FINAL PROJECT REPORT

HYDRAULIC MODEL STUDY

RAW WASTEWATER PUMPING STATION No. 2A

WASTEWATER TREATMENT PLANT
DETROIT, MICHIGAN

For

City of Detroit
Metcalf and Eddy of Michigan

By

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INTRODUCTION

The City of Detroit has planned an expansion of the existing wastewater treatment plant. A part of this expansion involves the construction of a second pumping station, hereafter referred to as Pumping Station 2A. Metcalf and Eddy has been contracted to provide the design for the pumping station. One purpose of this pumping station is to activate the North Interceptor-East Arm. Another objective during wet weather flows is to deliver additional sewage influent to the treatment plant and reduce overflows into the Rouge River. Also, Pumping Station 2A could be used to pump dry weather flows if it becomes necessary to shut down the existing Pumping Station 1 for any reason. Pumping Station 2A is designed to have a maximum pumping capacity of approximately 750 million gallons per day (MGD) through eight mixed flow pumps, seven of which will be installed in the initial phase of the construction. Pumping Station 2A consists of these pumps, two wet wells, each of which delivers flow to four pumps and an intake chamber which can be used to divert flow from three interceptors into the two wet wells as desired. The purpose of the physical model study was to examine the flow conditions within the wet wells with specific emphasis on the pump intake conditions.

The model testing sequence was intended to focus on several different issues associated with the flow in Wet Wells 1 and 2 in Pumping Station 2A. The primary concern was related to the inlet condition for the pumps. Vortices and inlet swirl have a detrimental effect on the operation of pumps, lowering efficiency and increasing wear. Severe vortexing can lead to pump vibration, cavitation and impeller pitting. Additional areas of interest in the model study related to general flow patterns and sediment accumulation within the wet wells.

The testing sequence included the following components:

- Examination of surface vortex patterns
- Examination of subsurface vortex patterns
- Measurement of swirl in flow into individual suction pipes
- Examination of sedimentation patterns and tendencies

If potential problems were indicated in any of the above areas, the physical model was to be used to obtain design alterations to be incorporated into the final pumping station design. This report documents the testing procedures and results that were used in the attainment of the project objectives.

GENERAL SYSTEM DETAIL

Pumping Station 2A is designed as a circular structure to satisfy structural and geotechnical concerns. The pumps are arranged radially around the two wet wells as indicated in the plan view in Fig. 1. The numbering convention used in referring to the pumps is also indicated in the figure with the pumps numbered sequentially from those in Pumping Station 1. Pumps 9 - 12 are located in Wet Well 1 and 13-16 in Wet Well 2. Of the four pumps in Wet Well 1, only three pumps will be initially installed with the fourth to be added at a future date. All pumps in Wet Well 1 are identical except that one will be a constant speed pump while the other two will have variable speed drives. Identical pumps will be installed in Wet Well 2, with one constant speed and three variable speed drives. An additional objective of the physical model study was to use the results to provide recommendations as to the placement of the constant speed pumps within each wet well. The flow passes through a bell mouth entrance into a 66 inch diameter suction line for each pump. A gate valve is located about six feet into the suction pipe from the wet well and beyond that the pipe bends 90 degrees upwards to pass through the pump.

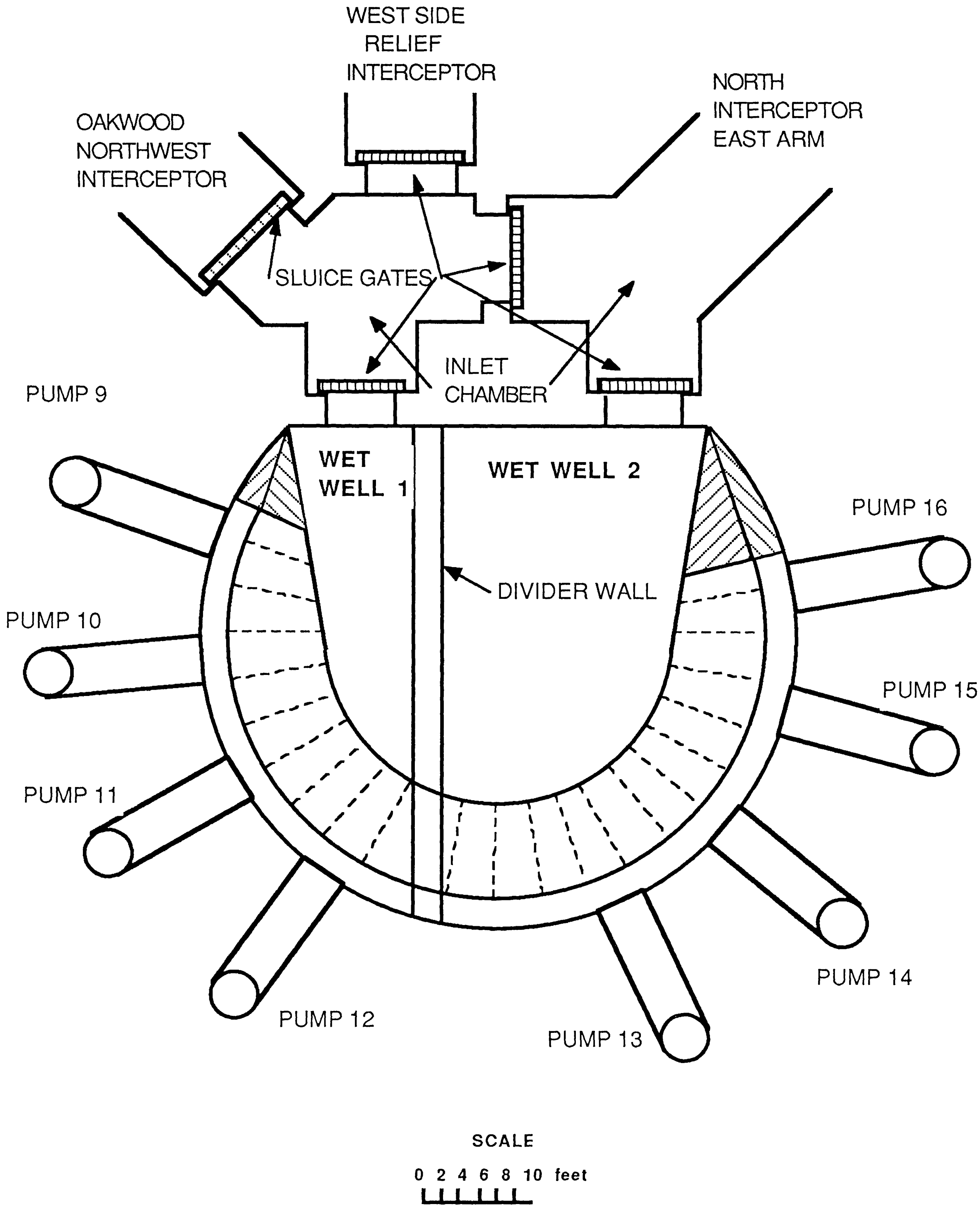


Figure 1. Plan View of Initial Wet Well Design.

Flow may enter Pumping Station 2A through three interceptors: 1.) the North Interceptor - East Arm (NI-EA); 2.) the Oakwood Northwest Interceptor (ONWI); and 3.) the proposed West Side Relief Interceptor (WSRI). The three interceptors discharge into an inlet chamber, as indicated in Fig. 1. The inlet chamber may be operated so as to isolate the NI-EA flow from that of the ONWI and WSRI and dedicate Wet Well 2 to the NI-EA. This allows for the NI-EA to be operated at a higher hydraulic level than the other two interceptors for energy savings (reduced pumping heads) during dry weather conditions. During wet weather conditions, the two wet wells would be operated at a common head. The NI-EA and ONWI are 13' - 6" diameter lines that are at approximately equal invert elevations of about 65 feet (Detroit datum). The ten foot diameter WSRI is much deeper with an invert elevation of approximately 42 feet. Wet Well 1 is required to be deeper than Wet Well 2 in order to accept the flow from the WSRI; it is designed to have a minimum floor elevation 19 feet lower than Wet Well 2. A cross-sectional view of the pumping station, cut through the wet wells, looking towards the inlet chamber is indicated in Fig. 2. The inlet chamber also has differences in bottom elevation (61.5 feet on the Wet Well 2 side and 42.06 on the Wet Well 1 side) on either side of the sluice gate indicated in Fig. 1 that may be lowered to separate the intake chamber and thus the flow into the two wet wells. The wet wells were designed to contain equal volumes at normal operating levels, hence the surface area of Wet Well 2 is greater than that of Wet Well 1. The inside of each wet well was initially designed to contain an elevated floor at a level equal to the invert elevations of the NI-EA (for Wet Well 2) and the WSRI (for Wet Well 1). Elevations in the corresponding sides of the inlet chamber are the same as the elevated floor levels in each wet well. Within the wet wells, this elevated floor extends along the center dividing wall and then drops down along a slope to the elevation of the bottom of the pump intake lines. A short horizontal floor as indicated in Figs. 1 and 2 exists in the bottom of the wet wells at their respective bottom elevations.

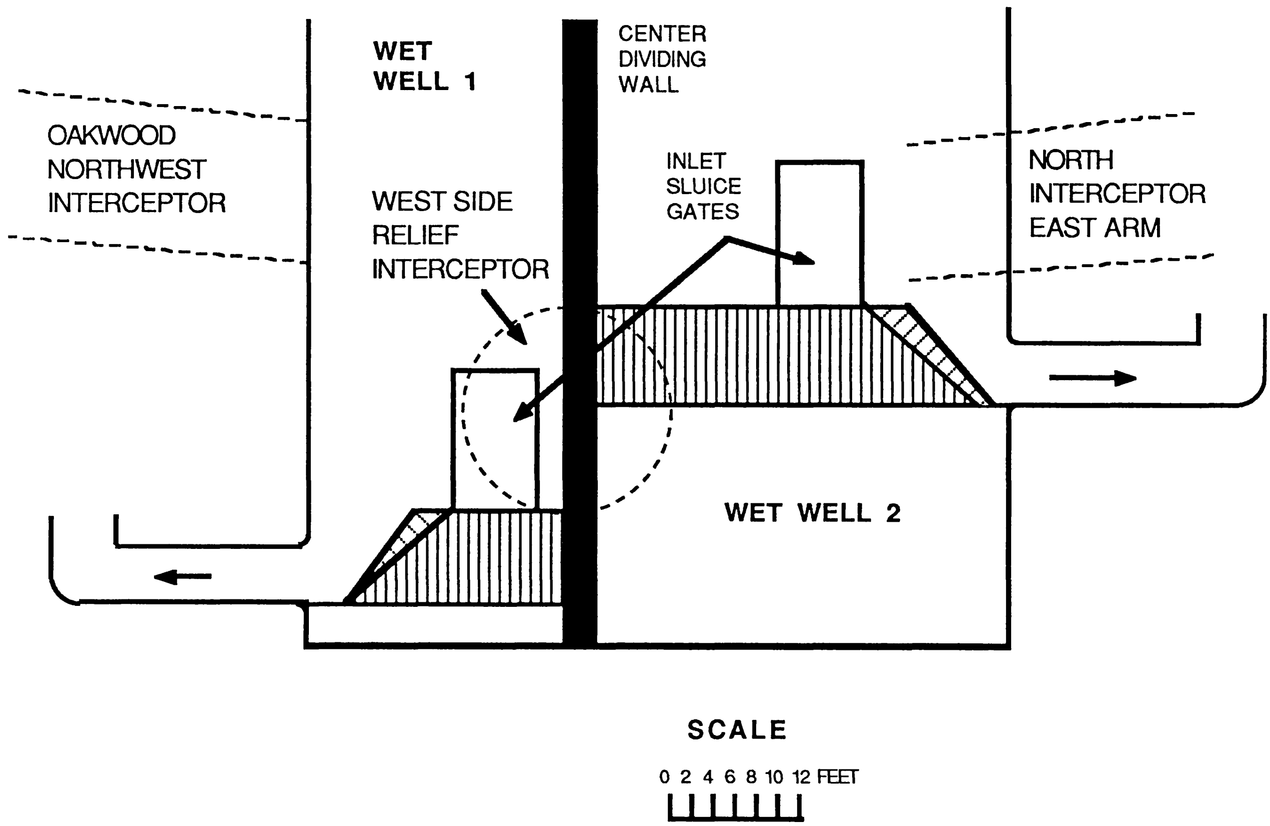


Figure 2. Cross-section of Initial Wet Well Design.

CONCLUSIONS AND RECOMMENDATIONS

Model tests were performed to define the flow conditions within the two wet wells in the proposed Pumping Station 2A as they would affect the conditions in the pump suction lines. The following results were obtained:

- The original wet well designs proved to be unacceptable in that swirl angles of up to seven times the allowable limits were measured. Similar findings were found in both wet wells, except that the swirl angles in Wet Well 1 were somewhat worse.
- There was no evidence of vortex problems in these tests for either the original design or in any modifications considered.
- By lowering wet well floor elevations and placing a baffle wall within each wet well in front of the inlet sluice gates, the swirl angles were reduced to levels that are acceptable. In the final configurations studied, there were a few flow cases in which unacceptable swirl angles were measured, but these could be avoided by limiting the combinations of pumps in operation within each wet well as follows:

  Wet Well 1: For low level cutout flows, avoid using the combination of Pumps 10 and 11 with two pumps operating and avoid using Pump 9 insofar as is possible;

  Wet Well 2: For dry weather flow avoid using the combination of Pumps 13 and 14 with two pumps operating. For wet weather flow, avoid the use of Pump 15 if less than four pumps are in operation. For low level cutout flows, avoid using the combination of Pumps 15 and 16 with two pumps in operation and avoid the use of Pump 15 with less than four pumps in operation.

- The location of the constant speed pumps is recommended as Pump 10 in Wet Well 1 and as Pump 14 in Wet Well 2. Furthermore, it is recommended from the considerations of the hydraulics that Pump 9 be the one reserved for future installation.

- Increasing the model flow rates by 50 percent to examine the possible influence of scale effects did not result in any vortex problems, or in significant changes in swirl angles.

- The installation of guide vanes to straighten the flow within the suction lines was of limited value, primarily because the vane length was constrained by the location of the gate valves in the suction lines. Decreases in swirl angles of perhaps 20-30 percent could be expected by installation of guide vanes.

- Any sediment that tends to be deposited within the wet wells during dry weather flow conditions is quickly scoured as the flow is increased to the wet weather flow condition and no significant sediment deposition within the wet wells is expected.

MODEL DESCRIPTION

Modelling Criteria

Physical models to examine flow patterns in free surface flow are performed using Froude number similarity, which fixes the relations between model and prototype conditions once the physical model scale has been selected. Dynamic similarity requires keeping all Froude numbers defined by $V/(gL)^{1/2}$ equal in the model and prototype, where V refers to any representative fluid velocity, g the acceleration due to gravity, and L is any system length. The relations between prototype and model parameters are related to the scale ratio $\mathbf{L_r}$ which is the geometric ratio between any length in the prototype and the corresponding one in the model ($\mathbf{L_r}$ = $Length_{model} / Length_{prototype}$). For a Froude scaled model, assuming the same fluid in model and prototype, the following relations must hold:

PARAMETER		**RATIO**
Length	$\mathbf{L_r}$	$\mathbf{L_r}$
Velocity	$\mathbf{V_r}$	$\mathbf{L_r}^{1/2}$
Discharge	$\mathbf{Q_r}$	$\mathbf{L_r}^{5/2}$
Time	$\mathbf{T_r}$	$\mathbf{L_r}^{1/2}$

Although prototype systems are largely unaffected by viscous effects, and thus their behavior is independent of Reynolds Number, these may be somewhat more important in a smaller model. This consideration generally fixes the minimum model size required to avoid distortion of the model results due to the effects of viscosity. Padmanabhan and Hecker (1984) suggest from the results of previous studies that a minimum Reynolds Number of greater than 30,000 be maintained in the physical model to correctly reproduce the effect of viscosity on the flow behavior. In the context of the present study, this Reynolds Number is to be defined in terms of the flow in the suction pipe as $Re = UD/\nu$, with U the average velocity in the suction pipe, D the diameter and ν the kinematic viscosity. This constraint was instrumental in the selection of the physical model scale.

For grit deposition within the wet wells to be examined, the essential parameter is the settling velocity of representative grit particles carried with the flow. In order to maintain dynamic similarity of settling characteristics, the ratio of particle settling velocity to any other representative flow velocity should remain constant between prototype and model. Since settling velocity is a function of both particle diameter and density, similarity can be maintained by adjusting the model particle submerged weight which in turn depends upon particle size and specific gravity.

Model Testing Facilities

The model study was conducted in the Civil Engineering Hydraulics Laboratory located in the G.G. Brown Building at the North Campus of The University of Michigan. The model was constructed in the model test basin which is 15 meters long by 11 meters wide.

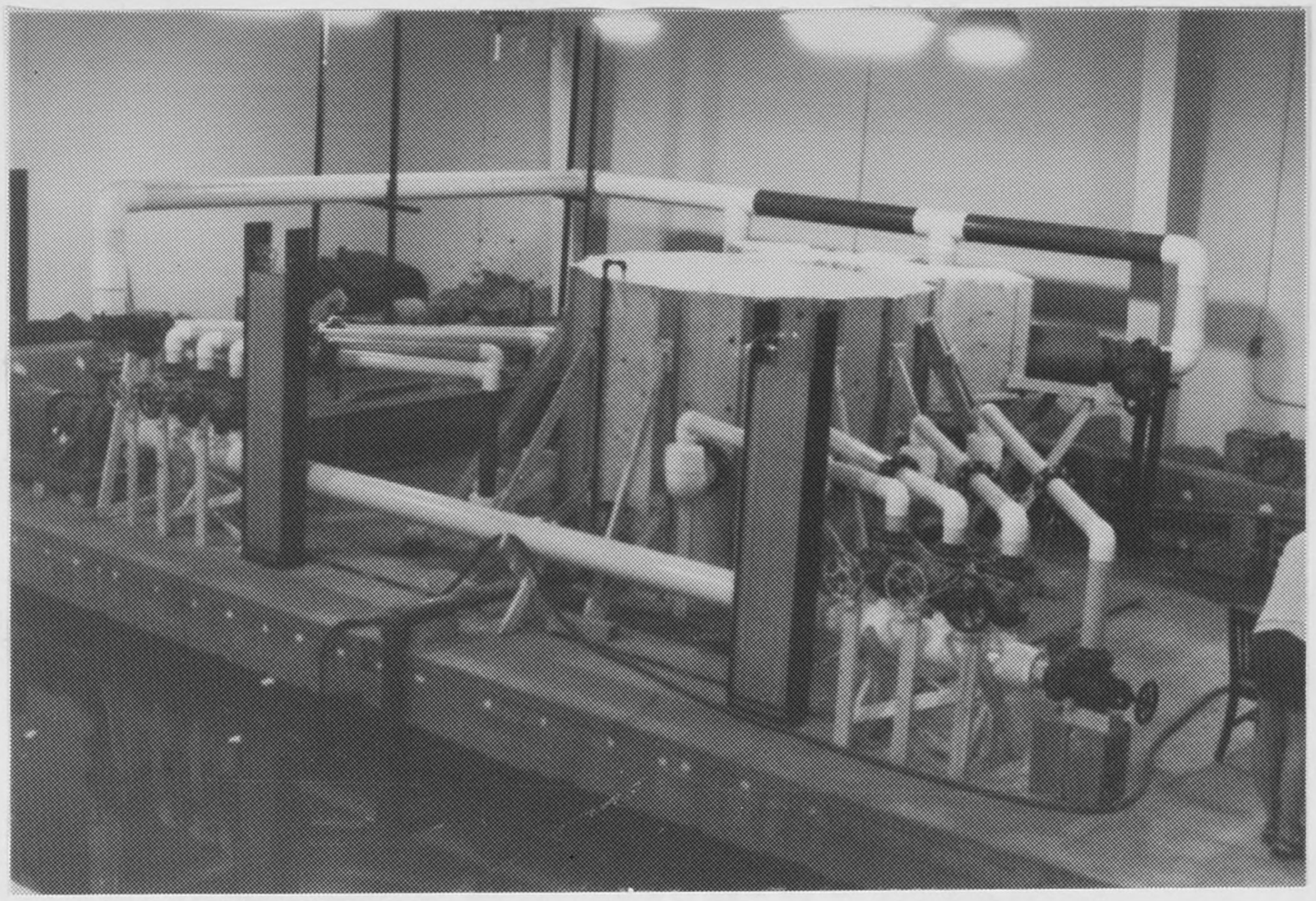
Model Construction

The physical model was constructed at a scale ratio of 1/8.8. The general model size was selected to keep Reynolds Numbers sufficiently above the recommended minimum of 30,000, while the exact model size was dictated by the size of available plexiglass conduit to model the 66 inch diameter pump intake lines. The physical model reproduces the exact detail of the two wet wells, the suction pipes of each individual pump up to the vertical bend, and the inlet chamber which receives the flow from the North Interceptor - East Arm (NI-EA), the Oakwood Northwest Interceptor (ONWI) and the proposed West Side Relief Interceptor (WSRI). A short section of pipe of the correct diameter to model the different interceptors was also included in the model construction. However, this was much too short to develop a uniform entrance flow; in order to accomplish this, a unit consisting of a section of honeycomb material plus a fiber mat was installed within the entrance pipe to straighten the flow and to produce sufficient head loss to provide a uniform inflow condition. The horizontal section of the pump suction lines were constructed from plexiglass so that the rotating cruciforms used to measure the inlet swirl angles could be seen to measure the swirl angles. No attempt was made to model the gate valve in the suction line. No specification was given in the original design as to the conditions of the inlet transition from the wet wells into the individual suction lines. After discussion with Metcalf and Eddy personnel, it was decided to construct the model with an entrance radius that was one-tenth of the suction diameter (66 inches prototype). The prototype design was later altered to increase the radius to 25 inches; however, the model was not altered to reflect this change since the model testing was under progress at that time. It was felt that the use of a smaller radius would give a worse entrance condition and therefore the continued use of the radius constructed in the model would give a somewhat conservative estimate of the wet well performance.

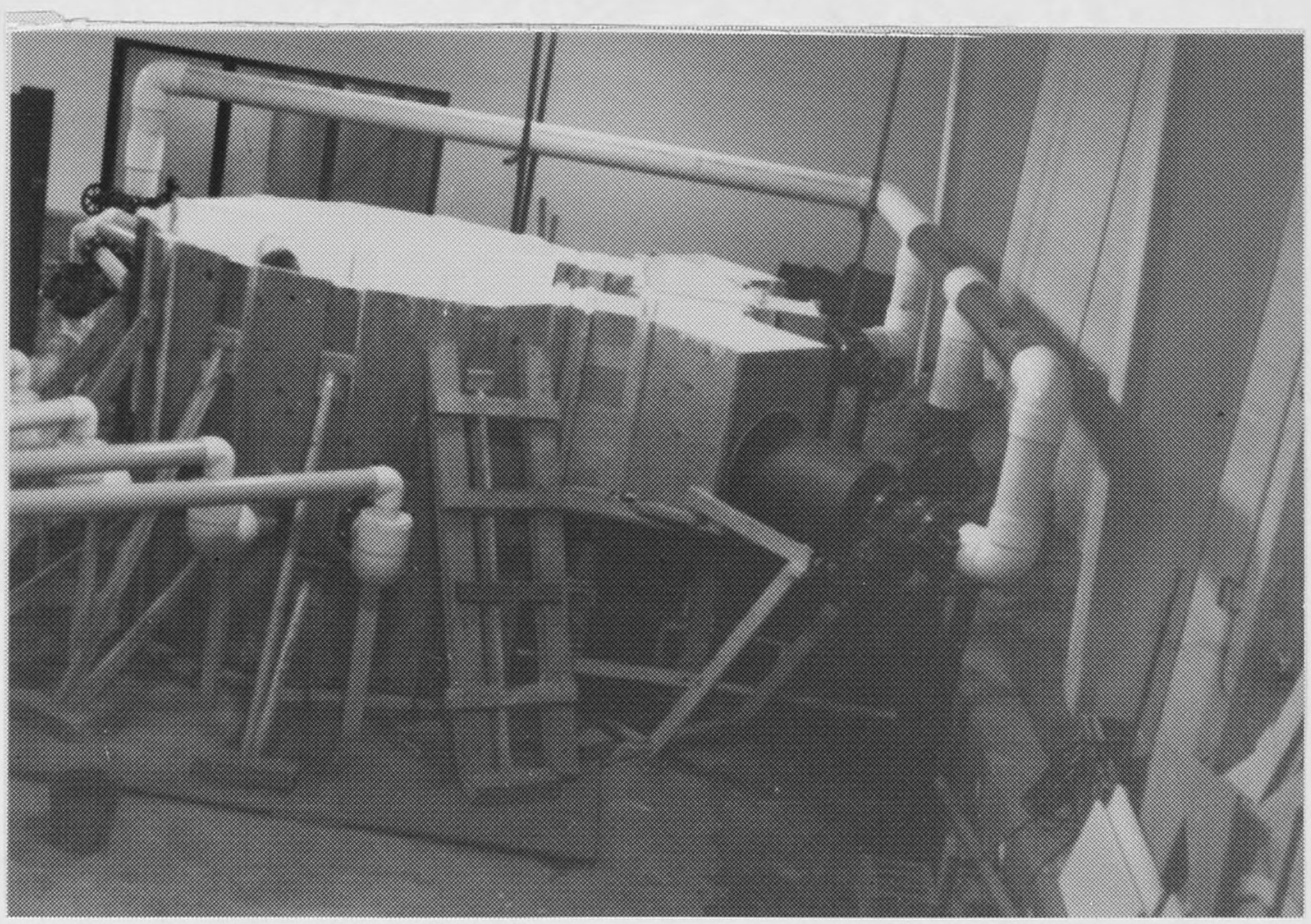
The vertical bend in the pump suction lines was reproduced in the model, only with a standard PVC elbow rather than the mitered bend to be used in the prototype. Therefore the flow should be dynamically similar only up to the bend. After the bend, no attempt was made to maintain geometric similarity and all suction lines were diverted into a common manifold connected to a recirculating pump which removed the flow from the wet wells, through the desired pump suction lines, and then passed it back around to the appropriate inlet conduit. The flow was regulated by means of a gate valve on each of the pump suction lines and with gate valves on each of the inlet pipes to obtain the desired total flow and control the flow distribution among individual lines. The flows were metered in each line by means of an installed pipe orifice meter. Valving on the recirculating system discharge line then diverted flow to the appropriate inlet. Photographs of the general system detail are provided in Fig. 3. Figure 3(a) is an overall view of the entire model including all piping. The pump is at the far left side of the photograph with the discharge piping in the background; the tees for the three interceptors are visible above the model with the ONWI to the left, the WSRI in the center and the NI-EA at the right. The valves regulating the discharge on the suction side of the pump are visible at the front with those from Wet Well 2 on the right. Two differential manometers are visible, one for each wet well, and the orifice meters are installed within the dark flanges visible at the center of the horizontal, smaller diameter PVC pipe. A slightly closer view of the model is indicated in Fig. 3(b), in which more details of the inlet chamber are visible on the right. The NI-EA is in the foreground in this photograph. Fig. 3(c) shows the control valve and pipe expansion simulating the NI-EA entrance into the inlet chamber, while Fig. 3(d) indicates the construction for a modeled pump discharge line. The plexiglass section of the model is visible in this latter photograph and the swirl meters were installed within that section.

Although the original plant design involved a center wall dividing the two wet wells that was three feet thick, this was altered to structurally strengthen the wall. The initial change involved the addition of pilasters on either side of the dividing wall, and these were incorporated into the model construction. However, these were shown to have a negative influence on the flow in Wet Well 1 and the design was again modified. The final configuration involved increasing the wall thickness to 8 feet with the increase in thickness added in Wet Well 2. This was correctly reproduced in the model.

No changes in the original design were made in the model except within the wet wells themselves. Therefore, the model detail indicated in Figs. 1-3 is the same for all tests with the exception of specific changes in the wet well configurations as discussed in the Results section.

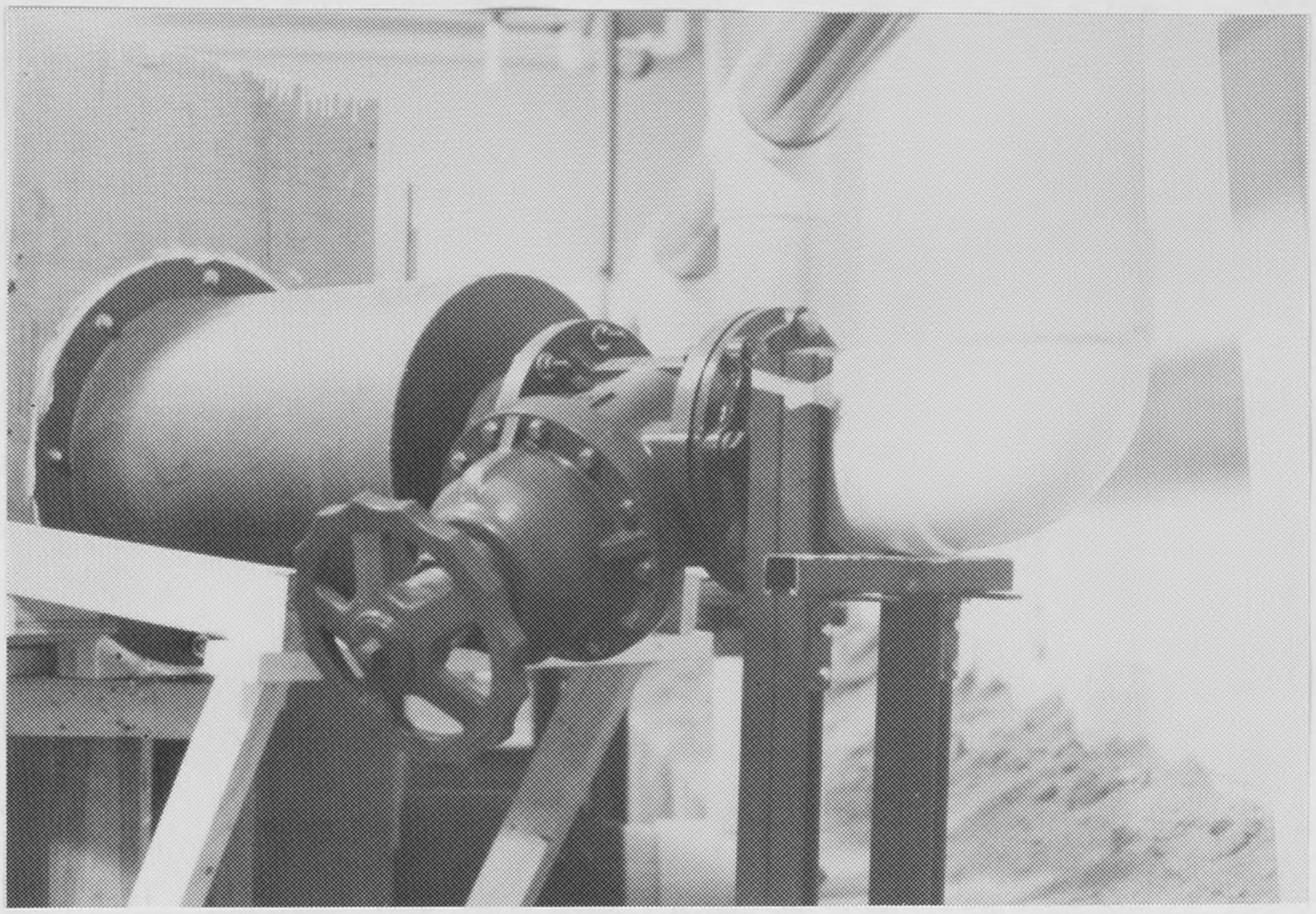


a.) Overall View of Model Construction.

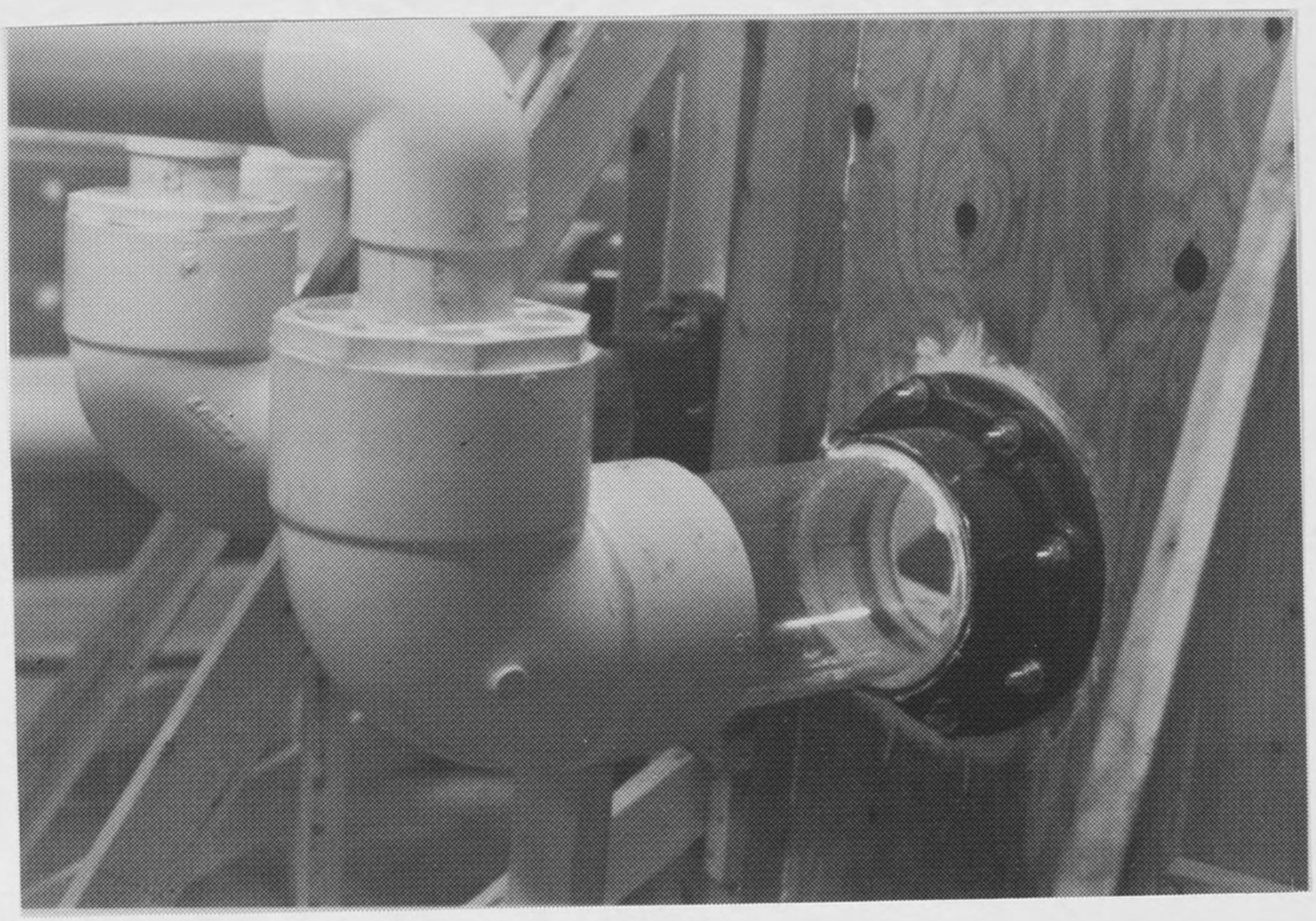


b.) View indicating Inlet Chambers.

Figure 3. Photographs of Pumping Station Model.



c.) View of NI-EA Inteceptor Inlet.



d.) View of Pump Suction Pipe.

Figure 3. Photographs of Pumping Station Model.

Instrumentation

Flow rates were measured using pipe orifice meters constructed to ASME specifications as described in Streeter and Wylie (1985). The orifice diameter was 3.375 inches and there were at least 10 upstream diameters of straight pipe and five diameters downstream from the orifice in order to minimize approach flow influences. The orifice discharge coefficients are defined in the discharge equation

$$Q = C_D A_o \sqrt{2 g h}$$

where Q is the discharge, C_D is the orifice discharge coefficient, A_o is the orifice area and h is the pressure head differential across the orifice. The discharge coefficient is given in Streeter and Wylie as a function of the pipe Reynolds number and the orifice to pipe area; Fig. 4 presents a plot of C_D versus area ratio for several given ratios and the one for the given meters. All model Reynolds numbers were in excess of 150,000 so the variation of the discharge coefficient was negligible, and a constant value of C_D = 0.812 was used in the determination of the discharge. The manometer taps were also located in accordance with the specifications and were positioned one diameter upstream from the orifice plate and one-half diameter downstream. Pressure differences were measured with water-air differential manometers. Accuracy of the flow determination was limited by the accuracy of the reading of manometer deflections. The head differential at the simulated rated pump discharge was approximately 100 cm, and the accuracy of the reading was estimated to be on the order of 2-5 cm. Thus, the flows were measured to about 2 percent accuracy. The minimum flows per suction line in the testing sequence were not significantly less than the design flow under the conditions tested, so this estimate of the measurement error should be valid over nearly the entire range of test conditions.

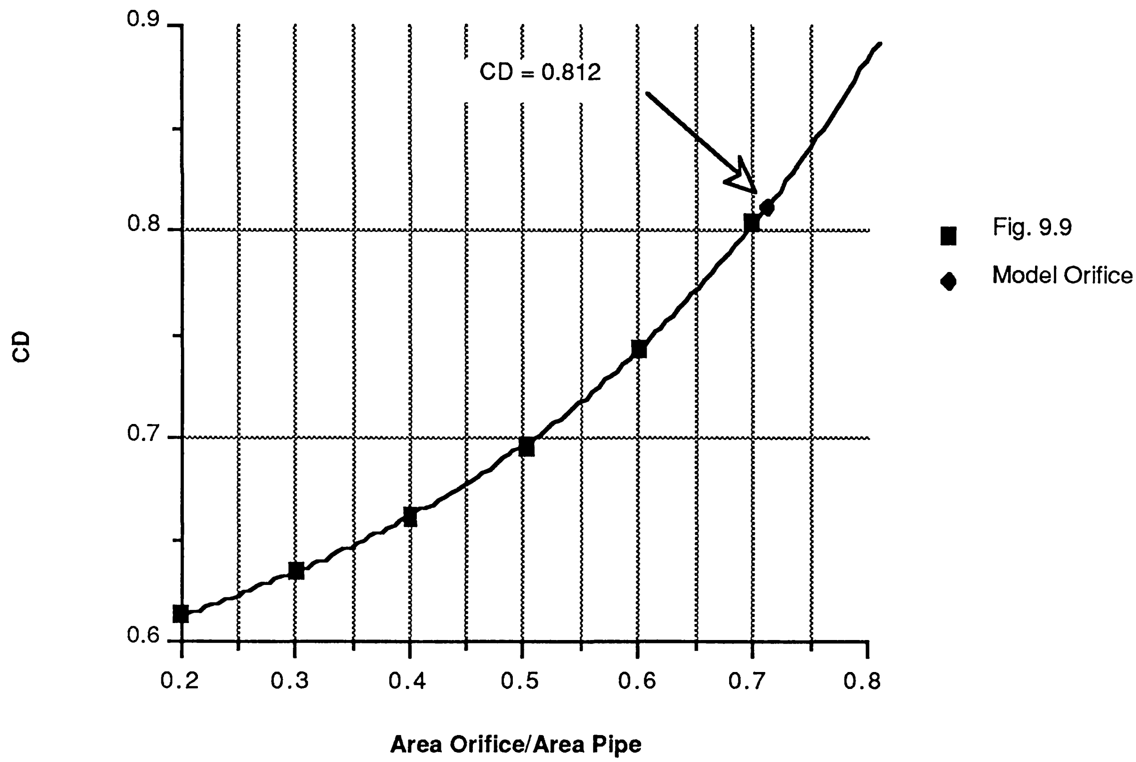


Figure 4. Determination of Discharge Coefficient for Model Orifices.

The swirl angles were measured with a rotating cruciform, the details of which are provided in Figure 5. The function of the cruciform is to rotate with the tangential direction of flow in the pump suction lines. Standard specifications of 0.8 of the pipe diameter for the length and diameter of the cruciforms were followed in the construction. The cruciform was mounted so that it rotated freely on a brass shaft installed along the pipe centerline. One vane was painted to orient the cruciform, especially in a rapidly rotating flow. Rotation counts were recorded to the closest quarter turn over 30 second counting intervals. More details on the procedure associated with the computation of swirl angles are presented below.

Sediment

The model sediment selected for use in the model study was a black silicon carbide powder obtained from a grinding supplies distributor. This allowed acquisition of a suitable size distribution to model the anticipated prototype settling velocities and of a product with a color that was suitable for viewing. The specific gravity of the silicon carbide was specified to be 3.2. The specific product used was a 120 grit "#37 Crystolon" silicon carbide powder produced by Norton Company. A sieve analysis of a representative sample yielded the size distribution indicated in Fig. 6. Since most of the material passes the 100 mesh sieve but is retained on the 120 mesh, the representative diameter of the majority of the sediment is 0.125-0.149 mm. These diameters are converted into settling velocities of about 0.53-0.62 ft/s according to the Sedimentation Engineering Manual (1975) with a water temperature of 60° F. Scaling these up to prototype velocities by the square root of the inverse of length scale ratio (8.8) and converting to diameters of prototype grit with specific gravity of 2.65 yields estimated diameters of 0.35-0.4 mm. In a separate model study performed for the City of Columbus, Ohio, a sample of grit entering the Columbus Wastewater Treatment Plant and settling in the wet wells ahead of the pumping station was found to entirely pass a 30 mesh sieve and be retained on a 100 mesh one. The Columbus system is also partially a combined sewer system and therefore the grit should have characteristics similar to that in the Detroit system. The model grit is therefore towards the upper end of the range of sieve sizes between 0.149 and 0.595 mm and should be representative of that entering into Pumping Station 2A. Without more detailed information on the size distribution of the grit at the Detroit WWTP, a better match of sedimentation particles could not be attained.

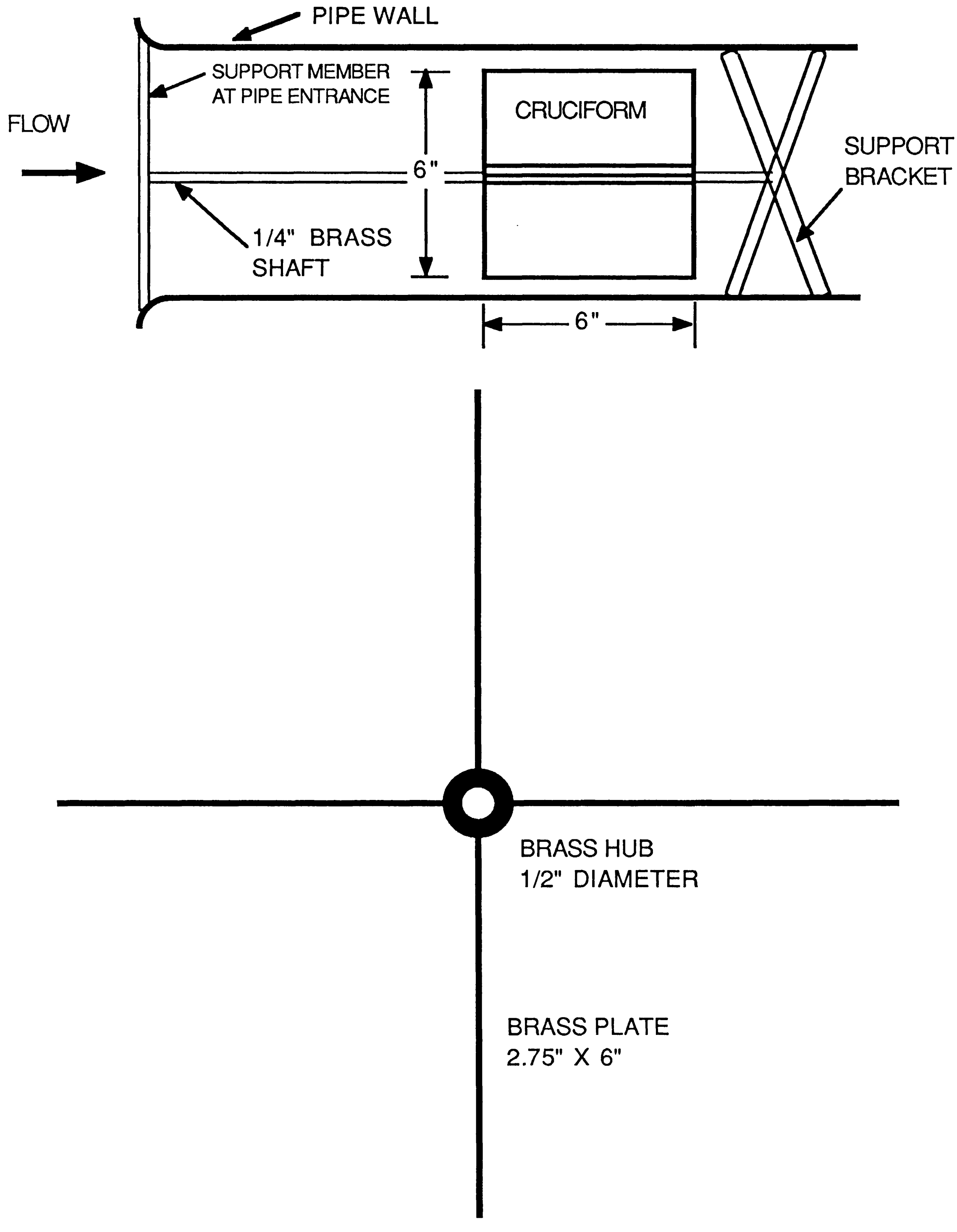


Figure 5. Detail of Rotating Cruciform.

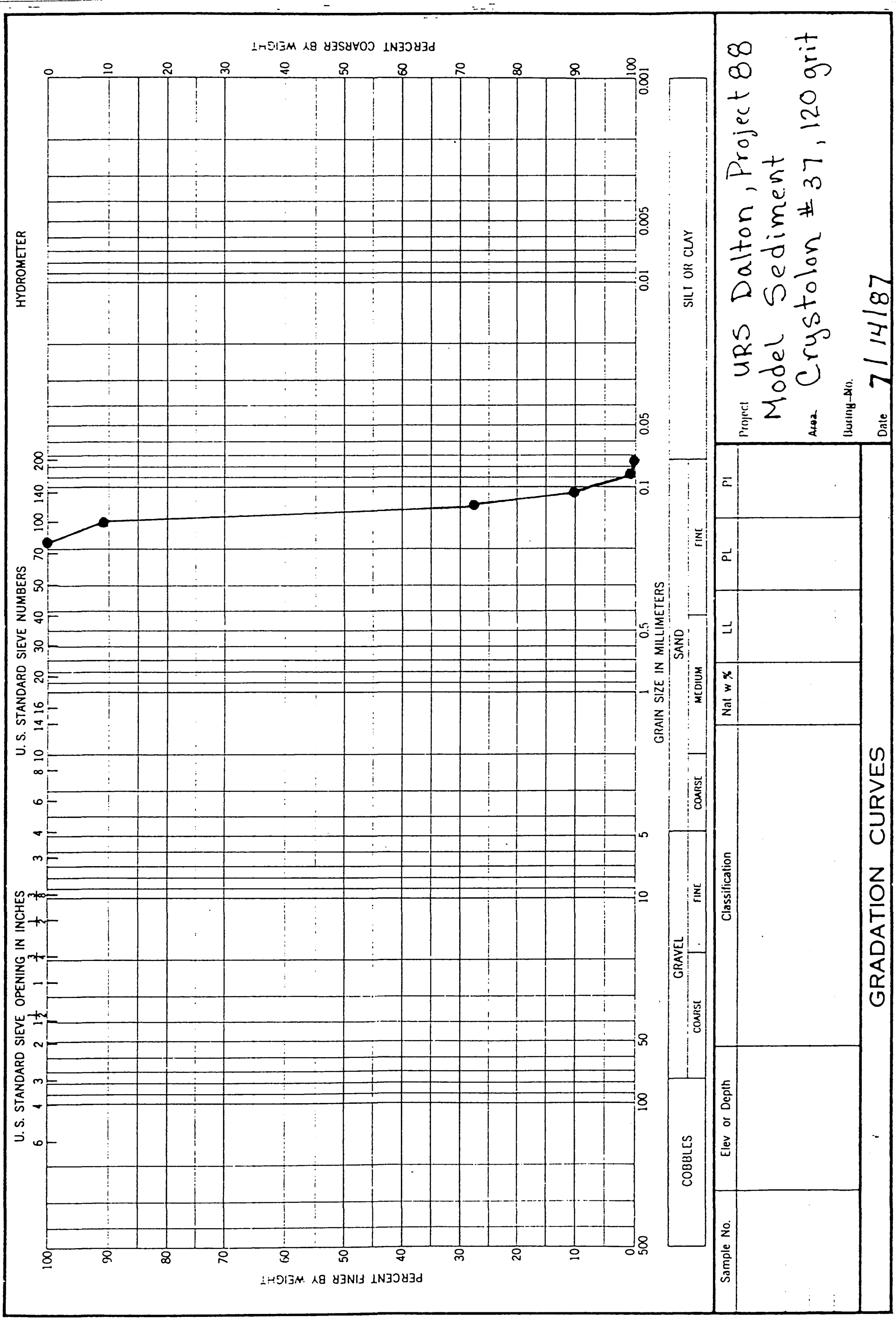


Figure 4. Gradation Curve for Model Sediment.

TESTING PROCEDURES

During dry weather flows, the wet wells will be separated and operate at different wet well levels. Wet Well 1 will serve the ONWI and the future WSRI while Wet Well 2 will serve the NI-EA. Wet Well 1 will be interconnected to the existing Pump Station 1 and will be held at elevations in the range of 76-80 feet to match the required elevation in Pumping Station 1. The water surface in Wet Well 2, however can be held at Elevation 90, to reduce pumping costs, without flooding the NI-EA.

The maximum wet weather flow of 600 MGD in the NI-EA exceeds the capacity of the four pumps in Wet Well 2. Therefore the sluice gate isolating the two wet wells must be opened so that some of this flow will be pumped by the pumps in Wet Well 1. Under this operating condition, both wet wells will operate at a wet well level in the range of Elevation 76 -80.

The model was constructed in such a way that the maximum water level elevation that could be tested was approximately 90.0 feet. In Wet Well 2, water levels can rise above the 90 ft elevation during dry weather conditions.

Specific details regarding the testing program are discussed below.

1. All observations of surface vortices were classified with respect to their appearance. Specifically, this involves a designation of the visual appearance of the vortex strength ranging from surface swirl to an air core vortex that exists all the way to the pump intake. Following Padmanabhan and Hecker (1984) the classification system is as follows:

Type 1: Surface swirl

Type 2: Surface dimple: coherent swirl

Type 3: Dye core to intake; coherent swirl throughout water column

Type 4: Vortex pulling floating trash but not air to intake

Type 5: Vortex pulling air bubbles to intake

Type 6: Solid air or vapor core to intake

No surface vortex more severe than an intermittent Type 2 dye core is generally regarded as an acceptable flow state. This was determined by visually examining the water surface for dimples and injecting dye to look for organized motions extending downwards to one of the suction intakes. Any vortices persisting less than about 10 seconds were considered to be intermittent.

2. Observations of subsurface vortices were made by dye injections into the model and observing the tendency for any organized vortex motion. Acceptance criteria allow no coherent subsurface vortex with organized swirl and core (Type 2).

3. With respect to entrance conditions into the pump suction lines, the swirl angle of the entering flow was measured in all inlet lines with a rotating cruciform as indicated in Figure 5. The swirl angle was defined by counting the rotations per unit time and computing the angle as

$$\theta = \tan^{-1}\left(\frac{\pi N D}{U}\right)$$

with θ the swirl angle, N the revolutions per unit time of the rotating cruciform, D the pipe diameter and U the average axial flow velocity (the line discharge divided by the pipe cross sectional area). For the purposes of this study swirl angles were defined as positive if the sense of the vane rotation was counter-clockwise looking into the suction pipes from the wet wells; a negative swirl angle implies clockwise rotation. The cruciforms were installed into the horizontal section of the suction pipe constructed from plexiglass (see Fig. 3d) so that they could be easily seen. The center of the cruciform was approximately 2.5 pipe diameters into the pipe from the suction entrance from the wet well. Since the pumps are actually further down the intake lines, it is presumed that the actual swirl angles at the pumps will be somewhat less than those measured at the location of the cruciforms. Five minute counts on vane rotation were used to define the swirl angles. However, counts on vane rotation were obtained over successive 30 second intervals so that shorter averaging periods could be also examined, if desired. In general, it was found that the 30 second rotation counts would show considerable variability, implying relatively long time scales associated with the fluctuations in the swirl motions. On one experiment, the vane rotations were collected at 30 second intervals over a 30 minute period to give an idea of the uncertainty in the estimate of the swirl angle due to the five minute sample period. The sample record was subdivided into successive sample records with periods ranging from 1/2 to 10 minutes and the sample standard deviation at that period computed; the results are presented in Fig. 7. The average for the total sample was 6.5 revolutions per 30 second counting interval. The minimum count in any 30 second period was 1.75 revolutions and the maximum was 9.5 revolutions. It can be seen from Fig. 7 that the sample standard deviation at the 30 second count was almost 25 percent and at the five minute averaging period is approximately 7.5 percent. If the range of expected counts can be expected to fall within plus or minus two standard deviations of the mean, the possible deviation with any five minute count is approximately 15 percent. It is probable that the relative deviation in the measurement increases with decreasing swirl angle, but the results presented in Fig. 7 are at a value close to the acceptance limit (average swirl angle of 10.3°), so should be a good measure of the general uncertainty in the measurements that were critical to the determination of wet well performance. In the actual testing phase, this magnitude of deviation was never sufficient to reject any option and the differences between different options were generally much greater than this.

Swirl angles of less than 5 degrees were considered as acceptable except that infrequent operating conditions such as the low level cut-out tests may allow intermittent swirl angles of up to 10 degrees.

4. Sedimentation was assessed by introducing the black silicon carbide grinding powder into the inlet chamber. A fixed mass of sediment (approximately 1-2

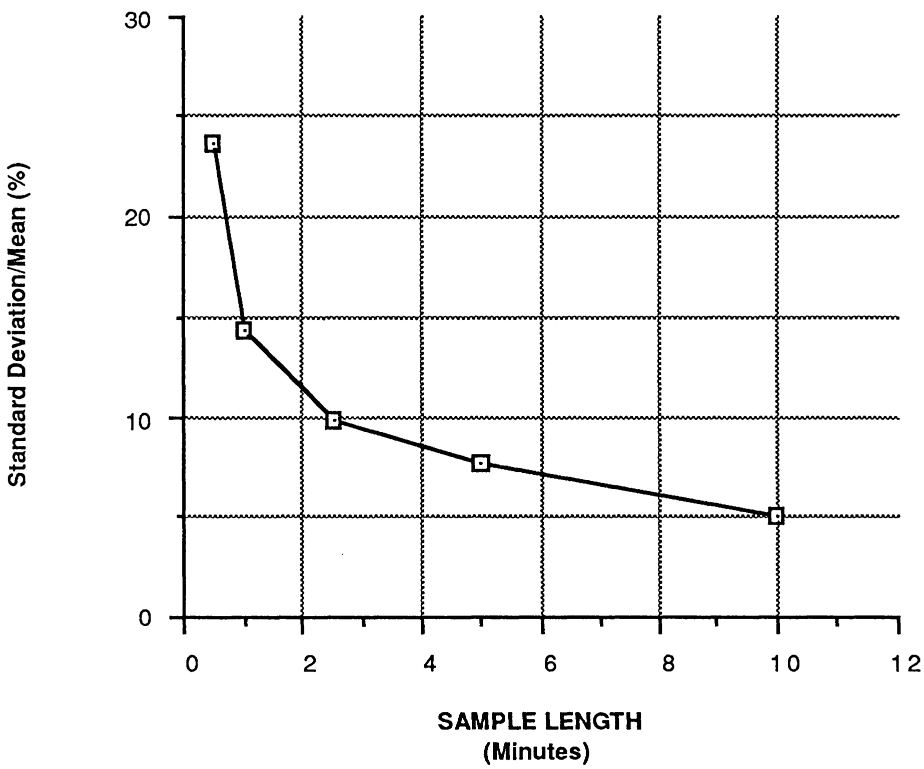


Figure 7. Sample Standard Deviation as a Function of Sample Length.

kilograms) was introduced into the system and the flow allowed to come to equilibrium. In general, the flow was one associated with a dry weather flow state that would create conditions conducive to sediment deposition such as the operation in Pumps 15 and 16 in Wet Well 2 which would tend to enhance deposition at the far end of the wet well. After the sedimentation patterns in the wet well bottom were observed to be in an equilibrium state (no further deposition apparent), the flow state was changed to the wet weather flow condition in order to observe whether the material deposited on the wet well bottom was scoured and remained in suspension.

TEST CONDITIONS

Test conditions examined included the following different cases:

A. Flows associated with the use of the pumping station with the water levels in the wet wells controlled by the low level cutout switches: This state may be intentionally set in order to periodically flush grit from the interceptors and could also be inadvertently attained due to the relatively short time required to draw the wet wells down from their other operating states, especially the wet weather flow in Wet Well 2. The low level cutout elevations are 47 ft in Wet Well 1 and 69 ft in Wet Well 2. In order to establish the system flows with all pumps operating in this limit state, the hydraulic profile information developed by Applied Science, Inc. for the treatment plant (discharge side of the pumps) was used along with the net head-discharge curves (total head minus station losses) through the pumps at rated speed. The other wet well is assumed to be operating with three pumps at rated capacity in determining the discharge water level elevations in this analysis although this is not a critical aspect of the computations. These two pieces of information are presented in Figs. 8 and 9 respectively. The points for each wet well are indicated on the figures and the flow per pump in Wet Well 1 is estimated to be approximately 42,000 gpm and about 69,000 gpm in Wet Well 2.

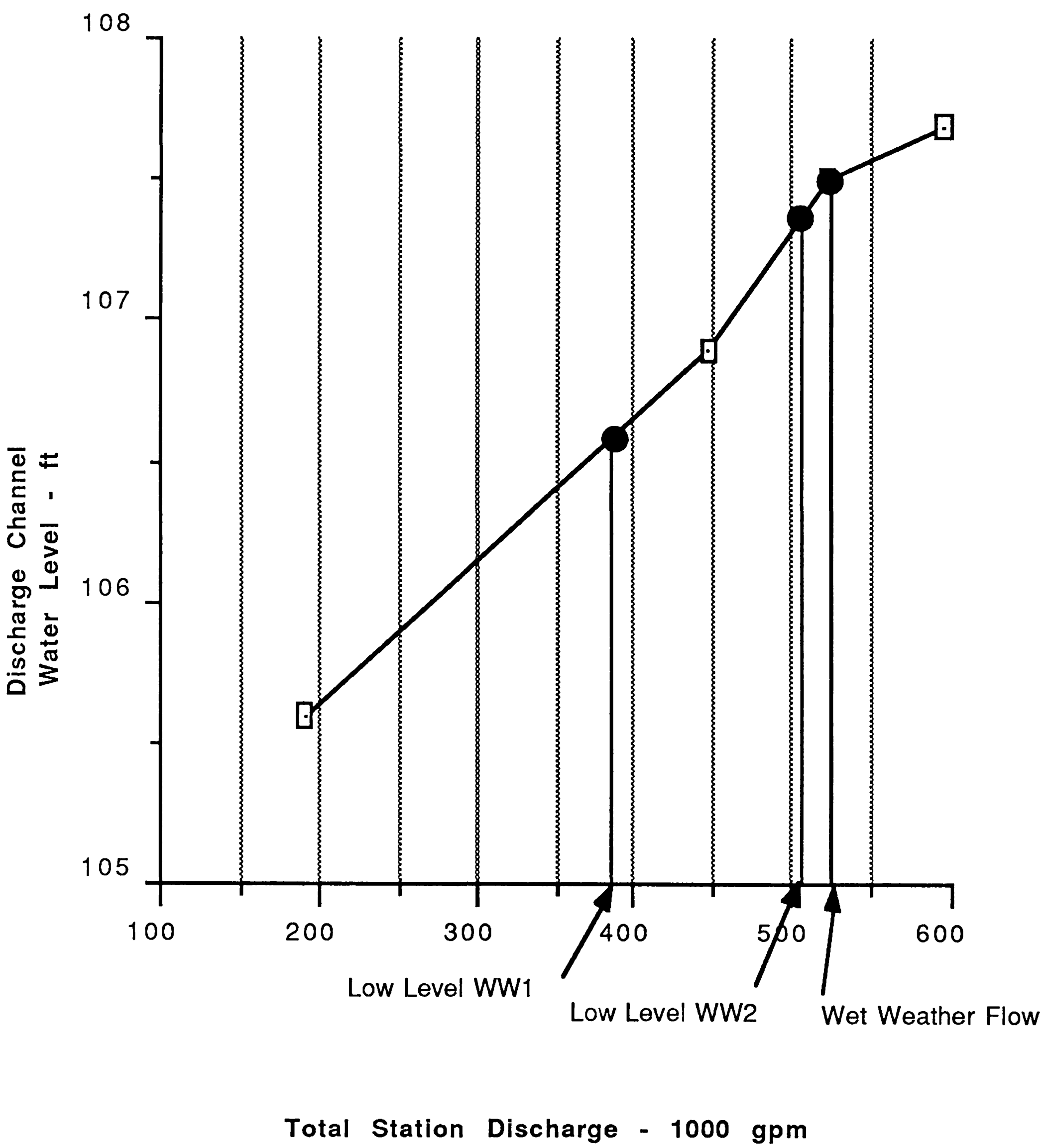


Figure 8. Station Discharge Elevation versus Discharge.

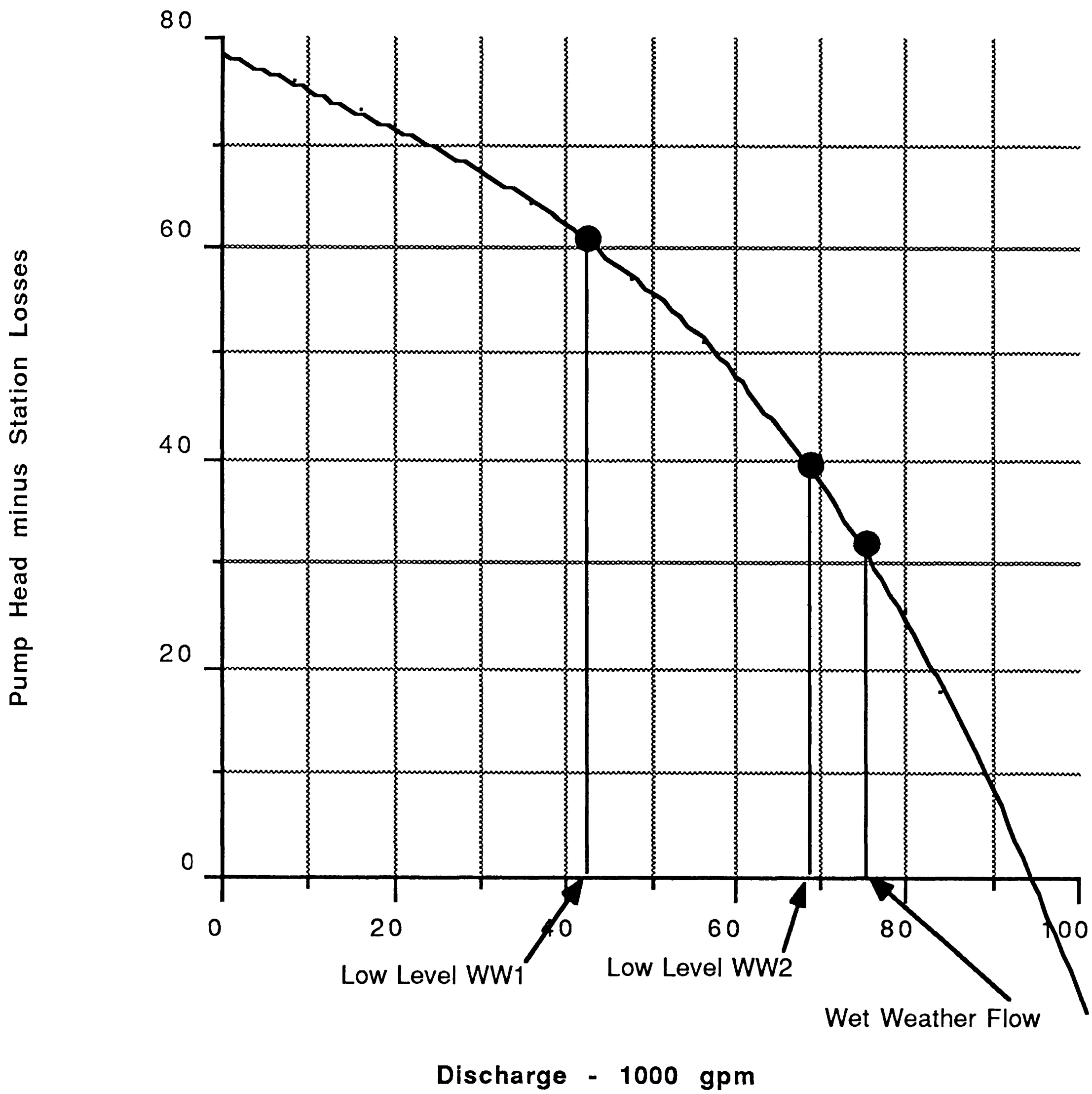


Figure 9. Net Head - Discharge Curves for Pumps at Full Speed.

Initially, it was specified that the low level cutout flow for scouring grit from the interceptors would be established with all four pumps in operation. However, during the course of the study, it was decided by Metcalf and Eddy that two pumps would be sufficient for this purpose. Therefore tests were performed with all combinations of two pumps (at least for the alternatives that were ultimately selected or seriously considered). In addition, tests were performed with all four pumps in operation, because it would be possible to attain this state inadvertently. The low level cutout flows for Wet Well 1 were specified for flushing the WSRI. It was presumed that this would be the only need to intentionally lower the wet well water surface elevation to the low level cutout level for grit removal purposes. Flow from the ONWI will cascade into the inlet chamber at a wet well water level of 47.0 feet.

B. "Average" dry weather operating conditions for each wet well: For Wet Well 1, this was specified to correspond as a pumping rate of 150 mgd and a water level of 76 feet. By analyzing the corresponding point on the pump curve rated at full speed, see Fig. 9, it appears that two pumps are required to deliver this flow. For Wet Well 2, the average dry weather operating condition was given as a pumping rate of 200 mgd and a wet well water level of 90 feet. Again, two (or possibly three) pumps will be required to deliver this flow near the point of maximum pump efficiency. Especially for the latter case, a pump operating at full speed with this pump head would be far off the point of maximum efficiency. Therefore, it is presumed that two variable speed pumps will be used in these flow states in each wet well. It was further assumed that the flow will be equally distributed between two pumps in each case and that the pump speeds will be adjusted to achieve these flow distributions. The two pump configuration represents a case worse than pumping through each of three pumps. The flow in Wet Well 1 was taken from the ONWI Interceptor and in Wet Well 2 from the NI-EA in the model tests.

C. Wet weather operating conditions: Both wet wells will be operated at a common water level of 76 feet during wet weather flows. A total pumping rate of 750 mgd is the design wet weather flow with 600 mgd entering from the NI-EA and 150 mgd from the Oakwood or WSRI. For purposes of testing, the model tests were performed with separate wet well flows. Wet Well 2 was studied with the entire flow from NI-EA and Wet Well 1 with approximately 150 mgd flow from the Oakwood Interceptor and the remainder from the NI-EA. Although this does not precisely model the flow in the inlet chamber on the NI-EA side, it does handle the flow distribution entering into the inlet chamber from the Oakwood side and no possible influence on the flow distribution in the wet well is visualized by this approach. The flow rates per pump in all cases are obtained from the curves in Figs. 8 and 9 as approximately 75,000 gpm. Therefore, seven pumps will be required to pass the design flow. For purposes of the model study, it was assumed that four of the seven pumps in operation will be in the particular wet well studied as this is expected to represent the worst case with respect to vortexing. Four pumps were considered in the operation of Wet Well 1 since this configuration will be ultimately installed. With respect to the possibility that only three of the pumps may be operating in a particular wet well, this is probably not a worst case situation for the wet weather flows.

D. Testing with greater than Froude scaled velocities. Hydraulic physical models do not reproduce all effects and certain limitations on the modelling are imposed by this consideration. It has been previously suggested that model tests should be conducted with velocities higher than those indicated by a Froude scaled model, although there appears to be little rational basis for this recommendation other than it represents a conservative basis for design. Previous studies have suggested that pump intake studies should be performed with a model Reynolds number that is at least 30,000, as discussed previously. With the Reynolds number based upon the average flow velocity in the suction pipe (and the lowest flow rate corresponding to 42,000 gpm prototype) and the pipe diameter, the minimum Reynolds number in this model study was about 75,000 or well above this limit. However, in order to examine the possible effect of scaling errors, the worst case condition from the tests described in (A-C) were examined with a flow rate 50 percent greater than the appropriate nominal flow. A total of six different flow conditions were examined for this purpose. It is reasonable to expect that only minor changes in the swirl angle would result from this increase in flow since the swirl angle is essentially a ratio of circumferential to axial velocity which should be approximately independent of total flow rate; however, the higher flow rates should enhance the possibility for vortex formation.

For the purposes of a permanent data record with respect to the general observations of the flow and the model construction, a videotape was made of relevant portions of the model testing sequence. A video camera system with 1/2 inch VHS format was used to record the details of the model construction and various portions of the testing sequence. In particular, various flows with the initial proposed design were recorded along with results from the final proposed configurations.

TEST RESULTS

In the following presentation, the results from the testing program are presented. The pump suction lines are referred to by pump number according to the convention indicated in Fig. 1. In order to discuss the results in a coherent fashion, the findings from the studies on the preliminary design are presented first. These are shown to result in unsatisfactory swirl angles, often considerably in excess of the acceptance criteria stated above. After these results were obtained, a series of modifications were made to the individual wet wells in order to obtain better flow conditions. These modifications are described more or less in the order performed in order to indicate the convergence towards an acceptable flow condition within each wet well. In many cases, not all flow conditions listed above were tested for a given configuration. Instead, if there was a clear problem indicated by an examination of what were estimated to be critical test conditions (i.e. certain pump and water level combinations gave consistently poor performance over many test configurations), the alternative was abandoned without completing the entire testing sequence. Also, some additional configurations were studied in a preliminary fashion with only one minute counts on vane rotation. In all cases, these indicated unacceptable behavior and are described only for completeness for purposes of documenting the testing program.

Initial Design

The initial model configuration involved the construction of the wet well geometries suggested in the preliminary design. A series of tests were performed for both Wet Wells 1 and 2 and generally similar results were found in both. It was originally anticipated that most difficulties would be experienced with the low level cutout elevations, so initial efforts were generally focussed on these flow conditions. There were two problems apparent from the initial investigation; 1.) the formation of a submerged type of radial hydraulic jump in both wet wells at the low level cutout elevations with four pumps in operation, and 2.) the occurrence of excessive swirl angles in certain of the suction lines. Figures 10 (Wet Well 1) and 11 (Wet Well 2) are photographs of the wet well surfaces and one suction discharge line to indicate the nature of these problems. The free surface is clearly much more covered with froth in Wet Well 1, but significant water surface disturbances are apparent in Wet Well 2. Also, a significant amount of air entrainment is observed in the plexiglass section in Fig. 11(b). In Wet Well 1, the amount of air entrainment was sufficient to prevent normal operation of the circulating pump and it was impossible to maintain a constant system discharge.

No problems were observed with respect to surface or subsurface vortices under any conditions examined in this initial investigation or in nearly all experiments performed later. Dye injection into the mouth of the suction lines never showed any tendency to form a coherent dye core and although surface vortices were often present in the wet wells, they never retained their identity for longer than perhaps ten seconds

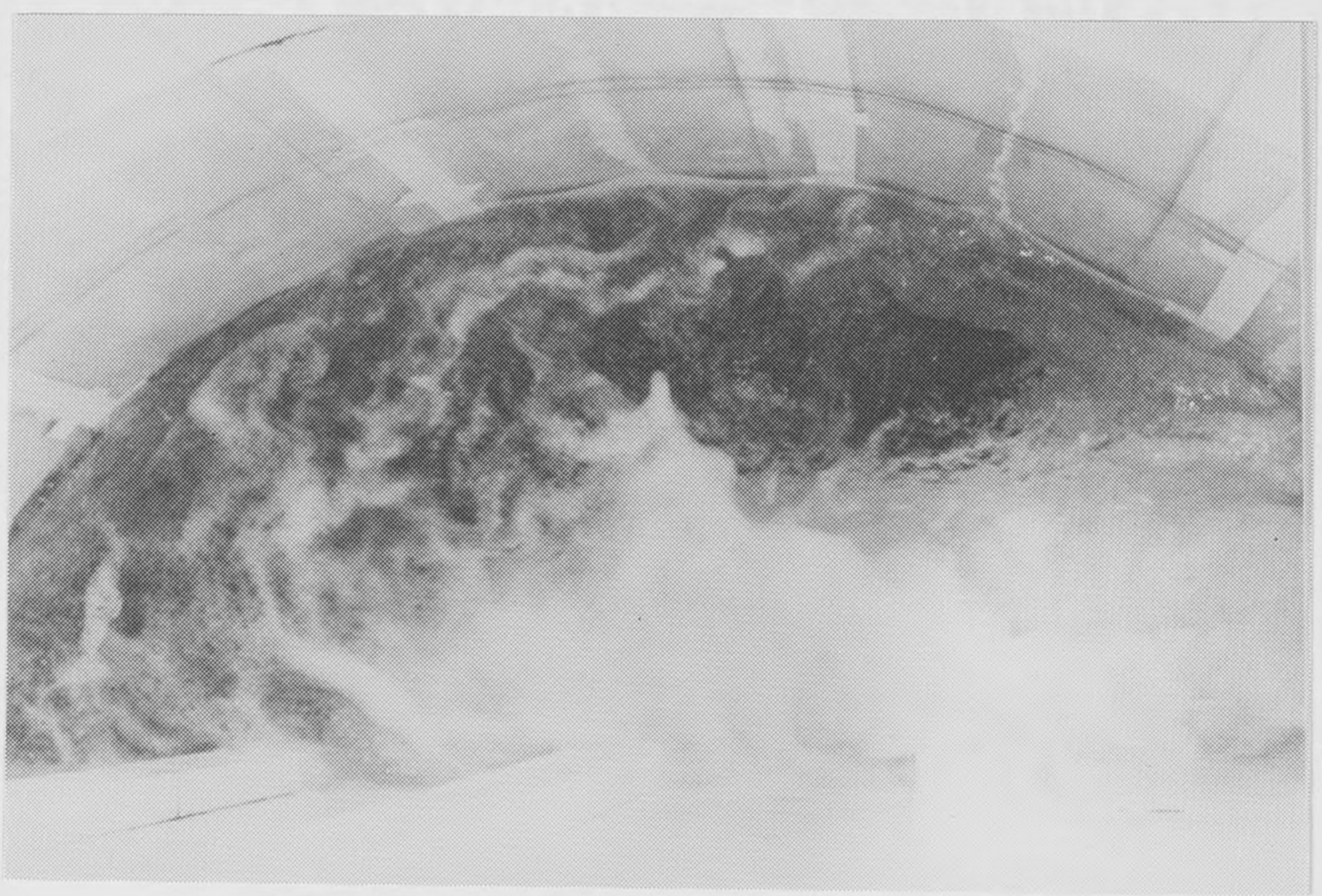
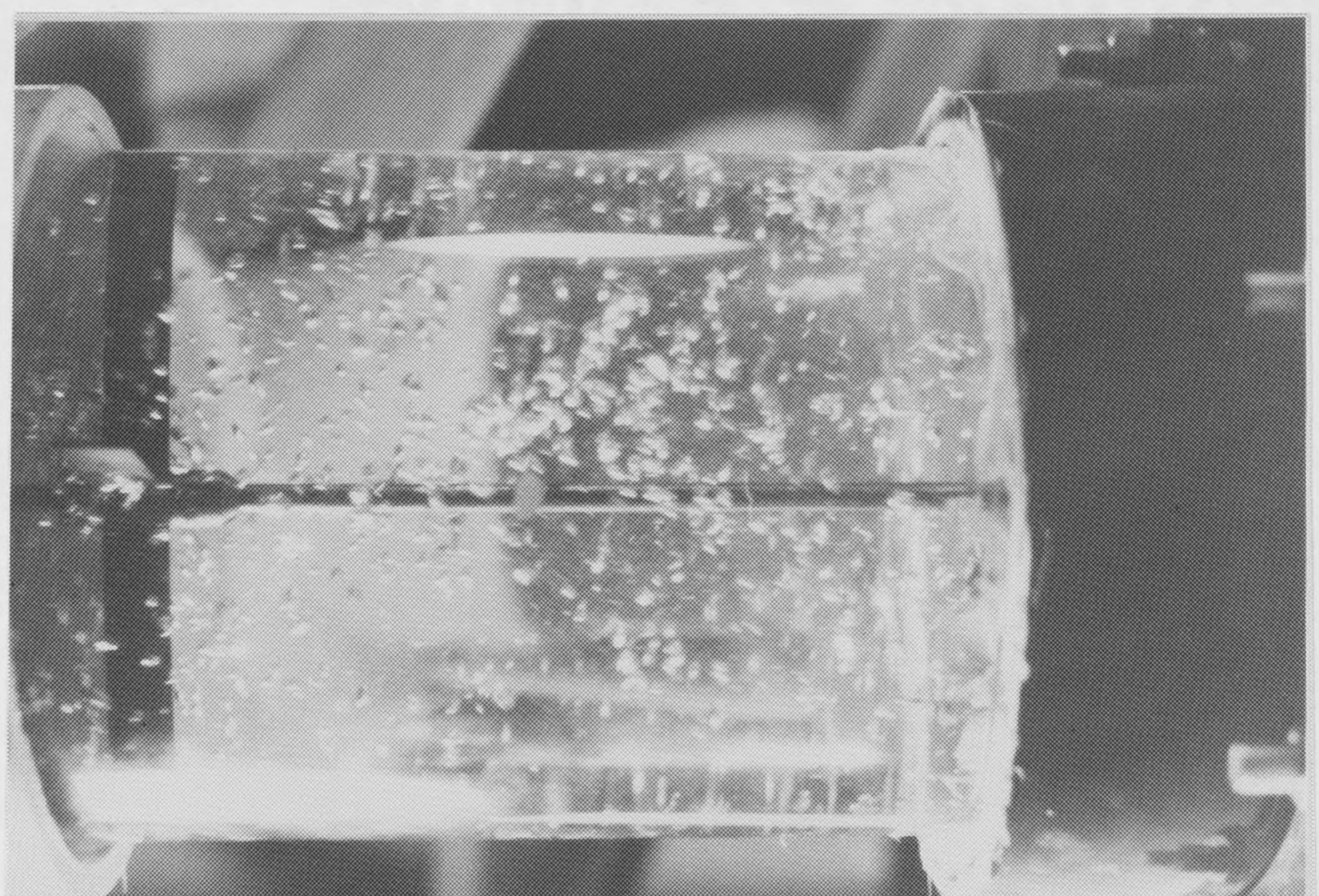


Figure 10. Photographs of Flow in Wet Well 1, Initial Design, Low Level Cutout Condition, All Four Pumps in Operation.

c.) View Inside of Wet Well from Center Dividing Wall.



d.) View of Air Entrainment into Pump Suction Pipe.

Figure 11. Photographs of Flow in Wet Well 2, Initial Design, Low Level Cutout Condition, All Four Pumps in Operation.

nor could a coherent core be identified that extended to a pump suction line. No sedimentation studies were performed on the initial design configuration as those experiments were reserved for the recommended wet well configurations.

The problem with the radial hydraulic jump was primarily that a significant amount of air was entrained into the flow and carried into the pump suction lines. The air entrainment appeared to be caused by the relatively high velocities through the sluice gate entering each wet well and the low level within the wet well. A well-defined jet of water tended to travel entirely across the wet well and impinge upon the outer wall at a different location in each wet well. Raising the water level in Wet Well 2 approximately 2-3 feet tended to eliminate the problem with the air entrainment while this phenomenon persisted in Wet Well 1 up to a water level elevation of approximately 60 feet. Decreasing the wet well flows (reducing the number of pumps in operation) similarly tended to eliminate air entrainment and tests with only two or three pumps in operation did not experience this phenomenon. An additional problem associated with the flow in Wet Well 1 was associated with the proximity of the sluice gate opening with the center dividing wall between the wet wells. Fluid impinging upon the pilasters protruding into the flow resulted in sprays of water and additional air entrainment. This problem was not observed along the center wall in Wet Well 2.

The swirl angles measured for various flow conditions are presented in Tables 1 and 2 for Wet Wells 1 and 2, respectively. A number of observations can be made from these test results. In general, it is seen that the flow tends to move across the wet well, down somewhere near the center (depending upon the specific pumps that are in use) and returns upwards in the corners. This tends to produce a stronger component of swirl in those pumps in the corners (Pumps 9 and 12 in Wet Well 1 and 13 and 16 in Wet Well 2). It is almost universally true that the worst swirl angles were found in the corner pumps. This is felt to be due to a combination of both high inlet velocities and restricted space down near the suction entrances. Another finding for Wet Well 1 is that wet weather flows exhibited smaller swirl angles than the worst of the dry weather or the low level cutout flow states; this was generally found to be the case with other configurations as discussed further below. The swirl angles were considerably in excess of the recommended limits of five degrees, especially in Wet Well 1 where swirl angles of up to approximately 30 degrees were recorded. Wet Well 2 exhibited swirl angles of over sixteen degrees and dry weather flows were not tested to find out what they would produce. With these results, however, a decision was made to modify the inside of the wet wells to obtain better hydraulic conditions. Since Wet Well 1 exhibited the highest swirl angles, initial attention was focussed on it.

Table 1. Swirl Angle Measurements for Wet Well 1 with the Initial Design.

WET WELL 1

DRY WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 75 MGD

PUMP	9	10	11	12
	9.1	-4.3		
SWIRL ANGLES	8.1		-1.9	
	4.0			-0.2
		-11.0	-16.4	
		0.7		-2.6
			-3.0	-22.0

WET WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 108 MGD

PUMP	9	10	11	12
SWIRL ANGLES	2.2	-4.6	-12.7	6.2

LOW LEVEL CUTOUT FLOW: Elevation - 47.0 ft ; Flow per Pump - 60 MGD

PUMP	9	10	11	12
	29.3	-13.1	-10.3	
	33.2		-6.41	-18.0
SWIRL ANGLES	15.4	-2.7		-23.9
		-0.6	-12.7	-21.2

Could not make system function with four pumps at low level cutout due to air entrainment, experiments were run with four pumps at wet well level 60.0 ft.

Oakwood Entrance	-6.4	-7.2	-15.0	-17.4
WSRI Entrance	-1.3	-2.2	-12.0	-14.8

Table 2. Swirl Angle Measurements for Wet Well 2 with the Initial Design.

WET WELL 2

DRY WEATHER FLOW : Elevation - 90.0 ft ; Flow per Pump - 100 MGD				
PUMP	**13**	**14**	**15**	**16**
SWIRL ANGLES				

WET WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 108 MGD				
PUMP	**13**	**14**	**15**	**16**
SWIRL ANGLES	-2.1	-0.5	4.5	14.6

LOW LEVEL CUTOUT FLOW: Elevation - 69.0 ft ; Flow per Pump - 99 MGD				
PUMP	**13**	**14**	**15**	**16**
	-2.3	-2.0	6.1	16.2
SWIRL ANGLES				14.2

Modifications to Wet Well 1

Since the presence of the pilasters in Wet Well 1 seemed to create a significant disturbance in Wet Well 1, an early decision was made to remove these and replace the original 3 foot thick center wall by one eight feet thick; the additional width was to go on the Wet Well 2 side. This change by itself was found to have only minor influences on the measured swirl angles. However, this modification was a permanent one in all further testing.

One preliminary attempt to reduce the swirl angles involved the placement of two vertical columns just inside of Wet Well 1 as indicated in Fig. 12. The intended objective was primarily to break up the high velocity jet entering the wet well through the sluice gate. The results of measurements for this configuration are indicated in Table 3. In general, no significant improvement in flow conditions from the initial design was observed for the test conditions investigated and this option was not considered further. Preliminary investigations involving similar arrangements with different column spacings or with baffle walls in similar locations proved equally unsuccessful.

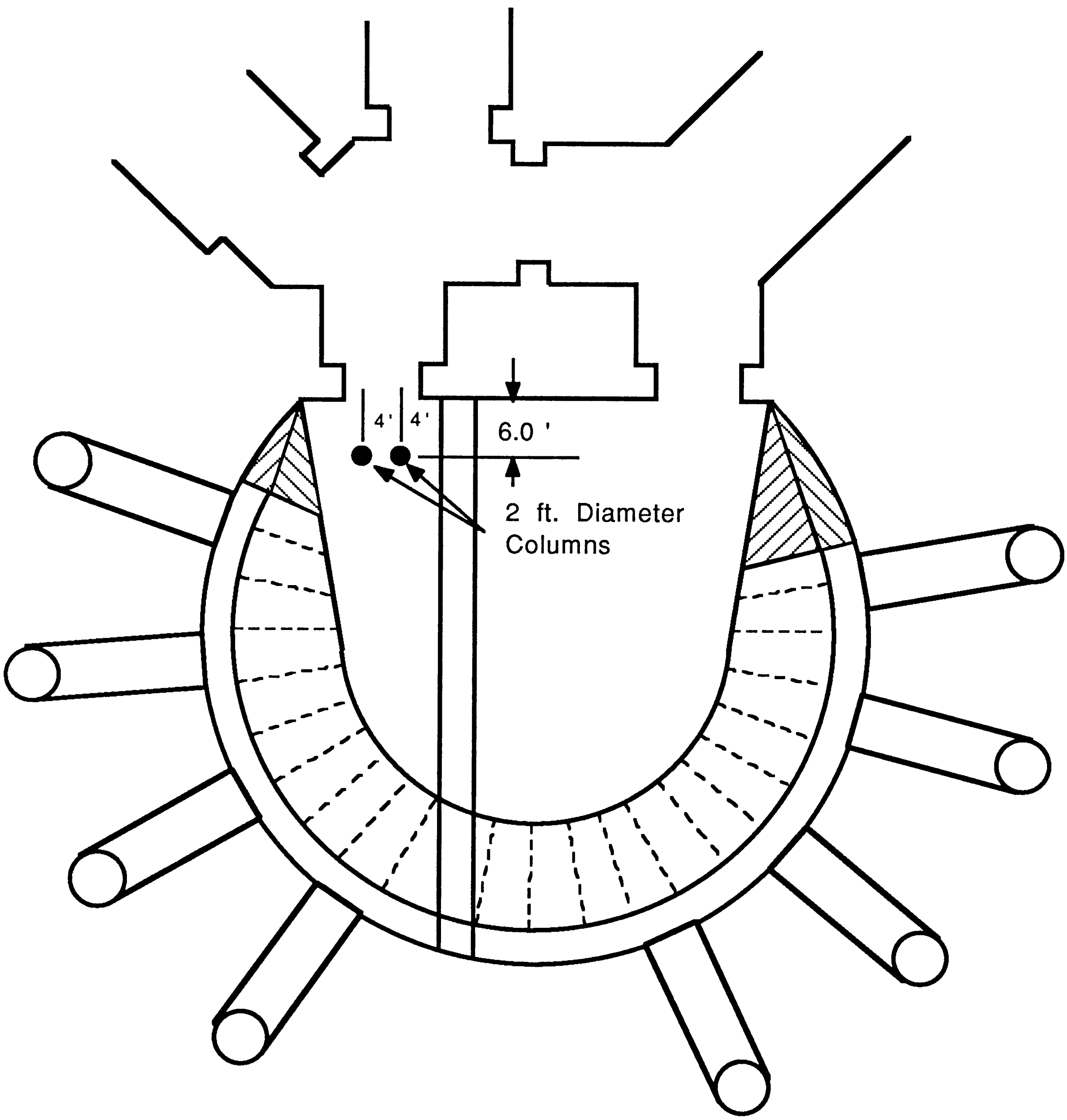


Figure 12. Modification to Wet Well 1 by Addition of Internal Columns.

Table 3. Swirl Angle Measurements for Wet Well 1 with the Vertical Columns within Wet Well.

WET WELL 1

DRY WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 75 MGD

PUMP	9	10	11	12
SWIRL ANGLES				

WET WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 108 MGD

PUMP	9	10	11	12
SWIRL ANGLES				

LOW LEVEL CUTOUT FLOW: Elevation - 47.0 ft ; Flow per Pump - 60 MGD

PUMP	9	10	11	12
	0.4	-12.9	-16.7	
SWIRL ANGLES		-4.55	-10.8	-22.9
	24.5		-11.2	-25.7

Additional alterations in the wet well geometry were directed towards increasing the flow area near the pump suction intakes. This was accomplished by removing the raised portion of the wet well floor, giving a floor elevation of 33.5 feet. One of the objectives behind the raised portion of the wet well bottom in the initial design was to prevent excessive sedimentation. This objective was kept in mind by also immediately considering a closely related alternative in which the floor was sloped down from the invert of the entrance sluice gate with a single slope as indicated schematically in Fig. 13. Both of these alternatives were subjected to extensive testing and the results are presented in Tables 4 and 5. In both of these configurations, the severe swirl conditions for the corner pumps was significantly diminished, apparently due to the increase in flow area within the wet well. The worst swirl condition was fairly consistently found in Pump 11 for these two configurations. This is approximately where the high velocity jet through the sluice gate impinges upon the outer wall of the wet well. This serves to indicate the combination of the two effects (high inlet velocity and restricted flow area near the intakes) in yielding the undesirable flow conditions in the wet well. However, several flows investigated still yielded swirl angles in excess of 9 degrees, for each of the different flow states within the wet well. However, it was observed that the geometry with the sloping bottom yielded generally better flow conditions and since it was expected that this would also serve to minimize sedimentation problems in the wet well, all further studies focussed on this general geometry.

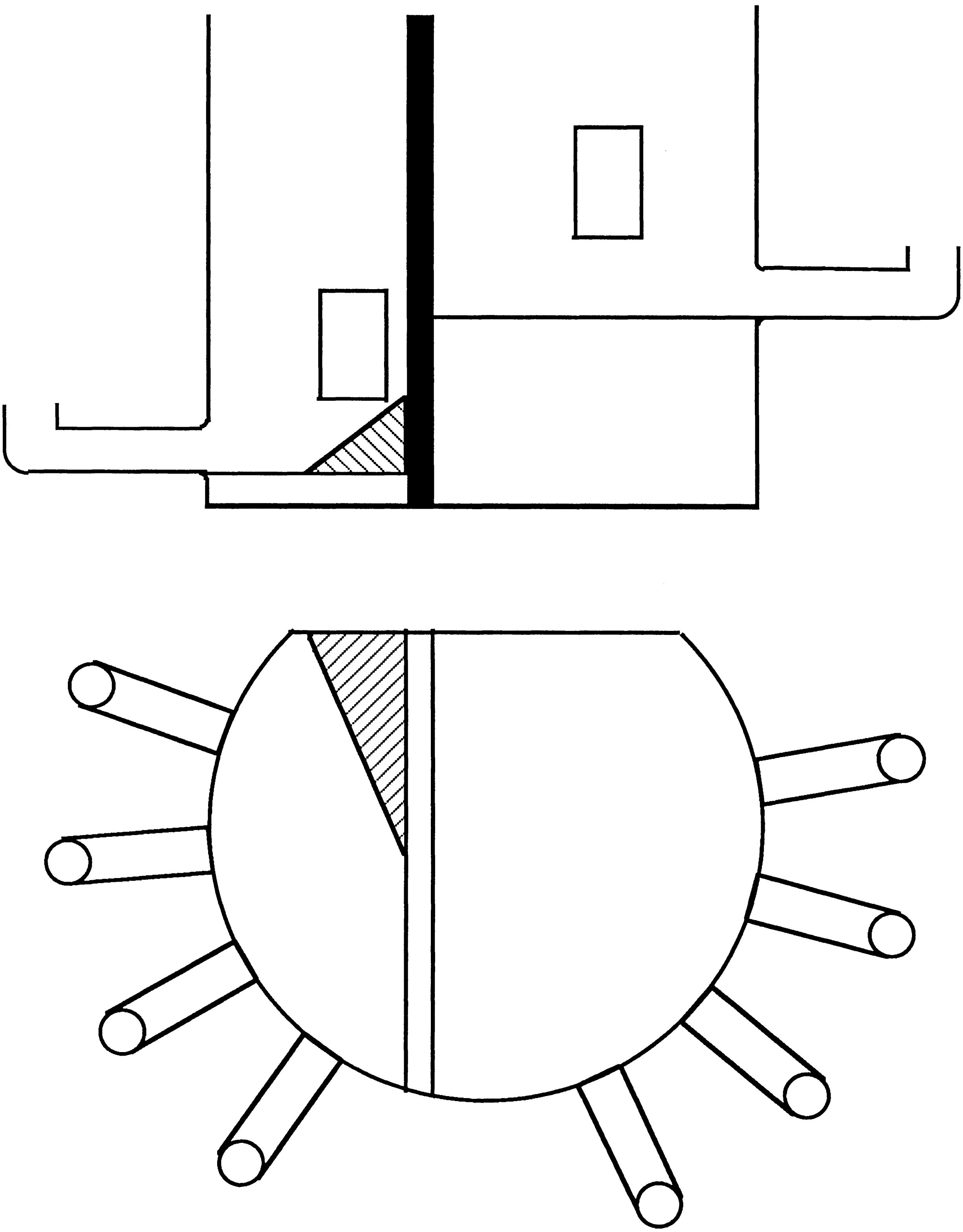


Figure 13. Sloping Floor Modification to Wet Well 1.

Table 4. Swirl Angle Measurements for Wet Well 1 with Flat Floor.

WET WELL 1

DRY WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 75 MGD

PUMP	9	10	11	12
SWIRL ANGLES				

WET WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 108 MGD

PUMP	9	10	11	12
SWIRL ANGLES	-0.3	-1.88	-9.5	-9.7

LOW LEVEL CUTOUT FLOW: Elevation - 47.0 ft ; Flow per Pump - 60 MGD

PUMP	9	10	11	12
	0.4	-12.9	-16.7	
SWIRL ANGLES	0.9		-11.5	-1.7
		-6.9	-10.1	0.9

Table 5. Swirl Angle Measurements for Wet Well 1 with Sloping Floor.

WET WELL 1

DRY WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 75 MGD				
PUMP	**9**	**10**	**11**	**12**
	0.7	1.9		
	0.3		1.0	
	-2.2			0.3
SWIRL ANGLES		1.2	-10.4	
			0.1	-8.5
		0.7		1.4
WET WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 108 MGD				
PUMP	**9**	**10**	**11**	**12**
SWIRL ANGLES	0.9	-0.1	-6.24	-4.5
LOW LEVEL CUTOUT FLOW: Elevation - 47.0 ft ; Flow per Pump - 60 MGD				
PUMP	**9**	**10**	**11**	**12**
SWIRL ANGLES		-2.6	-3.9	
			-9.4	-3.1

With the results from this round of testing, it was apparent that any additional improvement would have to come by reducing the strength of the jet through the entrance sluice gate. It was decided to place a baffle wall entirely across the wet well such that flow was forced both beneath and above the wall during normal wet well flow conditions. The initial attempt involved the placement of a 20 foot high by 30 foot long wall as indicated in Fig. 14. The bottom of the wall was level with the invert of the inlet sluice gate and the top extended five feet above the top of the gate. This height was selected to allow approximately ten feet of clearance above and below the wall during dry and wet weather flow conditions. This effort met with substantial success in reducing swirl angles as indicated in Table 6. Further investigations to determine whether or not other geometrical configurations might produce lower swirl angles failed to turn up substantial improvements and in fact generally produced some deterioration in the flow behavior. Included in Table 6 for purposes of comparison are the results of dry weather flow testing with two shorter wall heights (with the same bottom elevation as the 20 by 30 ft wall) and these are seen to be clearly less effective. Also examined were longer walls which extended farther down the center wall; these were found to give slightly higher swirl angles and were not considered further. Some investigations were made retaining the same wall height but lowering its elevation approximately 3 feet in the wet well. This was found to significantly increase the swirl angles in Pump 12 in the low level cutout state (with four pumps in operation, the measured swirl angle in the Pump 12 intake was approximately 45 degrees) and somewhat increase the swirl angles for the dry weather flows. No other configuration seemed to be able to provide as good of behavior as the 20 by 30 foot baffle wall in Fig. 14 over the range of flow conditions.

The results for the configuration in Fig. 14 clearly indicate much improved behavior for the dry weather and wet weather flows compared to all of the other alternatives investigated. The worst swirl angle in any of the tests for these flows was 3.5 degrees, which is sufficiently less than the acceptance criteria of five degrees. For all other dry weather flows, the swirl angle was less than 2 degrees. Wet weather flows only show two pump intakes with swirl conditions slightly greater than 3 degrees.

There are still some problems with the Fig. 14 configuration indicated at the low level cutout condition. In particular, Pump intake 9 shows fairly consistently poor performance with the worst condition of a swirl angle of 27° when all four pumps were in operation. However, it is noted that this is not considered to be a normal operating state and should be achievable only due to an inadvertent drawdown of the water level in the wet well. In that regard, it was observed during the testing sequence that the swirl performance deteriorated significantly just as the low level cutout condition was being attained, i.e. the performance was acceptable at slightly higher water levels, but became rapidly worse with lower water levels. In order to demonstrate this effect, additional measurements were made at the prototype water level of 48 feet or one foot greater and these are also presented in Table 6. It is seen, for example, that the swirl angle of 27° is significantly reduced down to an essentially acceptable level of 5.6 degrees. Therefore, the severe swirl condition would only be felt for the few seconds that it would take to draw the wet well levels down the last foot, after which the pumps would trip. Another solution to the problem, of course, would be to raise the low level cutout elevation an additional foot or so, but this is dependent upon other constraints in the wet well operation.

The same general conclusions and findings are also apparent when the tests with the different combinations of two pumps are examined. Again, Pump intake 9 fairly consistently indicates rather high swirl angles with a maximum of 19.5° even with the wet well at the elevation of 48 feet. This somewhat unexpected finding that the worst swirl tended to occur with a lesser number of pumps in operation was also confirmed in the later testing in Wet Well 2 as well. Again raising the water levels in the wet well tended to provide better performance and some consideration should be paid to the possibility of raising the low level cutout elevation to 48 feet. However, in this situation, another solution presents itself. It is seen that nearly all of the combinations of pumps that exhibit relatively large swirl angles are associated with the operation of Pump 9. Therefore, if the use of Pump 9 is prohibited for the relatively infrequent operation at this level to scour grit in the influent interceptors, generally acceptable hydraulic performance can be achieved. The preferred pump combination would be that of Pumps 11 and 12, although any combinations of the three would perhaps be satisfactory. A more detailed discussion of these results is given at the end of the Results section.

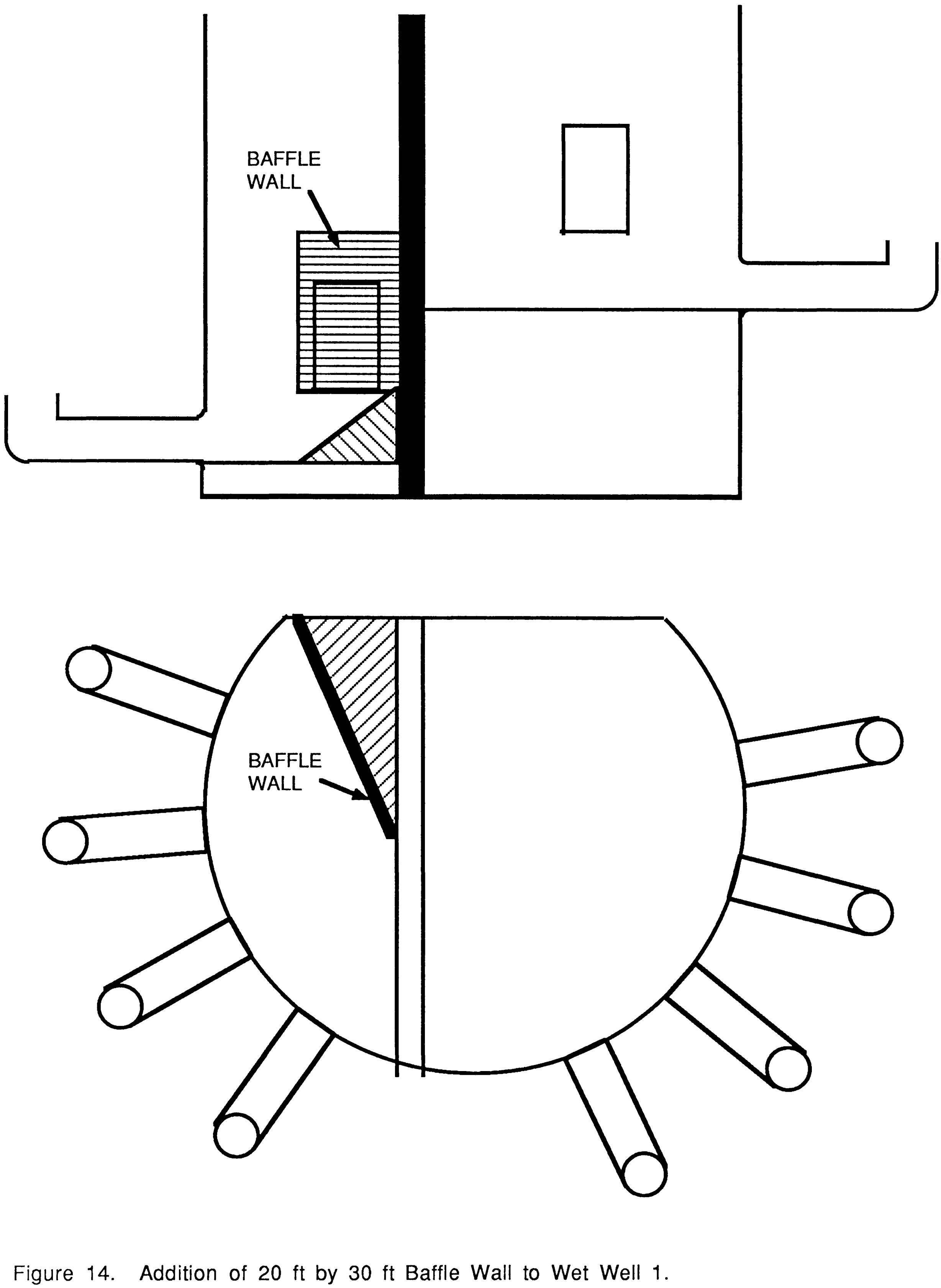


Figure 14. Addition of 20 ft by 30 ft Baffle Wall to Wet Well 1.

Table 6. Swirl Angle Measurements for Wet Well 1 with the 20 ft x 30 ft Baffle Wall.

WET WELL 1

DRY WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 75 MGD

PUMP	**9**	**10**	**11**	**12**
10 foot high wall	7.5	7.3		
15 foot high wall	5.2	6.6		
20 foot high wall	1.7	3.5		
	0.5		-1.8	
SWIRL	-1.4			0.7
ANGLES		0.3	1.6	
		0.9		0.7
			0.7	0.1

WET WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 108 MGD

PUMP	**9**	**10**	**11**	**12**
SWIRL ANGLES	3.1	3.3	0.4	2.3

LOW LEVEL CUTOUT FLOW: Elevation - 47.0 ft ; Flow per Pump - 60 MGD

PUMP	**9**	**10**	**11**	**12**
water level	10.3	0.5		
47.0 feet		8.1	-2.5	
			2.5	0.
water level	7.8	3.3		
48.0 feet	19.5		0.0	
	3.9			-8.7
SWIRL		1.9	-1.0	
ANGLES		0.0		4.7
			-1.3	0.4
water level 47 ft	27.0	3.6	-2.6	-3.6
water level 48 ft	5.6	-0.3	-2.7	2.7

Modifications to Wet Well 2

After performing the extensive testing on Wet Well 1, the flow state in Wet Well 2 was then considered with the expectation that it may be easier to arrive at an acceptable solution due to the large surface area and the fact that the maximum swirl angles were considerably less in the testing of the original design. This proved not to be the case and rather extensive testing was required in order to define acceptable alternatives. By the time of the initiation of these tests, it had already been decided that the pilasters on the dividing wall would be removed and that the wall thickness would be increased to eight feet with the additional width achieved by extending into Wet Well 2. Also, it had been decided to proceed to a similar wet well floor configuration to that in Wet Well 1.

The first round of testing was conducted with a completely flat floor at an elevation of 52.5 feet, which is the elevation of the suction pipe inverts. This testing was performed in part to obtain a set of control data against which any other modifications might be compared; the results are presented in Table 7. Only the low level cutout level combination of two pumps that appeared to give the worst flow condition was measured. It is seen that the worst swirl occurs in different pump intakes for each of the three water levels, a finding that was repeated for most other configurations studied. The maximum swirl angles are in the range of 8 - 9° for several flow conditions and thus above the acceptance limit of five degrees.

Table 7. Swirl Angle Measurements for Wet Well 2 with the Flat Floor.

WET WELL 2

DRY WEATHER FLOW : Elevation - 90.0 ft ; Flow per Pump - 100 MGD				
PUMP	**13**	**14**	**15**	**16**
	4.7	-1.1		
	7.4		1.0	
SWIRL	6.2			8.8
ANGLES		4.3	-6.7	
		1.7		4.2
			8.8	4.2

WET WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 108 MGD				
PUMP	**13**	**14**	**15**	**16**
SWIRL ANGLES	8.7	8.8	1.0	-2.3

LOW LEVEL CUTOUT FLOW: Elevation - 69.0 ft ; Flow per Pump - 99 MGD				
PUMP	**13**	**14**	**15**	**16**
	-1.1			8.3
SWIRL ANGLES	3.1	6.2	-3.3	-1.3

Efforts were then expended in attempting to define some modification to the floor slope alone that would result in sufficient improvement in the swirl angles to meet the acceptance criteria; however, this did not prove to be a success. Two such bottom configurations studied, a short floor slope and a long floor slope, are presented in Fig. 15 and the results tabulated in Tables 8 and 9. It can be seen from a comparison of these results that an improvement over the flat floor case in the flow conditions was not achieved by the addition of either sloping floor segment (in contrast to the results in Wet Well 1) and results are fairly similar to the flat floor configuration. The long slope configuration resulted in slightly worse flow conditions than the short slope configuration, as was also observed in Wet Well 1.

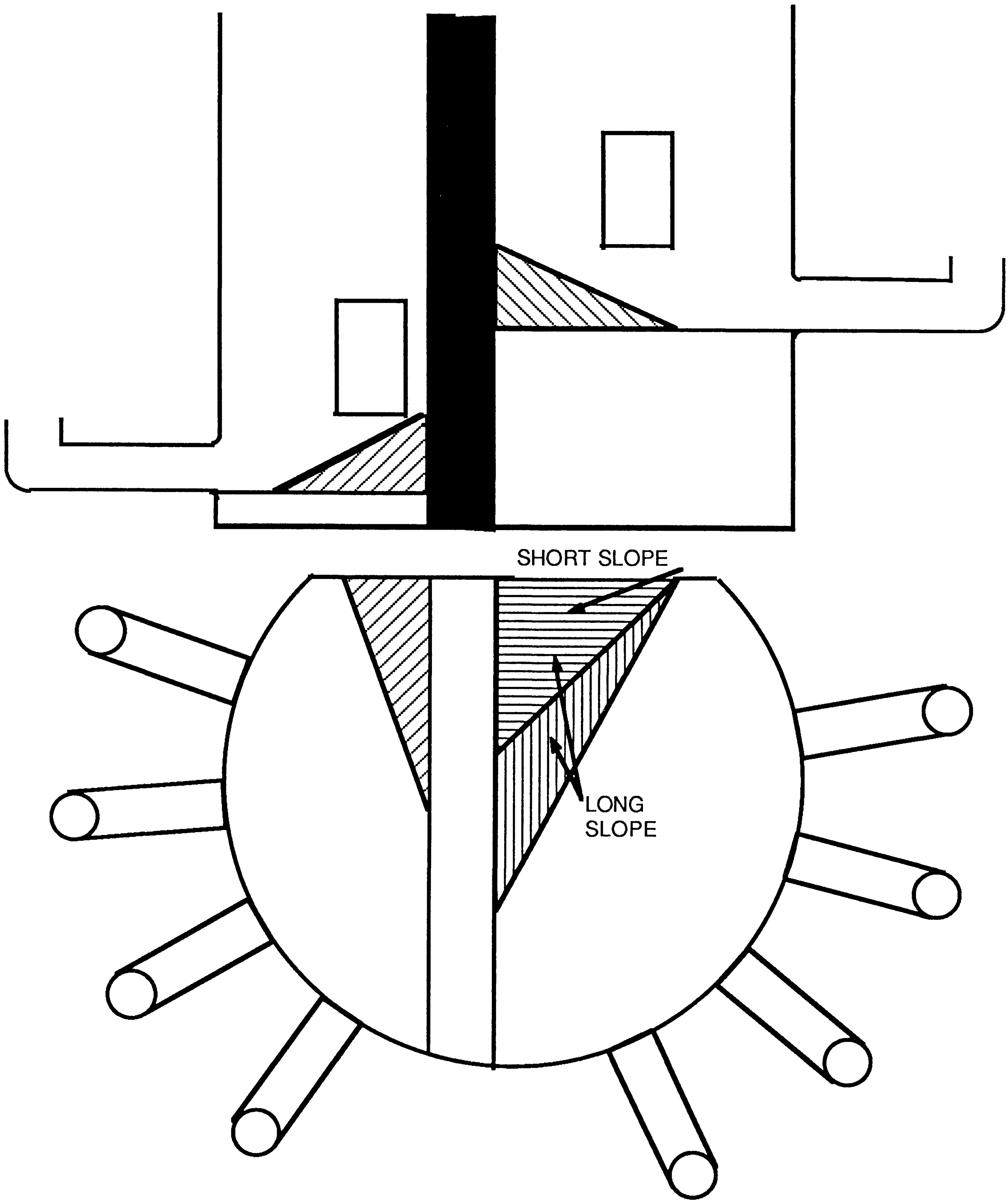


Figure 15. Two Configurations for Addition of Sloping Floor to Wet Well 2.

Table 8. Swirl Angle Measurements for Wet Well 2 with the Short Sloping Floor.

WET WELL 2

DRY WEATHER FLOW : Elevation - 90.0 ft ; Flow per Pump - 100 MGD

PUMP	13	14	15	16
SWIRL ANGLES	9.6	2.1		
	9.7			1.2

WET WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 108 MGD

PUMP	13	14	15	16
SWIRL ANGLES	3.6	-1.8	-3.7	4.2

LOW LEVEL CUTOUT FLOW: Elevation - 69.0 ft ; Flow per Pump - 99 MGD

PUMP	13	14	15	16
SWIRL ANGLES				

Table 9. Swirl Angle Measurements for Wet Well 2 with the Long Sloping Floor.

WET WELL 2

DRY WEATHER FLOW : Elevation - 90.0 ft ; Flow per Pump - 100 MGD				
PUMP	**13**	**14**	**15**	**16**
	7.5	-1.2		
SWIRL ANGLES	1.4			10.0
			11.9	-0.4

WET WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 108 MGD				
PUMP	**13**	**14**	**15**	**16**
SWIRL ANGLES	8.6	4.8	-1.6	-3.0

LOW LEVEL CUTOUT FLOW: Elevation - 69.0 ft ; Flow per Pump - 99 MGD				
PUMP	**13**	**14**	**15**	**16**
SWIRL ANGLES				

With these findings, it was decided to examine a similar configuration for Wet Well 2 to that in Wet Well 1 with a baffle wall in front of the sluice gate. Based on the findings in Wet Well 1, it was anticipated that a short baffle wall would not prove to be successful. The initial effort was therefore conducted with a wall of similar height and length as that in Wet Well 1 and arranged as indicated in Fig. 16. The one difficulty forseen with this configuration is that flow in the wet well during wet weather conditions would not be able to pass over the top of the baffle wall as in Wet Well 1. Therefore, although this configuration was studied, it was intended to look at additional configurations that would allow floating material to pass over the baffle during wet weather flow conditions. The results of this testing are presented in Table 10.

It is seen that the results are reasonably satisfactory with the exception of the flow in Pumps 15 and 16 at the low level cutout condition. Again, the flow at the low level cutout condition with all four pumps in operation is presumed to represent an transient flow state and the somewhat larger swirl angles for that case are presumed to be satisfactory for that transient flow state. In general, the operation of the wet well with this baffle wall configuration could be made acceptable by simply restricting the pump combinations that could be used to exclude the use of Pumps 13 and 14 together for dry weather flow and the use of both Pumps 15 and 16 for low level cutout flows.

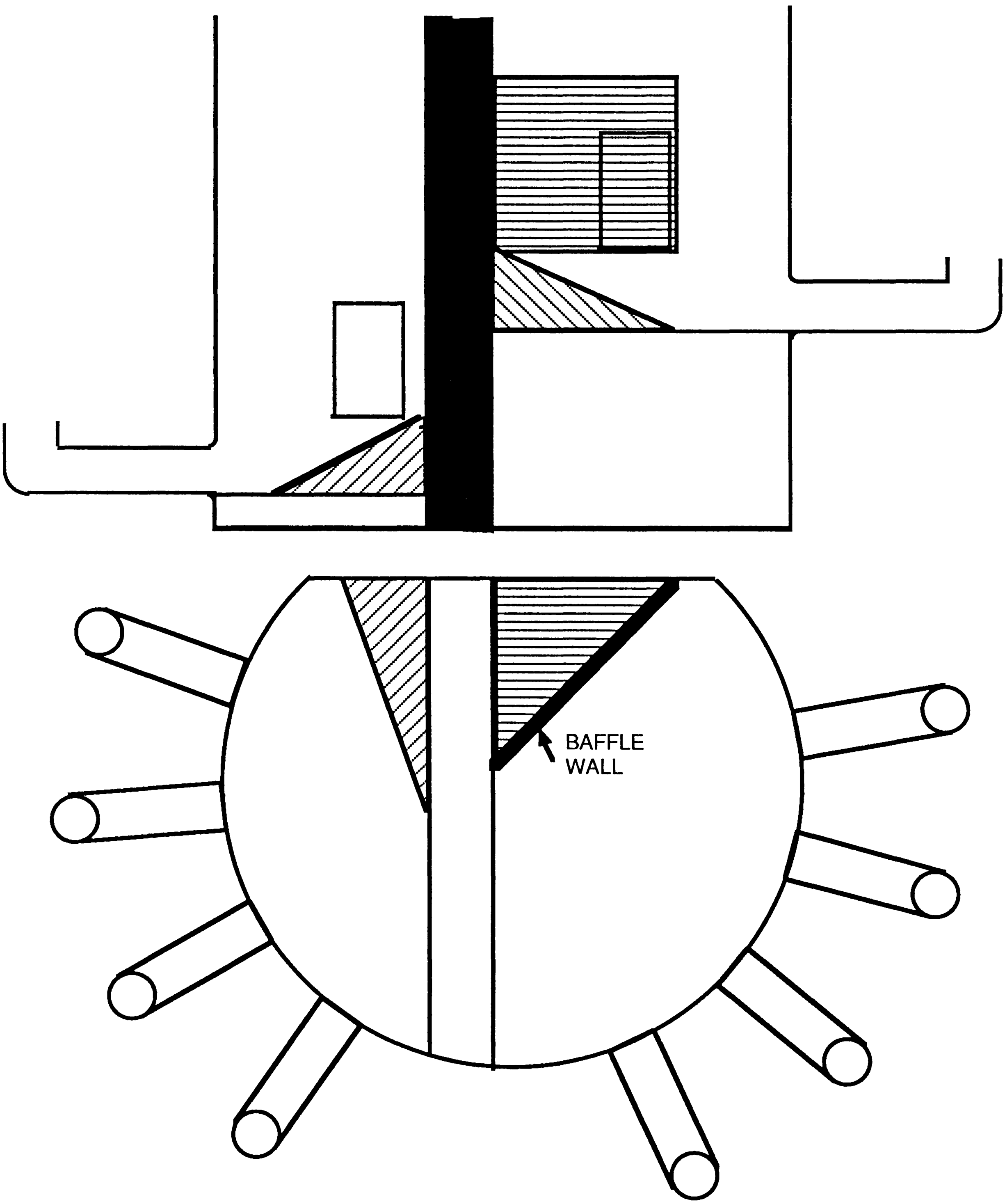


Figure 16. Addition of 20 ft by 30 ft Baffle Wall to Wet Well 2.

Table 10. Swirl Angle Measurements for Wet Well 2 with the 20 x 30 ft Baffle Wall.

WET WELL 2

DRY WEATHER FLOW : Elevation - 90.0 ft ; Flow per Pump - 100 MGD

PUMP	13	14	15	16
SWIRL ANGLES	-1.1	7.0		
	1.6		2.0	
	1.5			0.6
		-2.8	-1.9	
		0.3		0.8
			-2.7	-1.9

WET WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 108 MGD

PUMP	13	14	15	16
SWIRL ANGLES	-0.8	0.4	-6.1	1.4

LOW LEVEL CUTOUT FLOW: Elevation - 69.0 ft ; Flow per Pump - 99 MGD

PUMP	13	14	15	16
SWIRL ANGLES	2.5	-2.4	-9.3	-8.1
	5.4	0.2		
	1.3		0.0	
	1.2			1.4
		0.6	0.3	
		1.1		1.2
			-16.1	-8.5

This wet well configuration was then subjected to a series of modifications that were intended to determine whether or not it would be possible to pass floating material beyond the baffle wall during wet weather flow conditions. Initial attempts in this regard involved decreasing the baffle wall height to 12 feet so that the top was at an elevation of 72.5 feet or about 3.5 feet below the wet weather water level in the wet well. The two different 12 foot high wall configurations indicated in Fig. 17 were investigated in a preliminary fashion and the results in Table 11 were obtained. These results were similar to the findings in Wet Well 1 in that the shorter wall height caused a significant deterioration in performance, producing conditions worse than with no baffle wall at all. A second attempt at solving this problem involved retaining the 20 foot height but using 8 foot wide notches at either end of the baffle wall as indicated in Fig. 18. The results presented in Table 12 indicate similar behavior to that observed with the shorter baffle wall height of 12 feet.

An attempt was made to determine whether it would be possible to place a baffle over only a portion of the width of the wet well but positioned so that it would serve to deflect the flow and provide suitable swirl angles. An extensive set of trial and error placements with only one minute counts on the vane rotation found no configuration that would bring the swirl angles below 10° for at least one dry weather flow condition.

A final attempt was made with much smaller end notches as indicated in Fig. 19 with the results in Table 13. The low level cutout condition was not tested since it should be exactly equivalent to that in Table 10 as the bottoms of the notches were above the low level cutout water levels. It is seen that the swirl angles are roughly equivalent to those in Table 10 with a slight degradation in the performance of Pump intake 16. This could be improved by slightly reducing the notch width on the left (looking into the wet well from the entrance and increasing it on the right). Therefore, this does appear to be a viable alternative if it is deemed essential to have the capability to pass floating material beyond the baffle wall under wet weather flow conditions. Otherwise, there does not appear to be a good reason for selecting this alternative.

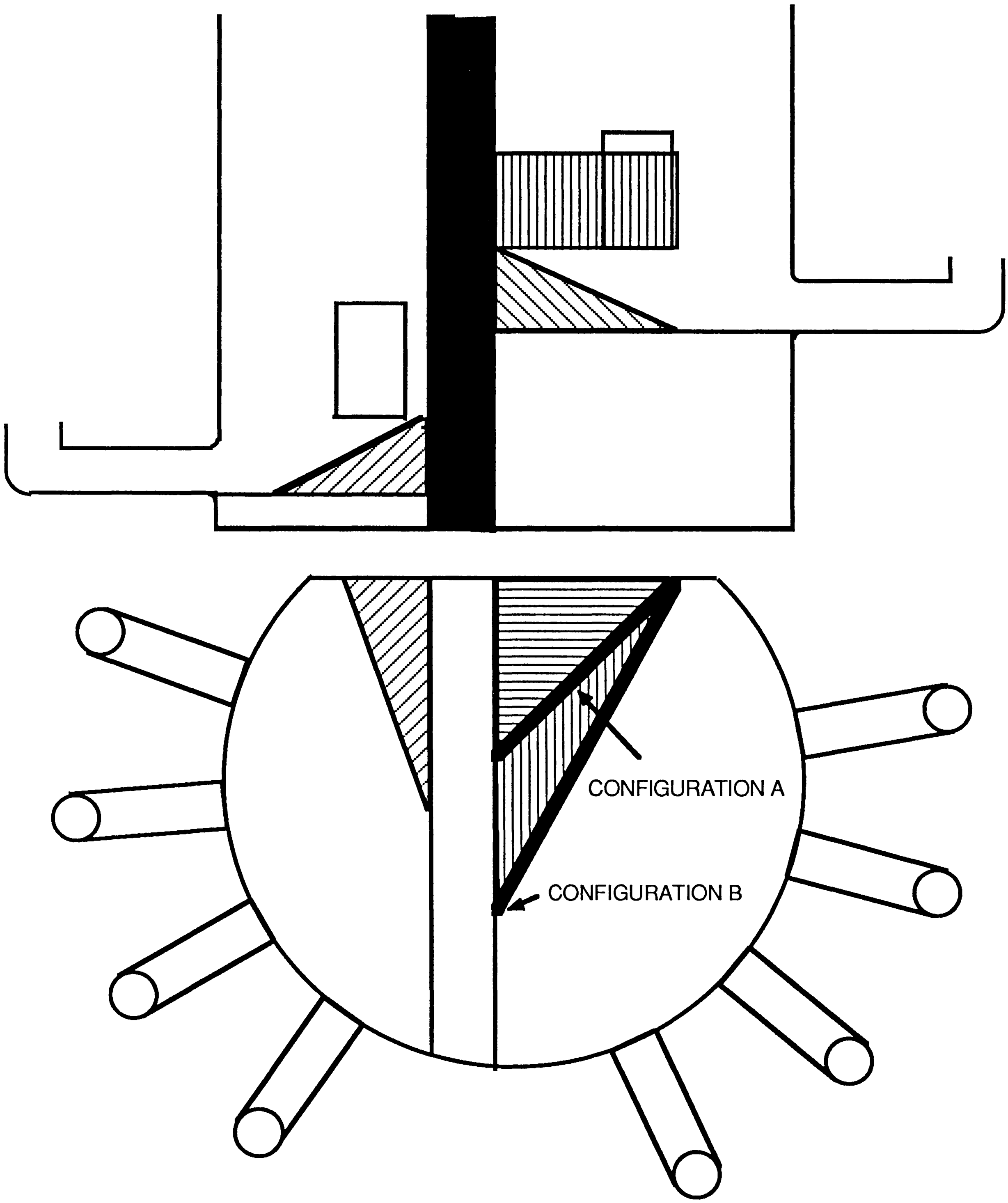


Figure 17. 12 Foot High Baffle Wall Configurations in Wet Well 2.

Table 11. Swirl Angle Measurements for Wet Well 2 with a 12 ft High Baffle Wall.

WET WELL 2

DRY WEATHER FLOW : Elevation - 90.0 ft ; Flow per Pump - 100 MGD

PUMP	13	14	15	16
Configuration A	10.3	-1.45		
		17.7	-11.1	
SWIRL ANGLES			13.5	-18.8
Configuration B		6.1	14.6	
			4.8	11.6

WET WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 108 MGD

PUMP	13	14	15	16
SWIRL ANGLES				

LOW LEVEL CUTOUT FLOW: Elevation - 69.0 ft ; Flow per Pump - 99 MGD

PUMP	13	14	15	16
SWIRL ANGLES				

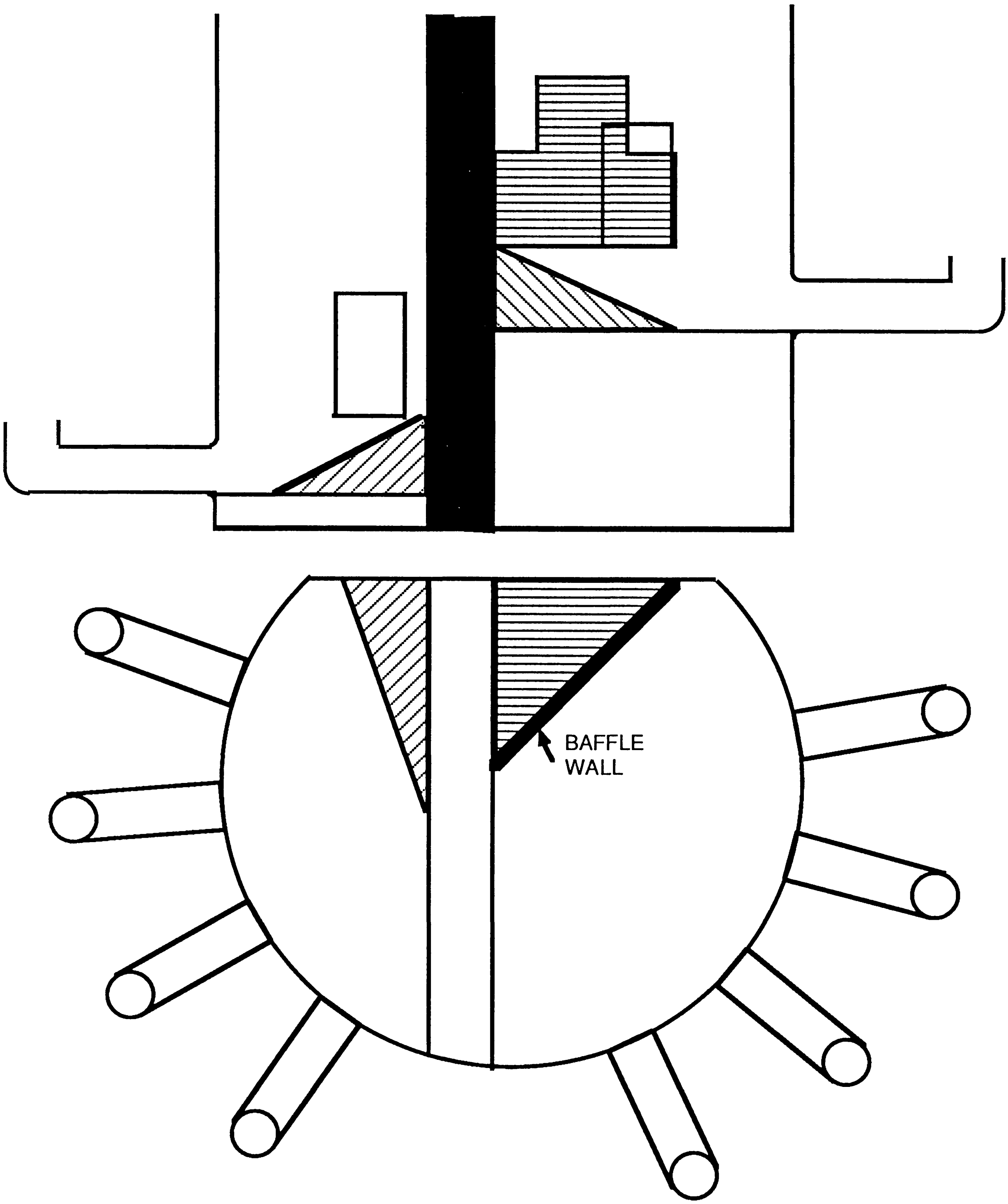


Figure 18. Modification to 20 Foot High Baffle Wall by Addition of Large End Notches.

Table 12. Swirl Angle Measurements for Wet Well 2 with the 20 ft. High Baffle Wall with Large End Notches.

WET WELL 2

DRY WEATHER FLOW : Elevation - 90.0 ft ; Flow per Pump - 100 MGD

PUMP	13	14	15	16
SWIRL ANGLES	-0.9			5.9
		16.3		-3.6
			18.3	8.4

WET WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 108 MGD

PUMP	13	14	15	16
SWIRL ANGLES				

LOW LEVEL CUTOUT FLOW: Elevation - 69.0 ft ; Flow per Pump - 99 MGD

PUMP	13	14	15	16
SWIRL ANGLES				

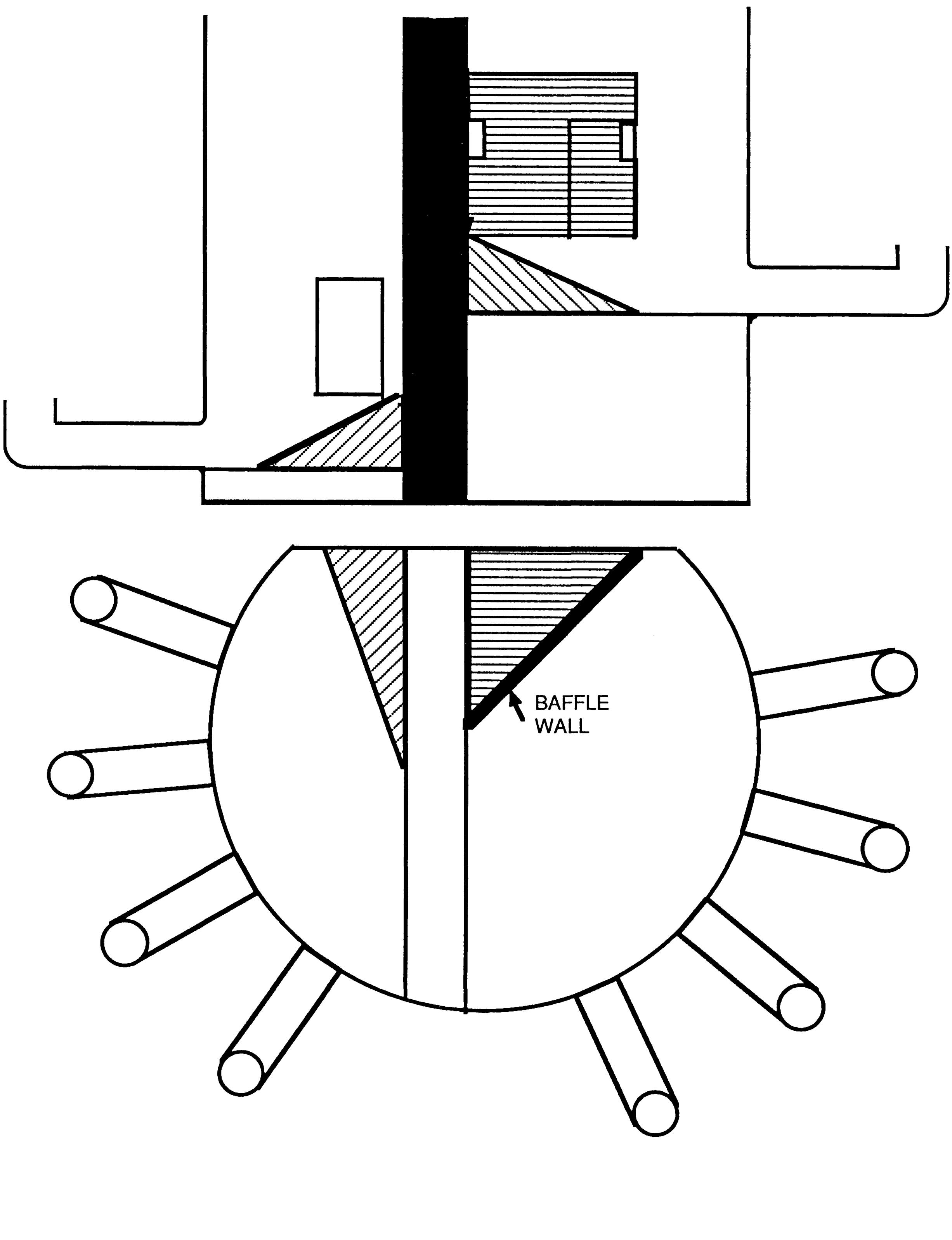


Figure 19. Modification of 20 Foot High Baffle Wall by Addition of Small End Notches.

Table 13. Swirl Angle Measurements for Wet Well 2 with the 20 ft. High Baffle Wall with Small End Notches.

WET WELL 2

DRY WEATHER FLOW : Elevation - 90.0 ft ; Flow per Pump - 100 MGD

PUMP	13	14	15	16
	0.4	2.0		
	-0.4		-1.5	
SWIRL	2.1			-6.9
ANGLES		-2.9	-1.2	
		-1.6		-1.8
			-2.5	-5.6

WET WEATHER FLOW : Elevation - 76.0 ft ; Flow per Pump - 108 MGD

PUMP	13	14	15	16
SWIRL ANGLES	-0.8	2.1	-2.7	0.5

LOW LEVEL CUTOUT FLOW: Elevation - 69.0 ft ; Flow per Pump - 99 MGD

PUMP	13	14	15	16
	2.5	-2.4	-9.3	-8.1
SWIRL	5.4	0.2		
ANGLES	1.3		0.0	
	1.2			1.4
		0.6	0.3	
		1.1		1.2
			-16.1	-8.5

A final attempt was made to improve the general performance of the flow by investigating the placement of guide vanes on the insides of the suction intakes. It is anticipated that the results will be applicable to any configuration in the sense that the effect will not be felt within the wet wells but only in the suction pipes themselves. The effectiveness of the guide vanes will be largely limited by the length available in which they can be installed as the presence of the gate valves in the suction lines will limit the placement to a maximum length of vane on the order of 4.5 feet directly at the entrance into the suction line. Actually, there is only a total of 3.0 feet from the end of the pump suction bellmouth to the gate valve flange so a somewhat shorter length may be required. However, from the drawings provided, a straight length of 3.9 feet precedes the gate valve flange allowing a maximum length of about 4.5 feet of vane, so this was used in the testing. Some preliminary tests were performed with the configuration indicated in Fig. 20 and the results presented in Table 14. For comparison, the results for a similar flow as given in Tables 6 and 10 are also repeated. It is seen that in general, a 20 - 30 percent reduction in swirl angles was achieved for the cases considered, so this would be a possible additional modification to any particular wet well configuration selected. The slight increase in swirl angle for the one case is presumably due to the variability in results due to the five minute averaging as discussed earlier. However, it is not a sufficient solution in that it cannot reduce the relatively large swirl angles found in most of the configurations tested to acceptable ranges, so this should be regarded as simply an enhancement to the preferred designs.

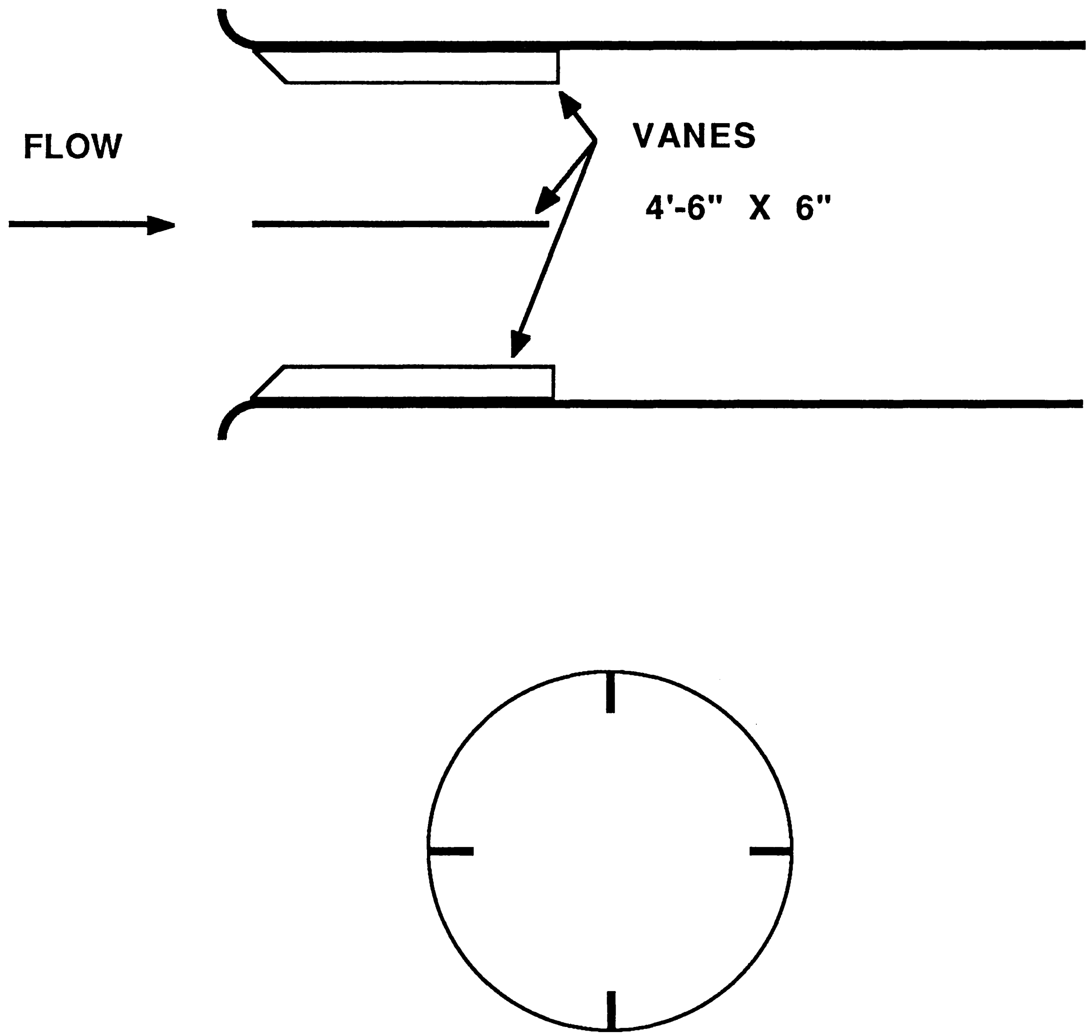


Figure 20. Guide Vanes Installed in Pump Suction Lines.

Table 14. Swirl Angle Measurements for Selected Flow Configurations with Vanes installed in Pump Suction Intakes.

Wet Well	Flow Configuration	Pumps	Original Swirl Angles	Swirl Angles, Vanes
1	Dry Weather	9		
		10	3.5	3.9
1	Low Level Cutout	10	8.1	4.8
	Elevation 48.0	11		
2	Dry Weather Flow	13		
		14	7.0	5.1
2	Low Level Cutout	15	-16.1	-15.6
		16		

Tests with Greater Than Froude Scaled Velocities

A series of different test configurations were repeated with the flow rate increased by 50 percent in order to try to assess the possible importance of scale effects. Since there were no problems observed with respect to vortex formation, this was not considered to be a major focus of the overall model study. Swirl angles are essentially a ratio of circumferential to axial flow velocity and should not change significantly, even with the increases in flow rate. This was generally found to be the case as indicated in Table 15 for the several cases studied. Fairly large variabilities were found in the swirl angles at the low level cutout levels and this should hardly be surprising for two reasons; 1) the fact that the absolute velocities within the wet well are increased more by the increased flow than at higher water levels, and 2) the fact that the results are so dependent upon slight changes in water level and the two sets of experiments may have small water level differences which result in changes in measured swirl angle. However, the two sets of data indicate swirl angles generally in agreement with the testing results at the Froude scaled flow rates. Again in these tests, no evidence of any significant problem with vortex formation was noted, so it was concluded that this is not a problem for the wet well designs tested.

Table 15. Swirl Angle Measurements for Selected Flow Configurations with 50 percent Higher Flow Rates.

Wet Well	Flow Configuration	Pumps	Original Swirl Angles	Swirl Angles, 1.5 Q
1	Dry Weather	9	1.7	0.9
		10	3.5	5.8
1	Low Level Cutout	9		27.7
	Elevation 47.0	11		-0.5
1	Low Level Cutout	9		29.0
	Elevation 47.0	12		-15.3
1	Low Level Cutout	9	19.5	15.5
	Elevation 48.0	11	0.0	0.0
1	Low Level Cutout	9	3.92	15.2
	Elevation 48.0	12	-8.7	-11.3
2	Dry Weather Flow	13	-1.1	-1.6
		14	7.0	5.8
2	Low Level Cutout	15	-16.1	-10.3
		16	-8.5	-1.6

Sedimentation Study

After the possible wet well configurations had been tentatively defined from the results of the swirl angle tests, sedimentation studies were conducted to determine the likelihood of the occurrence of grit deposition within the wet wells. It was probable that this would not be a major problem with the selected design involving the baffle walls because of the deflection of the flows under the walls. In order to verify this result, sediment was introduced into the wet wells with dry weather flow conditions established in the two pumps closest to the inlet (9 and 10 in Wet Well 1 and 15 and 16 in Wet Well 2). It was observed that sediment was deposited at the opposite end of the wet well in both cases. For the situations with the two pumps at the far end of the wet wells (11 and 12 or 13 and 14) in operation, the tendency for sedimentation was much lower and only minor grit deposition was noted. After allowing the system sufficient time to come to an equilibrium, the wet weather flow state was initiated without stopping the flow. In Wet Well 1, this consisted only of increasing the discharges and opening additional valves, while a decrease in wet well water level was also required in Wet Well 2. This action required a time interval of approximately five minutes or less to establish the correct flow state. This model time would correspond to a prototype time of 5 minutes x $(8.8)^{1/2}$ = 15 minutes, or far less time than the typical wet weather flow state would last. By the time that this was accomplished in either wet well, all material was scoured off the bottom of the wet well and remained in suspension thereafter. Additional tests at a flow rate of one-half the wet weather flow (but with all four pumps in operation) indicated that the sediment would be scoured from the wet well bottom in this situation as well. These results indicate that while deposition within the wet well may occur during periods of lower flow, the occasional wet weather flow will tend to resuspend the material deposited and no significant problems should be anticipated in this regard.

DISCUSSION

Assuming that the wet well configurations suggested in this report are adopted, additional considerations can be developed with respect to the placement of the constant speed versus the variable speed pumps. Also, there are some pump configurations that should be avoided in the various operating states. In the discussion presented below, some basic ideas in these regards are developed. It is assumed that Wet Well 1 will initially have two variable speed pumps and one constant speed pump with an additional variable speed pump to be installed at a later date. In Wet Well 2, it is assumed that three variable speed pumps and one constant speed pump will be installed.

Wet Well 1

In the tests associated with the recommended wet well configuration in Wet Well 1 (Table 6), there were a few problem areas indicated. In particular, these are:

- For dry weather flow, pump 10 has the highest swirl angle (3.5°);
- For wet weather flow pump 10 has the highest swirl angle (3.3°);
- For low level cutout flows, pumps 9 and 12 generally exhibit the worst swirl angles (up to 19.5° in pump 9 and 8.7° in pump 12);

In general, the fixed speed pump would not be used as often for dry weather flows, but could always be used in low level cutout and wet weather flow applications. Therefore, pumps 10 and 11 would be most likely candidates for the fixed speed pump. The swirl angles under both dry and wet weather flow conditions in Pump 10 are still no greater than about 3.5 degrees, so it is not clear that this is an important consideration with respect to pump placement. Since the dry weather flow will occur most often, Pump 11 should probably be reserved for that situation since it never showed swirl angles greater than 1.8 degrees for any dry weather case. This would indicate that Pump 10 should be the fixed speed pump. Since Pump 9 often had high swirl angles compared to other pump intakes, it should be the one used least often and therefore presumably also be the pump not initially installed. This action would be consistent with minimizing sedimentation as well. Recommendation for pump placement are therefore:

° Pump 9 - not initially installed, ultimately variable speed pump

° Pump 10 - fixed speed pump

° Pump 11- variable speed pump

° Pump 12 - variable speed pump

During initial dry weather flows, Pumps 11 and 12 would be in operation and these exhibited a maximum swirl angle of 0.7° in the dry weather tests. For low level cutout flows, Pump 9 should be especially avoided and the combination of Pumps 10 and 11 should also be avoided if the water level is drawn down to 47.0 feet. Possible configurations would be 11 and 12 or 10 and 12. The former combination (11 and 12) exhibited generally better swirl angles for this situation and they also have the lowest swirl angles for wet weather flows. Therefore, it appears as though they are the preferrable pumps for nearly all operation sequences. They would also tend to minimize sedimentation according the observations, so there appears to be no consideration associated with the wet well hydraulics that would indicate possible conflicts with these recommendations.

<u>Wet Well 2</u>

The situation in Wet Well 2 is somewhat more complex. It is presumed that the configuration in Fig. 16 is the preferred choice. A summary of the general problems associated with the various flow conditions in Table 10 is

- For dry weather flow, the combination of Pumps 13 and 14 gave the only large swirl angle in Pump 14 (7.0)°;
- For wet weather flow, Pump 15 had the only high swirl angle (6.1°);
- For low level cutout flows, Pumps 15 and 16 had generally unacceptable swirl

angles, both with all four pumps in operation and when they were the only two (up to 16.5° in Pump 15 and 8.5° in Pump 16).

The latter consideration clearly indicates that Pumps 13 and 14 should be the pumps used for the low level cutout flow. In order to place the fixed speed pump, if it is placed in the Pump 14 position, then it would not be used for the dry weather flow and eliminate the one bad dry weather flow studied. This leads to the following recommendation for pump placement:

° Pumps 13, 15 and 16 - variable speed pump

° Pump 14 - fixed speed pump

In cases of relatively high flows, but still below the plant capacity, the use of Pump 15 could be avoided and if it were the first pump put out of service when going to the low level cutout position, this would appear to be the most reasonable situation. For dry weather flows, Pumps 13 and 16 would be a good choice and Pumps 13 and 15 would be equally good. Since Pump 13 is at the far end of the wet well, its use would minimize the tendencies for sedimentation within the wet well.

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AIIM SCANNER TEST CHART # 2

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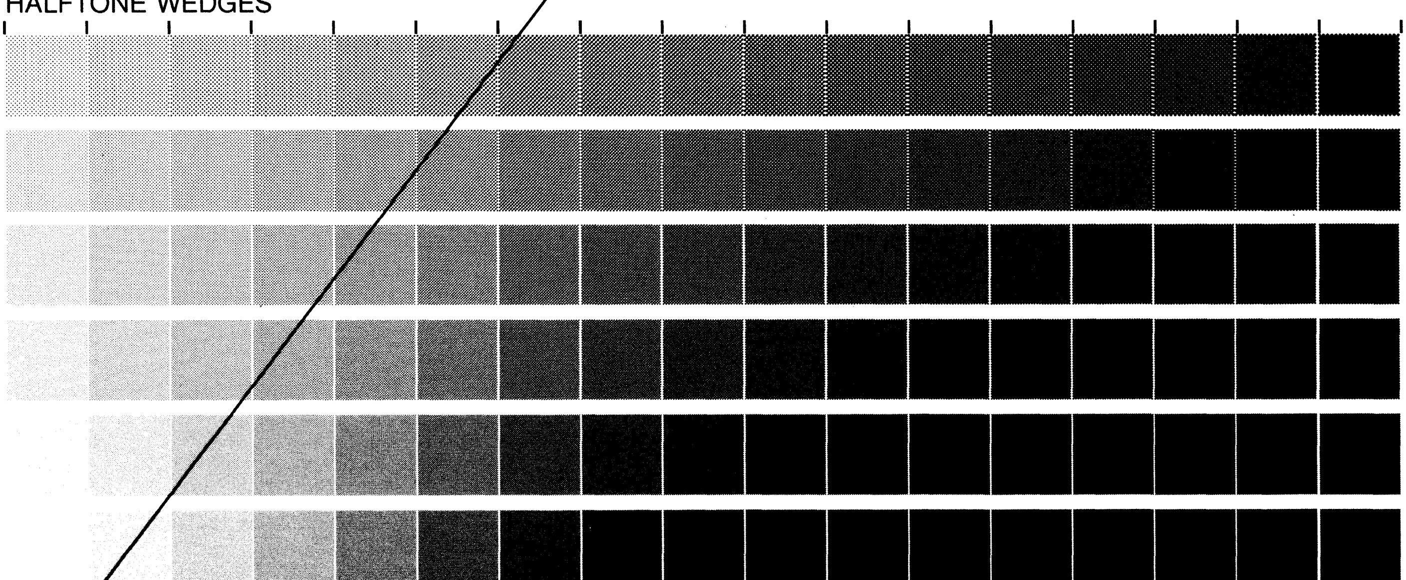

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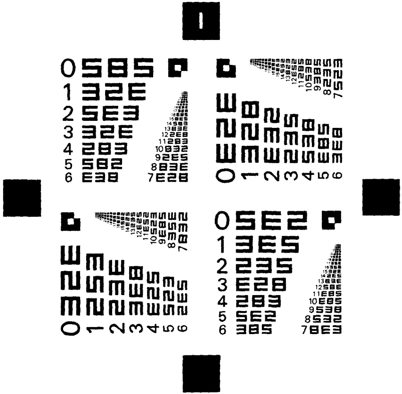

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