HYDRAULIC MODEL STUDY
Detroit Metropolitan Airport
Stormwater Pump Station No. 11
Report CEE 99-7

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EXECUTIVE SUMMARY

A 1:10 scale physical hydraulic model was constructed of Detroit Metropolitan Airport Pumping Station No. 11. The emphasis of the model testing was on pump intake conditions although other hydraulic conditions associated with the flow within the wet well were investigated as well. Testing was performed for various combinations of wet well water levels and number of pumps in operation to simulate the proposed operating rules for the pump station. An investigation of surge conditions within the wet well associated with pump startup and shutdown was conducted by development of a numerical model of the unsteady flow as water fills and drains from the pump discharge line. This model was run for assumed worst case flow conditions associated with pump operation.

Results of the initial hydraulic model testing indicated extremely high swirl angles associated with nearly every flow condition examined. Under the worst flow conditions, swirl angles approached fifty degrees in magnitude, far in excess of the recommended limit of five degrees. Many flow conditions also exhibited some combination of submerged or air-entraining surface vortices. In addition, excessive air entrainment was observed into intakes 1 or 6 at low water levels, especially with several pumps in operation.

A number of independent changes to the internal geometry were investigated to determine their influence on the wet well performance. After extensive experimentation, several design changes to the wet well geometry are recommended:

- Lowering the floor of the inlet chamber to 588.0 ft;
- Placement of three 20-inch diameter columns with twenty inches of clear spacing between them in front of the inlet tunnel;
- Cones beneath each pump intake; one design was found to be more effective than the others tested;
- A series of three baffle walls spaced along the perimeter each side of the wet well;
- Closure of one of the two proposed five by ten foot openings in the center wall of the wet well and the placement of a baffle to divert any flow occurring through the remaining opening.

Even with all these modifications, a few flow conditions still exhibited swirl angles somewhat in excess of five degrees and intermittent submerged and surface vortices were also observed in some operating conditions. However, given the intermittent nature of the station operation and the relatively small exceedance of performance criteria, this level of performance is deemed satisfactory. One additional design modification that would further improve some of the flow conditions would be to increase the suction bell diameter. A diameter of 75 inches eliminated most of the submerged vortices and further reduced the swirl angles for most cases that exceeded five degrees.

Structural design engineers raised questions regarding the magnitude of dynamic forces on the baffle walls. In order to address this issue, fluid velocities were measured in front of the upstream baffle wall that will experience the greatest velocity. Velocities were measured for three pumps in operation on a single side of the wet well and at several vertical locations for each of three different water levels. Maximum velocities were observed near the wet well floor. The values were recorded and can be used in a drag force computation to estimate a reasonable upper limit for the dynamic force to be experienced on the baffle walls.

Guidance was requested on the proposed placement of the water level sensors. None of the proposed modifications to the wet well geometry will have a negative impact on the flow at the location of the level sensor. There will be a difference in water surface elevation between the two sides of the wet for odd numbers of pumps in operation, but this difference will be less than four inches with the proposed center wall opening and will not interfere with station operation. Also, stilling wells with pressure taps placed at the location of the proposed bubbler recorded the observed water surface elevation to within measurement accuracy.

A qualitative investigation was performed on the transport of sediment particles within the wet well. Deposition of sediment will depend on the size and specific gravity of particles that are transported into the pumping station but some deposition is inevitable. The model did not indicate any regions of excess deposition.

The numerical investigation of surge effects indicates very little problem in this regard. No problem was indicated on pump startup with a fairly minimal change (less than 0.1 ft) in wet well elevation depending on the exact tunnel inflow rate. In the case of pump shutdown, the assumption of pump shutdown (linear decrease in pump head) over 1.25 seconds led to a prediction of cavitation within the discharge pipe. The air vents designed into the system should be adequate to avoid any significant pressure surges associated with vapor column formation and collapse. The maximum increase in wet well water surface elevation during pump shutdown was computed to be approximately 0.5 ft and this should not pose a significant problem with station operation.

INTRODUCTION

A new runway is being constructed as part of an expansion to the Detroit Metropolitan Wayne County Airport. A new storm sewer will service this runway and Pump Station 11 will lift flow from this sewer into an open drain. A proposed design for Pump Station 11 was subject to physical hydraulic model testing. The purpose of the hydraulic model study was to examine the flow conditions within the wet well of Pump Station 11 with specific emphasis on the pump intake conditions. The model was also used to examine the potential for solids deposition within the wet well. An additional issue examined in the hydraulic modeling relates to the location of wet well water level sensor to determine whether it provides an appropriate measure of the hydraulic grade line within the wet well.

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;
- Examination of subsurface vortex patterns;
- Measurement of swirl (pre-rotation) in flow into individual suction inlets.

An additional issue addressed within the scope of this study was the occurrence of surging conditions within the wet well due to pump startup and shutdown. Surging within the wet well cannot easily be addressed within the framework of a physical model since the model requires full dynamic similarity in modeling the characteristics of the individual pumps as well as the discharge piping. The surging issue was addressed by developing a numerical model of pump startup/shutdown conditions. Unsteady flow equations were formulated and solved incorporating estimated data on the characteristics of the proposed pumps. Solutions to these equations were used to assess the potential for detrimental effects in the wet well and discharge piping, including a determination of the maximum hydraulic grade line (HGL) elevation during on/off cycles.

GENERAL SYSTEM DETAIL

Flow enters the Pump Station 11 through an eleven-foot diameter storm sewer with an invert elevation of 595 ft. The pump station is to be constructed in the interior of a 65-foot diameter circular caisson. The inflow passes through an inlet chamber designed with a floor elevation of 593.5 ft, strikes a deflector wall on the opposite side of the inlet chamber, bifurcates and passes through a set of bar screens, and then enters the main wet well with a floor elevation of 582 ft. The wet well is effectively divided into two symmetric halves by the placement of a divider wall parallel with the axis of the inlet conduit. However, there are two proposed openings in the divider wall to allow flow between sides of the wet well. Six storm water pumps, three on each side of the wet well are to be located within the wet well to lift the flow into the surface drain. Figures 1 and 2 are drawings of the detail of the wet well as proposed in the original design.

The pump capacity for each of the six pumps is intended to be 140 cfs, with a small variation in discharge capacity depending on wet well water level. All six pumps are specified to be constant speed. Operational control elevations for sequencing the pumps were provided to establish ranges of wet well water level elevations for different combinations of pumps in operation. In order to limit pump cycle times, control logic for pump operation will be developed which allows for pump sequencing such that any pump could be in operation, for example, if only one pump is required. The testing required the consideration of various combinations of one to six pumps in operation at a time. However, it was understood that the control logic for pump operation would not allow conditions involving more than one additional pump in operation on one half of the wet well as compared to the other half.

The physical model included all relevant geometrical detail of the wet well and pump intakes up to the pump impellers as well as a length of the eleven-foot diameter inlet sewer in order to ensure appropriate inflow conditions.

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

PARAMETER		RATIO
Length	L_r	L_r
Velocity	V_r	$L_r^{1/2}$
Discharge	Q_r	$L_r^{5/2}$
Time	t_r	$L_r^{1/2}$

The critical factors with respect to model testing facilities are the model size and discharge. If the scale ratio is too small, both viscous effects and surface tension 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 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 ν 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. In satisfying these constraints and other considerations, the model scale selected was 1:10. This scale ratio maintains the model Reynolds number (based on the suction pipe diameter) at a value of approximately 120,000 for a pump intake at its capacity of 140 cfs. This Reynolds number is well above the limit discussed above; the Reynolds number based on submergence is even less critical with regards to satisfying the suggested minimum values.

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 1:10. The pump suction lines were constructed from Plexiglas so that the rotating cruciforms (swirl meters) used to measure the inlet swirl angles could be observed to visually count the swirl meter rotation and to also observe air entrainment into the intakes. A proposed design for the pump suction bells was provided and an inside mold was prepared for the suction bell. The model bells were then manufactured by heating Plexiglas conduit until flexible and forming over the molds. The actual intake bell diameter had not been determined at the time of model construction, so a prototype bell diameter of 65 inches was used as the basis for model construction; this is slightly on the small side. Figure 3 is an image of a portion of the Plexiglas pump suction line as constructed with the swirl meter installed. Figure 4 is an overhead image of the piping associated with the six pump suction lines installed within the circular wet well. The numbering convention on the pumps was 1 through 6, consecutively, from right to left in the image.

All six pump suction lines were joined into a common manifold connected to a re-circulating pump which removes the flow from the wet well through the desired pump suction lines, and back around to the inlet conduit. The complex piping is indicated in the image presented as Figure 5. Figure 6 shows the inlet chamber; the floor of the chamber is elevated relative to the wet well floor. Bar screens will be installed in the prototype on either side of the inlet chamber but were not included in the model since they are intended to have negligible head loss across them. The flows were metered in each individual line by means of an installed pipe orifice meter at the (dark) flanges shown in Figure 5. The flow in each pump intake line was independently regulated by means of an installed butterfly valve located downstream of the orifice meter.

Instrumentation

Flow rates were measured using pipe orifice meters constructed to ASME specifications (Brater and King, 1977). There was a ten-foot section of four-inch PVC pipe upstream of each orifice meter and the downstream piping was at least four feet in length. Pressure differences were measured with water-air differential manometers. The orifice meters had been previously calibrated and flow coefficients were taken from this previous calibration. The orifice meters were sized to provide a total manometer deflection of 15.5 inches at the model discharge corresponding to 140 cfs; at this deflection, a metering precision on the order of two percent is estimated.

Water level elevations within the wet well were measured by connecting a pressure tap mounted in the sidewall of the wet well to a stilling well. The pressure tap was located in proximity of the proposed location of the bubbler for the actual wet well. A piezometer and stilling well was installed on both sides of the wet well so that hydraulic grade line differences between the two sides could be recorded.

The presence of surface and subsurface vortices was investigated visually. Surface vortices were generally quite visible and often involved an air core down to a pump intake. Dye was injected at the surface in some cases to visualize the structure of the vortex core. Several types of submerged vortices were also observed visually, often by the ingestion of air bubbles that were present in the flow due to entrainment at the wet well entrance. The most common type of submerged vortex was a floor vortex with a nearly vertical axis that originated directly beneath the intake. Some submerged vortices were observed originating on the wet well walls, most often starting from the center divider wall and entering either of intakes 3 or 4. Finally, a submerged vortex, referred to as a "connected vortex" was occasionally observed. These vortices did not originate on a solid boundary but passed from one pump intake to another. They were always observed, if present, between the intake pairs, 2 and 3 or 4 and 5.

Swirl angles were measured with a rotating cruciform (swirl meter), the function of which is to rotate with the component of tangential flow in the pump suction line. The swirl meter is composed of four, zero-pitch vanes mounted on a hub installed on the intake centerline at the location of the pump impeller. Standard specifications of 0.8 of the intake pipe radius for the vane length and width were utilized in the construction of the vanes. One vane was black to visually orient the cruciform. Counts were made of the total number of rotations in a one-minute interval. Generally, observations were made over multiple, one-minute intervals to ensure repeatability of the results.

Sediment was introduced into the model to observe deposition patterns within the wet well. This consisted of the introduction of approximately two liters of black, silicon carbide grinding powder into the inflow in the wet well at a controlled rate and observing the transport through the wet well. This sediment was sized to be marginally transported by the velocities experienced within the wet well. It was scoured by the high velocities immediately under the pump intakes but would generally be deposited throughout most of the remainder of the wet well. The sediment was circulated through the system for approximately ten minutes before shutting the system down and observing the deposition patterns.

Videotape

A videotape in VHS format was made to document some of the conditions encountered in the testing of the original design, some of the design modifications, and the final recommended design proof testing.

TESTING PROCEDURES

Generally, the worst flow conditions appear at maximum flow rates and/or minimum water levels when wet well velocities are highest. However, vortices may also form in stagnant zones, so it is also necessary to check at low discharges and high water levels. In this wet well, each pump is designed to operate at a constant speed and therefore at essentially a constant flow rate. Level sensors will be used to control the number of pumps in operation at any one time and thus the overall flow rate. In general, pumps will be turned on at a high water level and off at a low water level. A preliminary design included on and off water levels for any pump in the operating sequence. Table 1 presents the water level elevation ranges proposed. In the results presented below, a code will be used which identifies the number of pumps in operation and the wet well water level elevation that was tested; 3-low, for example, refers to three pumps in operation (just prior to shutting off one of the three pumps) at the shutoff elevation of 597.0 ft

Table 1. Proposed wet well control elevations

Operation	Elevation (ft)
Start sixth pump	606.0
Start fifth pump	605.0
Start fourth pump	604.0
Start third pump	603.0
Start second pump	602.0
Start first pump	601.0
Stop sixth pump	600.0
Stop fifth pump	599.0
Stop fourth pump	598.0
Stop third pump	597.0
Stop second pump	596.0
Stop first pump	595.0

Note: reference to pump number refers to total number of pumps in operation; these could be any combination of the available pumps with the exception that no more than one additional pump can operate on one side of the wet well compared to the other side.

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 is 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 in and observing the tendency for any organized vortex motion. Also these vortices could often be visualized by the presence of air bubbles which were entrained into the flow at the wet well entrance. Submerged vortices were also classified according to whether they originated on the wet well floor (floor vortex), a wall (wall vortex), or passed from one intake to another (connected vortex). Acceptance criteria allow no coherent subsurface vortex with organized swirl and core (Type 3).

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

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

with θ the swirl angle, N the revolutions per unit time of the rotating cruciform, d the pipe diameter and U the average axial flow velocity (the line discharge divided by the pipe cross sectional area). Swirl angles of less than 5 degrees are generally considered as acceptable for axial flow pumps.

PHASE I TEST RESULTS

Vortices and Other Flow Conditions

A number of unacceptable flow conditions were noted in the Phase I testing which included the investigation of a number of combinations of one through four pumps in operation. A list of these follows:

- Excessive air entrainment in the flow entering the inlet chamber, upstream of the bar screens. This air tended to be transported to the pump intakes and passed through the pump intakes. In extreme conditions (large numbers of pumps in operations and low water levels) it was not even possible to measure the swirl angles because the large volume of air obscured the visibility to the point where it was not possible to see the swirl meter. Air entrainment was worst for the closest pump intakes, 1 and 6. At higher flow rates, air entrainment became significant in intakes 2 and 5 as well;
- A closely related problem is the surge up to the deflector wall opposite the inlet conduit. Figure 7 indicates the nature of this surge for a high discharge (six pumps in operation) and a high water level. The videotape also records the nature of this flow. Although the surge is greatest at low water levels, a problem could arise at high water levels with the surge rising up to the floor elevation of the floor above.
- 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 intakes 2 and 5, but were also seen in intakes 3 and 4. Air entraining vortices tended to develop, break down, and then re-form. The most likely reason for the susceptibility of these particular intakes to vortex formation is their distance from wet well walls.
- Other coherent surface vortices with organized core (Type 3); these were observed at all pump intakes in at least some of the conditions tested
- Submerged vortices of various types. Submerged vortices with coherent core were observed originating from the floor and side walls and also the connected type were observed when two pump combinations of intakes 2 and 3 or 4 and 5 were investigated.
- Excessive swirl angles as discussed in more detail below.

The sources of much of this undesirable flow behavior was readily apparent. The air entrainment at the inlet was due to the high velocity flow from the influent pipe passing through the inlet chamber and striking the deflector wall before bifurcating laterally. A type of hydraulic jump formed at the wall, which resulted in the air entrainment. The entrainment was worst at the "low" water levels as opposed to the "high" levels but was also present at high levels with a large number of pumps in operation. Most of the vorticity originated from the nature of the flow entering the wet well. Again, the entering flow impinged on the wall opposite the inlet and was bifurcated as it deflected laterally through the bar screens. This flow then impinged on the outside wall of the wet well and was again deflected along the outside wall into the main portion of the wet well. This flow resulted in a relatively high velocity jet along the perimeter of the wet well with a nearly stagnant zone at the interior. Flow left the wet well perimeter in order to enter an operating pump intake and set up a surface vortex consistent with the required flow path. Figure 8 presents a schematic of a typical flow condition.

Swirl Angles

Swirl angles were measured for various combinations of one, two, and three, and four pumps in operation. Table 2 summarizes the results of this testing. In almost all cases, the measured swirl angles were substantially above the five degree limit and most are over ten degrees. Most likely, there are several factors contributing to this high degree of pre-rotation including the concentrated flow along the perimeter of the wet well; the small size of the wet well in relation to the pumping capacity; the distance of the pump intakes from solid walls; and the relative proximity of the pump intakes to each other.

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

# of Pumps	Pump #	Water Level	Swirl Angle (degrees)
One	1	low	19
One	2	low	39
One	3	low	6
One	4	low	-10
One	5	low	-30
One	6	low	-19
One	1	high	22
One	2	high	31
One	3	high	23
One	4	high	-28
One	5	high	-25
One	6	high	-26
Two	1	low	18
	4		-12
Two	1	low	22
	5		-49
Two	1	low	18
Two	6		-24
Two	2	low	47
Two	5		-43
Two	1	high	28
Two	4		-34
Two	1	high	29
Two	5		-15
Two	1	high	32
Two	6		-31
Two	2	high	24
Two	4		-38
Three	2	low	-44
	3		-8

	4		-9
Three	2	low	49
	3		13
	5		too fast to count
Four	2	low	too much air
	3		22
	4		too much air
	5		too much air

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

WET WELL MODIFICATIONS

Because of the significant deviation from acceptable wet well conditions, it was concluded that a number of design modifications would probably be necessary in order to achieve a satisfactory performance. Therefore, a systematic approach was taken to define those factors that would have an influence on the flow behavior. Three somewhat independent sets of modifications were examined. These involved:

- Revision of the conditions in the inlet chamber, i.e. upstream of the bar screens;
- Revisions of conditions at the pump intakes;
- Revisions in the interior of the wet well.

Each of these is discussed separately below although ultimately, revisions of all types were required to obtain satisfactory flow performance.

Inlet Chamber Revisions

Three different sets of modifications were tested in the inlet chamber. One approach involved the placement of three vertical columns just inside the wet well. The purpose of these columns was to break up the velocity entering through the inlet conduit and reduce the magnitude of the hydraulic jump formed in the inlet chamber. The second revision was intended to accomplish the same purpose and consisted of lowering the floor elevation of the inlet chamber. The third revision was an attempt to reduce the flow along the perimeter of the wet well by providing openings through the deflector wall opposite the inlet conduit.

Table 3 presents some of the more relevant results associated with revisions in the inlet chamber. The floor of the inlet chamber was lowered to attempt to reduce the air entrainment in that portion of the flow. This was observed to be successful in all circumstances studied, but at the expense of increasing swirl angles. This was due to a general lowering of the location of the high velocity jet of water running along the wet well perimeter. After some trials, it was found that lowering the inlet chamber floor to an elevation of 588.0 ft as opposed to the original elevation of 593.5 would significantly reduce the air entrainment without resulting in excessive increases in swirl angles. Adding three vertical 20-inch diameter columns with 20 inch clear spacing between them directly in front of the inlet conduit reduced the air entrainment as well as the swirl angles by breaking up the velocity entering the wet well. Figure 9 indicates the location of the columns as developed in the testing.

Several efforts were made to locate openings in the deflector wall opposite the inlet conduit. The concept behind this revision was to split the flow entering either side of the main portion of the wet well, with the two streams on each side of the center dividing wall, effectively canceling each other out and thereby reducing the swirl angles. There were several negative aspects of this portion of the investigation. Although it was generally possible to define a wall opening size and geometry for a given flow rate into the wet well, the configuration would not be appropriate for other inflows and high swirl angles would still be observed at all but one flow rate. In addition, there was more air entrainment at the higher flow rates in the main portion of the wet well itself and therefore more air flowing into the air intakes. This approach was eventually discarded as not workable, but the two first modifications were retained.

Table 3. Swirl angles associated with various design modifications associated with the inlet chamber.

# Pumps	Pump #	Water Level	Swirl Angle (degrees)	
Lower Floor in Inlet Chamber				
Two	2	low	too fast to count	Lower to 582.0 ft
	6		too fast to count	Much less air entrained
One	4	low	-11	Lower to 588.0 ft
One	5	low	-49	Better pre-rotation than
One	6	low	-37	with floor at 582.0
Place Three Columns in front of Inlet Conduit				
One	1	high	18	
One	2	high	30	
One	3	high	18	
Two	1	high	16	
	4		-7	
Two	2	high	16	
	5		ñ32	
Opening in Inlet Chamber Wall				
One	1	low	25	
One	2		2.5	
One	3		4.6	
One	4		-9	
One	5		-2.9	
One	6		-17	
One	2	high	41.5	
Two	3	high	5.5	
	6		-9.0	
Two	2	high	22	
	5		-28	

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

Pump Intake Revisions

The primary revision to the pump intake consisted of placing a cone directly beneath the pump intake. Figure 10 is an image of the recommended geometry for the cone. The basic element of the cone is the four vertical plates, which serve to break up any rotation in the flow entering the pump intake. Initially the plates were triangular with a height of 3.0 ft (prototype) and a length equal to the radius of the intake bell (modeled at 32.5 inches). These cones were found to produce only a small reduction in measured swirl angles and the triangular plates were replaced with rectangular plates of the same height and length. Table 4 presents the results of a comparison for measurements with and without the cone in place on intake 2 and it is seen that a large reduction in swirl angle was achieved. Ultimately, the cones were altered to the configuration in Figure 10 because floor attached vortices were observed beneath the pump intakes for several flow conditions. Figure 11 shows the cone installed beneath a pump intake. This change largely eliminated the floor attached vortices.

Revisions to Wet Well Interior

Even though the cones were effective in reducing the swirl angles, they were insufficient to achieve the five degree target in all cases. In addition, air entraining vortices were still observed under some flow conditions, particularly with Pumps 2 and 5 operating in a one pump configuration at higher water levels. In order to eliminate these air entraining vortices and reduce the pre-rotation associated with them, a set of internal baffles were required to divert the flow from the wet well perimeter wall. These baffles were in the form of vertical rectangular columns approximately 3 ft in length projecting out from the wet well wall. Table 4 presents some results for tests with only baffle walls (no other wet well modifications in place) added to the model. The locations of the baffles were determined by trial-and-error and were positioned so as to provide the best performance over the entire range of flow conditions. It was found that they worked best if there was a small gap between the baffle and the wet well wall, allowing flow to pass both sides. It was also found that small differences in length could be important in some cases. The nature of the flow around the baffles resulted in vortex shedding from both sides and these vortices appeared to break up the more persistent rotation that would be observed in the absence of the baffle.

Other changes were tested in order to arrive at a final recommended design. In particular, difficulties in meeting test objectives were encountered in case where the pumping was unbalanced between the two halves of the wet well (for example, when one pump was operating on one side and two on the other side). Flow problems included the formation of air entraining vortices and excessive swirl angles. These flow problems were attributed to the flow through the two 5 ft by 10 ft openings in the center divider wall. A number of options were investigated in the model to improve the flow under these conditions. These modifications were implemented later in the testing and interfacing was required with the structural engineers who designed the wet well to ensure that any proposed change was structurally feasible. The final changes are discussed below and included closing off the opening closest to the pump intakes and placing a baffle on either side of the remaining opening. The details are provided in the next section.

Table 4. Swirl angles associated with various design modifications associated with the main portion of the wet well.

# Pumps	Pump #	Water Level	Swirl Angle (degrees)	
Cones under pump intakes				
One	2	high	3.4	Cone under Intake 2
One	2	high	50	Cone removed from Intake 2
Two	2	high	5.9	Cone under Intake 2
	5		-39	No Cone under Intake 5
Baffle wall along wet well perimeter				
One	5	high	-2.2	two baffles
One	6	high	-2.3	three baffles, gap between first baffle and wet well wall was required
One	6	low	3.0	three baffles, as above
One	5	low	24.2	three baffles, as above
	4	low	-4.3	three baffles, as above
Two	4	high	-10.0	three baffles, as above
	5		-5.3	
Two	4	low	9.6	three baffles, as above
	5		2.1	

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

RECOMMENDED DESIGN-PROOF TESTING

Vortices and Swirl Angles

With the results of the preliminary tests, it was possible to make internal modifications to the wet well and essentially satisfy the performance objectives. Final modifications to the wet well design included

- Placement of cones beneath each of the pump intakes. The detail of the proposed cone is presented in the image in Figure 10 and dimensions are provided in Figure 12;

- Baffle walls placed along the perimeter. Three are required on each half of the wet well. The location and dimensions of the recommended baffle walls are presented in Figure 13;

- Closure of one of the two 5 ft by 10 ft openings originally proposed in the divider wall and the placement of a baffle around the remaining opening. The baffle was required to prevent the formation of an air entraining vortex entering pumps 2 or 5. This occurred under circumstances with an unbalanced flow to the two sides of the wet well. (e.g. a three pump operation such as pumps 2, 3, and 5 would result in an entraining vortex entering intake 2) The detail of the recommended baffle is indicated in Figure 14;

- Lower the inlet chamber floor elevation to 588.0 ft;

- Place three vertical circular columns in front of the inlet conduit. The location of these columns is indicated with Figure 7.

Table 5 presents the testing results for this recommended configuration. The maximum swirl angle criterion of five degrees is met for most permutations of pump operation. Those tests that did not meet the criteria were only slightly over the acceptance criterion and no solution could be found that would simultaneously meet the criterion for all flow permutations.

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Table 5. Swirl angles associated with various flow conditions with recommended design.

# of Pumps	Pump #	Water Level	Swirl Angle (degrees)
One	1	low	1.2
One	2	low	4.3
One	3	low	2.3
One	4	low	-0.8
One	5	low	-3.9
One	6	low	-1.6
One	1	high	7.0
One	2	high	7.0
One	3	high	1.2
One	4	high	-0.8
One	5	high	-4.0
One	6	high	-6.8
Two	1	low	0
	5		0
Two	2	low	1.2
	5		0
Two	3	low	3.5
	5		0
Two	3	low	2.7
	4		-2.7
Two	1	high	4.7
	6		-8.5
Two	2	high	4.3
	6		-9.3
Two	3	high	2.0
	6		-7.0
Two	1	high	3.9
	5		-2.7
Two	2	high	3.9
	5		-2.7
Two	3	high	1.6
	5		-2.7

Three	1	low	3.9
	2		0.8
	5		0.
Three	2	low	4.0
	3		0.8
	5		-3.9
Three	1	low	0.
	3		1.6
	5		-0.8
Three	3	low	2.0
	4		1.6
	5		1.2
Three	2	low	4.7
	4		-0.8
	5		-0.8
Three	1	low	0
	4		0.8
	5		0
Three	2	high	5.7
	4		0.8
	5		-0.8
Three	3	high	2.0
	4		0.8
	5		0
Three	2	high	3.5
	3		1.2
	5		-2.7
Three	1	high	4.3
	3		0.4
	5		-2.0
Three	1	high	4.3
	2		4.3
	5		0

Four	1	low	-0.4
	3		0
	5		-0.8
	6		-1.6
Four	2	low	0
	3		0
	5		-0.8
	6		-3.9
Four	1	low	0.9
	2		0.4
	5		-1.1
	6		-3.9
Four	2	high	0
	3		1.6
	5		-1.2
	6		-5.3
Four	1	high	0.8
	2		3.5
	5		-0.6
	6		-4.7
Four	1	low	1.6
	3		0.8
	5		-0.8
	6		-3.9
Five	1	low	-5.3
	2		0.8
	3		0
	5		-2.0
	6		0
Five	2	low	-0.4
	3		0
	4		0
	5		0
	6		-2.0
Five	1	low	-1.6
	3		0.4
	4		-0.8
	5		0
	6		-2.0

Five	1	low	-2.0
	2		2.7
	4		-0.8
	5		-0.4
	6		-1.6
Five	1	high	1.2
	2		0.4
	4		0
	5		0.8
	6		-0.8
Five	2	high	-1.2
	3		0
	4		0.8
	5		-0.8
	6		1.2
Five	1	high	0.4
	3		0.4
	4		-0.8
	5		0
	6		-0.8
Five	1	high	-0.4
	2		0
	3		0
	5		0.8
	6		-3.5
Six	1	low	-3.5
	2		-1.2
	3		0
	4		0.8
	5		0
	6		0.8
Six	1	high	-1.6
	2		-0.8
	3		0
	4		0.4
	5		0.4
	6		2.7

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

Of the flows that exhibited swirl angles greater than five degrees, nearly all were associated with a small number of pumps (one or two) in operation at high water levels. In these conditions, the first two intakes (1 and 2, 6 and 5) on each side of the wet well were likely to show pre-rotation near the recommended limit. The flow at the back of the wet well was visually quite stagnant with these flow states and apparently led to conditions that favored the tendency for vortex formation. For lower water levels or with more pumps in operation, the increase in flow velocities within the wet well actually reduced the inlet swirl. Experimentation indicated that the location of the first baffle wall on each side of the wet well had the most influence on the resulting swirl angle in either of the inlets on that side with the location of the second baffle wall contributing as well. Several attempts were made to alter the location of these two baffle walls, resulting in improved performance in one of the intakes (e.g. intake 1), but worse in the other (intake 2). It was also possible to obtain air entraining vortices into either of the two inlets if the baffle walls were moved significantly from their recommended positions. Therefore, it was concluded that it would not be possible to reduce the intake swirl angles further without major and unknown additional modifications to the wet well.

In addition to the swirl angles for the few operating conditions that were somewhat above the performance limits, there were a few other flow conditions that were marginal in terms of stated performance goals. During flow conditions that resulted in the highest swirl angles in intakes 2 and 5, intermittent surface vortices appeared that could demonstrate coherent cores (Type 3). In addition, an intermittent Type 2 vortex was observed at intakes 1 or 6 for many of the flow conditions which involved a large number of pumps in operations; these often exhibited swirl angles near the five degree level as well. The videotape shows the nature of this vortex at intake 1 as visualized by the air entrained behind the intake Some of these same flows also demonstrated an intermittent type 3 vortex originating at the floor and entering the same intake. Finally under conditions (three or four pumps in operation) which involved the simultaneous operation of intakes 2 and 3 or 4 and 5 at low water levels, a connected vortex was observed to intermittently form between the adjacent intakes. Other than these noted conditions, all other flows met the stated performance criteria.

Although not all flow conditions met the stated performance criteria, the final conditions were a vast improvement on the conditions in the preliminary model testing. All of the recommended changes in wet well geometry were deemed necessary to achieve the observed improvement in flow conditions. Towards the end of the videotape, there is a sequence that indicates the difference in performance between the two sides of the wet well if the floor mounted cones beneath the pump intakes and the internal baffle walls were removed from one side. The difference is quite dramatic with large increases in swirl meter rotation and an air entraining vortex is formed on the side with these modifications removed. This pump station is anticipated to be in operation only a relatively few hours per year. The small exceedance of swirl angle above desired levels and the intermittent, coherent vortex formation should not significantly interfere with station performance.

One additional attempt was made to reduce the swirl angles and vortices for the flow conditions noted above. This involved increasing the diameter of the pump suction bell. As noted previously, the bell diameter produced in the model corresponded to a prototype diameter of 65 inches; this may be somewhat less than the actual prototype diameter that was not specified at the time of model construction. In order to investigate the potential influence of increasing the suction bell diameter, a Plexiglas skirt was produced which could be attached to a model intake to increase the bell diameter to a prototype dimension of 75 inches. The skirt was attached first to intake 2 and subsequently to intake 1 and experiments were repeated to observed the difference with and without the skirt in place. The skirt, when installed on intake 2, completely eliminated the connected vortex that formed between intakes 2 and 3 for the three-low or four-low operating conditions. It also reduced, but not completely eliminated the floor vortex beneath intake 1. In addition, the swirl angles at intake 2 were reduced by fifteen to twenty percent at the one-high and two-high operating conditions that indicated relatively large swirl angles. The reduction in the swirl angles in intake 1 were less dramatic, in the range of five to ten percent. These improvements in flow conditions, while still not meeting the stated performance criteria for all operating conditions, indicate that a somewhat larger suction bell on each pump intake will result in better wet well performance.

Effect of Beam at Wet Well Ceiling

As the hydraulic model testing was proceeding, changes in the structural design of the wet well were made that required increasing the depth of a beam under the ceiling of the wet well. The bottom elevation of the beam was proposed to be 602.25 ft. Water levels within the wet well would need to be quite high in order for the flow to interact with the beam since this bottom elevation is above the two high level of 602 ft. Model tests were made for combinations of three, four and five pumps in operation at the corresponding high water levels for which test results are reported in Table 5. No increase in swirl angles above the levels in Table 5 was observed, nor was there any indication of an increase in vortex activity. Therefore, it is concluded that the beam will not have any material effect on flow within the wet well and that the results in Table 5 are representative of those with the beam in place.

Location of Level Sensor

One of the objectives of the hydraulic model testing was to assess the effectiveness of the water level sensor location, which according to the drawings provided was roughly halfway along the wet well perimeter between the inlet and the back of the wet well. This location was in the region where the concentrated flow from the inlet was still quite pronounced and upstream of the baffle walls that were installed. In spite of the concentrated flow at this location, the velocities at this location should be quite persistent and these would not lead to any significant problem with the use of a bubbler in monitoring water levels. To the accuracy of the measurement of the actual water level, the elevation of the water level in the stilling well was consistent with that within the wet well. No vortices or other fluctuating flow characteristics were observed that would result in pressure fluctuations sufficient to interfere with the level sensor operation.

One issue that did arise during the testing was that the water level would be somewhat different on one side of the wet well compared to the other under those flow conditions in which an unbalance existed in the number of pumps on the two sides of the wet well. (one, three and five pump operating sequences) This was due to the fact that the flow entering the wet well tended to split equally to the two halves and an equalizing flow through the five by ten foot opening in the center wall was set up under these circumstances. A small head difference between the two sides of the wet well was necessary to set up this flow. An investigation indicated that the maximum head difference occurred during a one low pump operating condition, as expected since this produced the least opportunity to re-distribute the flow properly in the inlet chamber. Stilling wells on either side of the wet well with pressure taps set at the proposed location of the bubbler indicated a water level elevation difference of approximately four inches prototype under the one-low operating condition. This level difference will not have a significant influence on the wet well operation under the proposed pump sequencing rules and it is concluded that the water level variation between sides of the wet well is not important to the station operation.

Location and Degree of Solids Deposition

Once the recommended changes in internal wet well geometry were developed, additional tests were performed which examined solids deposition within the wet well. These tests were performed by introducing about two liters of a black, silicon carbide sand into the model and letting it circulate through the system for about ten minutes before shutting down the model. Several different flow conditions were observed, but photographs were obtained for a flow condition in which pumps 3 and 4 were operating at a water level midway between the high and low operating levels. Figures 15 and 16 are images of the general sedimentation patterns observed. The results are generally as expected in that sedimentation occurs where the flow is basically stagnant. If only one pump were in operation, considerable deposition would be observed in the opposite half of the wet well. Furthermore , if intakes 1 and 6 were operated instead of 3 and 4, more solids deposition would be observed in the back of the wet well. One area of fairly concentrated solids deposition was immediately behind the wall of the intake chamber. This is to be expected as the area is basically in a large stagnation zone. However, with the location of the five by ten foot opening through the center wall and the recommended baffle on that opening, the flow through the wall under an unbalanced pump operation (e.g. one or three pumps in operation) tends to sweep out the sediment in this area of deposition on the side that the flow through the opening passes into. In general, there does not appear to be excessive sedimentation in any one area, but it is generally distributed throughout the wet well. The sedimentation patterns at the baffle walls clearly indicates the nature of the flows set up in the wakes behind them.

Forces on Baffle Walls

Subsequent to the proposed modifications that involved the placement of baffle walls within the wet well, questions were raised by the structural design engineers regarding the magnitude of expected forces on the baffle walls. In order to address this issue, velocity measurements were made in the model upstream from the closest baffle wall. This baffle wall will experience the highest velocity and thus the largest dynamic force. Velocities were measured at several different vertical levels at three different water levels for a flow condition in which all the intakes on one side of the wet well were in operation. The velocity measurements were made with a mini-propeller meter installed approximately three inches upstream and on the center-line of the baffle wall. Measured velocities scaled to prototype levels using the Froude scaling criteria are presented in Table 6. Maximum velocities were always observed near the bottom of the wet well. The magnitudes of these velocities are roughly half the average velocity expected through the inlet tunnel at those flow conditions, indicating the relatively small dissipation in velocity through the inlet chamber, even with the circular columns. Forces on the baffle walls could be estimated using a drag force formulation with a drag coefficient with a magnitude of about 1.0:

$$F_{drag} = 0.5\, C_d\, \rho U^2 A_p$$

Here F_{drag} is the total drag force, C_d is the drag coefficient, ρ is the fluid density, U is velocity, and A_p is the projected area of the baffle wall.

Table 6. Magnitudes of velocities measured approaching upstream baffle wall.

Prototype water Level (ft)	Depth (ft) from Surface	Velocity ft/s
603	20.8	3.6-3.9
	18.3	3.3
	12.5	1.9-2.5
600	18.3	3.8-4.1
	12.5	3.3-3.6
	8.3	2.2-2.5
	4.2	2.5-2.8
597	15.0	5.7-6.0
	8.3	3.2-3.5
	4.2	3.5-4.1

Surging Conditions Within the Wet Well due to On/Off Cycles

A numerical model was developed to simulate the unsteady flow in the wet well and the pump intakes during conditions of pump startup and shut down. The results of this analysis are presented in Appendix 1.

CONCLUSIONS

The initial testing revealed significant problems associated with pre-rotation of the flow entering the pump intakes. Swirl angles considerably in excess of the recommended upper limit were encountered for every flow condition investigated. In addition, many flow conditions tested displayed air entraining surface vortices or other combinations of submerged vortices originating on the floor, the side walls, or extending between adjacent pump intakes. An additional problem associated with significant air entrainment was noted at conditions of low wet well water levels and several pump intakes in simultaneous operation.

A series of modifications were made to the internal geometry of the wet well in order to reduce these undesirable flow conditions. Two changes to the inlet chamber geometry were found to significantly reduce the air entrainment. A reduction in the floor elevation was found to be most effective, but too large of a reduction resulted in increased pre-rotation in the pump intakes. A floor elevation of 588.0 ft appeared to provide a reasonable compromise between the competing effects and is recommended for the final design. An additional change to the wet well geometry involved the placement of three, 20-inch diameter columns with twenty inches of clear space between them in front of the inlet tunnel into the wet well. The column location six feet from the wet well perimeter provided a reduction in the flow velocities in the inlet chamber and simultaneously reduced air entrainment as well as swirl angles.

The majority of the reduction in the swirl angles was accomplished by placing cones beneath the pump intakes. Several versions of the cone design were tested in order to achieve a significant reduction of swirl angles as well as eliminating the floor-attached vortices that were observed beneath several pump intakes. Even with the installation of cones, swirl angles could not be reduced to the recommended limits for several flow situations and air-entraining vortices as well as submerged vortices were observed for several conditions tested. It was necessary to place a series of three baffle walls on each side of the wet well in order to obtain further reduction in swirl angles and to eliminate the air-entraining vortices. Finally, changes in the openings in the center wall of the wet well were required in order to reduce unacceptable flow conditions (vortices and swirl angles) associated with flow through the openings from one side of the wet well to the other. All of the mentioned changes are indicated in the plan and section view of the wet well presented in Figures 17 and 18.

With all these changes, the swirl angles could be reduced below the five degree performance criterion for nearly all flow conditions. However, for a few flow conditions associated with high water levels and few pumps in operation (apparently associated with the nearly stagnant zone near the back of the wet well), some pump intakes exhibited swirl angles somewhat above the five degree limit. An extensive investigation was conducted to further improve the performance for these flow conditions, but it did not appear possible to meet the performance criteria for one flow condition without deteriorating the performance for some other flow. Increasing the pump bell diameter to 75 inches produced some improvement in swirl angles and also reduced the submerged vortices that were observed in some test conditions and this option should be considered if feasible. Otherwise, the swirl angles are fairly close to the five degree level in the worst cases, and the infrequent operation of the wet well probably does not warrant the pursuit of extensive wet well modifications which would be required to achieve additional improvement in performance.

The proposed location of the level sensor (air bubbler) will be adequate to determine the wet well water surface elevation. No problems associated with the level sensor location were introduced by the proposed design modifications to the wet well geometry. A relatively small elevation difference of less than four inches was observed between the two sides of the wet well under conditions in which an unequal number of pumps (one more on one side than the other) were operating on the two sides of the wet well. This difference was associated with the limited hydraulic connection between the two sides; however the elevation difference is sufficiently small that it will not interfere with station operation.

With regards to debris that could settle out of the flow, the exact deposition patterns will depend on the size and specific gravity of the debris. The model testing was conducted in a fashion in which deposition was inevitable and the locations of sediment deposition were observed. In general, deposition was more pronounced in stagnation zones such as behind the internal deflector wall on the inlet chamber. The modification to the five by ten foot opening in the center wall decreased the level of deposition for flows with an unbalanced number of pumps operating on the two sides of the wet well. Also, the most deposition in the back of the wet well occurred when intakes 1 and/or 6 were operating or if only one pump was operating, the deposition was significant on the opposite side of the wet well. However, the intended operation of the wet well cannot avoid these operating conditions at all times, and no abnormal problems were noted in the testing.

The issue of surge due to pump startup and shutdown is addressed in Appendix 1. The only obvious concern appears to be associated with pump shutdown. The analysis assumes a linear decrease in pump head over a specified time interval. Under the conditions of low wet well level, there is more than 33 ft (approximate atmospheric pressure head) between the wet well surface elevation and the horizontal portion of the piping. Consequently, there will be a potential for cavitation in the vertical portion of the pump discharge line, in particular, at the elbow. The cavitation itself is not necessarily a concern, but the subsequent pressure spikes that result from the vapor pocket collapse can potentially be a problem in these types of systems. The air vents that are to be installed just upstream from the flap gates are expected to be adequate to prevent any significant pressure fluctuations.

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Padmanabhan, M. and G.E. Hecker, (1984) *Scale Effects in Pump Sump Models,* ASCE Journal of Hydraulic Engineering, Vol. 110, No. 11, pp. 1540-1556.

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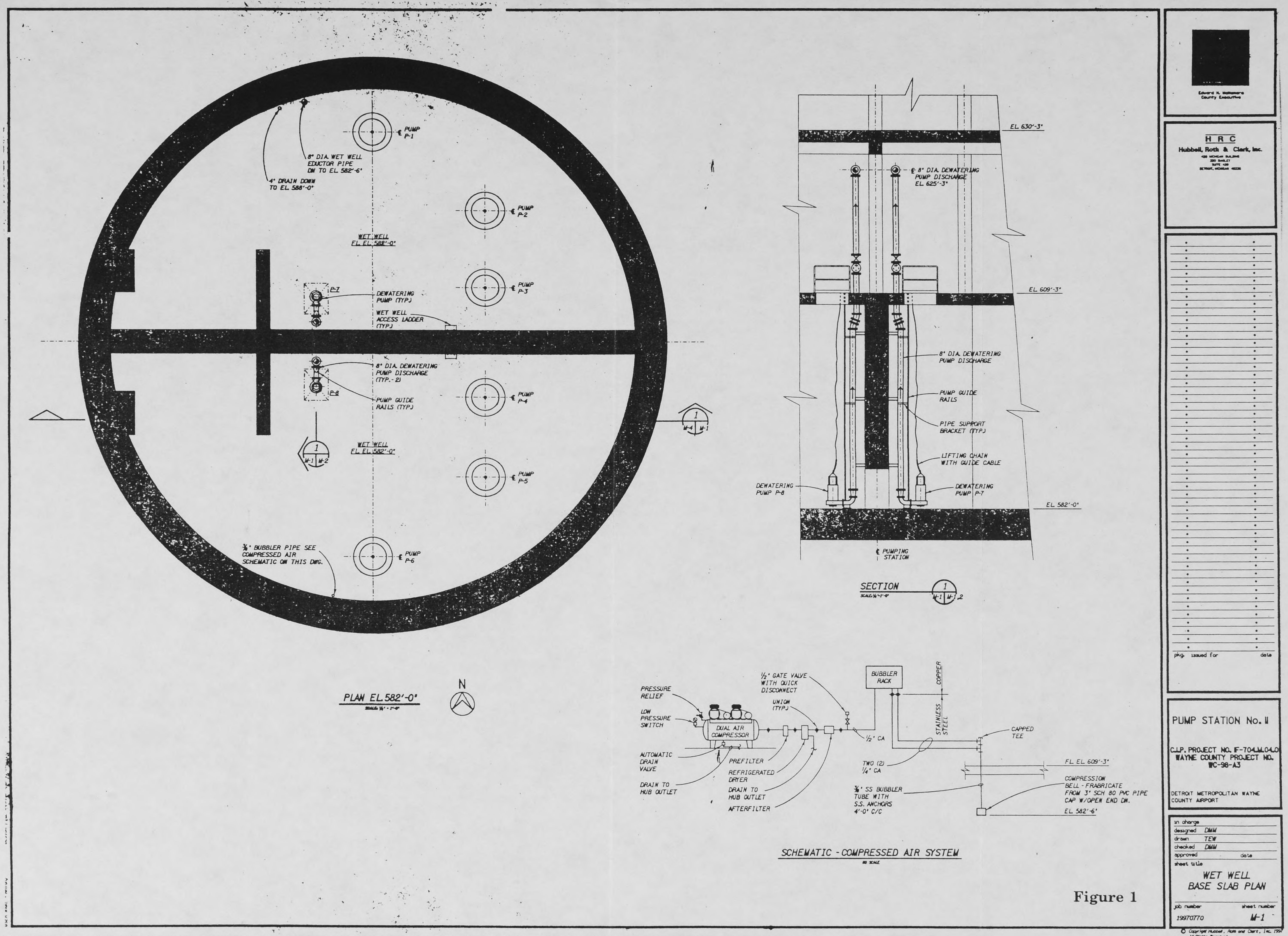
Padmanabhan, M. and G.E. Hecker, (1984) *Scale Effects in Pump Sump Models,* ASCE Journal of Hydraulic Engineering, Vol. 110, No. 11, pp. 1540-1556.


PUMP P-1
8" DIA. WET WELL EDUCTOR PIPE DN TO EL. 582'-6"
4" DRAIN DOWN TO EL. 588'-0"
PUMP P-2
WET WELL EL. EL. 582'-0"
PUMP P-3
P-7
DEWATERING PUMP (TYP.)
WET WELL ACCESS LADDER (TYP.)
8" DIA. DEWATERING PUMP DISCHARGE (TYP. - 2)
P-8
PUMP GUIDE RAILS (TYP.)
PUMP P-4
WET WELL EL. EL. 582'-0"
PUMP P-5
3/8" BUBBLER PIPE SEE COMPRESSED AIR SCHEMATIC ON THIS DWG.
PUMP P-6
PLAN EL. 582'-0"
N
EL. 630'-3"
8" DIA. DEWATERING PUMP DISCHARGE EL. 625'-3"
EL. 609'-3"
8" DIA. DEWATERING PUMP DISCHARGE
PUMP GUIDE RAILS
PIPE SUPPORT BRACKET (TYP.)
LIFTING CHAIN WITH GUIDE CABLE
DEWATERING PUMP P-8
DEWATERING PUMP P-7
EL. 582'-0"
PUMPING STATION
SECTION
PRESSURE RELIEF
LOW PRESSURE SWITCH
DUAL AIR COMPRESSOR
AUTOMATIC DRAIN VALVE
DRAIN TO HUB OUTLET
1/2" GATE VALVE WITH QUICK DISCONNECT
UNION (TYP.)
PREFILTER
REFRIGERATED DRYER
DRAIN TO HUB OUTLET
AFTERFILTER
1/2" CA
BUBBLER RACK
COPPER
STAINLESS STEEL
TWO (2) 1/4" CA
CAPPED TEE
FL. EL. 609'-3"
3/8" SS BUBBLER TUBE WITH S.S. ANCHORS 4'-0" C/C
COMPRESSION BELL - FRABRICATE FROM 3" SCH 80 PVC PIPE CAP W/OPEN END DN.
EL. 582'-6"
SCHEMATIC - COMPRESSED AIR SYSTEM
NO SCALE
Edward H. McNamara
County Executive
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checked DMM
approved date
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WET WELL BASE SLAB PLAN
job number 19970770
sheet number M-1
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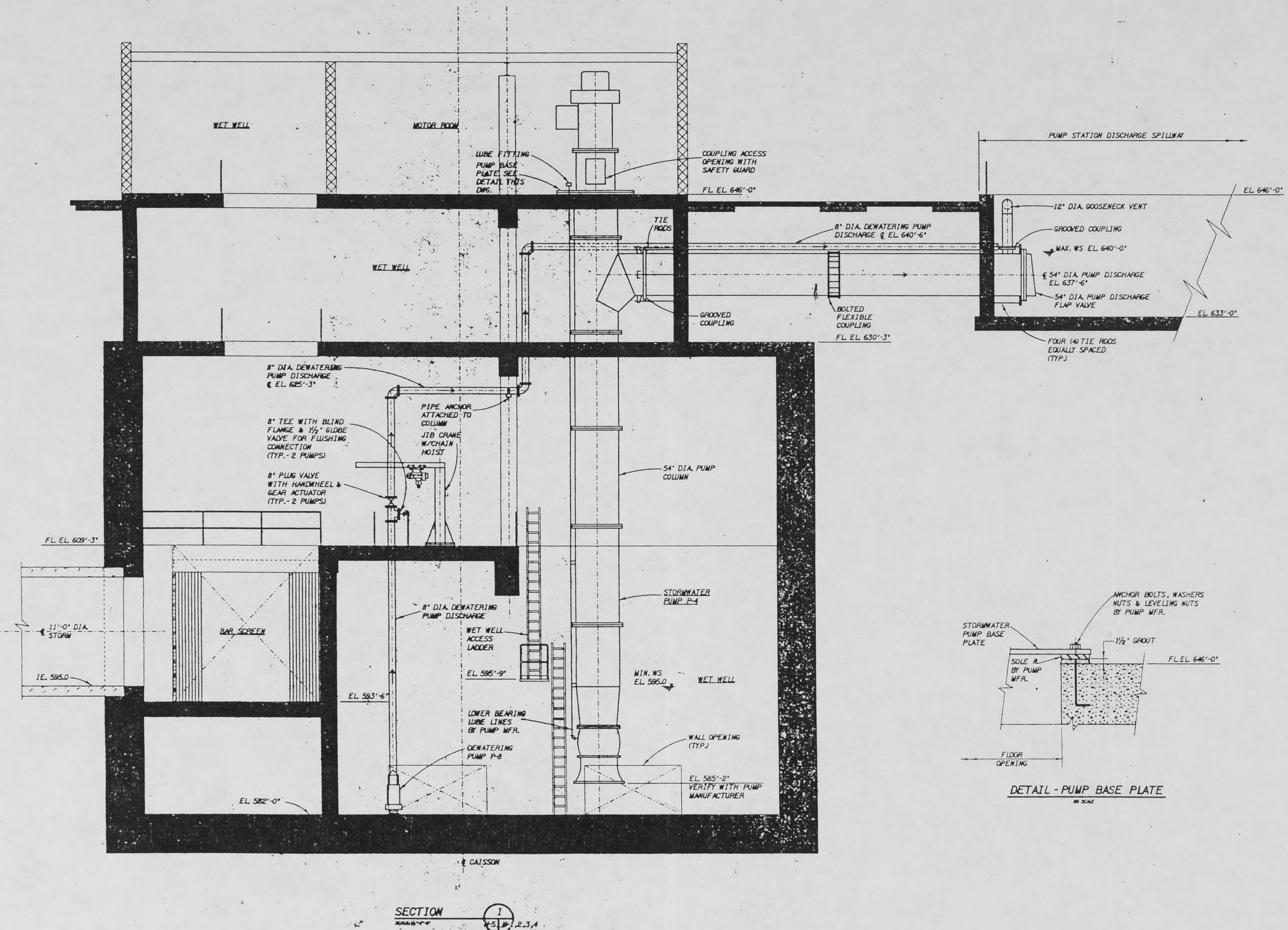
Figure 1



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drawn	TEW
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approved	date

sheet title

SECTIONS & DETAILS

job number 19970770
sheet number M-5

Figure 2

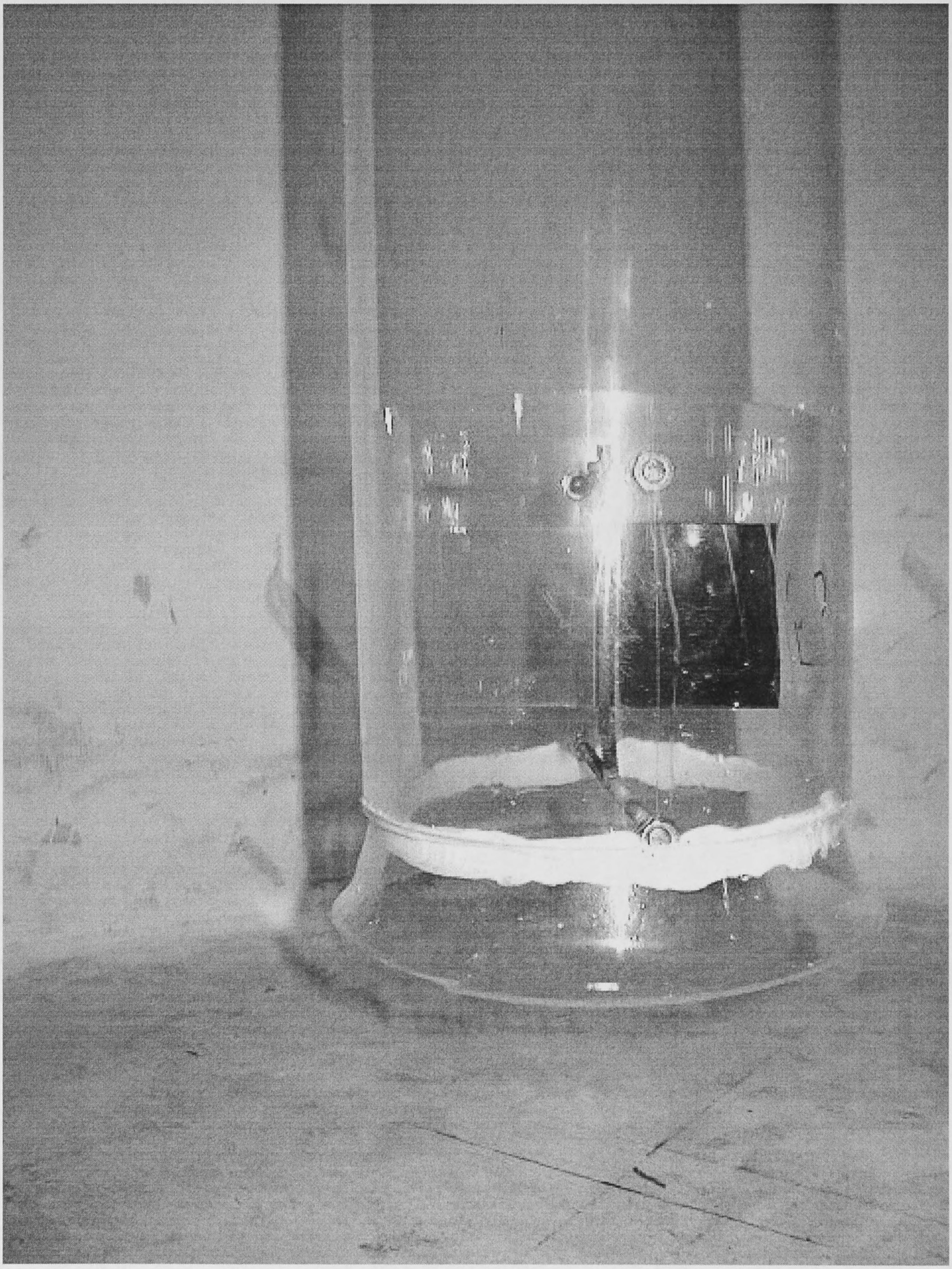


Figure 3. View of Pump Intake with Suction Bell and Swirl Meter Installed

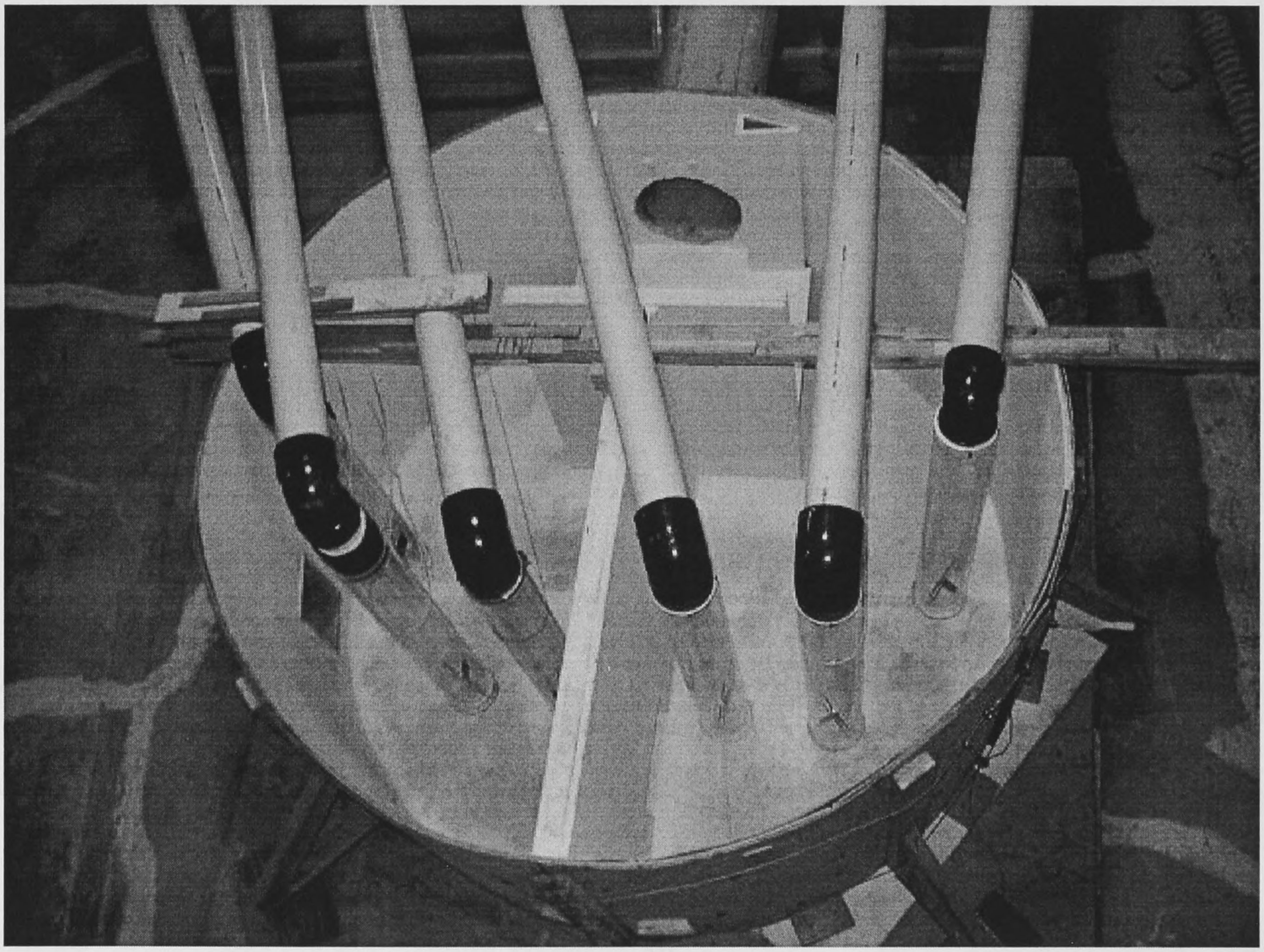


Figure 4. Overhead View of Model and Six Pump Intake Lines.

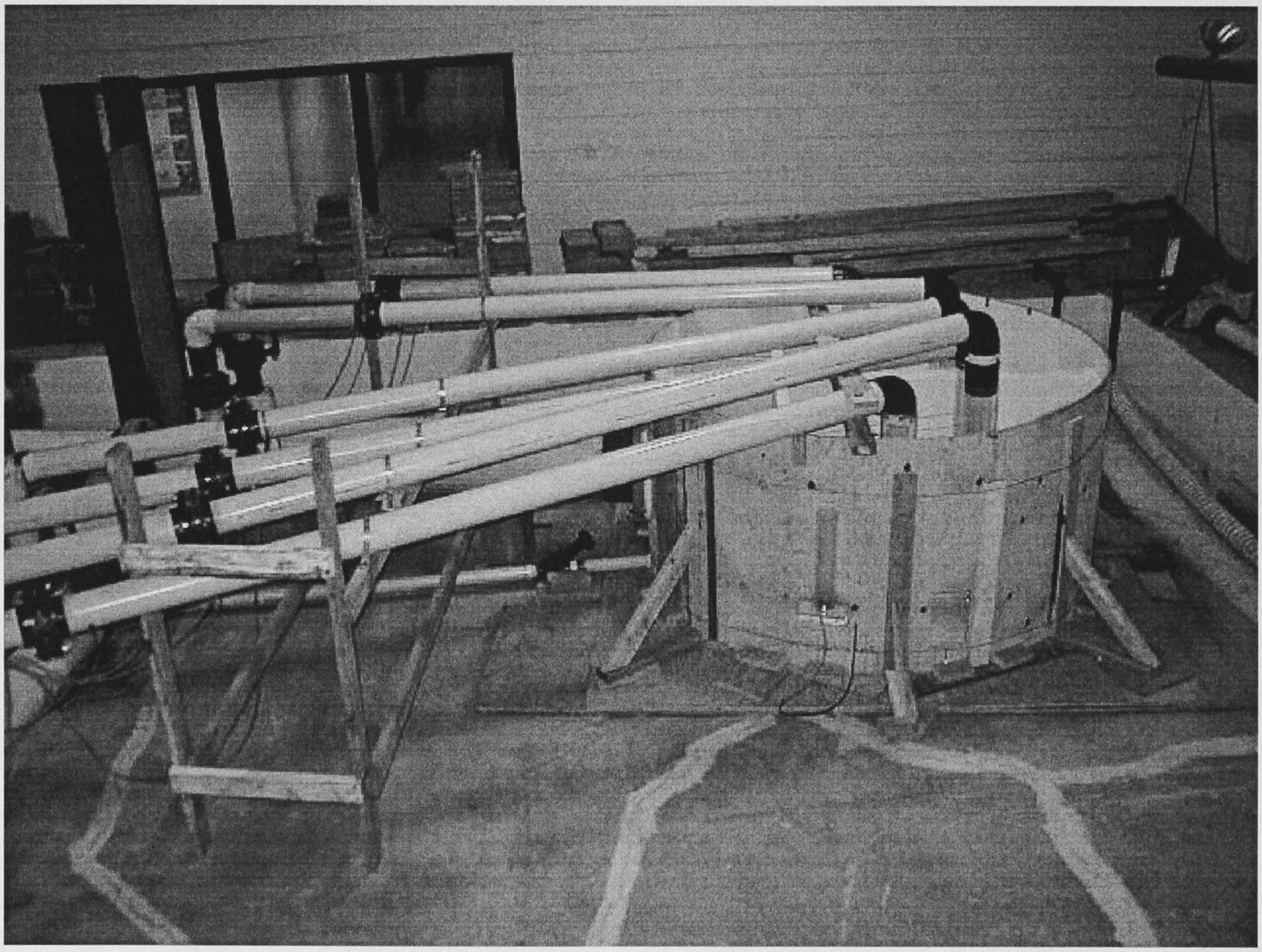


Figure 5. Piping System Associated with Recirculating Water Supply System. Recirculating Pump is to left of Image.

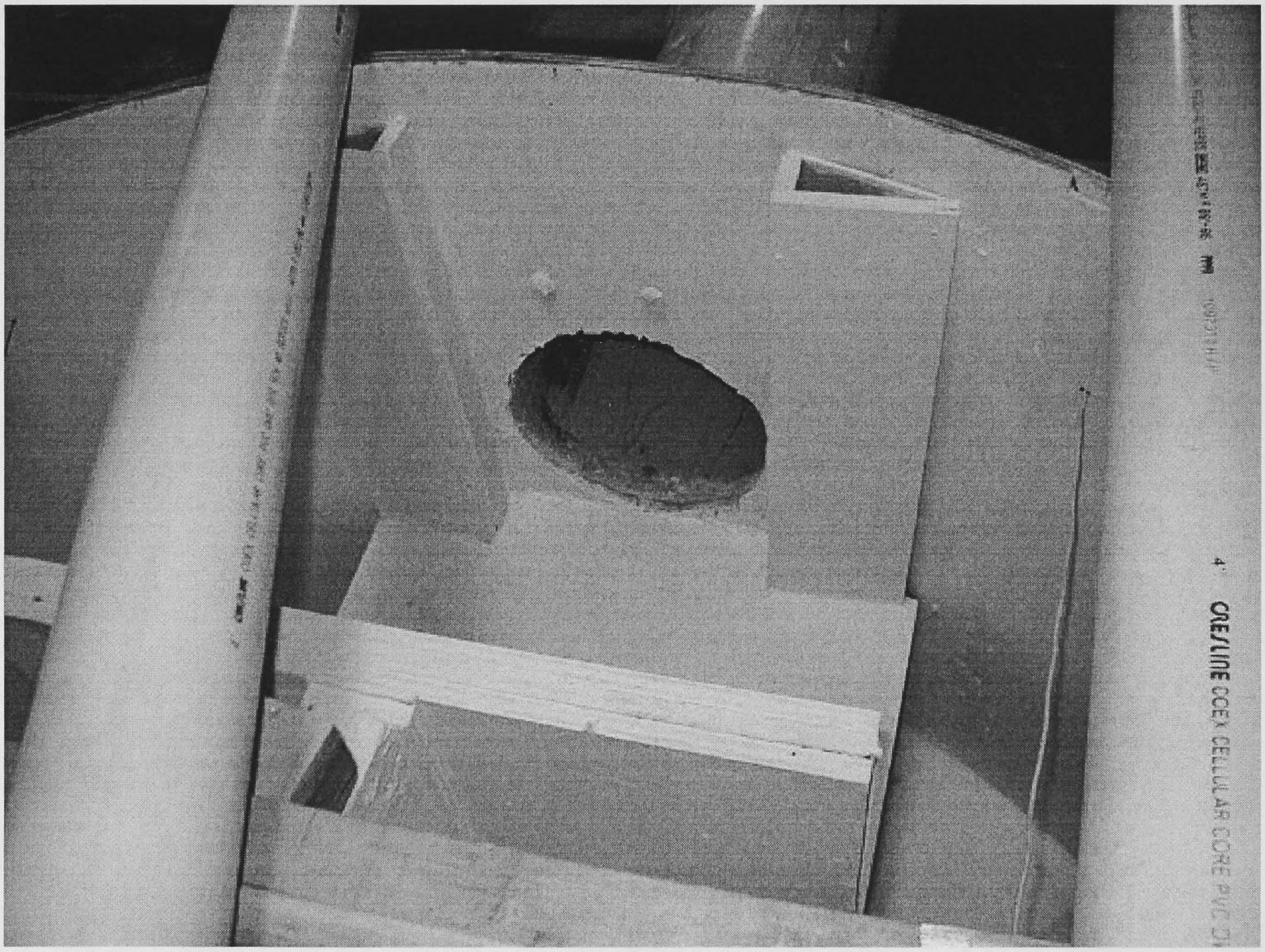


Figure 6. Inlet Tunnel into Wet Well. Note Elevated Inlet Chamber.

Figure 7. Nature of Flow in Inlet Chamber with Six Pumps in Operation at the High Water Level (Start the sixth pump). This image was taken after the design modifications were made.

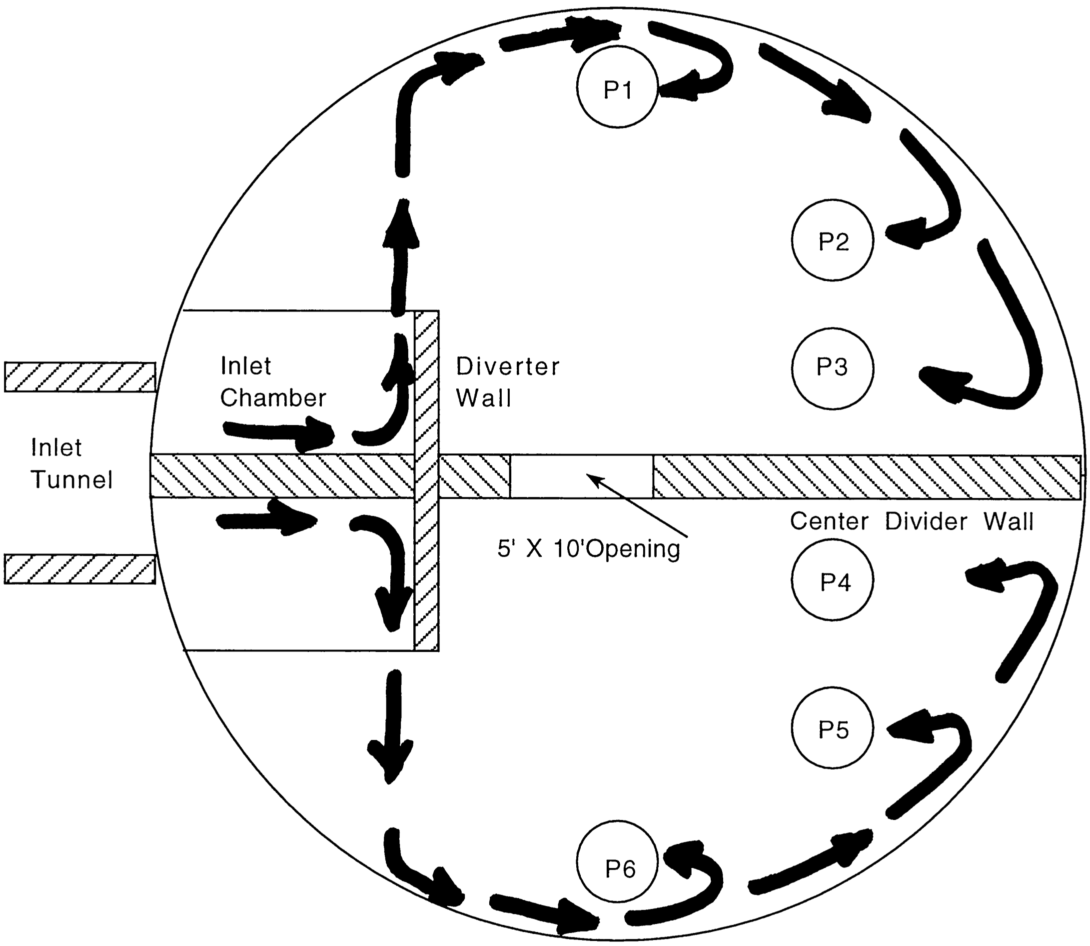


Figure 8. Generalized streamlines for flow entering Pump Station 11.

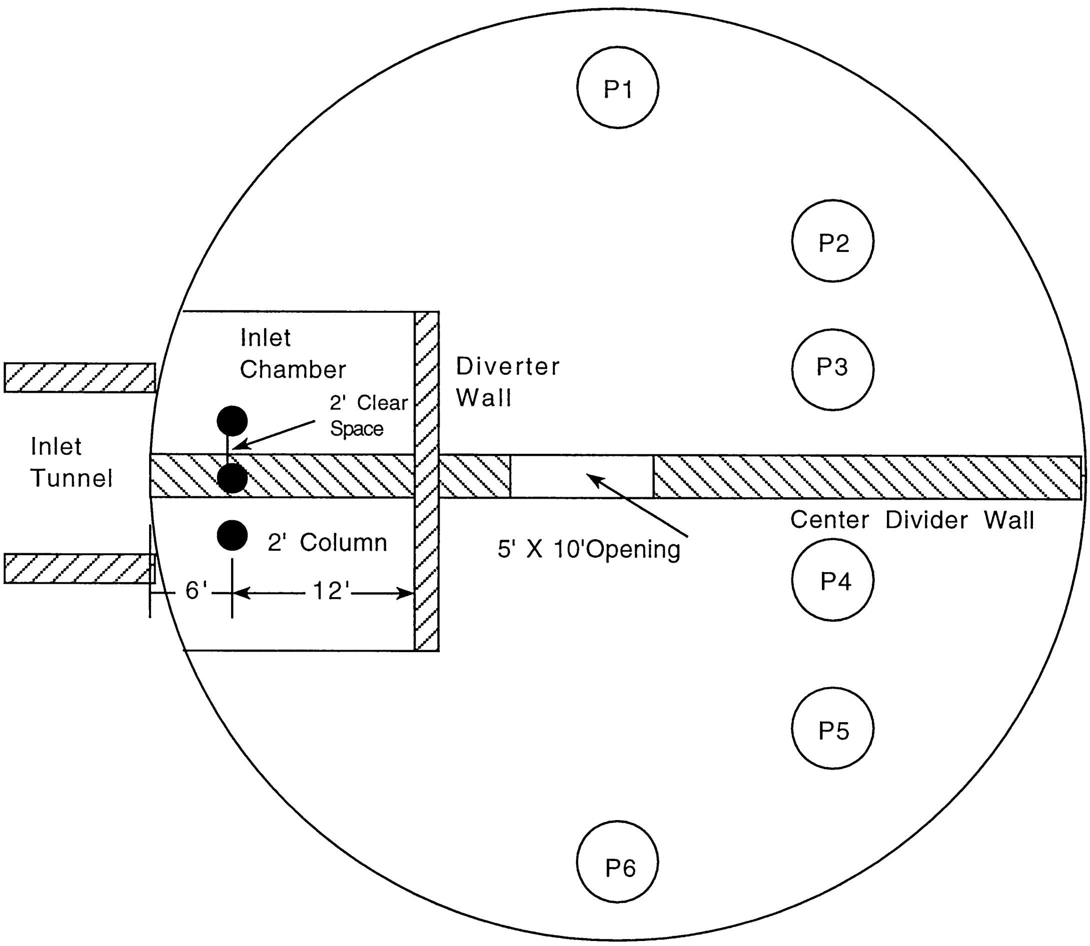


Figure 9. Locations of Proposed Columns in Inlet Chamber.

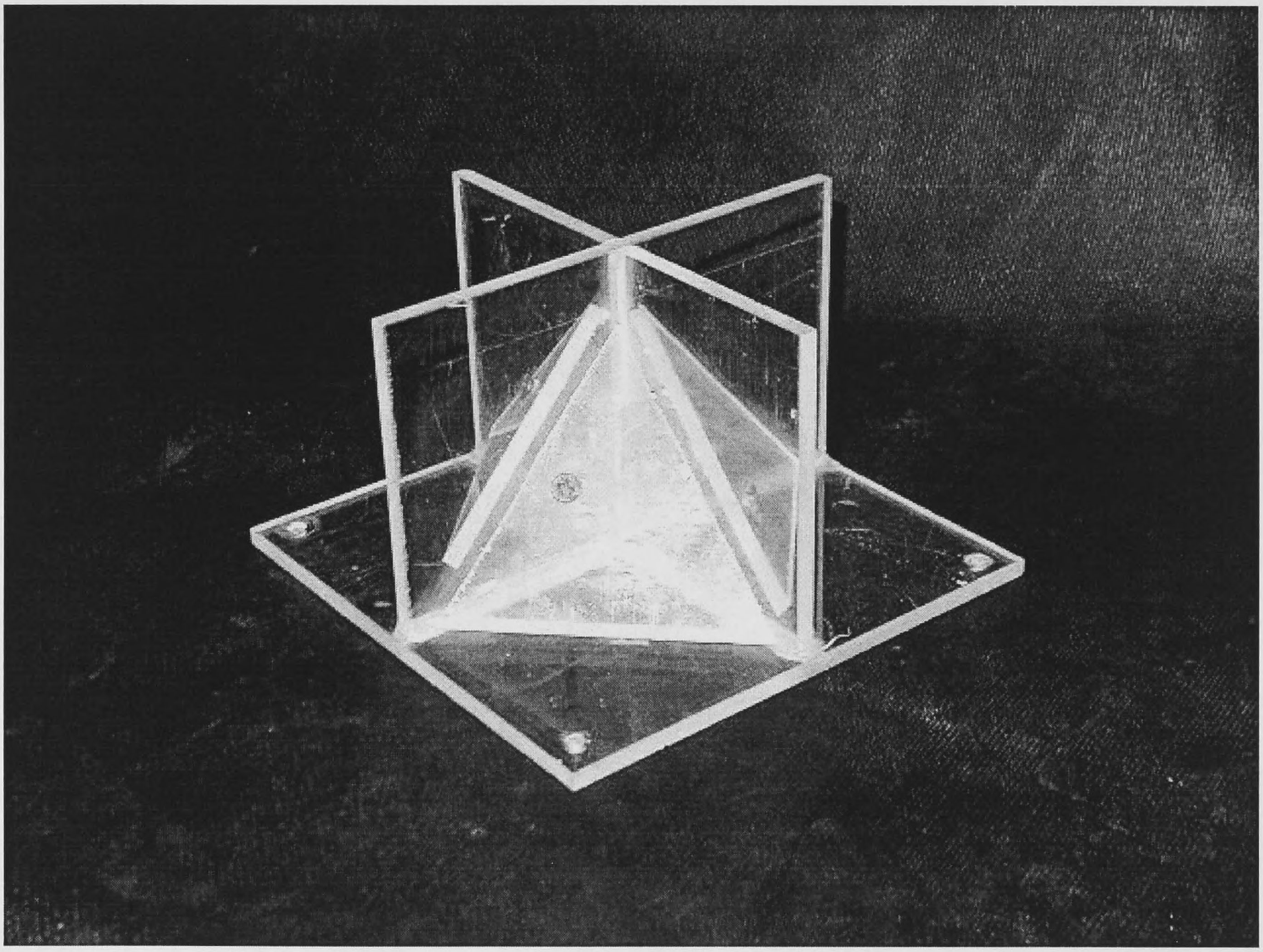


Figure 10. Cone Recommended to be Installed Beneath Pump Intakes.

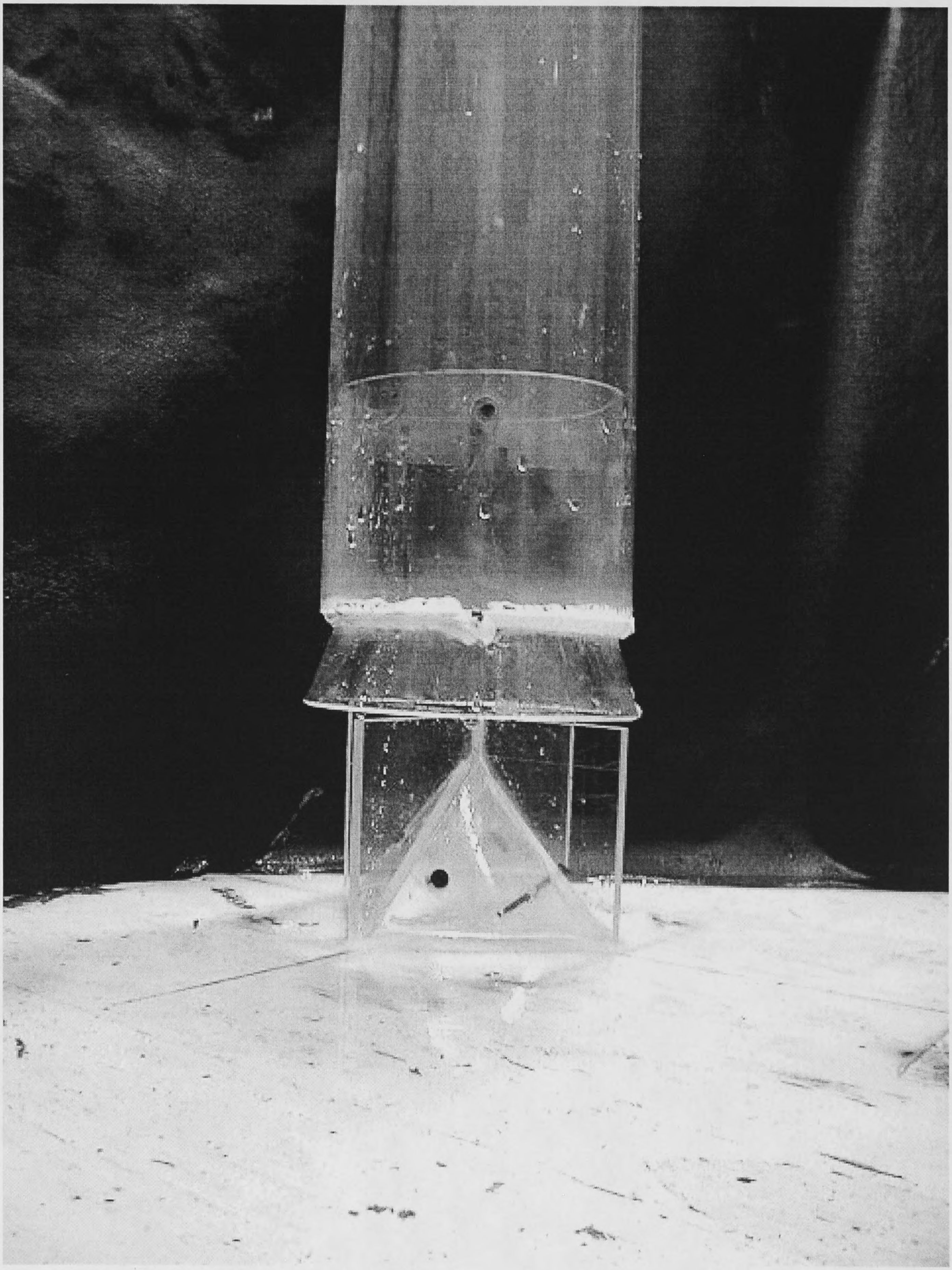


Figure 11. Pump Intake with Cone Installed Beneath it.

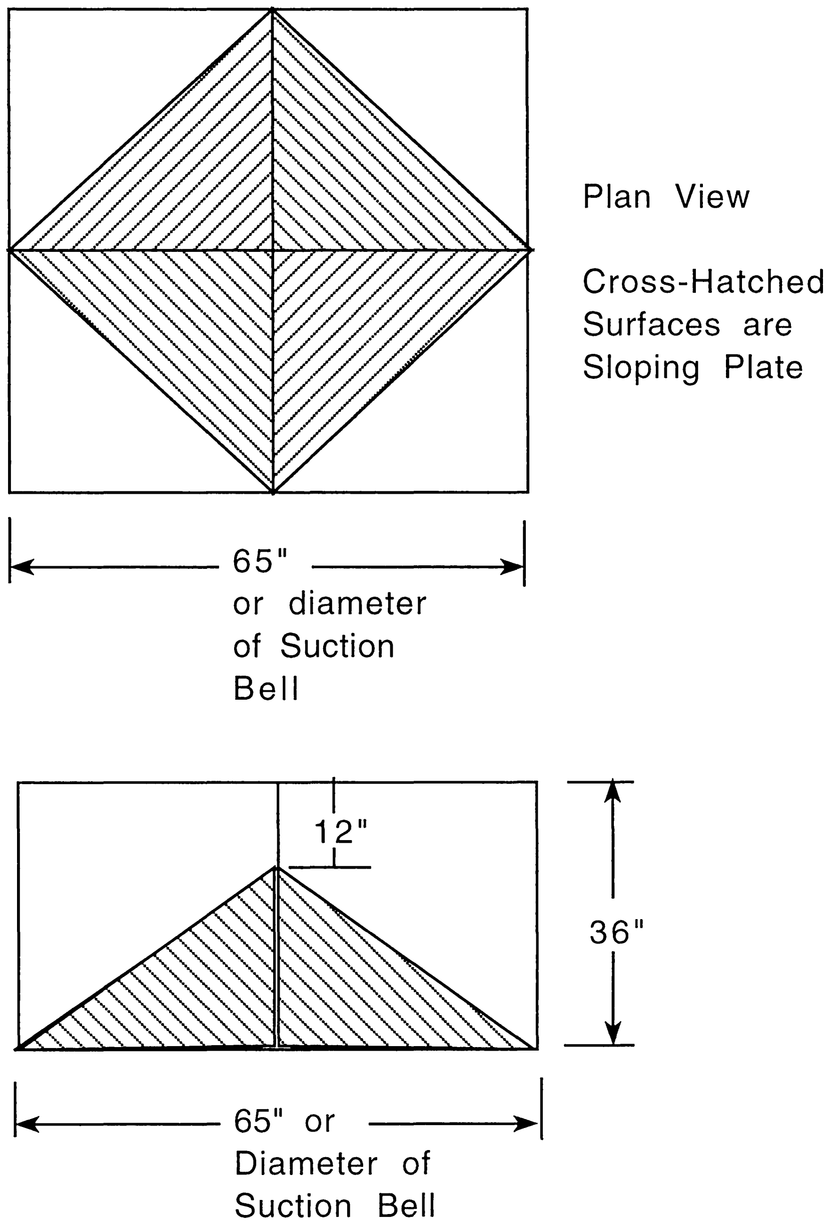


Figure 12. Dimensions of cones to be installed beneath pump instakes.

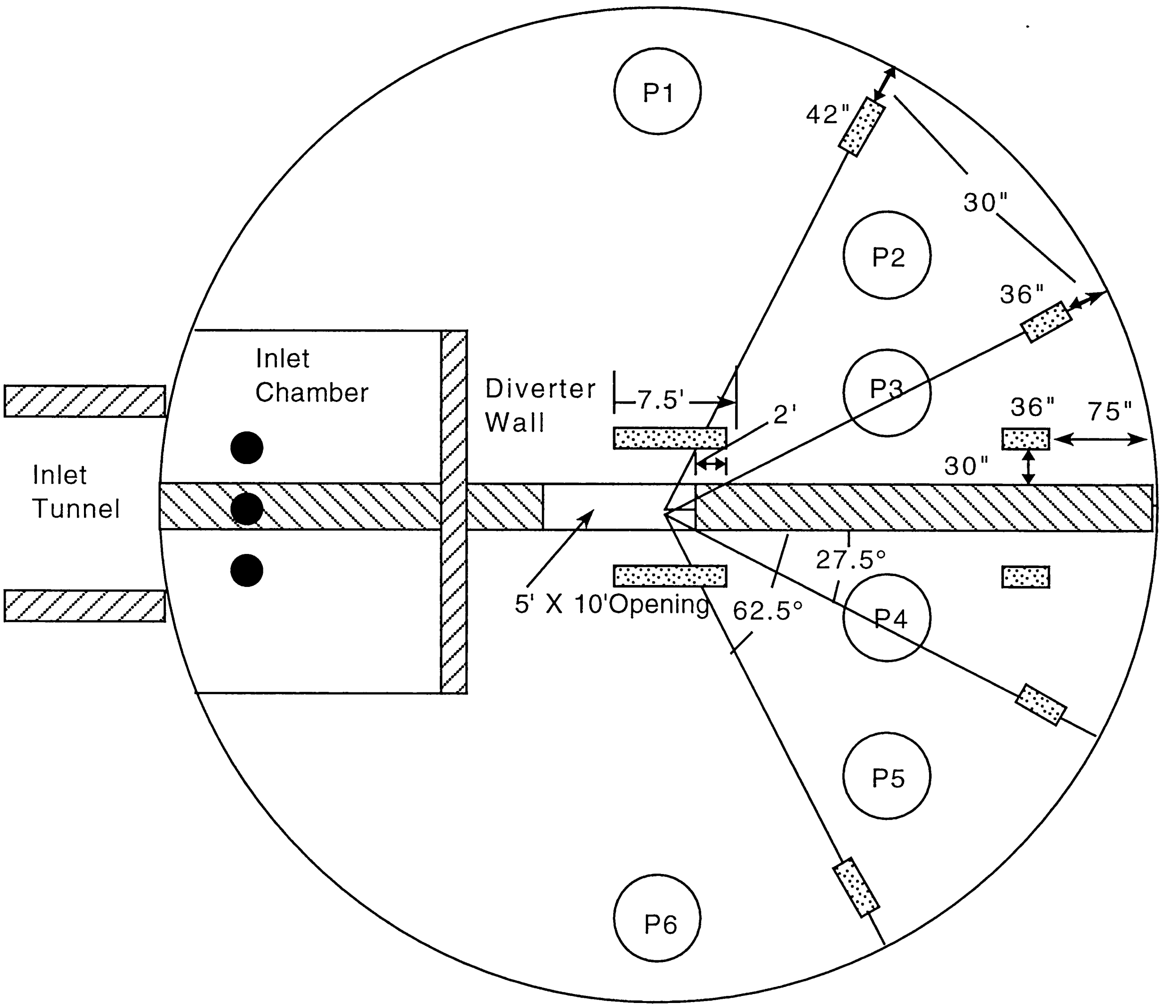


Figure 13. Locations of Proposed Baffle Walls in Wet Well Interior.

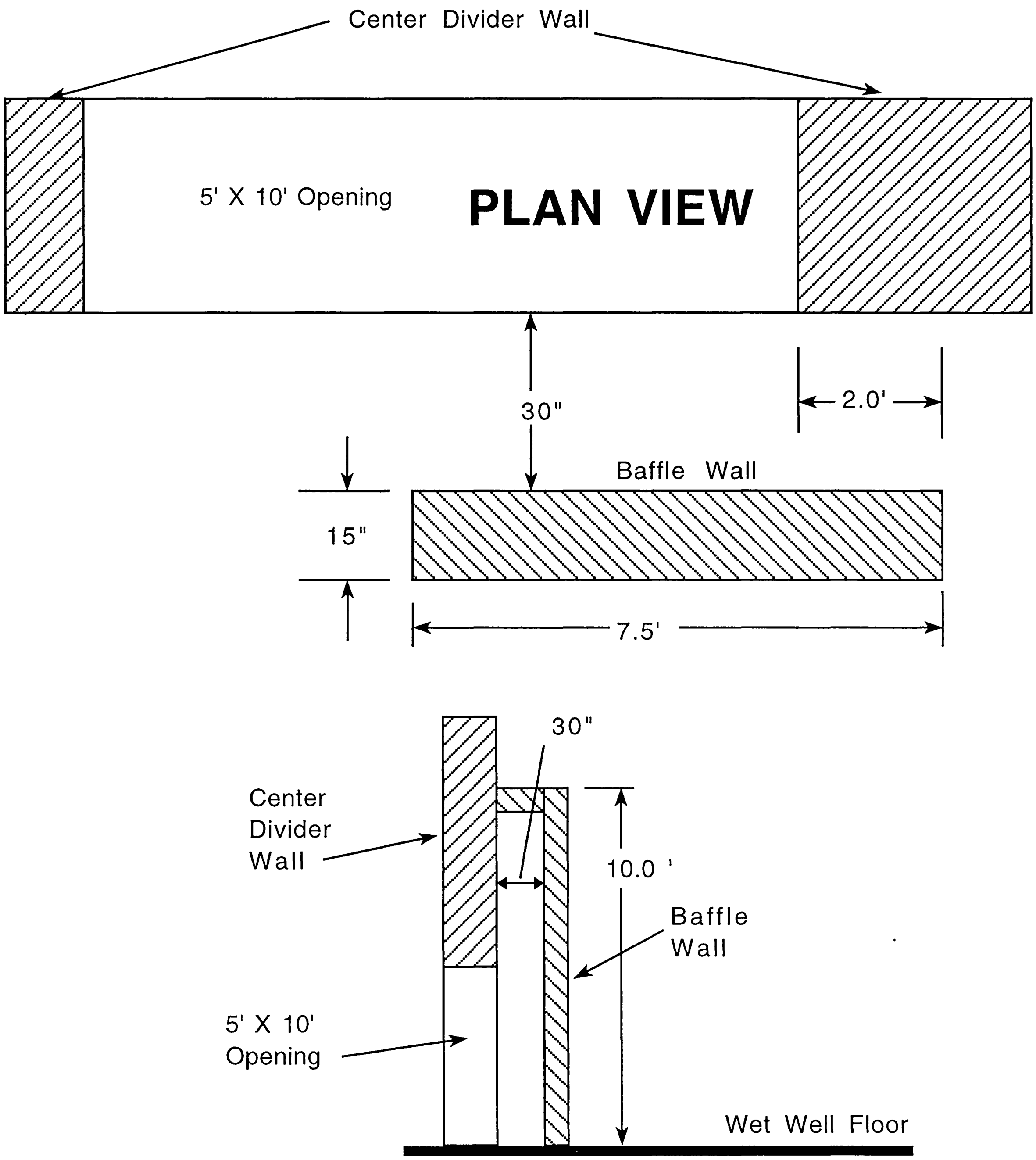


Figure 14. Details of Baffle Wall on Either Side of 5' by 10 ' Opening in Center Divider Wall.

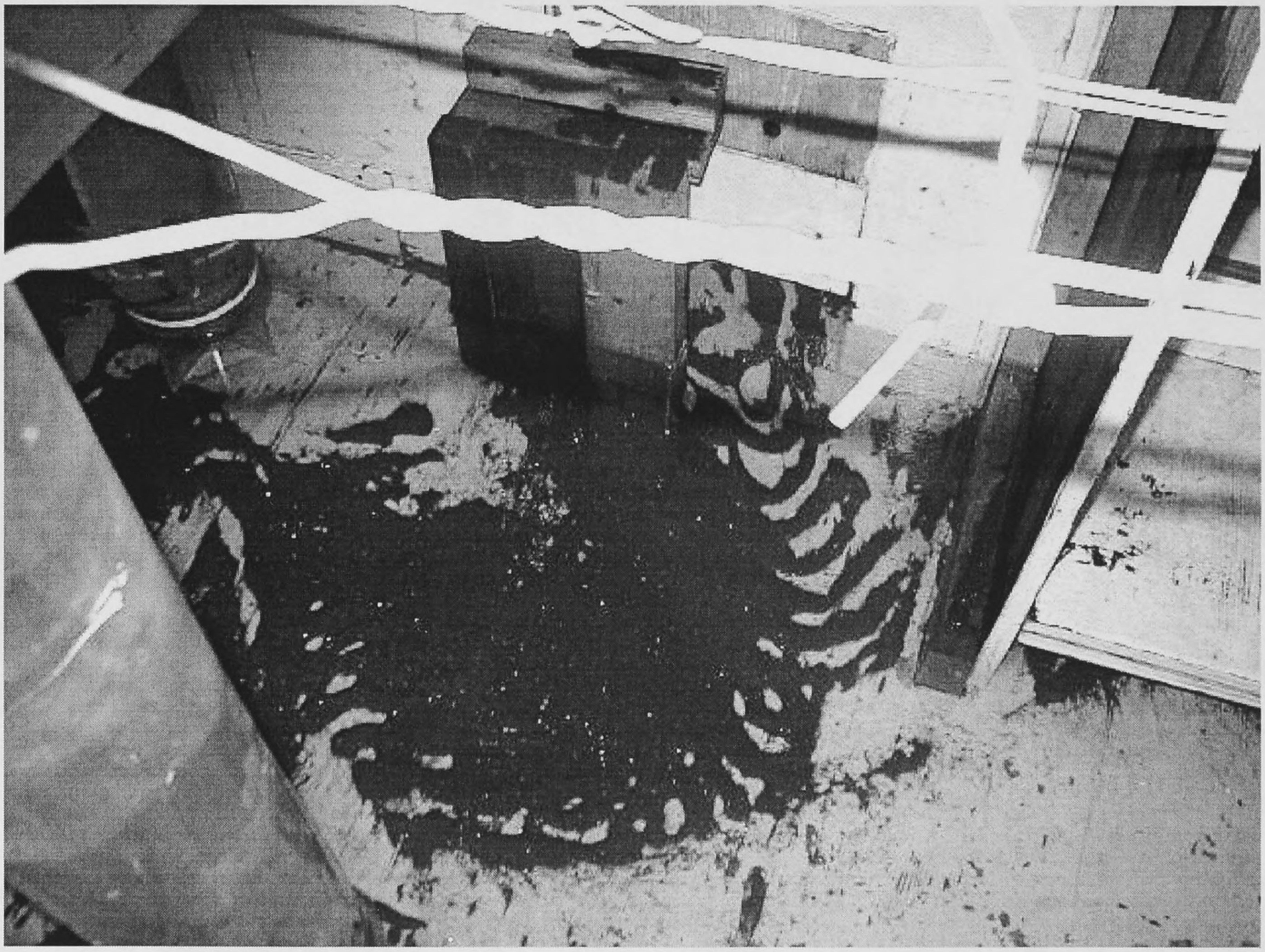


Figure 15. Sedimentation Patterns in Front of Intakes 2 and 3.

Figure 15. Sedimentation Patterns Behind Intakes 2 and 3.

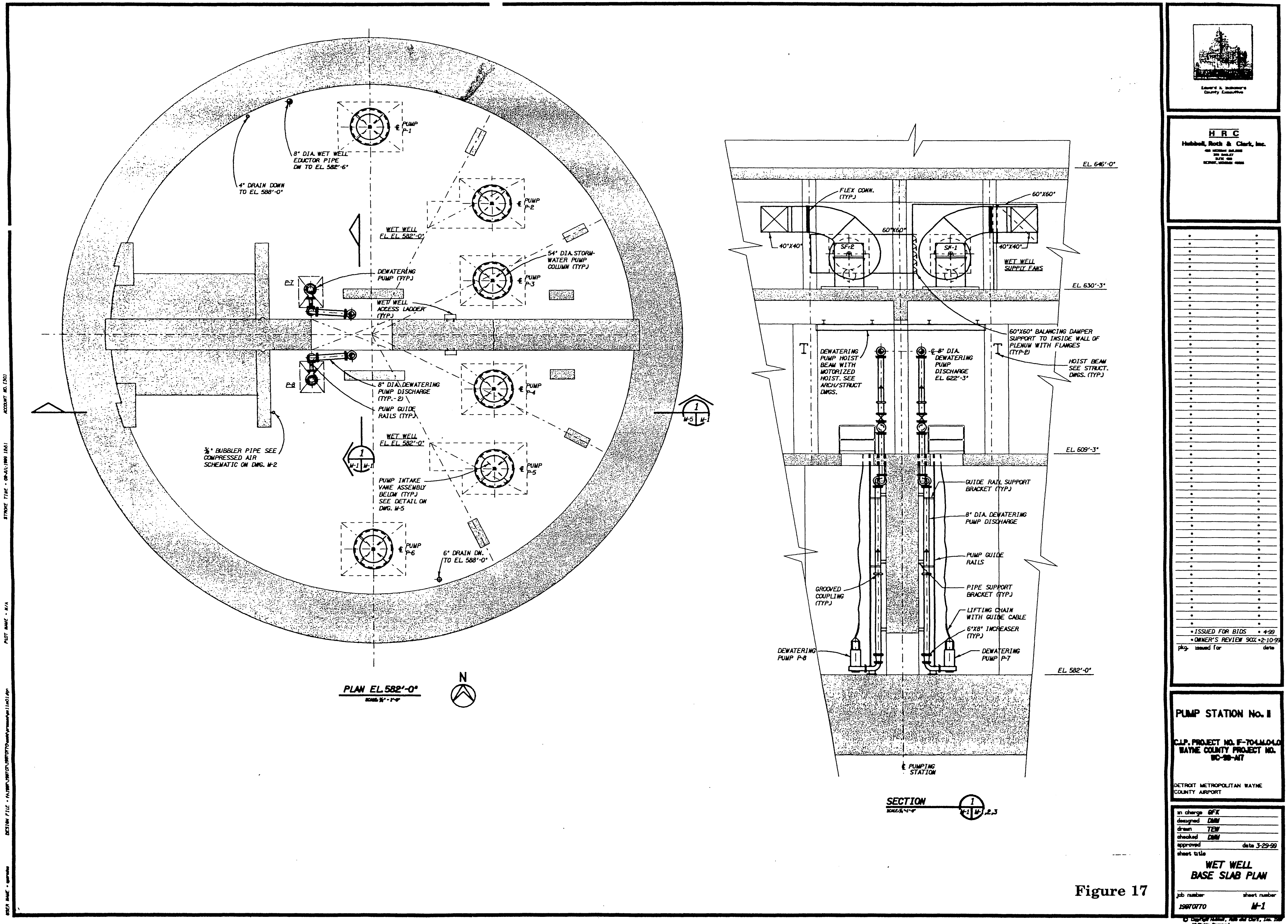

PUMP P-1
8" DIA. WET WELL EDUCTOR PIPE DN TO EL. 582'-6"
4" DRAIN DOWN TO EL. 588'-0"
PUMP P-2
WET WELL EL. EL. 582'-0"
54" DIA. STORM-WATER PUMP COLUMN (TYP.)
PUMP P-3
DEWATERING PUMP (TYP.)
P-7
WET WELL ACCESS LADDER (TYP.)
P-8
8" DIA. DEWATERING PUMP DISCHARGE (TYP.-2)
PUMP GUIDE RAILS (TYP.)
PUMP P-4
3/4" BUBBLER PIPE SEE COMPRESSED AIR SCHEMATIC ON DWG. M-2
WET WELL EL. EL. 582'-0"
PUMP INTAKE VANE ASSEMBLY BELOW (TYP.) SEE DETAIL ON DWG. M-5
PUMP P-5
PUMP P-6
6" DRAIN DN. TO EL. 588'-0"
PLAN EL. 582'-0"
N
EL. 646'-0"
FLEX CONN. (TYP.)
60"X60"
40"X40"
SF-2
SF-1
WET WELL SUPPLY FANS
EL. 630'-3"
60"X60" BALANCING DAMPER SUPPORT TO INSIDE WALL OF PLENUM WITH FLANGES (TYP-2)
DEWATERING PUMP HOIST BEAM WITH MOTORIZED HOIST. SEE ARCH/STRUCT DWGS.
8" DIA. DEWATERING PUMP DISCHARGE EL. 622'-3"
HOIST BEAM SEE STRUCT. DWGS. (TYP.)
EL. 609'-3"
GUIDE RAIL SUPPORT BRACKET (TYP.)
8" DIA. DEWATERING PUMP DISCHARGE
PUMP GUIDE RAILS
GROOVED COUPLING (TYP.)
PIPE SUPPORT BRACKET (TYP.)
LIFTING CHAIN WITH GUIDE CABLE
6"X8" INCREASER (TYP.)
DEWATERING PUMP P-8
DEWATERING PUMP P-7
EL. 582'-0"
℄ PUMPING STATION
SECTION 1 M-1 M-2,3
HRC
Hubbell, Roth & Clark, Inc.
ISSUED FOR BIDS 4-99
OWNER'S REVIEW 90% 2-10-99
pkg. issued for date
PUMP STATION No. II
C.I.P. PROJECT NO. F-70-I.M.O4.O
WAYNE COUNTY PROJECT NO. WC-98-AIT
DETROIT METROPOLITAN WAYNE COUNTY AIRPORT
in charge GFK
designed DMW
drawn TEW
checked DMW
approved date 3-29-99
sheet title
WET WELL BASE SLAB PLAN
job number 19970770
sheet number M-1

Figure 17

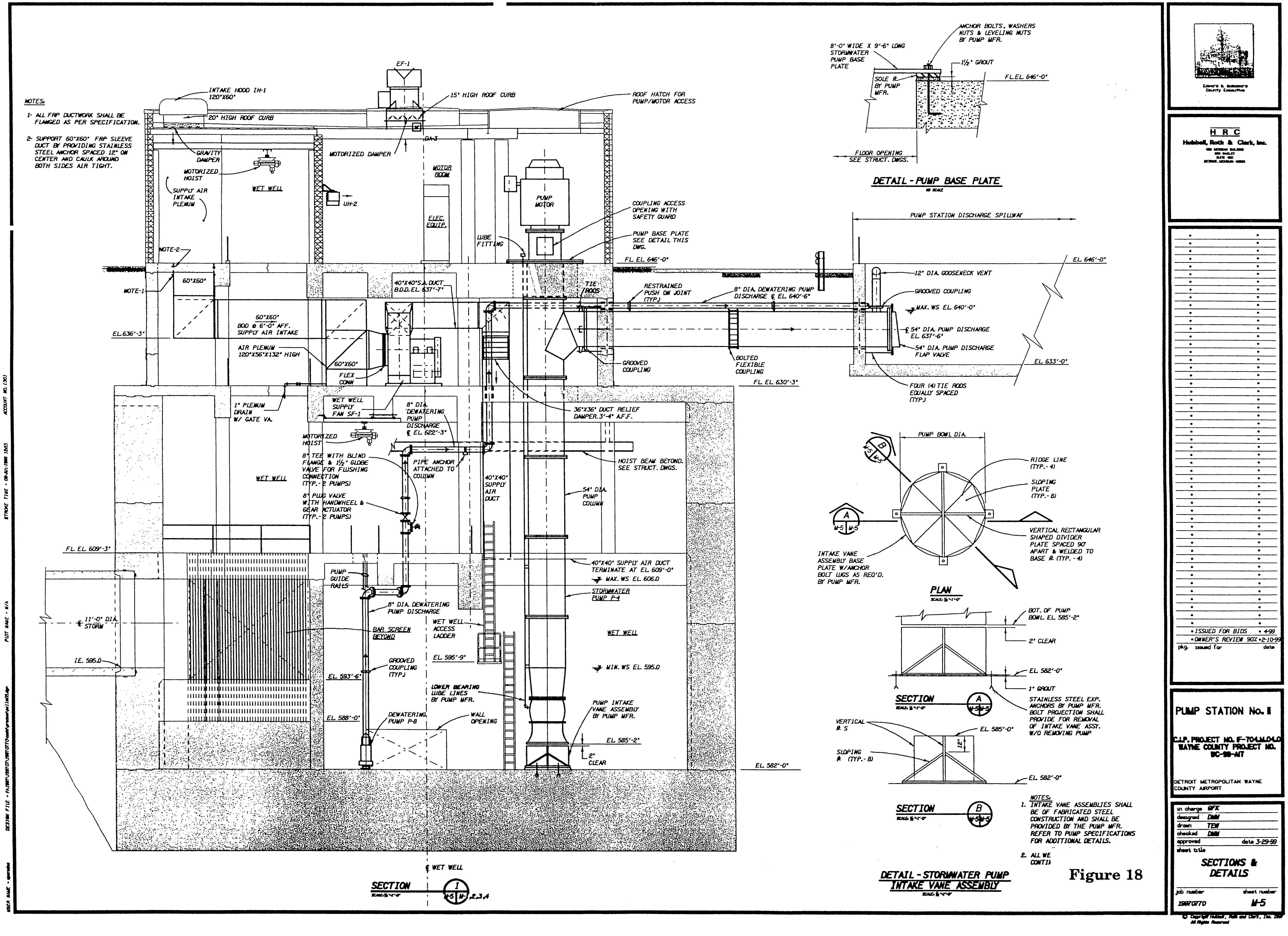

NOTES:
1- ALL FRP DUCTWORK SHALL BE FLANGED AS PER SPECIFICATION.
2- SUPPORT 60"X60" FRP SLEEVE DUCT BY PROVIDING STAINLESS STEEL ANCHOR SPACED 12" ON CENTER AND CAULK AROUND BOTH SIDES AIR TIGHT.
EF-1
INTAKE HOOD IH-1 120"X60"
15" HIGH ROOF CURB
ROOF HATCH FOR PUMP/MOTOR ACCESS
20" HIGH ROOF CURB
GRAVITY DAMPER
MOTORIZED DAMPER
MOTORIZED HOIST
SUPPLY AIR INTAKE PLENUM
WET WELL
MOTOR ROOM
UH-2
ELEC. EQUIP.
PUMP MOTOR
COUPLING ACCESS OPENING WITH SAFETY GUARD
LUBE FITTING
PUMP BASE PLATE SEE DETAIL THIS DWG.
NOTE-2
NOTE-1
60"X60"
FL EL 646'-0"
40"X40"S.A DUCT B.O.D. EL 637'-7"
TIE RODS
RESTRAINED PUSH ON JOINT (TYP.)
8" DIA. DEWATERING PUMP DISCHARGE ℄ EL 640'-6"
12" DIA. GOOSENECK VENT
GROOVED COUPLING
MAX. WS EL 640'-0"
54" DIA. PUMP DISCHARGE EL 637'-6"
54" DIA. PUMP DISCHARGE FLAP VALVE
EL 646'-0"
EL 633'-0"
PUMP STATION DISCHARGE SPILLWAY
EL 636'-3"
60"X60" BOD @ 6'-0" AFF. SUPPLY AIR INTAKE
AIR PLENUM 120"X56"X132" HIGH
60"X60"
FLEX CONN
GROOVED COUPLING
BOLTED FLEXIBLE COUPLING
FL EL 630'-3"
FOUR (4) TIE RODS EQUALLY SPACED (TYP.)
1" PLENUM DRAIN W/ GATE VA.
WET WELL SUPPLY FAN SF-1
8" DIA. DEWATERING PUMP DISCHARGE ℄ EL 622'-3"
36"X36" DUCT RELIEF DAMPER 3'-4" A.F.F.
MOTORIZED HOIST
8" TEE WITH BLIND FLANGE & 1½" GLOBE VALVE FOR FLUSHING CONNECTION (TYP.- 2 PUMPS)
PIPE ANCHOR ATTACHED TO COLUMN
HOIST BEAM BEYOND. SEE STRUCT. DWGS.
WET WELL
8" PLUG VALVE WITH HANDWHEEL & GEAR ACTUATOR (TYP.- 2 PUMPS)
40"X40" SUPPLY AIR DUCT
54" DIA. PUMP COLUMN
FL EL 609'-3"
PUMP GUIDE RAILS
40"X40" SUPPLY AIR DUCT TERMINATE AT EL 609'-0"
MAX. WS EL 606.0
STORMWATER PUMP P-4
8" DIA. DEWATERING PUMP DISCHARGE
11'-0" DIA. STORM
BAR SCREEN BEYOND
WET WELL ACCESS LADDER
WET WELL
IE. 595.0
EL 595'-9"
MIN. WS EL 595.0
EL 593'-6"
GROOVED COUPLING (TYP.)
LOWER BEARING LUBE LINES BY PUMP MFR.
PUMP INTAKE VANE ASSEMBLY BY PUMP MFR.
EL 588'-0"
DEWATERING PUMP P-8
WALL OPENING
EL 585'-2"
2" CLEAR
EL 582'-0"
℄ WET WELL
SECTION 1 M-5 M-2,3,4
8'-0" WIDE X 9'-6" LONG STORMWATER PUMP BASE PLATE
ANCHOR BOLTS, WASHERS NUTS & LEVELING NUTS BY PUMP MFR.
1½" GROUT
SOLE PL BY PUMP MFR.
FL EL 646'-0"
FLOOR OPENING SEE STRUCT. DWGS.
DETAIL - PUMP BASE PLATE
NO SCALE
PUMP BOWL DIA.
RIDGE LINE (TYP.- 4)
SLOPING PLATE (TYP.- 8)
VERTICAL RECTANGULAR SHAPED DIVIDER PLATE SPACED 90° APART & WELDED TO BASE PL (TYP. - 4)
INTAKE VANE ASSEMBLY BASE PLATE W/ANCHOR BOLT LUGS AS REQ'D. BY PUMP MFR.
PLAN
BOT. OF PUMP BOWL EL 585'-2"
2" CLEAR
EL 582'-0"
1" GROUT
STAINLESS STEEL EXP. ANCHORS BY PUMP MFR. BOLT PROJECTION SHALL PROVIDE FOR REMOVAL OF INTAKE VANE ASSY. W/O REMOVING PUMP
SECTION A M-5
VERTICAL PL S
EL 585'-0"
12"
SLOPING PL (TYP.- 8)
EL 582'-0"
SECTION B M-5
NOTES:
1. INTAKE VANE ASSEMBLIES SHALL BE OF FABRICATED STEEL CONSTRUCTION AND SHALL BE PROVIDED BY THE PUMP MFR. REFER TO PUMP SPECIFICATIONS FOR ADDITIONAL DETAILS.
2. ALL WE CONTI
DETAIL - STORMWATER PUMP INTAKE VANE ASSEMBLY
HRC
Hubbell, Roth & Clark, Inc.
ISSUED FOR BIDS 4-99
OWNER'S REVIEW 90% 2-10-99
pkg. issued for date
PUMP STATION No. II
C.I.P. PROJECT NO. F-704.M.O.L.O
WAYNE COUNTY PROJECT NO. WC-98-AIT
DETROIT METROPOLITAN WAYNE COUNTY AIRPORT
in charge GFK
designed DMW
drawn TEW
checked DMW
approved date 3-29-99
sheet title
SECTIONS & DETAILS
job number 19970770
sheet number M-5

Figure 18

APPENDIX 1

ANALYSIS OF PUMP STARTUP AND SHUTDOWN

APPENDIX 1

Analysis of Pump Startup and Shutdown

Objective

This analysis was performed to examine the potential for surge within the wet well associated with pump startup and shutdown. There are a wide variety of operating conditions that could be analyzed for this purpose and analyses were performed for the conditions associated with one to six pumps in operation at a time. The differences in results for these different cases is relatively minor. Since all of the individual are identical, they will all behave in a generally similar condition with the exception that some of the pumps have a slightly shorter discharge line than the others (approximately 90 ft vs. 104 ft). Therefore, no attempt was made to identify which particular pump was started or stopped and the results can be considered generic to all pumps.

The inflow into the wet well at a startup condition can vary from just greater than the capacity of the pumps that were previously in operation to just less than the combined capacity of all pumps in operation after the startup. In order to identify clearly the magnitude of the surge effect, the inflow into the wet well was assumed equal to the final steady state pumping capacity after the pump was started. In this approach, the wet well level will approach a constant elevation as steady state is approached and the deviations from this constant level will indicate the surge effect. A similar approach on pump shutdown analyses was taken in which the inflow into the wet well was assumed to be the steady state pumping capacity after the pump was completely stopped. The effect of storage within the inflow tunnel was also ignored since this additional storage will mitigate water level changes within the wet well. Also, at low wet well water levels, tunnel storage is irrelevant since the occurrence of critical flow at the inlet to the wet well will limit the flow into the wet well and negate any tunnel storage effects. Finally assumptions for the time required for the pump to come up to rated speed or spin down to a stop are required. Generic correlations for pump inertia as a function of pump characteristics were derived from the literature and the pump moment of inertia was used to estimate the startup or shutdown times.

Method of Analysis

Many fluid transient problems are analyzed using the method of characteristics. This method is derived from the unsteady momentum and continuity equations with the appropriate boundary conditions applied and tracks pressure waves traveling through the fluid. This method of analysis works extremely well in the case of a conduit flowing full over the entire length. However, in this particular application, the length of the water column is constantly changing during pump startup and shutdown since the outlet pipe is either filling or draining. Therefore, a wave will travel a different distance depending on the amount of water in the pipe. The method of characteristics is not easily applied in the situation of a variable length of fluid. Therefore, an alternate method must be utilized, which is possible if a few simplifying assumptions are made. These assumptions are:

1) The mass of water in the outlet pipe has a constant velocity along the entire length of pipe, instead of varying along the length as it would in the exact application of the method of characteristics.
2) The capacitance (the elasticity of the pipe and the compressibility of the fluid) is negligible in comparison to inertia.

3) Flow in the horizontal portions of the piping system is assumed to fill the pipe from top to bottom and advances as a distinct surge front as opposed to filling from the bottom to the top along the pipe; this assumption will be valid if the pipe fills rapidly which is the case in this application.

If these assumptions are made, the liquid mass is treated as a solid, and the equation of motion is used to describe the unsteady flow behavior of this slug of water. This analysis is termed rigid water column, lumped mass, or lumped inertia. Since this is a one-dimensional analysis, and the forces change depending on whether the water column is in the vertical or horizontal run of pipe, the analysis will change depending on the location of the water column. Also, in order to consider the head losses at elbows, it is necessary to analyze certain regions individually. Therefore, for both startup and shutdown, the analysis is split into distinct regimes, depending on the location of the water column front.

Validity of Lumped Mass Analysis

As mentioned above, some aspects of the analysis are inherently imprecise. However, to determine if the lumped mass assumption is valid, Wylie and Streeter (1993) propose an empirical relation between the period of the excitation element to the length of the pipeline. A conservative estimate requires that the element length be less than about 4 percent of the period times the wave speed. Since the main interest of this analysis is the overall system characteristics, the period should be that of the pump. When assuming lumped mass, the period is given as

$$T = \frac{2\pi \, I_T}{60 \, T_R}$$

in which T is the time scale for pump startup (or shutdown), I_T is the total rotational inertia of the pump and motor, N is the rotational speed of the pump in rpm and T_R is the rated torque. A typical value of this period for the discharge system is about 1.25 seconds as discussed below. Assuming a wave speed (represented as "a") of 3,000 ft/sec, which is a typical value for closed conduit flow, we have

$$L < 0.04\ T\ a\ =\ 0.04\ (1.25)\ (3000)\ =\ 150\ \text{ft}$$

Since the total discharge pipe length is only about 104 maximum feet for this case, it is expected that the lumped mass analysis is adequate to describe the overall system characteristics.

System Description

Each of the four independent pump lines have essentially the same characteristics although there are some minor differences in piping length. Figure A-1 is a schematic of the idealized piping system. The pipe diameter is approximated as a constant 54 inches. which is valid except through the pump itself. The piping system rises 52.3 ft vertically and through a 90° bend to a horizontal run of approximately 38 - 52 ft, passes through a flap gate and discharges into a canal. The system design includes a twelve-inch diameter air vent immediately upstream of the flap gate, allowing air to be vented at approximately atmospheric pressure.

TIME CONSTANTS FOR PUMPS

A time scale for pump startup or shutdown can be estimated from the relation presented by Wylie and Streeter (1993)

$$T = \frac{2\pi I_T}{60 T_R}$$

in which T is the time scale for pump startup (or shutdown), I_T is the total rotational inertia of the pump and motor, N is the rotational speed of the pump in rpm and T_R is the rated torque. The pump rotational speed is given as 440 rpm and the torque is the brake power in consistent units divided by the rotational speed expressed in radians per second. The rotational inertia of the pump and motor are taken from the correlations presented in Thorley (1991)

Motors: $I = 0.0043\,(P/N)^{1.48}$

Pumps $I = 0.03768\,(P/N^3)^{0.9556}$

in which the rotational speed is expressed in rpm and the brake power expressed in kilowatts and is estimated at 450 kw for the pumps in this application from the pump curves provided. Substituting into the above relations yields a time constant of approximately 1.25 s. This time constant will actually be an estimated time for the majority of the startup to occur and the actual total startup times will be somewhat greater. A conservative approach was taken by assuming the total startup time was equal to the time constant. In addition, the pump speed was assumed to increase linearly over the 1.25 s. With regards to pump shutdown, a similar conservative approach was taken by assuming that the pump head decreased linearly to zero over 1.25 s.

DEPTH vs. STORAGE VOLUME RELATION

The variation of wet well volume as a function of water level elevation is required in order to estimate wet well elevation changes during pump startup or shutdown. For this application, the cross-sectional area of the wet well is essentially constant over the entire range of possible flow depths during pump operation, 595 to 605 ft. An estimate of the cross sectional area of the wet well is 3046 ft^2. In the analysis below, the water surface elevation z was taken relative to the elevation of the pump intakes, or 585.17 ft.

PUMP STARTUP

As discussed previously, the equation of motion will be applied to determine the transient behavior. For pump startup, two different conditions must be analyzed in order to account for the different forces and head losses acting on the slug of water. The analysis is subdivided as:

1) The water column in the vertical section of discharge pipe
2) The surge front moving along the horizontal length

1) Vertical Section:

In this section of the pipe, the convention is as given below in Figure A-1. The water column is strictly vertical, and the forces acting on the liquid mass are the hydrostatic pressure caused by the water depth, the head supplied by the pump, the downward acting force resulting from the mass of the water column, and the wall shear due to pipe friction. Therefore, the equation of motion is applied as follows

$$\frac{d\,(\rho A V h)}{dt} - \rho Q V = P_{ent} A - \rho g\, hA - \tau_0\, \pi D h$$

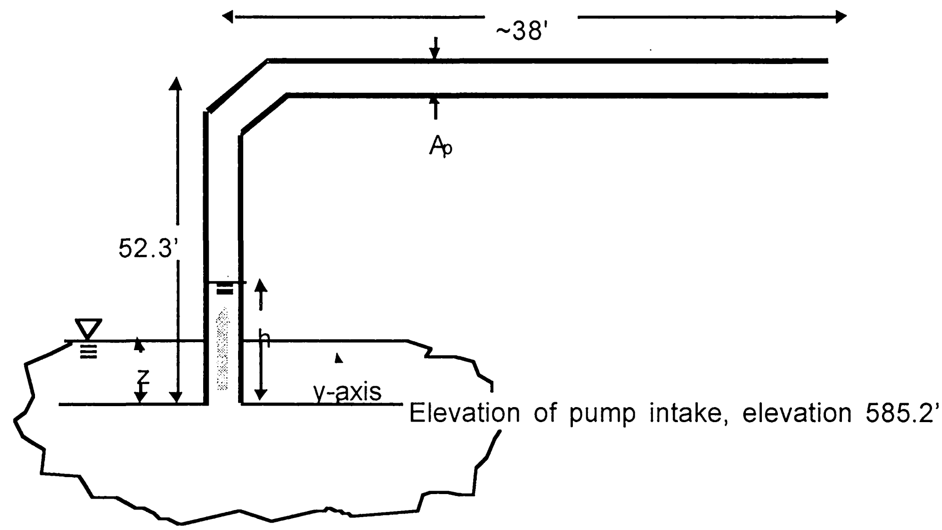


Figure A-1. Naming convention for flow in the vertical column during pump

in which ρ is the fluid density, A is the cross-sectional area of the pipe, V is the rigid column velocity, and h is the height of the water surface within the pipe above the pump inlet. The entrance pressure P_{ent} is estimated as

$$P_{ent} = \rho\, g\, z - k_{ent} \frac{\rho V^2}{2} + \rho\, g\, H_{pump}$$

and is actually the pressure on the discharge side of the pump. k_{ent} is the entrance loss coefficient for the pump bell and is estimated to have a value of approximately 0.1. The wall shear stress τ_0 is given by the Darcy-Weisbach equation as

$$\tau_0 = \frac{f}{8} \rho\, V^2$$

The momentum equation is algebraically manipulated to provide an equation for the rate of change of discharge with time:

$$\frac{dQ}{dt} = \frac{gA}{h}\left(z + H_{pump} - h - \left(\frac{fh}{D} + k_{ent}\right)\frac{Q^2}{2gA^2}\right)$$

Euler's formula can be used to approximate the derivative $dQ/dt \approx \Delta Q/\Delta t$. In general, H_{pump} is a function of flow rate and rotational speed since for pump startup, the steady-state operating speed has not been attained. In this analysis, the pump rotational speed is assumed to increase from zero to 440 rpm over 1.25 seconds. The pump curves at lower speeds are estimated from the homologous relations that are

$$Q/N = \text{constant and } H/N^2 = \text{constant}$$

in which Q and H refer to any point on the provided head discharge curve that scales down for the particular rotational speed computed for any instant in time. The head discharge curve for a proposed pump operating at 440 rpm was provided and a polynomial curve was used to approximate it in the analysis.

Since both z and h are also time-dependent, the equation for dQ must be solved simultaneously with the relations for these two variables. The relation for z can be found from conservation of mass as

$$\frac{dVol}{dt} = Q_{in} - Q$$

in which Vol is the wet well volume and Q_{in} is the inflow rate into the wet well. Rearranging in terms of z:

$$\frac{dz}{dt} = \frac{1}{A_{ww}}\frac{dVol}{dt} = \frac{1}{A_{ww}}(Q_{in} - Q)$$

where Aww is the cross-sectional area of the wet well. The water level in the piping system, h is simply related by

$$\frac{dh}{dt} = V = Q/A$$

The derivatives in the above expressions are all solved by the application of Euler's method utilizing a sufficiently short time interval that the simultaneous solution of the governing equations converges to the true solution.

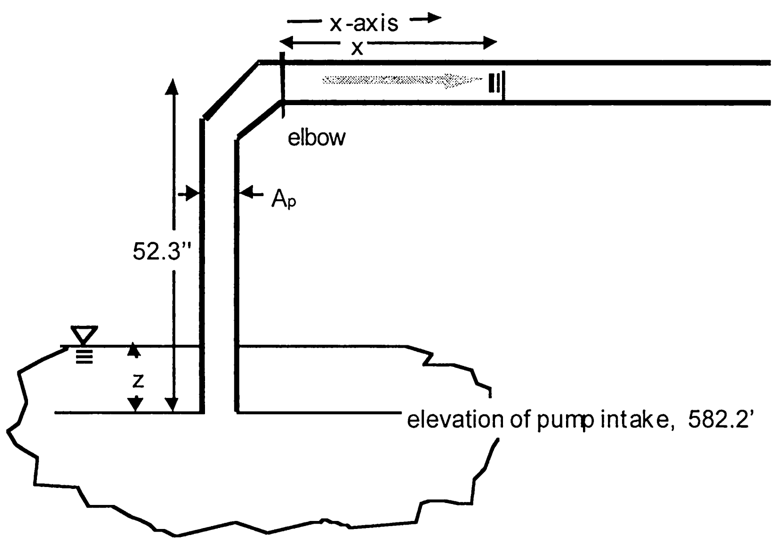
Constants:	
$f=$	0.011 assumed to be constant with flow rate.
$k_{L\ elbow} =$	0.33
$k_{L\ ent} =$	0.1
$t_{startup} =$	1.25 seconds
D=	54 inches
$A_{ww}=$	15.9 ft^2

Initial Conditions:	
$V_o=$	0.0 ft/sec
$Q_o=$	147.0 ft^3/sec (estimated)
$z_o=$	15.83 ft corresponds to 601 - 585.17 ft
$\cancel{V}_o=$	48,222 ft^3

The numerical results are tabulated in Appendix A and are discussed below

2) Horizontal Section:

After the water column has reached the top of the vertical section of pipe, it flows horizontally to the discharge canal. To account for this, the analysis proceeds as before, but the additional loss at the elbow must be considered. The naming convention is given below in Figure A-2.



Fiq ure A-2 Namina convention for flow in the horizontal lenath durina pumo startup

For this scenario, the equation of motion for the vertical portion of the pipe becomes

$$\frac{d(\rho AV L_z)}{dt} - \rho QV = A(\rho g z - k_{ent}\frac{\rho V^2}{2} + \rho g H_{pump} - P_1) - \tau_0 \pi D L_z$$

while a similar equation for the horizontal portion of the pipe is

$$\frac{d(\rho AV x)}{dt} - \rho QV = P_1 A - k_{elbow}\frac{\rho V^2}{2g} A - \tau_0 \pi D x$$

Here L_z is the length of the vertical section of the pipe, x is the distance measured from the elbow to the surge front, P_1 is the pressure just below the bend and k_{elbow} is a loss coefficient for the elbow taken equal to 0.33. Combining the two equations and solving for dQ yields:

$$\frac{dQ}{dt} = \frac{gA}{L_Z + x}\left(z + H_{pump} - L_Z - \left(\frac{f(L_Z + x)}{D} + k_{elbow} + k_{ent}\right)\frac{Q^2}{2gA^2}\right)$$

The additional relations are again

$$\frac{dx}{dt} = V = Q/A \quad \text{and} \quad \frac{dVol}{dt} = Q_{in} - Q$$

The initial conditions for this portion of the analysis come from the analysis of the filling of the vertical section of the pipe when the column has attained a height of 52.33 feet.

The numerical results are presented in Appendix A for the specific case of startup of the first pump in the system. These show very little change in total water surface elevation during the startup condition. First the water level in the wet well rises slightly as the wet well continues to fill while the pump is coming up to speed. Then, however, the flow accelerates past the steady state discharge due to the reduced losses while the pipe is still filling and the water level within the wet well begins to drop. Eventually the system approaches a steady state condition with a constant water level in the wet well since the inflow is matched by the pump discharge. The total change in water surface elevation in the wet well is less than 0.1 ft. Simulations were performed for startup of the second, third, etc. pumps in the system with essentially similar results. Therefore it is concluded that there will be little observable surge within the wet well during pump startup conditions.

PUMP SHUTDOWN

Again, a rigid water column analysis is performed for the case of pump shutdown. Here, the problem must be divided into three distinct analyses. These include:

1) Time required for the column of fluid to come to rest
2) Reverse flow through the horizontal reach of pipe
3) Reverse flow through the vertical section of pipe

In order to account for shutdown without knowing the extensive pump characteristics, it was assumed that the head supplied by the pump will decay linearly with time. For this case, it was assumed that the head will fall from the steady state operating point to zero in 1.25 seconds. Furthermore, it is assumed that when reverse flow does occur through the pump, the pump turbines with no losses.

1) Time Required for the Column of Fluid to Come to Rest

The conventions are exactly the same as for the horizontal flow during pump startup. The differential equation for discharge is similar to that for horizontal flow in the pump startup case with the length x replaced by the entire length of the horizontal portion of the pipe, L_h:

$$\frac{dQ}{dt} = \frac{gA}{L_z + L_h}\left(z + H_{pump} - L_z - \left(\frac{f(L_z + L_h)}{D} + k_{elbow} + k_{ent}\right)\frac{Q^2}{2gA^2}\right)$$

The pump head is assumed to vary linearly with time as

$$H_{pump} = H_{steady} \frac{t_{stop} - t}{t_{stop}}$$

With the additional equation for water surface elevation change in the wet well, the above equations are solved utilizing Euler's method until the fluid velocity goes to zero in the system. The initial conditions for this simulation are the appropriate combined pump discharge for the number of pumps in operation prior to the shutdown of a single pump, the pump head corresponding to the initial operating condition. The inflow into the wet well is assumed to be equal to the final steady discharge after the transient has dissipated. For example, when the last pump is to be turned off, the inflow into the wet well is set to zero. This approach yields the maximum wet well surface elevation change due to the pump shutdown event. Results of simulations are presented in Appendix B

2) Reverse flow in the horizontal portion of the piping

The convention on both discharge and the distance x are altered in this portion of the simulation. Discharge is defined as positive if back towards the wet well (reverse flow condition) and the distance x is measured from the downstream end of the piping system. Hydraulic losses in the flow through the pump bell are neglected. Using this different convention, the governing equations are:

$$\frac{dQ}{dt} = \frac{gA}{L_z + L_h - x}\left(L_z - z - \left(\frac{f(L_z + L_h - x)}{D} + k_{elbow}\right)\frac{Q^2}{2gA^2}\right)$$

$$\frac{dVol}{dt} = Q_{in} + Q$$

Again, Q_{in} is positive entering the pump station. The initial conditions for this portion of the simulation are simply zero flow and the pump head always went to zero prior to stoppage of the flow. Other conditions one wet well elevation and volume are taken from the results of the previous simulation.

3.) Reverse flow through the 52.3 ft vertical section of pipe

The convention is similar to that in Figure A-1 with h measured positive upwards from the pump inlet. The governing flow equation is simply

$$\frac{dQ}{dt} = \frac{gA}{h}\left(h - z - \frac{fh\ Q^2}{D\,2gA^2}\right)$$

and the continuity equation is the same as for the reverse flow in the horizontal section of pipe. The initial conditions are taken from the output for the preceding simulation as the fluid front reaches the elbow and the simulations proceed until the water level inside the pipe reaches the level in the wet well. The numerical results of the analyses are presented in Appendix B and the pipe discharge, the pressure head at the bend preceding the horizontal run of pipe. Although the surge within the wet well is again seen to be small (on the order of 0.5 ft change in the wet well during the entire flow reversal process), the pressure head at the elbow is computed to drop below the vapor pressure of the fluid. Under these circumstances, a vapor cavity would form at the bend and grow until the fluid is brought to rest and reverses direction. Upon flow reversal, the vapor cavity collapse would result in a pressure spike that could be sufficient to cause system damage. This process was not simulated in the analysis presented as the fluid pressure was allowed to decrease below vapor pressure which is not physically realistic.

The results presented above are sensitive to the assumed conditions on the pump spin down. A preliminary analysis which assumed instantaneous pump shutdown indicated even more larger negative pressures at the pipe elbow. The time for pump shutdown was probably too short compared to the actual shutdown time. Using too short a shutdown time will over-estimate the magnitude of the suction pressure at the elbow and therefore, it is not necessarily true that the flow should cavitate. More detailed information on pump shutdown characteristics would be required to assess this situation more precisely.

RESULTS AND CONCLUSIONS

Pump Startup

Using the lumped mass analysis, it is seen that the system tends to run out on the pump curve at a very early time. For the case of the first pump startup, the discharge increases to about 200 cfs before beginning to fall off to the steady state discharge. The exact value for the maximum discharge is dependent on the manner in which the pump is assumed to start up. Also, it is predicted that the column of fluid fills the vertical section of pipe in about 3.1 seconds. During this time, the flow rate has begun to gradually decrease towards the steady state value, whereas the pump head has begun to increase towards the operating point. The water surface elevation has decreased very little during this time, since this is such a short period. Simulations for starting the second and additional pumps indicated essentially the same results and wet well surge was not indicated to be significant (less than 0.1 ft) for all cases of pump startup.

It is also predicted that the surge front will travel the horizontal distance of 38 feet in about 5.2 seconds, with a gradual increase in the pump head and decrease in the flow rate toward the operating point. The velocity of the water column through the pipeline higher than the steady state velocity. This will therefore result in larger forces on the pipe bends than indicated by a steady state analysis.

Pump Shutdown

For pump shutdown, it was assumed that the head supplied by the pump decayed linearly to zero in 1.25 seconds. In general, the complete pump characteristics are necessary to solve a transient problem involving a turbomachine. Assuming this linear decay of pump head, the water column is expected to stop flowing in the forward direction after about 1.3 seconds. During this time, the pressure head at the elbow at the start of the horizontal length of pipe decreases drastically. For the case of the last pump being shut down, the pressure at the elbow falls from a steady state head of -5.5 ft, down to below vapor pressure. Since this analysis does not account for the formation of a vapor cavity, the analysis becomes flawed after this occurs. The twelve-inch air vent installed immediately upstream of the flap gates will provide for pressure relief and the short distance from the bend to the flap gate will limit any pressure surges associated with the collapse of the vapor column that forms near the bend.

As the pump was coming to a rest and the flow reversing, initially the water level in the wet well declines slightly before the fluid comes to rest and more flow is leaving the wet well than entering. However, once the flow reverses in the pipe, the water level in the wet well begins to rise again as the pipe empties. The volume of water inside the approximately 100 ft of 4.5 ft diameter piping will occupy about 0.5 ft of vertical space within the wet well. Therefore, the maximum surge on pump shutdown is of this order.

Neither analysis for pump startup or shutdown indicated significant surges within the wet well. It is concluded that this combination of system geometry and pumps will not result in significant wet well surging.

REFERENCES

Thorley, A.R. D. (1991) Fluid Transients in Pipeline Systems, D. & L. George Ltd.

Wylie, E.B. and V.L. Streeter (1993) Fluid Transients in Systems, Prentice Hall.

APPENDIX A
NUMERICAL COMPUTATIONS ASSOCIATED WITH PUMP STARTUP

PUMP P-1 STARTUP (one pump operates)

1. Vertical section in pipe

g =	32.17	ft/sec^2
f =	0.01011557	
k =	0.00015	
$k_{L\ elbow}$ =	0.33270833	
$k_{L\ entrance}$ =	0.10098221	
Viscosity =	0.00003	ft^2/sec
Diameter of Pipe (D) =	4.5	ft
Area of Pipe (A) =	15.9107143	ft^2
H_{pump} =	$-(9*10^{-6})*x^3+0.0011x^2-0.1285x+66.554$	ft
Start Pump P-1 Elevation =	601	ft
Stop Pump P-1 Elevation =	595	ft
Minimum Surface Elevation =	585.167	ft
Cross Sectional Area of Wet well =	3045.7	ft^2
v_0 =	0	ft/sec
Q_0 =	0	ft^3/sec
z_0 =	15.833	ft
V_0 =	48222.24	ft^3

Apply Euler's Formula:

$Q(t) = Q_{prev}+dQ$

$h(t) = h_{prev}+dh$

$V(t) = V_{prev}+dV$

$z(t) = V_0 / A = V_0 / 3045.7$

$$\frac{\partial Q}{\partial t} = \left[z + H_{pump} - h - \left(\frac{fh}{D} + k_{entrance}\right)\frac{Q^2}{2gA^2}\right]\frac{gA}{h}$$

where;

$dh = (Q/A)*dt$

$dV = (Q_{inflow}-Q)*dt$ Use Q_{inflow} = 147 cfs

dt = 0.001 sec

t(sec)	Q(cfs)	h(ft)	V(ft^3)	z(ft)	WSEL(ft)	H_{pump} ft	dQ	dh	dV	
0	0	15.833	48222.24	15.833	601	66.554	2.15155	0	0.147	0.001 dt_1
0.001	2.15155	15.833	48222.3826	15.833	601	66.28253	2.14278	0.00014	0.14485	
0.002	4.29433	15.833135	48222.5275	15.833	601.0001	66.02175	2.13432	0.00027	0.14271	
0.003	6.42865	15.833405	48222.6702	15.833	601.0001	65.77099	2.12616	0.0004	0.14057	
0.004	8.55481	15.833809	48222.8107	15.833	601.0002	65.52958	2.11829	0.00054	0.13845	
0.005	10.6731	15.834347	48222.9492	15.833	601.0002	65.29687	2.11066	0.00067	0.13633	
0.006	12.7838	15.835018	48223.0855	15.833	601.0003	65.07225	2.10328	0.0008	0.13422	
0.007	14.887	15.835821	48223.2197	15.833	601.0003	64.85511	2.09612	0.00094	0.13211	
0.008	16.9832	15.836757	48223.3518	15.833	601.0004	64.64485	2.08915	0.00107	0.13002	
0.009	19.0723	15.837824	48223.4819	15.833	601.0004	64.4409	2.08236	0.0012	0.12793	
0.01	21.1547	15.839023	48223.6098	15.833	601.0005	64.24269	2.07574	0.00133	0.12585	
0.011	23.2304	15.840352	48223.7356	15.833	601.0005	64.04968	2.06926	0.00146	0.12377	
0.012	25.2997	15.841813	48223.8594	15.834	601.0005	63.86133	2.06291	0.00159	0.1217	
0.013	27.3626	15.843403	48223.9811	15.834	601.0006	63.67711	2.05668	0.00172	0.11964	
0.014	29.4193	15.845122	48224.1007	15.834	601.0006	63.49651	2.05053	0.00185	0.11758	
0.015	31.4698	15.846971	48224.2183	15.834	601.0007	63.31902	2.04447	0.00198	0.11553	
0.016	33.5143	15.848949	48224.3338	15.834	601.0007	63.14415	2.03847	0.00211	0.11349	
0.017	35.5527	15.851056	48224.4473	15.834	601.0007	62.97142	2.03251	0.00223	0.11145	
0.018	37.5852	15.85329	48224.5588	15.834	601.0008	62.80036	2.02659	0.00236	0.10941	
0.019	39.6118	15.855652	48224.6682	15.834	601.0008	62.63049	2.02069	0.00249	0.10739	
0.02	41.6325	15.858142	48224.7756	15.834	601.0008	62.46137	2.01479	0.00262	0.10537	
0.021	43.6473	15.860759	48224.8809	15.834	601.0009	62.29255	2.00888	0.00274	0.10335	
0.022	45.6562	15.863502	48224.9843	15.834	601.0009	62.12359	2.00294	0.00287	0.10134	
0.023	47.6591	15.866372	48225.0856	15.834	601.0009	61.95406	1.99697	0.003	0.09934	
0.024	49.6561	15.869367	48225.185	15.834	601.001	61.78355	1.99095	0.00312	0.09734	
0.025	51.6471	15.872488	48225.2823	15.834	601.001	61.61163	1.98486	0.00325	0.09535	
0.026	53.6319	15.875734	48225.3777	15.834	601.001	61.43793	1.97869	0.00337	0.09337	
0.027	55.6106	15.879105	48225.471	15.834	601.0011	61.26203	1.97243	0.0035	0.09139	
0.028	57.583	15.8826	48225.5624	15.834	601.0011	61.08356	1.96608	0.00362	0.08942	
0.029	59.5491	15.886219	48225.6519	15.834	601.0011	60.90214	1.95961	0.00374	0.08745	
0.03	61.5087	15.889962	48225.7393	15.834	601.0012	60.71742	1.95301	0.00387	0.08549	
0.031	63.4617	15.893828	48225.8248	15.834	601.0012	60.52903	1.94628	0.00399	0.08354	
0.032	65.408	15.897816	48225.9083	15.834	601.0012	60.33664	1.9394	0.00411	0.08159	
0.033	67.3474	15.901927	48225.9899	15.834	601.0012	60.13991	1.93237	0.00423	0.07965	
0.034	69.2798	15.90616	48226.0696	15.834	601.0013	59.93851	1.92516	0.00435	0.07772	
0.035	71.2049	15.910514	48226.1473	15.834	601.0013	59.73215	1.91779	0.00448	0.0758	
0.036	73.1227	15.91499	48226.2231	15.834	601.0013	59.52052	1.91022	0.0046	0.07388	
0.037	75.0329	15.919585	48226.297	15.834	601.0013	59.30332	1.90246	0.00472	0.07197	
0.038	76.9354	15.924301	48226.3689	15.834	601.0014	59.0803	1.8945	0.00484	0.07006	
0.039	78.8299	15.929137	48226.439	15.834	601.0014	58.85118	1.88633	0.00495	0.06817	
0.04	80.7162	15.934091	48226.5072	15.834	601.0014	58.61571	1.87794	0.00507	0.06628	
0.041	82.5942	15.939164	48226.5735	15.834	601.0014	58.37366	1.86933	0.00519	0.06441	
0.042	84.4635	15.944355	48226.6379	15.834	601.0014	58.1248	1.86048	0.00531	0.06254	
0.043	86.324	15.949664	48226.7004	15.834	601.0015	57.86894	1.85139	0.00543	0.06068	
0.044	88.1754	15.95509	48226.7611	15.834	601.0015	57.60586	1.84206	0.00554	0.05882	

0.045	90.0174	15.960631	48226.8199	15.835	601.0015	57.3354	1.83248	0.00566	0.05698		
0.046	91.8499	15.966289	48226.8769	15.835	601.0015	57.05738	1.82265	0.00577	0.05515		
0.047	93.6726	15.972062	48226.932	15.835	601.0015	56.77167	1.81256	0.00589	0.05333		
0.048	95.4851	15.977949	48226.9854	15.835	601.0016	56.47812	1.80221	0.006	0.05151		
0.049	97.2873	15.983951	48227.0369	15.835	601.0016	56.17662	1.79159	0.00611	0.04971		
0.05	99.0789	15.990065	48227.0866	15.835	601.0016	55.86706	1.78071	0.00623	0.04792		
0.051	100.86	15.996292	48227.1345	15.835	601.0016	55.54937	1.76955	0.00634	0.04614		
0.052	102.629	16.002631	48227.1806	15.835	601.0016	55.22347	1.75813	0.00645	0.04437		
0.053	104.387	16.009082	48227.225	15.835	601.0016	54.88931	1.74643	0.00656	0.04261		
0.054	106.134	16.015643	48227.2676	15.835	601.0017	54.54685	1.73446	0.00667	0.04087		
0.055	107.868	16.022313	48227.3085	15.835	601.0017	54.19609	1.72222	0.00678	0.03913		
0.056	109.59	16.029093	48227.3476	15.835	601.0017	53.83701	1.70971	0.00689	0.03741		

0.057	111.3	16.035981	48227.385	15.835	601.0017	53.46963	1.69693	0.007	0.0357		
0.058	112.997	16.042976	48227.4207	15.835	601.0017	53.09398	1.68388	0.0071	0.034		
0.059	114.681	16.050078	48227.4547	15.835	601.0017	52.71012	1.67056	0.00721	0.03232		
0.06	116.352	16.057286	48227.4871	15.835	601.0017	52.31811	1.65698	0.00731	0.03065		
0.061	118.009	16.064598	48227.5177	15.835	601.0017	51.91803	1.64315	0.00742	0.02899		
0.062	119.652	16.072015	48227.5467	15.835	601.0017	51.50998	1.62905	0.00752	0.02735		
0.063	121.281	16.079536	48227.5741	15.835	601.0018	51.09407	1.6147	0.00762	0.02572		
0.064	122.895	16.087158	48227.5998	15.835	601.0018	50.67044	1.60011	0.00772	0.0241		
0.065	124.496	16.094882	48227.6239	15.835	601.0018	50.23922	1.58528	0.00782	0.0225		
0.066	126.081	16.102707	48227.6464	15.835	601.0018	49.80058	1.57021	0.00792	0.02092		
0.067	127.651	16.110631	48227.6673	15.835	601.0018	49.3547	1.55491	0.00802	0.01935		
0.068	129.206	16.118654	48227.6866	15.835	601.0018	48.90176	1.53939	0.00812	0.01779		
0.069	130.745	16.126775	48227.7044	15.835	601.0018	48.44196	1.52366	0.00822	0.01625		
0.07	132.269	16.134992	48227.7207	15.835	601.0018	47.97552	1.50772	0.00831	0.01473		
0.071	133.777	16.143305	48227.7354	15.835	601.0018	47.50266	1.49158	0.00841	0.01322		
0.072	135.268	16.151713	48227.7487	15.835	601.0018	47.02364	1.47525	0.0085	0.01173		
0.073	136.744	16.160215	48227.7604	15.835	601.0018	46.53868	1.45874	0.00859	0.01026		
0.074	138.202	16.168809	48227.7706	15.835	601.0018	46.04806	1.44205	0.00869	0.0088		
0.075	139.644	16.177496	48227.7794	15.835	601.0018	45.55205	1.4252	0.00878	0.00736		
0.076	141.07	16.186272	48227.7868	15.835	601.0018	45.05092	1.40819	0.00887	0.00593		
0.077	142.478	16.195139	48227.7927	15.835	601.0018	44.54496	1.39104	0.00895	0.00452		
0.078	143.869	16.204093	48227.7972	15.835	601.0018	44.03447	1.37376	0.00904	0.00313		
0.079	145.243	16.213136	48227.8004	15.835	601.0018	43.51974	1.35635	0.00913	0.00176		
0.08	146.599	16.222264	48227.8021	15.835	601.0018	43.00109	1.33883	0.00921	0.0004		
0.081	147.938	16.231478	48227.8025	15.835	601.0018	42.47883	1.32121	0.0093	-0.0009		
0.082	149.259	16.240776	48227.8016	15.835	601.0018	41.95327	1.30349	0.00938	-0.0023		
0.083	150.562	16.250157	48227.7993	15.835	601.0018	41.42474	1.28569	0.00946	-0.0036		
0.084	151.848	16.25962	48227.7958	15.835	601.0018	40.89355	1.26781	0.00954	-0.0048		
0.085	153.116	16.269164	48227.7909	15.835	601.0018	40.36004	1.24988	0.00962	-0.0061		
0.086	154.366	16.278787	48227.7848	15.835	601.0018	39.82452	1.2319	0.0097	-0.0074		
0.087	155.598	16.288489	48227.7774	15.835	601.0018	39.28734	1.21388	0.00978	-0.0086		
0.088	156.812	16.298269	48227.7688	15.835	601.0018	38.7488	1.19583	0.00986	-0.0098		
0.089	158.007	16.308125	48227.759	15.835	601.0018	38.20924	1.17776	0.00993	-0.011		
0.09	159.185	16.318055	48227.748	15.835	601.0018	37.66898	1.15969	0.01	-0.0122		
0.091	160.345	16.32806	48227.7358	15.835	601.0018	37.12835	1.14161	0.01008	-0.0133		
0.092	161.486	16.338138	48227.7225	15.835	601.0018	36.58765	1.12356	0.01015	-0.0145		
0.093	162.61	16.348288	48227.708	15.835	601.0018	36.04722	1.10552	0.01022	-0.0156		
0.094	163.716	16.358508	48227.6924	15.835	601.0018	35.50734	1.08752	0.01029	-0.0167		
0.095	164.803	16.368797	48227.6757	15.835	601.0018	34.96834	1.06957	0.01036	-0.0178		
0.096	165.873	16.379155	48227.6579	15.835	601.0018	34.43051	1.05167	0.01043	-0.0189		
0.097	166.924	16.389581	48227.639	15.835	601.0018	33.89415	1.03383	0.01049	-0.0199		
0.098	167.958	16.400072	48227.6191	15.835	601.0018	33.35954	1.01606	0.01056	-0.021		
0.099	168.974	16.410628	48227.5981	15.835	601.0018	32.82696	0.99837	0.01062	-0.022		
0.1	169.973	16.421248	48227.5762	15.835	601.0018	32.29669	0.98078	0.01068	-0.023		
0.11	170.953	16.431931	48227.5532	15.835	601.0017	31.76899	0.96328	0.10745	-0.024	0.01	dt_2
0.12	171.917	16.539377	48227.5292	15.835	601.0017	31.24413	0.93735	0.10805	-0.0249		
0.13	172.854	16.647427	48227.5043	15.835	601.0017	30.72708	0.91195	0.10864	-0.0259		
0.14	173.766	16.756067	48227.4785	15.835	601.0017	30.21803	0.88707	0.10921	-0.0268		
0.15	174.653	16.865281	48227.4517	15.835	601.0017	29.71713	0.86272	0.10977	-0.0277		
0.16	175.516	16.975051	48227.424	15.835	601.0017	29.22453	0.83889	0.11031	-0.0285		
0.17	176.355	17.085364	48227.3955	15.835	601.0017	28.74034	0.81557	0.11084	-0.0294		
0.18	177.17	17.196204	48227.3662	15.835	601.0017	28.26467	0.79277	0.11135	-0.0302		
0.19	177.963	17.307557	48227.336	15.835	601.0017	27.7976	0.77047	0.11185	-0.031		
0.2	178.733	17.419408	48227.305	15.835	601.0017	27.33921	0.74869	0.11234	-0.0317		
0.21	179.482	17.531743	48227.2733	15.835	601.0017	26.88954	0.7274	0.11281	-0.0325		
0.22	180.209	17.644549	48227.2408	15.835	601.0016	26.44863	0.70661	0.11326	-0.0332		
0.23	180.916	17.757812	48227.2076	15.835	601.0016	26.01651	0.6863	0.11371	-0.0339		
0.24	181.602	17.871519	48227.1737	15.835	601.0016	25.59319	0.66648	0.11414	-0.0346		
0.25	182.269	17.985657	48227.1391	15.835	601.0016	25.17867	0.64713	0.11456	-0.0353		
0.26	182.916	18.100215	48227.1038	15.835	601.0016	24.77294	0.62824	0.11496	-0.0359		
0.27	183.544	18.215179	48227.0679	15.835	601.0016	24.37597	0.60982	0.11536	-0.0365		
0.28	184.154	18.330538	48227.0314	15.835	601.0016	23.98773	0.59185	0.11574	-0.0372		
0.29	184.746	18.44628	48226.9942	15.835	601.0016	23.60817	0.57433	0.11611	-0.0377		
0.3	185.32	18.562394	48226.9565	15.835	601.0016	23.23725	0.55724	0.11648	-0.0383		
0.31	185.877	18.678869	48226.9181	15.835	601.0015	22.87491	0.54058	0.11683	-0.0389		
0.32	186.418	18.795694	48226.8793	15.835	601.0015	22.52107	0.52434	0.11717	-0.0394		
0.33	186.942	18.912859	48226.8398	15.835	601.0015	22.17567	0.50851	0.11749	-0.0399		
0.34	187.451	19.030354	48226.7999	15.834	601.0015	21.83862	0.49308	0.11781	-0.0405		
0.35	187.944	19.148168	48226.7595	15.834	601.0015	21.50984	0.47805	0.11812	-0.0409		
0.36	188.422	19.266293	48226.7185	15.834	601.0015	21.18924	0.46341	0.11842	-0.0414		
0.37	188.885	19.384717	48226.6771	15.834	601.0015	20.87672	0.44914	0.11872	-0.0419		
0.38	189.335	19.503433	48226.6352	15.834	601.0014	20.57218	0.43524	0.119	-0.0423		
0.39	189.77	19.622431	48226.5929	15.834	601.0014	20.27552	0.42171	0.11927	-0.0428		
0.4	190.192	19.741703	48226.5501	15.834	601.0014	19.98664	0.40852	0.11954	-0.0432		
0.41	190.6	19.86124	48226.5069	15.834	601.0014	19.70541	0.39568	0.11979	-0.0436		
0.42	190.996	19.981033	48226.4633	15.834	601.0014	19.43174	0.38318	0.12004	-0.044		
0.43	191.379	20.101075	48226.4193	15.834	601.0014	19.1655	0.37101	0.12028	-0.0444		
0.44	191.75	20.221358	48226.3749	15.834	601.0014	18.90658	0.35916	0.12052	-0.0447		
0.45	192.109	20.341875	48226.3302	15.834	601.0013	18.65486	0.34761	0.12074	-0.0451		
0.46	192.457	20.462616	48226.2851	15.834	601.0013	18.41023	0.33638	0.12096	-0.0455		
0.47	192.793	20.583577	48226.2396	15.834	601.0013	18.17257	0.32544	0.12117	-0.0458		

0.48	193.118	20.704749	48226.1938	15.834	601.0013	17.94175	0.31479	0.12138	-0.0461		
0.49	193.433	20.826125	48226.1477	15.834	601.0013	17.71765	0.30442	0.12157	-0.0464		
0.5	193.738	20.947699	48226.1013	15.834	601.0013	17.50016	0.29433	0.12177	-0.0467		
0.51	194.032	21.069465	48226.0545	15.834	601.0013	17.28915	0.2845	0.12195	-0.047		
0.52	194.317	21.191415	48226.0075	15.834	601.0012	17.08451	0.27493	0.12213	-0.0473		
0.53	194.591	21.313545	48225.9602	15.834	601.0012	16.8861	0.26562	0.1223	-0.0476		
0.54	194.857	21.435847	48225.9126	15.834	601.0012	16.69382	0.25656	0.12247	-0.0479		
0.55	195.114	21.558316	48225.8647	15.834	601.0012	16.50755	0.24773	0.12263	-0.0481		
0.56	195.361	21.680946	48225.8166	15.834	601.0012	16.32716	0.23914	0.12279	-0.0484		

0.57	195.601	21.803732	48225.7683	15.834	601.0012	16.15255	0.23078	0.12294	-0.0486		
0.58	195.831	21.926669	48225.7197	15.834	601.0011	15.98358	0.22263	0.12308	-0.0488		
0.59	196.054	22.04975	48225.6708	15.834	601.0011	15.82016	0.21471	0.12322	-0.0491		
0.6	196.269	22.172971	48225.6218	15.834	601.0011	15.66216	0.20699	0.12336	-0.0493		
0.61	196.476	22.296328	48225.5725	15.834	601.0011	15.50947	0.19947	0.12349	-0.0495		
0.62	196.675	22.419814	48225.523	15.834	601.0011	15.36199	0.19216	0.12361	-0.0497		
0.63	196.867	22.543426	48225.4734	15.834	601.0011	15.2196	0.18503	0.12373	-0.0499		
0.64	197.052	22.667158	48225.4235	15.834	601.001	15.0822	0.17809	0.12385	-0.0501		
0.65	197.23	22.791007	48225.3734	15.834	601.001	14.94967	0.17134	0.12396	-0.0502		
0.66	197.402	22.914968	48225.3232	15.834	601.001	14.82192	0.16476	0.12407	-0.0504		
0.67	197.566	23.039036	48225.2728	15.834	601.001	14.69884	0.15835	0.12417	-0.0506		
0.68	197.725	23.163208	48225.2222	15.834	601.001	14.58033	0.15211	0.12427	-0.0507		
0.69	197.877	23.28748	48225.1715	15.834	601.001	14.46628	0.14604	0.12437	-0.0509		
0.7	198.023	23.411847	48225.1206	15.834	601.0009	14.35661	0.14012	0.12446	-0.051		
0.71	198.163	23.536306	48225.0696	15.834	601.0009	14.25122	0.13435	0.12455	-0.0512		
0.72	198.297	23.660853	48225.0185	15.834	601.0009	14.15	0.12873	0.12463	-0.0513		
0.73	198.426	23.785484	48224.9672	15.834	601.0009	14.05288	0.12326	0.12471	-0.0514		
0.74	198.549	23.910196	48224.9157	15.834	601.0009	13.95975	0.11793	0.12479	-0.0515		
0.75	198.667	24.034986	48224.8642	15.834	601.0009	13.87052	0.11274	0.12486	-0.0517		
0.76	198.78	24.15985	48224.8125	15.834	601.0008	13.78512	0.10767	0.12493	-0.0518		
0.77	198.888	24.284785	48224.7607	15.834	601.0008	13.70344	0.10274	0.125	-0.0519		
0.78	198.991	24.409787	48224.7088	15.834	601.0008	13.62542	0.09794	0.12507	-0.052		
0.79	199.088	24.534854	48224.6569	15.834	601.0008	13.55096	0.09325	0.12513	-0.0521		
0.8	199.182	24.659983	48224.6048	15.834	601.0008	13.47999	0.08869	0.12519	-0.0522		
0.81	199.27	24.78517	48224.5526	15.834	601.0008	13.41242	0.08424	0.12524	-0.0523		
0.82	199.355	24.910413	48224.5003	15.834	601.0007	13.34818	0.0799	0.1253	-0.0524		
0.83	199.435	25.035708	48224.448	15.834	601.0007	13.2872	0.07567	0.12535	-0.0524		
0.84	199.51	25.161055	48224.3955	15.834	601.0007	13.22939	0.07155	0.12539	-0.0525		
0.85	199.582	25.286448	48224.343	15.834	601.0007	13.17468	0.06753	0.12544	-0.0526		
0.86	199.649	25.411887	48224.2904	15.834	601.0007	13.12301	0.06361	0.12548	-0.0526		
0.87	199.713	25.537368	48224.2378	15.834	601.0007	13.07431	0.05978	0.12552	-0.0527		
0.88	199.773	25.662889	48224.1851	15.834	601.0006	13.02849	0.05605	0.12556	-0.0528		
0.89	199.829	25.788447	48224.1323	15.834	601.0006	12.98551	0.05242	0.12559	-0.0528		
0.9	199.881	25.914041	48224.0795	15.834	601.0006	12.94529	0.04887	0.12563	-0.0529		
0.91	199.93	26.039668	48224.0266	15.834	601.0006	12.90778	0.04541	0.12566	-0.0529		
0.92	199.975	26.165325	48223.9737	15.834	601.0006	12.8729	0.04203	0.12569	-0.053		
0.93	200.017	26.291011	48223.9207	15.834	601.0006	12.84059	0.03874	0.12571	-0.053		
0.94	200.056	26.416724	48223.8677	15.834	601.0005	12.81081	0.03553	0.12574	-0.0531		
0.95	200.092	26.54246	48223.8146	15.834	601.0005	12.78348	0.03239	0.12576	-0.0531		
0.96	200.124	26.66822	48223.7615	15.834	601.0005	12.75856	0.02933	0.12578	-0.0531		
0.97	200.153	26.793999	48223.7084	15.833	601.0005	12.73599	0.02634	0.1258	-0.0532		
0.98	200.18	26.919797	48223.6552	15.833	601.0005	12.7157	0.02343	0.12581	-0.0532		
0.99	200.203	27.045611	48223.6021	15.833	601.0004	12.69766	0.02058	0.12583	-0.0532		
1	200.224	27.171441	48223.5489	15.833	601.0004	12.68181	0.0178	0.12584	-0.0532		
1.01	200.242	27.297283	48223.4956	15.833	601.0004	12.6681	0.01509	0.12585	-0.0532		
1.02	200.257	27.423136	48223.4424	15.833	601.0004	12.65647	0.01244	0.12586	-0.0533		
1.03	200.269	27.548999	48223.3891	15.833	601.0004	12.64688	0.00985	0.12587	-0.0533		
1.04	200.279	27.674869	48223.3359	15.833	601.0004	12.63929	0.00732	0.12588	-0.0533		
1.05	200.286	27.800746	48223.2826	15.833	601.0003	12.63365	0.00485	0.12588	-0.0533		
1.06	200.291	27.926628	48223.2293	15.833	601.0003	12.6299	0.00244	0.12588	-0.0533		
1.07	200.294	28.052512	48223.176	15.833	601.0003	12.62802	8.7E-05	0.12589	-0.0533		
1.08	200.294	28.178398	48223.1227	15.833	601.0003	12.62795	-0.0022	0.12589	-0.0533		
1.09	200.291	28.304284	48223.0694	15.833	601.0003	12.62966	-0.0045	0.12588	-0.0533		
1.1	200.287	28.430169	48223.0161	15.833	601.0003	12.6331	-0.0067	0.12588	-0.0533		
1.11	200.28	28.55605	48222.9628	15.833	601.0002	12.63824	-0.0088	0.12588	-0.0533		
1.12	200.272	28.681928	48222.9096	15.833	601.0002	12.64502	-0.0109	0.12587	-0.0533		
1.13	200.261	28.8078	48222.8563	15.833	601.0002	12.65343	-0.013	0.12587	-0.0533		
1.14	200.248	28.933665	48222.803	15.833	601.0002	12.66342	-0.015	0.12586	-0.0532		
1.15	200.233	29.059523	48222.7498	15.833	601.0002	12.67495	-0.0169	0.12585	-0.0532		
1.16	200.216	29.18537	48222.6966	15.833	601.0002	12.68798	-0.0188	0.12584	-0.0532		
1.17	200.197	29.311207	48222.6433	15.833	601.0001	12.7025	-0.0207	0.12583	-0.0532		
1.18	200.176	29.437033	48222.5901	15.833	601.0001	12.71845	-0.0225	0.12581	-0.0532		
1.19	200.154	29.562845	48222.537	15.833	601.0001	12.73581	-0.0243	0.1258	-0.0532		
1.2	200.129	29.688643	48222.4838	15.833	601.0001	12.75454	-0.0261	0.12578	-0.0531		
1.21	200.103	29.814425	48222.4307	15.833	601.0001	12.77462	-0.0278	0.12577	-0.0531		
1.22	200.075	29.940192	48222.3776	15.833	601	12.79601	-0.0295	0.12575	-0.0531		
1.23	200.046	30.065941	48222.3245	15.833	601	12.81869	-0.0311	0.12573	-0.053		
1.24	200.015	30.191671	48222.2715	15.833	601	12.84262	-0.0327	0.12571	-0.053		
1.25	199.982	30.317382	48222.2184	15.833	601	12.86777	-0.0343	0.12569	-0.053		
1.26	199.948	30.443072	48222.1655	15.833	601	12.89412	-0.0358	0.12567	-0.0529		
1.27	199.912	30.568741	48222.1125	15.833	601	12.92165	-0.0373	0.12565	-0.0529		
1.28	199.875	30.694387	48222.0596	15.833	600.9999	12.95031	-0.0388	0.12562	-0.0529		
1.29	199.836	30.820009	48222.0067	15.833	600.9999	12.9801	-0.0403	0.1256	-0.0528		
1.3	199.795	30.945608	48221.9539	15.833	600.9999	13.01098	-0.0417	0.12557	-0.0528		
1.31	199.754	31.071181	48221.9011	15.833	600.9999	13.04293	-0.0431	0.12555	-0.0528		
1.32	199.711	31.196727	48221.8483	15.833	600.9999	13.07592	-0.0444	0.12552	-0.0527		
1.33	199.666	31.322247	48221.7956	15.833	600.9999	13.10993	-0.0457	0.12549	-0.0527		
1.34	199.621	31.447739	48221.743	15.833	600.9998	13.14494	-0.047	0.12546	-0.0526		
1.35	199.574	31.573202	48221.6903	15.833	600.9998	13.18093	-0.0483	0.12543	-0.0526		
1.36	199.525	31.698635	48221.6378	15.833	600.9998	13.21787	-0.0496	0.1254	-0.0525		
1.37	199.476	31.824038	48221.5852	15.833	600.9998	13.25574	-0.0508	0.12537	-0.0525		

1.38	199.425	31.94941	48221.5328	15.833	600.9998	13.29452	-0.052	0.12534	-0.0524		
1.39	199.373	32.07475	48221.4803	15.833	600.9998	13.33419	-0.0531	0.12531	-0.0524		
1.4	199.32	32.200058	48221.428	15.833	600.9997	13.37473	-0.0543	0.12527	-0.0523		
1.41	199.266	32.325332	48221.3756	15.833	600.9997	13.41613	-0.0554	0.12524	-0.0523		
1.42	199.21	32.450571	48221.3234	15.833	600.9997	13.45835	-0.0565	0.12521	-0.0522		
1.43	199.154	32.575776	48221.2712	15.833	600.9997	13.50139	-0.0576	0.12517	-0.0522		
1.44	199.096	32.700946	48221.219	15.833	600.9997	13.54522	-0.0587	0.12513	-0.0521		
1.45	199.037	32.826079	48221.1669	15.833	600.9996	13.58984	-0.0597	0.1251	-0.052		
1.46	198.978	32.951176	48221.1149	15.833	600.9996	13.63521	-0.0607	0.12506	-0.052		

1.47	198.917	33.076234	48221.0629	15.833	600.9996	13.68132	-0.0617	0.12502	-0.0519		
1.48	198.855	33.201255	48221.011	15.833	600.9996	13.72816	-0.0627	0.12498	-0.0519		
1.49	198.792	33.326237	48220.9591	15.833	600.9996	13.77571	-0.0637	0.12494	-0.0518		
1.5	198.729	33.45118	48220.9073	15.833	600.9996	13.82396	-0.0646	0.1249	-0.0517		
1.51	198.664	33.576082	48220.8556	15.833	600.9995	13.87288	-0.0655	0.12486	-0.0517		
1.52	198.599	33.700944	48220.8039	15.833	600.9995	13.92247	-0.0664	0.12482	-0.0516		
1.53	198.532	33.825765	48220.7524	15.833	600.9995	13.9727	-0.0673	0.12478	-0.0515		
1.54	198.465	33.950544	48220.7008	15.832	600.9995	14.02358	-0.0682	0.12474	-0.0515		
1.55	198.397	34.075281	48220.6494	15.832	600.9995	14.07507	-0.0691	0.12469	-0.0514		
1.56	198.328	34.199974	48220.598	15.832	600.9995	14.12716	-0.0699	0.12465	-0.0513		
1.57	198.258	34.324625	48220.5466	15.832	600.9994	14.17985	-0.0707	0.12461	-0.0513		
1.58	198.187	34.449231	48220.4954	15.832	600.9994	14.23312	-0.0715	0.12456	-0.0512		
1.59	198.116	34.573793	48220.4442	15.832	600.9994	14.28696	-0.0723	0.12452	-0.0511		
1.6	198.043	34.69831	48220.3931	15.832	600.9994	14.34135	-0.0731	0.12447	-0.051		
1.61	197.97	34.822782	48220.342	15.832	600.9994	14.39629	-0.0739	0.12443	-0.051		
1.62	197.896	34.947208	48220.2911	15.832	600.9994	14.45175	-0.0746	0.12438	-0.0509		
1.63	197.822	35.071587	48220.2402	15.832	600.9993	14.50773	-0.0754	0.12433	-0.0508		
1.64	197.746	35.195919	48220.1893	15.832	600.9993	14.56422	-0.0761	0.12429	-0.0507		
1.65	197.67	35.320204	48220.1386	15.832	600.9993	14.6212	-0.0768	0.12424	-0.0507		
1.66	197.593	35.444442	48220.0879	15.832	600.9993	14.67866	-0.0775	0.12419	-0.0506		
1.67	197.516	35.56863	48220.0373	15.832	600.9993	14.7366	-0.0782	0.12414	-0.0505		
1.68	197.438	35.692771	48219.9868	15.832	600.9993	14.79501	-0.0789	0.12409	-0.0504		
1.69	197.359	35.816862	48219.9364	15.832	600.9992	14.85386	-0.0795	0.12404	-0.0504		
1.7	197.279	35.940903	48219.886	15.832	600.9992	14.91316	-0.0802	0.12399	-0.0503		
1.71	197.199	36.064895	48219.8357	15.832	600.9992	14.97289	-0.0808	0.12394	-0.0502		
1.72	197.118	36.188836	48219.7855	15.832	600.9992	15.03304	-0.0814	0.12389	-0.0501		
1.73	197.037	36.312726	48219.7354	15.832	600.9992	15.0936	-0.0821	0.12384	-0.05		
1.74	196.955	36.436565	48219.6854	15.832	600.9992	15.15457	-0.0827	0.12379	-0.05		
1.75	196.872	36.560353	48219.6354	15.832	600.9991	15.21593	-0.0833	0.12374	-0.0499		
1.76	196.789	36.684089	48219.5856	15.832	600.9991	15.27768	-0.0839	0.12368	-0.0498		
1.77	196.705	36.807772	48219.5358	15.832	600.9991	15.33981	-0.0844	0.12363	-0.0497		
1.78	196.621	36.931402	48219.4861	15.832	600.9991	15.4023	-0.085	0.12358	-0.0496		
1.79	196.536	37.05498	48219.4364	15.832	600.9991	15.46516	-0.0856	0.12352	-0.0495		
1.8	196.45	37.178504	48219.3869	15.832	600.9991	15.52837	-0.0861	0.12347	-0.0495		
1.81	196.364	37.301974	48219.3375	15.832	600.999	15.59192	-0.0867	0.12342	-0.0494		
1.82	196.277	37.42539	48219.2881	15.832	600.999	15.65581	-0.0872	0.12336	-0.0493		
1.83	196.19	37.548752	48219.2388	15.832	600.999	15.72002	-0.0877	0.12331	-0.0492		
1.84	196.102	37.672059	48219.1896	15.832	600.999	15.78456	-0.0882	0.12325	-0.0491		
1.85	196.014	37.795311	48219.1405	15.832	600.999	15.84941	-0.0887	0.1232	-0.049		
1.86	195.925	37.918507	48219.0915	15.832	600.999	15.91457	-0.0892	0.12314	-0.0489		
1.87	195.836	38.041647	48219.0426	15.832	600.999	15.98003	-0.0897	0.12308	-0.0488		
1.88	195.746	38.164732	48218.9937	15.832	600.9989	16.04578	-0.0902	0.12303	-0.0487		
1.89	195.656	38.28776	48218.945	15.832	600.9989	16.11182	-0.0907	0.12297	-0.0487		
1.9	195.566	38.410731	48218.8963	15.832	600.9989	16.17814	-0.0912	0.12291	-0.0486		
1.91	195.474	38.533646	48218.8478	15.832	600.9989	16.24473	-0.0916	0.12286	-0.0485		
1.92	195.383	38.656503	48218.7993	15.832	600.9989	16.31158	-0.0921	0.1228	-0.0484		
1.93	195.291	38.779302	48218.7509	15.832	600.9989	16.3787	-0.0925	0.12274	-0.0483		
1.94	195.198	38.902044	48218.7026	15.832	600.9988	16.44607	-0.093	0.12268	-0.0482		
1.95	195.105	39.024727	48218.6544	15.832	600.9988	16.51369	-0.0934	0.12263	-0.0481		
1.96	195.012	39.147352	48218.6063	15.832	600.9988	16.58155	-0.0938	0.12257	-0.048		
1.97	194.918	39.269919	48218.5583	15.832	600.9988	16.64965	-0.0942	0.12251	-0.0479		
1.98	194.824	39.392426	48218.5104	15.832	600.9988	16.71798	-0.0946	0.12245	-0.0478		
1.99	194.729	39.514874	48218.4626	15.832	600.9988	16.78654	-0.0951	0.12239	-0.0477		
2	194.634	39.637263	48218.4148	15.832	600.9987	16.85531	-0.0955	0.12233	-0.0476		
2.01	194.539	39.759592	48218.3672	15.832	600.9987	16.92431	-0.0959	0.12227	-0.0475		
2.02	194.443	39.881861	48218.3197	15.832	600.9987	16.99351	-0.0962	0.12221	-0.0474		
2.03	194.346	40.004069	48218.2722	15.832	600.9987	17.06291	-0.0966	0.12215	-0.0473		
2.04	194.25	40.126217	48218.2249	15.832	600.9987	17.13252	-0.097	0.12209	-0.0472		
2.05	194.153	40.248305	48218.1776	15.832	600.9987	17.20232	-0.0974	0.12203	-0.0472		
2.06	194.055	40.370331	48218.1305	15.832	600.9987	17.27231	-0.0977	0.12197	-0.0471		
2.07	193.958	40.492297	48218.0834	15.832	600.9986	17.34249	-0.0981	0.1219	-0.047		
2.08	193.86	40.614201	48218.0365	15.832	600.9986	17.41285	-0.0985	0.12184	-0.0469		
2.09	193.761	40.736043	48217.9896	15.832	600.9986	17.48338	-0.0988	0.12178	-0.0468		
2.1	193.662	40.857823	48217.9428	15.832	600.9986	17.55409	-0.0992	0.12172	-0.0467		
2.11	193.563	40.979541	48217.8962	15.832	600.9986	17.62496	-0.0995	0.12166	-0.0466		
2.12	193.464	41.101197	48217.8496	15.832	600.9986	17.696	-0.0999	0.12159	-0.0465		
2.13	193.364	41.22279	48217.8032	15.832	600.9985	17.76719	-0.1002	0.12153	-0.0464		
2.14	193.264	41.344321	48217.7568	15.832	600.9985	17.83855	-0.1005	0.12147	-0.0463		
2.15	193.163	41.465788	48217.7105	15.832	600.9985	17.91005	-0.1008	0.1214	-0.0462		
2.16	193.062	41.587193	48217.6644	15.831	600.9985	17.9817	-0.1012	0.12134	-0.0461		
2.17	192.961	41.708534	48217.6183	15.831	600.9985	18.05349	-0.1015	0.12128	-0.046		
2.18	192.86	41.829811	48217.5723	15.831	600.9985	18.12543	-0.1018	0.12121	-0.0459		
2.19	192.758	41.951025	48217.5265	15.831	600.9985	18.1975	-0.1021	0.12115	-0.0458		
2.2	192.656	42.072175	48217.4807	15.831	600.9984	18.2697	-0.1024	0.12109	-0.0457		
2.21	192.553	42.19326	48217.4351	15.831	600.9984	18.34203	-0.1027	0.12102	-0.0456		
2.22	192.451	42.314281	48217.3895	15.831	600.9984	18.41448	-0.103	0.12096	-0.0455		
2.23	192.348	42.435238	48217.3441	15.831	600.9984	18.48706	-0.1033	0.12089	-0.0453		
2.24	192.244	42.55613	48217.2987	15.831	600.9984	18.55976	-0.1036	0.12083	-0.0452		
2.25	192.141	42.676957	48217.2535	15.831	600.9984	18.63257	-0.1039	0.12076	-0.0451		
2.26	192.037	42.797719	48217.2083	15.831	600.9983	18.70549	-0.1041	0.1207	-0.045		
2.27	191.933	42.918415	48217.1633	15.831	600.9983	18.77852	-0.1044	0.12063	-0.0449		

2.28	191.828	43.039047	48217.1184	15.831	600.9983	18.85166	-0.1047	0.12057	-0.0448		
2.29	191.724	43.159612	48217.0735	15.831	600.9983	18.9249	-0.105	0.1205	-0.0447		
2.3	191.619	43.280112	48217.0288	15.831	600.9983	18.99824	-0.1052	0.12043	-0.0446		
2.31	191.514	43.400546	48216.9842	15.831	600.9983	19.07168	-0.1055	0.12037	-0.0445		
2.32	191.408	43.520913	48216.9397	15.831	600.9983	19.14521	-0.1058	0.1203	-0.0444		
2.33	191.302	43.641215	48216.8953	15.831	600.9982	19.21883	-0.106	0.12023	-0.0443		
2.34	191.196	43.76145	48216.851	15.831	600.9982	19.29254	-0.1063	0.12017	-0.0442		
2.35	191.09	43.881618	48216.8068	15.831	600.9982	19.36633	-0.1065	0.1201	-0.0441		
2.36	190.983	44.001719	48216.7627	15.831	600.9982	19.44021	-0.1068	0.12003	-0.044		

2.37	190.877	44.121754	48216.7187	15.831	600.9982	19.51416	-0.107	0.11997	-0.0439	
2.38	190.77	44.241721	48216.6748	15.831	600.9982	19.5882	-0.1073	0.1199	-0.0438	
2.39	190.662	44.361621	48216.6311	15.831	600.9982	19.6623	-0.1075	0.11983	-0.0437	
2.4	190.555	44.481454	48216.5874	15.831	600.9981	19.73648	-0.1077	0.11977	-0.0436	
2.41	190.447	44.601219	48216.5438	15.831	600.9981	19.81074	-0.108	0.1197	-0.0434	
2.42	190.339	44.720917	48216.5004	15.831	600.9981	19.88505	-0.1082	0.11963	-0.0433	
2.43	190.231	44.840546	48216.457	15.831	600.9981	19.95944	-0.1084	0.11956	-0.0432	
2.44	190.123	44.960108	48216.4138	15.831	600.9981	20.03388	-0.1086	0.11949	-0.0431	
2.45	190.014	45.079602	48216.3707	15.831	600.9981	20.10839	-0.1089	0.11943	-0.043	
2.46	189.905	45.199027	48216.3277	15.831	600.9981	20.18295	-0.1091	0.11936	-0.0429	
2.47	189.796	45.318384	48216.2848	15.831	600.998	20.25757	-0.1093	0.11929	-0.0428	
2.48	189.687	45.437672	48216.242	15.831	600.998	20.33224	-0.1095	0.11922	-0.0427	
2.49	189.577	45.556891	48216.1993	15.831	600.998	20.40697	-0.1097	0.11915	-0.0426	
2.5	189.467	45.676042	48216.1567	15.831	600.998	20.48174	-0.11	0.11908	-0.0425	
2.51	189.358	45.795124	48216.1142	15.831	600.998	20.55656	-0.1102	0.11901	-0.0424	
2.52	189.247	45.914136	48216.0719	15.831	600.998	20.63143	-0.1104	0.11894	-0.0422	
2.53	189.137	46.03308	48216.0296	15.831	600.998	20.70634	-0.1106	0.11887	-0.0421	
2.54	189.026	46.151954	48215.9875	15.831	600.9979	20.78129	-0.1108	0.1188	-0.042	
2.55	188.916	46.270758	48215.9455	15.831	600.9979	20.85629	-0.111	0.11873	-0.0419	
2.56	188.805	46.389493	48215.9036	15.831	600.9979	20.93131	-0.1112	0.11867	-0.0418	
2.57	188.693	46.508158	48215.8618	15.831	600.9979	21.00638	-0.1114	0.1186	-0.0417	
2.58	188.582	46.626753	48215.8201	15.831	600.9979	21.08148	-0.1116	0.11853	-0.0416	
2.59	188.471	46.745278	48215.7785	15.831	600.9979	21.15661	-0.1118	0.11846	-0.0415	
2.6	188.359	46.863733	48215.737	15.831	600.9979	21.23177	-0.112	0.11838	-0.0414	
2.61	188.247	46.982118	48215.6957	15.831	600.9979	21.30696	-0.1121	0.11831	-0.0412	
2.62	188.135	47.100433	48215.6544	15.831	600.9978	21.38218	-0.1123	0.11824	-0.0411	
2.63	188.022	47.218677	48215.6133	15.831	600.9978	21.45742	-0.1125	0.11817	-0.041	
2.64	187.91	47.33685	48215.5722	15.831	600.9978	21.53269	-0.1127	0.1181	-0.0409	
2.65	187.797	47.454953	48215.5313	15.831	600.9978	21.60797	-0.1129	0.11803	-0.0408	
2.66	187.684	47.572985	48215.4905	15.831	600.9978	21.68328	-0.1131	0.11796	-0.0407	
2.67	187.571	47.690946	48215.4499	15.831	600.9978	21.75861	-0.1132	0.11789	-0.0406	
2.68	187.458	47.808835	48215.4093	15.831	600.9978	21.83395	-0.1134	0.11782	-0.0405	
2.69	187.344	47.926654	48215.3688	15.831	600.9977	21.90931	-0.1136	0.11775	-0.0403	
2.7	187.231	48.044401	48215.3285	15.831	600.9977	21.98469	-0.1138	0.11768	-0.0402	
2.71	187.117	48.162077	48215.2883	15.831	600.9977	22.06007	-0.1139	0.1176	-0.0401	
2.72	187.003	48.279682	48215.2481	15.831	600.9977	22.13547	-0.1141	0.11753	-0.04	
2.73	186.889	48.397215	48215.2081	15.831	600.9977	22.21088	-0.1143	0.11746	-0.0399	
2.74	186.775	48.514676	48215.1682	15.831	600.9977	22.2863	-0.1144	0.11739	-0.0398	
2.75	186.66	48.632065	48215.1285	15.831	600.9977	22.36172	-0.1146	0.11732	-0.0397	
2.76	186.546	48.749383	48215.0888	15.831	600.9977	22.43715	-0.1148	0.11725	-0.0395	
2.77	186.431	48.866628	48215.0493	15.831	600.9976	22.51258	-0.1149	0.11717	-0.0394	
2.78	186.316	48.983801	48215.0098	15.831	600.9976	22.58802	-0.1151	0.1171	-0.0393	
2.79	186.201	49.100902	48214.9705	15.831	600.9976	22.66346	-0.1153	0.11703	-0.0392	
2.8	186.086	49.217931	48214.9313	15.831	600.9976	22.7389	-0.1154	0.11696	-0.0391	
2.81	185.97	49.334887	48214.8922	15.831	600.9976	22.81434	-0.1156	0.11688	-0.039	
2.82	185.855	49.451771	48214.8533	15.831	600.9976	22.88977	-0.1157	0.11681	-0.0389	
2.83	185.739	49.568582	48214.8144	15.831	600.9976	22.96521	-0.1159	0.11674	-0.0387	
2.84	185.623	49.68532	48214.7757	15.831	600.9976	23.04064	-0.116	0.11667	-0.0386	
2.85	185.507	49.801985	48214.737	15.831	600.9975	23.11606	-0.1162	0.11659	-0.0385	
2.86	185.391	49.918578	48214.6985	15.831	600.9975	23.19148	-0.1163	0.11652	-0.0384	
2.87	185.274	50.035097	48214.6601	15.831	600.9975	23.26689	-0.1165	0.11645	-0.0383	
2.88	185.158	50.151544	48214.6219	15.831	600.9975	23.34229	-0.1166	0.11637	-0.0382	
2.89	185.041	50.267917	48214.5837	15.83	600.9975	23.41768	-0.1168	0.1163	-0.038	
2.9	184.925	50.384217	48214.5457	15.83	600.9975	23.49306	-0.1169	0.11623	-0.0379	
2.91	184.808	50.500443	48214.5077	15.83	600.9975	23.56843	-0.1171	0.11615	-0.0378	
2.92	184.691	50.616596	48214.4699	15.83	600.9975	23.64378	-0.1172	0.11608	-0.0377	
2.93	184.573	50.732675	48214.4322	15.83	600.9974	23.71912	-0.1174	0.11601	-0.0376	
2.94	184.456	50.848681	48214.3947	15.83	600.9974	23.79445	-0.1175	0.11593	-0.0375	
2.95	184.338	50.964613	48214.3572	15.83	600.9974	23.86976	-0.1176	0.11586	-0.0373	
2.96	184.221	51.080471	48214.3199	15.83	600.9974	23.94505	-0.1178	0.11578	-0.0372	
2.97	184.103	51.196255	48214.2827	15.83	600.9974	24.02032	-0.1179	0.11571	-0.0371	
2.98	183.985	51.311965	48214.2456	15.83	600.9974	24.09558	-0.1181	0.11564	-0.037	
2.99	183.867	51.427601	48214.2086	15.83	600.9974	24.17081	-0.1182	0.11556	-0.0369	
3	183.749	51.543163	48214.1717	15.83	600.9974	24.24602	-0.1183	0.11549	-0.0367	
3.01	183.63	51.65865	48214.135	15.83	600.9973	24.32121	-0.1185	0.11541	-0.0366	
3.02	183.512	51.774064	48214.0983	15.83	600.9973	24.39638	-0.1186	0.11534	-0.0365	
3.03	183.393	51.889402	48214.0618	15.83	600.9973	24.47153	-0.1187	0.11526	-0.0364	
3.04	183.275	52.004666	48214.0254	15.83	600.9973	24.54665	-0.1189	0.11519	-0.0363	
3.05	183.156	52.119856	48213.9891	15.83	600.9973	24.62174	-0.119	0.11511	-0.0362	
3.0501	183.037	52.234971	48213.953	15.83	600.9973	24.69681	-0.1191	0.00115	-0.036	0.0001
3.0502	182.918	52.236121	48213.917	15.83	600.9973	24.77185	-0.1184	0.00115	-0.0359	
3.0503	182.799	52.237271	48213.881	15.83	600.9973	24.84632	-0.1177	0.00115	-0.0358	
3.0504	182.682	52.23842	48213.8452	15.83	600.9972	24.92023	-0.1169	0.00115	-0.0357	
3.0505	182.565	52.239568	48213.8096	15.83	600.9972	24.99358	-0.1162	0.00115	-0.0356	
3.0506	182.448	52.240715	48213.774	15.83	600.9972	25.06638	-0.1155	0.00115	-0.0354	
3.0507	182.333	52.241862	48213.7385	15.83	600.9972	25.13863	-0.1148	0.00115	-0.0353	
3.0508	182.218	52.243008	48213.7032	15.83	600.9972	25.21034	-0.1141	0.00115	-0.0352	
3.0509	182.104	52.244153	48213.668	15.83	600.9972	25.28151	-0.1134	0.00114	-0.0351	
3.051	181.991	52.245298	48213.6329	15.83	600.9972	25.35216	-0.1127	0.00114	-0.035	
3.0511	181.878	52.246441	48213.5979	15.83	600.9972	25.42227	-0.1121	0.00114	-0.0349	
3.0512	181.766	52.247585	48213.563	15.83	600.9972	25.49187	-0.1114	0.00114	-0.0348	

3.0513	181.654	52.248727	48213.5283	15.83	600.9971	25.56094	-0.1107	0.00114	-0.0347		
3.0514	181.544	52.249869	48213.4936	15.83	600.9971	25.62951	-0.11	0.00114	-0.0345		
3.0515	181.434	52.25101	48213.4591	15.83	600.9971	25.69757	-0.1094	0.00114	-0.0344		
3.0516	181.324	52.25215	48213.4246	15.83	600.9971	25.76513	-0.1087	0.00114	-0.0343		
3.0517	181.216	52.25329	48213.3903	15.83	600.9971	25.8322	-0.1081	0.00114	-0.0342		
3.0518	181.108	52.254429	48213.3561	15.83	600.9971	25.89877	-0.1074	0.00114	-0.0341		
3.0519	181	52.255567	48213.322	15.83	600.9971	25.96485	-0.1068	0.00114	-0.034		
3.052	180.893	52.256704	48213.288	15.83	600.9971	26.03045	-0.1061	0.00114	-0.0339		
3.0521	180.787	52.257841	48213.2541	15.83	600.9971	26.09558	-0.1055	0.00114	-0.0338		

PUMP P-1 STARTUP (one pump operates)

2. Horizontal section in pipe

g =	32.17	ft/sec^2
f =	0.01012	
k =	0.00015	
$k_{L\ elbow}$ =	0.33271	
$k_{L\ entrance}$ =	0.10098	
Viscosity =	0.00003	ft^2/sec
Diameter of Pipe (D) =	4.5	ft
Area of Pipe (A) =	15.9107	ft^2
H_{pump} =	$-(9*10^{-6})*x^3+0.0011x^2-0.1285x+66.554$	ft

Start Pump P-1 Elevation =	601	ft
Stop Pump P-1 Elevation =	595	ft
Minimum Surface Elevation =	585.167	ft

Cross Sectional Area of Wet well = 3045.7 ft^2

Q_0 =	175.0617	ft^3/sec
V_0 =	11.00276	ft/sec
Z_0 =	15.82939	ft
V_0 =	48211.25	ft^3
Length of Pipe for horizontal section=	52	ft
Length of Pipe for vrtical section=	52.33	ft

Apply Euler's Formula:

$Q(t) = O_{previous}+dQ$ where,

$$\frac{P_{elbow}}{\gamma}=z+H_{pump}-52.33-\left(\frac{f\times 52.33}{D}+k_{entrance}+k_{elbow}\right)\times\frac{Q^2}{2gA^2}$$

$X(t) = X_{previous}+dx$

$V(t) = V_{previous}+dV$ $dx = (Q/A) * dt$

$z(t) = V_0 / A = V_0 / 3045.7$ $dV = (Q_{inflow} - Q)* dt$ Use Q_{inflow} = 147 cfs

$$\partial Q=\left[\frac{P_{elbow}}{\gamma}-\frac{fx}{D}\frac{Q^2}{2gA^2}\right]\times A\times\frac{g}{52.33+x}\times\partial$$

t(sec)	Q(cfs)	x(ft)	V(ft^3)	z(ft)	WSEL(ft)	H_{pump}(ft)	p_{elbow}/γ	dQ	dx	dV	
3.0586	175.0617	0.00	48211.3	15.82939393	600.996	29.4844	-8.0535	-0.7877	0.110027559	-0.2806	0.01
3.0686	174.274	0.11	48211	15.82930179	600.996	29.9318	-7.5969	-0.7421	0.109532465	-0.2727	
3.0786	173.5319	0.22	48210.7	15.82921224	600.996	30.3492	-7.1709	-0.6996	0.109066069	-0.2653	
3.0886	172.8323	0.33	48210.4	15.82912513	600.996	30.7391	-6.7729	-0.66	0.10862638	-0.2583	
3.0986	172.1723	0.44	48210.2	15.82904031	600.996	31.1037	-6.4007	-0.623	0.108211578	-0.2517	
3.1086	171.5493	0.55	48209.9	15.82895767	600.996	31.445	-6.0522	-0.5885	0.107819991	-0.2455	
3.1186	170.9608	0.65	48209.7	15.82887706	600.996	31.765	-5.7255	-0.5563	0.107450085	-0.2396	
3.1286	170.4045	0.76	48209.4	15.82879839	600.996	32.0651	-5.419	-0.5261	0.107100449	-0.234	
3.1386	169.8783	0.87	48209.2	15.82872155	600.996	32.347	-5.1311	-0.4979	0.10676978	-0.2288	
3.1486	169.3805	0.97	48209	15.82864643	600.996	32.612	-4.8605	-0.4714	0.106456877	-0.2238	
3.1586	168.9091	1.08	48208.8	15.82857295	600.996	32.8612	-4.6059	-0.4465	0.106160628	-0.2191	
3.1686	168.4627	1.19	48208.5	15.82850101	600.996	33.096	-4.3662	-0.4231	0.105880005	-0.2146	
3.1786	168.0395	1.29	48208.3	15.82843054	600.995	33.3171	-4.1402	-0.4012	0.105614054	-0.2104	
3.1886	167.6383	1.40	48208.1	15.82836146	600.995	33.5257	-3.9272	-0.3806	0.10536189	-0.2064	
3.1986	167.2577	1.50	48207.9	15.8282937	600.995	33.7225	-3.7261	-0.3612	0.105122689	-0.2026	
3.2086	166.8965	1.61	48207.7	15.82822719	600.995	33.9084	-3.5362	-0.3429	0.104895687	-0.199	
3.2186	166.5536	1.71	48207.5	15.82816186	600.995	34.084	-3.3568	-0.3257	0.104680169	-0.1955	
3.2286	166.2279	1.82	48207.3	15.82809766	600.995	34.2501	-3.1871	-0.3095	0.104475472	-0.1923	
3.2386	165.9185	1.92	48207.1	15.82803453	600.995	34.4073	-3.0265	-0.2942	0.104280975	-0.1892	
3.2486	165.6243	2.03	48206.9	15.82797241	600.995	34.556	-2.8745	-0.2797	0.104096098	-0.1862	
3.2586	165.3446	2.13	48206.7	15.82791126	600.995	34.697	-2.7305	-0.2661	0.103920299	-0.1834	
3.2686	165.0785	2.24	48206.6	15.82785103	600.995	34.8305	-2.594	-0.2532	0.10375307	-0.1808	
3.2786	164.8254	2.34	48206.4	15.82779167	600.995	34.9572	-2.4646	-0.241	0.103593938	-0.1783	
3.2886	164.5843	2.44	48206.2	15.82773314	600.995	35.0774	-2.3418	-0.2295	0.103442457	-0.1758	
3.2986	164.3548	2.55	48206	15.82767541	600.995	35.1914	-2.2252	-0.2186	0.10329821	-0.1735	
3.3086	164.1362	2.65	48205.8	15.82761843	600.995	35.2998	-2.1145	-0.2083	0.103160803	-0.1714	
3.3186	163.9279	2.75	48205.7	15.82756216	600.995	35.4027	-2.0093	-0.1986	0.103029871	-0.1693	
3.3286	163.7293	2.86	48205.5	15.82750658	600.995	35.5006	-1.9093	-0.1893	0.102905065	-0.1673	
3.3386	163.54	2.96	48205.3	15.82745165	600.994	35.5936	-1.8142	-0.1806	0.102786063	-0.1654	
3.3486	163.3594	3.06	48205.2	15.82739735	600.994	35.6821	-1.7238	-0.1723	0.102672556	-0.1636	
3.3586	163.1871	3.16	48205	15.82734363	600.994	35.7664	-1.6376	-0.1645	0.102564257	-0.1619	
3.3686	163.0226	3.27	48204.8	15.82729049	600.994	35.8467	-1.5556	-0.157	0.102460896	-0.1602	
3.3786	162.8656	3.37	48204.7	15.82723788	600.994	35.9231	-1.4775	-0.1499	0.102362215	-0.1587	
3.3886	162.7157	3.47	48204.5	15.82718579	600.994	35.996	-1.4031	-0.1432	0.102267973	-0.1572	
3.3986	162.5724	3.57	48204.4	15.82713419	600.994	36.0654	-1.3321	-0.1369	0.102177944	-0.1557	
3.4086	162.4355	3.68	48204.2	15.82708306	600.994	36.1317	-1.2644	-0.1308	0.102091912	-0.1544	
3.4186	162.3047	3.78	48204.1	15.82703238	600.994	36.1949	-1.1998	-0.1251	0.102009675	-0.153	
3.4286	162.1796	3.88	48203.9	15.82698213	600.994	36.2552	-1.1381	-0.1197	0.10193104	-0.1518	
3.4386	162.0599	3.98	48203.8	15.82693229	600.994	36.3128	-1.0792	-0.1145	0.101855828	-0.1506	
3.4486	161.9454	4.08	48203.6	15.82688284	600.994	36.3679	-1.023	-0.1096	0.101783866	-0.1495	
3.4586	161.8358	4.19	48203.5	15.82683377	600.994	36.4205	-0.9692	-0.1049	0.101714994	-0.1484	
3.4686	161.7309	4.29	48203.3	15.82678506	600.994	36.4708	-0.9178	-0.1005	0.101649057	-0.1473	
3.4786	161.6304	4.39	48203.2	15.82673669	600.994	36.5188	-0.8687	-0.0962	0.101585911	-0.1463	
3.4886	161.5342	4.49	48203	15.82668866	600.994	36.5648	-0.8217	-0.0922	0.10152542	-0.1453	
3.4986	161.442	4.59	48202.9	15.82664093	600.994	36.6089	-0.7767	-0.0884	0.101467452	-0.1444	
3.5086	161.3536	4.69	48202.7	15.82659352	600.994	36.651	-0.7336	-0.0848	0.101411885	-0.1435	

3.5186	161.2688	4.80	48202.6	15.82654639	600.994	36.6914	-0.6924	-0.0813	0.101358602	-0.1427	
3.5286	161.1875	4.90	48202.4	15.82649954	600.993	36.7301	-0.6529	-0.078	0.101307493	-0.1419	
3.5386	161.1094	5.00	48202.3	15.82645296	600.993	36.7671	-0.615	-0.0749	0.101258453	-0.1411	
3.5486	161.0345	5.10	48202.2	15.82640663	600.993	36.8027	-0.5787	-0.0719	0.101211382	-0.1403	
3.5586	160.9626	5.20	48202	15.82636055	600.993	36.8368	-0.5438	-0.0691	0.101166187	-0.1396	
3.5686	160.8936	5.30	48201.9	15.82631471	600.993	36.8695	-0.5104	-0.0664	0.101122777	-0.1389	
3.5786	160.8272	5.40	48201.7	15.82626909	600.993	36.9009	-0.4783	-0.0638	0.101081068	-0.1383	
3.5886	160.7634	5.50	48201.6	15.82622369	600.993	36.9311	-0.4475	-0.0613	0.10104098	-0.1376	
3.5986	160.7021	5.60	48201.5	15.8261785	600.993	36.96	-0.4179	-0.059	0.101002435	-0.137	
3.6086	160.6431	5.71	48201.3	15.82613351	600.993	36.9879	-0.3895	-0.0568	0.100965361	-0.1364	

3.6186	160.5863	5.81	48201.2	15.82608872	600.993	37.0147	-0.3622	-0.0546	0.100929689	-0.1359	
3.6286	160.5317	5.91	48201.1	15.82604411	600.993	37.0404	-0.3359	-0.0526	0.100895354	-0.1353	
3.6386	160.4791	6.01	48200.9	15.82599968	600.993	37.0652	-0.3106	-0.0507	0.100862292	-0.1348	
3.6486	160.4284	6.11	48200.8	15.82595542	600.993	37.089	-0.2862	-0.0488	0.100830445	-0.1343	
3.6586	160.3796	6.21	48200.6	15.82591133	600.993	37.112	-0.2627	-0.0471	0.100799757	-0.1338	
3.6686	160.3325	6.31	48200.5	15.8258674	600.993	37.1341	-0.2402	-0.0454	0.100770173	-0.1333	
3.6786	160.2871	6.41	48200.4	15.82582363	600.993	37.1554	-0.2184	-0.0438	0.100741642	-0.1329	
3.6886	160.2434	6.51	48200.2	15.82578	600.993	37.176	-0.1974	-0.0423	0.100714118	-0.1324	
3.6986	160.2011	6.61	48200.1	15.82573652	600.993	37.1958	-0.1772	-0.0408	0.100687552	-0.132	
3.7086	160.1603	6.71	48200	15.82569318	600.993	37.215	-0.1576	-0.0394	0.100661901	-0.1316	
3.7186	160.1209	6.81	48199.8	15.82564997	600.993	37.2334	-0.1388	-0.0381	0.100637124	-0.1312	
3.7286	160.0828	6.92	48199.7	15.82560689	600.993	37.2513	-0.1206	-0.0368	0.10061318	-0.1308	
3.7386	160.0459	7.02	48199.6	15.82556393	600.993	37.2685	-0.103	-0.0356	0.100590032	-0.1305	
3.7486	160.0103	7.12	48199.5	15.8255211	600.993	37.2852	-0.0859	-0.0345	0.100567644	-0.1301	
3.7586	159.9758	7.22	48199.3	15.82547838	600.992	37.3013	-0.0695	-0.0334	0.100545981	-0.1298	
3.7686	159.9425	7.32	48199.2	15.82543578	600.992	37.3169	-0.0536	-0.0323	0.100525011	-0.1294	
3.7786	159.9102	7.42	48199.1	15.82539328	600.992	37.332	-0.0382	-0.0313	0.100504703	-0.1291	
3.7886	159.8789	7.52	48198.9	15.82535089	600.992	37.3466	-0.0233	-0.0303	0.100485026	-0.1288	
3.7986	159.8485	7.62	48198.8	15.82530861	600.992	37.3608	-0.0088	-0.0294	0.100465953	-0.1285	
3.8086	159.8191	7.72	48198.7	15.82526642	600.992	37.3745	0.0052	-0.0286	0.100447456	-0.1282	
3.8186	159.7905	7.82	48198.6	15.82522433	600.992	37.3878	0.0188	-0.0277	0.100429511	-0.1279	
3.8286	159.7628	7.92	48198.4	15.82518234	600.992	37.4008	0.032	-0.0269	0.100412091	-0.1276	
3.8386	159.7359	8.02	48198.3	15.82514043	600.992	37.4133	0.0448	-0.0262	0.100395175	-0.1274	
3.8486	159.7097	8.12	48198.2	15.82509861	600.992	37.4255	0.0572	-0.0254	0.100378739	-0.1271	
3.8586	159.6843	8.22	48198	15.82505688	600.992	37.4373	0.0693	-0.0247	0.100362763	-0.1268	
3.8686	159.6596	8.32	48197.9	15.82501524	600.992	37.4488	0.081	-0.0241	0.100347226	-0.1266	
3.8786	159.6356	8.42	48197.8	15.82497367	600.992	37.46	0.0924	-0.0234	0.10033211	-0.1264	
3.8886	159.6121	8.52	48197.7	15.82493218	600.992	37.4709	0.1035	-0.0228	0.100317394	-0.1261	
3.8986	159.5893	8.62	48197.5	15.82489077	600.992	37.4815	0.1143	-0.0222	0.100303063	-0.1259	
3.9086	159.5671	8.72	48197.4	15.82484944	600.992	37.4919	0.1249	-0.0217	0.100289099	-0.1257	
3.9186	159.5455	8.82	48197.3	15.82480818	600.992	37.5019	0.1351	-0.0211	0.100275486	-0.1255	
3.9286	159.5243	8.92	48197.2	15.82476699	600.992	37.5117	0.1451	-0.0206	0.100262209	-0.1252	
3.9386	159.5037	9.02	48197	15.82472586	600.992	37.5213	0.1549	-0.0201	0.100249253	-0.125	
3.9486	159.4836	9.12	48196.9	15.82468481	600.992	37.5307	0.1644	-0.0197	0.100236604	-0.1248	
3.9586	159.4639	9.22	48196.8	15.82464382	600.992	37.5398	0.1737	-0.0192	0.10022425	-0.1246	
3.9686	159.4447	9.32	48196.7	15.8246029	600.992	37.5487	0.1828	-0.0188	0.100212177	-0.1244	
3.9786	159.426	9.42	48196.5	15.82456204	600.992	37.5574	0.1917	-0.0184	0.100200373	-0.1243	
3.9886	159.4076	9.53	48196.4	15.82452124	600.992	37.5659	0.2003	-0.018	0.100188827	-0.1241	
3.9986	159.3896	9.63	48196.3	15.8244805	600.991	37.5743	0.2088	-0.0176	0.100177528	-0.1239	
4.0086	159.372	9.73	48196.2	15.82443982	600.991	37.5824	0.2171	-0.0172	0.100166465	-0.1237	
4.0186	159.3548	9.83	48196	15.8243992	600.991	37.5904	0.2253	-0.0169	0.100155627	-0.1235	
4.0286	159.3379	9.93	48195.9	15.82435864	600.991	37.5983	0.2333	-0.0166	0.100145006	-0.1234	
4.0386	159.3213	10.03	48195.8	15.82431813	600.991	37.606	0.2411	-0.0163	0.100134593	-0.1232	
4.0486	159.305	10.13	48195.7	15.82427767	600.991	37.6135	0.2487	-0.016	0.100124377	-0.1231	
4.0586	159.2891	10.23	48195.5	15.82423727	600.991	37.6209	0.2563	-0.0157	0.100114352	-0.1229	
4.0686	159.2734	10.33	48195.4	15.82419692	600.991	37.6281	0.2636	-0.0154	0.100104508	-0.1227	
4.0786	159.258	10.43	48195.3	15.82415662	600.991	37.6352	0.2709	-0.0151	0.100094839	-0.1226	
4.0886	159.2429	10.53	48195.2	15.82411638	600.991	37.6422	0.278	-0.0149	0.100085337	-0.1224	
4.0986	159.2281	10.63	48195.1	15.82407618	600.991	37.6491	0.285	-0.0146	0.100075994	-0.1223	
4.1086	159.2134	10.73	48194.9	15.82403603	600.991	37.6559	0.2919	-0.0144	0.100066805	-0.1221	
4.1186	159.199	10.83	48194.8	15.82399593	600.991	37.6625	0.2987	-0.0142	0.100057763	-0.122	
4.2186	159.1849	10.93	48194.7	15.82395588	600.991	37.6691	0.3053	-0.1395	1.000488608	-1.2185	0.1
4.3186	159.0454	11.93	48193.5	15.8235558	600.991	37.7335	0.3709	-0.1192	0.9996119	-1.2045	
4.4186	158.9262	12.93	48192.3	15.82316031	600.99	37.7885	0.4267	-0.1071	0.998862602	-1.1926	
4.5186	158.819	13.93	48191.1	15.82276874	600.99	37.8379	0.4768	-0.0998	0.998189315	-1.1819	
4.6186	158.7192	14.92	48189.9	15.82238068	600.989	37.8837	0.5234	-0.0953	0.997562004	-1.1719	
4.7186	158.6239	15.92	48188.7	15.82199589	600.989	37.9275	0.5678	-0.0925	0.996962921	-1.1624	
4.8186	158.5314	16.92	48187.6	15.82161424	600.989	37.9699	0.6109	-0.0907	0.996381462	-1.1531	
4.9186	158.4407	17.91	48186.4	15.82123563	600.988	38.0115	0.653	-0.0896	0.995811229	-1.1441	
5.0186	158.3511	18.91	48185.3	15.82085999	600.988	38.0525	0.6946	-0.0888	0.995248323	-1.1351	
5.1186	158.2623	19.91	48184.1	15.82048729	600.987	38.093	0.7357	-0.0882	0.994690349	-1.1262	
5.2186	158.1741	20.90	48183	15.82011751	600.987	38.1333	0.7765	-0.0878	0.994135818	-1.1174	
5.3186	158.0863	21.89	48181.9	15.81975063	600.987	38.1733	0.8171	-0.0875	0.9935838	-1.1086	
5.4186	157.9988	22.89	48180.8	15.81938663	600.986	38.2132	0.8576	-0.0873	0.993033708	-1.0999	
5.5186	157.9115	23.88	48179.7	15.8190255	600.986	38.2528	0.8978	-0.0871	0.992485169	-1.0911	
5.6186	157.8244	24.87	48178.6	15.81866724	600.986	38.2924	0.9379	-0.0869	0.991937941	-1.0824	
5.7186	157.7375	25.87	48177.5	15.81831184	600.985	38.3318	0.9779	-0.0867	0.99139187	-1.0738	
5.8186	157.6508	26.86	48176.4	15.81795929	600.985	38.3711	1.0177	-0.0866	0.990846854	-1.0651	
5.9186	157.5643	27.85	48175.4	15.81760959	600.985	38.4102	1.0575	-0.0864	0.990302827	-1.0564	
6.0186	157.4778	28.84	48174.3	15.81726273	600.984	38.4493	1.0971	-0.0863	0.989759743	-1.0478	
6.1186	157.3916	29.83	48173.3	15.8169187	600.984	38.4882	1.1366	-0.0861	0.989217573	-1.0392	
6.2186	157.3055	30.82	48172.2	15.81657751	600.984	38.527	1.176	-0.086	0.988676296	-1.0305	
6.3186	157.2195	31.81	48171.2	15.81623915	600.983	38.5657	1.2153	-0.0858	0.988135897	-1.0219	
6.4186	157.1336	32.79	48170.2	15.81590361	600.983	38.6044	1.2545	-0.0857	0.987596366	-1.0134	
6.5186	157.0479	33.78	48169.2	15.81557089	600.983	38.6429	1.2936	-0.0856	0.987057697	-1.0048	
6.6186	156.9624	34.77	48168.1	15.81524098	600.982	38.6812	1.3325	-0.0854	0.986519882	-0.9962	
6.7186	156.8769	35.76	48167.2	15.81491388	600.982	38.7195	1.3714	-0.0853	0.985982917	-0.9877	
6.8186	156.7916	36.74	48166.2	15.81458959	600.982	38.7577	1.4102	-0.0852	0.9854468	-0.9792	
6.9186	156.7065	37.73	48165.2	15.8142681	600.981	38.7958	1.4488	-0.085	0.984911527	-0.9706	
7.0186	156.6214	38.71	48164.2	15.8139494	600.981	38.8338	1.4874	-0.0849	0.984377096	-0.9621	
7.1186	156.5365	39.70	48163.3	15.8136335	600.981	38.8716	1.5258	-0.0848	0.983843503	-0.9537	
7.2186	156.4518	40.68	48162.3	15.81332038	600.98	38.9094	1.5642	-0.0846	0.983310748	-0.9452	
7.3186	156.3671	41.66	48161.4	15.81301004	600.98	38.947	1.6024	-0.0845	0.982778828	-0.9367	
7.4186	156.2826	42.65	48160.4	15.81270249	600.98	38.9846	1.6405	-0.0844	0.982247741	-0.9283	

7.5186	156.1983	43.63	48159.5	15.81239771	600.979	39.022	1.6786	-0.0842	0.981717486	-0.9198	
7.6186	156.114	44.61	48158.6	15.8120957	600.979	39.0594	1.7165	-0.0841	0.98118806	-0.9114	
7.7186	156.0299	45.59	48157.7	15.81179645	600.979	39.0966	1.7543	-0.084	0.980659462	-0.903	
7.8186	155.946	46.57	48156.8	15.81149997	600.978	39.1338	1.7921	-0.0838	0.98013169	-0.8946	
7.9186	155.8621	47.55	48155.9	15.81120625	600.978	39.1708	1.8297	-0.0837	0.979604742	-0.8862	
8.0186	155.7784	48.53	48155	15.81091527	600.978	39.2077	1.8672	-0.0836	0.979078618	-0.8778	

8.1186	155.6948	49.51	48154.1	15.81062705	600.978	39.2446	1.9047	-0.0834	0.978553314	-0.8695	
8.1196	155.6114	50.49	48153.2	15.81034157	600.977	39.2813	1.942	-0.0008	0.009780288	-0.0086	0.001
8.1206	155.6105	50.50	48153.2	15.81033874	600.977	39.2817	1.9424	-0.0008	0.009780236	-0.0086	
8.1216	155.6097	50.51	48153.2	15.81033591	600.977	39.282	1.9427	-0.0008	0.009780184	-0.0086	
8.1226	155.6089	50.52	48153.2	15.81033309	600.977	39.2824	1.9431	-0.0008	0.009780131	-0.0086	
8.1236	155.608	50.53	48153.2	15.81033026	600.977	39.2828	1.9435	-0.0008	0.009780079	-0.0086	
8.1246	155.6072	50.54	48153.2	15.81032743	600.977	39.2831	1.9439	-0.0008	0.009780026	-0.0086	
8.1256	155.6064	50.55	48153.2	15.81032461	600.977	39.2835	1.9442	-0.0008	0.009779974	-0.0086	
8.1266	155.6055	50.56	48153.2	15.81032178	600.977	39.2839	1.9446	-0.0008	0.009779922	-0.0086	
8.1276	155.6047	50.57	48153.2	15.81031896	600.977	39.2842	1.945	-0.0008	0.009779869	-0.0086	
8.1286	155.6039	50.58	48153.1	15.81031613	600.977	39.2846	1.9453	-0.0008	0.009779817	-0.0086	
8.1296	155.603	50.59	48153.1	15.81031331	600.977	39.285	1.9457	-0.0008	0.009779765	-0.0086	
8.1306	155.6022	50.60	48153.1	15.81031048	600.977	39.2853	1.9461	-0.0008	0.009779712	-0.0086	
8.1316	155.6014	50.61	48153.1	15.81030766	600.977	39.2857	1.9465	-0.0008	0.00977966	-0.0086	
8.1326	155.6005	50.62	48153.1	15.81030483	600.977	39.2861	1.9468	-0.0008	0.009779608	-0.0086	
8.1336	155.5997	50.63	48153.1	15.81030201	600.977	39.2864	1.9472	-0.0008	0.009779555	-0.0086	
8.1346	155.5989	50.64	48153.1	15.81029918	600.977	39.2868	1.9476	-0.0008	0.009779503	-0.0086	
8.1356	155.598	50.65	48153.1	15.81029636	600.977	39.2872	1.948	-0.0008	0.009779451	-0.0086	
8.1366	155.5972	50.66	48153.1	15.81029354	600.977	39.2875	1.9483	-0.0008	0.009779398	-0.0086	
8.1376	155.5964	50.67	48153.1	15.81029072	600.977	39.2879	1.9487	-0.0008	0.009779346	-0.0086	
8.1386	155.5955	50.67	48153.1	15.81028789	600.977	39.2883	1.9491	-0.0008	0.009779293	-0.0086	
8.1396	155.5947	50.68	48153.1	15.81028507	600.977	39.2886	1.9494	-0.0008	0.009779241	-0.0086	
8.1406	155.5939	50.69	48153	15.81028225	600.977	39.289	1.9498	-0.0008	0.009779189	-0.0086	
8.1416	155.593	50.70	48153	15.81027943	600.977	39.2894	1.9502	-0.0008	0.009779136	-0.0086	
8.1426	155.5922	50.71	48153	15.81027661	600.977	39.2897	1.9506	-0.0008	0.009779084	-0.0086	
8.1436	155.5914	50.72	48153	15.81027378	600.977	39.2901	1.9509	-0.0008	0.009779032	-0.0086	
8.1446	155.5905	50.73	48153	15.81027096	600.977	39.2905	1.9513	-0.0008	0.009778979	-0.0086	
8.1456	155.5897	50.74	48153	15.81026814	600.977	39.2908	1.9517	-0.0008	0.009778927	-0.0086	
8.1466	155.5889	50.75	48153	15.81026532	600.977	39.2912	1.9521	-0.0008	0.009778875	-0.0086	
8.1476	155.588	50.76	48153	15.8102625	600.977	39.2916	1.9524	-0.0008	0.009778822	-0.0086	
8.1486	155.5872	50.77	48153	15.81025968	600.977	39.2919	1.9528	-0.0008	0.00977877	-0.0086	
8.1496	155.5864	50.78	48153	15.81025686	600.977	39.2923	1.9532	-0.0008	0.009778718	-0.0086	
8.1506	155.5855	50.79	48153	15.81025404	600.977	39.2927	1.9535	-0.0008	0.009778665	-0.0086	
8.1516	155.5847	50.80	48153	15.81025123	600.977	39.293	1.9539	-0.0008	0.009778613	-0.0086	
8.1526	155.5839	50.81	48152.9	15.81024841	600.977	39.2934	1.9543	-0.0008	0.009778561	-0.0086	
8.1536	155.5831	50.82	48152.9	15.81024559	600.977	39.2938	1.9547	-0.0008	0.009778508	-0.0086	
8.1546	155.5822	50.83	48152.9	15.81024277	600.977	39.2941	1.955	-0.0008	0.009778456	-0.0086	
8.1556	155.5814	50.84	48152.9	15.81023995	600.977	39.2945	1.9554	-0.0008	0.009778404	-0.0086	
8.1566	155.5806	50.85	48152.9	15.81023714	600.977	39.2949	1.9558	-0.0008	0.009778351	-0.0086	
8.1576	155.5797	50.86	48152.9	15.81023432	600.977	39.2952	1.9561	-0.0008	0.009778299	-0.0086	
8.1586	155.5789	50.87	48152.9	15.8102315	600.977	39.2956	1.9565	-0.0008	0.009778247	-0.0086	
8.1596	155.5781	50.88	48152.9	15.81022868	600.977	39.296	1.9569	-0.0008	0.009778194	-0.0086	
8.1606	155.5772	50.89	48152.9	15.81022587	600.977	39.2963	1.9573	-0.0008	0.009778142	-0.0086	
8.1616	155.5764	50.90	48152.9	15.81022305	600.977	39.2967	1.9576	-0.0008	0.00977809	-0.0086	
8.1626	155.5756	50.91	48152.9	15.81022024	600.977	39.2971	1.958	-0.0008	0.009778037	-0.0086	
8.1636	155.5747	50.92	48152.8	15.81021742	600.977	39.2974	1.9584	-0.0008	0.009777985	-0.0086	
8.1646	155.5739	50.93	48152.8	15.8102146	600.977	39.2978	1.9587	-0.0008	0.009777933	-0.0086	
8.1656	155.5731	50.94	48152.8	15.81021179	600.977	39.2982	1.9591	-0.0008	0.00977788	-0.0086	
8.1666	155.5722	50.95	48152.8	15.81020897	600.977	39.2985	1.9595	-0.0008	0.009777828	-0.0086	
8.1676	155.5714	50.96	48152.8	15.81020616	600.977	39.2989	1.9599	-0.0008	0.009777776	-0.0086	
8.1686	155.5706	50.97	48152.8	15.81020335	600.977	39.2993	1.9602	-0.0008	0.009777723	-0.0086	
8.1696	155.5697	50.98	48152.8	15.81020053	600.977	39.2996	1.9606	-0.0008	0.009777671	-0.0086	
8.1706	155.5689	50.99	48152.8	15.81019772	600.977	39.3	1.961	-0.0008	0.009777619	-0.0086	
8.1716	155.5681	51.00	48152.8	15.8101949	600.977	39.3004	1.9614	-0.0008	0.009777566	-0.0086	
8.1726	155.5672	51.01	48152.8	15.81019209	600.977	39.3007	1.9617	-0.0008	0.009777514	-0.0086	
8.1736	155.5664	51.02	48152.8	15.81018928	600.977	39.3011	1.9621	-0.0008	0.009777462	-0.0086	
8.1746	155.5656	51.03	48152.8	15.81018647	600.977	39.3015	1.9625	-0.0008	0.009777409	-0.0086	
8.1756	155.5647	51.04	48152.7	15.81018365	600.977	39.3018	1.9628	-0.0008	0.009777357	-0.0086	
8.1766	155.5639	51.05	48152.7	15.81018084	600.977	39.3022	1.9632	-0.0008	0.009777305	-0.0086	
8.1776	155.5631	51.06	48152.7	15.81017803	600.977	39.3025	1.9636	-0.0008	0.009777252	-0.0086	
8.1786	155.5622	51.07	48152.7	15.81017522	600.977	39.3029	1.964	-0.0008	0.0097772	-0.0086	
8.1796	155.5614	51.08	48152.7	15.81017241	600.977	39.3033	1.9643	-0.0008	0.009777148	-0.0086	
8.1806	155.5606	51.09	48152.7	15.8101696	600.977	39.3036	1.9647	-0.0008	0.009777095	-0.0086	
8.1816	155.5597	51.10	48152.7	15.81016678	600.977	39.304	1.9651	-0.0008	0.009777043	-0.0086	
8.1826	155.5589	51.11	48152.7	15.81016397	600.977	39.3044	1.9654	-0.0008	0.009776991	-0.0086	
8.1836	155.5581	51.11	48152.7	15.81016116	600.977	39.3047	1.9658	-0.0008	0.009776938	-0.0086	
8.1846	155.5572	51.12	48152.7	15.81015835	600.977	39.3051	1.9662	-0.0008	0.009776886	-0.0086	
8.1856	155.5564	51.13	48152.7	15.81015554	600.977	39.3055	1.9666	-0.0008	0.009776834	-0.0086	
8.1866	155.5556	51.14	48152.7	15.81015274	600.977	39.3058	1.9669	-0.0008	0.009776781	-0.0086	
8.1876	155.5547	51.15	48152.6	15.81014993	600.977	39.3062	1.9673	-0.0008	0.009776729	-0.0086	
8.1886	155.5539	51.16	48152.6	15.81014712	600.977	39.3066	1.9677	-0.0008	0.009776677	-0.0086	
8.1896	155.5531	51.17	48152.6	15.81014431	600.977	39.3069	1.968	-0.0008	0.009776624	-0.0086	
8.1906	155.5522	51.18	48152.6	15.8101415	600.977	39.3073	1.9684	-0.0008	0.009776572	-0.0086	
8.1916	155.5514	51.19	48152.6	15.81013869	600.977	39.3077	1.9688	-0.0008	0.00977652	-0.0086	
8.1926	155.5506	51.20	48152.6	15.81013588	600.977	39.308	1.9692	-0.0008	0.009776468	-0.0086	
8.1936	155.5497	51.21	48152.6	15.81013308	600.977	39.3084	1.9695	-0.0008	0.009776415	-0.0085	
8.1946	155.5489	51.22	48152.6	15.81013027	600.977	39.3088	1.9699	-0.0008	0.009776363	-0.0085	
8.1956	155.5481	51.23	48152.6	15.81012746	600.977	39.3091	1.9703	-0.0008	0.009776311	-0.0085	
8.1966	155.5473	51.24	48152.6	15.81012466	600.977	39.3095	1.9707	-0.0008	0.009776258	-0.0085	
8.1976	155.5464	51.25	48152.6	15.81012185	600.977	39.3099	1.971	-0.0008	0.009776206	-0.0085	
8.1986	155.5456	51.26	48152.5	15.81011904	600.977	39.3102	1.9714	-0.0008	0.009776154	-0.0085	
8.1996	155.5448	51.27	48152.5	15.81011624	600.977	39.3106	1.9718	-0.0008	0.009776101	-0.0085	
8.2006	155.5439	51.28	48152.5	15.81011343	600.977	39.311	1.9721	-0.0008	0.009776049	-0.0085	
8.2016	155.5431	51.29	48152.5	15.81011063	600.977	39.3113	1.9725	-0.0008	0.009775997	-0.0085	

8.2026	155.5423	51.30	48152.5	15.81010782	600.977	39.3117	1.9729	-0.0008	0.009775944	-0.0085
8.2036	155.5414	51.31	48152.5	15.81010502	600.977	39.3121	1.9733	-0.0008	0.009775892	-0.0085
8.2046	155.5406	51.32	48152.5	15.81010221	600.977	39.3124	1.9736	-0.0008	0.00977584	-0.0085
8.2056	155.5398	51.33	48152.5	15.81009941	600.977	39.3128	1.974	-0.0008	0.009775788	-0.0085
8.2066	155.5389	51.34	48152.5	15.81009661	600.977	39.3132	1.9744	-0.0008	0.009775735	-0.0085
8.2076	155.5381	51.35	48152.5	15.8100938	600.977	39.3135	1.9747	-0.0008	0.009775683	-0.0085
8.2086	155.5373	51.36	48152.5	15.810091	600.977	39.3139	1.9751	-0.0008	0.009775631	-0.0085
8.2096	155.5364	51.37	48152.5	15.8100882	600.977	39.3143	1.9755	-0.0008	0.009775578	-0.0085
8.2106	155.5356	51.38	48152.4	15.81008539	600.977	39.3146	1.9759	-0.0008	0.009775526	-0.0085
8.2116	155.5348	51.39	48152.4	15.81008259	600.977	39.315	1.9762	-0.0008	0.009775474	-0.0085
8.2126	155.5339	51.40	48152.4	15.81007979	600.977	39.3154	1.9766	-0.0008	0.009775421	-0.0085
8.2136	155.5331	51.41	48152.4	15.81007699	600.977	39.3157	1.977	-0.0008	0.009775369	-0.0085
8.2146	155.5323	51.42	48152.4	15.81007418	600.977	39.3161	1.9773	-0.0008	0.009775317	-0.0085
8.2156	155.5314	51.43	48152.4	15.81007138	600.977	39.3165	1.9777	-0.0008	0.009775265	-0.0085
8.2166	155.5306	51.44	48152.4	15.81006858	600.977	39.3168	1.9781	-0.0008	0.009775212	-0.0085
8.2176	155.5298	51.45	48152.4	15.81006578	600.977	39.3172	1.9785	-0.0008	0.00977516	-0.0085
8.2186	155.5289	51.46	48152.4	15.81006298	600.977	39.3175	1.9788	-0.0008	0.009775108	-0.0085
8.2196	155.5281	51.47	48152.4	15.81006018	600.977	39.3179	1.9792	-0.0008	0.009775055	-0.0085
8.2206	155.5273	51.48	48152.4	15.81005738	600.977	39.3183	1.9796	-0.0008	0.009775003	-0.0085
8.2216	155.5264	51.49	48152.4	15.81005458	600.977	39.3186	1.9799	-0.0008	0.009774951	-0.0085
8.2226	155.5256	51.50	48152.3	15.81005178	600.977	39.319	1.9803	-0.0008	0.009774899	-0.0085
8.2236	155.5248	51.51	48152.3	15.81004898	600.977	39.3194	1.9807	-0.0008	0.009774846	-0.0085
8.2246	155.524	51.52	48152.3	15.81004618	600.977	39.3197	1.9811	-0.0008	0.009774794	-0.0085
8.2256	155.5231	51.53	48152.3	15.81004338	600.977	39.3201	1.9814	-0.0008	0.009774742	-0.0085
8.2266	155.5223	51.54	48152.3	15.81004059	600.977	39.3205	1.9818	-0.0008	0.009774689	-0.0085
8.2276	155.5215	51.55	48152.3	15.81003779	600.977	39.3208	1.9822	-0.0008	0.009774637	-0.0085
8.2286	155.5206	51.55	48152.3	15.81003499	600.977	39.3212	1.9825	-0.0008	0.009774585	-0.0085
8.2296	155.5198	51.56	48152.3	15.81003219	600.977	39.3216	1.9829	-0.0008	0.009774533	-0.0085
8.2306	155.519	51.57	48152.3	15.81002939	600.977	39.3219	1.9833	-0.0008	0.00977448	-0.0085
8.2316	155.5181	51.58	48152.3	15.8100266	600.977	39.3223	1.9837	-0.0008	0.009774428	-0.0085
8.2326	155.5173	51.59	48152.3	15.8100238	600.977	39.3227	1.984	-0.0008	0.009774376	-0.0085
8.2336	155.5165	51.60	48152.2	15.810021	600.977	39.323	1.9844	-0.0008	0.009774323	-0.0085
8.2346	155.5156	51.61	48152.2	15.81001821	600.977	39.3234	1.9848	-0.0008	0.009774271	-0.0085
8.2356	155.5148	51.62	48152.2	15.81001541	600.977	39.3238	1.9851	-0.0008	0.009774219	-0.0085
8.2366	155.514	51.63	48152.2	15.81001262	600.977	39.3241	1.9855	-0.0008	0.009774167	-0.0085
8.2376	155.5131	51.64	48152.2	15.81000982	600.977	39.3245	1.9859	-0.0008	0.009774114	-0.0085
8.2386	155.5123	51.65	48152.2	15.81000703	600.977	39.3249	1.9863	-0.0008	0.009774062	-0.0085
8.2396	155.5115	51.66	48152.2	15.81000423	600.977	39.3252	1.9866	-0.0008	0.00977401	-0.0085
8.2406	155.5106	51.67	48152.2	15.81000144	600.977	39.3256	1.987	-0.0008	0.009773957	-0.0085
8.2416	155.5098	51.68	48152.2	15.80999864	600.977	39.326	1.9874	-0.0008	0.009773905	-0.0085
8.2426	155.509	51.69	48152.2	15.80999585	600.977	39.3263	1.9877	-0.0008	0.009773853	-0.0085
8.2436	155.5081	51.70	48152.2	15.80999305	600.977	39.3267	1.9881	-0.0008	0.009773801	-0.0085
8.2446	155.5073	51.71	48152.2	15.80999026	600.977	39.3271	1.9885	-0.0008	0.009773748	-0.0085
8.2456	155.5065	51.72	48152.1	15.80998747	600.977	39.3274	1.9889	-0.0008	0.009773696	-0.0085
8.2466	155.5057	51.73	48152.1	15.80998467	600.977	39.3278	1.9892	-0.0008	0.009773644	-0.0085
8.2476	155.5048	51.74	48152.1	15.80998188	600.977	39.3281	1.9896	-0.0008	0.009773592	-0.0085
8.2486	155.504	51.75	48152.1	15.80997909	600.977	39.3285	1.99	-0.0008	0.009773539	-0.0085
8.2496	155.5032	51.76	48152.1	15.8099763	600.977	39.3289	1.9903	-0.0008	0.009773487	-0.0085
8.2506	155.5023	51.77	48152.1	15.8099735	600.977	39.3292	1.9907	-0.0008	0.009773435	-0.0085
8.2516	155.5015	51.78	48152.1	15.80997071	600.977	39.3296	1.9911	-0.0008	0.009773383	-0.0085
8.2526	155.5007	51.79	48152.1	15.80996792	600.977	39.33	1.9915	-0.0008	0.00977333	-0.0085
8.2536	155.4998	51.80	48152.1	15.80996513	600.977	39.3303	1.9918	-0.0008	0.009773278	-0.0085
8.2546	155.499	51.81	48152.1	15.80996234	600.977	39.3307	1.9922	-0.0008	0.009773226	-0.0085
8.2556	155.4982	51.82	48152.1	15.80995955	600.977	39.3311	1.9926	-0.0008	0.009773173	-0.0085
8.2566	155.4973	51.83	48152.1	15.80995676	600.977	39.3314	1.9929	-0.0008	0.009773121	-0.0085
8.2576	155.4965	51.84	48152	15.80995397	600.977	39.3318	1.9933	-0.0008	0.009773069	-0.0085
8.2586	155.4957	51.85	48152	15.80995118	600.977	39.3322	1.9937	-0.0008	0.009773017	-0.0085
8.2596	155.4948	51.86	48152	15.80994839	600.977	39.3325	1.9941	-0.0008	0.009772964	-0.0085
8.2606	155.494	51.87	48152	15.8099456	600.977	39.3329	1.9944	-0.0008	0.009772912	-0.0085
8.2616	155.4932	51.88	48152	15.80994281	600.977	39.3333	1.9948	-0.0008	0.00977286	-0.0085
8.2626	155.4923	51.89	48152	15.80994002	600.977	39.3336	1.9952	-0.0008	0.009772808	-0.0085
8.2636	155.4915	51.90	48152	15.80993724	600.977	39.334	1.9955	-0.0008	0.009772755	-0.0085
8.2646	155.4907	51.91	48152	15.80993445	600.977	39.3344	1.9959	-0.0008	0.009772703	-0.0085
8.2656	155.4899	51.92	48152	15.80993166	600.977	39.3347	1.9963	-0.0008	0.009772651	-0.0085
8.2666	155.489	51.93	48152	15.80992887	600.977	39.3351	1.9967	-0.0008	0.009772599	-0.0085
8.2676	155.4882	51.94	48152	15.80992608	600.977	39.3355	1.997	-0.0008	0.009772546	-0.0085
8.2686	155.4874	51.95	48152	15.8099233	600.977	39.3358	1.9974	-0.0008	0.009772494	-0.0085
8.2696	155.4865	51.96	48151.9	15.80992051	600.977	39.3362	1.9978	-0.0008	0.009772442	-0.0085
8.2706	155.4857	51.97	48151.9	15.80991772	600.977	39.3365	1.9981	-0.0008	0.00977239	-0.0085
8.2716	155.4849	51.98	48151.9	15.80991494	600.977	39.3369	1.9985	-0.0008	0.009772337	-0.0085
8.2726	155.484	51.98	48151.9	15.80991215	600.977	39.3373	1.9989	-0.0008	0.009772285	-0.0085
8.2736	155.4832	51.99	48151.9	15.80990937	600.977	39.3376	1.9993	-0.0008	0.009772233	-0.0085
8.2746	155.4824	52.00	48151.9	15.80990658	600.977	39.338	1.9996	-0.0008	0.009772181	-0.0085

APPENDIX B
NUMERICAL COMPUTATIONS ASSOCIATED WITH PUMP SHUTDOWN

PUMP P-1 SHUTDOWN (no pump operates)

1. Before column of fluid comes to rest

g =	32.17	ft/sec^2
f =	0.010115567	(assume constant for all Reynolds number)
k =	0.00015	
$k_{L\ elbow}$ =	0.332708333	
$k_{L\ entrance}$ =	0.100982212	
Viscosity =	0.00003	ft^2/sec
Diameter of Pipe (D) =	4.5	ft
Area of Pipe (A) =	15.91071429	ft^2
H_{pump} =	66.554 - t * 66.554 / t_{shutdo}	ft (assume that the pump has no inertia and turbines

Start Pump P-1 Elevation =	601	ft	Cross Sectional Area of Wet well =
Stop Pump P-1 Elevation =	595	ft	
Minimum Surface Elevation =	585.167	ft	

Assume the pump slows down linearly with time, from 66.554 ft to 0 ft

$t_{shutdown}$ =	1.25	sec
	0.99	sec
Q_0 =	155.4823734	ft^3/sec
V_0 =	9.772180592	ft/sec
Z_0 =	9.833	ft
V_0 =	48166.92243	ft^3
Length of Pipe for horizontal section=	52	ft
Length of Pipe for vrtical section=	52.33	ft

Q is positive entering the pump station

Apply Euler's Formula:

Q(t) = $Q_{previous}$+dQ where,

$$\frac{P_{elbow}}{\gamma} = z - 52.33 + H_{pump} - \left[\frac{f(52.33+52)}{D} + k_{entrance} + k_{elbow}\right]\frac{Q^2}{2gA^2}$$

$$\frac{\partial Q}{\partial t} = \frac{P_{elbow}}{\gamma} * \frac{gA}{(52.33+52)}$$

X(t) = $X_{previous}$+dx

V(t) = $V_{previous}$+dV

z(t) = V_0 / A = V_0 / 3045.7

dh = 0.0

dV = (Q_{inflow} - Q)* dt , assume Q_{inflow} = 0

H_{pump} = 38 - t * 38 / $t_{shutdown}$

t(sec)	Q(cfs)	x(ft)	$V(ft^3)$	z(ft)	WSEL(ft)	H_{pump}(ft)	p_{elbow2}/γ	dQ	dh
0	155.482373	104.33	29948.16161	9.833	595	38	-5.4888	-0.2693	0
0.01	155.2130911	104.33	29946.60678	9.8325	595	37.696	-5.7899	-0.2841	0
0.02	154.9290378	104.33	29945.05465	9.832	595	37.392	-6.0908	-0.2988	0
0.03	154.6302224	104.33	29943.50536	9.8315	595	37.088	-6.3915	-0.3136	0
0.04	154.3166539	104.33	29941.95906	9.831	595	36.784	-6.692	-0.3283	0
0.05	153.988341	104.33	29940.41589	9.8305	595	36.48	-6.9924	-0.343	0
0.06	153.6452927	104.33	29938.87601	9.83	595	36.176	-7.2925	-0.3578	0
0.07	153.2875176	104.33	29937.33956	9.8294	595	35.872	-7.5925	-0.3725	0
0.08	152.9150244	104.33	29935.80668	9.8289	595	35.568	-7.8924	-0.3872	0
0.09	152.5278217	104.33	29934.27753	9.8284	595	35.264	-8.192	-0.4019	0
0.1	152.125918	104.33	29932.75225	9.8279	594.99	34.96	-8.4915	-0.4166	0
0.11	151.7093218	104.33	29931.23099	9.8274	594.99	34.656	-8.7908	-0.4313	0
0.12	151.2780416	104.33	29929.7139	9.8269	594.99	34.352	-9.0899	-0.446	0
0.13	150.8320855	104.33	29928.20112	9.8264	594.99	34.048	-9.3889	-0.4606	0
0.14	150.3714618	104.33	29926.6928	9.826	594.99	33.744	-9.6877	-0.4753	0
0.15	149.8961787	104.33	29925.18908	9.8255	594.99	33.44	-9.9863	-0.4899	0
0.16	149.4062443	104.33	29923.69012	9.825	594.99	33.136	-10.285	-0.5046	0
0.17	148.9016664	104.33	29922.19606	9.8245	594.99	32.832	-10.583	-0.5192	0
0.18	148.3824531	104.33	29920.70704	9.824	594.99	32.528	-10.881	-0.5338	0
0.19	147.8486121	104.33	29919.22322	9.8235	594.99	32.224	-11.179	-0.5485	0
0.2	147.3001511	104.33	29917.74473	9.823	594.99	31.92	-11.477	-0.5631	0
0.21	146.7370778	104.33	29916.27173	9.8225	594.99	31.616	-11.775	-0.5777	0
0.22	146.1593995	104.33	29914.80436	9.822	594.99	31.312	-12.072	-0.5923	0
0.23	145.5671238	104.33	29913.34277	9.8216	594.99	31.008	-12.37	-0.6069	0
0.24	144.960258	104.33	29911.8871	9.8211	594.99	30.704	-12.667	-0.6214	0
0.25	144.3388092	104.33	29910.43749	9.8206	594.99	30.4	-12.964	-0.636	0
0.26	143.7027845	104.33	29908.99411	9.8201	594.99	30.096	-13.261	-0.6506	0
0.27	143.052191	104.33	29907.55708	9.8197	594.99	29.792	-13.558	-0.6652	0
0.28	142.3870354	104.33	29906.12656	9.8192	594.99	29.488	-13.855	-0.6797	0
0.29	141.7073245	104.33	29904.70269	9.8187	594.99	29.184	-14.151	-0.6943	0
0.3	141.013065	104.33	29903.28561	9.8183	594.99	28.88	-14.448	-0.7088	0
0.31	140.3042634	104.33	29901.87548	9.8178	594.98	28.576	-14.744	-0.7233	0
0.32	139.580926	104.33	29900.47244	9.8173	594.98	28.272	-15.04	-0.7379	0
0.33	138.843059	104.33	29899.07663	9.8169	594.98	27.968	-15.336	-0.7524	0
0.34	138.0906688	104.33	29897.6882	9.8164	594.98	27.664	-15.632	-0.7669	0
0.35	137.3237611	104.33	29896.30729	9.816	594.98	27.36	-15.928	-0.7814	0
0.36	136.542342	104.33	29894.93405	9.8155	594.98	27.056	-16.223	-0.7959	0
0.37	135.7464171	104.33	29893.56863	9.8151	594.98	26.752	-16.519	-0.8104	0
0.38	134.9359921	104.33	29892.21117	9.8146	594.98	26.448	-16.814	-0.8249	0
0.39	134.1110723	104.33	29890.86181	9.8142	594.98	26.144	-17.11	-0.8394	0
0.4	133.2716631	104.33	29889.5207	9.8137	594.98	25.84	-17.405	-0.8539	0
0.41	132.4177697	104.33	29888.18798	9.8133	594.98	25.536	-17.7	-0.8684	0
0.42	131.5493971	104.33	29886.8638	9.8129	594.98	25.232	-17.995	-0.8828	0

0.43	130.6665501	104.33	29885.54831	9.8124	594.98	24.928	-18.29	-0.8973		0
0.44	129.7692335	104.33	29884.24164	9.812	594.98	24.624	-18.585	-0.9118		0
0.45	128.8574518	104.33	29882.94395	9.8116	594.98	24.32	-18.88	-0.9262		0
0.46	127.9312095	104.33	29881.65538	9.8112	594.98	24.016	-19.174	-0.9407		0
0.47	126.9905108	104.33	29880.37606	9.8107	594.98	23.712	-19.469	-0.9552		0
0.48	126.0353598	104.33	29879.10616	9.8103	594.98	23.408	-19.763	-0.9696		0
0.49	125.0657603	104.33	29877.8458	9.8099	594.98	23.104	-20.058	-0.984		0
0.5	124.0817162	104.33	29876.59515	9.8095	594.98	22.8	-20.352	-0.9985		0
0.51	123.0832311	104.33	29875.35433	9.8091	594.98	22.496	-20.646	-1.0129		0
0.52	122.0703083	104.33	29874.1235	9.8087	594.98	22.192	-20.941	-1.0274		0

0.43	130.6665501	104.33	29885.54831	9.8124	594.98	24.928	-18.29	-0.8973	0
0.44	129.7692335	104.33	29884.24164	9.812	594.98	24.624	-18.585	-0.9118	0
0.45	128.8574518	104.33	29882.94395	9.8116	594.98	24.32	-18.88	-0.9262	0
0.46	127.9312095	104.33	29881.65538	9.8112	594.98	24.016	-19.174	-0.9407	0
0.47	126.9905108	104.33	29880.37606	9.8107	594.98	23.712	-19.469	-0.9552	0
0.48	126.0353598	104.33	29879.10616	9.8103	594.98	23.408	-19.763	-0.9696	0
0.49	125.0657603	104.33	29877.8458	9.8099	594.98	23.104	-20.058	-0.984	0
0.5	124.0817162	104.33	29876.59515	9.8095	594.98	22.8	-20.352	-0.9985	0
0.51	123.0832311	104.33	29875.35433	9.8091	594.98	22.496	-20.646	-1.0129	0
0.52	122.0703083	104.33	29874.1235	9.8087	594.98	22.192	-20.941	-1.0274	0

0.53	121.0429512	104.33	29872.90279	9.8083	594.98	21.888	-21.235	-1.0418	0
0.54	120.0011627	104.33	29871.69237	9.8079	594.97	21.584	-21.529	-1.0562	0
0.55	118.9449457	104.33	29870.49235	9.8075	594.97	21.28	-21.823	-1.0706	0
0.56	117.874303	104.33	29869.3029	9.8071	594.97	20.976	-22.117	-1.0851	0
0.57	116.7892371	104.33	29868.12416	9.8067	594.97	20.672	-22.411	-1.0995	0
0.58	115.6897504	104.33	29866.95627	9.8063	594.97	20.368	-22.705	-1.1139	0
0.59	114.5758449	104.33	29865.79937	9.806	594.97	20.064	-22.999	-1.1283	0
0.6	113.4475226	104.33	29864.65361	9.8056	594.97	19.76	-23.292	-1.1427	0
0.61	112.3047854	104.33	29863.51914	9.8052	594.97	19.456	-23.586	-1.1572	0
0.62	111.1476348	104.33	29862.39609	9.8048	594.97	19.152	-23.88	-1.1716	0
0.63	109.9760721	104.33	29861.28461	9.8045	594.97	18.848	-24.174	-1.186	0
0.64	108.7900986	104.33	29860.18485	9.8041	594.97	18.544	-24.467	-1.2004	0
0.65	107.5897151	104.33	29859.09695	9.8038	594.97	18.24	-24.761	-1.2148	0
0.66	106.3749226	104.33	29858.02105	9.8034	594.97	17.936	-25.055	-1.2292	0
0.67	105.1457215	104.33	29856.95731	9.8031	594.97	17.632	-25.349	-1.2436	0
0.68	103.9021122	104.33	29855.90585	9.8027	594.97	17.328	-25.642	-1.258	0
0.69	102.6440948	104.33	29854.86683	9.8024	594.97	17.024	-25.936	-1.2724	0
0.7	101.3716694	104.33	29853.84039	9.802	594.97	16.72	-26.23	-1.2868	0
0.71	100.0848355	104.33	29852.82667	9.8017	594.97	16.416	-26.523	-1.3012	0
0.72	98.78359267	104.33	29851.82582	9.8014	594.97	16.112	-26.817	-1.3157	0
0.73	97.46794021	104.33	29850.83798	9.801	594.97	15.808	-27.111	-1.3301	0
0.74	96.13787715	104.33	29849.86331	9.8007	594.97	15.504	-27.404	-1.3445	0
0.75	94.7934023	104.33	29848.90193	9.8004	594.97	15.2	-27.698	-1.3589	0
0.76	93.43451427	104.33	29847.95399	9.8001	594.97	14.896	-27.992	-1.3733	0
0.77	92.0612114	104.33	29847.01965	9.7998	594.97	14.592	-28.286	-1.3877	0
0.78	90.67349184	104.33	29846.09904	9.7995	594.97	14.288	-28.58	-1.4021	0
0.79	89.27135347	104.33	29845.1923	9.7992	594.97	13.984	-28.874	-1.4166	0
0.8	87.85479395	104.33	29844.29959	9.7989	594.97	13.68	-29.168	-1.431	0
0.81	86.42381068	104.33	29843.42104	9.7986	594.97	13.376	-29.462	-1.4454	0
0.82	84.97840084	104.33	29842.5568	9.7983	594.97	13.072	-29.756	-1.4598	0
0.83	83.51856136	104.33	29841.70702	9.798	594.97	12.768	-30.05	-1.4743	0
0.84	82.04428889	104.33	29840.87183	9.7978	594.96	12.464	-30.344	-1.4887	0
0.85	80.55557988	104.33	29840.05139	9.7975	594.96	12.16	-30.639	-1.5031	0
0.86	79.05243048	104.33	29839.24583	9.7972	594.96	11.856	-30.933	-1.5176	0
0.87	77.53483661	104.33	29838.45531	9.797	594.96	11.552	-31.228	-1.532	0
0.88	76.00279394	104.33	29837.67996	9.7967	594.96	11.248	-31.522	-1.5465	0
0.89	74.45629784	104.33	29836.91993	9.7965	594.96	10.944	-31.817	-1.561	0
0.9	72.89534346	104.33	29836.17537	9.7962	594.96	10.64	-32.112	-1.5754	0
0.91	71.31992565	104.33	29835.44642	9.796	594.96	10.336	-32.407	-1.5899	0
0.92	69.73003902	104.33	29834.73322	9.7958	594.96	10.032	-32.702	-1.6044	0
0.93	68.12567788	104.33	29834.03592	9.7955	594.96	9.728	-32.997	-1.6188	0
0.94	66.5068363	104.33	29833.35466	9.7953	594.96	9.424	-33.292	-1.6333	0
0.95	64.87350803	104.33	29832.68959	9.7951	594.96	9.12	-33.588	-1.6478	0
0.96	63.22568659	104.33	29832.04086	9.7949	594.96	8.816	-33.883	-1.6623	0
0.97	61.56336517	104.33	29831.4086	9.7947	594.96	8.512	-34.179	-1.6768	0
0.98	59.88653672	104.33	29830.79297	9.7945	594.96	8.208	-34.475	-1.6913	0
0.99	58.19519386	104.33	29830.1941	9.7943	594.96	7.904	-34.771	-1.7059	0
1	56.48932896	104.33	29829.61215	9.7941	594.96	7.6	-35.067	-1.7204	0
1.01	54.76893407	104.33	29829.04725	9.7939	594.96	7.296	-35.363	-1.7349	0
1.02	53.03400096	104.33	29828.49957	9.7937	594.96	6.992	-35.66	-1.7495	0
1.03	51.2845211	104.33	29827.96923	9.7935	594.96	6.688	-35.956	-1.764	0
1.04	49.52048565	104.33	29827.45638	9.7934	594.96	6.384	-36.253	-1.7786	0
1.05	47.74188547	104.33	29826.96118	9.7932	594.96	6.08	-36.55	-1.7932	0
1.06	45.94871112	104.33	29826.48376	9.793	594.96	5.776	-36.848	-1.8078	0
1.07	44.14095285	104.33	29826.02427	9.7929	594.96	5.472	-37.145	-1.8224	0
1.08	42.3186006	104.33	29825.58286	9.7928	594.96	5.168	-37.443	-1.837	0
1.09	40.48164398	104.33	29825.15967	9.7926	594.96	4.864	-37.741	-1.8516	0
1.1	38.63007231	104.33	29824.75486	9.7925	594.96	4.56	-38.039	-1.8662	0
1.11	36.76387457	104.33	29824.36856	9.7924	594.96	4.256	-38.337	-1.8808	0
1.12	34.88303943	104.33	29824.00092	9.7922	594.96	3.952	-38.636	-1.8955	0
1.13	32.98755521	104.33	29823.65209	9.7921	594.96	3.648	-38.935	-1.9101	0
1.14	31.07740993	104.33	29823.32221	9.792	594.96	3.344	-39.234	-1.9248	0
1.15	29.15259127	104.33	29823.01144	9.7919	594.96	3.04	-39.533	-1.9395	0
1.16	27.21308656	104.33	29822.71991	9.7918	594.96	2.736	-39.833	-1.9542	0
1.17	25.25888282	104.33	29822.44778	9.7917	594.96	2.432	-40.132	-1.9689	0
1.18	23.2899667	104.33	29822.19519	9.7916	594.96	2.128	-40.433	-1.9836	0
1.19	21.30632453	104.33	29821.96229	9.7916	594.96	1.824	-40.733	-1.9984	0
1.2	19.30794229	104.33	29821.74923	9.7915	594.96	1.52	-41.034	-2.0131	0
1.21	17.29480559	104.33	29821.55615	9.7914	594.96	1.216	-41.335	-2.0279	0
1.22	15.26689972	104.33	29821.3832	9.7914	594.96	0.912	-41.636	-2.0427	0
1.23	13.2242096	104.33	29821.23053	9.7913	594.96	0.608	-41.938	-2.0575	0
1.24	11.16671977	104.33	29821.09829	9.7913	594.96	0.304	-42.24	-2.0723	0
1.25	9.094414448	104.33	29820.98662	9.7912	594.96	0	-42.542	-2.0871	0
1.26	7.007277458	104.33	29820.89568	9.7912	594.96	-0.304	-42.845	-2.102	0
1.27	4.905292266	104.33	29820.82561	9.7912	594.96	-0.608	-43.148	-2.1169	0
1.28	2.788441967	104.33	29820.77655	9.7912	594.96	-0.912	-43.451	-2.1317	0
1.29	0.656709282	104.33	29820.74867	9.7912	594.96	-1.216	-43.755	-2.1466	0
1.3	-1.489923447	104.33	29820.7421	9.7912	594.96	-1.52	-44.059	-2.1616	0

PUMP P-1 SHUTDOWN (no pump operates)

2. Horizontal section in pipe

g =	32.17	ft/sec^2	
f =	0.0101156	(assume constant for all Reynold numbers)	
k =	0.00015		
$k_{L\ elbow}$ =	0.3327083		
$k_{L\ entrance}$ =	0.1009822		
Viscosity =	0.00003	ft^2/sec	
Diameter of Pipe (D) =	4.5	ft	
Area of Pipe (A) =	15.910714	ft^2	
H_{pump} =	0	ft	
Start Pump P-1 Elevation =	601	ft	Cross Sectional Area of Wet well = 3045.679 ft^2
Stop Pump P-1 Elevation =	595	ft	
Minimum Surface Elevation =	585.167	ft	

Q_0 =	0	ft^3/sec
V_0 =	0	ft/sec
Z_0 =	9.791163843	ft
V_0 =	29820.7421	ft^3
Length of Pipe for horizontal section=	52	ft

Q is positive when entering the pump station

Apply Euler's Formula:

$$\frac{\partial Q}{\partial t}=\frac{gA}{52.33+52+x}*\left[z+H_{pump}-52.33+\frac{f(52.33+52+x)}{D}*\frac{Q^2}{2gA^2}+k_{elbow}\frac{Q^2}{2gA^2}\right]$$

$Q(t) = Q_{previous}+dQ$ where,

$X(t) = X_{previous}+dx$

$V(t) = V_{previous}+dV$

$dx = (Q/A) * dt$

$H_{pump} = 38 - t * 38 / t_{shutdown}$ **for $t<t_{shutdown}$**

$H_{pump} = 0$ for $t>t_{shutdown}$

Q is positive entering the pump station and assume Q_{inflow} to the wet well is zero

$z(t) = V_0 / A = V_0 / 3045.7$

$dV = (Q_{inflow} + Q)* dt$

t(sec)	Q(cfs)	x(ft)	V(ft^3)	z(ft)	WSEL(ft)	H_{pump}(ft)	dQ	dx	dV	
1.3	0	0	29826.725	9.7931281	594.958164	0.0	-2.0869	0	0	0.01
1.31	-2.086878092	0	29826.725	9.7931281	594.958164	0.0	-2.0869	-0.001311618	0.020868781	
1.32	-4.173748743	-0.00131	29826.745	9.793134952	594.958171	0.0	-2.0869	-0.002623232	0.041737487	
1.33	-6.260622972	-0.00393	29826.787	9.793148656	594.958184	0.0	-2.0869	-0.003934847	0.06260623	
1.34	-8.347511794	-0.00787	29826.85	9.793169212	594.958205	0.0	-2.0869	-0.005246472	0.083475118	
1.35	-10.43442623	-0.01312	29826.933	9.793196619	594.958232	0.0	-2.087	-0.006558113	0.104344262	
1.36	-12.52137729	-0.01967	29827.038	9.793230879	594.958267	0.0	-2.087	-0.007869777	0.125213773	
1.37	-14.60837601	-0.02754	29827.163	9.793271991	594.958308	0.0	-2.0871	-0.009181471	0.14608376	
1.38	-16.69543338	-0.03673	29827.309	9.793319955	594.958356	0.0	-2.0871	-0.010493202	0.166954334	
1.39	-18.78256045	-0.04722	29827.476	9.793374772	594.958411	0.0	-2.0872	-0.011804976	0.187825604	
1.4	-20.86976822	-0.05902	29827.664	9.793436442	594.958472	0.0	-2.0873	-0.013116802	0.208697682	
1.41	-22.95706772	-0.07214	29827.872	9.793504964	594.958541	0.0	-2.0874	-0.014428685	0.229570677	
1.42	-25.04446997	-0.08657	29828.102	9.79358034	594.958616	0.0	-2.0875	-0.015740632	0.2504447	
1.47	-27.13198599	-0.10231	29828.352	9.793662569	594.958698	0.0	-10.438	-0.085263256	0.27131986	0.05
1.52	-37.57019012	-0.18757	29828.624	9.793751653	594.958787	0.0	-10.441	-0.118065693	0.375701901	
1.57	-48.01113187	-0.30564	29828.999	9.793875009	594.958911	0.0	-10.445	-0.150876733	0.480111319	
1.62	-58.45622274	-0.45652	29829.48	9.794032646	594.959068	0.0	-10.451	-0.183700812	0.584562227	
1.67	-68.90687533	-0.64022	29830.064	9.794224577	594.95926	0.0	-10.458	-0.216542369	0.689068753	
1.72	-79.36450395	-0.85676	29830.753	9.794450822	594.959487	0.0	-10.466	-0.249405849	0.793645039	
1.77	-89.83052533	-1.10616	29831.547	9.794711403	594.959747	0.0	-10.476	-0.282295702	0.898305253	
1.82	-100.3063592	-1.38846	29832.445	9.795006347	594.960042	0.0	-10.487	-0.315216393	1.003063592	
1.87	-110.793429	-1.70368	29833.448	9.795335687	594.960371	0.0	-10.5	-0.348172392	1.10793429	
1.92	-121.2931625	-2.05185	29834.556	9.795699459	594.960735	0.0	-10.514	-0.381168187	1.212931625	
1.97	-131.8069924	-2.43302	29835.769	9.796097706	594.961133	0.0	-10.529	-0.414208281	1.318069924	
2.02	-142.336357	-2.84723	29837.087	9.796530473	594.961566	0.0	-10.546	-0.447297194	1.42336357	
2.07	-152.882701	-3.29452	29838.51	9.796997812	594.962034	0.0	-10.565	-0.480439465	1.52882701	
2.12	-163.4474761	-3.77496	29840.039	9.797499778	594.962536	0.0	-10.585	-0.513639656	1.634474761	
2.17	-174.0321414	-4.2886	29841.674	9.798036431	594.963072	0.0	-10.606	-0.546902352	1.740321414	
2.22	-184.6381646	-4.8355	29843.414	9.798607838	594.963644	0.0	-10.629	-0.580232167	1.846381646	
2.27	-195.2670221	-5.41574	29845.261	9.799214068	594.96425	0.0	-10.653	-0.61363374	1.952670221	
2.32	-205.9202003	-6.02937	29847.213	9.799855196	594.964891	0.0	-10.679	-0.64711174	2.059202003	
2.37	-216.5991956	-6.67648	29849.272	9.800531302	594.965567	0.0	-10.706	-0.680670873	2.165991956	
2.42	-227.305516	-7.35715	29851.438	9.801242471	594.966278	0.0	-10.735	-0.714315875	2.27305516	

2.47	-238.0406808	-8.07147	29853.711	9.801988792	594.967025	0.0	-10.766	-0.748051522	2.380406808	
2.52	-248.8062222	-8.81952	29856.092	9.802770361	594.967806	0.0	-10.797	-0.781882629	2.488062222	
2.57	-259.6036855	-9.6014	29858.58	9.803587276	594.968623	0.0	-10.831	-0.815814051	2.596036855	
2.62	-270.4346301	-10.4172	29861.176	9.804439643	594.969475	0.0	-10.866	-0.849850689	2.704346301	
2.67	-281.3006302	-11.2671	29863.88	9.805327572	594.970363	0.0	-10.903	-0.883997491	2.813006302	
2.72	-292.2032755	-12.1511	29866.693	9.806251178	594.971287	0.0	-10.941	-0.918259452	2.922032755	
2.77	-303.1441722	-13.0693	29869.615	9.807210581	594.972246	0.0	-10.981	-0.952641619	3.031441722	
2.82	-314.1249436	-14.022	29872.647	9.808205906	594.973242	0.0	-11.022	-0.987149093	3.141249436	
2.87	-325.147231	-15.0091	29875.788	9.809237285	594.974273	0.0	-11.065	-1.021787033	3.25147231	
2.92	-336.2126944	-16.0309	29879.039	9.810304854	594.975341	0.0	-11.11	-1.056560656	3.362126944	
2.97	-347.3230138	-17.0875	29882.402	9.811408755	594.976444	0.0	-11.157	-1.09147524	3.473230138	
3.02	-358.4798893	-18.1789	29885.875	9.812549134	594.977585	0.0	-11.205	-1.126536128	3.584798893	
3.07	-369.685043	-19.3055	29889.46	9.813726145	594.978762	0.0	-11.255	-1.161748732	3.69685043	
3.12	-380.9402188	-20.4672	29893.156	9.814939947	594.979976	0.0	-11.307	-1.197118533	3.809402188	
3.17	-392.2471843	-21.6643	29896.966	9.816190704	594.981226	0.0	-11.361	-1.232651084	3.922471843	
3.22	-403.6077311	-22.897	29900.888	9.817478584	594.982514	0.0	-11.416	-1.268352017	4.036077311	
3.27	-415.0236761	-24.1653	29904.924	9.818803766	594.98384	0.0	-11.473	-1.304227041	4.150236761	
3.32	-426.4968624	-25.4696	29909.075	9.82016643	594.985202	0.0	-11.532	-1.340281947	4.264968624	
3.37	-438.0291603	-26.8099	29913.34	9.821566764	594.986603	0.0	-11.593	-1.376522614	4.380291603	
3.42	-449.6224684	-28.1864	29917.72	9.823004963	594.988041	0.0	-11.656	-1.412955007	4.496224684	
3.47	-461.2787145	-29.5993	29922.216	9.824481226	594.989517	0.0	-11.721	-1.449585186	4.612787145	
3.52	-472.999857	-31.0489	29926.829	9.825995761	594.991032	0.0	-11.788	-1.486419304	4.72999857	
3.57	-484.7878856	-32.5353	29931.559	9.827548781	594.992585	0.0	-11.857	-1.523463614	4.847878856	
3.62	-496.6448231	-34.0588	29936.407	9.829140504	594.994176	0.0	-11.928	-1.560724472	4.966448231	
3.67	-508.5727256	-35.6195	29941.373	9.830771158	594.995807	0.0	-12.001	-1.598208341	5.085727256	
3.72	-520.5736847	-37.2177	29946.459	9.832440975	594.997477	0.0	-12.076	-1.635921793	5.205736847	
3.77	-532.649828	-38.8537	29951.665	9.834150196	594.999186	0.0	-12.153	-1.673871513	5.32649828	
3.82	-544.8033208	-40.5275	29956.991	9.835899066	595.000935	0.0	-12.233	-1.712064308	5.448033208	
3.87	-557.0363669	-42.2396	29962.439	9.837687841	595.002724	0.0	-12.315	-1.750507101	5.570363669	
3.92	-569.3512104	-43.9901	29968.01	9.839516781	595.004553	0.0	-12.399	-1.789206946	5.693512104	
3.97	-581.7501367	-45.7793	29973.703	9.841386154	595.006422	0.0	-12.485	-1.828171025	5.817501367	
4.02	-594.2354741	-47.6075	29979.521	9.843296238	595.008332	0.0	-12.574	-1.867406653	5.942354741	
4.021	-606.8095946	-49.4749	29985.463	9.845247315	595.010283	0.0	-0.2533	-0.038138426	6.068095946	0.001
4.022	-607.0629011	-49.513	29991.531	9.847239677	595.012275	0.0	-0.2533	-0.038154346	6.070629011	
4.023	-607.3162274	-49.5512	29997.602	9.849232871	595.014269	0.0	-0.2533	-0.038170268	6.073162274	
4.024	-607.5695737	-49.5893	30003.675	9.851226897	595.016263	0.0	-0.2534	-0.038186191	6.075695737	
4.025	-607.8229399	-49.6275	30009.751	9.853221754	595.018257	0.0	-0.2534	-0.038202115	6.078229399	
4.026	-608.076326	-49.6657	30015.829	9.855217444	595.020253	0.0	-0.2534	-0.038218041	6.08076326	
4.027	-608.329732	-49.704	30021.91	9.857213965	595.02225	0.0	-0.2534	-0.038233967	6.08329732	
4.028	-608.583158	-49.7422	30027.993	9.859211319	595.024247	0.0	-0.2534	-0.038249895	6.08583158	
4.029	-608.8366038	-49.7804	30034.079	9.861209504	595.026245	0.0	-0.2535	-0.038265825	6.088366038	
4.03	-609.0900696	-49.8187	30040.167	9.863208522	595.028244	0.0	-0.2535	-0.038281755	6.090900696	
4.031	-609.3435552	-49.857	30046.258	9.865208372	595.030244	0.0	-0.2535	-0.038297687	6.093435552	
4.032	-609.5970608	-49.8953	30052.351	9.867209054	595.032245	0.0	-0.2535	-0.03831362	6.095970608	
4.033	-609.8505862	-49.9336	30058.447	9.869210568	595.034246	0.0	-0.2535	-0.038329554	6.098505862	
4.034	-610.1041315	-49.9719	30064.546	9.871212915	595.036249	0.0	-0.2536	-0.03834549	6.101041315	
4.035	-610.3576967	-50.0103	30070.647	9.873216094	595.038252	0.0	-0.2536	-0.038361427	6.103576967	
4.085	-610.6112818	-50.0486	30076.75	9.875220106	595.040256	0.0	-0.2536	-1.918868226	6.106112818	
4.135	-610.8648868	-51.9675	30082.857	9.877224951	595.042261	0.0	-0.2618	-1.919665188	6.108648868	

PUMP P-1 SHUTDOWN (no pump operates)

3. Vertical section in pipe

g =	32.17	ft/sec^2
f =	0.0101156	(assume constant for all Reynold numbers)
k =	0.00015	
$k_{L\ elbow}$ =	0.3327083	
$k_{L\ entrance}$ =	0.1009822	
Viscosity =	0.00003	ft^2/sec
Diameter of Pipe (D) =	4.5	ft
Area of Pipe (A) =	15.910714	ft^2
H_{pump} =	0	ft

Start Pump P-1 Elevation =	601	ft
Stop Pump P-1 Elevation =	595	ft
Minimum Surface Elevation =	585.167	ft

Cross Sectional Area of Wet well = 3045.679 ft^2

Q_0 =	-612.602	ft^3/sec
V_0 =	-38.50248	ft/sec
Z_0 =	9.5212837	ft
V_0 =	28998.774	ft^3
Length of Pipe for horizontal section=	52	ft

Q is positive when entering the pump station

Apply Euler's Formula:

$Q(t) = Q_{previous}+dQ$ where,

$$\frac{\partial Q}{\partial t}=\frac{gA}{(523.3-h)}\left[(523.3-h)-z+\frac{f(523.3-h)}{D}\frac{Q^2}{2gA^2}\right]$$

$X(t) = X_{previous}+dx$

$V(t) = V_{previous}+dV$

$z(t) = V_0 / A = V_0 / 3045.7$

dh = (Q/A) * dt

dV = $(Q_{inflow} + Q)$* dt

Q is positive entering the pump station

and assume Q_{inflow} to the wet well is zero

t(sec)	Q(cfs)	h(ft)	V(ft^3)	z(ft)	WSEL(ft)	H_{pump}(ft)	dQ	dh	dV	
4.135	-612.602	0	28998.774	9.5213	595.0423	0.0	8.904577	-0.770049641	12.25203983	0.02
4.155	-603.6974	0.77	29011.026	9.5253	595.0463	0.0	8.860659	-0.758856457	12.07394828	
4.175	-594.8368	1.5289	29023.1	9.5293	595.0502	0.0	8.816606	-0.74771848	11.89673509	
4.195	-586.0201	2.2766	29034.996	9.5332	595.0542	0.0	8.772413	-0.736635877	11.72040297	
4.215	-577.2477	3.0133	29046.717	9.537	595.058	0.0	8.728074	-0.725608826	11.54495472	
4.235	-568.5197	3.7389	29058.262	9.5408	595.0618	0.0	8.683584	-0.714637511	11.37039325	
4.255	-559.8361	4.4535	29069.632	9.5445	595.0655	0.0	8.63894	-0.703722118	11.19672156	
4.275	-551.1971	5.1572	29080.829	9.5482	595.0692	0.0	8.594137	-0.692862845	11.02394276	
4.295	-542.603	5.8501	29091.853	9.5518	595.0728	0.0	8.549171	-0.682059889	10.85206002	
4.315	-534.0538	6.5322	29102.705	9.5554	595.0764	0.0	8.50404	-0.671313456	10.6810766	
4.335	-525.5498	7.2035	29113.386	9.5589	595.0799	0.0	8.45874	-0.660623754	10.51099581	
4.355	-517.0911	7.8641	29123.897	9.5624	595.0833	0.0	8.413269	-0.649990995	10.34182101	
4.375	-508.6778	8.5141	29134.239	9.5658	595.0867	0.0	8.367625	-0.639415394	10.17355564	
4.395	-500.3102	9.1535	29144.412	9.5691	595.0901	0.0	8.321807	-0.628897167	10.00620315	
4.415	-491.9884	9.7824	29154.419	9.5724	595.0934	0.0	8.275815	-0.618436534	9.839767002	
4.435	-483.7125	10.401	29164.258	9.5756	595.0966	0.0	8.229648	-0.608033714	9.674250701	
4.455	-475.4829	11.009	29173.933	9.5788	595.0998	0.0	8.183307	-0.597688926	9.509657738	
4.475	-467.2996	11.607	29183.442	9.5819	595.1029	0.0	8.136793	-0.58740239	9.345991594	
4.495	-459.1628	12.194	29192.788	9.585	595.106	0.0	8.090109	-0.577174322	9.183255727	
4.515	-451.0727	12.771	29201.971	9.588	595.109	0.0	8.043255	-0.567004937	9.021453557	
4.535	-443.0294	13.338	29210.993	9.591	595.1119	0.0	7.996237	-0.556894448	8.860588449	
4.555	-435.0332	13.895	29219.853	9.5939	595.1148	0.0	7.949059	-0.546843061	8.700663703	
4.575	-427.0841	14.442	29228.554	9.5967	595.1177	0.0	7.901724	-0.536850979	8.541682533	
4.595	-419.1824	14.979	29237.096	9.5995	595.1205	0.0	7.85424	-0.526918396	8.383648054	
4.615	-411.3282	15.506	29245.479	9.6023	595.1233	0.0	7.806612	-0.517045502	8.226563262	
4.635	-403.5216	16.023	29253.706	9.605	595.126	0.0	7.758849	-0.507232477	8.070431021	
4.655	-395.7627	16.53	29261.776	9.6076	595.1286	0.0	7.710959	-0.497479491	7.915254039	
4.675	-388.0517	17.027	29269.692	9.6102	595.1312	0.0	7.662952	-0.487786702	7.761034853	
4.695	-380.3888	17.515	29277.453	9.6128	595.1338	0.0	7.614839	-0.478154259	7.607775806	
4.715	-372.774	17.993	29285.061	9.6153	595.1363	0.0	7.56663	-0.468582296	7.455479031	
4.735	-365.2073	18.462	29292.516	9.6177	595.1387	0.0	7.51834	-0.459070931	7.304146426	
4.755	-357.689	18.921	29299.82	9.6201	595.1411	0.0	7.46998	-0.449620269	7.153779636	
4.775	-350.219	19.371	29306.974	9.6225	595.1435	0.0	7.421568	-0.440230395	7.004380029	
4.795	-342.7974	19.811	29313.978	9.6248	595.1458	0.0	7.373118	-0.430901376	6.855948671	
4.815	-335.4243	20.242	29320.834	9.627	595.148	0.0	7.324648	-0.421633259	6.708486312	
4.835	-328.0997	20.663	29327.543	9.6292	595.1502	0.0	7.276176	-0.412426069	6.561993351	
4.855	-320.8235	21.076	29334.105	9.6314	595.1524	0.0	7.227723	-0.403279809	6.416469822	
4.875	-313.5958	21.479	29340.521	9.6335	595.1545	0.0	7.179308	-0.394194456	6.271915364	
4.895	-306.4165	21.873	29346.793	9.6356	595.1565	0.0	7.130955	-0.385169961	6.128329199	
4.915	-299.2855	22.258	29352.921	9.6376	595.1585	0.0	7.082685	-0.376206247	5.985710108	

4.935	-292.2028	22.635	29358.907	9.6395	595.1605	0.0	7.034525	-0.367303208	5.844056404		
4.955	-285.1683	23.002	29364.751	9.6414	595.1624	0.0	6.986499	-0.358460708	5.703365911		
4.975	-278.1818	23.36	29370.455	9.6433	595.1643	0.0	6.938635	-0.349678577	5.563635934		
4.995	-271.2432	23.71	29376.018	9.6451	595.1661	0.0	6.89096	-0.340956612	5.424863241		
5.015	-264.3522	24.051	29381.443	9.6469	595.1679	0.0	6.843506	-0.332294574	5.287044031		
5.035	-257.5087	24.383	29386.73	9.6487	595.1696	0.0	6.796301	-0.323692188	5.150173917		
5.055	-250.7124	24.707	29391.88	9.6504	595.1713	0.0	6.749378	-0.315149138	5.014247896		
5.075	-243.963	25.022	29396.895	9.652	595.173	0.0	6.70277	-0.306665071	4.879260331		
5.095	-237.2602	25.329	29401.774	9.6536	595.1746	0.0	6.656511	-0.298239591	4.745204924		
5.115	-230.6037	25.627	29406.519	9.6552	595.1761	0.0	6.610637	-0.289872259	4.612074696		
5.135	-223.9931	25.917	29411.131	9.6567	595.1777	0.0	6.565182	-0.281562593	4.479861965		
5.155	-217.4279	26.199	29415.611	9.6581	595.1791	0.0	6.520185	-0.273310063	4.348558325		
5.175	-210.9077	26.472	29419.96	9.6596	595.1806	0.0	6.475683	-0.265114096	4.218154628		
5.195	-204.432	26.737	29424.178	9.661	595.1819	0.0	6.431716	-0.256974067	4.088640964		
5.215	-198.0003	26.994	29428.266	9.6623	595.1833	0.0	6.388323	-0.248889307	3.960006646		
5.235	-191.612	27.243	29432.226	9.6636	595.1846	0.0	6.345544	-0.240859092	3.832240193		
5.255	-185.2665	27.484	29436.059	9.6649	595.1858	0.0	6.303421	-0.23288265	3.705329313		
5.275	-178.963	27.717	29439.764	9.6661	595.1871	0.0	6.261995	-0.224959159	3.579260897		
5.295	-172.7011	27.942	29443.343	9.6673	595.1882	0.0	6.221308	-0.21708774	3.454021002		
5.315	-166.4797	28.159	29446.797	9.6684	595.1894	0.0	6.181403	-0.209267465	3.329594843		
5.335	-160.2983	28.368	29450.127	9.6695	595.1905	0.0	6.142322	-0.201497352	3.20596679		
5.355	-154.156	28.569	29453.333	9.6705	595.1915	0.0	6.104108	-0.193776364	3.083120357		
5.375	-148.0519	28.763	29456.416	9.6715	595.1925	0.0	6.066804	-0.186103411	2.961038203		
5.395	-141.9851	28.949	29459.377	9.6725	595.1935	0.0	6.030452	-0.17847735	2.839702129		
5.415	-135.9547	29.128	29462.217	9.6734	595.1944	0.0	5.995097	-0.170896984	2.719093079		
5.435	-129.9596	29.299	29464.936	9.6743	595.1953	0.0	5.960778	-0.16336106	2.599191148		
5.455	-123.9988	29.462	29467.535	9.6752	595.1962	0.0	5.92754	-0.155868274	2.479975581		
5.475	-118.0712	29.618	29470.015	9.676	595.197	0.0	5.895422	-0.148417271	2.361424788		
5.495	-112.1758	29.766	29472.376	9.6768	595.1978	0.0	5.864465	-0.141006639	2.243516352		
5.515	-106.3114	29.907	29474.62	9.6775	595.1985	0.0	5.83471	-0.133634921	2.126227043		
5.535	-100.4766	30.041	29476.746	9.6782	595.1992	0.0	5.806196	-0.126300605	2.009532835		
5.555	-94.67045	30.167	29478.756	9.6789	595.1999	0.0	5.778959	-0.119002132	1.893408922		
5.575	-88.89149	30.286	29480.649	9.6795	595.2005	0.0	5.753037	-0.111737896	1.777829743		
5.595	-83.13845	30.398	29482.427	9.6801	595.2011	0.0	5.728465	-0.104506245	1.662769005		
5.615	-77.40999	30.502	29484.09	9.6806	595.2016	0.0	5.705277	-0.097305481	1.548199706		
5.635	-71.70471	30.6	29485.638	9.6811	595.2021	0.0	5.683505	-0.090133865	1.434094166		
5.655	-66.0212	30.69	29487.072	9.6816	595.2026	0.0	5.663181	-0.082989615	1.32042406		
5.675	-60.35802	30.773	29488.392	9.682	595.203	0.0	5.644332	-0.075870915	1.207160445		
5.695	-54.71369	30.849	29489.599	9.6824	595.2034	0.0	5.626986	-0.068775907	1.094273804		
5.715	-49.0867	30.918	29490.694	9.6828	595.2038	0.0	5.611169	-0.061702703	0.981734077		
5.735	-43.47554	30.979	29491.675	9.6831	595.2041	0.0	5.596902	-0.054649382	0.8695107		
5.755	-37.87863	31.034	29492.545	9.6834	595.2044	0.0	5.584208	-0.047613994	0.757572653		
5.775	-32.29442	31.082	29493.303	9.6837	595.2046	0.0	5.573104	-0.040594563	0.645888497		
5.795	-26.72132	31.122	29493.948	9.6839	595.2048	0.0	5.563607	-0.03358909	0.534426421		
5.815	-21.15771	31.156	29494.483	9.684	595.205	0.0	5.555731	-0.026595555	0.423154285		
5.835	-15.60198	31.182	29494.906	9.6842	595.2052	0.0	5.549487	-0.019611921	0.312039672		
5.836	-10.0525	31.202	29495.218	9.6843	595.2053	0.0	0.277244	-0.000631807	0.201049935	0.001	
5.837	-9.775252	31.203	29495.419	9.6843	595.2053	0.0	0.277235	-0.000614382	0.19550505		
5.838	-9.498017	31.203	29495.615	9.6844	595.2054	0.0	0.277226	-0.000596957	0.189960345		
5.839	-9.220791	31.204	29495.805	9.6845	595.2055	0.0	0.277218	-0.000579533	0.184415816		
5.84	-8.943573	31.204	29495.989	9.6845	595.2055	0.0	0.27721	-0.00056211	0.178871456		
5.841	-8.666363	31.205	29496.168	9.6846	595.2056	0.0	0.277202	-0.000544687	0.173327262		
5.842	-8.389161	31.205	29496.341	9.6847	595.2056	0.0	0.277194	-0.000527265	0.167783228		
5.843	-8.111967	31.206	29496.509	9.6847	595.2057	0.0	0.277186	-0.000509843	0.16223935		

AIIM SCANNER TEST CHART # 2

Spectra

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

Times Roman

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

Century Schoolbook Bold

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

News Gothic Bold Reversed

4 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
6 PT ABCDEFGHIJKLMNOPQRSTUVWXYZabcdefghijklmnopqrstuvwxyz;:",./?$0123456789
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Bodoni Italic

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

Greek and Math Symbols

4 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⋟⋞⋗⋖≡
6 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⋟⋞⋗⋖≡
8 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⋟⋞⋗⋖≡
10 PT ΑΒΓΔΕΞΘΗΙΚΛΜΝΟΠΦΡΣΤΥΩΧΨΖαβγδεξθηικλμνοπφρστυωχψζ≧∓",./≦±=≠°><⋟⋞⋗⋖≡

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Isolated Characters

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RIT ALPHANUMERIC RESOLUTION TEST OBJECT, RT-1-71

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