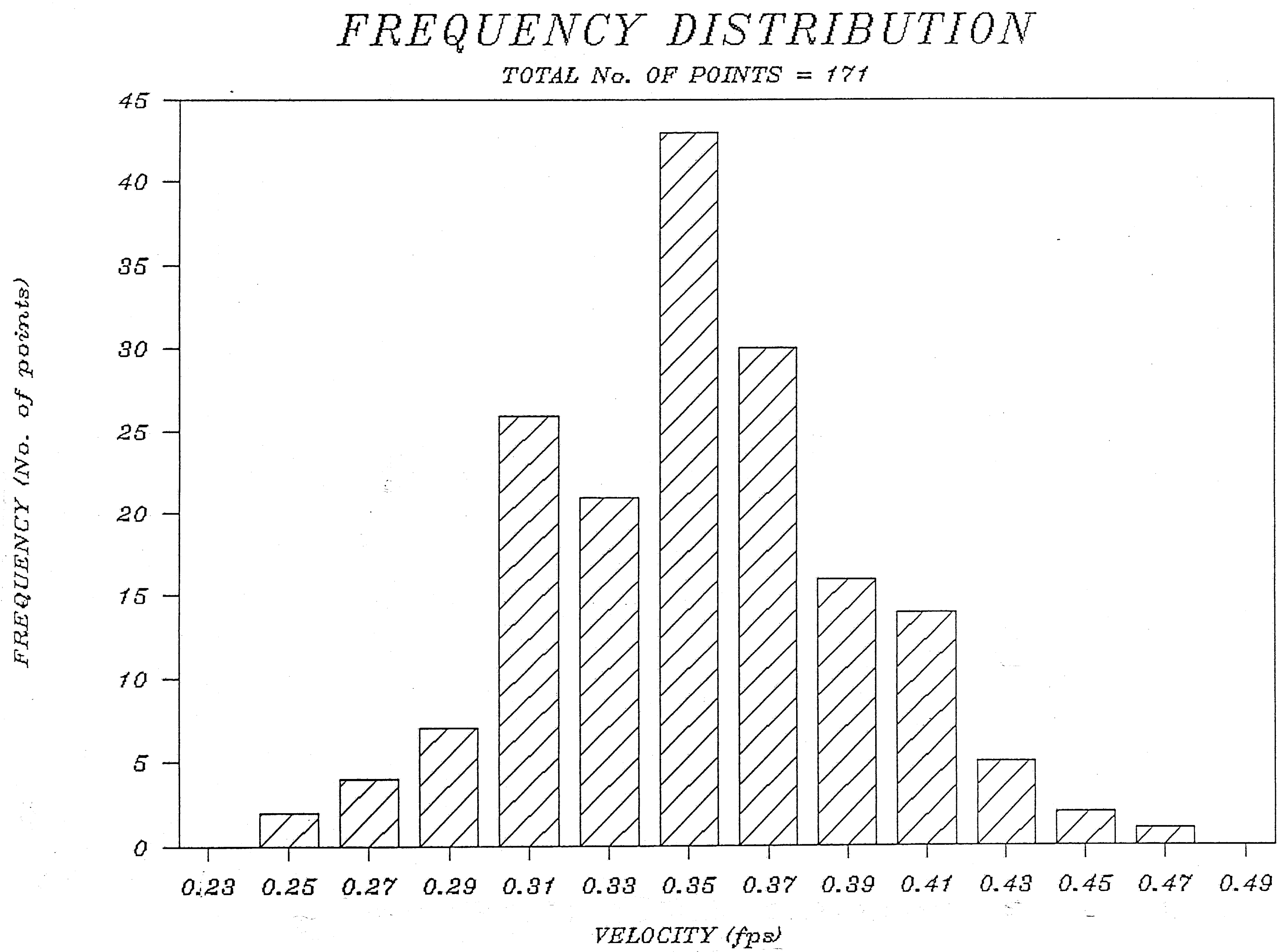

FREQUENCY DISTRIBUTION
TOTAL No. OF POINTS = 171
FREQUENCY (No. of points)
45
40
35
30
25
20
15
10
5
0
0.23 0.25 0.27 0.29 0.31 0.33 0.35 0.37 0.39 0.41 0.43 0.45 0.47 0.49
VELOCITY (fps)

Figure 19

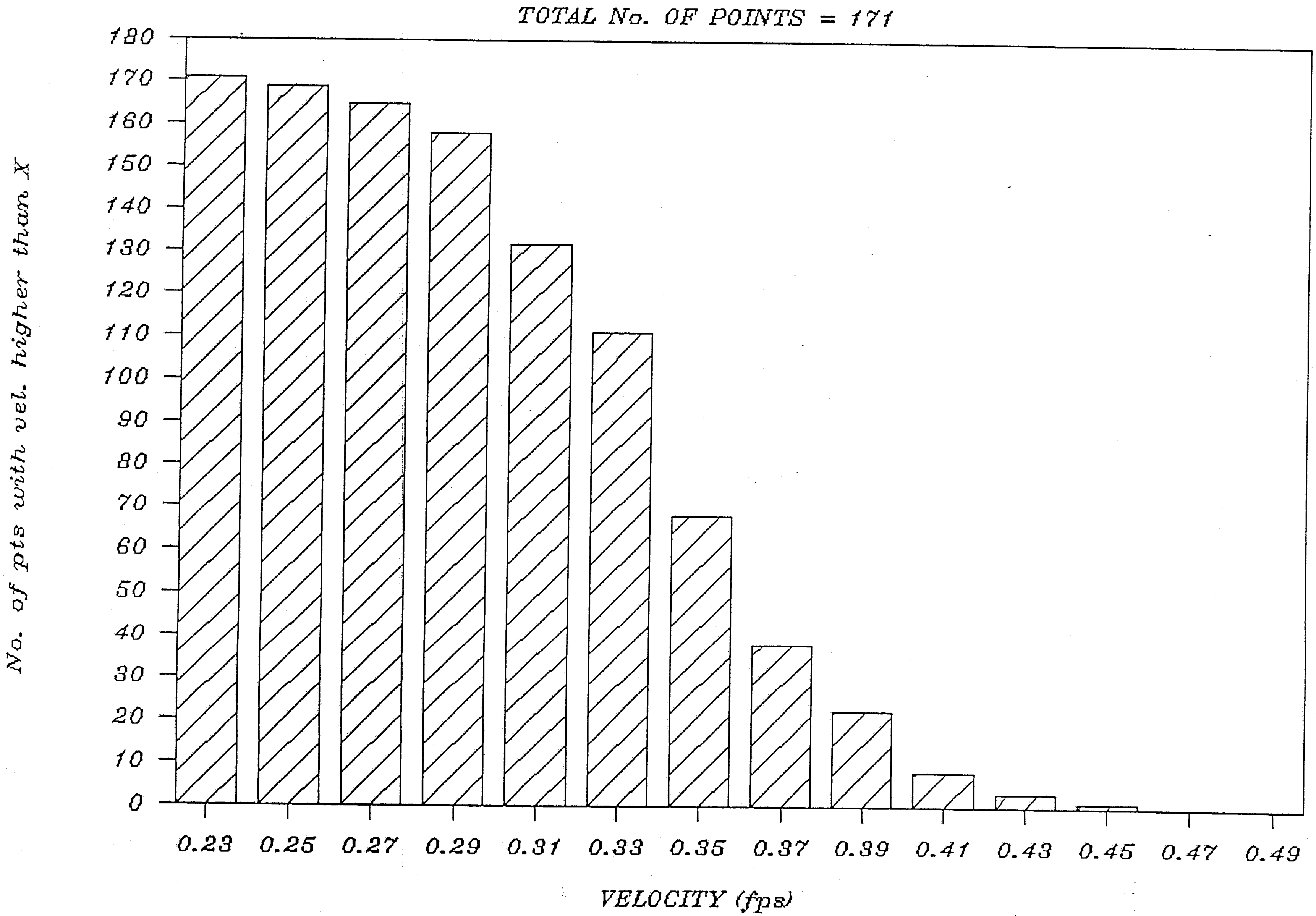
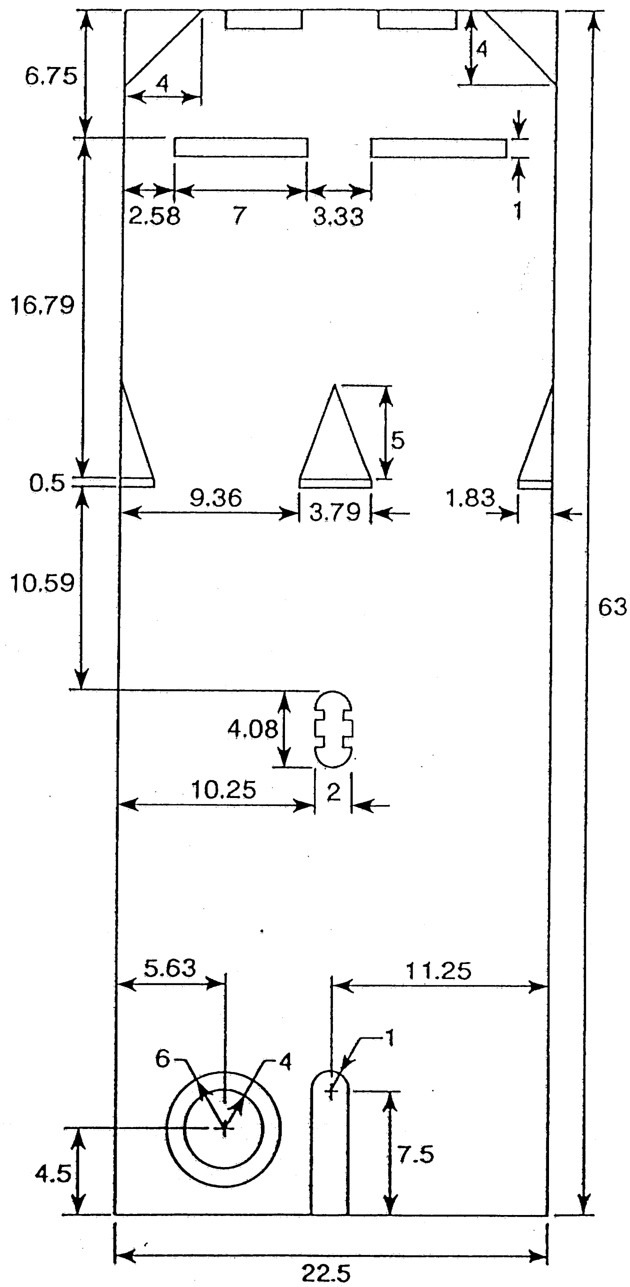

TOTAL No. OF POINTS = 171
No. of pts with vel. higher than X
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0.23
0.25
0.27
0.29
0.31
0.33
0.35
0.37
0.39
0.41
0.43
0.45
0.47
0.49
VELOCITY (fps)

Figure 20



CONFIGURATION U
ALL DIMENSIONS IN FEET

Figure 21

Figure 22. VELOCITY DISTRIBUTION

Config. U
Run No: s a,b,c

Location: Right Side
W.S. Elev. 5066.1
Discharge: L = 61.75, R = 61.75 cfs

Z	1.3	3.8	6.4	9.0	11.5	14.1
1.0	x 0.26	x 0.42	x 0.58	x 0.64	x 0.34	x 0.10
3.2	x 0.30	x 0.45	x 0.63	x 0.64	x 0.47	x 0.25
5.4	x 0.40	x 0.49	x 0.56	x 0.56	x 0.48	x 0.29
7.6	x 0.28	x 0.32	x 0.48	x 0.52	x 0.54	x 0.41
9.8	x 0.20	x 0.27	x 0.43	x 0.64	x 0.70	x 0.55
12.0	x 0.12	x 0.13	x 0.45	x 0.63	x 0.61	x 0.49

$\overline{V}$ = 0.43 ft/sec
Q = 58.30 cfs

Figure 23. VELOCITY DISTRIBUTION

Config. U
Run No: s a,b,c

Location: Left Side
W.S. Elev. 5066.1
Discharge: L = 61.75, R = 61.75 cfs

Z	1.3	3.8	6.4	9.0	11.5	14.1
1.0	x 0.56	x 0.64	x 0.71	x 0.58	x 0.34	x –0.19
3.2	x 0.57	x 0.64	x 0.80	x 0.66	x 0.45	x 0.01
5.4	x 0.58	x 0.53	x 0.60	x 0.65	x 0.49	x 0.20
7.6	x 0.64	x 0.67	x 0.69	x 0.52	x 0.39	x 0.14
9.8	x 0.84	x 0.79	x 0.82	x 0.50	x 0.31	x 0.03
12.0	x 0.67	x 0.78	x 0.73	x 0.41	x 0.22	x –0.06

$\overline{V}$ = 0.50 ft/sec
Q = 66.80 ft/sec

Figure 24. VELOCITY DISTRIBUTION

Config. U
Run No: S–R

Location: Right Side
W.S. Elev. 5063.4
Discharge: L = 0 , R = 92.6 cfs

	1.3	3.8	6.4	9.0	11.5	14.1
1.3	x 0.13	x 0.14	x 0.01	x –0.08	x –.16	x –.11
3.9	x 0.02	x 0.17	x 0.05	x –.12	x –.07	x 0.00
6.5	x 0.12	x 0.18	x 0.01	x 0.03	x 0.00	x 0.03
9.1	x 0.12	x 0.20	x 0.14	x 0.06	x 0.00	x –.10
Z						

$\overline{V}$ = 0.032 fps
Q = 3.41 cfs

Figure 25. VELOCITY DISTRIBUTION

Config. U
Run No: S–R

Location: Left Side
W.S. Elev. 5063.4
Discharge: L = 0 , R = 92.6 cfs

	1.3	3.8	6.4	9.0	11.5	14.1
1.3	x 1.12	x .98	x .92	x .76	x .68	x .47
3.9	x .98	x .91	x .92	x .84	x .96	x .61
6.5	x .79	x .84	x .87	x .96	x 1.02	x .67
9.1	x .91	x 1.07	x .96	x 1.09	x 1.04	x .65
Z						

$\overline{V}$ = .876 fps
Q = 93.38 cfs

Figure 26. VELOCITY DISTRIBUTION

Config. U
Run No: S–L

Location: Right. Side
W.S. Elev. 5063.4
Discharge: L = 92.6 , R = 0 cfs

	1.3	3.8	6.4	9.0	11.5	14.1
1.3	x .92	x .94	x 1.00	x 1.25	x 1.09	x 1.15
3.9	x .88	x .95	x .94	x 1.13	x .79	x .73
6.5	x .80	x 1.08	x 1.06	x .98	x .83	x .89
9.1	x .92	x 1.09	x 1.27	x 1.20	x .95	x .92
Z						

$\overline{V}$ = .99 fps
Q = 105.53 cfs

Figure 27. VELOCITY DISTRIBUTION

Config. U
Run No: S–L

Location: Left Side
W.S. Elev. 5063.4
Discharge: L = 92.6 , R = 0 cfs

	1.3	3.8	6.4	9.0	11.5	14.1
1.3	x –.29	x –.41	x –.20	x –.17	x .04	x .19
3.9	x –.42	x –.50	x –.24	x –.35	x .32	x –.20
6.5	x –.45	x –.50	x –.27	x –.17	x .22	x .02
9.1	x –.46	x –.23	x –.15	x –.15	x .08	x –.09
Z						

$\overline{V}$ = –.148 fps
Q = –15.78 cfs

Figure 28. VELOCITY DISTRIBUTION

Config. U
Run No: S–H

Location: Right Side
W.S. Elev. 5076.5
Discharge: L = 68.6 , R = 68.6 cfs

Z	1.3	3.8	6.4	9.0	11.5	14.1
1.5	x .12	x .01	x .11	x .53	x .58	x .44
4.5	x .02	x .08	x .27	x .50	x .54	x .53
7.5	x .23	x .37	x .21	x .37	x .40	x .27
10.5	x .38	x .27	x .38	x .27	x .22	x .25
13.5	x .25	x .25	x .25	x .31	x .28	x .35
16.5	x .29	x .33	x .33	x .33	x .39	x .34
19.5	x .27	x .22	x .29	x .45	x .59	x .56
22.5	x .24	x .21	x .51	x .84	x .88	x .58

$\overline{V}$ = .35 fps
Q = 84.31 cfs

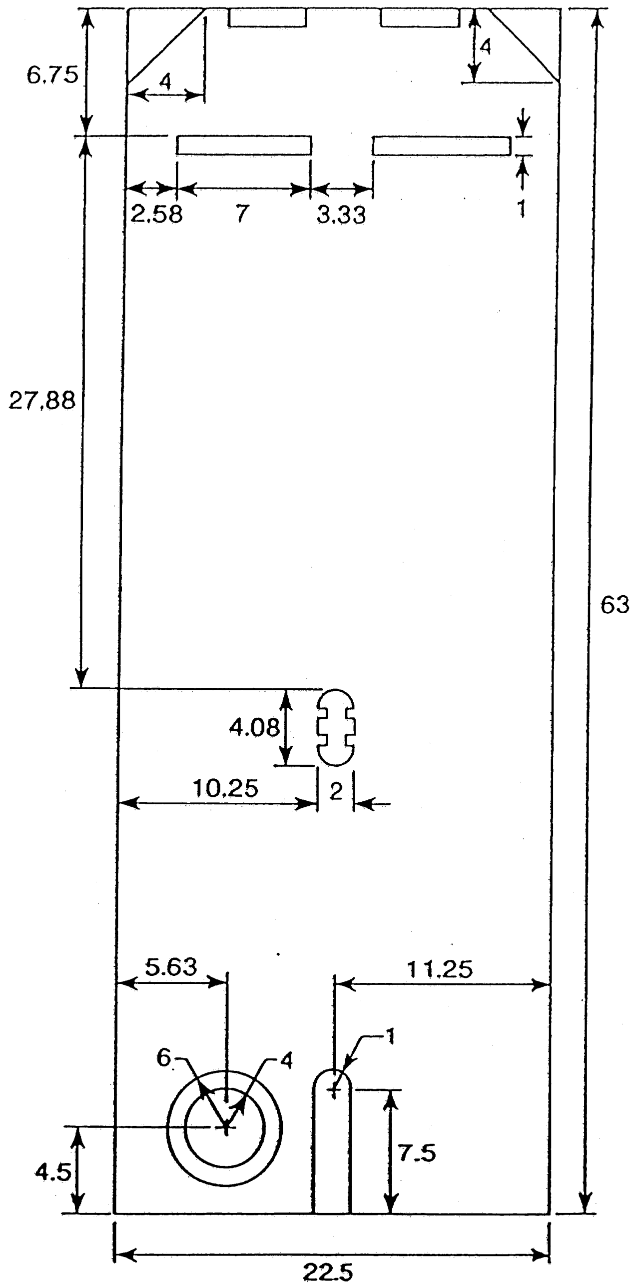
Figure 29. VELOCITY DISTRIBUTION

Config. U
Run No: S–H

Location: Left Side
W.S. Elev. 5076.5
Discharge: L = 68.6 , R = 68.6 cfs

Z	1.3	3.8	6.4	9.0	11.5	14.1
1.5	x –.21	x 0.00	x .32	x .69	x .50	x .73
4.5	x –.18	x .03	x .14	x .59	x .64	x .74
7.5	x –.16	x –.04	x .08	x .24	x .50	x .31
10.5	x –.18	x .02	x .09	x .29	x .42	x .56
13.5	x –.10	x .08	x .13	x .21	x .28	x .36
16.5	x .08	x .24	x .33	x .24	x .29	x .36
19.5	x –.03	x .13	x .36	x .46	x .48	x .39
22.5	x –.18	x .11	x .25	x .42	x .33	x .65

$\overline{V}$ = .25 fps
Q = 60.22 cfs



CONFIGURATION V
ALL DIMENSIONS IN FEET

Figure 30.

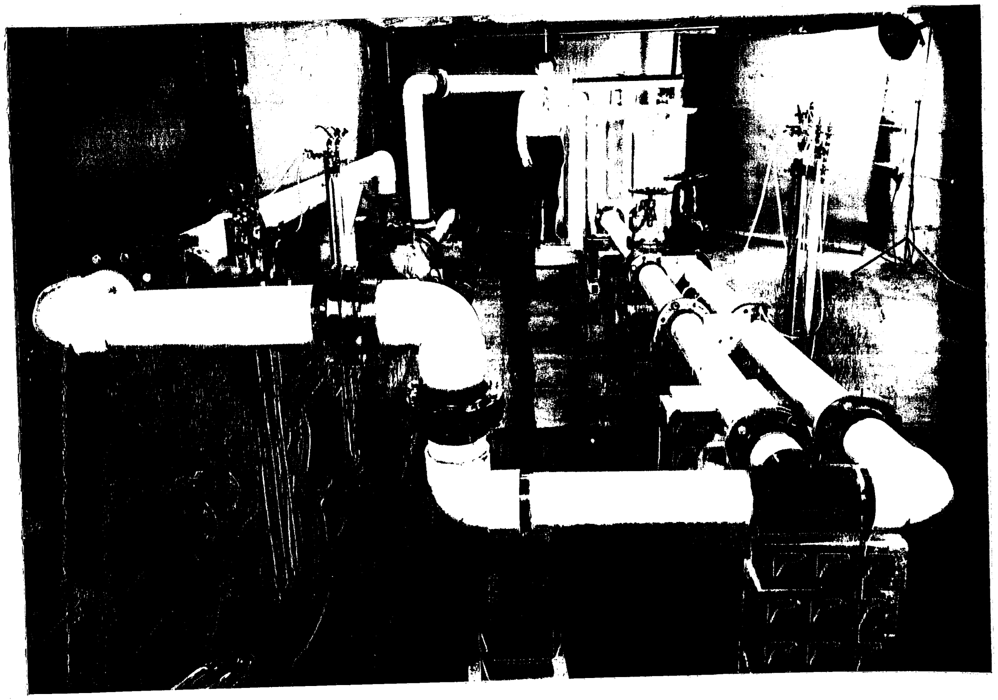


Photo 1 Overall View of the Model

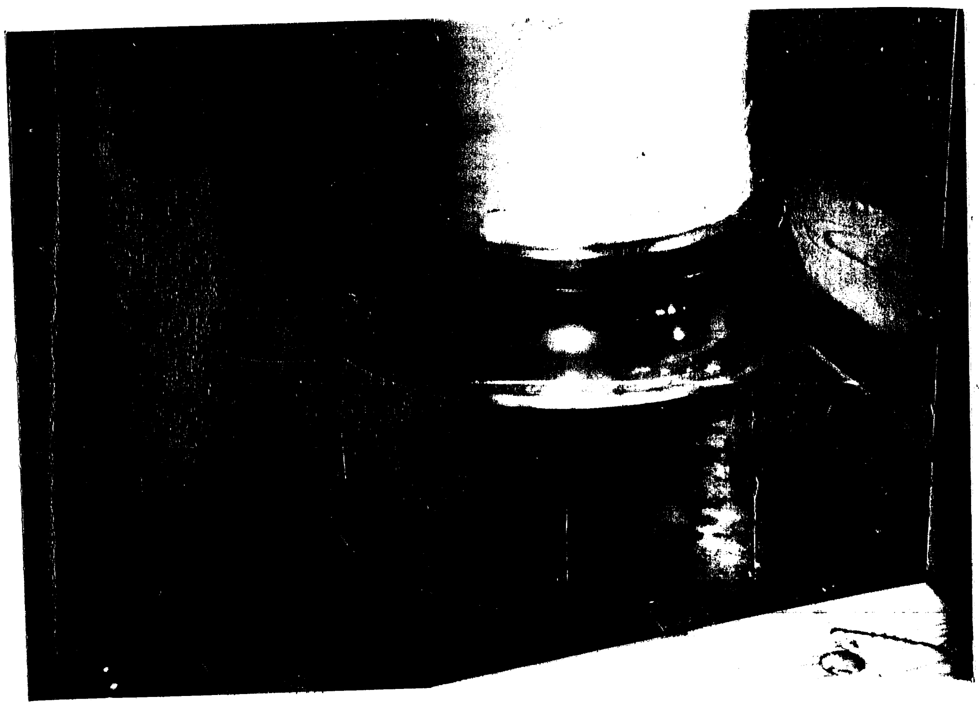


Photo 2 Close–up of Pump Bellmouth

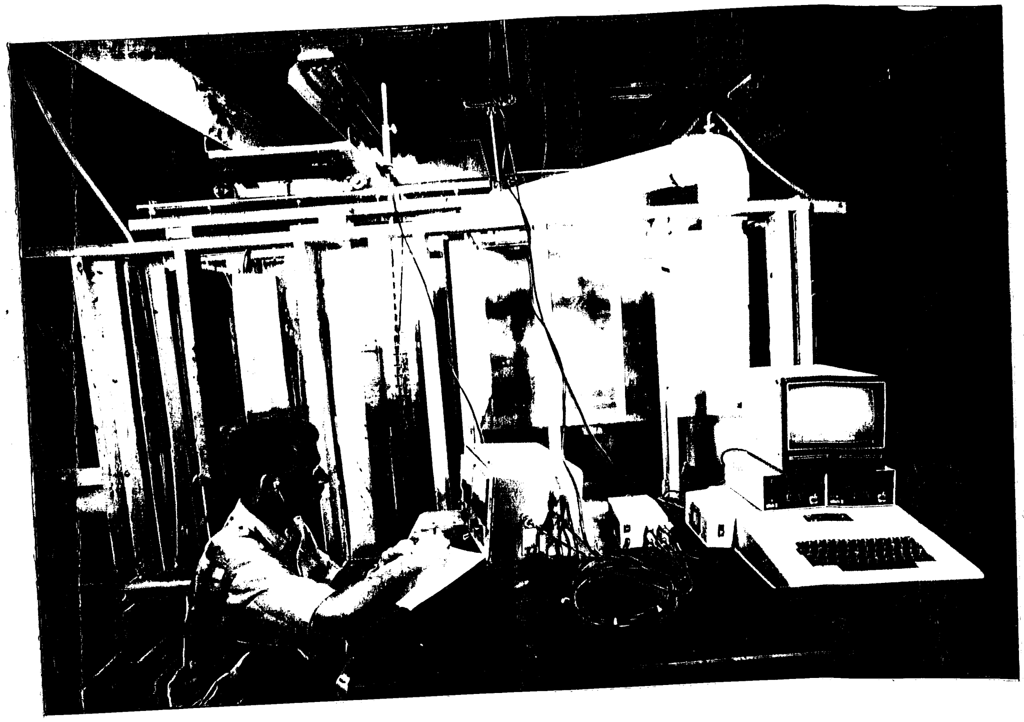


Photo 3 Instrumentation for Velocity Measurements

Photo 4 Inlet Flow near Baffle Plate, Condition 1, Configuration T

Photo 5 Flow Pattern into Bellmouth, Condition 1, Configuration T

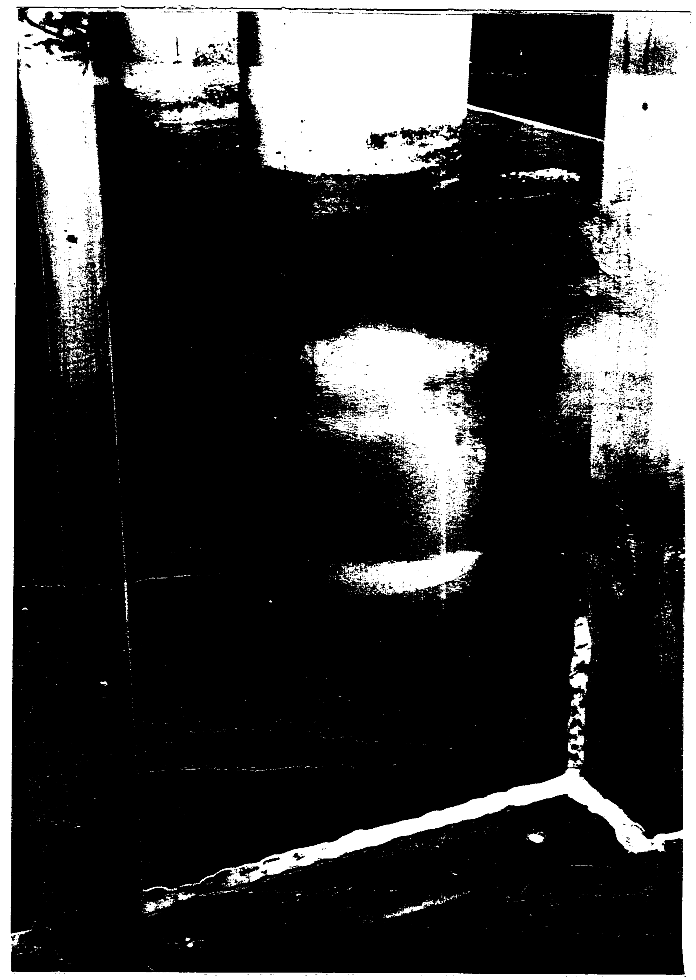


Photo 6 Flow Pattern into Bellmouth, Condition 1, Configuration T

Photo 7 Flow Pattern into Bellmouth, Condition 1, Configuration T

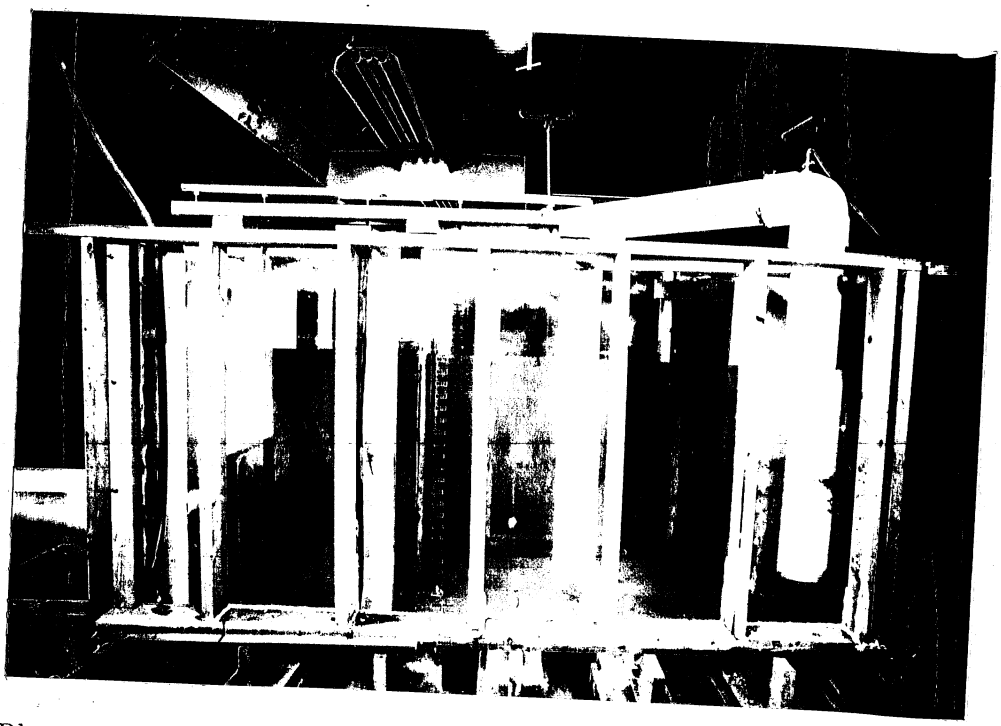


Photo 8 Overall View of Model, Stationary Screens, Condition 3, Configuration U

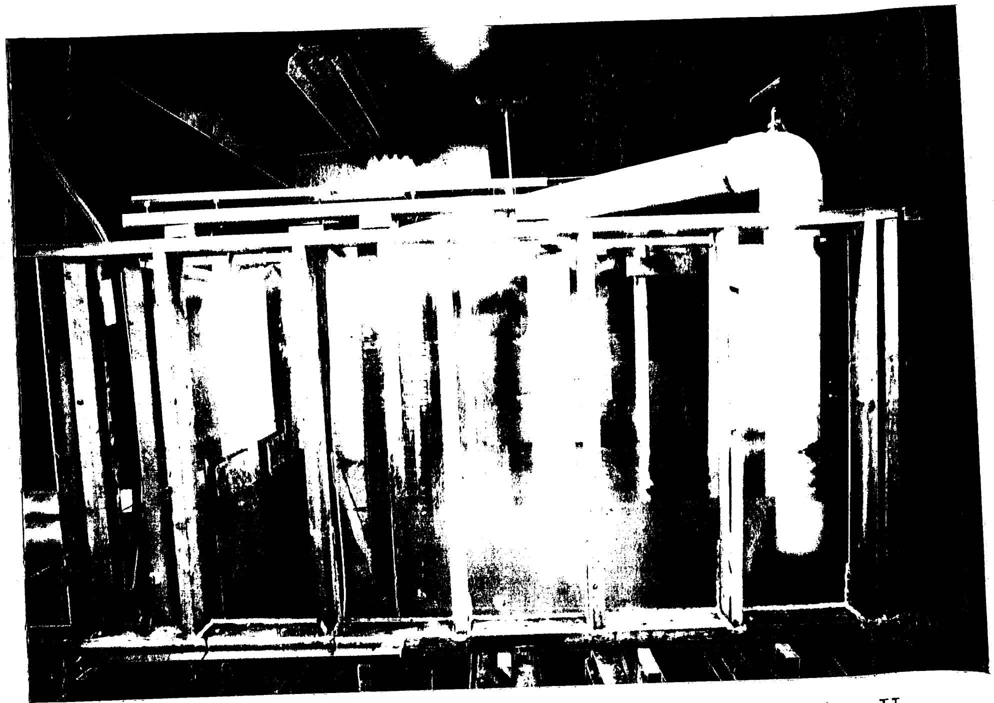


Photo 9 Stationary Screens, Condition 2, Configuration U

Photo 10 Bellmouth, Condition 2, Configuration U

Photo 11   Bellmouth, Conditon 2, Configuration U