

# HYDRAULIC MODEL STUDY Genesee County Northeast Extension Sewer Contract 2B Pumping Station Report CEE 05-08

Final Project Report to Hubbell Roth & Clark

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### Genesee County Northeast Extension Sewer Contract 2B Pumping Station Report CEE 05-08

Final Project Report to Hubbell Roth & Clark Bloomfield Hills, Michigan

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### **EXECUTIVE SUMMARY**

A physical hydraulic model of the flow through the junction chamber and the wet well for the Genesee County Northeast Extension Sewer Contract 2B Pumping Station was constructed at a 1:5 scale of the prototype and was tested based on Froude number dynamic similarity criteria. The purpose of the model was to investigate the inlet flow conditions within the wet well to identify whether the proposed design was adequate to prevent excessive vortex formation and/or pre-rotation of the flow entering the pumps. An additional study objective was to determine whether different proposed clearances between the pump intakes and the wet well floor would provide satisfactory operating conditions. Model construction was based on blueprints and other design documents detailing dimensions and other pertinent features of the wet well and junction chamber.

Flow tests were performed on the model of the pump station for a variety of permutations of pump operation and at different wet well water surface elevations based on preliminary plans for pump operation. These preliminary tests indicated several configurations with poor flow behavior. In particular, subsurface vortices were observed originating from the wet well floor and/or the walls entering the inlets to all pumps, depending on the specific pump operating sequence. These submerged vortices were observed over the range of proposed wet well operation for pumps 2 and 3. In one case of three pumps operating at a wet well elevation of 697 feet, an intermittent, submerged vortex was observed extending from the pump 3 to the pump 4 intake. In addition, excessive swirl angles were observed at several pump inlets; in particular in pumps 1 and 3 that respectively had 15 and 21 inches of clearance between the pump intake and the wet well floor. High swirl angles were observed most often in the pump 1 intake with maximum values up to about ten degrees or more than twice the value generally considered to be acceptable. During the course of experiments, it was observed that problematic flow conditions, such as high swirl angles, usually tended to get worse with increasing number of operating pumps. However, lowering the flow rate in each pump at constant water level, while reducing the number of rotations observed with the swirl meter, did not have a significant impact on swirl angle and a low flow of 9 or 10 MGD per pump was as likely to have a large swirl angle as a 23 MGD flow through the same pump.

Modifications were made to the wet well design to attempt to reduce the rotation in the flow. Initial efforts involved the placement of a fillet along the corner between the wet well floor and the back wall behind the pump intake or the placement of a splitter from the back wall beneath the center of the pump intake. Neither of these modifications significantly improved the problem of vortex formation or significantly reduced the swirl angles. Further modifications consisted of the placement of a cross (either 15" or 10" high depending on the pump intake clearance) mounted beneath each pump intake. The placement of crosses resulted in a situation in which subsurface vortices were rarely observed at pump intakes and all swirl angles were maintained below five degrees, usually well below five degrees. Small, intermittent vortices were observed only at the pump 2 intake for two cases: 1 - Pumps 1, 2 and 3 operating at 14 MGD with a water surface elevation of 697 feet. 2 - Pumps 1, 2 and 3 operating at 10 MGD with an elevation of 696 feet.

Additional recommendations were obtained regarding pump station operation as the results of this model study in response to specific issues that were requested to be addressed:

- In the original configuration of the wet well, swirl angles well above 5° were observed at pump 3 with 21 inches of clearance off the wet well floor compared to pump 2 with 15 inches clearance in which all measured swirl angles were below 5°. A similar result was observed comparing pumps 1 and 4 except that the initially lower clearance of 15 inches investigated for pump 1 consistently produced significantly higher swirl angles compared to pump 4 with 21 inches of clearance. This leads to a recommendation to install the outside pumps (1 and 4) with a clearance of 21 inches and to utilize a clearance of 15 inches for the inside pumps (2 and 3). Subsequent testing in this configuration verified this choice of different clearances for the various pumps.
- A request was made to investigate the potential impact of raising the elevation of the interceptor flowing into the upstream junction chamber by 2.5-3 ft and increasing its diameter from 60 to 72 inches. In order to easily facilitate this assessment, a barrier was installed in the supply pipe entering the junction chamber; this barrier blocked off the lower half of the inflow pipe. This effectively raised the elevation of the inflow by about 2.5 feet and increased the inflow area, reducing the inflow velocity in a manner that

would be qualitatively similar to increasing the pipe diameter. Tests in this configuration showed nominally higher swirl angles than the original configuration, but the maximum swirl angle was still only 4 degrees, indicating that such an alteration in the inlet condition would not be unacceptable.

• In response to questions regarding the potential impact of adding the crosses when pumping raw wastewater, an investigation was performed in which sediment was added to the inflow into the wet well. The inflow was decreased until significant deposition was observed on the wet well floor (10 MGD). Tests performed both with and without the crosses in place showed similar degrees of sediment deposition indicating that there would not be a significant accumulation of sediment on the back side of the crosses. In order to avoid the possibility of string-like material hanging up on the crosses, a slight modification in the configuration tested is recommended.

Although the final configuration tested and recommended for the wet well proved to be acceptable in reducing vortices and swirl angles, one consistent observation was that at low wet well elevations, a fair amount of air was entrained into the plunging inflow (not due to air entraining vortices) and passed through the pump intakes, primarily through the inside pumps 2 and 3. Since all pumps are variable speed pumps and are intended to be operated at low flow rates for the lower wet well elevations, an investigation was performed to determine a maximum flow rate at a given wet well elevation that minimized the entrainment of air. The results of these experiments are presented for information in the Results section of the report. It is known that air entrainment in plunging inflows does not scale properly in a Froude scaled model and no attempt was made to measure air concentrations so these results are presented for general guidance.

### INTRODUCTION

The Genesee County Northeast Extension Sewer (NEES) Contract 2B Pumping Station has a maximum pumping capacity of 30 MGD (46 cfs), achieved with four 10 MGD pumps with approximately 800 HP. The firm capacity of 30 MGD will be achieved with a maximum of three of the four pumps in operation. The station pumps the influent through a 4 mile force main to the outlet located near Stanley road. The design of the pumping station will include provisions for the future when a second force main will be constructed and the firm capacity of the pump station will be raised to 60 MGD. After installing the second force main, the effluent from the pumps will be distributed between the two force mains; usually two pumps discharging to one force main and one pump discharging to the other force main.

The purpose of the physical hydraulic model study was to examine the inlet conditions associated with flow into the pumps through the wet well. The model included the inlet interceptor, the junction chamber and the pipes connecting to the wet well. The wet well and discharge intakes were modeled up to the location of the pump intakes. The model was operated in accordance with Froude number dynamic similarity requirements and testing was performed over the ranges of wet well operating levels and number of pumps in operation.

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

- Examination of vortex patterns at the pump inlets;
- Examination of air-entrainment through each pump
- Measurement of swirl in flow into individual suction inlets;

Requests were made to investigate the impacts of various other design parameters on the wet well performance. One issue involved the clearance between the pump intakes and the wet well floor while another issue involved the possible alteration of the elevation and size of the interceptor entering the junction chamber upstream from the wet well. Modifications were made to the model to systematically evaluate the consequences

of these design modifications.

This report describes the physical model construction, the operating procedures, experimental results for the originally proposed wet well design and the modifications that were made to the design to produce acceptable system performance.

### **GENERAL SYSTEM DETAIL**

Flow enters the pump stations through a 5-ft diameter influent sewer at an invert elevation of 701.5 ft. that flows into a small junction chamber from where it passes through two 4 ft. diameter pipes carrying flow through coarse bar screens and into the wet well. The flow drops into the main wet well from an invert elevation of 697.5 ft to the wet well floor elevation of 686.5 ft. Four vertical suction inlets arranged along the back wall lift the flow through the pumps to the discharge force main. Figures 1 and 2 show the schematic top and side view of the junction chamber, main wet well, and pump intakes. Larger scale reproductions of these drawings are provided in Appendix A.

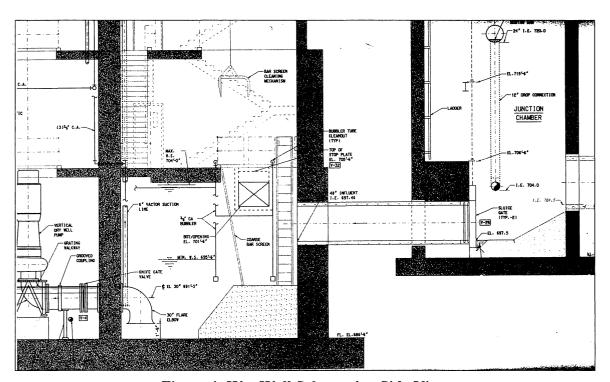


Figure 1. Wet Well Schematic - Side View

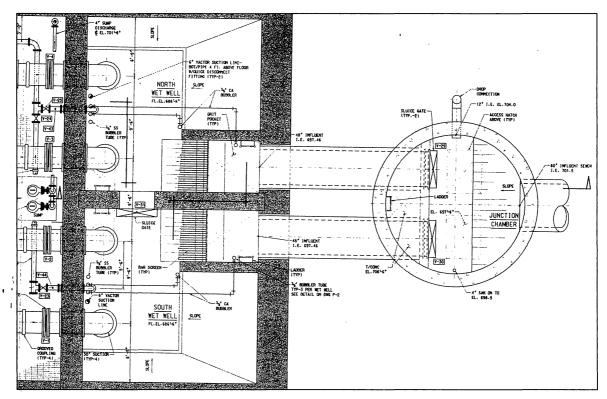


Figure 2. Wet Well Schematic - Top View

Each of the four pumps will be operated using a variable frequency controller to attain flow rates ranging from 9 to 23 MGD. In the current state, the maximum required capacity of the pumping station will be 30 MGD and will be attained with a maximum of three pumps in operation. In the future, the design pumping capacity will increase to 60 MGD, again with a maximum of three pumps in operation. The pumps will be operated in different combinations of one, two, and three pumps and the combinations will be alternated to increase the pump lifetimes in a "first on-first off" sequence. In this kind of sequence, the pump that has been on the longest or the lead pump would be shut off first. It is intended to avoid operation of two pumps on one side of the wet well unless one pump is also operating on the opposite side. A small opening (4 ft x 4 ft) in the wall separating the two halves of the wet well allows for equalization in the flow between the two sides when an uneven number of pumps (one or three pumps) are operating in the wet well. Table 1 below shows the approximate water levels that will be used to activate each pump as it will be needed. If a high flow rate into the pump station caused the water level to rise from a lower level, pumps would be turned on one at a time as the water level reaches the target elevation indicated in Table 1.

**Table 1. Sequence of Operation** 

Sequence of Operation	<b>Elevation</b>
High Level Alarm	705.0
Start Emergency 4 <sup>th</sup> Pump	704.0
Start 3 <sup>rd</sup> Pump	702.0
Start 2 <sup>nd</sup> Pump	700.5
Start 1 <sup>st</sup> Pump	698.5
Stop All Pumps	695.5

After the first pump is activated, it will ramp up from an initial 9 MGD pumping rate and increase this pumping rate up to the maximum if the water level continues to rise. If the first pump reaches its maximum, a second pump would be turned on at its minimum speed and the first pump or lead pump speed would also be reduced. With two pumps on, the speeds would again be increased till they reach their maximum if the water level were to continue rising. When the two pumps reach their maximum and the water level continues to increase, a third pump will be activated and all three will be set to their lowest speeds and then increased until the required maximum pumping capacity is achieved.

As the water level recedes the pumps would be shut off according to the "first onfirst off" sequence. Pumps would also be shut off if multiple pumps were operating below their maximum speed. A pump may then be shut off if the remaining pumps would be able to handle the current capacity.

### **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,  $L_r$ , which is the geometric ratio between any length in the model and

the corresponding one in the prototype ( $\mathbf{L_r} = \mathrm{Length_{model}}$  /  $\mathrm{Length_{prototype}}$ ). 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	L <sub>r</sub>	$ m L_r$
Velocity	$\mathbf{V_r}$	$\mathbf{L_r}^{1/2}$
Discharge	$Q_r$	$\mathbf{L_r}^{5/2}$
Time	$t_{r}$	$\mathbf{L_r}^{1/2}$

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 with viscous effects considered to be the controlling factor for scale effects. 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 swirl intensity caused by inlet vortices. This Reynolds number is to be defined in terms of the flow in the suction pipe as Re = Q/Sv, with Q the flow rate in the suction pipe, S the pump intake submergence in the wet well, and v the kinematic viscosity. found no Reynolds number effects for Reynolds numbers Re = VD/v, (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 1:5 was selected for this model study. In order to evaluate the effects of viscous forces in the model, the Reynolds number for the worst case or the smallest flow rate should be calculated. The smallest prototype flow rate that was tested in the model was 10 MGD that corresponds to a model flow rate of 0.277 MGD through each pump. For this pumping rate, a Reynolds number only slightly smaller than the suggested limit would occur (on the order of 67,000). Although this is slightly below the suggested limit, higher prototype flow rates were associated with model Reynolds numbers well above this limit. Since organized surface vortices were never observed in the model, the Reynolds Number criterion based on pump submergence should not be relevant. In conclusion, the effects of viscous forces can be ignored in the model and the similarity of gravitational forces would be the major factor in operation of the model.

### **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 1:5. This general model size was selected to keep the Reynolds numbers previously defined to generally be greater than the recommended minimum suggested by Padmanabhan and Hecker (1984). All relevant details of the junction chamber, wet well (including the bar screen) and the connecting effluent and influent pipes and the wet well were reproduced at this scale from dimensions provided on a series of blueprints. In general, the model was constructed from PVC (piping and sheet) and allowed operation over the range of wet well elevations from 695.5 up to 702 feet.

One of the objectives of the model study was to determine whether the clearance between the pump inlet and the wet well floor could be reduced from the originally proposed 21 inches down to 15 inches. Because of the symmetry in the wet well, it was decided to address this question directly in the preliminary testing by installing the intakes on one side of the wet well with the larger clearance and using the smaller clearance in the two intakes on the opposite side of the wet well.

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 right after the intake were constructed from Plexiglas so that the rotating cruciforms

(or swirl meters) used to measure the inlet swirl angles could be visually observed to determine the swirl angles. All four pump suction lines were joined in a common manifold connected to a re-circulating pump that removes the flow from the wet well, through the desired pump suction lines, and back around to the inlet conduit (the influent sewer to the junction chamber). The maximum model discharge rate of approximately 750 gpm (93 cfs prototype) was achieved with this single re-circulation pump. The flow distribution was regulated by means of an installed butterfly valve on each of the four pump suction lines. The flows were metered in each individual suction line by means of an installed orifice meter. The pressure difference measured across the orifice meter is used to compute the discharge through each of the pump intakes in operation during a particular experimental sequence.

An overall view of the model is provided in Figure 3, while close-ups of various aspects of the model construction are provided in Figures 3 to 10.

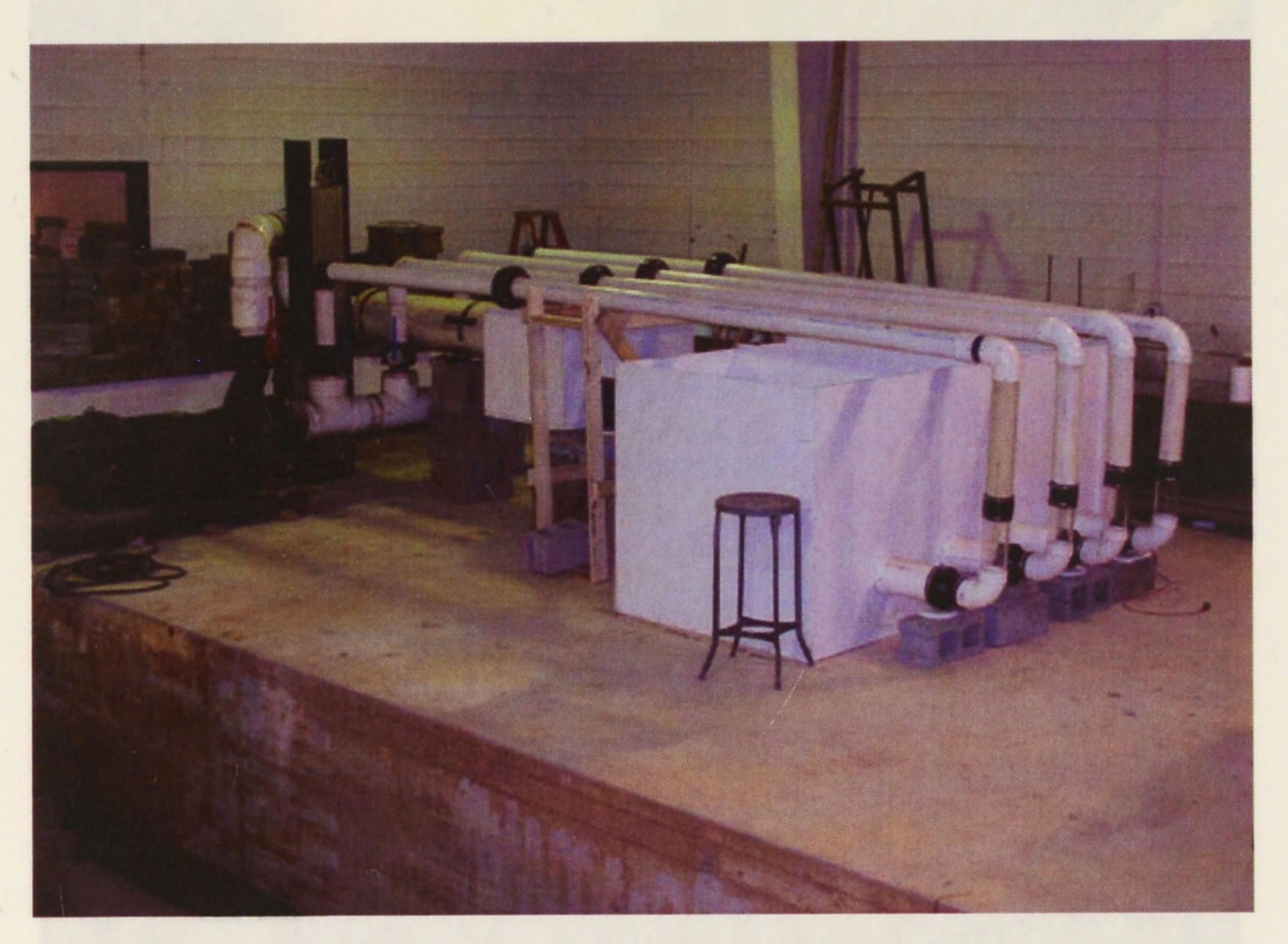


Figure 3. Overall View of the Model

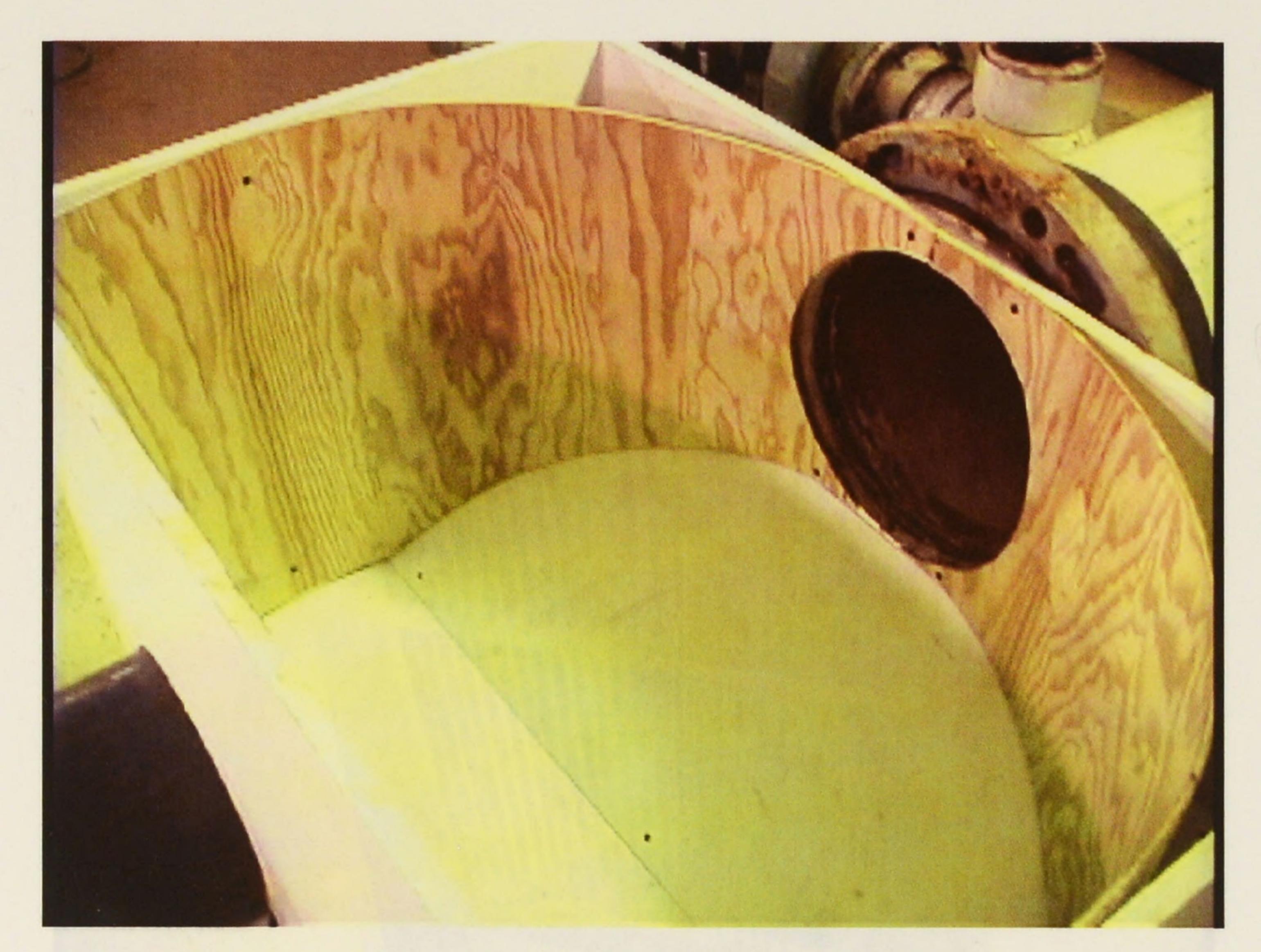


Figure 4. The Junction Chamber

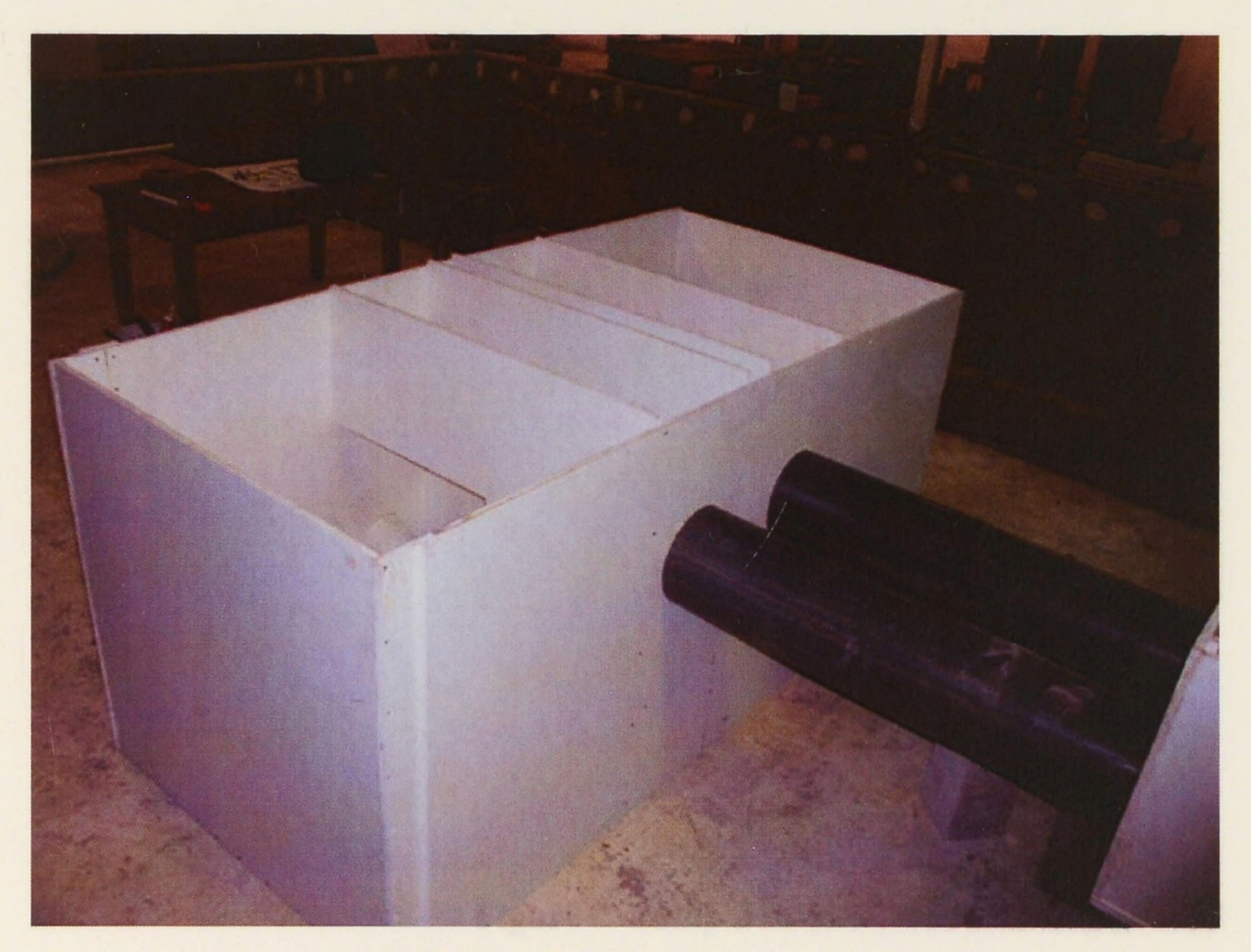


Figure 5. Outlets from the Junction Chamber to the Wet Well

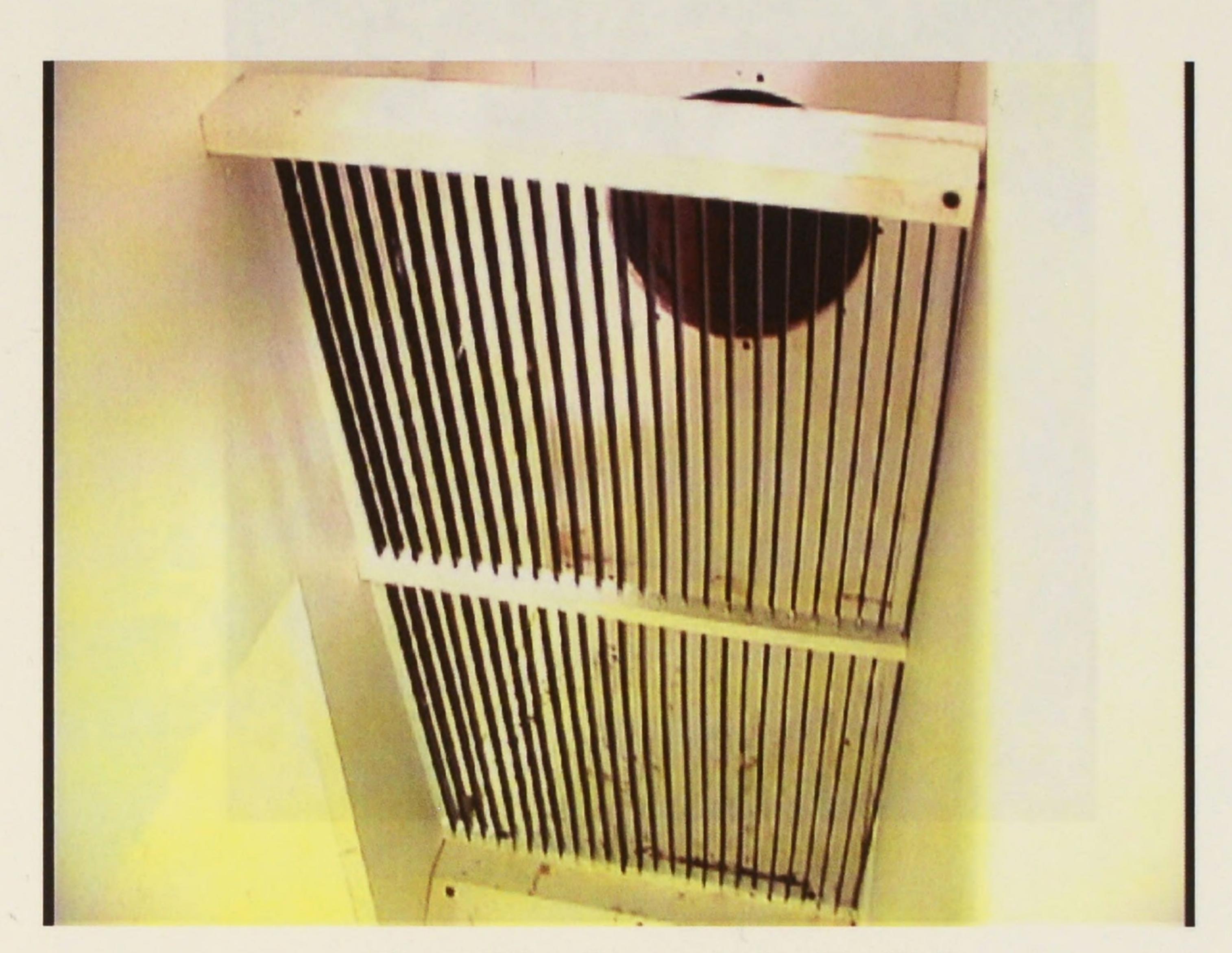


Figure 6. Bar Screens in the Wet Well

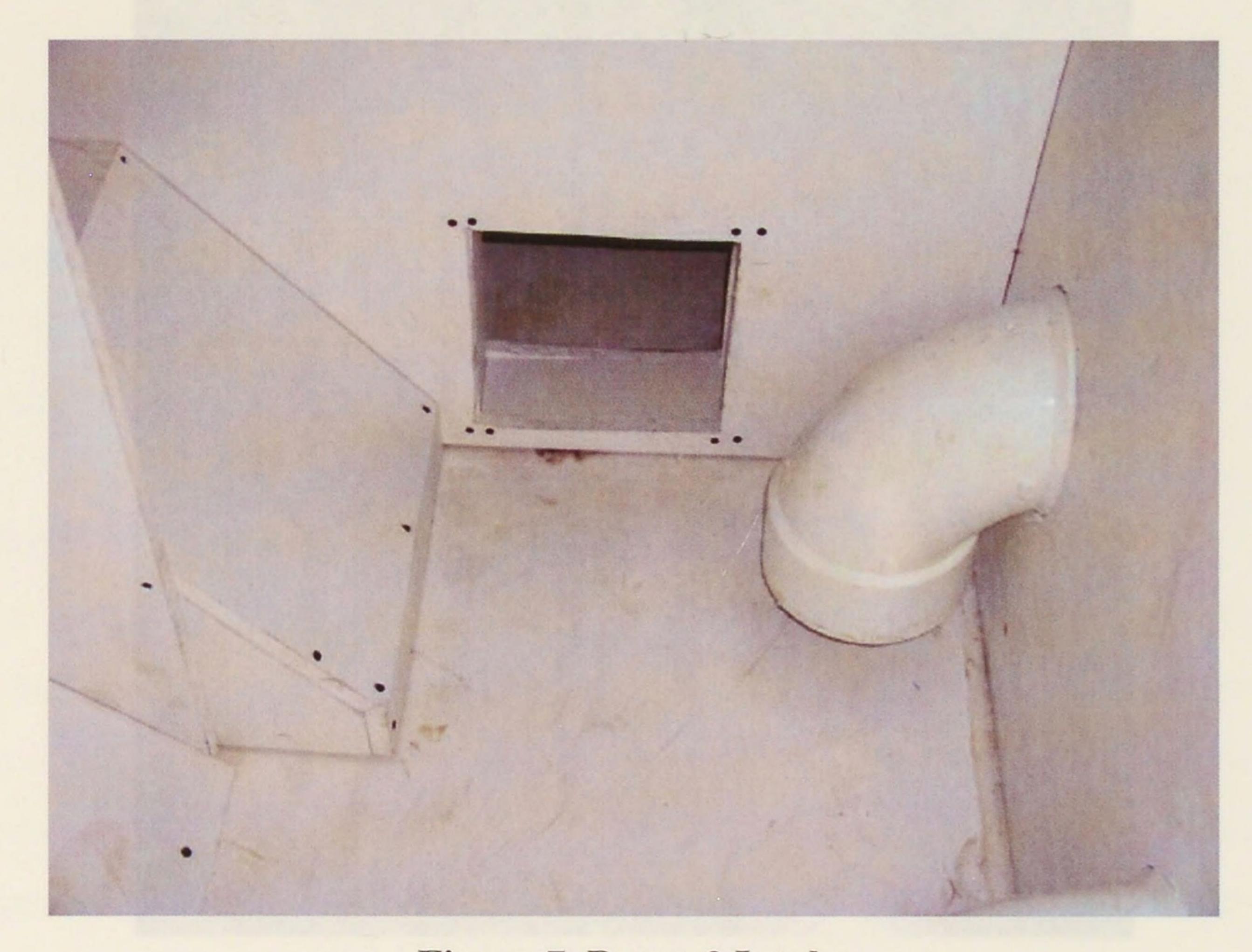


Figure 7. Pump 2 Intake



Figure 8. Suction Lines



Figure 9. Suction Lines to the Manifold

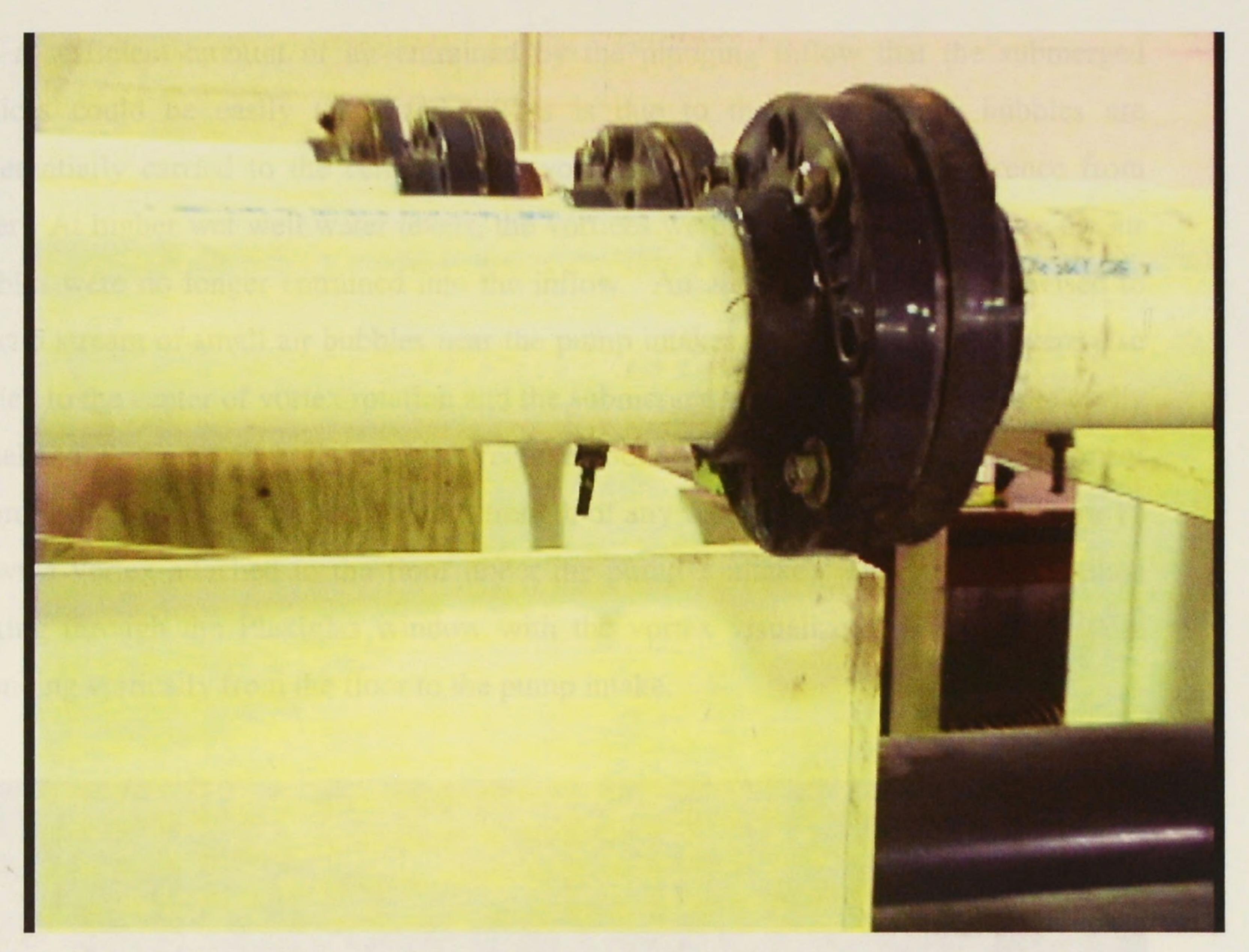


Figure 10. Installed Orifice Meters with Pressure Taps

### Instrumentation

The flow rate through each individual pump intake was measured using pipe orifice meters constructed to ASME specifications in the return piping (Figure 10). There were at least 30 upstream diameters of straight pipe and 15 diameters downstream from the orifice plates in order to minimize approach flow influences on the meter behavior following Hydraulic Institute standards. Pressure differences across the orifice meters were measured with water-air differential manometers.

There were never air-entraining surface vortices observed under any of the experimental test conditions. However, preliminary testing indicated the presence of coherent rotation in the suction pipe as evidenced by the motion of air entrained into the flow associated with the inflow into the wet well. In order to search for submerged vortices, small Plexiglas windows were installed in the back wall of the wet well between pumps 1 and 2 and between pumps 3 and 4. At lower wet well water elevations, there

was a sufficient amount of air entrained by the plunging inflow that the submerged vortices could be easily visualized. This is due to the fact that air bubbles are preferentially carried to the center of the vortex due to their density difference from water. At higher wet well water levels, the vortices were not observable because the air bubbles were no longer entrained into the inflow. An air bubble probe was devised to inject a stream of small air bubbles near the pump intakes. These air bubbles were also carried to the center of vortex rotation and the submerged vortices were again quite easily visualized. Pertinent observations were recorded both on digital video and in a permanent record of notes indicating location and strength of any vortex motion observed. Figure 11 shows a vortex attached to the floor under the pump 3 intake. This image was taken looking through the Plexiglas window with the vortex visualized by a solid air core extending vertically from the floor to the pump intake.

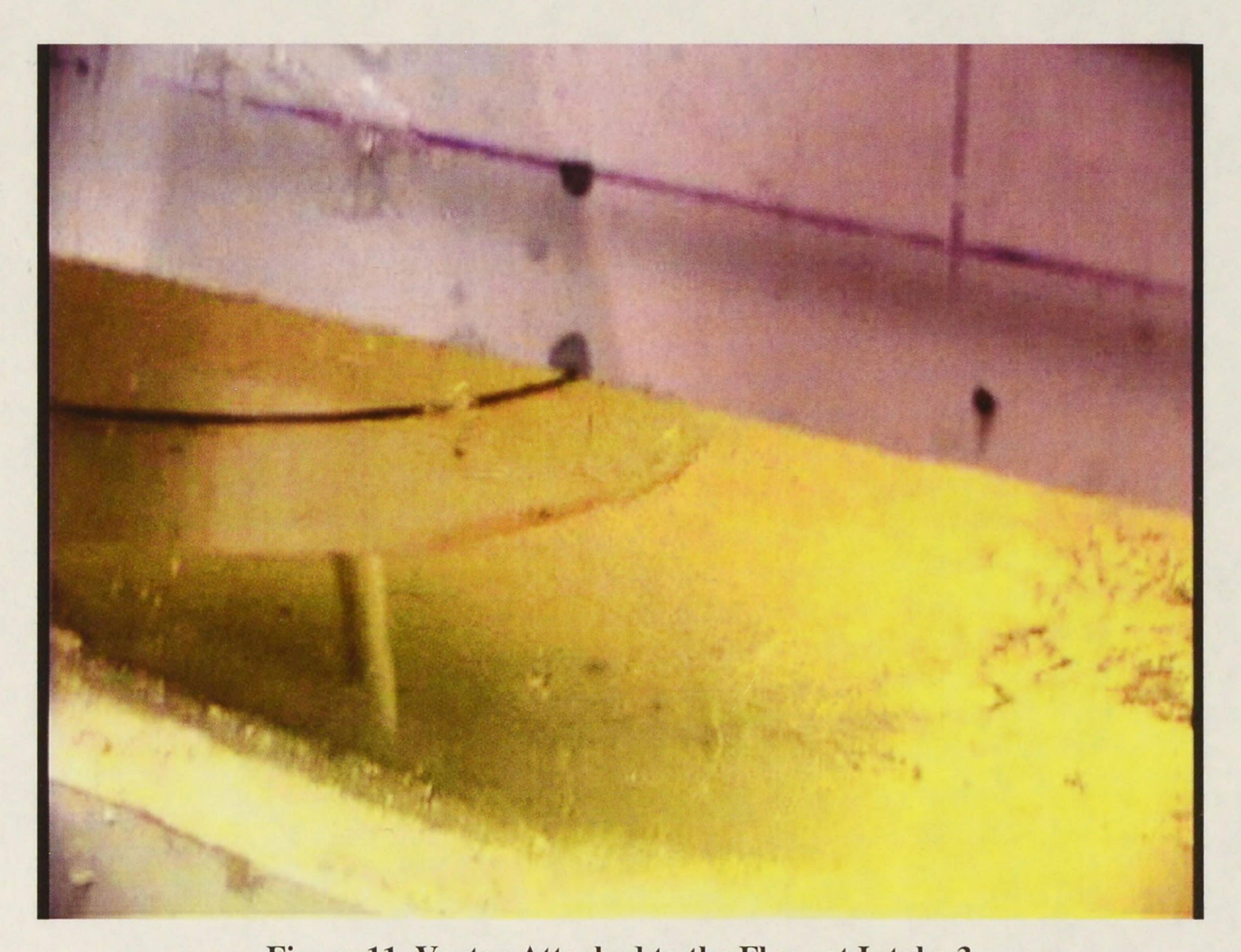


Figure 11. Vortex Attached to the Floor at Intake 3

The swirl angles were measured with a rotating cruciform or swirl meter, 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 intake lines in Figure 12. Following Hecker (1987), standard specifications of 0.75 of the pipe diameter for the length and diameter of the cruciforms were utilized so that they occupy the "solid body" rotational field. 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 1 minute counting intervals. In the study convention, a negative sign denotes counterclockwise rotation when looking down on the model, and a positive sign denotes clockwise rotation.

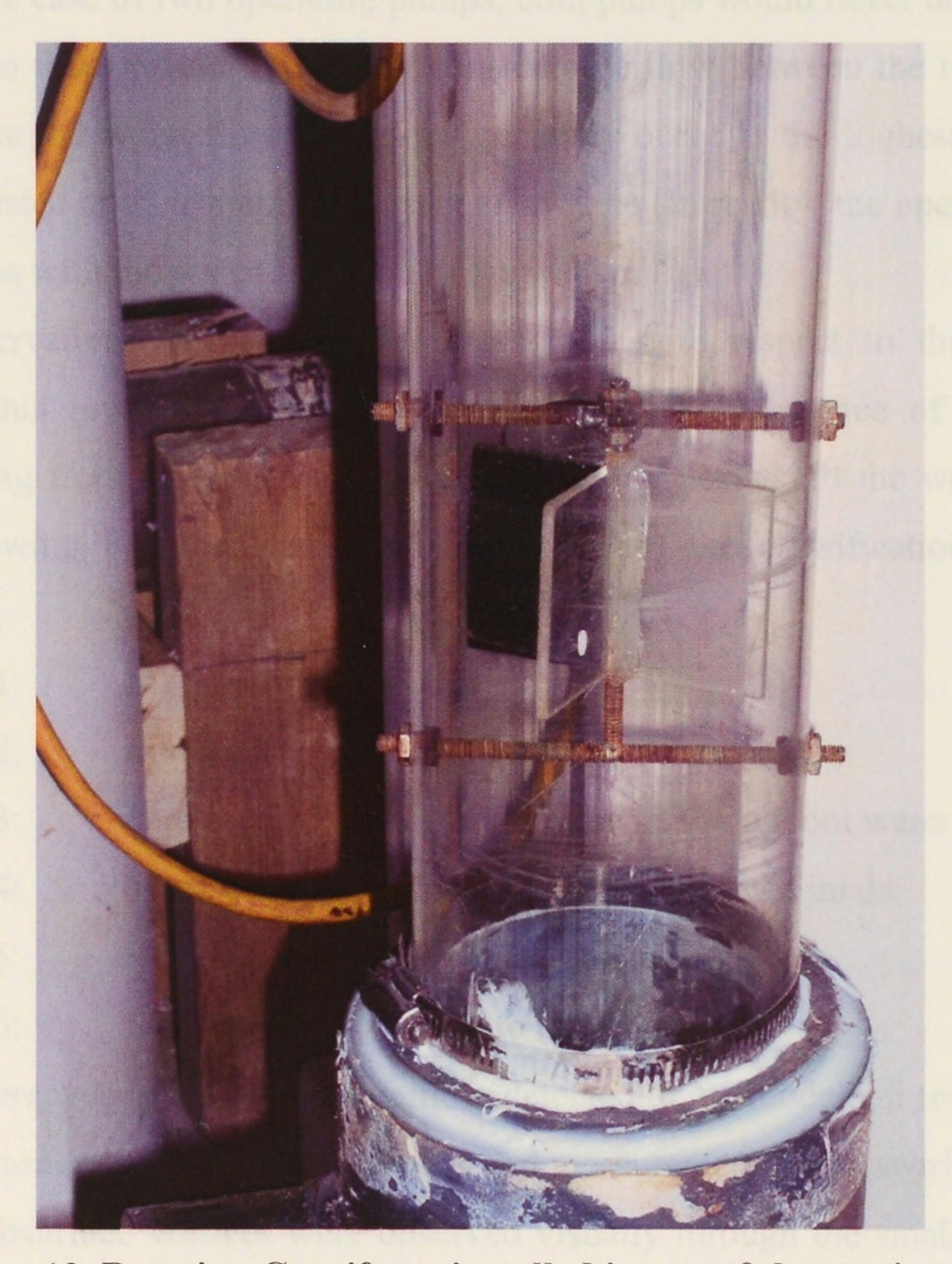


Figure 12. Rotating Cruciform installed in one of the suction lines.

### TESTING PROCEDURES

Tests were performed by first adjusting the flows for the desired pump operation scenario and at a prescribed wet well elevation. The water elevations were marked on the wet well wall ranging from 695.5 to 702.0 feet in intervals of 0.5 foot. Since between one and three pumps (with different clearances) could be in operation at any time, there were many possible permutations that could be considered in the testing. However, the preliminary portion of the study was more focused on finding the worst flow conditions. In order to quickly determine the worst flow conditions, only the combinations of single and three operating pumps were tested under the assumption that the inside pumps (2 and 3) would behave more poorly in the presence of cross flow between the two sides of the wet well. In the case of two operating pumps, both pumps would never be on one side of the wet well so there would not be any considerable flow between the two sides of the wet well. Since the worst flow conditions generally occur at the highest flow rates, all pumps were tested at their maximum design flow rate (In reality, the operating flow rate should decrease with the water elevation in the wet well.)

All observations of vortices were classified with respect to their appearance. Specifically, this involves a designation of the visual appearance of surface vortex strength ranging from a 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

Since there were never surface vortices detected in the model, all tests were limited to the observation of the subsurface vortices and measurement of the swirl angles:

1. Subsurface vortices were observed visually through the small windows next to the intakes. At high water levels, air was injected near the intakes to observe the tendency for any organized vortex motion. Acceptance criteria allow no coherent

subsurface vortex with organized swirl and core (Type 2). Any vortices persisting more than about 10 seconds are considered to be coherent. In most model tests, the vortices tend to fluctuate due to the turbulent nature of the flow and a key aspect to the classification is the vortex persistence.

2. With respect to entrance condition into the pump, 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 of the rotating cruciform per unit time, 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 pumps (Hecker, 1987).

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 construction and 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

### **Effect of Intake Clearance**

The original design as proposed specified a 21-inch clearance between the pump intake and the wet well floor. It was subsequently requested to examine the consequences of reducing that clearance to 15 inches. In order to make that determination relatively early in the testing program, the initial model construction proceeded with the intakes on pumps 1 and 2 set with a 15-inch clearance while pumps 3 and 4 were set with a 21-inch clearance. Due to the symmetries in the wet well, various configurations could be studied to gain an understanding of the wet well performance with both clearances. The Phase I testing results showed that the clearance did have an observable effect with the outcome that the inside pumps (2 and 3) exhibited better performance with the smaller clearance while the outside pumps (1 and 4) had better performance with the greater clearance. Table 2 shows a comparison for the single pump

tests. In this set of tests, pump 2 indicates maximum swirl angles of 3.5 degrees while pump 3 indicated a maximum swirl angle of 8 degrees. The swirl angles were much more variable in pump 3 with water level indicating that the greater spacing resulted in greater variation in the vortices that formed and contributed to the pre-rotation associated with the larger swirl angles. Although the differences between the two outside pumps 1 and 4 were relatively minor for the single pump configurations, pump 1 exhibited larger swirl angles than pump 4 when three pump combinations were studied; some of these results are indicated in Table 3. Appendix B contains a complete set of measurements from the experiments. In general, pump 1 exhibited greater swirl angles when operated in the three pump configuration compared to the single pump operation condition. These findings led to a recommendation whereby the smaller spacing would be used for the two inside pumps and the larger spacing for the two outside pumps. Although the model was not re-configured to reflect this condition until after the Phase I testing results were completed, subsequent testing confirmed that this configuration was preferable in maintaining low swirl angle conditions in the various pumps.

Table 2. Single Pump Combination @23MGD: Original Configuration

Pump #				
V	1	2	3	4
Elevation				
695.5	4.86	2.6	-0.82	-4.52
696		2.95	0.55	-2.95
696.5	4.04	3.49	-0.34	-1.44
697	1.85	2.74	-4.79	-5.06
697.5	5.2	0.75	-6.69	-5.47
698	3.29	2.12	-8.04	-1.51
698.5	3.42	2.33	-4.38	-1.17
699	1.37	2.33	-2.74	-1.71
699.5	1.99	1.85	-2.33	-2.88
700	1.44	2.47	-1.78	-3.29
700.5	1.23	2.19	-4.11	-2.33
701	1.78	2.19	-6.01	
701.5	1.78	2.33	-6.01	
702	2.33	2.95	-4.52	

Table 3. Effect of Clearance on Results of Three Pump Permutations

Elevation	Flow Rate	Pump #	Swirl Angle	Pump #	Swirl Angle
	18.5	1	7.79	4	-3.24
699.5	18.5	2		3	-6.11
	23	3	-3.15	2	3.15
	18.5	1	7.29	4	-1.70
700.5	18.5	2		3	-6.20
	23	3	-2.74	2	1.44
	10	1	4.09	4	-0.95
700.5	10	2		3	-5.50
	10	3	-2.84	2	1.58
	18.5	1	5.61	4	-0.51
702	18.5	2	2.21	3	-4.25
	23	3	-2.88	2	0.14

### **Vortices and Other Flow Conditions**

Flow conditions within the wet well at high flow rates were dominated by the turbulence associated with the inflow, especially at low wet well water levels. It was difficult to observe the flow in and above the two inside pumps 2 and 3 to determine the formation of air-entraining vortices or other organized vortex motion at the surface. However, there was no evidence of air-entraining surface vortices during the Phase I and any subsequent testing. There were other issues associated with the Phase I testing results as discussed below:

• There was considerable air entrainment in the flow due to the influent into the wet well, at low wet well water levels. This was primarily associated with the fact that the two inlet pipes conveying flow into the wet well provided a hydraulic control on flow upstream in the junction chamber 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 over-fall. The plunging flow then resulted in air entrainment within the wet well as depicted in Figure 13. Entrained air tended to be transported to the pump intakes and passed up the pump intakes especially pumps 2 and 3. This effect was more pronounced at high flow rates through the wet well. Figure 14 indicates the nature of this air entrainment. It is difficult to gain the full sense of the air content from this Figure since the bubbles travel so rapidly through the pipe that they appear as streaks. Further consideration of the air entrainment is discussed further below in this report.

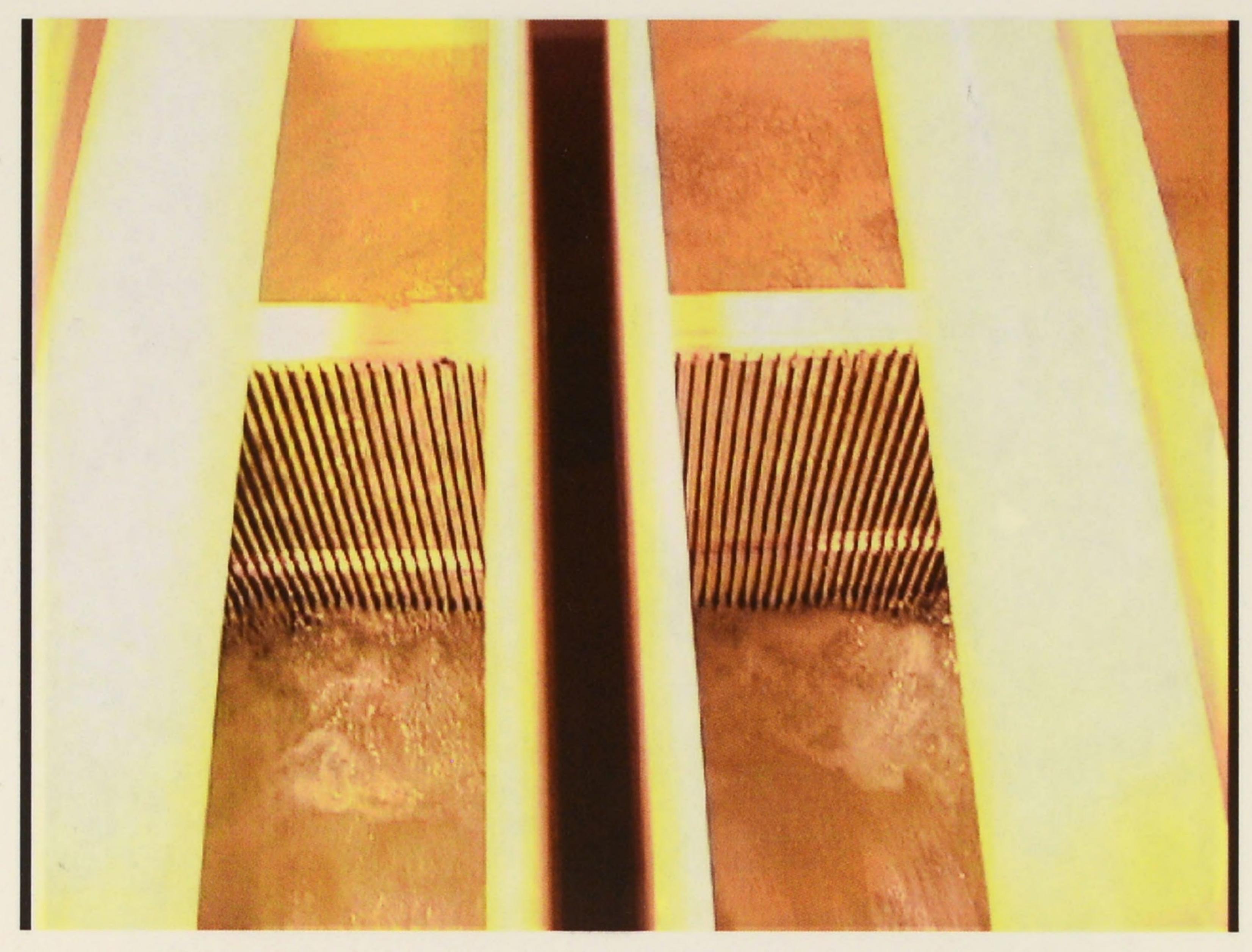


Figure 13. View of the wet well from above looking downstream, low wet well elevation and three pump operation. Note the plunging flow entering the wet well at the bottom of the image and air carried through the bar screens to the region above pumps 2 and 3.

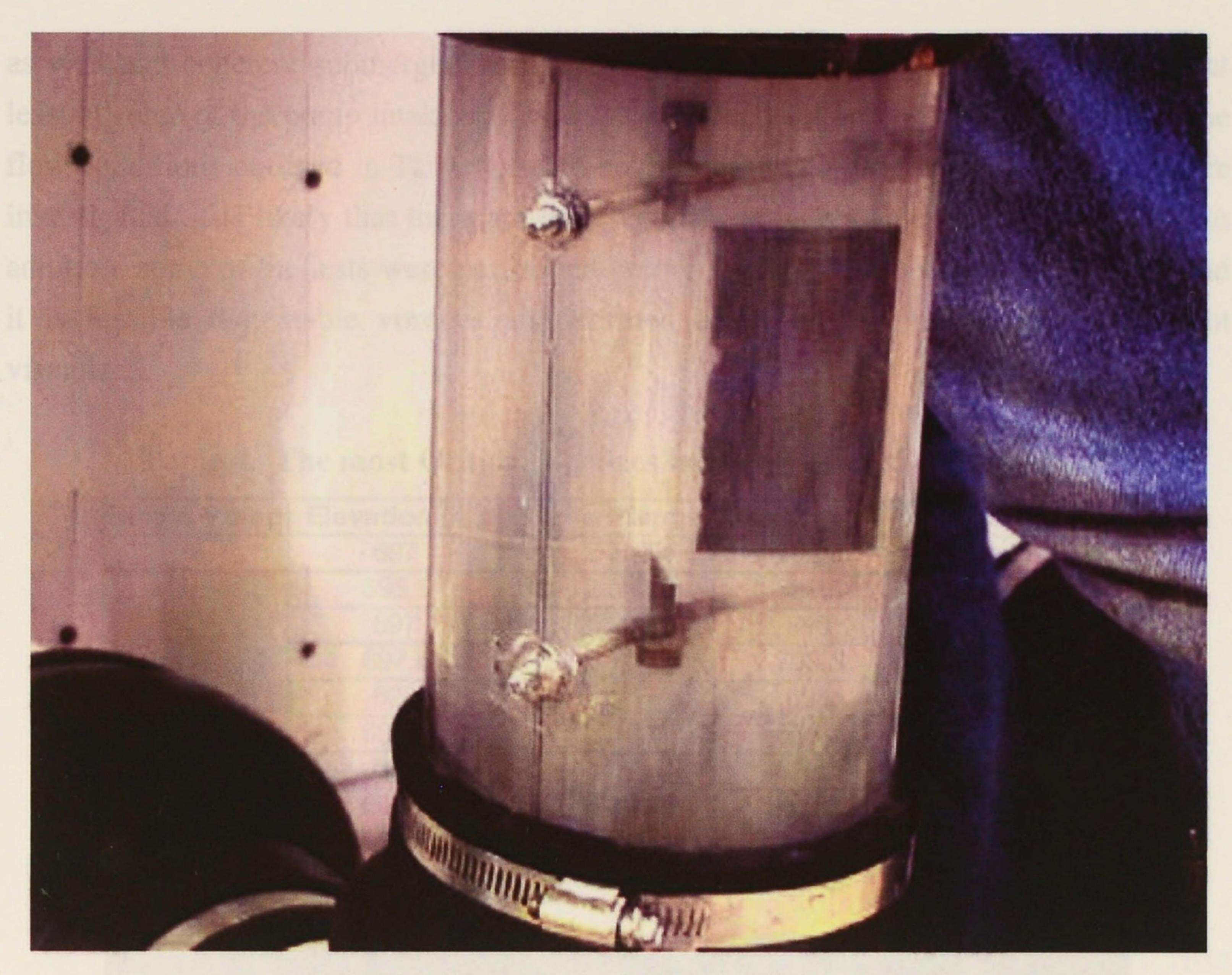


Figure 14. Air Entrainment into Pump 2

• The air entrained into the flow led to the ready visualization of coherent submerged vortices at all of the pump intakes. There were essentially three different types of submerged vortices observed. The most common type was a vortex originating on the back wall of the wet well and extending into the pump intake as visualized in Figure 15. In the case of this particular image, the vortex attaches to the Plexiglas viewing window between Pumps 3 and 4. This type of vortex was observed at each of the pump intakes for some combination of flow conditions. A second type of vortex originated from the wet well floor and extended into the pump intake as indicated previously in Figure 11. Finally, in one specific three pump combination with pumps 3 and 4 in operation and a water level of approximately 697 feet, an intermittent vortex was observed extending between the intakes of pumps 3 and 4, see Figure 16. Originally, the vortices were only observed at low water levels but it was eventually recognized that the vortices were observable only by the air entrained by the inflow into the wet well at low wet well water surface elevations. After construction of a probe to inject air bubbles into the wet well near the pump intakes, vortices were observable at higher water elevations

as well and coherent submerged vortices were observable over the entire test range at least at some of the pump intakes. The most pronounced vortices were observed for the flow conditions outlined in Table 4; since not all permutations of pump operations were investigated, it is likely that there are more conditions with stable vortex formation. In addition, some of the tests were performed before the bubble probe was constructed and it is feasible that stable vortices also formed under these conditions but were not visualized.

Table 4. The most Critical Vortices in the Original Configuration

Single Pump	Elevation (ft.)	Three Pumps	Elevation (ft.)	Vortex	
2	697	1, 2 and 4	699.5	at pump 1	
	695.5	1, 2 and 3	699.5	at pump 1	
	697		698	at pumps 3 and 4	
	697.5	1,3 and 4	1,3 and4	700.5	at pump 1
3	698			698	at pump 4
	698.5		698.5	at pump 3	
	699		699.5	at pumps 2 and 3	
	699.5	2,3 and4	700.5	at pump 3	
4	697.5		702	at pump 3	

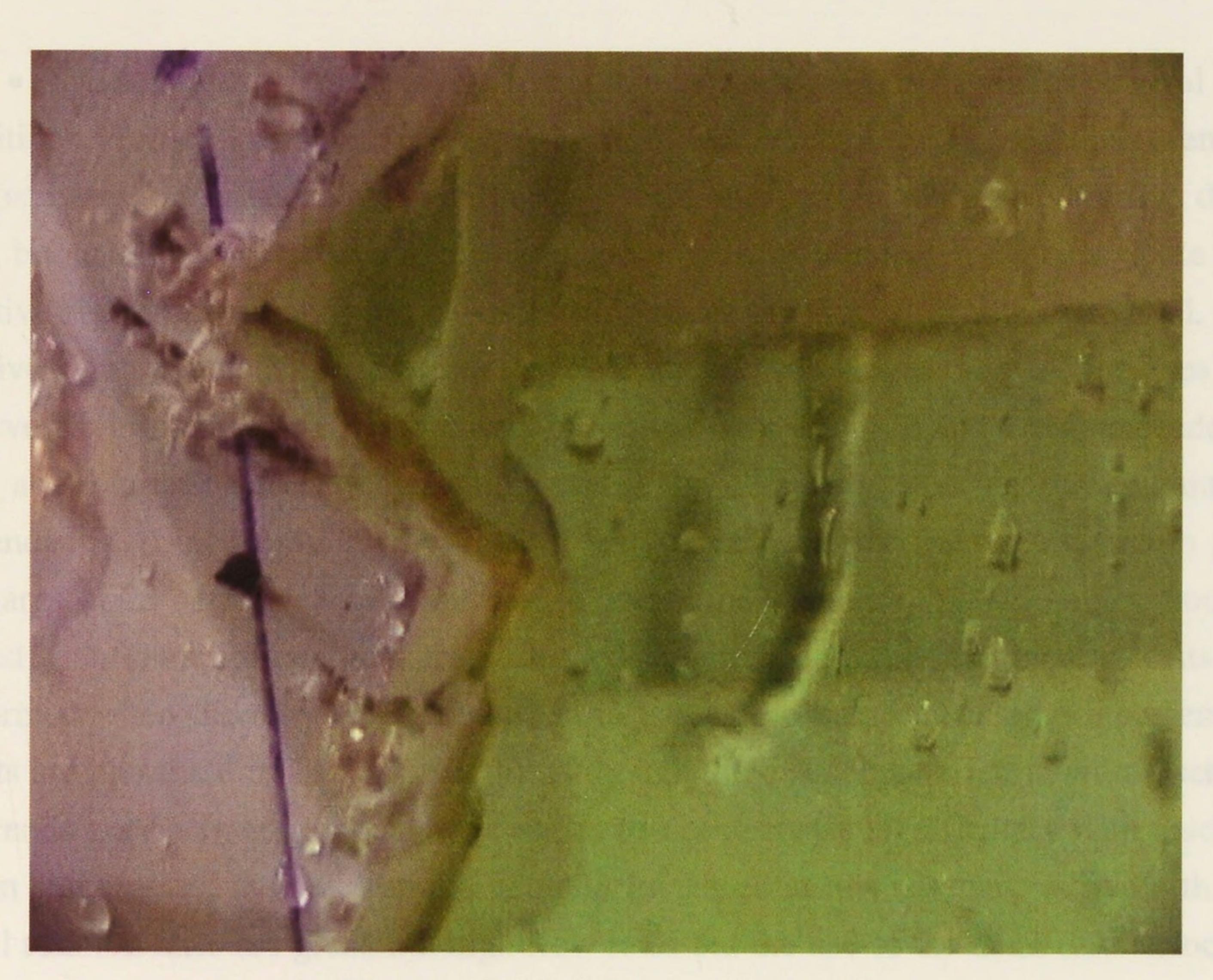


Figure 15. Wall Vortex Pump #3

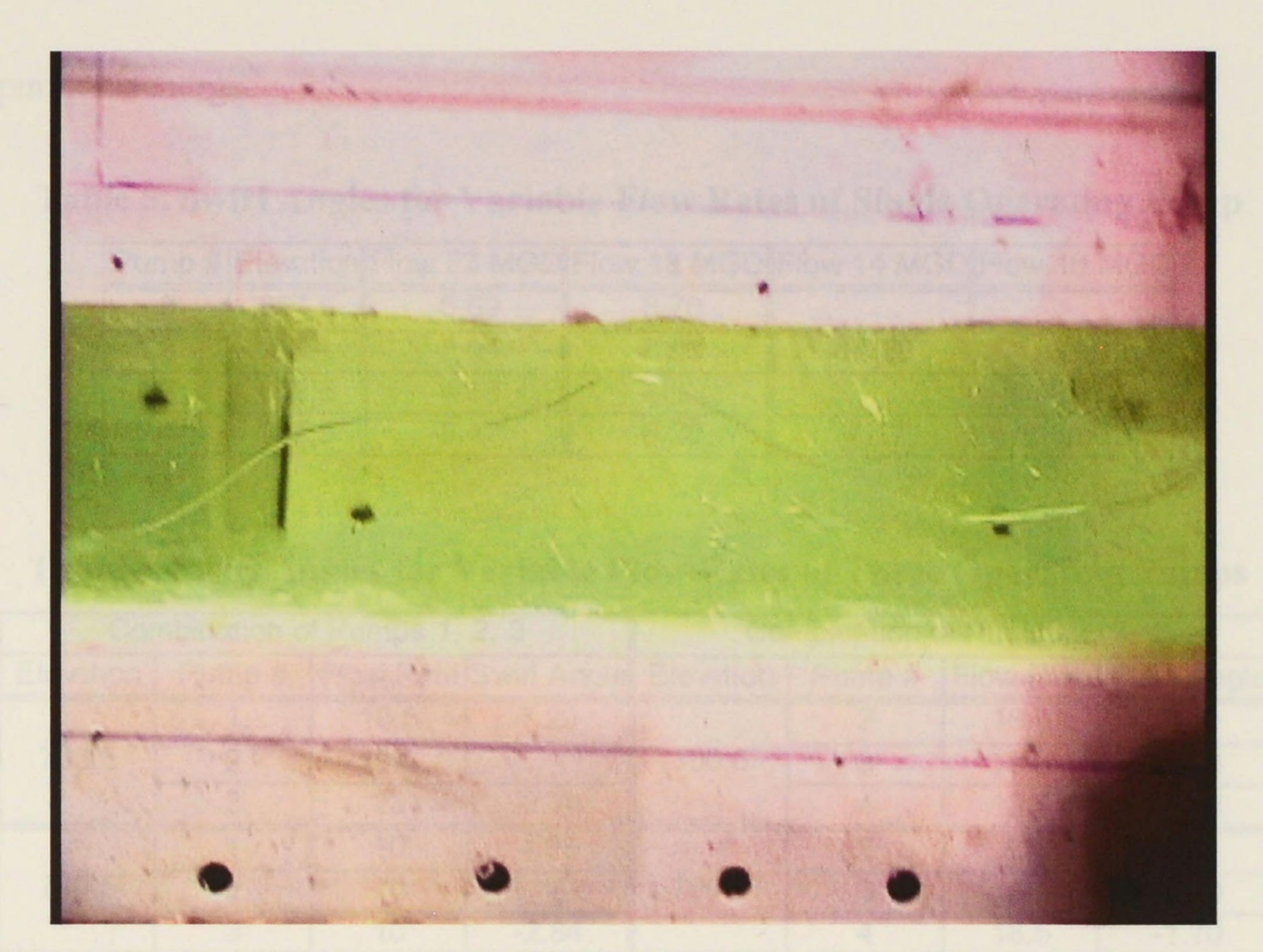


Figure 16. Vortex Extending from Pump 3 to 4

• Swirl angles in excess of five degrees were observed under several flow conditions. Tables 2 and 3 above show the results of some of the Phase I measurements. 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 almost ten degrees. Note that a negative sign denotes counterclockwise rotation when looking down on the model, and a positive sign denotes clockwise rotation. Nearly all swirl angles above 5 degrees were observed in Pumps 1 and 3 (particularly in Pump 3) but Pumps 2 and 4 also exceeded the swirl angle criterion for a single pump test. The complete set of data is contained in Appendix B. Since most of the Phase I tests were performed at the maximum pump discharge of 23 MGD, it was of interest to determine whether the swirl angles would be altered if the pump discharge were decreased. Therefore a limited number of tests were performed when the only change between tests was the pump discharge; representative results are presented in Tables 5 and 6. Although there is some variation with discharge, the trends generally are for the swirl angles to not decrease significantly with discharge and in some cases, the swirl angles actually increased at low discharges. Note that the actual rotation rates are greater at high flow rates but the use of the axial flow velocity in the computation of the swirl angle results in similar swirl angles at different discharges. Therefore, there is reason to believe that the swirl angles are somewhat independent of the pump discharge.

Table 5. Swirl Angles for Variable Flow Rates of Single Operating Pump

Pump #	Elevation	Flow 23 MGD	Flow 18 MGD	Flow 14 MGD	Flow 10 MGD
3	697.5	-6.69	-6.70		
3	698	-8.04	-8.63	-10.69	-6.90
3	698.5	-4.38			-5.97
4	697.5	-5.47	-6.28	-7.17	-6.59

Table 6. Swirl Angles for Variable Flow Rates of Three Operating Pumps

Cor	Combination of Pumps 1, 2, 3 Combination of Pumps 2, 3, 4			3, 4			
Elevation	Pump #	Flow Rate	Swirl Angle	Elevation	Pump #	Flow Rate	Swirl Angle
	1	18.5	7.29		2	18.5	1.19
700.5	2	18.5		700.5	3	18.5	-5.94
	3	23	-2.74		4	18.5	-1.28
	1	10	4.09		2	23	1.44
700.5	2	10		700.5	3	18.5	-6.20
	3	10	-2.84		4	18.5	-1.70
	1	18.5	5.61		2	14	1.58
702	2	18.5	2.21	700.5	3	14	-4.50
	3	23	-2.88		4	14	-1.69
	1	10	6.59		2	10	1.58
702	2	. 10		700.5	3	10	-5.50
	3 ·	10	-1.73		4	10	-0.95

### PHASE II - WET WELL MODIFICATIONS

After it was determined that the wet well performance was unsatisfactory in a number of the Phase I tests, various modifications were tested in order to create a functional design. In previous studies, a variety of methods have been employed to eliminate poor pump intake conditions. These include baffle walls, inclined plates, splitter plates, crossing plates, cones beneath pump intakes, etc. (e.g. Wright and Schläpfer, 1988 or EHI, 1989). Internal baffle walls were not felt to be practical due to the short flow distance across the wet well. Since the subsurface vortices were only originating from the floor or back wall of the wet well behind the intakes, a solution that altered the flow in the region close to the intakes was sought.

The following list outlines various modifications that were implemented to find the final design. (Note: All dimensions given in this section correspond to prototype wet

well dimensions, not model dimensions) In the early phase of the modification, the original clearances (15 inches on pumps 2 and 3 and 21 inches on pumps 3 and 4) were maintained but ultimately the change was made to the recommendation of 15 inch clearance on pumps 2 and 3 and 21 inches on pumps 1 and 4.

1. In the first phase of modification, a separate modification was implemented on either side of the wet well. On the pumps 1 and 2 side, a fillet was placed along the back wall of the wet well. This fillet was 15 inches high and extended out from the back wall an equal distance. On the pumps 3 and 4 side, flow splitters were placed beneath each of the two pumps. These splitters were simply 15 inch high plates that extended from the back wall of the wet well out to the front edge of the pump intake.

The modifications at intakes 3 and 4 improved the flow conditions. The swirl angles at all elevation(s) appeared within the acceptable range. The submerged vortices were still present, but appeared to be weaker than in the Phase I tests and occurred less frequently.

Unlike pumps 3 and 4, the flow conditions at pump 1 were worsened. The vortices were more coherent, and in some cases originated from the fillet. Furthermore, swirl angles at both pumps 1 and 2 were slightly higher than the original configuration. Results of this testing is provided in Appendix B.

2. Subsequently, the fillet behind intakes 1 and 2 was replaced by flow splitters similar to those installed on the opposite side of the wet well. They were similar to those used for intakes 3 and 4, except that the plates were 10 inches high.

The flowing conditions at these intakes were greatly improved; however similar to pump 3, coherent subsurface vortices were still present at some elevations near intakes 2. At this stage, the swirl angles only rarely exceeded the five degree limit.

3. From the Phase I testing results, it was apparent that inside pumps would perform better with smaller clearance and outside pumps with greater clearance off the floor. The model was adjusted to provide this condition with 15 inches of clearance beneath pumps 2 and 3 and 21 inches beneath pumps 1 and 4. Based on the previous results, it was felt that the outside pumps might still present unacceptable swirl angles and the splitter plates were replaced by crosses. The crosses divided the intake into four equal segments, with a height of fifteen inches and extending to the outside edge of the

pump intake except on the back side where it was extended to the back wall of the wet well. An image of the crosses used is shown in Figure 17.

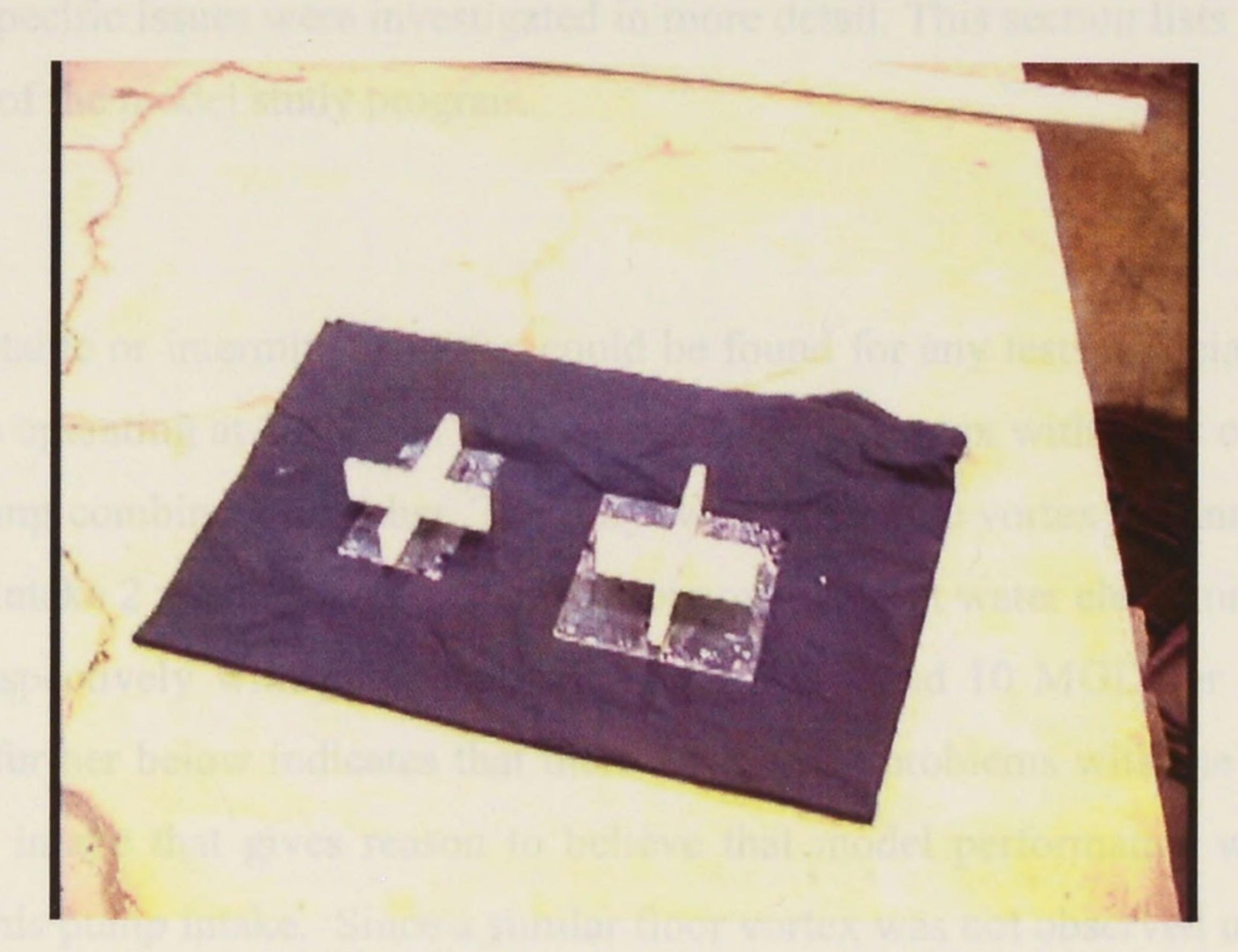


Figure 17. The Crosses installed under the Intakes

The only problems associated with this configuration were that submerged vortices were still present at the pumps 2 and 3 intakes and swirl angles that were barely below five degrees.

4. At this stage, crosses were also installed under intakes 2 and 3 to avoid formation of vortices at these intakes. They were similar to the ones used for intakes 1 and 4 except that they were 10 inches high. These crosses were greatly effective in dissipating the rotational flow patterns. At first, the test configurations that were most problematic in the earlier tests were investigated with the new configuration. These preliminary tests all produced acceptable swirl angles and no observable submerged vortices. These final modifications proved to be basically successful as indicated in the proof test results presented below.

## RECOMMENDED DESIGN - PROOF TESTING

As was described in the previous section, the final recommended set of modification to wet well includes installation of crosses under all four intakes and setting

the clearances to 21" for outside pumps and to 15" for inside pumps. 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.

### **Vortices**

No stable or intermittent vortex could be found for any tests associated with any single pump operating at 23 MGD. There was no stable vortex with clear core observed in 2 or 3 pump combinations either. The only weak but stable vortex originated from the floor under intake 2 when pumps 1, 2 and 3 were operating at water elevations of 697 and 696 feet (respectively with pumping rates of 14 MGD and 10 MGD for each pump). Discussion further below indicates that there were some problems with the geometry of the pump 2 intake that gives reason to believe that model performance was not quite correct for this pump intake. Since a similar floor vortex was not observed under pump 3 for the mirror image flow condition, it is concluded that coherent submerged vortices will not be an issue with the wet well geometry considered in this testing.

When various combinations of two pumps (one on either side of the wet well) were investigated no submerged vortices were observed.

### **Swirl Angles**

The swirl angles for all cases of single operating pump are provided in Tables 7 to 10. As the water elevation in the wet well drops from 700.5 ft. to 655.5 ft., the pumping capacity of a single operating pump should be reduced accordingly. However, higher flow rates up to the maximum rate of 23 MGD were tested at each water elevation (for pumps 1 and 4) to guarantee that the pumps are even able to function satisfactorily under unexpected discharge conditions.

Table 7. Swirl Angles for Single Operating Pump 1

Pump #	Elevation	Single Pun	np at 23 MGD	Single Pump at 18.5 MGD		
Fullip#	Lievation	N(rot/min)	Swirl Angle	N(rot/min)	Swirl Angle	
1	695.5	3	0.41			
1	696	5	0.69			
1	696.5	8	1.10	2	0.34	
1	697	7.5	1.03	6.5	1.11	
1	697.5	8	1.10	5.5	0.94	
1	698	4	0.55	3	0.51	
1	698.5	4.5	0.62	3	0.51	
1	699	5	0.69			
1	699.5	4	0.55	4	0.68	
1	700	5	0.69			
1	700.5	5	0.69	5	0.85	

Table 8. Swirl Angles for Single Operating Pump 2

Pump #	Elevation	Single Pun	np at 23 MGD
Fullip#	Lievation	N(rot/min)	Swirl Angle
2	695.5	7	0.96
2	696	13	1.78
2	696.5	15	2.06
2	697	13	1.78
2	697.5	11	1.51
2	698	1	0.14
2	698.5	2.75	0.38
2	699	5.5	0.75
2	699.5	6.25	0.86
2	700	4.75	0.65
2	700.5	-1.5	-0.21

Table 9. Swirl Angles for Single Operating Pump 3

Pump #	Elevation	Single Pump at 23 MGD		· · · · · · · · · · · · · · · · · · ·		Single Pur	np at 14 MGD	Single Pum	p at 10 MGD
Fump #	Elevation	N(rot/min)	Swirl Angle	N(rot/min)	Swirl Angle	N(rot/min)	Swirl Angle	N(rot/min)	Swirl Angle
3	695.5	6	0.82						
3	696	2.5	0.34	1					
3	696.5	4.5	0.62						
3	697	2	0.27						
3	697.5	4	0.55						
3	698	10.5	1.44	4.5	0.77	4	0.90	4.50	1.42
3	698.5	12	1.64						
3	699	9.5	1.30	8.5	1.45	6.5	1.46	3.00	0.95
3	699.5	10.5	1.44						
3	700	13	1.78	8.5	1.45	6	1.35	3.50	1.10
3	700.5	11	1.51	8	1.36	8	1.80	4.00	1.26

Table 10. Swirl Angles for Single Operating Pump 4

Pump #	Elevation	Single Pun	np at 23 MGD
r ump #	Lievation	N(rot/min)	Swirl Angle
4	695.5	-5	-0.69
4	696	-8	-1.10
4	696.5	-3	-0.41
4	697	-11.5	-1.58
4	697.5	-6.5	-0.89
4	698	2	0.27
4	698.5	-1	-0.14
4	699	5.5	0.75
4	699.5	4	0.55
4	700	4.5	0.62
4	700.5	2	0.27

All experiments with combinations of two or three pumps in operation did not result in large swirl angles with a 3.3 degree angle being the largest value observed for one three pump configuration (Pump for Pumps 1,3, and 4 combination at 697 ft elevation). The swirl angles for three different combinations of two and three operating pumps are provided in the Tables in Appendix B.

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 only slightly decreased. One thing that was observed was an increased tendency to generate the highest swirl angles at wet well water levels from 696 ft. to 697.5 ft. for all pumps except pump 3 which had its highest swirls at elevations between 698 feet and 700.5 feet. In any case, all swirl angles were well below the allowed limit of five degrees; the maximum swirl angle observed for single pump operation was 2 degrees for pump 2 at water elevation of 696.5 feet.

Due to the symmetry in the wet well, the performance in the two inside pumps should be similar as should the performance for the two outside pumps. The only difference would be that the signs of the swirl angles on each side of the wet well should be opposite of the other side. However, comparing the swirl angles between pumps 1, 4 and pumps 2, 3 does not verify this fact. The asymmetrical results are even greater in the case of three pump combinations. Results comparing sets of pumps are included in Figures 18-20. This is an indication of how sensitive the swirl angles are to any slight

change in the layout of the intakes and possibly the crosses added beneath the intakes. A review of the data indicates that the largest discrepancies occur at low wet well elevations where the highest wet well velocities will be experienced. A detailed investigation of the model geometry was undertaken to attempt to uncover the source of this lack of symmetry. The primary thing that could be detected was that the distance from the pump intake to the back wall varied somewhat among the various intakes. In particular, the wet well floor beneath pump 2 was not totally horizontal and in order to keep a constant clearance between the intake and the floor, the spacing between the pump intake and the back wall was approximately three-eights of an inch (actual model) less than that for pump 3 which was close to the correct distance required for geometric similarity). Since the swirl angles for all pump configurations tested were well below the five degree limit, these discrepancies were not considered to be significant since they are mostly on the order of one degree or less.

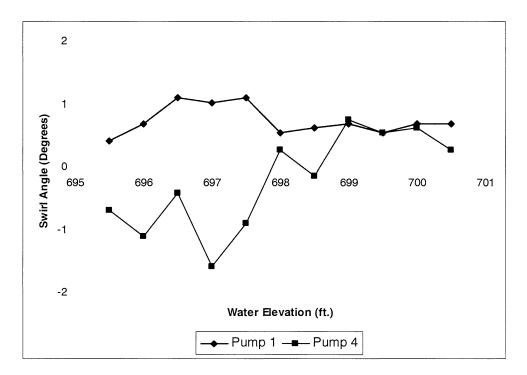


Figure 18. Comparison between Pumps 1 and 4

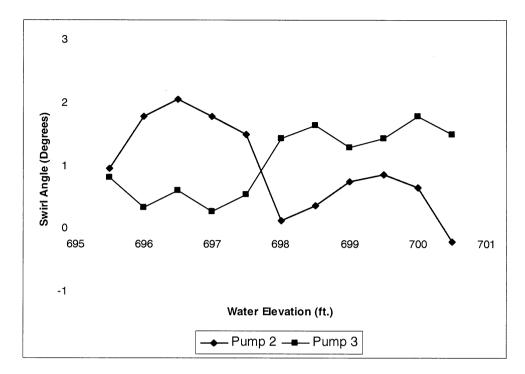


Figure 19. Comparison between Pumps 2 and 3

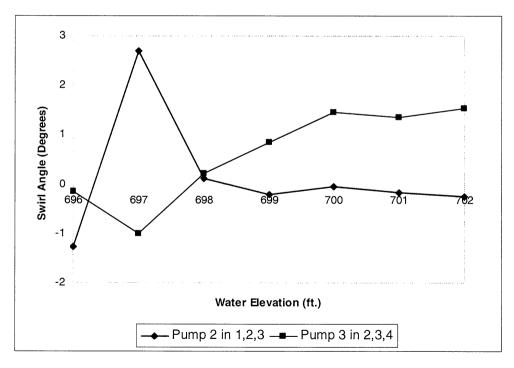


Figure 20. Comparison between Pumps 2 and 3 in three Pump Operation

Configuration

# Effect of Altering Inlet Interceptor

During the period of the model testing, it was indicated that a possible change to the pumping station configuration would be to increase the invert elevation of the inlet interceptor by 2-3 feet and to increase the diameter from 60 to 72 inches. There was not a convenient way to alter the model to directly test the influence of these changes. However, modifications were made to qualitatively investigate the effects of such a modification. First of all, it should be noted that the inlet interceptor enters the junction chamber upstream of the wet well and it should be expected that the effect should be relatively small. However, model operation, especially at relatively high discharges indicated that the small volume of the junction chamber results in strong internal motions (see Figure 21), so altering the interceptor will probably influence the flow distribution through the two connecting conduits into the wet well, especially at low wet well elevations. It is also noted that the inlet conduit never flowed full even under maximum discharge conditions. A barrier weir was installed at the inlet into the junction chamber that occupied the lower half of the inlet conduit, forcing flow over the top of the barrier.



Figure 21. Flow within Junction Chamber at High Inflow Rate

This effectively increases the height of the inflow by at least 2.5 feet prototype (the words "at least" is used because the flow over the sharp upper edge of the weir may force the flow even higher than the physical height of the weir) and increases the effective flow area similar to what would happen in a larger diameter interceptor. Tests were performed in the model with this altered configuration. The swirl angles for three pump combinations of 1, 2, 3 and 2, 3, 4 were measured. There were two major issues detected in the new configuration:

- 1. Since the water fell down into the junction chamber from a relatively high elevation, there was more air entrainment observed at the pump intakes compared to the configuration without this modification. This problem was more pronounced at high water levels where there was not a problem of air-entrainment in the original configuration at such high elevations.
- 2. The swirl angles, for the new configuration with the weir in place, are included in Tables 11 and 12 along with the swirl angles for the final recommendation. Comparing the individual or absolute sum of swirl angles of these two cases shows an increase with the barrier weir present. Figure 22 compares swirl angles of pump 4 in the combination of pumps 2, 3 and 4 with and without the weir in the inlet interceptor. Larger and more persistent submerged vortices under the pump 2 intake at wet well elevations of 699.5 and 697 feet compared to the as-designed interceptor provides another indication of somewhat worse intake conditions.

Table 11. Swirl Angles with Pumps 1, 2 and 3 Operating

Elevation (ft.)	Dumn #	Flow Rate (MGD)	Final Reco	omendation	With the weir	
Elevation (it.)	Fump #	Flow Rate (MGD)	N(rot/min)	Swirl Angle	N(rot/min)	Swirl Angle
	1	10	1.75	0.55	10	3.15
696	2	10	-4	-1.26	4	1.26
	3	10	0.75	0.24	3	0.95
	1	14	7.75	1.75	16	3.60
697	2	14	12	2.70	4	0.90
	3	14	4.5	1.01	5.5	1.24
	1	14	0	0.00	12	2.70
698	2	14	0.5	0.11	-2	-0.45
	3	14	4.5	1.01	2	0.45
	1	18.5	0.5	0.09	4.25	0.72
699	2	18.5	-1.25	-0.21	-7	-1.19
	3	18.5	5	0.85	7	1.19
	1	18.5	0.25	0.04	7.75	1.32
700	2	18.5	-0.25	-0.04	-7	-1.19
	3	18.5	6.5	1.11	7	1.19
	1	18.5	0.5	0.09	7.25	1.24
701	2	18.5	-1	-0.17	-6	-1.02
	3	23	4	0.55	6.25	0.86
	1	18.5	0.5	0.09	5	0.85
702	2	18.5	-1.5	-0.26	-5	-0.85
	3	23	1.75	0.24	7	0.96
	Abs	loute Sum		12.36		27.29

Table 12. Swirl Angles with Pumps 2, 3 and 4 Operating

Elevation (ft.)	Dump #	Flow Rate (MGD)	Final Reco	omendation	With t	he weir
Elevation (it.)	Fullip#	Flow Rate (MGD)	N(rot/min)	Swirl Angle	N(rot/min)	Swirl Angle
	2	10	-1.5	-0.47	-1.5	-0.47
696	3	10	-0.5	-0.16	1.5	0.47
	4	10	0	0.00	13	4.09
	2	14	3	0.68	13.5	3.04
697	3	14	-4.5	-1.01	3.5	0.79
	4	14	-7	-1.58	-11	-2.48
	2	14	0	0.00	-2.75	-0.62
698	3	14	1	0.23	5.5	1.24
	4	14	-5	-1.13	-10	-2.25
	2	18.5	-1	-0.17	-6.25	-1.07
699	3	18.5	5	0.85	7	1.19
	4	18.5	-1	-0.17	-3	-0.51
	2	18.5	-3	-0.51	-6.5	-1.11
700	3	18.5	8.5	1.45	11	1.87
	4	18.5	3	0.51	-6	-1.02
	2	23	0	0.00	-5.25	-0.72
701	3	18.5	8	1.36	10.5	1.79
	4	18.5	-2.5	-0.43	-3	-0.51
	2	23	1	0.14	-3.75	-0.51
702	3	18.5	9	1.53	11.5	1.96
	4	18.5	-3	-0.51	-6.5	-1.11
	Abs	loute Sum		12.88		28.83

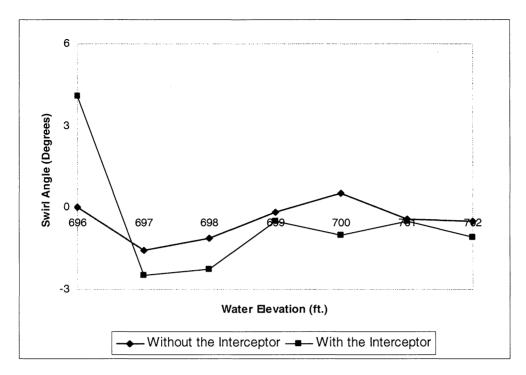


Figure 22. Pump 4 in Combination of 2,3, 4 with and without the Weir in the Inlet
Interceptor

#### **Deposition of Residues**

Since the final recommendation of the wet well consists of a cross beneath each intake, questions were raised as to whether there would be any issues associated with pumping raw wastewater subject to only the removal of large solids at the 2-inch coarse bar screens at the wet well inlet. It was decided to investigate issues associated with possible excess solids deposition on the back sides of the crosses. 120 grit silicon carbide was introduced into the model to simulate potential solids deposition in the prototype. The silicon carbide has a specific gravity of 3.2, which is higher than the specific gravity of common sediments in the prototype. The sedimentation experiments were conducted with and without the crosses in order to determine the probable effects on the solids deposition. The strategy was to reduce the pump discharge until a significant amount of deposition occurred within the wet well and then repeat the experiments both with and without the presence of the crosses. As was expected, deposition would more closely approach the intake when the flow rate was reduced; however, the placing of the crosses did not have any significant impact on the deposition of residues. Figure 23 shows the

deposition of silicon carbide near the single operating pump 3 with the crosses in place and Figure 24 shows the same flow configuration without the crosses. There is a clear boundary between the regions of deposition and no-deposition and this boundary is essentially the same in both pictures. There is no indication of solids deposition behind the crosses due to the higher flow velocities from the radially converging flow near the pump intakes. It is therefore concluded that there will not be any significant issues with solids deposition. One additional consideration was made to alter the final recommended cross design. In principle, it would be possible for string-like material in the plant influent to hang up on the three exposed outside edges of each cross. In order to avoid this possibility, the edge could be constructed on a 45 degree angle. More details are provided in the Recommendations and Conclusions section.

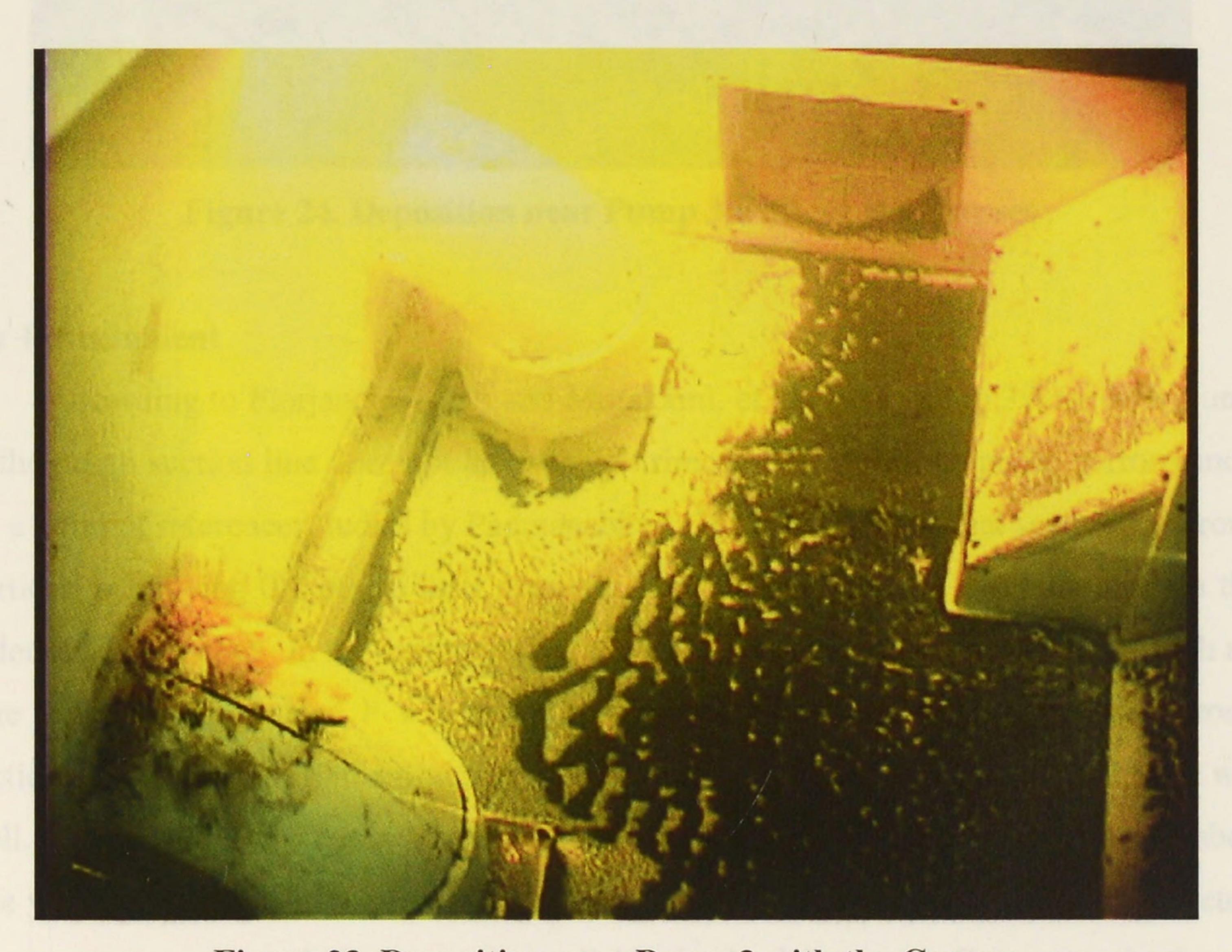


Figure 23. Deposition near Pump 3 with the Crosses



Figure 24. Deposition near Pump 3 without the Crosses

# Air Entrainment

According to Florjancic(1970) and Murakami, et al (1969) up to 3% air by volume in the pump suction line does not have any detrimental effect on the pump performance. As a point of reference, studies by Padmanabhan (1982) had shown that seemingly strong vortices, occupying 0.1 of the inlet diameter, would generate void fractions only in the order of 1-2 per cent. In the current study, the air entrainment was not associated with air core vortices, but instead it was more broadly distributed throughout the flow cross-section and originated from entrainment in the plunging inflow from the inlet into the wet well. Some of the air could also be transported from the upstream junction chamber. The volume of the air in the suction line is usually measured with a void fraction meter; this measurement capability was not available in the laboratory. Consequently the air content of the flow was determined visually and the results in this section are qualitative only.

The air entrainment level was studied for the combination of pumps 1, 2 and 3 in simultaneous operation. Preliminary testing indicated that the air entrainment level could

be greatly reduced by decreasing the flow rate. Testing was performed by gradually decreasing the pumping flow rates until the amount of air passing through the suction line was visually reduced significantly. In actuality, the air content reduces continuously with flow rate so there is not a clear transition where the air concentration drops dramatically. The flow rates at which the air content was observed to be significantly reduced is presented in Table 13 and Figure 25. The flow rate for water elevations below 697 ft had to be reduced to values below the minimum intended pumping rate of 9 MGD. However, this flow rates correspond to air contents that are surely well below three percent.

Table 13. Recommended Flow Rates to Reduce the Air Entrainment

Elevation (ft.)	Pump#	Recommended How Rate (MGD)
	1	8
695.5	2	8
	3	8
	1	8
696	2	8
	3	8
	1	8
696.5	2	8
	3	9
	1	9
697	2	8
	3	10
	1	10
697.5	2	10
	3	10
	1	11
698	2	11
	3	12
	1	12
698.5	2	12
	3	12
	1	14
699	2	14
	3	15
	1	16
699.5	2	15
	3	16
	1	17
700	2	17
	3	17
	1	19
700.5	2	19
	3	23
	1	23
701	2	23
	3	23
	1	23
701.5	2	23
	3	23
	1	23
702	2	23
	3	23

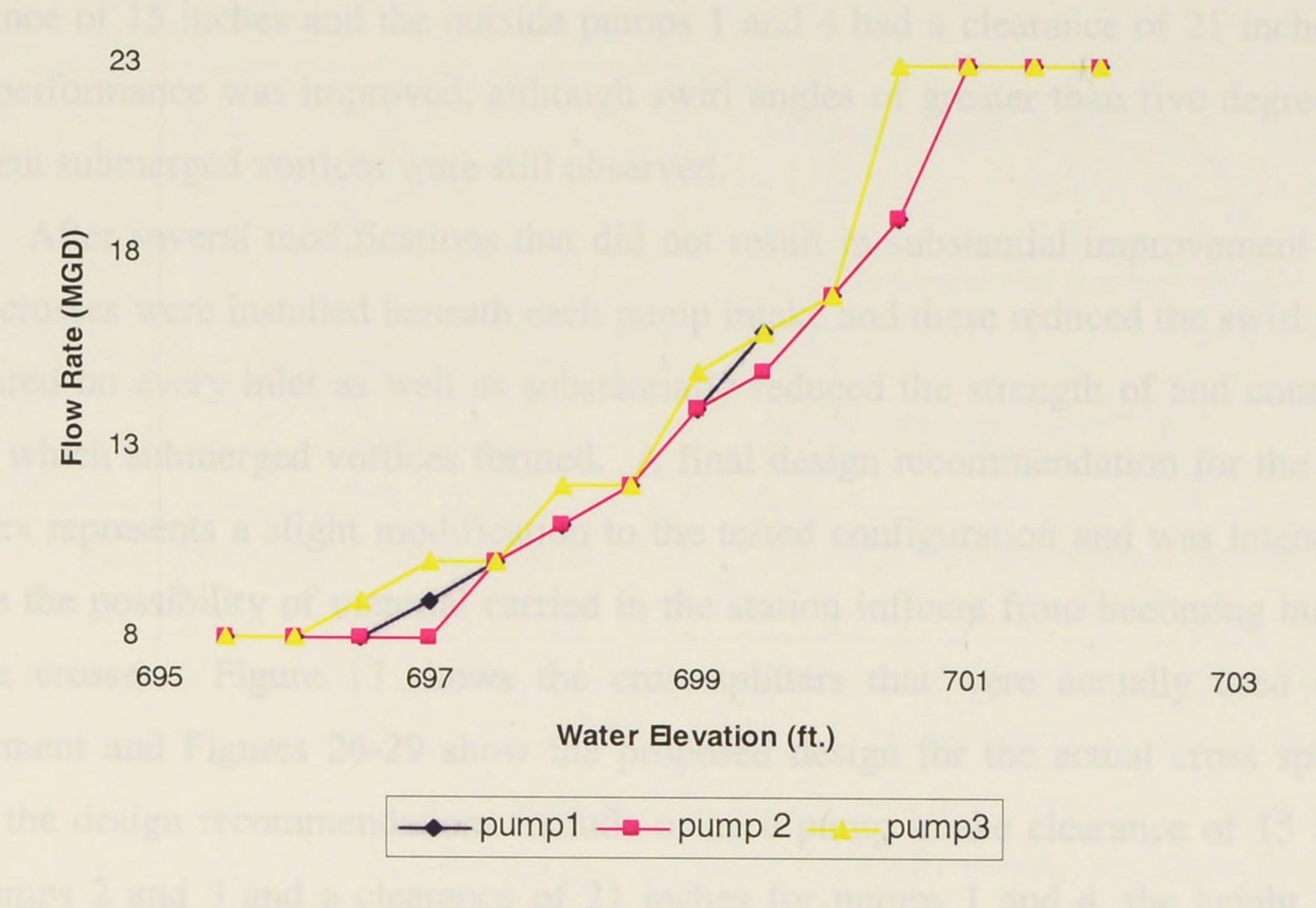


Figure 25. Recommended Flow Rate for Each Pump to Reduce the Air Entrainment

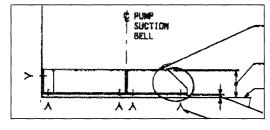
# RECOMMENDATIONS AND CONCLUSIONS

This study of the wet well flow conditions of the Genesee County Contract 2B Pumping Station has shown that the overall design will be successful with some minor modifications. Studies of the original proposed design indicated poor flow conditions at the pump intakes. Specifically, submerged vortices were observed over a range of flow conditions and some configurations indicated swirl angles in excess of recommended limits of five degrees, up to a maximum of approximately ten degrees. Subsequent modifications to the original design were successful in eliminating these objectionable flow conditions.

The original model was constructed with a small clearance between the pump intake and the wet well floor of 15 inches on pumps 1 and 2 and with a greater clearance of 21 inches on pumps 3 & 4. When the model was operated in this configuration, the outside pump 1 with low clearance experienced swirl angles that were sometimes greater than five degrees, up to a maximum of ten degrees. The inside pump 3 with the high clearance also experienced swirl angles that often exceeded five degrees. When the pumps intake configuration was switched so that the inside pumps 2 and 3 had a

clearance of 15 inches and the outside pumps 1 and 4 had a clearance of 21 inches, the flow performance was improved, although swirl angles of greater than five degrees and coherent submerged vortices were still observed.

After several modifications that did not result in substantial improvement in the flow, crosses were installed beneath each pump intake and these reduced the swirl angles measured on every inlet as well as substantially reduced the strength of and conditions under which submerged vortices formed. A final design recommendation for the crosssplitters represents a slight modification to the tested configuration and was intended to reduce the possibility of material carried in the station influent from becoming hung up on the crosses. Figure 17 shows the cross-splitters that were actually used in the experiment and Figures 26-29 show the proposed design for the actual cross splitters. Since the design recommendations include using a pump intake clearance of 15 inches for pumps 2 and 3 and a clearance of 21 inches for pumps 1 and 4, the height of the crosses will also vary with the pump clearance. Specifically, the crosses beneath intakes 2 and 3 should be 10 inches in height while the crosses beneath intakes 1 and 4 should be 15 inches. With this configuration, swirl angles remained well below five degrees for all pumping configurations tested. Testing was also performed to examine the deposition of solids injected into the inflow at the upstream junction chamber and deposition patterns were similar both with and without the crosses in place, indicating that the crosses should not have any significant impact on the movement of solids through the wet well.



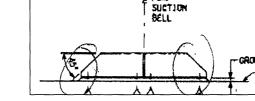
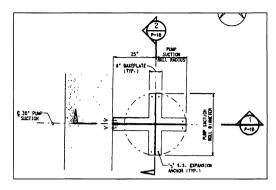


Figure 26. Side View - Side View of Splitter

Figure 27. Side View - Front View of Splitter



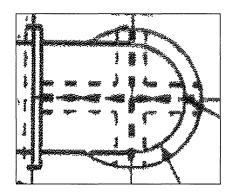


Figure 28. Top View - Cross-splitters

Figure 29. Top View - Inlet & Splitters

During the testing sequence, it was requested that the impact of increasing the invert elevation and the diameter of the inlet interceptor. A modification was made to the model that only approximately reproduced the conditions that may occur with such a revision; it was found that this somewhat increased the swirl angles, but these remained below the five degree limit with a maximum swirl angle of four degrees.

It is understood that there is not currently an operational plan in place that specifies how the variable speed pumps will be adjusted to vary the flow rate through each pump with wet well elevation, although the intention is to generally maintain similar flow rates through each pump in operation. Testing performed to measure swirl angles as a function of flow rate, all other factors being held constant indicated that swirl angles did not change significantly with the flow rate. The only potential issue that was indicated from the experiments was that a significant amount of air was entrained by the inflow into the wet well at low wet well elevations and high pump discharges. A qualitative investigation was performed with a single three pump configuration to determine flow rates below which air entrainment was significantly reduced at various wet well elevations. These results are presented in Table 13 and Figure 25. It should be noted that since the air concentrations were not measured during the experiments, higher pumping rates may not necessarily result in detrimental pump performance. The flow rates recommended here results in only small amounts of air entrainment, well below limits that are suggested as resulting in impacts on pump performance.

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
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
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Appendix A - Larger scale drawings of the junction chamber and wet well





### **Appendix B - Complete Model Test Results**

NOTE: THOSE RESULTS THAT ARE INCLUDED IN THE BODY OF THE REPORT AND NOT REPEATED IN THIS APPENDIX

## Original Configuration - Clearances 15", 15", 21" and 21" respectively for Pumps 1, 2, 3 and 4:

#### • Single Pump with Variable Flow Rate:

Pump#	Elevation	_	onfiguration .5 MGD	Original Configuration @ 14 MGD		Original Configuration @ 10 MGD	
		N(rot/min)	Swirl Angle	N(rot/min)	Swirl Angle	N(rot/min)	Swirl Angle
3	697.5	-39.5	-6.70				
3	698	-51	-8.63	-48	-10.69	-22	-6.90
3	698.5					-19	-5.97
4	697.5	-37	-6.28	-32	-7.17	-21	-6.59

Elevation	D #	Flow Rate	Original Co	onfiguration
(ft.)	Pump#	(MGD)	N (rot/min)	Swirl Angle
	1	10	31	9.68
698.5	2	10	10	3.15
	3	10	-17.5	-5.50
	1	18.5	46	7.79
699.5	2	18.5		
	3	23	-23	-3.15
	1	18.5	43	7.29
700.5	2	18.5		
	3	23	-20	-2.74
	1	10	13	4.09
700.5	2	10		
	3	10	-9	-2.84
	1	18.5	33	5.61
702	2	18.5	13	2.21
	3	23	-21	-2.88
	1	10	21	6.59
702	2	10		
	3	10	-5.5	-1.73

Elevation	Dumn #	Flow Rate	Original Co	onfiguration
(ft.)	Pump#	(MGD)	N (rot/min)	Swirl Angle
	2	23	23	3.15
699.5	3	18.5	-36	-6.11
	4_	18.5	-19	-3.24
	2	18.5	7	1.19
700.5	3	18.5	-35	-5.94
	4	18.5	-7.5	-1.28
	2	23	10.5	1.44
700.5	3	18.5	-36.5	-6.20
	4	18.5	-10	-1.70
	2	14	7	1.58
700.5	3	14	-20	-4.50
	4	14	-7.5	-1.69
	2	10	5	1.58
700.5	3	10	-17.5	-5.50
	4	10	-3	-0.95
	2	23	1	0.14
702	3	18.5	-25	-4.25
	4	18.5	-3	-0.51

Elevation	Pump#	Flow Rate	Original Configuration	
(ft.)	rump#	(MGD)	N (rot/min)	Swirl Angle
	1	18.5	51	8.63
699.5	2	18.5	11.5	1.96
	4	23		
	1	18.5	47	7.96
` 700.5	2	18.5	6.5	1.11
	4	23	-17.5	-2.40
	1	18.5	28	4.76
702	2	18.5	11.5	1.96
	4	23	-3.5	-0.48

#### PRELIMINARY MODIFICATIONS

Splitters (15") under Pumps 3&4 and Fillet (10") under Pumps 1&2 - Clearances 15", 15", 21" and 21" respectively for Pumps 1, 2, 3 and 4:

#### • Single Pump at 23 MGD:

Pump#	Pump # Elevation		Splitters (15") under 3&4 Fillet under 1&2		
		N(rot/min)	Swirl Angle		
1	695.5	40	5.47		
1	696	20	2.74		
1	697	14	1.92		
1	697.5	46	6.28		
2	696	24	3.29		
2	696.5	9	1.23		
2	697	11	1.51		
3	697.5	7	0.96		
3	698	-2.5	-0.34		
3	698.5	7	0.96		
4	695.5	-10	-1.37		
4	697	-17	-2.33		
4	697.5	-19	-2.60		

Elevation	Pump#	Flow Rate (MGD)	1 -	") under 3&4 nder 1&2
(ft.)		(IVIGD)	N(rot/min)	Swirl Angle
	2	23	28	3.83
700.5	3	18.5	12	2.04
	4	18.5	-2	-0.34

Elevation (ft.)	Pump#	Flow Rate (MGD)	,	") under 3&4 nder 1&2
(11.)	)	(WGD)	N(rot/min)	Swirl Angle
	1	23	54.5	7.43
698	3	18.5	-10	-1.70
	4	18.5	-13.5	-2.30

Splitters (10") under Pumps 1&2 and Splitters (15") under Pumps 3&4 - Clearances 15", 15", 21" and 21" respectively for Pumps 1, 2, 3 and 4:

#### • Single Pump at 23 MGD:

Pump#		Splitters (10") under 1&2 Splitters (15") under 3&4		
		N(rot/min)	Swirl Angle	
1	695.5	16	2.19	
1	697.5	28	3.83	
2	695.5	-25	-3.42	
2	697	-26.5	-3.63	
2	698.5	-16	-2.19	
2	700.5	-8	-1.10	

Elevation (ft.)	Pump#	Flow Rate (MGD)	Splitters (10") under Splitters (15") under	
(11.)		(IVIGD)	N(rot/min)	Swirl Angle
	2	23	-6.5	-0.89
698	3	18.5	-11.5	-1.96
	4	18.5	-11	-1.87
	2	23	-42.5	-5.81
700.5	3	18.5	10	1.70
,	4	18.5		

Elevation (ft.)	Pump#	Flow Rate (MGD)	Splitters (10") under 1 Splitters (15") under 3	
(11.)		(MGD)	N(rot/min)	Swirl Angle
	1	23	6	0.82
698	3	18.5	9	1.53
	4	18.5	-6.5	-1.11
	1	23	7	0.96
699.5	3	18.5	11	1.87
	4	18.5	-2.5	-0.43

Splitters (10") under Pumps 1&2 and Splitters (15") under Pumps 3&4 with the Weir at the Inlet Interceptor - Clearances 15", 15", 21" and 21" respectively for Pumps 1, 2, 3 and 4:

#### • Single Pump at 23 MGD:

Pump#	Elevation	Splitters (1	)") under 1&2 5") under 3&4 he Weir
		N(rot/min)	Swirl Angle
2	695.5	-25	-3.42
2	697	-24.5	-3.36
2	698.5	-15.5	-2.12
2	700.5	-16	-2.19

Elevation (ft.)	Pump#	Flow Rate (MGD)	Splitters (10") under 18 Splitters (15") under 38 with the Weir	
			N(rot/min)	Swirl Angle
	2	23	-43	-5.87
698.5	3	18.5	8.5	1.45
	4	18.5	2.5	0.43
١	2	23	-42	-5.74
699.5	3	18.5	8	1.36
	4	18.5	1.5	0.26
	2	23	-40	-5.47
700.5	3	18.5	13.5	2.30
	4	18.5	1	0.17
702	2	23	-25	-3.42
	3	18.5	6.5	1.11
	4	18.5	1.5	0.26

Elevation (ft.)	Pump#	Flow Rate (MGD)	with the Weir	
			N(rot/min)	Swirl Angle
	1	23	21	2.88
698	3	18.5	-6.5	-1.11
	4	18.5	-17	-2.90
	1	23	6	0.82
699.5	3	18.5	6	1.02
	4	18.5	1.5	0.26
700.5	1	23	37	5.06
	3	18.5	15.5	2.64
	4	18.5	1	0.17

Cross Splitters (15") only under Pumps 1&4 - Clearances 21", 15", 15" and 21" respectively for Pumps 1, 2, 3 and 4:

#### • Single Pump at 23 MGD:

		•	ers (15") only	
Pump#	Elevation	under 1&4		
		N(rot/min)	Swirl Angle	
2	697.5	8.5	1.17	
2	698.5	28	3.83	
2	699.5	19.5	2.67	
2	700	25	3.42	
3	695.5	-10.5	-1.44	
3	696.5	-2	-0.27	
3	697.5	-25.5	-3.49	
3	698.5	-14.5	-1.99	
3	699.5	-31	-4.24	
3	700.5	-35	-4.79	
4	695.5	-8	-1.10	
4	696.5	-4	-0.55	
4	697.5	-15.5	-2.12	

Elevation (ft.)	Pump#	Flow Rate (MGD)	Cross Splitters (15") on under 1&4	
(11.7			N(rot/min)	Swirl Angle
	1	18.5	3	0.51
702	2	18.5	21.5	3.66
	3	23	-9	-1.23

Elevation (ft.)	Pump#	Flow Rate (MGD)	Cross Splitters (15") o under 1&4	
(16.)		(IVIGD)	N(rot/min)	Swirl Angle
	2	23	17.5	2.40
699.5	3	18.5	-1	-0.17
	4	18.5	-2	-0.34
	2	23	23	3.15
700.5	3	18.5	-1	-0.17
	4	18.5	-3.5	-0.60
	2	23	3	0.41
702	3	18.5	21.5	3.66
	4	18.5	-9	-1.53

#### FINAL RECOMMENDATION

### Clearances 21", 15", 15" and 21" respectively for Pumps 1, 2, 3 and 4:

#### • Two Pump Combinations:

Elevation (ft.)	Pump # Flow Rate (MGD)	Final Recon	nmendation	
Lievation (it.)	Fullip#	Flow Rate (MGD)	N(rot/min)	Swirl Angle
700.5	1	23	0.25	0.03
700.5	3	23	3.25	0.45
701	1	23	0.25	0.03
701	3	23	2.25	0.31
701.5	1	23	0	0.00
701.5	3	23	2.25	0.31
702	1	23	1.5	0.21
102	3	23	2	0.27

Elevation (ft.)	Pump#	Flow Rate (MGD)	Final Recon	nmendation
Lievation (it.)	Fullip#	Flow Rate (MGD)	N(rot/min)	Swirl Angle
695.5	2	10	-1	-0.32
093.5	3	10	1	0.32
700.5	2	23	1	0.14
700.5	3	23	3.5	0.48
701	2	23	3	0.41
701	3	23	3	0.41
701.5	2	23	-4.25	-0.58
701.5	3	23	1.25	0.17
702	2	23	1.25	0.17
102	3	23	2	0.27

Elevation (ft.)	Dumn #	Flow Rate (MGD)	Final Recor	nmendation
Elevation (it.)	Pump #	Flow Rate (WIGD)	N(rot/min)	Swirl Angle
695.5	2	10	-1.75	-0.55
093.3	4	10	1	0.32
700.5	2	23	-1	-0.14
700.5	4	23	-2	-0.27
701	2	23	0	0.00
701	4	23	-3.5	-0.48
701.5	2	23	2.5	0.34
701.0	4	23	3.25	0.45
702	2	23	4	0.55
102	4	23	3.75	0.51

Elevation (ft.)	Dump #	tiFlow Rate (MGD)⊫	Final Reco	omendation
Lievation (it.)	Fump #	Flow Rate (MGD)	N(rot/min)	Swirl Angle
•	1	10	4.5	1.42
696	3	10	1.5	0.47
	4	10	-9.25	-2.91
	1	14	2.25	0.51
697	3	14	4.25	0.96
	4	14	-14.75	-3.32
	1	14	1.5	0.34
698	3	14	2.75	0.62
	4	14	-14.75	-3.32
	1	18.5	0	0.00
699	3	18.5	7	1.19
	4	18.5	-0.75	-0.13
	1	18.5	0.5	0.09
700	3	18.5	11.5	1.96
	4	18.5	3.25	0.55
	1	23	0.5	0.07
701	3	18.5	10.5	1.79
	4	18.5	-6	-1.02
	1	23	2	0.27
702	3	18.5	11	1.87
	4	18.5	-1.75	-0.30
	Abs	loute Sum		23.11

Floration (ft )	Bump #	Pump # Flow Rate (MGD)	Final Recommendation		
Elevation (it.)	Fullip #	Flow Rate (WIGD)	N(rot/min)	Swirl Angle	
	2	23	0	0.00	
698	3	18.5	0.5	0.09	
	4	18.5	4.5	0.77	
	2	23	-5.5	-0.75	
699.5	3	18.5	8.5	1.45	
	4	18.5	1.5	0.26	
	2	23	-8	-1.10	
700.5	3	18.5	8	1.36	
	4	18.5	-0.5	-0.09	

Final Recommendation with the Weir at the Inlet Interceptor - Clearances 21", 15", 15" and 21" respectively for Pumps 1, 2, 3 and 4:

#### • Single Pump at 23 MGD

Pump#	Elevation	Final Recommendation with the Weir		
		N(rot/min)	Swirl Angle	
2	695.5	4.25	0.58	
2	696	9.5	1.30	
2	696.5	19.5	2.67	
2	697	-1	-0.14	
2	697.5	7	0.96	
2	698	12.5	1.71	
2	698.5	-2.5	-0.34	
2	699	6	0.82	
2	699.5	9.75	1.34	
2	700	11	1.51	
2	700.5	11.75	1.61	

Elevation (ft.)	Pump#	Flow Rate	Final Recommendation with the Weir	
	•	(MGD)	N(rot/min)	Swirl Angle
695.5	1	10	5.75	1.81
	2	10	5	1.58
	3	10	2.5	0.79
	1	10	10	3.15
696	2	10	4	1.26
	3	10	3	0.95
	1	10	10	3.15
696.5	2	10	1.5	0.47
	3	10	-2.25	-0.71
	1	14	16	3.60
697	2	14	4	0.90
	3	14	5.5	1.24
	1	14	13.5	3.04
697.5	2	14	10	2.25
	3	14	3	0.68
	1	14	12	2.70
698	2	14	-2	-0.45
	3	14	2	0.45
	1	14	5.25	1.18
698.5	2	14	-6	-1.35
	3	14	5	1.13
	1	18.5	4.25	0.72
699	2	18.5	-7	-1.19
	3	18.5	7	1.19
	1	18.5	4	0.68
699.5	2	18.5	-6	-1.02
	3	18.5	7	1.19
	1	18.5	7.75	1.32
700	2	18.5	-7	-1.19
	3	18.5	7	1.19
	1	18.5	6.75	1.15
700.5	2	18.5	-7.5	-1.28
	3	18.5	6	1.02
701	1	18.5	7.25	1.24
	2	18.5	-6	-1.02
	3	23	6.25	0.86
701.5	1	18.5	5.25	0.89
	2	18.5	-6	-1.02
	3	23	5	0.69
702	1	18.5	5	0.85
	2	18.5	-5	-0.85
	3	23	7	0.96

Elevation (ft.)	Pump#	Flow Rate (MGD)	Final Recommendation with the Weir	
(11.)		(MGD)	N(rot/min)	Swirl Angle
	2	10	2.75	0.87
695.5	3	10	4	1.26
	4	10	-0.25	-0.08
	2	10	-1.5	-0.47
696	3	10	1.5	0.47
	4	10	13	4.09
	2	10	8.5	2.68
696.5	3	10	1	0.32
	4	10	-5	-1.58
	2	14	13.5	3.04
697	3	14	3.5	0.79
	4	14	-11	-2.48
	2	14	18	4.05
697.5	3	14	8.5	1.91
	4	14	-5	-1.13
	2	14	-2.75	-0.62
698	3	14	5.5	1.24
	4	14	-10	-2.25
	2	14	-5	-1.13
698.5	3	14	4	0.90
	4	14	-4.5	-1.01
	2	18.5	-6.25	-1.07
699	3	18.5	7	1.19
	4	18.5	-3	-0.51
	2	18.5	-8	-1.36
699.5	3	18.5	9	1.53
	4	18.5	-6	-1.02
	2	18.5	-6.5	-1.11
700	3	18.5	11	1.87
	4	18.5	-6	-1.02
	2	18.5	-5.5	-0.94
700.5	3	18.5	7.5	1.28
	4	18.5	-1.25	-0.21
701	2	23	-5.25	-0.72
	3	18.5	10.5	1.79
	4	18.5	-3	-0.51
701.5	2	23	-4	-0.55
	3	18.5	10.5	1.79
	4	18.5	-6	-1.02
702	2	23	-3.75	-0.51
	3	18.5	11.5	1.96
	4	18.5	-6.5	-1.11

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