# HYDRAULIC MODEL STUDY
## Wyandotte Wastewater Treatment Plant
## Influent Pump Station Wet Well
## Report CEE 04-02

**Final Project Report to**
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# EXECUTIVE SUMMARY

A physical hydraulic model of the flow through the wet well at the Wyandotte Wastewater Treatment Plant was constructed at a 1:7 scale of the prototype and was tested based on Froude number scaling criteria. The purpose of the model was to investigate the possibility of poor flow conditions in the flows into the inlets of the six pumps that lift flow from the wet well. Model construction was based on blueprints and other design documents detailing dimensions and other pertinent features of the wet well including information on current operation strategies for the wet well which is manually controlled by station operators.

Flow tests were performed on the model of the existing wet well for a variety of permutations of pump operation and at different wet well water surface elevations. These preliminary tests indicated several configurations with poor flow behavior. In particular, air entraining vortices were observed in the area of the wet well between the two curtain walls with the vortices variously entering the inlets to pumps 2, 3 or 5. These air-entraining vortices were normally observed only for wet well elevations below about 543 feet, but some were observed at somewhat higher water levels. In addition, excess swirl angles were observed at several pump inlets, in particular in pumps 4, 5, and 6; these are the highest capacity pumps in the station. High swirl angles were observed most often in the pump 6 intake with maximum values up to about ten degrees or more than twice the value generally considered to be acceptable. At low wet well water surface levels excessive air entrainment into pump 6 inlet is observed due to the recycle flow line. Flow conditions tended to be worse when multiple pumps were operated only on one side of the wet well.

Modifications were made to the wet well design to reduce the rotation in the flow. These modifications consisted of the placement of a series of small plates mounted vertically along the back wall of the wet well, generally in proximity to pumps where poor performance was observed. A series of iterations in plate dimensions and placement resulted in an option in which no air entraining vortices were observed down to wet well elevations of 542 feet and for which all swirl angles were maintained below five degrees.

The following recommendations are made regarding future pump station operation as a result of this model study:

- It is recommended to make the modifications to the wet well involving the placement of the plates as depicted in Figure 13 in order to reduce the swirl angles and air entraining vortices observed in the current station operation;
- It is recommended to select pump operation such that operating pumps are not concentrated on one side or the other of the wet well insofar as possible;
- It is recommended to maintain a minimum operating level of about 543.5 feet within the wet well to the extent possible. Doing so will prevent problems with air entrainment into pump 6 due to the recycle line inflow. It will also avoid the occurrence of strong intermittent vortices observed at high station flows and low wet well elevations (below about 543 feet);

Although plans have been previously developed for automatic control of pump operation as a function of wet well elevation, the low operation levels (down to 537 feet) are not feasible for a variety of reasons, in particular due to excessive air entrainment into pump 6 from the recycle line inflow, air entraining vortices at pumps 2, 3, and 5; and also due to general air entrainment induced by the plunging inflow at the wet well entrance. If an automatic mode of pump operation is desired, the operating plan should be reformulated to keep wet well elevations above about 543.5 feet as recommended above.

## INTRODUCTION

The Wyandotte Wastewater Treatment Plant influent pump station has a total pumping capacity of 200 mgd (310 cfs), achieved with six pumps with different pumping capacities. The firm pumping capacity is 150 mgd. The original pumps were replaced in 1998 with new pumps of approximately the same pumping capacities. Since then, the pumps have experienced bearing failures, excess vibration and unusual pump noise. The purpose of this physical model study was to examine the flow conditions within the influent pump station wet well to determine whether hydraulic conditions within the wet well are responsible for the reported problems with pump performance. In the event that undesirable inlet flow conditions were identified, the hydraulic model was to be used to develop the necessary modifications to eliminate these problems.

Vortices and inlet swirl have a detrimental effect on the operation of pumps, lowering efficiency and increasing wear. Severe vortexing can also lead to pump vibration, cavitation and impeller pitting. The testing sequence included the following components:

- Examination of surface vortex patterns, including air entrainment;
- Examination of subsurface vortex patterns;
- Measurement of swirl in flow into individual suction inlets;
- Survey of the spatial and temporal variation in velocities at the inlets to the pump intakes.

In the first phase of the testing, the original wet well configuration was tested and a number of problematic flow conditions associated with this configuration were identified. A variety of splitter plate configurations were installed on the back wall of the wet well and tested in order to correct the problems. The final recommendation consists of a plate configuration that provides acceptable flow conditions for all ordinary operating conditions.

## GENERAL SYSTEM DETAIL

Flow enters the pump station through two six-foot diameter influent sewers that combine in a junction chamber, pass through a coarse bar screen and into the wet well. The wet well is constructed in the interior of a 50 foot diameter circular caisson. The inflow passes through an inlet with two 6-ft diameter openings at an invert elevation of 537.5 ft and drops down to the wet well floor elevation of 530 ft. Six pump intakes arranged along and internal wall within the caisson lift the flow into the wastewater treatment plant. These pumps have different pumping capacities varying from 10 to 50 mgd. With the identification system employed at the wastewater treatment plant, the nominal pumping capacities of the six pumps are as follows:

| **Pump** | **Pumping Capacity (mgd)** |
|---|---|
| 1 | 10 |
| 2 | 20 |
| 3 | 30 |
| 4 | 40 |
| 5 & 6 | 50 |

The smallest pump has a vertical suction inlet while the other five are flush mounted in the wet well wall opposite the inlet. A schematic of the wet well is indicated in Figure 1. The four smallest pumps are fixed speed pumps while the two larger ones have variable speed drives and are currently operated to vary the pumping capacity between about 30 and 50 mgd. Each pump has an over-design capacity of approximately 10-15% of listed pumping capacity. This over-design was to account for anticipated future performance losses due to impeller wear such has been observed in the pumps that were replaced. The over-design implies that the smaller four pumps are currently pumping more than their listed capacity since they are fixed-speed pumps, while this is not necessarily true of the largest pumps, #5 and #6 with variable speed motors. At least one pump, #2, has been observed to produce flows of 117% of its rated pumping capacity of 20 mgd.

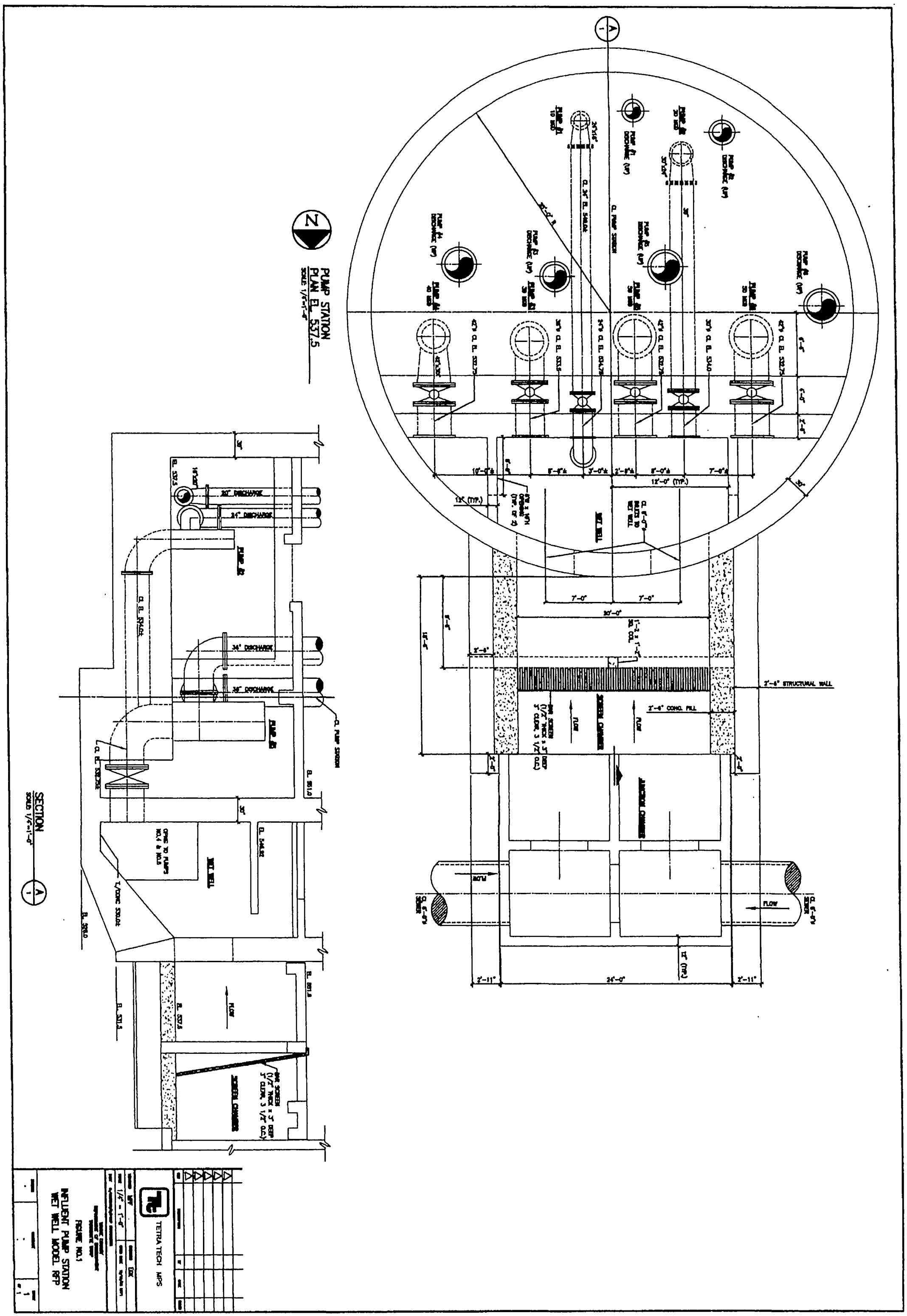

Figure 1. Wet Well Schematic.

In addition to the flow entering the wet well through the influent sewers, a recycle flow from the activated sludge process discharges into the wet well through a 42-inch diameter pipe with an invert elevation of approximately 551.4 ft. Typical inflows through this recycle line are on the order of 4-6 mgd. Flow from the recycle line enters near the corner of the wet well directly above the inlet to pump 6 and drops through a 2 ft diameter manhole in a one foot thick down to the free surface of the main wet well flow below. The elevation of the top of the manholr is approximately 547 feet and at sufficiently high wet well water levels, there is no free fall beneath the manhole as the water surface may be up to the bottom of the floor.

The wet well itself only occupies a small fraction of the 50 foot diameter caisson with the wet well wall located twelve feet into the wet well from the inlet openings. Curtain walls approximately twelve feet off the station centerline walls on either side of the wet well restrict the flow from spreading further laterally. Flow entering the two outside pumps, 4 and 6, must first pass through six-foot wide by ten-foot high openings in these curtain. The pump station is currently operated manually with wet well elevations generally maintained in the range of 542 to 545 feet. A typical pump operating plan has been provided and is included in Table 1 below.

| Rate | Pumps Combinations |
|---|---|
| 20 MGD | #2 |
| 30 MGD | #1 and #2, #3 alone, #5 alone at reduced speed, #6 alone at reduced speed |
| 40 MGD | #4, #5 alone at reduced speed, #6 alone at reduced speed |
| 50 MGD | #2 and #3, #5 alone, #6 alone |
| 60 MGD | #2 and #4 |
| 70 MGD | #2 and #5, #2 and #6, #3 and #4 |
| 80 MGD | #3 and #5, #3 and #6 |
| 90 MGD | #4 and #5, #4 and #6 |
| 100 MGD | #5 and #6 |

Table 1. Pump Station Operating Plan.

For higher flow rates the wet well elevations may range up to a high level limit of 548.5 feet and the following pump operation scenarios have been suggested as likely ones:

| Rate | Pumps |
|---|---|
| 130 MGD | #3, #5 and #6 |
| 150 MGD | #2, #3, #5 and #6 |

An automatic mode of pump operation was identified in the development of the station-operating plan and would be associated with lower wet well elevations in the range of 537 to 543 feet. It is understood that this automatic model has not been implemented due to perceived difficulties in operating in that range of water levels.

## MODEL DESCRIPTION

### Modeling Criteria

Physical models to examine flow behavior 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 model and the corresponding one in the prototype ($\mathbf{L_r}$ = $\text{Length}_{\text{model}}$ / $\text{Length}_{\text{prototype}}$). For a Froude scaled model, the following relations must hold in which the ratio, $\mathbf{Q_r}$, for example, represents the ratio of the discharge in the model to the corresponding prototype flow rate:

| **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 | $\mathbf{t_r}$ | $\mathbf{L_r}^{1/2}$ |

The critical factors with respect to model testing facilities are the model size and discharge. If the scale ratio is too small, both viscous and surface tension effects may become too great in the model. This consideration generally fixes the minimum model size required to avoid distortion of the model flow. 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. This Reynolds number is to be defined in terms of the flow in the suction pipe as $Re = Q/S\nu$, with Q the flow rate in the suction pipe, $S$ the pump intake submergence in the wet well, and $\nu$ the kinematic viscosity. They also found no Reynolds number effects for Reynolds numbers $Re = VD/\nu$, (with V the flow velocity in the suction pipe and $D$ the suction pipe diameter) greater than about 70,000. No influence due to surface tension effects was indicated in these results. The Reynolds number constraints become instrumental in the selection of the minimum physical model size. A length scale ratio of approximately 1:7 was selected for this model study. For the smallest pump (Pump 1), with a pumping capacity of 10 mgd prototype, a Reynolds number on the order of 53,000 is indicated. Although this is slightly below the suggested limit, each of the other five pumps had a model Reynolds number greater than 85,000 and the smallest pump was never found to be associated with the worst operating conditions in the wet well.

## Model Testing Facilities

The model study was conducted in the Civil and Environmental Engineering Hydraulics Laboratory located in the G.G. Brown Building at the North Campus of The University of Michigan.

## Model Construction

The physical model was constructed at a scale ratio of 1:7. This general model size was selected to keep the Reynolds numbers previously defined to be greater than the recommended minima suggested by Padmanabhan and Hecker (1984) with the possible exception of the smallest capacity pump as noted above. All relevant detail of the influent sewers, the junction and screen chambers (including the bar screen) and the wet well were reproduced at this scale from dimensions provided on a series of blueprints. In general, the model was constructed from exterior plywood and PVC (piping and sheet) and allowed operation over the range of wet well elevations up to 548.5 feet.

Individual pumps are not used in the model, but all pump inlet piping is reproduced at the correct scale up to the location of the suction side of the pump. The pump suction lines were constructed from Plexiglas so that the rotating cruciforms used to measure the inlet swirl angles could be visually observed to determine the swirl angles. All six pump suction lines were joined into a common manifold connected to a recirculating pump which removes the flow from the wet well, through the desired pump suction lines, and back around to the inlet conduits (the two influent sewers as well as the recycle line). The maximum model discharge rate of approximately 800 gpm (232 cfs prototype) was achieved with a single recirculation pump. The flow distribution was regulated by means of a butterfly valve on each of the six pump suction lines and with separate valves on each of the inflow source lines to obtain the desired total flow and control the flow distribution among individual lines. The flows were metered in each individual suction line by means of an installed flow meter. Since the flow distribution among the two influent sewers can vary (they are two independent interceptors), these flows were visually adjusted to divide them approximately equally and the recycle line was adjusted to the range of 4-5 mgd (prototype) with a bucket and stopwatch.

An overall view of the model is provided in Figure 2, while close-ups of various aspects of the model construction are provided in Figures 3 to 7.

Figure 2. Wyandotte WWTP Influent Pump Station physical hydraulic model.

Figure 3. Wet Well and Pump Intakes.

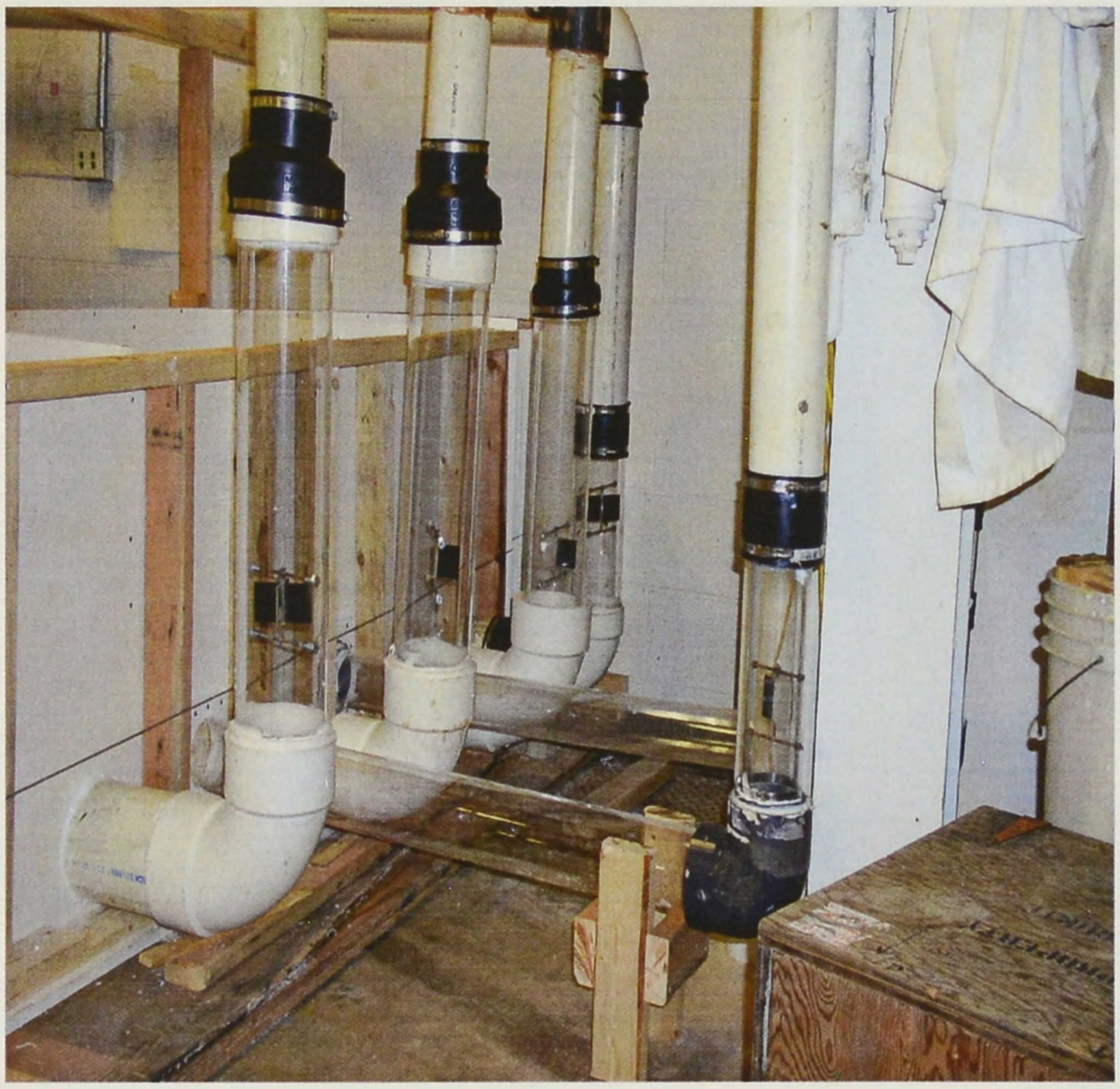

Figure 4. Pump suction lines.

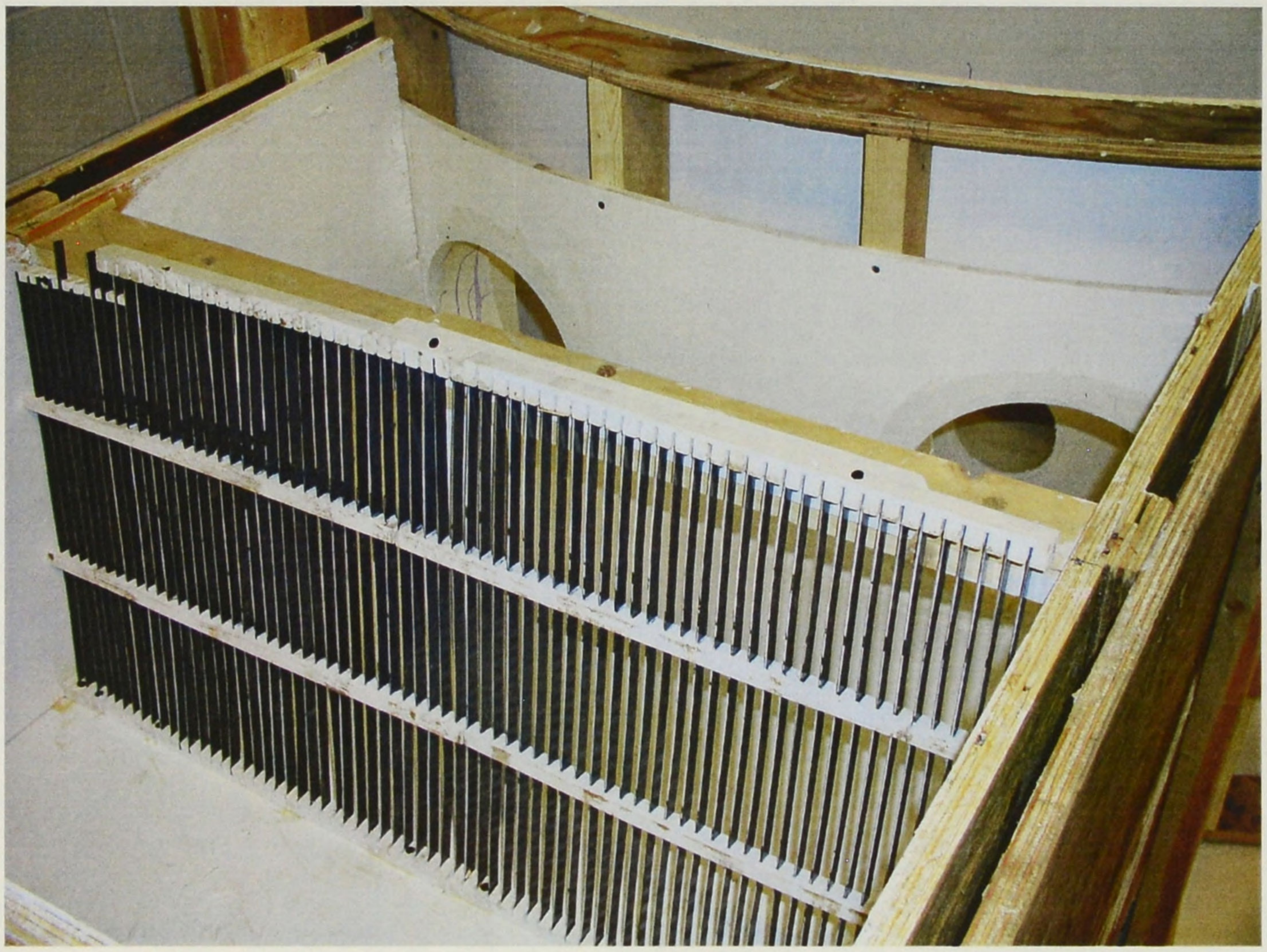

Figure 5. Bar Screen within the Junction Chamber.

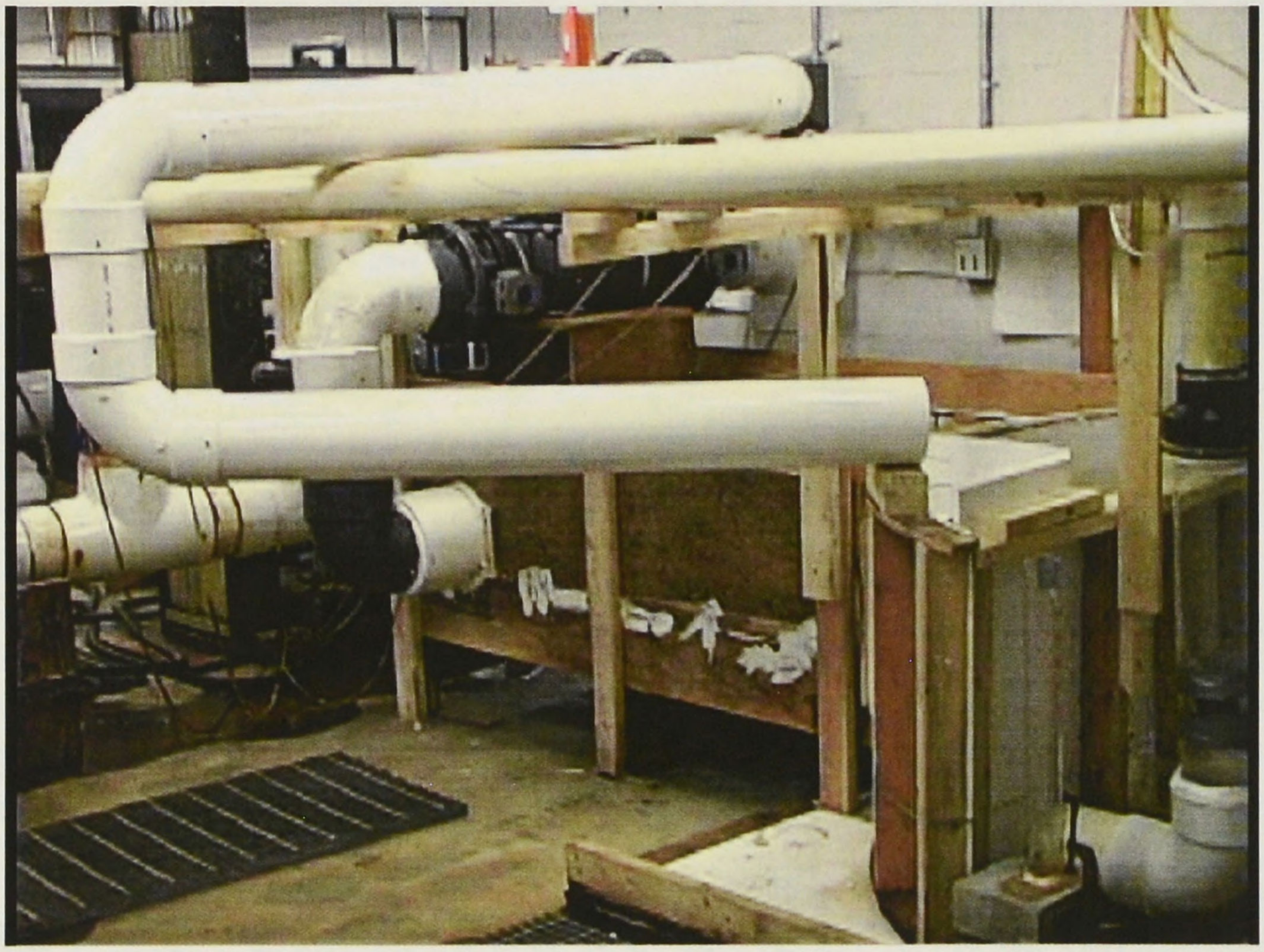

Figure 6. Recycle line set up.

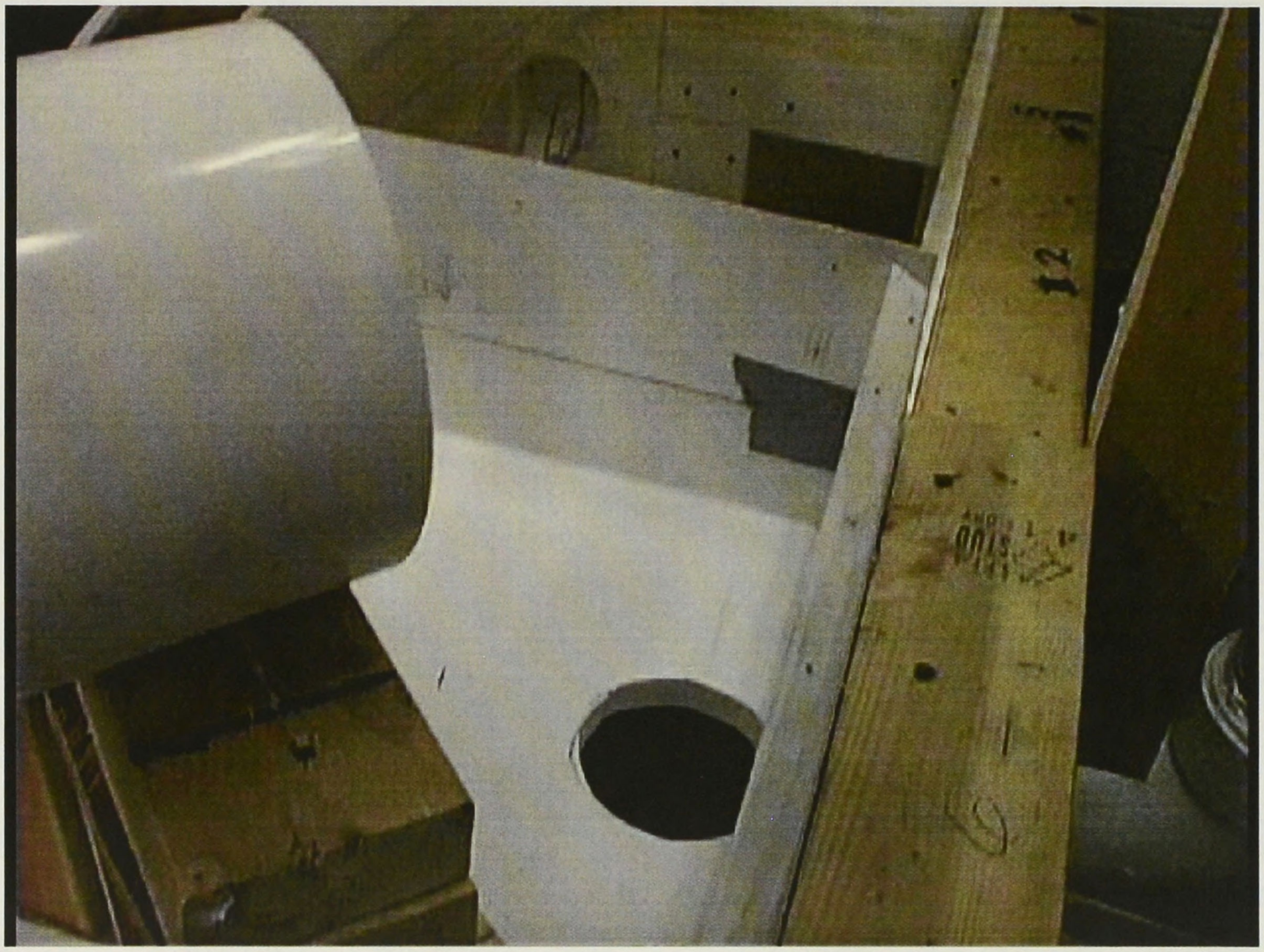

Figure 7. Detail of the recycle flow through manhole.

**Instrumentation**

Flow rates were measured using pipe orifice meters constructed to ASME specifications. In the case of the lines from pumps 5 & 6, the flows were measured with calibrated elbow meters. There were at least 10 upstream diameters of straight pipe and five diameters downstream from the orifice plates in order to minimize approach flow influences on the meter behavior following Hydraulics Institute standards. Pressure differences were measured with water-air differential manometers.

The presence of surface and subsurface vortices were investigated visually including the injection of dye into the model. Pertinent observations were recorded both on digital video and in a permanent record of notes indicating location and strength of any vortex motion observed.

The swirl angles were measured with a rotating cruciform, the function of which is to rotate with the component of tangential flow in the pump suction line. This zero pitch vane is indicated in one of the installations in Figure 8. Standard specifications of 0.8 of the pipe diameter for the length and diameter of the cruciforms were utilized in the construction. The cruciform is mounted so that it rotates freely on a hub installed on the pipe centerline. One vane is colored to orient the cruciform, especially in a rapidly rotating flow. Rotation counts were recorded to the closest quarter turn over 2 minute counting intervals.

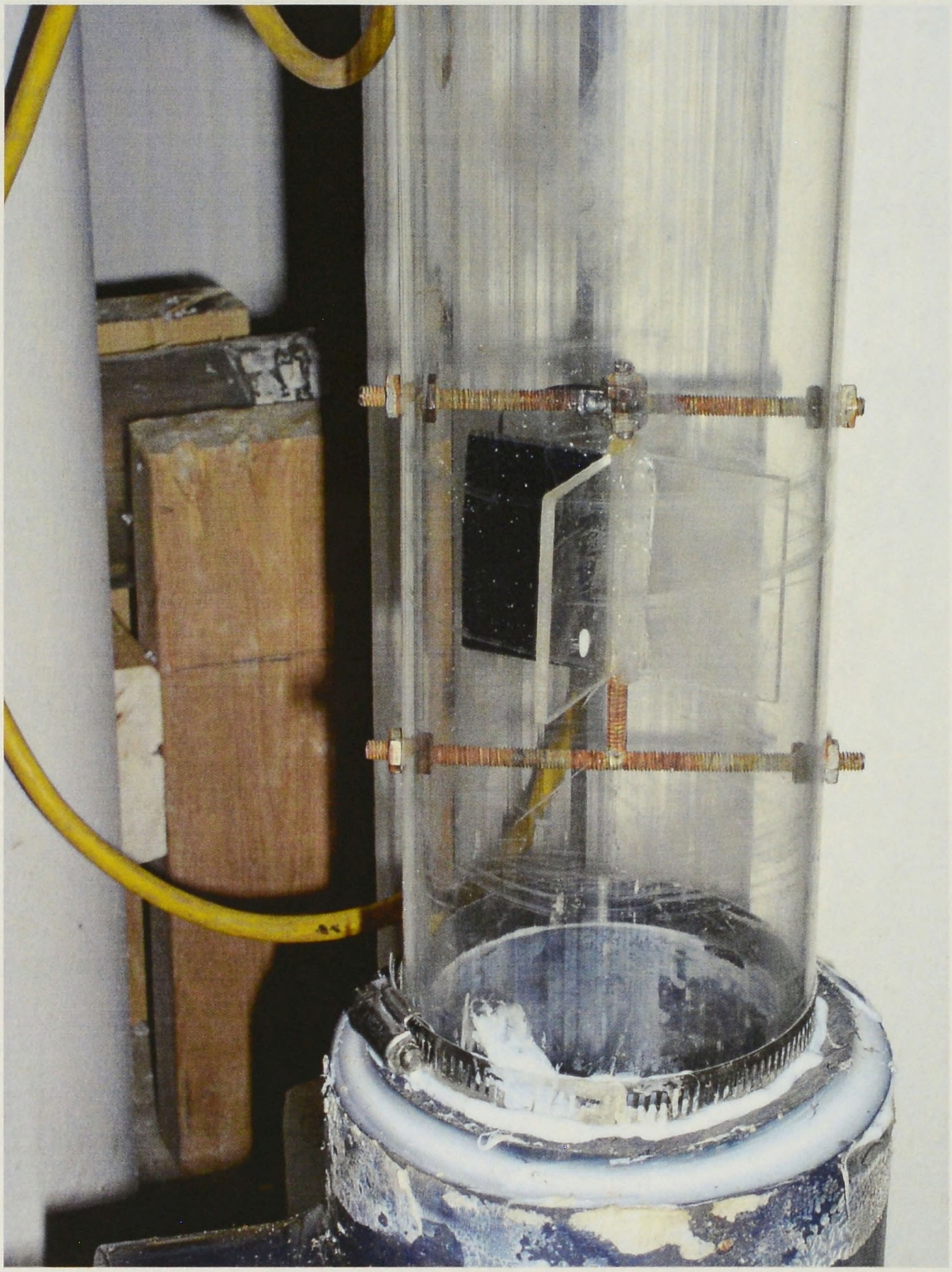

Figure 8. Rotating Cruciform installed in one of the suction lines.

Pump inlet velocities were measured in the wet well in front of pump intakes to determine the presence of turbulence and/or non-uniform flow distribution. Measurements were made with an acoustic Doppler velocimeter that is capable of resolving all three velocity components as well as turbulence intensities at a given measurement location. Measurements were made at 45-degree increments around the circumference of the pump inlet (on the circumference of the inlet but 5 cm from the wall) by re-positioning the probe between measurements. Two-minute measurement runs were made and the data analyzed to obtain a time series of instantaneous total velocity magnitudes at each sampling location. Both the magnitude of the average total velocity as well as the root-mean-square value of the deviation from this velocity magnitude as well as individual velocity components are computed. It was desirable to obtain velocity measurements at the inlets of both pump #5 and pump #6, pump 5 being representative of a location directly in front of the inflow into the wet well while pump 6 is in a corner of the wet well. Measurements were taken for pump 5 but space limitation prevented probe access to measure velocities in front of the pump 6 intake.

## TESTING PROCEDURES

Tests were performed adjusting the flows for the desired pump operation scenario and at a prescribed wet well elevation. The wet well elevation was measured in a stand tube connected to the wet well in the same location as the actual bubbler stand tube that is used to measure wet well elevations in the prototype. Since between one and five pumps could be in operation at any time, there were many possible permutations that could be considered in the testing. In order to quickly determine the worst flow conditions, various combinations of pumps ranging from one pump to four pumps were tested, generally at both the 543' and 546' water levels specified as the operating range in the original information provided describing pump station operation. In addition, several pump combinations were tested at water level intervals of 0.5 feet ranging from 538' to 546', depending on the test. Since the worst flow conditions generally occur at the highest flow rates, all pumps were tested at their maximum design flow rate, including pumps #5 and #6, which are variable speed pumps. Tests included the following:

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 are 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 condition into the pump suction line, the swirl angle of the entering flow was measured in all inlet lines with a rotating cruciform. The swirl angle, $\theta$, is defined by:

$$\theta = \tan^{-1}(\pi ND/U)$$

where N is 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). Swirl angles of less than 5 degrees are generally considered as acceptable for axial flow pumps (Knauss, 1977).

With regards to velocity variations, general criteria exist with regards to both spatial variations in velocity as well as temporal variations at individual measurement locations. Ideally, time-averaged velocities around the circumference of the pump inlet should not vary by more than ten percent, while the root-mean-square of the velocity fluctuations at any point should be less than 25-30 percent of the time-averaged approach velocity.

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 digital video camera (capable of conversion to 1/2 inch VHS format) was used to record the details of the model construction and various portions of the testing sequence.

## PHASE I TEST RESULTS

### Vortices and Other Flow Conditions

In general, intake conditions were observed to be reasonably satisfactory, but a number of unacceptable flow conditions were noted in the Phase I testing which involved the investigation of a number of combinations of one, two, three or four pumps in operation. A list of these follows:

- Excessive air entrainment in the flow entering the wet well, at low wet well water levels. This was primarily associated with the fact that the two inlet pipes flowing into the wet well provided a hydraulic control on flow upstream in the junction and screen chambers at low wet well elevations. Under these circumstances, the flow passed through critical depth at the entrance into the wet well and essentially entered as a free overfall. The plunging flow then resulted in air entrainment within the wet well. Pump #6, when operating alone indicated significant air entrainment at levels below about 540'. Pumps #5 and #6 operating together caused significant air entrainment at water levels less than 540' as did the combination of Pumps #3 and #4. Simultaneous operation of pumps #2, #3, #5, and #6 showed a loss of hydraulic control at 541', and air entrainment became excessive below this level. Entrained air tended to be transported to the pump intakes and passed up the pump intakes. One implication of these observations is that an automatic control model of operation with wet well elevations down to 537 or 538 feet will not be feasible due to this air entrainment.

- Air entrainment due to the presence of Type 6 (air-entraining) vortices. These vortices tended to be intermittent in nature and were most common at low water levels. In the case of pump #6 operating singly, the curtain wall and inflow turbulence seemed to prevent any air entraining vortex from reaching the pump intake at water levels below 540', but above 540' vortexing formed inside of the curtain wall and vortices reached the pump intake. Pumps #5 and #6 running together caused air-entraining vortices (into pump 5) at water levels below 543'. Pumps #2 and #6 together caused air-entraining vortices at water levels below about 543.5'. Pumps #3 and #4 created air-entraining vortices below elevations of about 543'. Simultaneous operation of pumps #2, #3, #5, and #6 caused air-filled vortices to intermittently enter the intakes of pumps #2 and #5 at 543' with an especially large amount of entrained air in pump 5. A number of these flow conditions were recorded on video. Figure 9 shows the air entrained into pumps 5 and 6 for a wet well level of about 543'.

- Other coherent surface vortices; these were generally observed at all pump intakes in at least some of the conditions tested but would generally meet the criteria discussed above, as in most cases, the vortices were intermittent. Their degree of persistence varied among the specific tests.

Figure 9. Air Entrainment into Pumps 5 and 6, for a low wet well level.

- Excessive swirl angles as discussed in more detail below. In most cases, the unacceptable swirl angles were only marginally above the five degree limit, but in a few cases, they ranged up to a maximum of approximately ten degrees. Nearly all swirl angle exceedances were observed in Pumps 4 and 6 (particularly in Pump 6) but Pump 5 also exceeded the swirl angle criterion for a test with Pumps 2, 3, 5, and 6 in operation at low wet well level (543 feet) due to the formation of a large air entraining vortex in that flow configuration. Most of the unacceptable swirl angles formed at wet well levels between about 545 and 546 feet.

The sources of much of this undesirable flow behavior were readily apparent. The flow entering the wet well through each of the two inlets can have inflow velocities ranging up to nearly five feet per second. BHRA guidelines (Prosser, 1977) generally call for approach velocities to pump intakes below one foot per second. The short distance between the inlets and the wall in which the pump inlets are located will result in very little attenuation of the inflow velocity. This high velocity impinges on the wall and begins to spread laterally in both directions along the wall. In cases of high inflow rates, surface vortices that appeared to be associated only with the impinging flow were observed to form on either side of the impinging flow. This statement is made since these vortices were observed even in cases where no pumps were in operation in front of one of the two inflow sections. The vorticity generated by this impinging flow was however transferred into a nearby pump inlet if it was operating. Air entraining vortices would then form at low wet well water levels. At sufficiently high flow rates, these vortices were periodically disturbed by the turbulence due to the high velocities within the wet well but they quickly reformed. At higher wet well elevations, the vortices were more persistent but the submergence was sufficient to prevent air entrainment.

Pumps 4 and 6 exhibited the highest swirl angles because the flow impinging on the back wall of the wet well flowed laterally into the confined space in the corner of the wet well where these pumps were located. This flow was then forced to turn again to enter the pump intake, generating additional vorticity. Strong turning of the flow is often associated with poor intake conditions (Arboleda and El-Fadelm, 1996). At lower water levels, the surface vortex pulled to these intakes formed to the inside of the curtain walls, but at higher water levels, the surface vortex would shift to the other side of the curtain walls. This shift generally resulted in a significant increase in the swirl angle. Figures 10 through 12 indicate some of the air entraining vortices observed in the model.

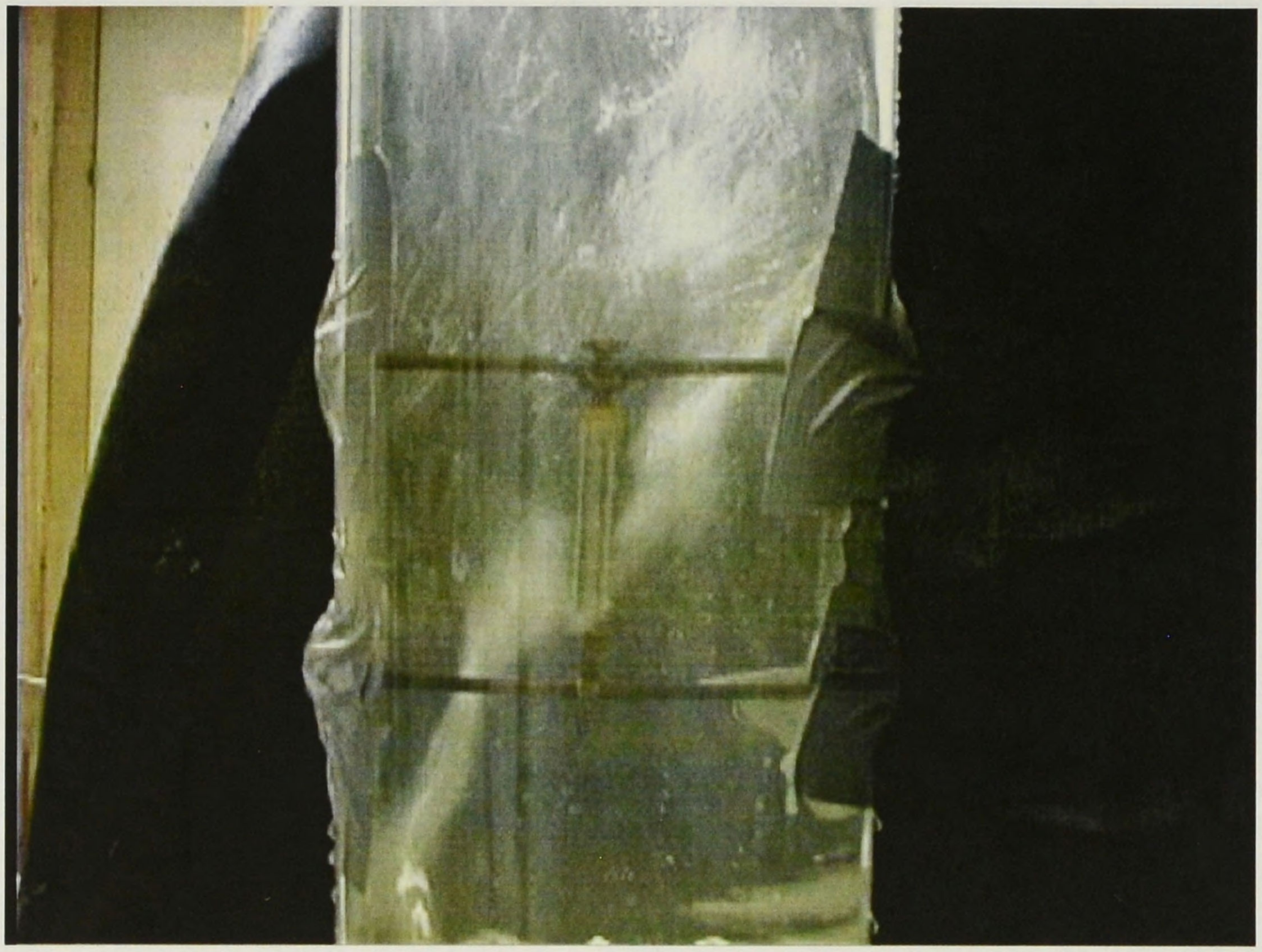

Figure 10. An air-entraining vortex into Pump #5.

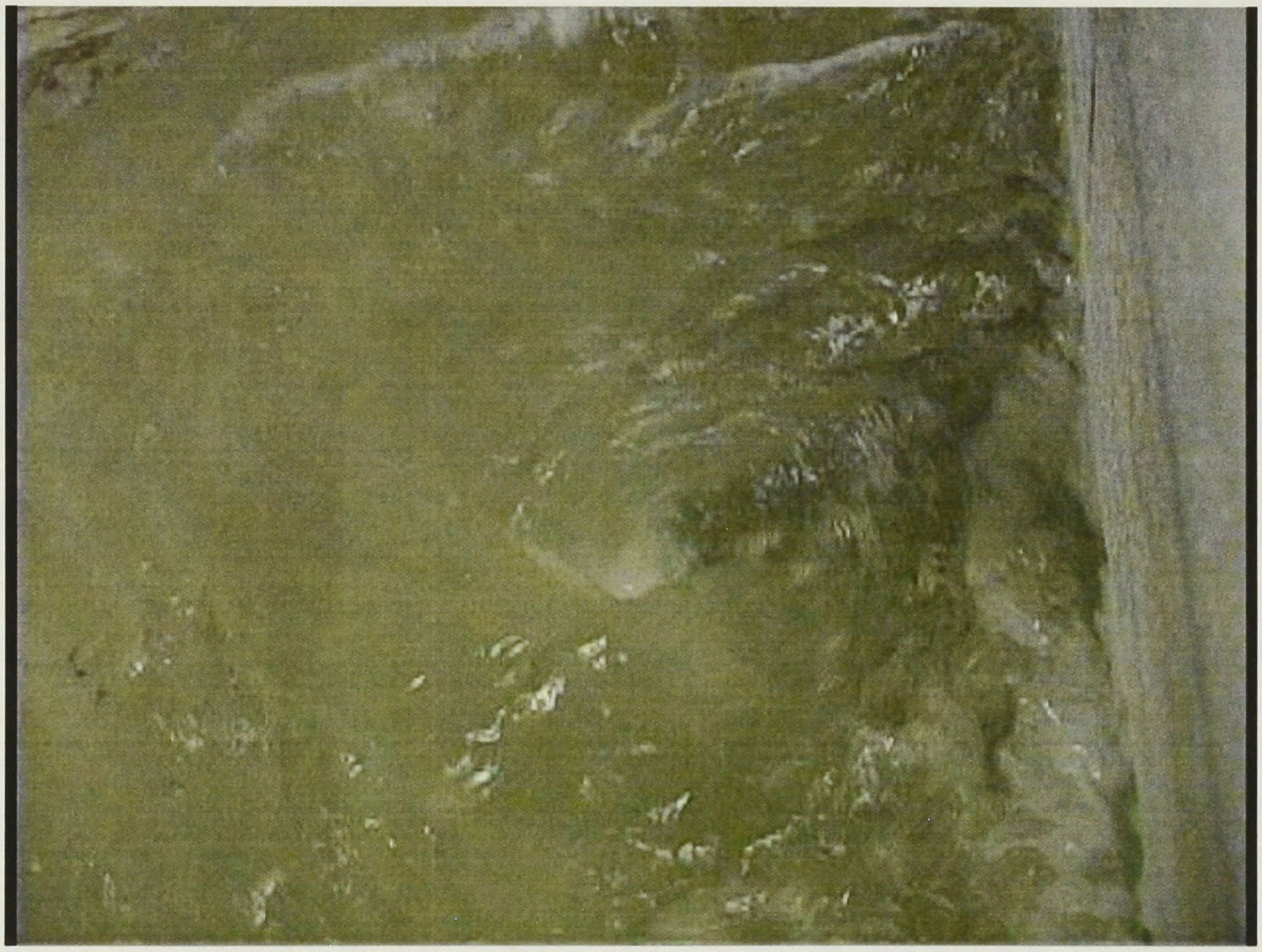

Figure 11. Vortex formation at larger flow rates and low wet well levels

Figure 12. Vortex formation at low flow rates.

**Swirl Angles**

- Swirl angles were measured for various combinations of one through four pumps in operation in part to determine those conditions that result in largest swirl angles. Table 2 summarizes the results of this testing. Initially, tests were performed at either a low water level of 543 ft or a higher level of 546 ft. In general, most of the higher water levels indicated larger swirl angles, especially associated with Pump 6. This led to additional testing for a few cases that indicated higher swirl angles in the preliminary testing in which the water level was varied in 0.5 ft increments. Table 3 lists the results of these tests. These additional tests showed that highest swirl angles were observed generally in the 544.5-545 ft range. In some cases, the measured swirl angles were above the limits generally recommended for axial flow pumps especially for pump 6, the large capacity pump in the corner of the wet well. Pumps 4 also indicated several instances where the swirl angle criterion was exceeded.

These tests were conducted without the recycle line in operation, in part due to the fact that the initial configuration did not have the recycle line construction completed. The effect of the recycle line on the swirl angles is discussed in more detail further below.

**Table 2.** Swirl angles associated with various flow conditions with original design.

| Pump Combination | Pump # | Flow Rate (MGD) | Water Level (ft) | Swirl Angle |
|---|---|---|---|---|
| #6 alone | 6 | 50 | 43 | -5.04 |
| | | 50 | 46 | -5.54 |
| #5 alone | 5 | 50 | 43 | 0.00 |
| | 5 | 50 | 46 | -0.40 |
| #2,#6 | 2 | 20 | 43 | 0.76 |
| | 6 | 50 | 43 | -2.63 |
| | 2 | 20 | 46 | 0.49 |
| | 6 | 50 | 46 | -3.64 |
| #5,#6 | 5 | 50 | 43 | -1.62 |
| | 6 | 50 | 43 | -1.21 |
| | 5 | 50 | 46 | -2.63 |
| | 6 | 50 | 46 | -1.21 |
| #3,#5,#6 | 3 | 30 | 43 | -3.31 |
| | 5 | 50 | 43 | 1.92 |
| | 6 | 50 | 43 | -3.43 |
| | 3 | 30 | 46 | -5.09 |
| | 5 | 50 | 46 | -0.40 |
| | 6 | 50 | 46 | -3.03 |
| #2,#3,#5,#6 | 2 | 20 | 43 | 0.79 |
| | 3 | 30 | 43 | -3.06 |
| | 5 | 50 | 43 | 8.43 |
| | 6 | 50 | 43 | -6.64 |
| | 2 | 20 | 46 | 1.40 |
| | 3 | 30 | 46 | -2.17 |
| | 5 | 50 | 46 | -1.21 |
| | 6 | 50 | 46 | -5.14 |
| #3,#4 | 3 | 30 | 43 | -0.30 |
| | 4 | 40 | 43 | 2.17 |
| | 3 | 30 | 46 | 1.99 |
| | 4 | 40 | 46 | 4.07 |

Note: negative sign denotes counterclockwise rotation when looking down on model, positive sign denotes clockwise rotation.

**Table 3.** Swirl angles for two pump configurations at 0.5 ft elevation intervals.

| Pump Combination | Pump | Wet Well Level (ft) | Swirl Angle degrees |
|---|---|---|---|
| #2,#6 | 2 | 42 | 3.4 |
| | 6 | 42 | -2.7 |
| | 2 | 42.5 | 2.9 |
| | 6 | 42.5 | -3.6 |
| | 2 | 43 | 1.9 |
| | 6 | 43 | -2.6 |
| | 2 | 43.5 | 1.6 |
| | 6 | 43.5 | -6.4 |
| | 2 | 44 | 3.0 |
| | 6 | 44 | -6.4 |
| | 2 | 44.5 | 3.5 |
| | 6 | 44.5 | -8.4 |
| | 2 | 45 | 3.5 |
| | 6 | 45 | -8.8 |
| | 2 | 45.5 | 4.0 |
| | 6 | 45.5 | -9.2 |
| | 2 | 46 | 3.2 |
| | 6 | 46 | -6.6 |
| #3,#4 | 4 | 41.5 | -0.5 |
| | 3 | 41.5 | 2.0 |
| | 4 | 42 | -0.6 |
| | 3 | 42 | 1.5 |
| | 4 | 42.5 | 1.0 |
| | 3 | 42.5 | 1.5 |
| | 4 | 43 | -0.3 |
| | 3 | 43 | 2.2 |
| | 4 | 43.5 | 1.2 |
| | 3 | 43.5 | 3.2 |
| | 4 | 44 | 3.8 |
| | 3 | 44 | 5.8 |

|   |   |   |
|---|---|---|
| 4 | 44.5 | 5.8 |
| 3 | 44.5 | 4.8 |
| 4 | 45 | 5.2 |
| 3 | 45 | 4.2 |
| 4 | 45.5 | 3.0 |
| 3 | 45.5 | 4.1 |
| 4 | 46 | 2.0 |
| 3 | 46 | 4.1 |

## PHASE II. WET WELL MODIFICATIONS

After it was determined that the wet well performance was unsatisfactory in a number of the categories described above for various pump combinations and water levels, various modifications were tested in order to create a functional design. These tests were conducted iteratively, starting with a design predicted to correct the most significant problems at the most common flow conditions, and then successively modifying the design until one was found that satisfied a majority of the requirements. In previous studies, a variety of methods have been employed to eliminate poor pump intake conditions. These include baffle walls, splitter plates, cones beneath pump intakes, etc. (e.g. Wright and Schläpfer, 1988 or EHI, 1989). However, in this particular wet well, the number of options available was somewhat limited. Internal baffle walls were not felt to be practical due to the short flow distance across the wet well. Since the pre-rotation appeared to originate from the flow impingement and spread along the back wall of the wet well, a solution that resulted in deflecting that flow along the wall was sought.

The following list outlines various steps that were implemented to determine the final design. (Note: All dimensions given in this section correspond to actual wet well dimensions, not model dimensions)

- The first set of modifications tested was the addition of two 20-inch wide x 5 ft high plates vertically located between 535' and 540'—one located halfway between the intakes for pumps #2 and #6 and the other halfway between the intakes for pumps #3 and #4; and the addition of two 20"x10' plates—one located halfway between the intakes for pumps #2 and #5 and the other halfway between the intakes for pumps #1 and #2. These two plates extend down to the floor of the wet well. Several pump combinations were tested at high water levels. In several of the tests, pump #6 still exceeded the maximum allowable swirl angle.. There was also an increase in vortex behavior in the center of the wet well, particularly near the inlet to pumps 3 and 5.

- The second set of modifications was designed to correct the issues of swirl angle in pump #6 and the air entraining vortices in the wet well that were observed after the first modification. The plate between the intakes of pumps #2 and #6 was moved closer to the curtain wall in order to reduce the flow of water that had deflected off the back wall of the wet well toward pump #6. Additionally, the plate between pump #2 and #5 was increased in width by 12" so that it measured 32"x10'. These modifications improved the swirl angles in pump 6 for most flow conditions tested. The modifications did little to reduce the air entraining vortices at various pump intakes between the curtain walls. A subsequent trial indicated that moving the internal plates so that they were immediately above the intakes for pumps 2 and 5 largely eliminated the air entraining vortices at those locations but that placing a similar plate above the inlet to pump 3 actually made the air entraining vortex stronger there. These observations led to the next modification described next.

- The third modification largely solved the air entraining vortex problem. This modification involved the placement of 20-inch wide by 5-ft high plates centered on and directly above the inlets to pumps 2 and 5. A similar size of plate was placed along the floor roughly halfway between pumps 1 and 2. The flow conditions previously tested did not indicate significant exceedance of the swirl angle criterion but when additional testing was done for pump 6 alone, relatively large positive swirl angles were observed at lower water levels as opposed to the previous tests in which large negative swirl angles were measured.

- The fourth set of modifications tested involved placing four 7" diameter circular holes in the plate between the intakes of pumps #2 and #6. The holes were placed close to the back wet well wall. The concept was that flow would pass through the holes into the area behind the curtain wall and negate the rotation in the flow passing around and under the plate, thus reducing overall rotation in the vicinity of the intake for pump #6 to reduce swirl angle and vorticity. This modification yielded improved performance for pump #6 but did not quite satisfy the swirl angle criteria for all configurations tested.

- The fifth set of modifications that were tested involved replacing the circular holes in the plate between intakes #2 and #6 with a single 18" x 9.5" notch at the bottom of the plate directly adjacent to the back wet well wall. The notch was intended to direct flow into the area behind the curtain wall to negate rotation near the bottom of the wet well where the flow enters the intake for pump #6 and serve essentially the same function that the circular holes in the previous option served. Additional modifications were made by increasing the total height of the plates above pumps 2 and 5 as this change appeared to reduce the formation of air entraining vortices at very low wet well levels. These final modifications proved to be basically successful as indicated in the proof test results presented below. Figure 13 present the details of the plate sizes and locations in this final modification. Pictures of the final modifications are presented in Figures 14 and 15.

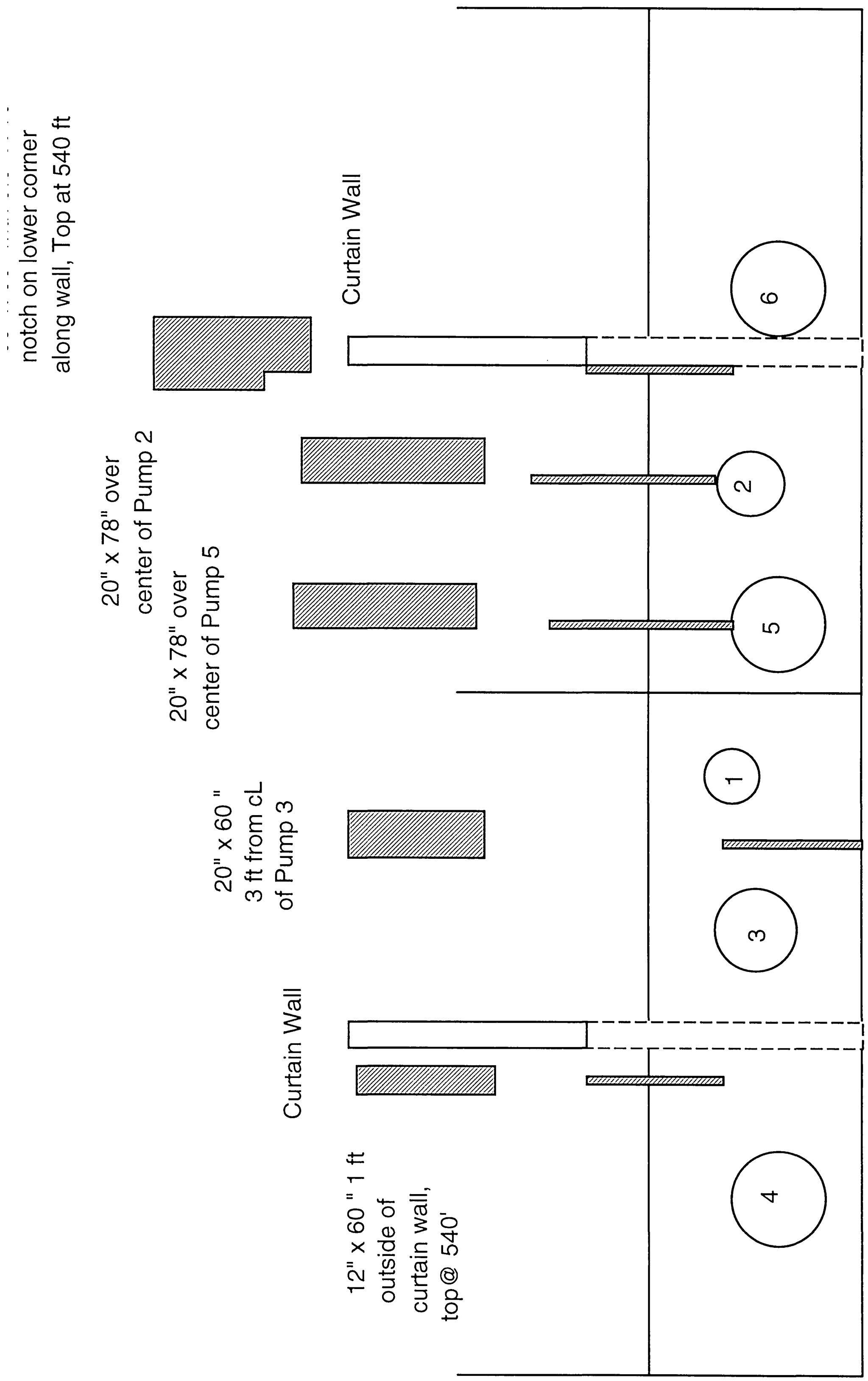

Figure 13. Final Modification to the Pump Station Wet Well. Plate sizes and locations.

Figure 14. Plates located near intakes of pumps #4, #3 and #5.

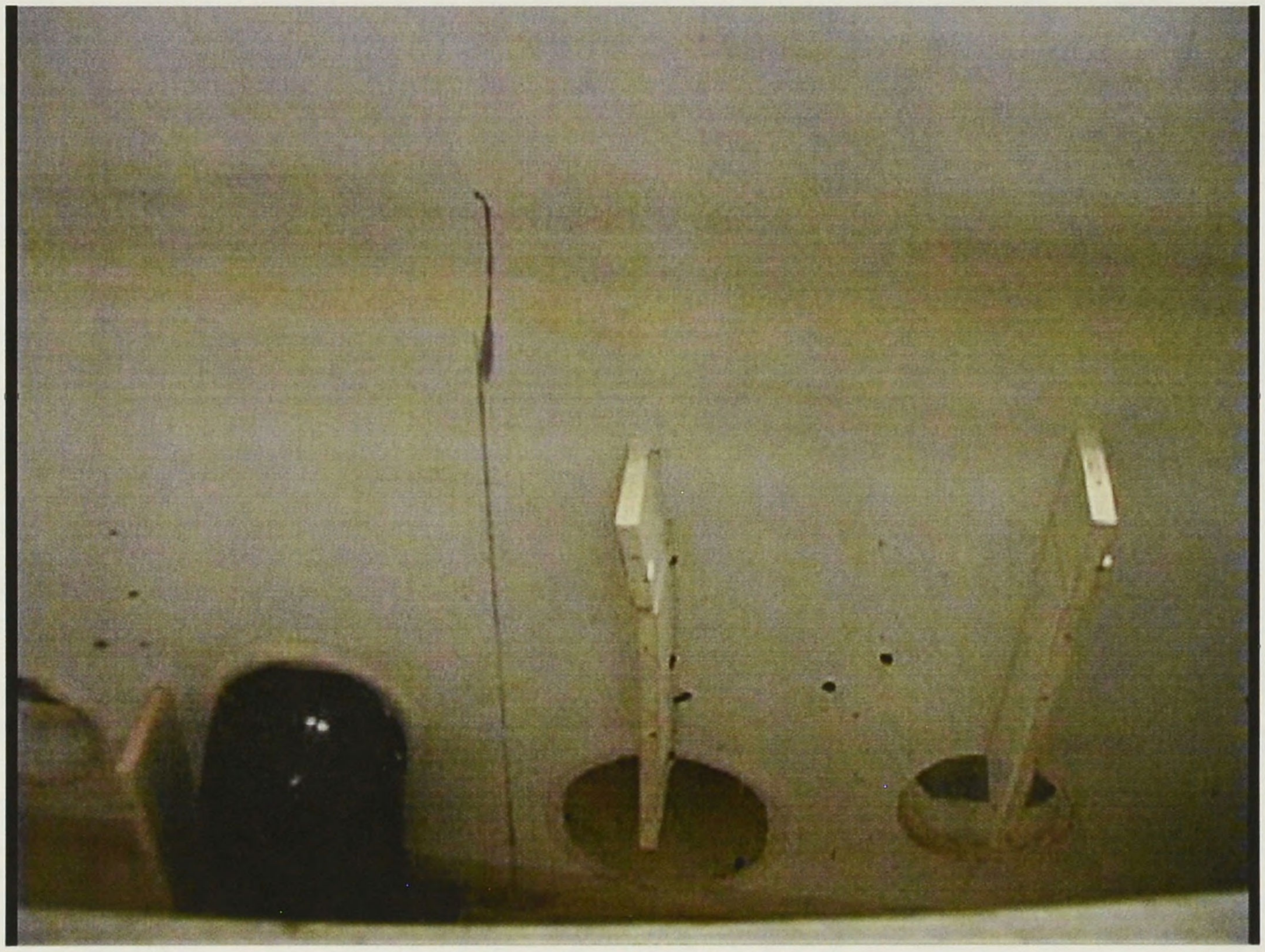

Figure 15. Plates located near intakes of pumps #3, #5 and #6.

## RECOMMENDED DESIGN – PROOF TESTING

As the proof testing was conducted, a larger number of flow configurations were investigated. In addition, a number of specific issues were investigated in more detail. This section lists the results of this portion of the model study program.

One of the specific issues addressed was that of the actual pump capacities being higher than the nominal values specified for the individual pumps. A series of tests were performed at flows equal to the nominal values and at flows equal to 117 percent of the nominal rates (an apparent upper bound for the actual flow through any pump. Table 4 presents a comparison of the results of this testing. Although the number of rotations increased with the increased flow, the increase in axial velocity tended to offset this in a way that the swirl angle changes very little with the increase in flow rate or slightly decreased in most cases. One thing that was observed was an increased tendency to form air-entraining vortices at low wet well water levels. At the nominal pump flow rates, air entraining vortices were generally not observed at elevations down to 542 feet while (especially for larger station flows), the 117 percent flows would indicate air entraining vortices for the same wet well levels. This effect is shown in a very significant way for the pump combination of 2, 3, 4, and 6 in Table 4 where the swirl angle changes from +2.9 degrees at the nominal flow condition to -5.9 degrees at the 117 percent condition. At the higher system flow, a surface vortex forms outside the curtain and creates the large negative swirl angle. This phenomenon vanishes at water levels just above 543 feet. One issue that is unclear is whether it is reasonable to conduct a test, for example, with the flows through pumps 2, 3, 5, and 6 at 117 percent of the nominal flow as this corresponds to a total pumping rate of about .175 mgd, and it is presumed that 150 mgd is the hydraulic capacity of the treatment plant itself. The same argument holds for the pump combination 2, 3, 4 and 6 where the total pumping rates will be 164 mgd at the 117 percent flow condition. Nevertheless, it does not appear to be good practice to operate the wet well at an elevation below about 543.5 feet due to the possibility for the formation of air entraining vortices. Some information provided indicates that current station operations sometimes allow the wet well level to go below that level. This consideration is more important for high station flow rates and is less of a concern at normal dry weather flow conditions.

Table 4. Results of testing at nominal flow rates and at 117 percent flows.

| Pump Combination | Pump # | Flow Rate (MGD) | Water Level (ft) | Swirl Angle |
|---|---|---|---|---|
| #2,#6- 1.0Q | 2 | 20 | 543 | 1.22 |
|  | 6 | 50 | 543 | 1.82 |
|  | 2 | 20 | 546 | 1.95 |
|  | 6 | 50 | 546 | -3.64 |
| #2,#6- 1.17Q | 2 | 23.4 | 543 | 1.04 |
|  | 6 | 58.5 | 543 | 0.86 |
|  | 2 | 23.3 | 546 | 1.46 |
|  | 6 | 58.5 | 546 | -3.28 |
| #2,#5,#6- 1.0Q | 2 | 20 | 543 | 0.73 |
|  | 5 | 50 | 543 | 2.43 |
|  | 6 | 50 | 543 | 0.61 |
|  | 2 | 20 | 546 | 2.43 |
|  | 5 | 50 | 546 | -0.40 |
|  | 6 | 50 | 546 | -5.64 |
| #2,#5,#6- 1.17Q | 2 | 23.4 | 543 | 0.83 |
|  | 5 | 58.5 | 543 | 2.07 |
|  | 6 | 58.5 | 543 | 1.04 |
|  | 2 | 23.4 | 546 | 2.19 |
|  | 5 | 58.5 | 546 | -0.69 |
|  | 6 | 58.5 | 546 | -5.51 |
| #2,#3,#5,#6- 1.0Q | 2 | 20 | 547 | 4.01 |
|  | 3 | 30 | 547 | -0.38 |
|  | 5 | 50 | 547 | 0.20 |
|  | 6 | 50 | 547 | -6.04 |
| #2,#3,#5,#6- 1.17Q | 2 | 20 | 547 | 2.91 |
|  | 3 | 30 | 547 | -1.09 |
|  | 5 | 50 | 547 | 0.35 |
|  | 6 | 50 | 547 | -4.83 |

| | | | | |
|---|---|---|---|---|
| #2,#3,#4,#6 - 1.0Q | 2 | 20 | 543 | 2.68 |
| | 3 | 30 | 543 | -0.38 |
| | 4 | 40 | 543 | 2.89 |
| | 6 | 50 | 543 | -3.64 |
| #2,#3,#4,#6 - 1.17Q | 2 | 23.4 | 543 | 3.53 |
| | 3 | 35.1 | 543 | 0.87 |
| | 4 | 46.8 | 543 | -5.94 |
| | 6 | 58.5 | 543 | -2.25 |

In the subsequent presentation of results, several test results are presented for flow rates that were increased above the nominal levels, usually by 110 percent. It is felt that these adequately represent the flow conditions that are to be expected during the pump station operation and the small variations in discharge are not important to interpretation of the results.

A second issue is that the wet well elevations are allowed to raise up to 548.5 feet at high flow conditions. It is understood that operating at this high a level is not a normal operating condition but essentially represents a limit for emergency operation at extreme flow conditions. Table 5 presents the results of a few high flow tests with wet well levels raised in generally half-foot increments up to the control limit of 548.5 feet. For the cases studied, the swirl angles decreased once the wet well level was above a level on the order of 546-547 feet. Therefore, it is expected that the more comprehensive results presented below for water levels up to 546 feet consider all worst cases conditions with respect to swirl angle.

Table 5. Swirl angles results for water levels exceeding 546 feet

| | | | | |
|---|---|---|---|---|
| #2,#3,#5,#6 - 1.0Q | 2 | 20 | 546 | 3.89 |
| | 3 | 30 | 546 | -0.64 |
| | 5 | 50 | 546 | 0.20 |
| | 6 | 50 | 546 | -5.44 |
| | 2 | 20 | 547 | 4.01 |
| | 3 | 30 | 547 | -0.38 |
| | 5 | 50 | 547 | 0.20 |
| | 6 | 50 | 547 | -6.04 |
| | 2 | 20 | 548 | 1.58 |
| | 3 | 30 | 548 | -2.55 |
| | 5 | 50 | 548 | -0.81 |
| | 6 | 50 | 548 | -4.44 |
| | 2 | 20 | 548.5 | 1.52 |

| | | | | |
|---|---|---|---|---|
| | 3 | 30 | 548.5 | -2.17 |
| | 5 | 50 | 548.5 | 0.00 |
| | 6 | 50 | 548.5 | -5.04 |
| #2,#3,#5,#6 - 1.17Q | 2 | 23.4 | 543 | 0.26 |
| | 3 | 35.1 | 543 | -2.40 |
| | 5 | 58.5 | 543 | 0.95 |
| | 6 | 58.5 | 543 | 1.12 |
| | 2 | 23.4 | 545 | 2.29 |
| | 3 | 35.1 | 545 | -3.16 |
| | 5 | 58.5 | 545 | -1.30 |
| | 6 | 58.5 | 545 | -4.14 |
| | 2 | 23.4 | 547 | 2.91 |
| | 3 | 35.1 | 547 | -1.09 |
| | 5 | 58.5 | 547 | 0.35 |
| | 6 | 58.5 | 547 | -4.83 |
| | 2 | 23.4 | 548.5 | 1.46 |
| | 3 | 35.1 | 548.5 | -2.18 |
| | 5 | 58.5 | 548.5 | 0.35 |
| | 6 | 58.5 | 548.5 | -4.66 |

Table 6 summarizes a more comprehensive set of tests performed to measure swirl angles and observe for vortex formation for a wide variety of pump configurations. Pump 6 typically exhibits the worst swirl angle conditions, with values right at the acceptance criteria limits or slightly above for some operating configurations. Specifically, swirl angles up to about six degrees are found in pump 6 for the 2, 5, and 6 and the 2, 3, 5, and 6 pump configurations at high water levels. In addition, the swirl angle in pump 4 exceeds the five degree limit for water levels of 543 feet for the 2, 3, 4, and 5 and the 2, 3, 4, and 6 configurations (117 percent flow case only). It is noted that the swirl angles in pump 4 reduced dramatically at water levels slightly above 534 feet in these latter tests. All the other pumps were generally well within the five-degree limit, thus the performance of the modified wet well is considered to be acceptable in this regard.

Table 6. Additional swirl angle test results.

| Pump Combination | Pump # | Flow Rate (MGD) | Water Level (ft) | Swirl Angle |
|---|---|---|---|---|
| #6 – 1.0Q | 6 | 50 | 43 | 3.0 |
| | 6 | 50 | 45 | 1.3 |
| #5 – 1.0Q | 5 | 50 | 43 | 0.3 |
| | 5 | 50 | 46 | 0.6 |
| #5,#6 1.0Q | 5 | 50 | 43 | 0.6 |
| | 6 | 50 | 43 | 1.1 |
| | 5 | 50 | 46 | -0.8 |
| | 6 | 50 | 46 | -3.8 |
| #3,#4 – 1.0Q | 3 | 30 | 43 | 2.0 |
| | 4 | 40 | 43 | -0.4 |
| | 3 | 30 | 46 | 1.8 |
| | 4 | 40 | 46 | 2.1 |
| #2,#3,#4,#5 1.0Q | 2 | 22 | 43 | 4.9 |
| | 3 | 33 | 43 | 1.0 |
| | 4 | 44 | 43 | -5.4 |
| | 5 | 55 | 43 | -0.6 |
| | 2 | 22 | 46 | 3.6 |
| | 3 | 33 | 46 | 2.5 |
| | 4 | 44 | 46 | -1.9 |
| | 5 | 55 | 46 | 1.1 |
| #3, 1.0Q | 3 | 30 | 43 | 2.0 |

Additional testing was performed with the recycle line in operation. Although some of the earlier testing was performed with the recycle line in operation, the exact configuration of the discharge was not properly reproduced. Once the necessary corrections were made to the model, a set of tests were performed for a particular configuration both with and without the recycle line operating; results of these tests are presented in Table 7. Both Pumps 2 and 6 were observed to be influenced by the recycle line discharge. The comparison in Table 7 indicate that the recycle flow actually serves to reduce the swirl angles and therefore, the results presented above are conservative in that the recycle flow was not included in those test results. One additional issue is that air entrainment into the pump 6 inlet due to the plunging of the recycle flow into the wet well was observed for some flow configurations. Air entrainment was observed for wet well elevations below about 544 feet and increased as the wet well elevation was lowered below that level. No air entrainment was ever observed in the next closest pump intake, pump 2, even if pump 6 was not operating. Figures 16 and 17 shows the recycle line in operation for a low wet well level and pump 6 in operation.

Table 7

| Pump Combination | Pump # | Flow Rate (MGD) | Water Level (ft) | Swirl Angle |
|---|---|---|---|---|
| #6 - w/recycle | 6 | 50 | 546 | 0.00 |
| #6 - w/orecycle | 6 | 50 | 546 | 0.40 |
| | | | | |
| #2,#6 - w/recycle | 2 | 20 | 546 | 1.95 |
| | 6 | 50 | 546 | -3.43 |
| #2,#6 - w/o recycle | 2 | 20 | 546 | 2.80 |
| | 6 | 50 | 546 | -3.64 |
| | | | | |
| #2,#5,#6 w/recycle | 2 | 2 | 546 | 1.95 |
| | 5 | 50 | 546 | -1.21 |
| | 6 | 50 | 546 | -5.44 |
| #2,#5,#6 w/o recycle | 2 | 20 | 546 | 2.80 |
| | 5 | 50 | 546 | -0.81 |
| | 6 | 50 | 546 | -5.84 |

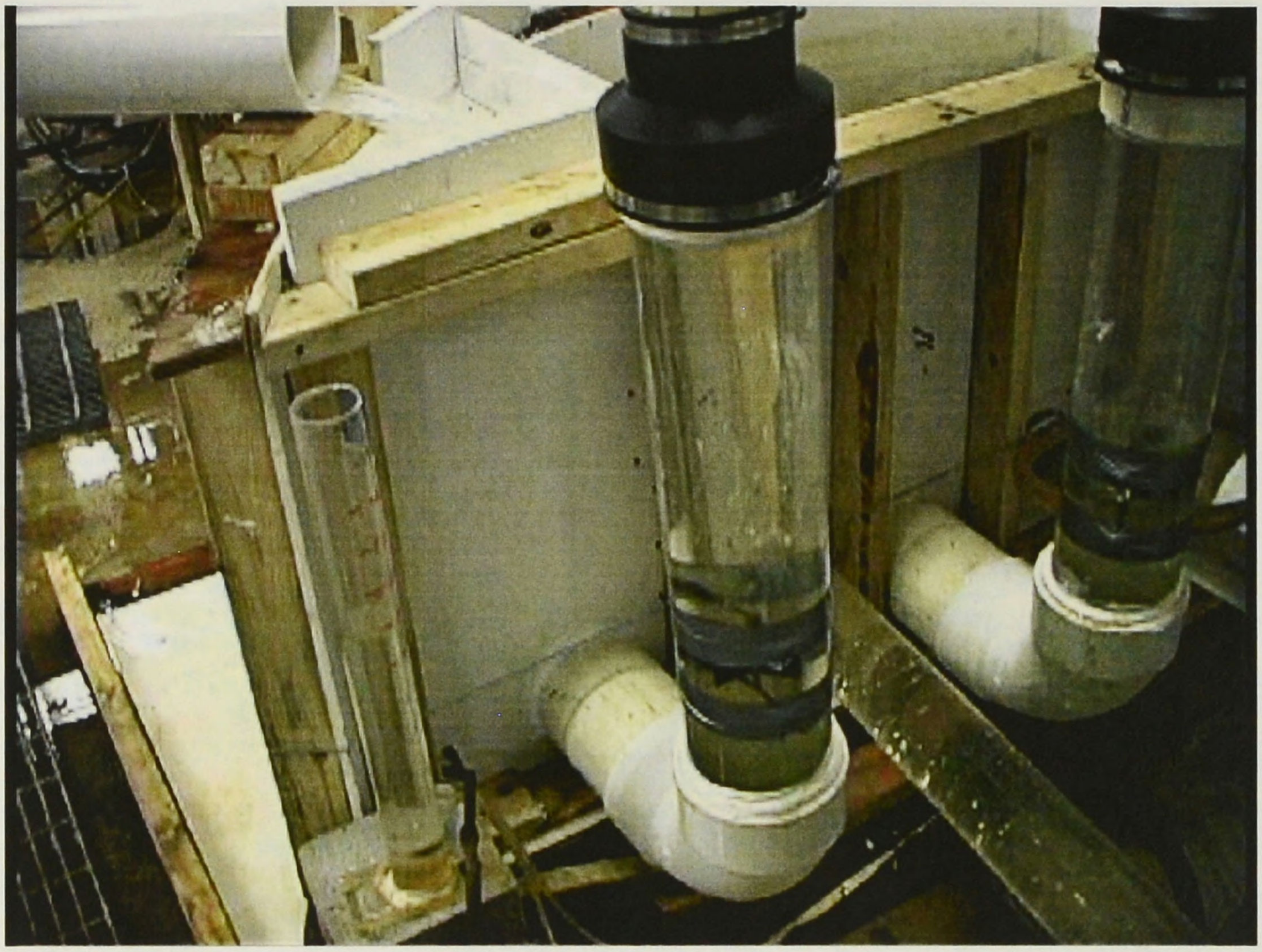

Figure 16. Recycle line in operation for a wet well level of 543 ft.

Figure 17. Detail of the discharge of the recycle flow into the wet well.

With regards to the occurrence of vortices within the wet well, the performance of the wet well generally tended to deteriorate at low wet well elevations, on the order of 543 feet or below. A specific conclusion depends on the assumed values for the flows through individual pumps. If all pumps are capable of delivering 117 percent of the nominal pump flow rate, then the wet well performance is marginal with respect to strong but intermittent vortex formation even at 543 feet. This statement is particularly true at high station flow rates in excess of 115 mgd. Information provided during the course of this study indicated that the wet well has been operated at least occasionally in the past at levels below 542 feet. Model test results indicate that operating at this low of level is problematic with the current configuration and may continue to be so even with the recommended modifications.

Velocity measurements were made at the inlet to pump 5 in order to detect velocity variations around the perimeter of the pump inlet. A primary reason for examining that particular pump inlet is that, looking downstream; the right side of the pump inlet is located approximately aligned with the left side of the right inlet conduit to the wet well. Since the inlet inflow will traverse the wet well and impinge directly on the wall near this pump intake, velocity non-uniformities associated with the wet well inflow should be exacerbated at this location. Other key locations where significant velocity variations may be expected are at the inlets to pumps 4 or 6. However, the constricted flow area in the corners of the wet well do not allow the positioning of the acoustic Doppler velocimeter (ADV) probe around the entire pump inlet perimeter. Even if velocity non-uniformities exist, there are not many practical options to modify the approach velocities to the pump inlets. This set of experiments is simply regarded as a quantification of general flow conditions within the wet well as opposed to a demonstration that a particular flow objective was met.

The ADV probe was positioned such that it measured velocities approximately 5 cm off the back wall of the wet well and on the perimeter of the pump inlet. Velocity measurements were made at the bottom of the inlet and at 45-degree increments around the perimeter. The plate installed at the top of the pump inlet precluded a measurement at the top of the pump inlet, so individual measurements were made at seven locations around the perimeter. Two-minute sampling periods were utilized and the instantaneous three components of velocity were combined to generate a time series of total velocity magnitudes. This time series was then analyzed to compute the temporal average of the velocity magnitudes as well as the root-mean-square value of the velocity deviation from the mean. Table 8 presents the results of the measurements for four different pump operation configurations: Pump 5 operating alone at wet well elevations of 543 and 545 feet and Pumps 2, 5, and 6 in operation at the same wet well levels. Variations in velocity around the perimeter as well as the maximum rms value of the velocity fluctuations are recorded in the table. The results are more or less as expected with greater velocity variations at lower water elevations (forcing higher wet well velocities) and with more pumps in operation. The spatial velocity variations are greater than generally would be desirable, but there are no apparent straightforward modifications to the wet well that would rectify this situation. Root-mean-square fluctuations of velocity are within acceptable limits, but much higher at high station flow rates, consistent with the visual impression of much greater turbulence under these operating conditions.

Table 8. Results of Acoustic Doppler Velocimeter measurements at Pump 5 inlet.

| Pump Combination | Water Level (ft) | Maximum Velocity (cm/s) | Minimum Velocity (cm/s) | % difference | rms (%) |
|---|---|---|---|---|---|
| #5 | 543 | 42.29 | 32.66 | 26 | 11.4 |
| #5 | 545 | 40.1 | 34.3 | 15.3 | 10.2 |
| #2,#5,#6 | 543 | 52.5 | 38.1 | 33.8 | 23 |
| #2,#5,#6 | 545 | 50.1 | 36.4 | 33.6 | 19.6 |

## RECOMMENDATIONS AND CONCLUSIONS

Flow conditions within the existing wet well, while not severe, result in undesirable operating conditions, namely excessive pre-rotation in the flow (at higher water levels) and air entraining vortices at low wet well elevations. Based on conversations with WWTP personnel, it appears that the latter problem is more likely to have influenced pump operation based on the perception that the wet well is more commonly operated at lower wet well elevations. This situation is more problematic with respect to the pumps that are located between the curtain walls, namely pumps 2, 3, and 5. In the RFP for this project, it was not indicated that these particular pumps were experiencing the perceived operating problems preferentially compared to the remaining pumps. Excess swirl angles were primarily observed in pump 6 (and in pump 4 to a lesser degree) at relatively high wet well elevations. Again, there is no indication of problems with pump 6 operation compared to the other pumps. Therefore, the observed cases with poor flow conditions cannot be directly related to specific issues that have been identified as problematic with respect to pump operation.

In spite of the above observation, flow conditions generally considered to be unacceptable in wet well operation have been identified. Therefore, it is recommended that changes be made to the system in order to improve the flow conditions. By placement of five plates along the back wall of the wet well, it was possible to reduce swirl angles to below acceptance criteria and to largely eliminate air-entraining vortices. There are more general criteria that are often used to guide wet well design, e.g. Prosser (1977). In that document, it is recommended to keep inflow velocities into the wet well below 2 ft/s and to keep approach velocities to individual pumps below 1 ft/s. In the present wet well, the two six foot-diameter inlet conduits control inflow velocities. At a design flow of 150 mgd with equally split of flow between the two conduits and each flowing full, an inflow velocity of 4.1 ft/s would result. This is without consideration of any contraction off the upstream face of these conduits, which would increase the inflow velocity even more. However, there is little option to this situation with the existing wet well configuration. Even if the entire width of the screen chamber were opened as an inflow area into the wet well, the inflow velocity would only decrease to about 2 ft/s for a six-foot flow depth. This flow would be scarcely attenuated across the narrow width of the wet well and therefore an approach velocity only slightly below 2 ft/s would be expected for those pumps directly in front of the screen chamber. It is expected that there are structural constraints that would prevent such an option from being implemented. In spite of these issues, the relatively minor changes to the wet well geometry have been shown to be sufficient to reduce pre-rotation and vortex behavior below generally accepted criteria. Therefore, it is recommended that these changes be implemented in the wet well to improve the flow conditions within the wet well.

Most of the poor flow conditions observed were associated with cases in which pumps, primarily on one side or the other of the wet well, were in operation simultaneously. For example, if only pumps 3 and 4 are operating (both located on the left side of the wet well), there is a tendency for air-entraining vortices to develop near the left curtain wall at low wet well elevations. Similarly if Pumps 2 and 6 or Pumps 2, 5, and 6 (located in the right half of the wet well) are the only ones in operation, the swirl angles, in pump 6, are generally the greatest. As a practical matter, it is recommended that pump operation be chosen in such a manner as to avoid operating conditions where only pumps on one side or the other of the wet well are in simultaneous operation. It is understood that there are some practical limits to operation decisions, but it would be prudent to make this a general consideration during station operation

One issue that remains to be discussed relates to operating water levels. Since the pump station is operated manually, it is not possible to state with precision exactly what the range of operating levels are as a function of station discharge and, based on discussion with WWTP personnel, it is likely that there is not a clear set of rules that guides the selection of operating levels. However, information was presented indicating that at least at some times, the station has been operated at wet well elevations below 542 feet. One statement provided is that operators try to maintain water levels between 542 and 545 feet. It is recommended that the lower limit be increased to at least 543 feet. Observations with the modified wet well did not indicate any air entraining vortices down to levels of 542 feet. However, when the pumps were operating at a nominal discharge of 150 mgd, but with the individual discharges increased by 17 percent, intermittent air entraining vortices were observed at water levels between 542 and 543 feet. It is not recommended that the station be operated at those low levels, say for discharges in excess of 100 mgd.

A second reason why the station should not be operated at low levels is that the plunging flow from the recycle line tends to entrain air at low wet well elevations. This is only a major issue when pump 6 is operating as no significant air entrainment was observed into the pump 2 intake when pump 6 was shut off under any reasonable wet well level. With pump 6 in operation, air entrainment was observed to commence at a wet well elevation a little below 544 feet and to become progressively worse as the water level is decreased to lower elevations. By operating pump 6 with a wet well elevation above, say 543.5 ft, the amount of air entrained into the pump inlet should have a negligible influence on pump performance.

Finally, instructions have been developed for automatic control of the pump starts and stops and are included in the operations and maintenance manual describing the revisions to the pumps station. The instructions indicate that the larger pumps (3-6) could be operated down to wet well elevations of 537 feet. Based on observations in the model, this low an operating level will result in a number of undesirable flow conditions, including air entraining vortices, excessive air entrainment in the inflow into the wet well and, in the case of pump 6, air entrainment due to the recycle line inflow. It is not recommended that the pump station be operated in any manner that allows operation at this low of a wet well elevation.

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# AIIM SCANNER TEST CHART #2

## Spectra

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**6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789**
**8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789**
**10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789**

## *Bodoni Italic*

*4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789*
*6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789*
*8 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789*
*10 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789*

## Greek and Math Symbols

4 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨZαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⊅⊄⩾⩽≡
6 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨZαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⊅⊄⩾⩽≡
8 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨZαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⊅⊄⩾⩽≡
10 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨZαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⊅⊄⩾⩽≡

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Isolated Characters

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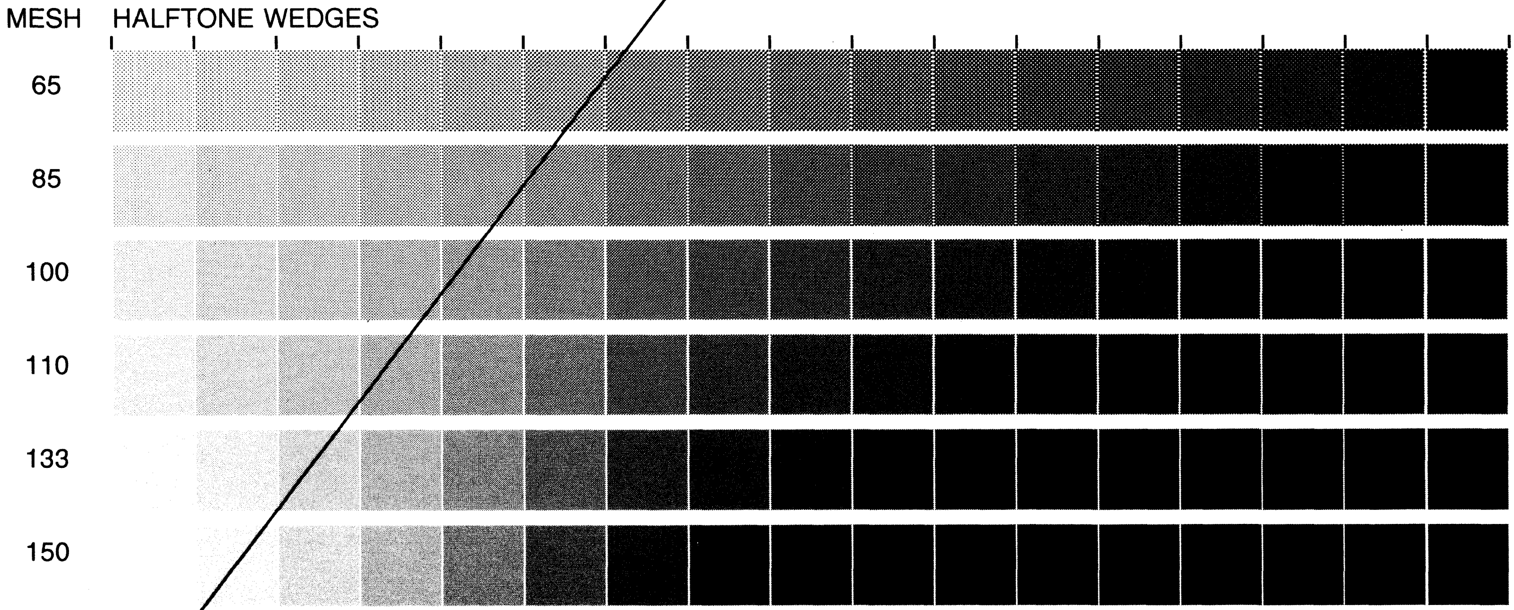

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RIT ALPHANUMERIC RESOLUTION TEST OBJECT, RT-1-71

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