ABSTRACT

AIR/GAS ENTRAINMENT IN SEWER FORCE MAINS: A CASE STUDY

By

Kirstin Byrne

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Air and gas pocket entrainment in pressurized sewer systems are a major issue for many wastewater agencies due to decreased capacity, increased pumping and maintenance costs, corrosion, and reduction in efficiency. The Orange County Sanitation District has been concerned about air pocket formation in their Newport Force Main Network. In this study, we performed field tests to determine if air pockets existed within OCSD's large diameter force main from the Bitter Point Pump Station to Plant 2 and the effects of air entrapment on the hydraulic performance of the system. Several flow scenarios were analyzed during the field tests, which were performed with air valves open and air valves closed to compare flow and pressure fluctuations when air cannot escape the system. The effective flow area was analyzed to determine the decrease experienced when large quantities of air were present within the force main. Little information is available in regards to field studies performed on air and gas pocket formation outside of a controlled laboratory, so the type of tests and the methodology proposed in this study could be used as guidelines by other agencies facing similar problems.

AIR/GAS ENTRAINMENT IN SEWER FORCE MAINS: A CASE STUDY

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Committee Members:

Antonella Sciortino, Ph.D. (Chair)
William Cassidy, P.E.
Bruce Phillips, P.E.

College Designee:

Burkhard Englert, Ph.D.

By Kirstin Byrne

B.S., 2010, California State University, Long Beach

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INTRODUCTION

Purpose and Objective

The purpose of this study is to analyze air and gas pocket formation and behavior in the Orange County Sanitation District's (OCSD) Newport Force Main Network (NFMN). The goal is to fill the gap between experimental studies and field applications. Air and gas pocket formation occurs in many pressurized pipelines and cause negative effects in systems.

Several literature studies have focused on the assessment of hydraulic performance in pressurized pipelines when air pockets form inside. These studies were either conducted in controlled environments of experimental facilities or were simply based on the results of numerical models. Little information is available that pertains to actual field installations. This study focuses on a large diameter sewer force main that experiences low to high flows and is a vital component of conveying wastewater to the treatment plant.

The objective was to determine if air and gas pockets are present within OCSD's NFMN, perform field testing to determine flow and pressure fluctuations, and develop hydraulic calculations based on field measurements. The study presents conclusions for OCSD on their NFMN pipeline based on results from the field testing and hydraulic calculations. These conclusions can assist with future plans to rehabilitate and improve the upstream reaches of the NFMN and may provide guidelines for other agencies interested in analyzing similar problems.

Research Methodology

In this study, numerous field tests were performed on OCSD's NFMN. Each field test scenario was run under two separate conditions: air valves open and air valves closed. Hydraulic calculations were performed for the compressed air field tests to determine the capacity reduction and additional friction in the pipeline.

Thesis Overview

Chapter 2 discusses the hydraulic behavior of air and gas pockets and the hydraulic effects air and gas pockets have on systems based on a comprehensive literature review. Laboratory experiments and computer models developed to simulate the effects of air and gas pockets on pressurized systems are also described in this chapter.

Chapter 3 provides a detailed description of OCSD's NFMN system. This description includes information on pump stations, pump sizes, pipeline sizes, design capacities, pipeline lengths, and overall system configuration.

Chapter 4 presents the methods used for the field testing experiments.

Chapter 5 presents results from the field testing.

In Chapter 6, the hydraulic calculations for the compressed air tests are described and presented.

Chapter 7 discusses the conclusions and recommendations for the system under investigation.

CHAPTER 2

HYDRAULICS OF SYSTEMS WITH AIR/GAS POCKETS/REVIEW OF EXPERIMENTAL STUDIES

Description of Air Pockets/Bubbles

Pressurized pipelines, called force mains, are major components of many water and wastewater treatment plants. Because water naturally has dissolved air in it and air can also be entrained in the pipe through pumping, accumulation of air can occur at high points in pipelines (Zloczower 2010) as shown in Figure 1.

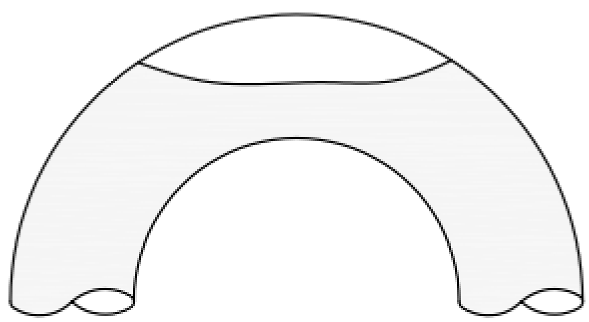


FIGURE 1. Air pocket accumulation at high point (Zloczower 2010).

The behavior of gas pockets in sewer force mains has not been studied extensively, but is a concern for many wastewater agencies due to the resulting decreased capacity of the pipe and additional pumping costs associated with them. Research has been performed using models to understand the behavior of air/gas pockets in water systems, their formation, movement with and against flow, and their effects on the hydraulics of the system.

The conventional term for the simultaneous flow of air and water is two-phase flow (Falvey 1980). If the air and water move in the same direction, it is considered concurrent flow. If the air moves in the opposite direction of the water, it is called countercurrent flow. These flow patterns depend on the airflow rate compared to the water flow rate and the slope of the pipeline. Airflow can be classified into four different types of flow: bubble flow, plug flow, stratified flow, and slug flow. Bubble flow occurs when air bubbles form at the upper surface of the pipe and travel at approximately the same speed as the water. The bubbles can also be dispersed throughout the water. A schematic of bubble flow is presented in Figure 2.

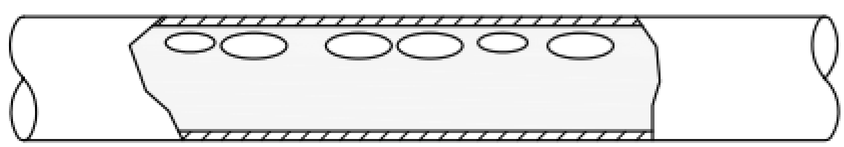


FIGURE 2. Bubble flow (Falvey 1980).

Plug flow, which contains air and gas pockets, occurs when the airflow rate increases and the air bubbles coalesce to join or develop pockets. The air pockets flow along the top of the pipe as shown schematically in Figure 3.

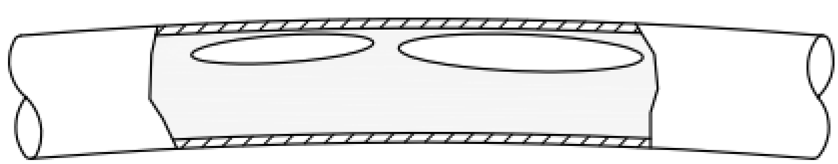


FIGURE 3. Plug flow (Falvey 1980).

Stratified flow occurs when there is a distinct horizontal interface that separates the air and water flows. Slug flow occurs when wave amplitudes seal the conduit and the large air pocket travels at a higher velocity than the average liquid velocity as shown in Figure 4.

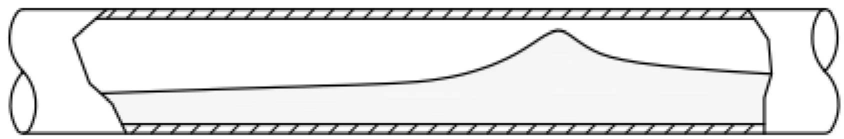


FIGURE 4. Slug flow (Falvey 1980).

In systems where pumping is required, all intermediate summits in the pipeline are potential locations for air pockets to collect. If air pockets develop at these points, the hydraulic gradient downstream of the high point will approximately equal the pipe slope in the area the air pocket has formed. For pipe slopes greater than the full-flow hydraulic gradient, the air pocket will require a greater differential head to produce a specified discharge. Where there is constant head differential, the air pocket will result in decreased water discharges. When complete blockage of flow in a pumping system occurs, a phenomena known as air binding, the pump shutoff head will be reached (Falvey 1980). American Water Works Association [AWWA] (2001) states that the water velocity is typically sufficient to prevent complete air binding of a pipeline and will carry a portion of the air pocket downstream.

Cause of Formation and Mechanism of Entrance and Entrapment

Gas pockets develop in force mains for a variety of reasons and their behavior once they are in the force main are of major concern. AWWA (2001) states that water contains at least two percent dissolved air under standard conditions and the air content varies with pressure and temperature. When water is pressurized, such as in pumping systems, water has the ability to withhold more air. Once the air is released from the solution, it does not have the ability to return to the solution and will instead collect in pockets at high points along the pipeline. Air can escape the solution in low-pressure zones in the pipeline such as at partially open valves, cascading flows in a partially filled pipe, variations in flow velocity due to pipe size fluctuations and slopes, and changes in pipeline elevations. Air can also enter through leaky joints where the pressure in the pipeline falls below atmospheric pressure which occurs when the pipeline is above the hydraulic grade line. Air can enter through air/vacuum and combination air valves during pump shutdown, orifices of air release valves when the pressure is less than atmospheric, and at pump suctions lines that were not properly designed for vortices. According to Pozos et al. (2010), air entrainment can occur from air left in the pipeline from pipe filling that was not released through an air release valve. Zloczower (2010) states that when a pipeline is empty, it is full of air and when filling a pipeline, the air must be discharged so water or wastewater can take its place. Air can also become entrapped in a pipeline when water column separation occurs from pump stoppage because the pressure falls below atmospheric pressure. Air can enter pipelines in above ground pipe sections through faulty joints, poorly positioned seals and gaskets, pipe appurtenances, cracks, or other gaps in the pipeline. Lift stations that have wet wells or sewage collection basins are subject to entrained air due to plunging jets. A plunging jet at OCSD's Bitter Point Pump Station wet well shown in Figure 5 is a source for air entrainment.

FIGURE 5. Plunging jet into wet well (Courtesy of OCSD).

During cyclic operation, some sections of the force mains empty out at the end of each pumping cycle allowing air to enter the pipeline. Drop manholes also entrain air into the system from the plunging jet of sewage. When the pressure drops and temperature rises, dissolved air and gas are released from the solution. For example, the water warms up as it is driven through the pump and can warm up as it flows through the pipeline due to resistance or friction. If the environment surrounding the pipeline is warmer than the pipeline, the water solution can warm up and release more dissolved air or gas. When the pressure drops downstream of the pump, air and gas are released from the water. Turbulence in the pump and pipeline, such as a hydraulic jump, also result in the release of dissolved air and gas. Lubbers and Clemens (2006) reported that low flow velocities that occur during dry weather cause gas pockets to accumulate in high points of force mains. Dry weather flows occur over most of the year and this is when gas is entrained into the system and accumulates at high points. Walski et al. (1994) pointed out that gas pockets in force mains result from air release or vacuum breaker valves when the hydraulic grade line is below the pipe causing open channel flow and where atmospheric pressure exists in the gas phase. Air can be entrained in the pipeline if the pump drains the wet well to the bell-mouth level of the pump (Pothof and Clemens 2008). Biochemical processes involving carbon dioxide, nitrogen, and methane can also cause gas pockets to form in the pipeline. Intermittent operation (start up and shut down) of pressurized wastewater mains cause gas to accumulate at the high points in the system. If the force main is subject to negative pressures, whether in normal operation or from transients, air can enter through air valves. According to Wylie and Streeter (1993), pipelines that vary in elevation tend to experience column separation near the high points in the piping profile. A vapor cavity forms from vapor pressure that develops due to velocity variations from a reduction in pressure and tends to remain stationary on the downstream side of the high point, with liquid flowing below the cavity. This vapor cavity may continue to grow until the velocity on the upstream end accelerates and overtakes the downstream column. If the pressure increases significantly during the collapse of the vapor cavity, the pipe may rupture (Wylie and Streeter 1993).

Once gas pockets have formed in the pressure mains they should be removed, however their behavior is not well understood to many engineers or public agencies. Bucur (2008) pointed out that air moves freely in upward sloping force mains independently of water flow, due to its own buoyancy. Pozos et al. (2010) reported that downward sloping pipelines in the direction of the flow are subjected to air accumulation. Gas pockets are affected by buoyancy and drag forces with the pipe wall. Drag forces hold the gas pocket in place, while the buoyancy force moves the gas pocket upstream, and gravity forces move them downstream. Equilibrium is achieved when the upstream and downstream forces are equal and the pocket remains trapped. The buoyancy of a gas pocket prevents it from being dragged downstream to an outlet and the water velocity prevents the pocket from traveling upstream to an air release valve. Once the pockets reach a steep slope, the buoyancy forces overcome the drag forces and the gas pocket can grow larger (Pozos et al. 2010).

Free surface flow conditions can exist in force mains during low flow periods, exposing the top of the pipe to air. During high flow periods, the force mains can flow full across the entire pipe. During these high flow conditions, the air and gas pockets are likely to be removed from the system. When flows transition from a full pipe to a partially full pipe regime, the gas pockets may form at locations that are not necessarily the high point. In general, they form at a certain distance upstream of the high point (Walski et al. 1994). Zloczower (2010) stated that in the late-night and early-morning hours, when flows are minimal and the removal velocity cannot be met, air and gas bubbles can grow to sizes that fast flowing water cannot carry downstream. They are more likely to break down into smaller air pockets and be spread downstream to form an elongated air pocket from the crown of the pipe. Because the flow velocity is often above this removal velocity in operational systems, the air pockets are not stationary and do not remain uniform in shape and size. They break down, combine, change shape, move, and may change direction of movement. Large air pockets that travel in the opposite direction of water flow from the buoyancy force tend to break up into smaller pockets and bubbles and change direction to flow with the water, while the larger air pockets continue to travel upstream. The air pockets and bubbles that are small enough to travel with the water flow tend to break up and disperse throughout the water and travel at different velocities. All air pocket movement disrupts the water flow.

When transitioning from a partially full pipe to a full pipe on a steep slope, a hydraulic jump may follow, but if a mild slope is present, a smooth transition will occur. The hydraulic jump can entrain air into the pipe and cause a larger gas pocket to form. Gas pockets do not have a specific size or shape and the gas pockets tend to deform based on the slope of the pipe and velocity of the flow (Walski et al. 1994). According to Pothof and Clemens (2008), the hydraulic jump that develops at the tail of the gas pocket can eject gas bubbles from the gas pocket, transport them, and ultimately eject the gas bubbles at the bottom of the declining section. The gas pockets length is measured from the upstream end of the pocket to the hydraulic jump. Lubbers and Clemens (2006) described gas transport to be chaotic under stationary conditions (constant flow and gas discharge). In a downward sloping pipe, the gas tends to transport only when there is a hydraulic jump. They observed that the gas accumulates upstream of the high points. If large amounts of gas are supplied to this high point, the volume of the pocket will increase and the water depth will decrease. The air pocket will not be transported until the water reaches a critical depth that corresponds to a Froude number of 1. Once this depth is reached, the water level will not decrease anymore and the gas pocket will extend downstream. At the end of the gas pocket, a hydraulic jump will occur. Once the flow rate increases (ex. from dry to wet weather flows or daily diurnal fluctuations), the water level in the pipe will be higher and transport and removal of the gas occurs. The increase in water depth will decrease the volume of the gas pocket, the gas will become entrained in the hydraulic jump, and the velocity will increase, so the drag/buoyancy ratio will be higher (Lubber and Clemens 2006).

Effects

Gas pockets can have many negative effects on pipelines, pumps, and operating costs. AWWA (2001) stated that air pockets can cause water hammer, pipeline breaks, pipeline noise, corrosion, and erratic operation of control valves, meters, and equipment.

According to Wylie and Streeter (1993), the propagation velocity of a pressure wave in a pipeline containing a liquid can be greatly reduced if gas bubbles are dispersed throughout the liquid. The gas or air bubbles reduce the speed of the pressure pulse. The pressure wave travels through the liquid at a lower velocity than in a homogeneous liquid because the wave transmits from one gas bubble to another rather than one water particle to the next. When dissolved air or gas is present in the fluid, a reduction in pressure below saturation pressure will cause gas pocket formation. Bucur (2008) stated that two-phase flows can arise in pressurized pumping stations that cause fluctuations in pressure, which may result in significant damage to the pipeline and pressure system. Air accumulation that occurs in downward sloping pipelines can influence maximum peak pressures during pressure transients (Walski et al. 1994). If the air pockets are not removed, they can be compressed after pump start-up and shut-down and can lead to peak pressures. Releasing entrapped air from an orifice can also cause high peak pressures and can be a source for surges. Theoretical and experimental investigations have suggested that the storage and release of trapped air pockets initiates high pressure surges. Peak pressures are experienced when the air pocket volume is small and these pressures can have such a significant effect to cause pipe failure. On the other hand, large air pockets can have a positive effect by behaving as a cushion to absorb energy from transient pressure waves (Pozos et al 2010). Bucur (2008) suggests that surges, or high shock loads, can be generated when air pockets encounter valves, pipe bends, or cause an obstruction to the flow. After pump shut-down, small pockets that result from large pocket break up can significantly intensify peak pressures. The degree of peak pressure enhancement is dependent on the position of the air pocket and the location along the pipeline that is under investigation. Bucur (2008) found that small air pockets have the potential to intensify the frequency and amplitude of pressure waves. When air pockets are in the upstream section of a pipe and near the pump, there is a higher probability for destructive pressures. Small air pockets produce higher pressures at upstream junctions of pipelines and large air pockets produce higher pressures at downstream junctions. Small air pockets have a critical size that increases peak pressures and depends on the system configuration and the air pocket location in the system. Peak pressures caused by air pockets can be large enough to cause pipe fracture and failure. According to Zhou et al. (2001), air-induced pressure is severe when filling is rapid, air is trapped, and where an intermediate orifice size exit exists for air to escape the system. Ciraolo and Ferreri (2008) found that the major components affecting the amplitude and frequency of oscillations are the initial thickness and the initial pressure of the air pocket. These factors determine the air pocket compression stiffness and the elastic pulsation characteristics. The stiffness increases as the pressure increases and the thickness decreases (Ciraolo and Ferreri 2008). In the Netherlands, inventory was done on the wastewater collection systems that showed half of the pressure mains were experiencing increased pressure losses. One of the causes for pressure loss was gas entrainment in the pipelines (Lubbers and Clemens 2006).

Gas pockets that are stationary in a pipeline may contain hydrogen sulfide, which can oxidize (by reacting with the oxygen in the air pocket) into sulfuric acid and damage the top of the pipe wall (Walski et al. 1994). According to Zloczower (2010), water and wastewater contain dissolved oxidants such as oxygen and chlorine, which when in contact with metallic iron, present a driving force for corrosion. The corrosion rate is likely limited to the rate at which oxygen released from the solution is provided to the surface. Air pockets are a major source of oxygen and are a contributor to corrosion. Wastewater systems are prone to internal hydrogen sulfide corrosion and air pockets make force main systems susceptible to this. Zloczower (2010) reports that according to a US EPA study, "Since the pipes are generally full of wastewater, corrosion will not occur within surcharged pipes unless they contain air pockets. If an air pocket exists, corrosion may occur very quickly" (p. 454). Surges that occur in force mains that are weakened by corrosion can cause severe damage to the pipeline and result in health endangerment and contaminant intrusion into soil and drinking water systems.

Bucur (2008) stated that the presence of air in pressure systems can lead to loss of capacity, disruption of flow (turbulence and wall shear), reduced pump efficiency, and can have effects on the pipe materials and pipeline structure. The fluid properties, such as density and elasticity, can also change. Blow-back of air bubbles from a hydraulic jump restricts air from traveling downstream and can lead to vibration and structural damage in the pipe, as well as instabilities of the water surface. Admission of air into a pump can cause water hammer and loss of pump priming. Transitioning from a partially full pipe to a full pipe can cause vibrations in the pipelines that can result in surges. Pressure fluctuations that are significantly large due to air pockets in the pipeline may cause pipe fracture and pipe failure. As air pocket size increases, the cross sectional area for the water flow decreases, resulting in head losses from increased friction, that lead to decreased flow capacity and increased energy consumption (Zloczower 2010). In pumping systems, gas and air pockets result in increased energy consumption and, therefore, higher energy costs for public agencies. Discharge reduction occurs when the air pockets cannot be transported downstream and released. Flow can even completely stop because the cumulative head losses produced from the air pockets are larger than pumping head capacity. 75% of operational costs are from pumping and entrapped air in the pipelines can reduce the efficiency of a pumping station by 30%. Most systems have air pockets that increase the required pressure head by 20% leading to an increased energy demand of 20% (Pozos et al. 2010). According to Lubbers and Clemens (2006), free gas within pressurized pipelines can significantly reduce flow capacity. When this flow capacity does not correlate with the design flows, spills and efficiency loss can occur in the system. The additional head loss and capacity reduction from gas pockets cannot be predicted with sufficient accuracy, causing unknown effects on the system (Pothof and Clemens 2008). These negative effects are the reason why a solution to remove the gas pockets is needed and it should be developed in a cost effective manner, which is very challenging for force main systems.

Removal

Due to the many negative effects, removal of air pockets from pressurized pipes is necessary, and if it cannot be accomplished by flushing with high water velocities, air pockets should be removed from the system using air release valves or other methods. Falvey (1980) stated that the purpose of air venting structures is to evacuate air during filling, remove air during operation, and prevent pipe collapse during draining. If air is to be removed only during filling, a large orifice (25 mm or larger) air valve should be used (Falvey 1980). These valves open when the pipeline pressure drops below atmospheric pressure and allows air to enter the pipe to prevent a vacuum from occurring. Small orifice air valves and open-vent structures are used to remove air from the pipeline during operation. The connection of these structures must be large enough to collect air bubbles and pockets that travel to the crown of the pipe. If the collection port is too small, portions of the air pockets may pass by the vent or air valve. Small orifice air valves are used to remove air from high pressure pipelines and the small orifice assures the opening force of the float is not exceeded by the closing force. Air valves are typically placed at the high points of the pipeline profile or at locations where the pipeline profile begins a steep downward slope. AWWA (2001) defines air valves as hydro-mechanical devices developed to automatically release and/or admit air into the system during filling, draining, and normal operation. Safe operation and efficiency of a pipeline network are dependent on the continuous removal of air from the network and air valves can provide this function. There are three different types of air valves that are used to control air in pressurized pipelines: air-release valves, air/vacuum valves, and combination air valves. Air-release valves, which are small orifice valves, are designed to release small air pockets from the pipeline when under pressure. Air/vacuum valves, which are large orifice valves, exhaust large quantities of air during pipe filling and admit large quantities of air when the pressure is below atmospheric, such as pipe draining or during a power failure. Air/vacuum valves are used to prevent formation of a vacuum that can cause pipe collapse and surges. These valves do not operate under pressure conditions and do not serve a purpose during normal operation. Combination air valves have the same function as an air/vacuum valve, but they also release air pockets when the pipeline is under pressure like an air-release valve. Combination air valves are available in a single-body and dual-body configuration. Air valves are reliable and efficient if the application is feasible and cost effective. Air valves are readily available and prevent the development and accumulation of air pockets to avert damages such as surges and corrosion. Wastewater air valves are available in body shapes and textures that resist buildup and clogging, in numerous materials, and many coats to enable dependable, corrosion free, and damage free use (Zloczower 2010). If the accumulated air can be removed hydraulically from the system there will be large cost savings, but if air cannot be removed hydraulically, considerable costs will be associated with the purchase, installation, and maintenance of air valves (Bucur 2008).

The location of air valves along a pipeline is extremely important to ensure proper air removal and efficient operation of the system. AWWA (2001) pointed out that improperly locating an air valve can render the valve ineffective. Combination air valves should be installed along the profile at high points, mainline isolation valves, abrupt increases in downslope, abrupt decreases in upslope, long ascents, long descents, and horizontal runs. The combination air valve should be located on the draining side of the mainline valves. At long ascents and descents and horizontal runs the combination air valves should be placed at intervals of a quarter mile to a half-mile. The valves should also be placed at the beginning and end of long horizontal runs. Air/vacuum valves should be installed on the draining side of mainline valves, at abrupt decreases in upslope and on long ascents at intervals of a quarter to half mile. Air-release valves should be located on long descents and on horizontal runs at intervals of a quarter to a half-mile.

AWWA (2001) found that water hammer may occur when the last bit of air is released from air/vacuum or combination air valves due to abrupt closure. If possible, the air valves should be equipped with slow-closing devices to minimize the water hammer effect. Pipelines are also likely to experience water hammer during filling because the air valves can only provide limited air discharge. The filling rate should be regulated to a velocity of about 1 foot per second to prevent water hammer effects. When air pockets pass through restrictions such as partially open valves or from one high point to another, water hammer can occur. The AWWA manual (2001) provides guidelines for minimizing water hammer effects of air in a pipeline that include: (1) Fill slowly at a velocity of 1 foot per second, (2) Install air/vacuum or combination air valves that do not release air under high pressures during filling, (3) Install air release valves at pipeline peaks or equal intervals if the pipeline is flat, (4) Flush the system at velocities between 2 and 4 feet per second and low pressures to move the air to the air valves, (5) Install air valves upstream of control valves so air does not pass through them, and (6) Use combination air valves where possible to provide air regulation during filling, draining, and normal pipeline operation.

Proper installation and maintenance of air valves is extremely important to ensure proper operation. AWWA (2001) recommends that air valves be placed in a valve vault with screened ventilation in order to provide adequate ventilation of the structure. These vaults should be maintained and should have proper drainage to ensure flooding of the vault does not occur. If the vault floods and submerges the air intake on the valve, the valves may not operate correctly and contamination of the pipeline may occur. Underground structures should have proper ventilation for gases that are released from the air valves as well as a combustible gas and low-oxygen detector. All air valves should be opened, flushed, and maintained at least annually to ensure proper operation of the valves (AWWA 2001).

Air pocket removal can be achieved when flows and velocities are high enough in the pipeline system. According to Pothof and Clemens (2008), full gas transport, also known as the clearing velocity, occurs at higher discharges, where the entrained gas pockets are transported as bubbles to the bottom of the downward slope minimizing head losses that developed from the gas pockets. The steeper the slope in a force main, the smaller the gas pocket length and clearing velocity. The clearing velocity for stable gas pockets is smaller than the clearing velocity for large gas pockets that have hydraulic jumps and air entrainment. If the gas pockets are injected upstream of the downward slope, the greatest clearing velocity is at approximately 10 degree slopes, where larger slopes have gradually smaller clearing velocities. This decrease in clearing velocity occurs because the gas is transported as an entire pocket and the pockets are smaller at steeper slopes. On the other hand, clearing velocities for gas bubbles increase with increased downward slopes and are driven by the hydraulic grade line, which includes friction. Zloczower (2010) reported that a minimum (critical) water flow velocity is required to transport fine bubbles entrained in the water in down-sloping and level pipeline sections. The critical velocity to transport these bubbles depends on the size, shape, and concentration of the bubbles and the down-slope and diameter of the pipeline.

Governing Equations for Critical Velocity

Bucur (2008) reported that the velocities of air pockets in upward sloping pipes are similar to velocities in downward sloping pipes. A critical velocity is essential to transport air pockets through the downward sloping sections of the force mains. Because the air pocket is at the top of the pipeline and two-phase flow is occurring, the pipeline is assumed to undergo open channel flow conditions and the clearing velocity is related to the Froude number. The critical velocity, v, determined from experiments, is calculated using the following equation (Bucur 2008):

$$\frac{v}{\sqrt{gD}} = Sf(0.56\sqrt{sinS} + c) \qquad (2\text{-}1)$$

where: Sf is the safety factor advised for engineering applications, g is the gravity, D is the diameter of the pipe, and:

c equals: 0.45 for $n<0.06$

0.50 for $0.06 \le n < 0.12$

0.57 for $0.12 \le n < 0.30$

0.61 for $0.30 \le n < 2$

and the parameter n is calculated using:

$$n = \frac{4Va}{\pi D^3} \qquad (2\text{-}2)$$

where: Va is the volume of the air pocket and D is the diameter of the pipeline. Pothof and Clemens (2008) reported that under certain flow regimes, such as the blow-back flow regime where there are small flows, the bubbles coalesce and blow back upward, limiting gas transport. The net gas transport is determined by the flow characteristics below the hydraulic jump that are described with the Froude-scaled dimensionless velocity due to open channel flow conditions from the air pocket. The Froude-scaled dimensionless velocity, vi, can be determined using (Pothof and Clemens 2008):

$$\frac{vi}{\sqrt{gD}} = \frac{4}{\pi}\sqrt{\frac{sin\theta}{0.71}} \tag{2-3}$$

where: g is the gravity, D is the diameter of the pipeline, and sinθ is the pipe slope relative to the horizontal plane.

<u>Experimental Studies</u>

Laboratory controlled experiments have been conducted and models have been developed to evaluate the working conditions of theoretical systems and existing force main systems.

Lubbers and Clemens (2005) developed a laboratory model to obtain a quantitative understanding of the dynamics of air and gas pockets within pressure systems. The facility was specially designed to inject a known quantity of air into the pipeline with liquid flow. Water was pumped from a constant head reservoir into the facility. Control valves and flow meters were adjusted for the water and air to the set values for the experiment. The model consisted of a horizontal section followed by a downward sloping section to another horizontal section. The pipeline was made of a transparent material to observe the behavior occurring in the pipeline and had an internal diameter of 220mm. Air was injected between the first horizontal section and the downward sloping section. The water flow control valve was adjusted to ensure constant flow was obtained during increasing head conditions from the air injection. Pressure reading transmitters were located at the horizontal test sections to prevent air from disturbing the pressure readings. Results from the experiments showed that at higher flow rates the head losses were similar to those without air injected into the pipeline. This demonstrated that air pockets were removed at the higher flow rates. When an air pocket was present, small air bubbles transported downstream at the downstream end of an air pocket, while pockets that formed from aggregation of bubbles moved upstream. When an air bubble was injected into the pipe and there was not an existing air pocket, the air bubble became stationary and little head loss in the pipeline was experienced. On the other hand, if an air bubble was injected into the pipeline and an air pocket already existed, larger head losses were experienced within the pipeline. If air was consistently injected into the pipeline, the head loss was observed to drop linearly with an increasing flow rate. This indicates that more air is expelled from the pipeline as the flow rate increases. The model showed that the 20 and 30 degree bends always had air pockets that were never removed, but air pockets were removed at the 10 degree bends only when the air supply to the system was removed. Application of air valves at the 20 and 30 degree bends could be recommended. On the other hand, air valves on slightly sloped pipelines, under 10 degrees, could be ineffective because the air pocket can extend to the sloped section of the pipeline. It was also observed that a mixing zone downstream of the air pocket develops and demonstrates open channel and closed conduit characteristics. Open channel phenomena include a hydraulic jump and closed conduit behavior includes air pockets moving upstream.

In a later study, Lubbers and Clemens (2006) studied multi-phase flow and transportation of gas on the system described above. Air injection tests were run on the scaled model and it was determined that gas discharge capacity was higher at higher flow rates and the volume of the gas pocket was smaller at higher flow rates. As the gas pocket decreased, the hydraulic jump moved up, and the removal of the gas decreased. This is a result of the gas becoming entrained at the bottom of the hydraulic jump and recirculating back in to the pocket. The authors also determined that gas removal was much larger for 30 degree slopes than 10 degree slopes because the gas pocket takes an "umbrella" shape that has a larger surface area perpendicular to the flow causing a large drag to buoyancy ratio. Based on this experiment, the authors recommended that designers decrease the size of the pipe in order to decrease the air pocket volume occurring from the higher water depth and increased air pocket removal.

Pozos et al. (2010) performed an experiment on a scaled model to confirm that flow under a large air pocket in a pressurized system undergoes gradually varied open channel flow. A scaled model of the system was constructed and water run through it with air injection. A constant head tank supplied the pipeline system with water with a centrifugal pump. Acrylic pipe with an internal diameter of 76.2 mm was used and sloped between 0% and 27%. The flow depth below the air pocket was measured using an acoustic metallic sensor and electronic sound system and the hydraulic grade line was measured using a differential manometer. A few experiments were run on this system and observations were recorded. For the first experiment, the flow rates and air addition varied in the system. Some observations revealed that air pockets remained at the slope transition for a range of flow rates, large air pockets expanded in the upstream direction, and once equilibrium was met the air pockets expanded only in the downstream direction to end with a hydraulic jump. The authors discovered that if the flow rate was increased and no air was injected in the pipe, the large air pocket would move downstream without changing its shape. Furthermore, it was noted that with a constant flow rate and exhaustion of air, the air pocket size would decrease only on the downward sloping section, causing the hydraulic jump to occur sooner. During the second experiment, known air volumes were injected into the pressurized system. The air that was injected into the pipe moved to the slope change and formed an air pocket there. There was a steep slope immediately following the high point in the system causing a hydraulic jump that entrained air into the pipe. It was determined that the pressure in the system was higher than atmospheric pressure causing the air to compress and decrease the volume of the air pocket. This decrease in air pocket volume can be explained by Boyle's Law which states the volume of a defined gas quantity is inversely proportional to its pressure. From the observations taken from the experiment the authors concluded that when increasing the air in the pipe and keeping a constant flow, the air pocket only grows in the downstream direction. Boyle's Law can approximate the volume of the air pockets at high points, and the hydraulic grade line along a large air pocket is parallel to the water surface (Pozos et al. 2010).

Physical experiments performed by Bucur (2008) showed that rapidly filling a horizontal pipeline that was initially dry can induce high peak pressures, especially when air leakage occurred. Three pressure patterns were observed in these experiments. In the first case, when no air was released from the pipeline, the air pocket provided a cushioning effect preventing water hammer and high peak pressures from occurring. The pressure oscillation period in this case had a long period, but the pressure remained constant. In the second case, when the orifice size at the pipe exit is large, there is no cushioning effect and the water can impact the pipe, which is capable of causing water hammer pressures. When the orifice is large, there are typically large amounts of air entrained. Water is able to escape through large orifices and this mitigates the water hammer effect. In the third case, where the orifice size at the pipe exit is intermediate and there is a moderate amount of air in the pipeline, the pressure oscillations have long and short periods. The long periods occur when air bubbles and pockets are present and the short period pressure oscillations occur when water hammer dominates due to air pocket release. The pressure increases as the air pocket cushioning effect decreases and the air release rate increases.

Experiments performed by Zhou et al. (2001) showed that for closed flow and when the orifice size was small, the pressure pattern has a long period with a decaying peak magnitude caused by the cushioning effect of the air pocket trapped in the water column. When there is an intermediate orifice size, a long period pressure pattern followed by a short period pressure pattern is observed. The long period pressure oscillation occurs from the air pocket compression and the short period pressure oscillation results from the water column slamming into the orifice because the cushion effect is reduced drastically after most of the air is released through the orifice. When large amounts of air are released from the system, water hammer pressure dominates because the orifice is large enough to release the trapped air. As the orifice size increases, the peak pressure increases. The peak pressures drop as the air volume increases.

CHAPTER 3

NEWPORT FORCE MAIN NETWORK CONFIGURATION

The Orange County Sanitation District (OCSD) is a special district chartered by the State of California to provide regional sanitary sewer service to the northern two-thirds of Orange County. OCSD provides regional collection and treatment of wastewater for 21 cities, 3 special districts, and unincorporated areas of Orange County that are within its service area. OCSD receives and treats an average of 210 million gallons per day of wastewater from residential and commercial sources through its 587 miles of gravity pipelines, 20 miles of force mains, 15 pump stations, and 2 treatment plants in Fountain Valley and Huntington Beach.

The force mains of concern in this study are located in Newport Beach and are part of OCSD's Newport Force Main Network (NFMN). The network currently consists of two reaches, one upstream of OCSD's Bitter Point Pump Station and the other downstream of Bitter Point Pump Station. The upstream reach runs beneath Pacific Coast Highway (PCH) and consists of two parallel, interconnected pipelines that vary in size between 22 and 36 inches in diameter. The upstream reach extends from OCSD's Bay Bridge Pump Station that is located at the mouth of Upper Newport Bay to Bitter Point Pump Station's wet well that is located near the mouth of the Santa Ana River. The parallel force mains are interconnected at four locations along the 15,000 feet length to provide redundancy. This allows a segment to be isolated due to damage or failure without shutting down either or both lines completely. The loss of either line entirely would cripple the system by greatly reducing the capacity. Bay Bridge, Rocky Point, and Lido Pump Stations discharge to the upstream reach of the NFMN. The downstream reach consists of two 36-inch parallel force mains that extend from the Bitter Point Pump Station to a discharge structure within OCSD's Treatment Plant 2 where flow gravities to the Plant's headworks structure to begin treatment. The two lines are approximately 6,700 feet in length and cross beneath the Santa Ana River. These pipelines were designed to operate one duty, one standby to provide complete redundancy if a failure occurred.

The NFMN is an extremely important component in transporting wastewater to the treatment plant because it conveys all wastewater from Newport Beach and Corona Del Mar and travels parallel to the ocean, bays, harbors, and under major public areas. A failure in this force main, such as a leak or capacity reduction from an air or gas pocket, could pose a serious environmental hazard for the entire area served by the main as sewer leakage or a sanitary sewage overflow will pollute the soil, may cause a threat to drinking water systems, and can contaminate the ocean. The areas served by the NFMN also have some of the most valuable real estate properties in Orange County. Therefore, it is imperative for OCSD to ensure the NFMN is operating effectively.

Due to the significance of this collection system, OCSD has been replacing or rehabilitating many of the components within the NFMN over the past 10 years. Earlier versions of the Rocky Point and Bitter Point Pump Stations were replaced with the stations that are in operation today. Lido Pump Station's pumps were replaced to improve reliability. Valves within the upstream reach have been removed or replaced.

The force mains and gravity system downstream of the Bitter Point Pump Station were replaced. The systems pump station and force main operation were reconfigured from a single reach where all four pump stations operated in parallel to a two-reach configuration where the upstream reach operates in parallel until reaching Bitter Point Pump Station, where it operates in series. The force mains upstream of the Bitter Point Pump Station are to be rehabilitated and/or replaced in the future to ensure operability under all conditions.

Bay Bridge Pump Station, built in 1963, is the oldest of the four pump stations in the NFMN and has not yet been rehabilitated. The station is equipped with 2 – 250 horsepower (hp) (one duty, one standby) and 2 – 50 hp (one duty, one standby) centrifugal pumps as shown in Figure 6.

FIGURE 6. Bay Bridge Pump Station valves and discharge piping (Courtesy of OCSD).

The pumps are powered by variable frequency drives (VFD's) controlled by an early generation Programmable Logic Controller (PLC). As the wastewater level in the wet well rises or drops, the PLC selects the correct duty pump to start or stop and varies the pumps speed with the level in the wet well. If a duty pump fails, the standby pump will automatically take its place. The station was designed for 18.8 mgd at 63 feet of Total Dynamic Head (TDH) based on master plan flow projections and hydraulic models prior to its construction in the 1960's. Although future peak wet weather flow projections have remained the same, the projected TDH levels have proven incorrect and are much higher.

Rocky Point Pump Station is the newest of the pump stations that operate in parallel and was rehabilitated in 2011. Rocky Point is equipped with 4 – 55 hp (three duty, one standby) screw centrifugal pumps as shown in Figure 7.

FIGURE 7. Rocky Point Pump Station pumps with suction and discharge piping (Courtesy of OCSD).

The pumps are powered by VFD's controlled by the latest generation PLC. The lead pump starts and stops as the wet level rises and drops below set levels. The speed of the lead pump is varied by the PLC to maintain a constant wet well level that is set between the start and stop levels of the lead pump. The lag and standby pumps will start and stop based on the lead pumps speed. If influent flows increase, the lead pumps speed increases to maintain the wet well level. Should the lead pumps speed increase above set levels, the PLC will start the lag pumps to match and vary with the lead pumps speed to maintain the specified wet well level. Once started, the lag pump(s) will stop as the lead pumps speed decreases below set levels. If any duty pump fails, the standby will automatically take its place. The station was designed for 6.5 mgd at 40 feet of TDH based on the latest strategic plan flow projections and hydraulic models of the current network configuration.

Lido Pump Station, constructed in 1999, was the first OCSD pump station whose control logic is based on maintaining a constant wet well level. The station is equipped with 3 – 75 hp (two duty, one standby) centrifugal pumps as shown in Figure 8.

The two duty pumps are powered by VFD's controlled by the latest PLC of the time. The standby pump is driven by a constant speed motor. The lead pump starts and stops as the wet well level rises or drops below set levels. The speed of the lead pump is varied by the PLC to maintain a set wet well level and the set point is between the start and stop levels of the lead pump. The lag pump will start and stop based on the lead pumps speed. If the influent flow increases, the lead pumps speed will increase to maintain the wet well level. Should the lead pumps speed increase above set levels, the PLC will start the lag pump and match and vary the lead pumps speed to maintain the wet

FIGURE 8. Lido Pump Station pumps (Courtesy of OCSD).

well level. Once started, the lag pump will stop as the lead pumps speed decreases below set levels. Should any duty pump fail, the standby will automatically take its place. Since this standby pump operates as constant speed, the station undergoes a fill and draw operation. The station was designed for a flow of 5.5 mgd at 40 feet of TDH based on the strategic plan flow projections and hydraulic model of the force main configuration at that time.

Bay Bridge, Rocky Point, and Lido Pump Stations discharge into the upstream reach of the NFMN. The reach's two pipelines stretch approximately 15,000 feet between Bay Bridge and Bitter Point Pump Stations. The two lines, north and south, differ in profiles, pipe sizes, materials of construction, and years of service. The profiles differ in that the northern line has 7 peaks and valleys, while the southern line has 2. The northern line also has 4 manual vents and 1 drain, while the southern line contains none.

The north force main consists of pipelines with nominal diameters varying between 22 and 36 inches and have been in service between 1 year and 29 years. The material of the pipe is High Density Polyethylene (HDPE) or ductile iron lined with cold tar epoxy, cement mortar, or Poly-bond. The south force main consists of pipelines with nominal diameters varying between 20 and 36 inches and have been in service between 14 and 28 years. The material of the pipe is either HDPE or ductile iron lined with cold tar epoxy, cement mortar, poly-bond, or ceramic epoxy. The north force main is 13,807 feet long while the south force main is 14, 515 feet long. Hydraulic models have indicated a 40 north – 60 south flow split between the two force mains, but visual inspection of the discharge point indicates there is a larger flow split. OCSD is currently in the middle of a project to assess the physical condition and the hydraulic performance of the ductile iron pipes in the upstream reach. In addition to visible inspection, the assessment has included a new technology based on acoustic sensors. The sensors are embedded in a device shaped as a ball, called "Smartball", which is inserted into the pipeline and is carried along with the flow. As the ball travels, it generates acoustic signals that detect leaks and gas pockets at several locations along the pipeline. The tests conducted by OCSD discovered no leaks, but several gas pockets were found.

The Bitter Point Pump Station is OCSD's newest pump station and was completed in 2012, as shown in Figure 9.

The station was designed for 39.4 mgd at 68 feet of TDH based on the latest strategic plan flow projections and hydraulic models for the downstream force mains. The pump station is equipped with five 150 hp screw centrifugal pumps that operate 4 duty, 1 standby. The pumps are powered by VFD's controlled with the latest generation

FIGURE 9. Bitter Point Pump Station in Newport Beach (Courtesy of OCSD).

PLC. The lead pump starts and stops as the wet well level rises and drops below set points. The speed of the lead pump is controlled by the PLC to maintain a set wet well level and the set point is between the start and stop levels of the lead pump. The lag and standby pumps will start and stop based on the lead pumps speed. As the influent flows increases, the lead pumps speed is increased to maintain the wet well level. If the lead pumps speed increases above set levels, the PLC will start the lag pumps and match and vary the lead pumps speed to maintain the desired wet well level. Once started, the lag pumps will stop as the lead pumps speed decreases below set levels. Should any duty pump fail, the standby pump will automatically take its place. The wet well level is measured by a sonic level transmitter that sends a proportional signal to the PLC. A second sonic level transmitter equipped with contacts serves as a backup to the PLC/lead level transmitter. Should either the primary level transmitter or the PLC fail and the wet well continues to rise, the backup will operate the pumps in a fill and draw manner at their rated speed until the PLC or primary level transmitter is returned to operation. If power failure is experienced at the station, OCSD will activate an emergency procedure at the upstream pump stations where the operational wet well levels are remotely reset to higher levels. The upstream stations will store additional wastewater in order to provide more time to get the Bitter Point Pump Station operating. This emergency operation is employed to reduce the risk of sanitary sewer overflows.

The downstream reach of OCSD's NFMN were the force mains of concern for this study. The two parallel force mains travel 6,745-feet from the Bitter Point Pump Station to OCSD's Treatment Plant 2 in Huntington Beach. The force mains discharge into a drop structure from which flows gravity to the Plant's headworks. Figure 10 shows the force main manifold and east and west force mains within the station before leaving the station and traveling underground to Plant 2.

FIGURE 10. East and west force mains (Courtesy of OCSD).

Pipe sizes and materials of construction vary along the length of the two force mains. The force mains inside the station are 36-inch internal diameter steel. Once outside the station walls, the west force main is High Density Polyethylene (HDPE) pipe with an internal diameter of 36.8 inches for approximately 200 feet. The next 4,825 feet are fusible Polyvinyl Chloride (PVC) pipe with an internal diameter of 36.4-inches. The last approximately 1,730 feet of pipe is made of HDPE with a 36.8 internal diameter. Once outside the pump station, the east force main is HDPE pipe with an internal diameter of 36.8-inches for 6,745 feet from the station to the discharge structure.

Each force main is equipped with combination air valves. The west force main has two air valves while the east has four air valves. Each force main has an air valve placed inside the Bitter Point Pump Station and another just prior to diving beneath the Santa Ana River. The two remaining air valves on the east force main are located along the pipe between the station and the river. The 4-inch diameter air valves inside Bitter Point Pump Station are shown in Figure 11.

The two 3-inch air valves placed intermediately on the pipeline between the Bitter Point Pump Station and the Santa Ana River are shown in Figure 12.

The intermediate combination air valves are placed to the side of the force main. A manway was constructed on the pipeline forming a high point for air to collect. Air valve piping is connected from the manway to the air valves as shown in the Record Drawing in Figure 13 to aid in the release and admission of air into the pipeline.

Once the pipeline reaches the Santa Ana River, there are 2-45 degree bends so the pipeline runs perpendicular to the ground surface. The 4-inch combination air valves are

FIGURE 11. 4-inch air valves on east and west force mains (Courtesy of OCSD).

FIGURE 12. 3-inch intermediate air valve (Courtesy of OCSD).

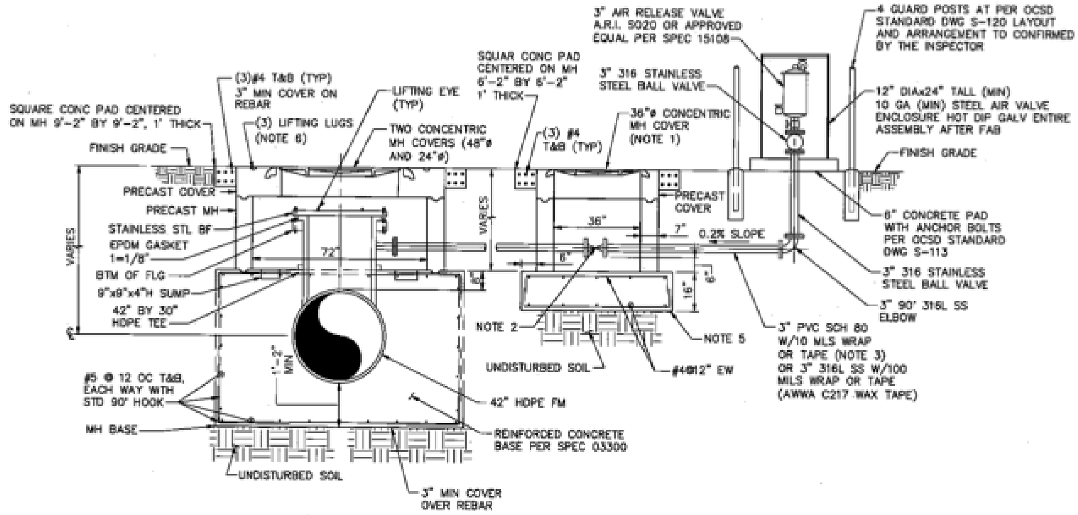


FIGURE 13. Air valve and manway configuration (Courtesy of OCSD).

installed directly above where the pipelines run perpendicular to the ground surface as shown in the Record Drawing reported in Figure 14.

These air valves are manufactured by A.R.I. and are model D-020 combination air valves. The force main goes under the river and comes back up and enters OCSD’s vortex structure where the wastewater returns to gravity in Plant 2 and will ultimately be treated and released to the ocean.

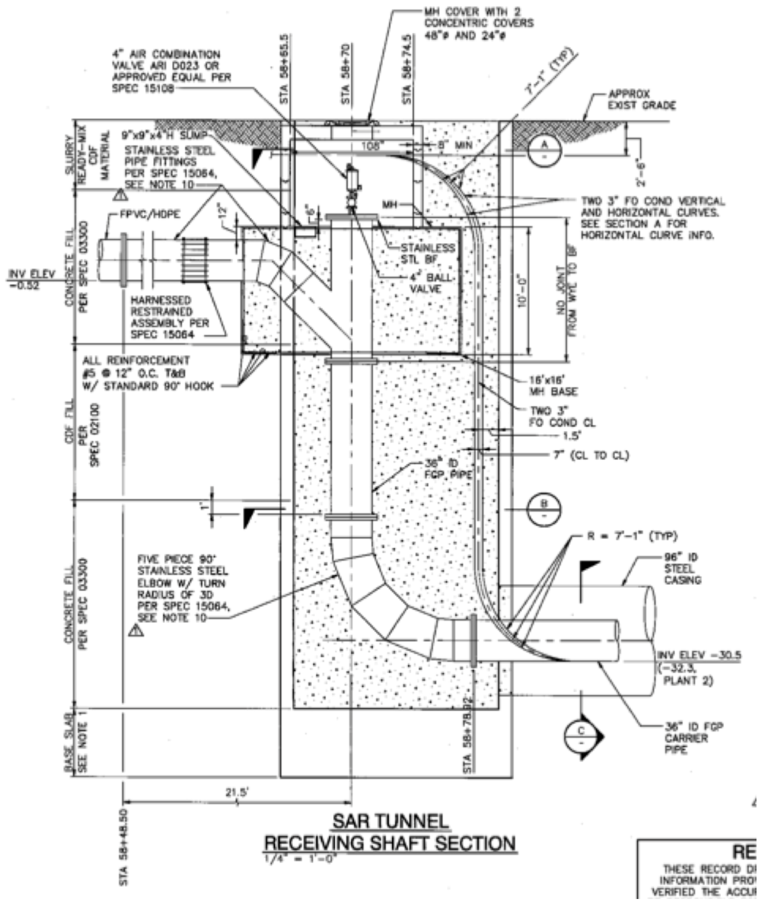


FIGURE 14. Air valve and piping configuration prior to Santa Ana River (Courtesy of OCSD).

CHAPTER 4

FIELD TESTING METHODOLOGY

The field studies described in this chapter focus on the hydraulic performance of entrapped air and gas pockets in the pressurized sewer pipelines that connect the Bitter Point Pump Station to OCSD's Plant 2. As highlighted in Chapter 2, most studies dealing with air entrapment in sewer mains were either based on experiments in highly controlled facilities or on numerical simulations. Both approaches involve considerable simplifications that often do not reflect actual field conditions. Because little information is available that pertains to field scenarios, field test protocols were developed in collaboration with the OCSD engineers.

The following tests were performed: low flow test, high flow test, low to high flow test, high to low flow test, and two tests where compressed air was injected into the pipeline. Each test, except for the compressed air tests, were performed once with the air valves open and once with the air valves closed.

For each field test, the following data was collected each minute from OCSD's Supervisory Control and Data Acquisition (SCADA) system: wet well level, discharge flow in million gallons per day (mgd), force main manifold pressure (psi), and pump speed for all 5 pumps at the pump station. Normal operating data for the pump station was provided to compare the test results with what is normally experienced at the station. The field tests were run on the east force main, which is the force main typically in operation, because it had more air valves to admit air in during the tests run with the air valves open. The purpose of performing each test with the air valves open and the air valves closed was to determine if there were any pressure or flow differences that occur when the air cannot escape through air valves, allowing an air pocket to develop and possibly decrease the capacity of the pipeline. OCSD's operators were located at each air valve on the pipeline and would manually close them, so the pipeline would act as though no air valves existed. The purpose of each field test and methodology used to perform the tests are described below.

Low Flow Tests

The low flow tests were performed to monitor the changes in flows and pressures when the air valves were open and when the air valves were closed. The flows and pressures from these tests could be compared to the normal operating data and the high to low flow and low to high flow test results to determine if an air pocket existed. The low flow tests were run for about an hour and fifteen minutes at a flow between 7 to 8 mgd. It takes approximately an hour and fifteen minutes for the wastewater to travel from the pump station to the Plant at the specified low flow.

The tests were run to ensure that the pipeline was flushed once through at the desired flow. One pump was operated between 56% and 60% speed in order to hold a steady flow between 7 and 8 mgd. Because this station is fed by three other pump stations, as well as its own service area, some wastewater had to be stored at other pump stations in order to avoid overloading Bitter Point's wet well.

High Flow Tests

The high flow tests were performed to monitor changes in flows and pressures with the air valves open and air valves closed. The flows and pressures from these tests could be compared to the high to low flow and low to high flow test results to determine if an air pocket existed and was possibly pushed out by the higher flow.

The high flow tests were run for about fifteen minutes with a targeted flow rate between 37 and 38 mgd, which corresponds to the pump station design flow. It takes approximately fifteen minutes for the wastewater to travel from the pump station to the Plant at the specified high flow. Four to five pumps were operated at 100% speed in order to obtain a flow between 37 and 38 mgd. It was more difficult to control the flows with four to five pumps running so flows fluctuated above and below the targeted high flows at numerous times throughout the tests. In order to run the pumps at the design flow for approximately fifteen minutes, all four pump stations in the NFMN were shut down, and wastewater was stored to the high wet well levels. Once each stations wet wells were full, Bitter Point started the pumps and gradually reached 37 to 38 mgd. The amount of flow sent to Bitter Point from the other three pump stations was coordinated depending on the flow required at the station to complete the test.

Low to High Flow Tests

The low to high flow tests were performed to monitor the flow and pressure variations with the air valves open and air valves closed. The flows and pressures from these tests could be compared to the normal operating data, high to low flow, low flow, and high flow test results to determine if an air pocket existed during the lower flow portion of the test that was possibly pushed out by the higher flows towards the end of test.

The low to high flow tests were run for between 40 and 70 minutes at a flow that varied from 7 mgd to 38 mgd. The tests were designed for the flow to increase about 1 mgd per minute, but sometimes the flows were increased at a slower rate depending on the pump station controls. The test began with one pump running at approximately 50% speed, and increasing the speed and the number of operating pumps gradually over the duration of the test until all four pumps were operating at 100% speed to obtain the high flow. In order to run the test for approximately thirty minutes, all four pump stations in the NFMN were shut down, and wastewater was stored to the high wet well levels in order not to run out of water. Once each stations wet wells were full, Bitter Point started the pumps and gradually increased the flow from 7 mgd to 38 mgd. The amount of flow sent to Bitter Point from the other three pump stations was coordinated depending on what flow rate the station needed to complete the test.

High to Low Flow Tests

The high to low flow tests were performed to monitor the flow and pressure variations with the air valves open and air valves closed. The flows and pressures from these tests could be compared to the normal operating data, low to high flow, low flow, and high flow test results to determine if an air pocket developed when low flows were experienced.

The high to low flow tests were run for about thirty minutes at a flow that varied from 38 mgd to 7 mgd. The tests were designed for the flow to decrease about 1 mgd per minute. The test began by gradually increasing from one pump to four pumps at 100% speed till 38 mgd was reached. Once the high flow was reached, the pump speeds and the number of operating pumps were gradually decreased over the thirty minute duration of the test until only one pump was running at approximately 55% speed to obtain the low flow. In order to run the test for approximately thirty minutes, all four pump stations in the NFMN were shut down, and wastewater was stored to the high wet well levels in order not to run out of water. Once each stations wet wells were full, Bitter Point started the pumps and gradually increased to 38 mgd and then gradually decreased down to 7 mgd. The amount of flow sent to Bitter Point from the other three pump stations was coordinated depending on what flow rate the station needed, mainly at the beginning of the test. By the end of the test, since the flows were very low, the three pump stations that feed Bitter Point, were storing wastewater so not to overload Bitter Point's wet well.

<u>Compressed Air Tests</u>

The compressed air tests were performed to monitor the system when a large quantity of air was present in the pipeline. In order to fill a portion of the pipeline with air, the air valves were closed, and an air valve within the pump station was removed so air could be injected through that port as shown in Figure 15.

FIGURE 15. Air injection port (Courtesy of OCSD).

While the pipeline was being filled with air, the wastewater was redirected through the parallel, west force main that is typically used for backup. Once the tests were ready to be run, the force main operations were switched, so the test could be run through the pipeline with no air valves. The flows and pressures from these tests could be compared to the normal operating data and all other field test results to observe the effect air has on the force main system.

The compressed air tests were run for about an hour with flow increasing from about 7 mgd to 38 mgd. Flows were increased slowly, depending on what the system was experiencing from the compressed air. The test began by gradually increasing from one pump operating at about 75% speed to four pumps at 100% speed till 38 mgd was reached. The pumps had to be started at a higher speed because the check valve would not open at the lower speeds due to the increased pressure from the compressed air in the pipeline. In order to run the test, all four pump stations in the NFMN were shut down, and wastewater was stored to the high wet well levels in order not to run out of water. Once each stations wet wells were full, Bitter Point started the pumps and gradually increased the flow from 7 mgd to 38 mgd. The amount of flow sent to Bitter Point from the other three pump stations was coordinated depending on the flow rate required at the station.

CHAPTER 5

RESULTS

The results from the field tests are reported in this chapter. Flow and pressure data are plotted versus time for all field test conditions under the valve settings described in the previous chapter. Normal operating conditions that show typical flow and pressure relations demonstrate that as the flow increases, the pressure increases in the same manner as displayed in Figure 16.

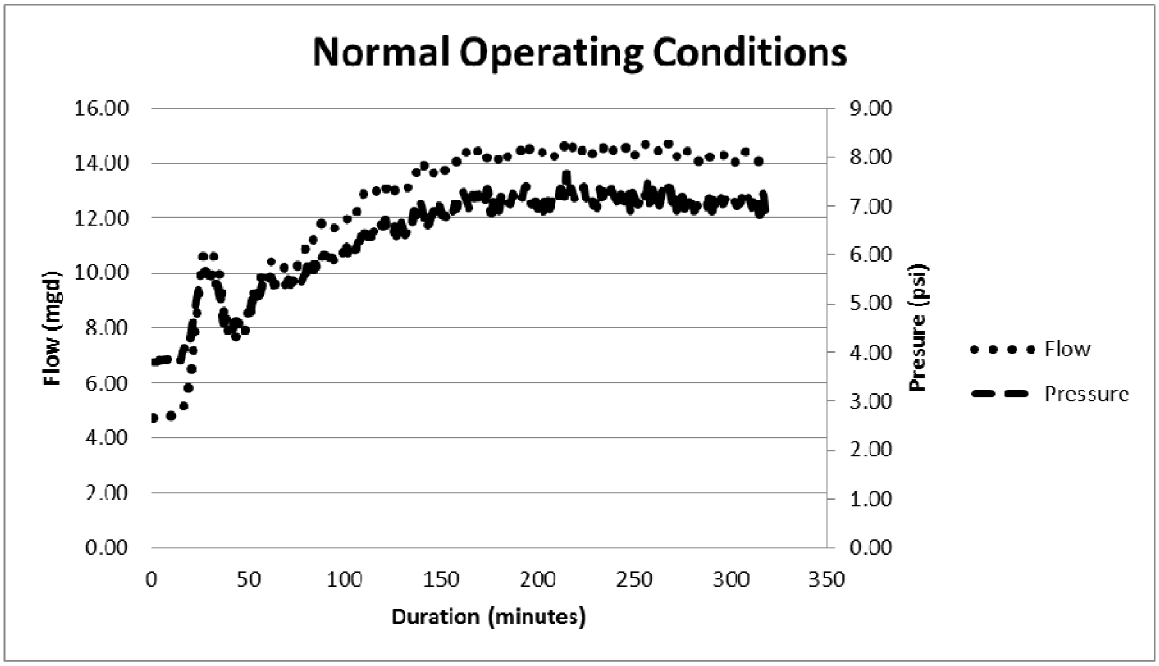


FIGURE 16. Normal operating flows and pressures.

Low Flow Test

The low flow test with air valves open was run for approximately 75 minutes with a flow set between 7 and 8 mgd. The pressure during this test increased from approximately 6 psi to about 18 psi in the first 20 minutes of the test. After that interval of time, the pressure remained steady just above 18 psi for the remainder of the test. The flow and pressure variations are illustrated in Figure 17 below. The pipeline does not flow full at flow rates below approximately 20 to 25 mgd and air enters the pipeline to fill the head space through the air valves until the pressure reaches a full pipe flow pressure that occurs somewhere around 18 psi and is likely what occurred during the air valves open test. The pump speed was increased slowly for the first 25 minutes of the test from approximately 60 to 80 percent to overcome the increase in pressure occurring from the air entering the pipeline through the air valves. Once the system was in equilibrium, with a constant pressure of 18psi, the pump speed no longer had to be increased and remained steady at approximately 80 percent speed. This flow only occurs about 6 hours each day during normal operation and typically occurs during fill and draw operation where the pumps cycle on and off. Due to the short time span during which the system operates at these low flow rates under normal operating conditions, the increase in pressure observed in the low flow test where the low flow was maintained for a long period of time cannot be observed under normal operation.

The low flow test with air valves closed was run for approximately 75 minutes with a flow between 7 and 8 mgd. The pressure during this test remained constant throughout at about 4.5 psi. The flow and pressure trends during this field test are illustrated in Figure 18. The low flow test with air valves closed experienced a steady

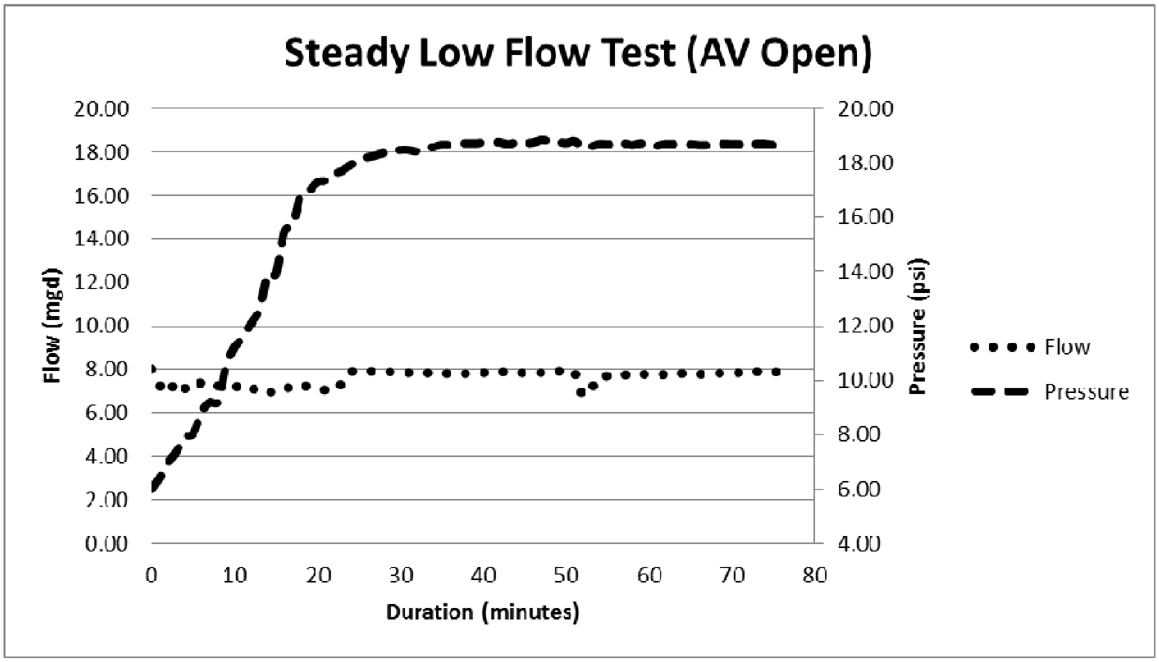


FIGURE 17. Steady low flow test results with air valves open.

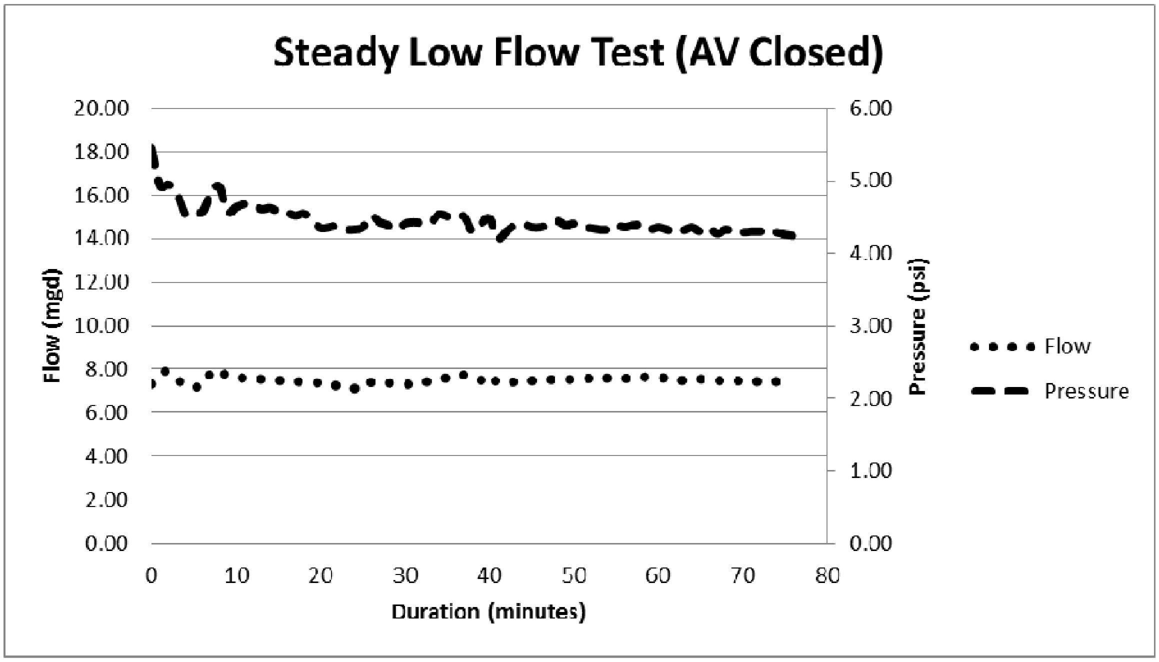


FIGURE 18. Steady low flow test results with air valves closed.

pressure around 4.5 psi as should be experienced during a steady flow and the pressure is similar to the pressure at 7 mgd during normal operation.

The pressure data collected during the steady low flow tests with air valves open and air valves closed illustrate a different system behavior. During the low flow test with valves open, air entered the pipeline through the air valves. The pressure increase noticed in the system however is not due to air pocket formation, but is the result of normal functioning of the air valves that are expected to admit air into the system during low flow to prevent a vacuum from forming. Because the low flow test with air valves closed experienced pressures similar to what are experienced during normal operation we concluded that air pocket formation likely did not occur.

High Flow Test

The steady high flow test with air valves open was run for approximately 13 minutes with flow varying between 36 and 44 mgd. The flow and pressure trends for the steady high flow test with air valves open are illustrated in Figure 19 below. The variation in flow observed at the beginning and at the end of the test are due to pump settings. Initially we had four pumps running simultaneously, then we added a fifth pump, which was later shut down and the system returned to four pumps operating simultaneously. Accordingly, the pressure remained steady at about 27 psi during the period in which the flow was steady and experiences fluctuations at the beginning and end of the test.

The steady high flow test with air valves closed was run for approximately 17 minutes with flow varying between 37 and 39 mgd. The pressure remained fairly steady

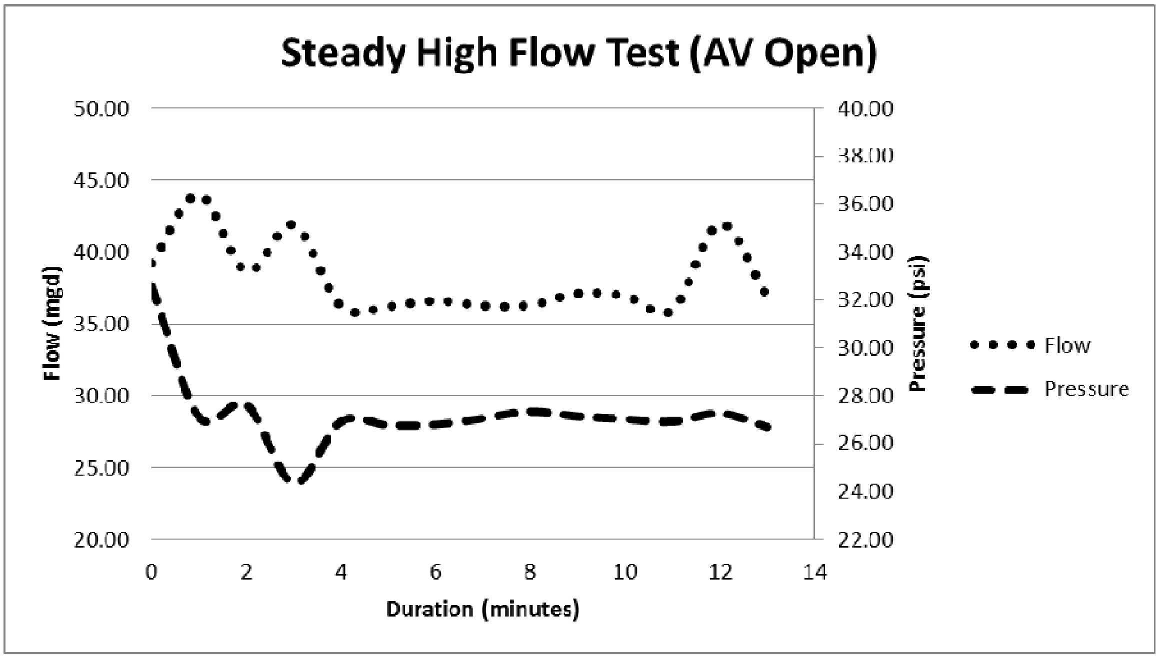


FIGURE 19. Steady high flow test results with air valves open.

between 24 and 26 psi. The pressure and flow trends for this test are illustrated in Figure 20 below.

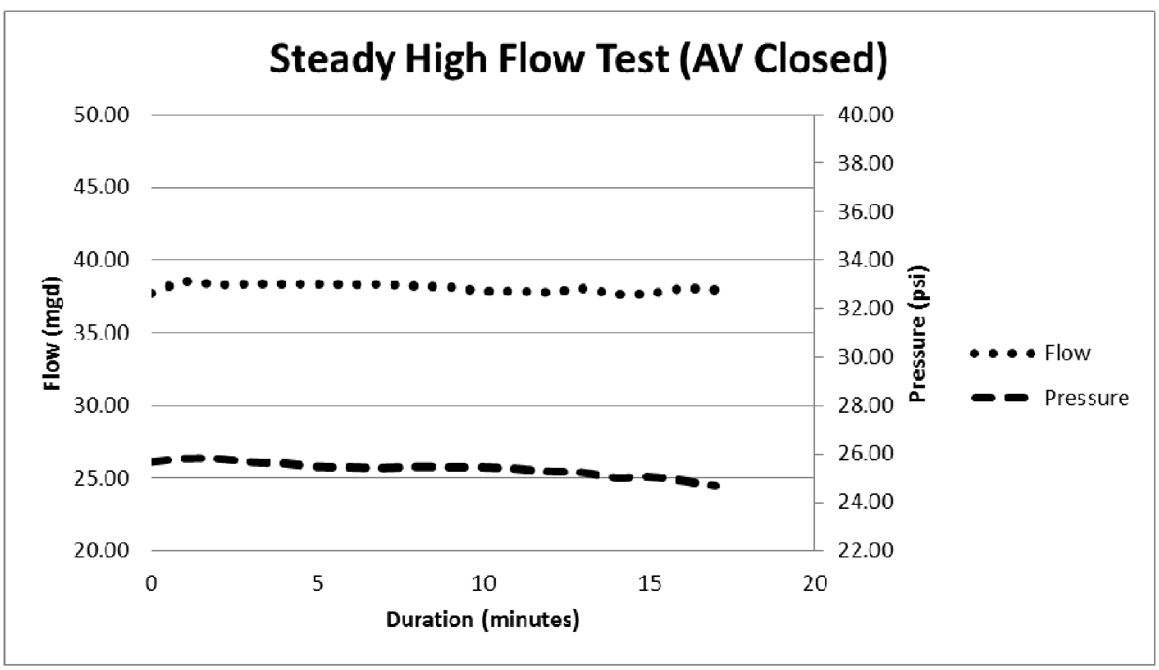


FIGURE 20. Steady high flow test results with air valves closed.

The pressures during the air valves open and air valves closed tests were similar around 24 to 27 psi indicating that air pockets did not exist in the pipeline and none were pushed out because a significant pressure decrease was not observed. The force main and pumps do not typically operate at flow rates above 15mgd, so data pertaining to normal operating conditions for the pressure values recorded during the test are not available for comparison.

Low to High Flow Test

The low to high flow test with air valves open was run for approximately 70 minutes with a flow varying from about 7 mgd to about 38 mgd. As the flows increased, so did the pressures. The flows fluctuated during certain portions of the test because the system was being operated as it would during normal operation where when a second pump was started, the lead pumps speed was decreased to the minimum speed and then both pumps speeds were increased together. This method was used for starting the third and fourth pumps as well. The pressure increased from approximately 5 psi at 7 mgd to approximately 27.5 psi at 38 mgd. Values of flow and pressure recorded during this test are illustrated in Figure 21 below. The increasing trend of the pressure with the flow increase is expected and follows the same pattern as the normal operating data provided. The pressures values of up to 14 mgd recorded in the test are similar to the pressures measured during normal operating conditions.

The Low to High flow test with air valves closed was run for approximately 40 minutes by varying the flow from about 7 mgd to 38 mgd. The flows and pressures

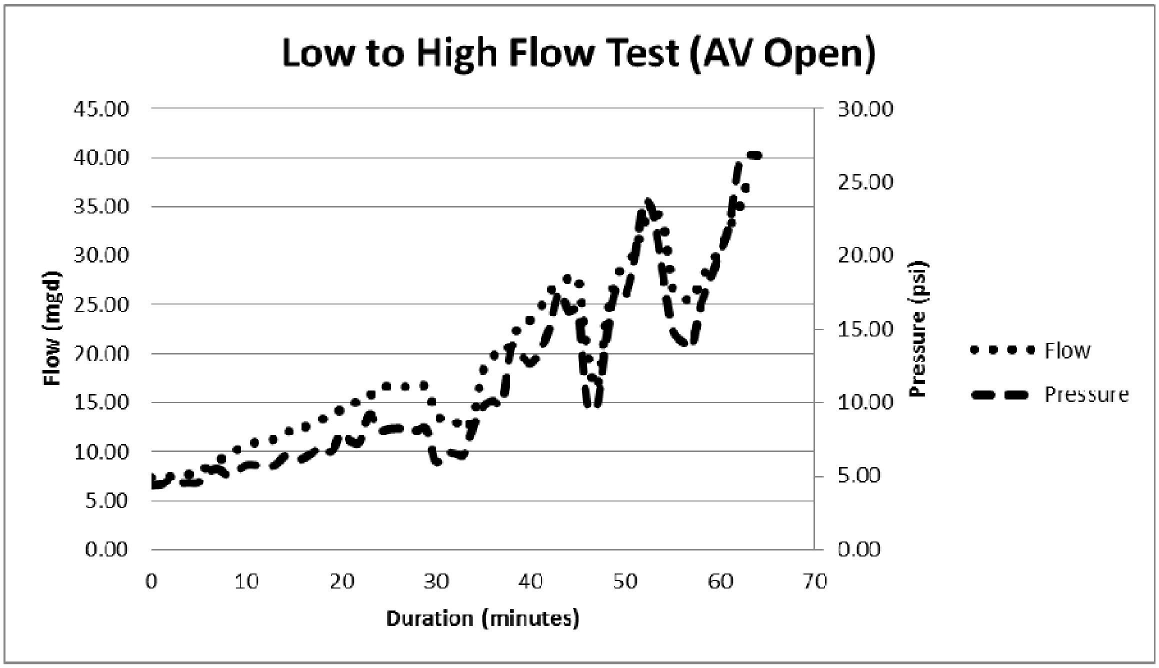


FIGURE 21. Low to high flow test results with air valves open.

increased in the same manner as the Low to High flow test with air valves open and from approximately 5 psi to approximately 27.5 psi. The flow and pressure values recorded during the test are illustrated in the Figure 22. The expected increase of pressure with flow increase follows the same trend observed during normal operating conditions.

Because the flows and pressures have a similar trend in the two configurations with the air valves open and air valves closed, the data indicates that air pockets did not exist in the pipeline and no air pockets were released at the higher flows because a significant decrease in pressure was not experienced.

High to Low Flow Tests

The High to Low flow test with air valves open was run for approximately 30 minutes. The flow decreased from approximately 38 mgd to about 7 mgd. As the flow decreased, so did the pressure. The pressure went from about 27.5 psi at 38 mgd to about

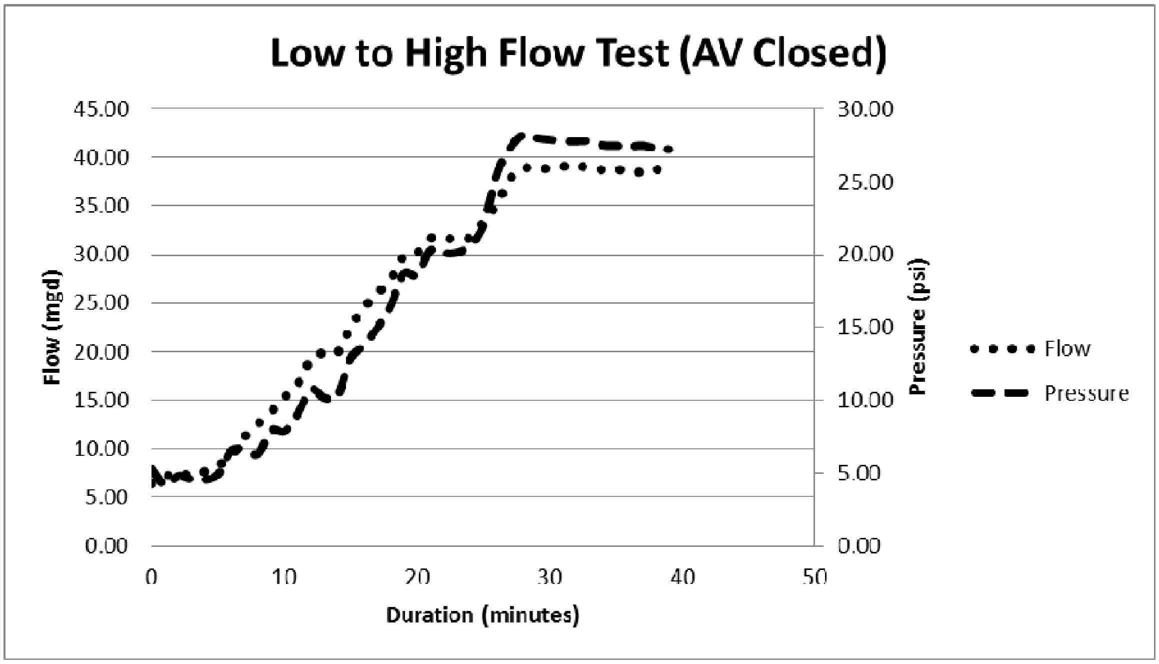


FIGURE 22. Low to high flow test results with air valves closed.

5 psi at 7 mgd. The flow and pressure trends were similar as illustrated in Figure 23. The decrease of pressure with the flow follows the same trend as shown in the normal operating data and the pressures are similar to those measured during normal operating flows.

The High to Low Flow test with air valves closed was run for approximately 30 minutes. The flows decreased in the same manner as the air valves open test from approximately 38 mgd to about 7 mgd. The pressure decreased from about 27.5 psi to about 5 psi, which is the same decrease reported during the the air valves open test, and is illustrated in Figure 24 below. The pressures follow the decreasing pattern of the flow similar to the observed normal operating pattern in Figure 16.

Because the flows and pressures were almost identical for the two configurations of air valves open and air valves closed, the data indicates that air pockets did not exist in

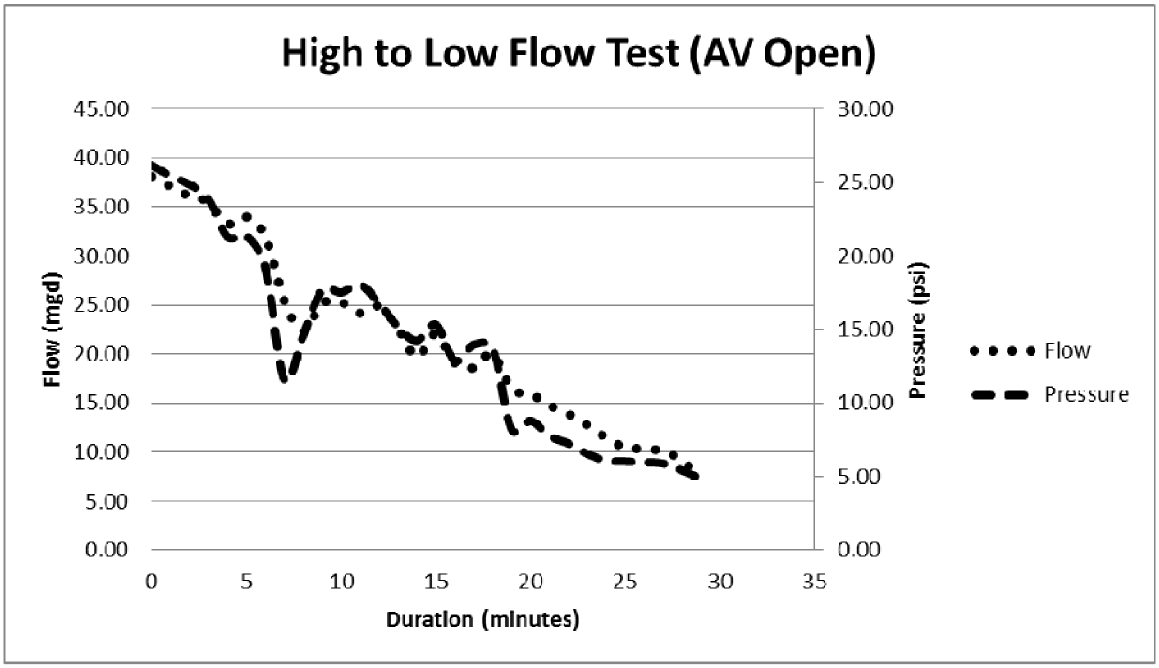


FIGURE 23. High to low flow test results with air valves open.

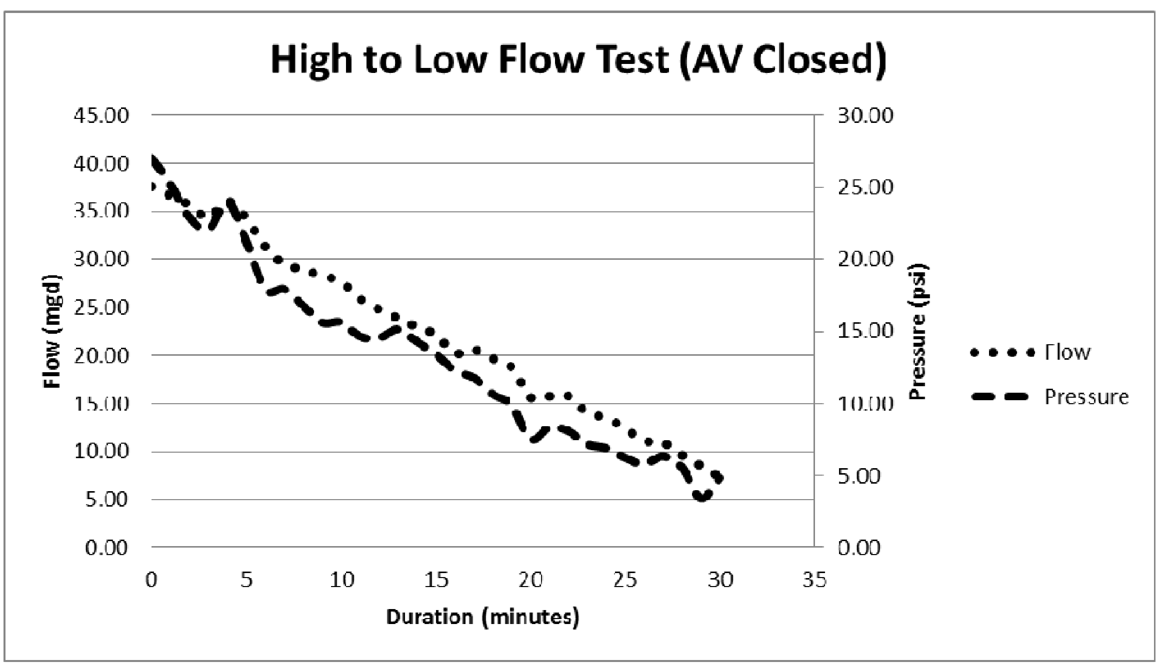


FIGURE 24. High to low flow test results with air valves closed.

the pipeline and none developed because there was not a pressure increase when the flows were decreasing. The same pressures were experienced at the same flows during both low to high flow tests further indicating air pockets were not present during any of the high to low flow or low to high flow tests.

Compressed Air Tests

The first compressed air test was performed on October 12th and ran for approximately one hour. This test was performed to understand and observe how the system would be affected and react if a large amount of air was injected into the pipeline. For all other field tests, the first pump started at 50% speed, but for the compressed air test, the pump speed required to open the check valve was 75%. This increased pump speed was required because the manually injected air increased the pressure in the pipeline. Once the check valve was open, there was a flow output of about 7.5 mgd. The pressure experienced in the pipeline at 7.5 mgd during all other field tests was about 5 psi, while the compressed air tests pressure started at approximately 15 psi. The additional 10 psi experienced in the pipeline resulted in the increased pump speed of 75% to obtain the flow output of 7.5 mgd. The flow was steadily increased for about 10 to 15 minutes to approximately 13 mgd when a large flow increase was suddenly experienced and a large pressure drop was observed. A large air pocket, in the form of a slug, was likely swept through the system and released into OCSD’s vortex structure and ultimately into the atmosphere. The flow increased dramatically from about 13 mgd to about 26 mgd in 4 minutes without any adjustments to the pump controls. The pressure dropped from about 21 psi to about 3 psi within 4 minutes without any adjustments to the pump controls as well. Within 5 minutes of the slug release, Plant staff communicated a large burst of odor was experienced at the Plant. This odor likely occurred because the air was in the line for several hours causing septic conditions to occur and possible hydrogen sulfide gas to form. The flow was decreased manually by adjusting the pump speeds to prevent overloading Plant 2 with a large amount of flow. The system was run steady for about 10 minutes at about 15 mgd before increasing the flow again. After the slug was released and the system recovered after about 5 minutes, the pressure increased to about 21 psi, which is where the pressure was prior to the slug release. As the flow was increased from about 15 mgd to 30 mgd, the pressure increased above what was normally experienced in the other field tests. At about 30 mgd, another pressure drop occurred from about 27 psi to 22 psi. Another air pocket, likely much smaller than the first, was released from the system at which point the system operation returned to nearly normal operating flows and pressures. The flow and pressure data for this compressed air test are reported in Figure 25.

The second compressed air test was conducted on October 19th and ran for approximately 65 minutes. At a pump speed of 50 percent, the check valve opened with a flow output of about 3 mgd. Similar to the compressed air test performed on October 12th, the pump speed was about 70 percent at a flow of 7.5 mgd. The pressure was about 10 psi greater than what was experienced during all other field tests at 7.5 mgd, showing a behavior similar to the one observed during the October 12th compressed air test. The flow was steadily increased for about 20 minutes to approximately 15 mgd when a large flow increase was experienced and a large pressure drop observed. A large air pocket, in the form of a slug, was likely swept through the system and released into OCSD's vortex structure and ultimately into the atmosphere. The flow increased dramatically from about

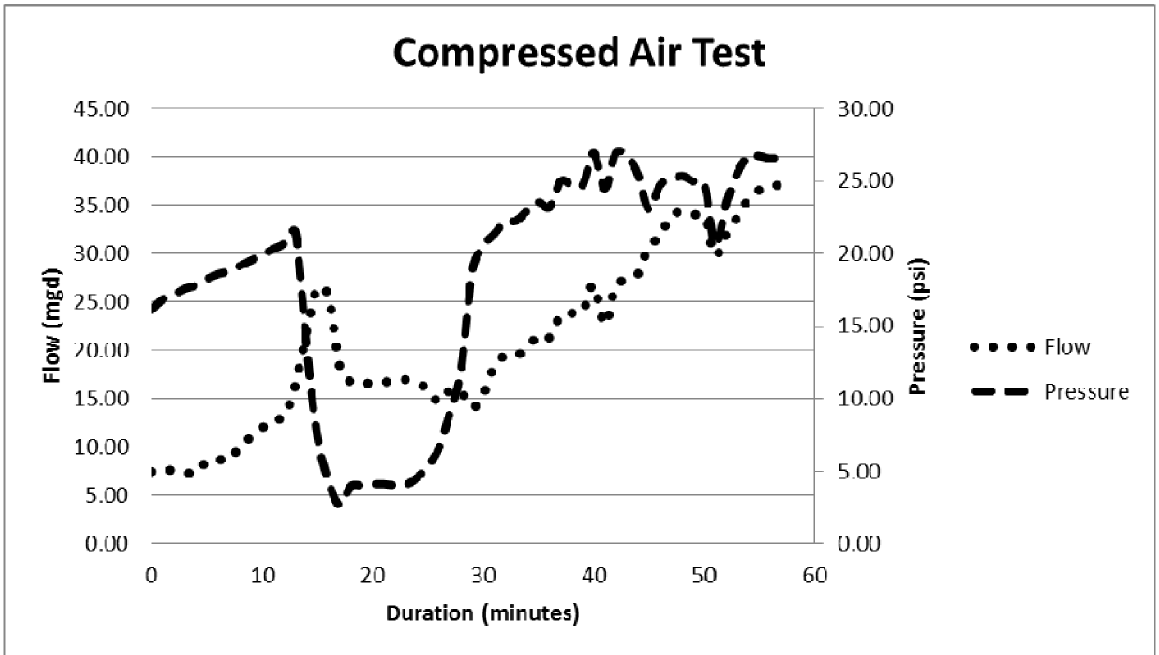


FIGURE 25. October 12th compressed air test results.

15 mgd to about 27 mgd in 4 minutes without any adjustments to the pump controls. The pressure dropped from about 21 psi to about 3 psi within 4 minutes without any adjustments to the pump controls as well. The flow was decreased manually by adjusting the pump speeds to prevent overloading Plant 2 with a large amount of flow. Soon after the slug release, Plant staff communicated that the vortex structure lid had blown off. This was likely due to the large amount of air being pushed through the system and being abruptly released when exiting the pressurized system. The system was run between 10 and 20 mgd for about 10 minutes before increasing the flow again. After the slug was released and the system recovered after about 5 minutes, the pressure increased to about 25 psi, just a few psi higher than prior to the slug release. As the flow was increased from about 15 mgd to 30 mgd, the pressure increased above what was normally experienced in the other field tests. At about 30 mgd, multiple, smaller pressure drops

occurred from about 27 psi to 21 psi. Possibly a few more smaller air pockets were released from the system at which point the system operation returned to nearly normal operating flows and pressures. The flows and pressures experienced during this compressed air test are illustrated in Figure 26.

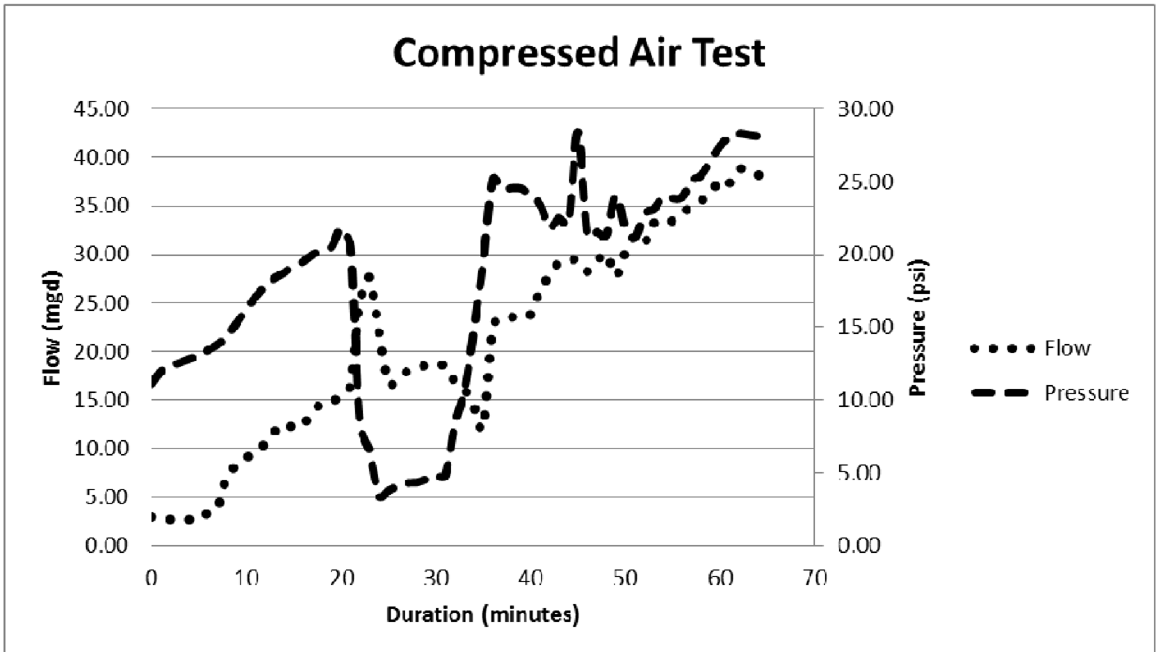


FIGURE 26. October 19th compressed air test results.

The compressed air tests experienced similar flow and pressure changes. These tests showed that the Bitter Point Pump Station and the force main network flows and pressures were significantly affected by the large quantity of air in the pipeline. The tests indicate that the system can release large air pockets from the system under design conditions. The amount of air injected into the system would likely never be experienced, but the system is capable of hydraulically ejecting a large amount of air.

CHAPTER 6

HYDRAULIC CALCULATIONS

This chapter describes the hydraulic calculations performed in EXCEL using the data collected during the compressed air tests to determine (1) the approximate effective flow area reduction and (2) the increased friction factor. The Hazen-Williams equation was used to determine the friction losses in the pipeline and all bend and appurtenant losses were included as well. According to the Hazen-Williams equation, the head loss, h, in a pipeline can be expressed as:

$$h = .002083 \left(\frac{100}{C}\right)^{1.85} \frac{q^{1.85}}{d^{4.8655}} L \qquad (6\text{-}1)$$

where: h [ft] is the head loss, C [-] is the Hazen-Williams coefficient that depends on the pipe material, q [gpm] is the flow, d [in] is the diameter of the pipe, and L [ft] is the length of the pipe.

Reduced Effective Flow Area

To calculate the resulting reduction in flow area due to the presence of air, a Hazen-Williams coefficient of 120 was used for the HDPE while 100 was used for the steel. All minor loss coefficients were extracted from Jones et al. (2008). Detailed calculations showing lengths of pipe and number of bends and valves are presented in Appendix C.

The calculations were performed in 3 different segments: (1) full pipe flow from the Santa Ana River to the vortex structure in Plant 2, (2) decreased pipe flow from the

Santa Ana River to the pump station with HDPE pipe, and (3) decreased pipe flow from the pump station to the pressure transmitter with steel pipe. It was assumed that the full pipe flow was experienced from the Santa Ana River to Plant 2 because the buoyancy force of the air would prevent a stratified behavior from occurring in the vertical pipeline as described in Chapter 2. This portion of the force main likely traveled full until the large air slug was released from the system, then returned to full pipe flow. It is assumed that the entire pipeline from within the pump station to the Santa Ana River experienced a uniform, stratified layer of air on the top of the pipeline based on the large quantity of air injected and the amount of air that was released from the air valves after the test was completed.

Calculations were performed for flow rates prior to the slug release from the system. Data collected after the slug release was erratic and the Hazen-Williams equation would not apply. An iterative process was developed to determine the decreased effective flow area with respect to the full flow area. Flow rates and pressures were obtained directly from the field data and were used to calculate the reduced area that corresponded to the pressure head experienced during the Compressed Air field tests performed on October 12th and October 19th. We assumed the reduced flow area continued to be a full circular area with a reduced diameter as compared with the diameter of the pipe. This assumption is likely to produce overestimated area reductions and refined calculations that take into account the change in cross sectional shape generated by the air pocket should be performed.

Results from the calculations for the October 12th field test indicated that the flow area at the beginning of the test with a flow rate of 7.58 mgd was reduced to 30% of the pipe area. The increase in the flow rate resulted in an increase in the flow area during the test due to the compression of air. At 13.15 mgd, just before the air pocket was released, the flow area was 42% of full pipe area. The effective flow area grew larger as the flow rate increased until the air had no other place to go except under the river and to the vortex structure in Plant 2.

Results from the calculations for the October 19th field test show that the flow area was about 16% the full pipe flow area at the beginning of the test with a flow rate of 2.72 mgd. The increasing flow rate compressed the air and resulted in an increase in the flow area. At 15.48 mgd, just before the air pocket was released, the effective flow area was 50%.

Increased Friction

The increased friction, which results in a decreased Hazen-Williams Coefficient, from the air present in the pipeline was calculated to determine the additional friction experienced in the pipeline from the air. All minor loss coefficients were extracted from Jones et al. (2008). Detailed calculations showing lengths of pipe and number of bends and valves are presented in Appendix C.

The calculations were performed in 2 different segments: (1) 36.8-Inch Internal Diameter HDPE and (2) 36-Inch Internal Diameter Steel. Calculations were performed for flow rates prior to the slug release from the system. Data collected after the slug release was erratic and the Hazen-Williams equation would not apply. An iterative process was developed to determine the additional friction experienced in the system during the compressed air tests assuming full pipe flow or flow through the entire pipe area. Flow rates and pressures were obtained directly from the field data and Hazen-

Williams Coefficients were estimated in order to produce the friction losses observed during the Compressed Air field tests performed on October 12th and October 19th.

Results from the calculations for the October 12th field test determined the Hazen-Williams Coefficient at the beginning of the test with a flow rate of 7.58 mgd was reduced to 35. This is a very large decrease in the Hazen-Williams Coefficient where the system typically operates with a Hazen-Williams Coefficient of 120. This decrease in the Hazen-Williams Coefficient corresponds to the additional friction experienced in the system due to the presence of compressed air. The Hazen-Williams Coefficient increased throughout the test due the increasing flow rate that compressed the air. At 13.15 mgd, just before the air pocket was released, the Hazen-Williams Coefficient was increased to 50. The Hazen-Williams Coefficient increased as the flow rate increased due to the compression of the air. Results from the calculations for the October 19th field test determined the Hazen-Williams Coefficient at the beginning of the test with a flow rate of 2.72 mgd to be 16.5. This Hazen-Williams Coefficient is extremely low and the system experienced a large amount of friction. This Hazen-Williams Coefficient occurred when the flow area was only 16% the full pipe area which describes why the Hazen-William coefficient is so low. The Hazen-Williams Coefficient increased throughout the test due the increasing flow rate that compressed the air. At 15.48 mgd, just before the air pocket was released, the Hazen-Williams Coefficient increased to 60.

Both compressed air tests followed an upward trend for the effective flow area and the friction in the pipeline with respect to flow. The effective flow areas differed by about 2% and the Hazen-Williams Coefficient differed by up to 6 for corresponding flows likely due to the different amounts of air injected in the pipeline during the two tests. The effective flow area was reduced significantly for both tests, below 50% the full pipe flow area before a slug of air was released from the system. The Hazen-Williams Coefficient reduction was significant for both tests, below 56 before the slug release from the system where the system normally experiences a Hazen-Williams Coefficient of 120. This calculation only takes into account the friction experienced in the system and not the decrease in the flow area, so this Hazen-Williams Coefficient is not reflective of what was actually occurring inside the pipeline and an equation that utilizes both area and friction fluctuations would be more accurate.

Figure 27 shows the percent effective flow area and the Hazen-Williams Coefficient experienced with respect to the flow for the October 12th Compressed Air Test. As the flow increased, the effective flow area increased, and the Hazen-Williams Coefficient increased.

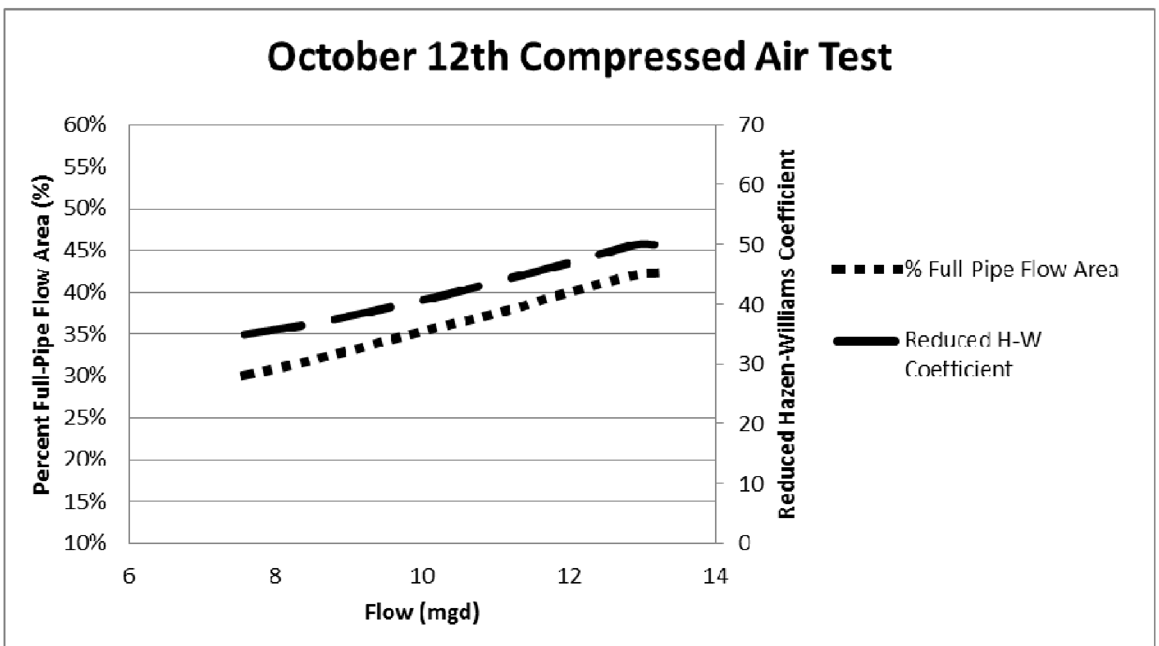


FIGURE 27. October 12th compressed air test effective flow area and H-W Coefficient.

Figure 28 shows the percent effective flow area and the Hazen-Williams Coefficient experienced with respect to the flow for the October 19th Compressed Air Test. As the flow increased, the flow area increased, and the Hazen-Williams Coefficient increased in the same manner as the October 12th Compressed Air Test.

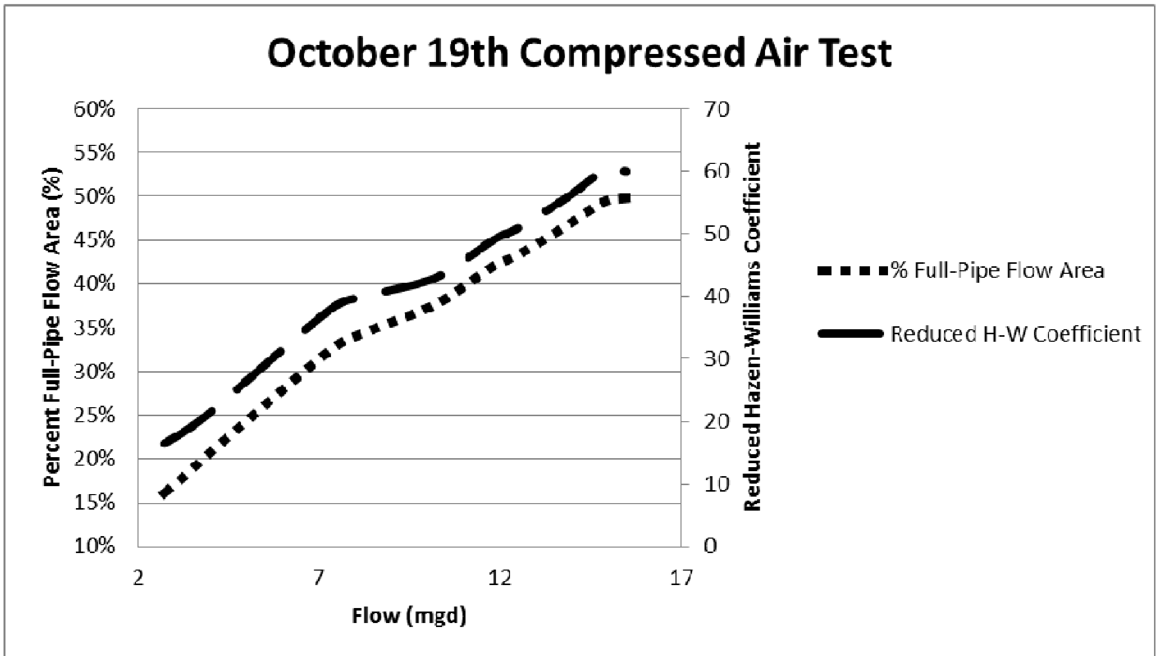


FIGURE 28. October 19th compressed air test effective flow area and H-W Coefficient.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE STUDIES

In this case study we performed several field tests to determine the presence of air pockets within sewage force mains and the response of the system. The field data collected from OCSD's SCADA system showed that under normal operating conditions the force main network from the Bitter Point Pump Station to OCSD's Plant 2 does not experience air pockets. OCSD's system likely does not experience air pockets because the air valves are placed on manways. These manways form high points within the force main system that do not affect the capacity of the pipeline. Tests performed by injecting pressurized air demonstrated that the force main system is capable of hydraulically releasing large amounts of air.

Hydraulic calculations were performed to determine the decrease in effective pipe flow area and the increased friction within the sewage force mains during the compressed air tests. The flow area decrease was substantial for both compressed air tests between 84 and 50 percent the full pipe area and the increased friction was significant experiencing Hazen-Williams Coefficients between 16.5 and 60. The force main system was capable of releasing these large quantities air that decreased the flow area and increased the friction.

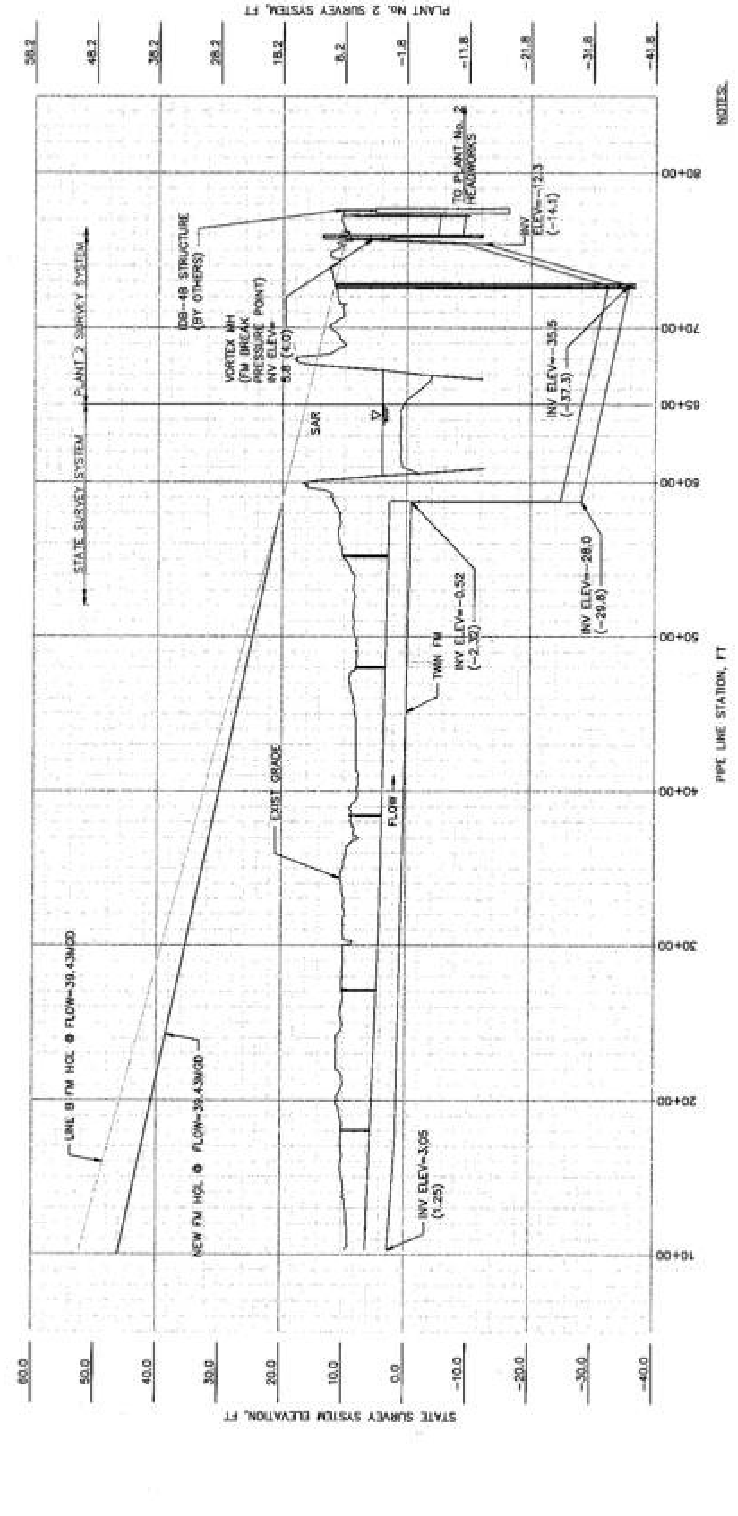
The Orange County Sanitation District should continue to research air pocket development in their force main networks, especially the Newport Force Main Network upstream of the Bitter Point Pump Station. The system is aging and many of the pipelines do not contain air valves at high points within the network allowing the system to be prone to air pocket development. The results from the Compressed Air tests indicate air pockets could be the cause of the flow decrease in the upstream reaches of the Newport Force Main Network and should be studied following a procedure similar to the one proposed in this study to determine if the flow decrease can be attributed to air pocket development. Future field tests should include data collection at numerous points along the pipelines of concern to determine the influence of air on the hydraulics at different points within the system.

Additional field test methods and simulation scenarios to determine the presence of air pockets in force main networks should be developed. Finally, a comprehensive model should be developed to simulate the system under several operating conditions in order to predict the performance response and to implement effective rehabilitation strategies.

APPENDICES

APPENDIX A

HYDRAULIC PROFILE


PLANT No. 2 SURVEY SYSTEM, FT
STATE SURVEY SYSTEM ELEVATION, FT
PIPE LINE STATION, FT
NOTES:
STATE SURVEY SYSTEM
PLANT 2 SURVEY SYSTEM
LINE B FM HGL @ FLOW=39.43MGD
NEW FM HGL @ FLOW=39.43MGD
EXIST GRADE
FLOW
TWIN FM
INV ELEV=3.05 (1.25)
INV ELEV=-0.52 (-2.32)
INV ELEV=-28.0 (-29.8)
INV ELEV=-35.5 (-37.3)
SAR
VORTEX MH (FM BREAK PRESSURE POINT) INV ELEV= 5.8 (4.0)
DB-48 STRUCTURE (BY OTHERS)
TO PLANT No. 2 HEADWORKS
INV ELEV=-12.3 (-14.1)
10+00
20+00
30+00
40+00
50+00
60+00
65+00
70+00
80+00
60.0
50.0
40.0
30.0
20.0
10.0
0.0
-10.0
-20.0
-30.0
-40.0
58.2
48.2
38.2
28.2
18.2
8.2
-1.8
-11.8
-21.8
-31.8
-41.8

APPENDIX B

FIELD TEST DATA

Normal Operating Data

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
1	9/28/2012 6:40	111.4	4.73	3.80	0.0	49.9	0.0	0.0	0.0
2	9/28/2012 6:41	110.7	4.73	3.80	0.0	49.9	0.0	0.0	0.0
3	9/28/2012 6:42	109.7	4.71	3.80	0.0	49.9	0.0	0.0	0.0
4	9/28/2012 6:43	108.8	4.70	3.85	0.0	49.9	0.0	0.0	0.0
5	9/28/2012 6:44	109.3	4.68	3.83	0.0	49.9	0.0	0.0	0.0
6	9/28/2012 6:45	111.4	4.73	3.85	0.0	49.9	0.0	0.0	0.0
7	9/28/2012 6:46	113.4	4.74	3.86	0.0	49.9	0.0	0.0	0.0
8	9/28/2012 6:47	114.3	4.79	3.85	0.0	49.9	0.0	0.0	0.0
9	9/28/2012 6:48	115.5	4.79	3.88	0.0	49.9	0.0	0.0	0.0
10	9/28/2012 6:49	115.5	4.81	3.86	0.0	49.9	0.0	0.0	0.0
11	9/28/2012 6:50	115.8	4.77	3.83	0.0	49.9	0.0	0.0	0.0
12	9/28/2012 6:51	115.7	4.79	3.85	0.0	49.9	0.0	0.0	0.0
13	9/28/2012 6:52	116.1	4.82	3.89	0.0	49.9	0.0	0.0	0.0
14	9/28/2012 6:53	117.7	4.81	3.91	0.0	49.9	0.0	0.0	0.0
15	9/28/2012 6:54	119.5	4.94	3.83	0.0	49.9	0.0	0.0	0.0
16	9/28/2012 6:55	121.8	5.09	4.02	0.0	51.3	0.0	0.0	0.0
17	9/28/2012 6:56	124.4	5.22	4.10	0.0	51.8	0.0	0.0	0.0
18	9/28/2012 6:57	125.7	5.48	4.04	0.0	52.2	0.0	0.0	0.0
19	9/28/2012 6:58	128.3	5.82	4.27	0.0	53.8	0.0	0.0	0.0
20	9/28/2012 6:59	129.9	6.20	4.29	0.0	54.9	0.0	0.0	0.0
21	9/28/2012 7:00	131.8	6.78	4.54	0.0	57.8	0.0	0.0	0.0
22	9/28/2012 7:01	133.5	7.48	4.71	0.0	59.9	0.0	0.0	0.0
23	9/28/2012 7:02	135.7	8.22	5.04	0.0	62.9	0.0	0.0	0.0
24	9/28/2012 7:03	137.1	9.02	5.26	0.0	67.0	0.0	0.0	0.0
25	9/28/2012 7:04	138.4	9.76	5.52	0.0	69.1	0.0	0.0	0.0
26	9/28/2012 7:05	138.5	10.19	5.56	0.0	72.4	0.0	0.0	0.0
27	9/28/2012 7:06	137.2	10.74	5.64	0.0	73.7	0.0	0.0	0.0
28	9/28/2012 7:07	136.1	10.78	5.67	0.0	74.6	0.0	0.0	0.0
29	9/28/2012 7:08	134.3	10.87	5.58	0.0	74.6	0.0	0.0	0.0
30	9/28/2012 7:09	132.2	10.81	5.58	0.0	74.4	0.0	0.0	0.0
31	9/28/2012 7:10	130.8	10.67	5.56	0.0	73.6	0.0	0.0	0.0
32	9/28/2012 7:11	129.7	10.62	5.67	0.0	73.5	0.0	0.0	0.0
33	9/28/2012 7:12	128.0	10.48	5.42	0.0	72.4	0.0	0.0	0.0
34	9/28/2012 7:13	127.6	10.31	5.40	0.0	71.8	0.0	0.0	0.0
35	9/28/2012 7:14	126.0	9.96	5.20	0.0	70.7	0.0	0.0	0.0
36	9/28/2012 7:15	123.9	9.52	5.02	0.0	68.2	0.0	0.0	0.0
37	9/28/2012 7:16	121.6	8.87	4.60	0.0	65.2	0.0	0.0	0.0
38	9/28/2012 7:17	120.8	8.24	4.60	0.0	62.9	0.0	0.0	0.0
39	9/28/2012 7:18	121.3	8.03	4.70	0.0	61.1	0.0	0.0	0.0
40	9/28/2012 7:19	121.6	7.64	4.55	0.0	60.5	0.0	0.0	0.0
41	9/28/2012 7:20	122.6	7.54	4.42	0.0	59.5	0.0	0.0	0.0
42	9/28/2012 7:21	123.3	7.52	4.49	0.0	59.5	0.0	0.0	0.0
43	9/28/2012 7:22	125.3	7.64	4.64	0.0	59.8	0.0	0.0	0.0
44	9/28/2012 7:23	126.6	7.72	4.65	0.0	60.4	0.0	0.0	0.0
45	9/28/2012 7:24	126.6	7.81	4.58	0.0	60.2	0.0	0.0	0.0
46	9/28/2012 7:25	126.4	7.65	4.60	0.0	59.8	0.0	0.0	0.0
47	9/28/2012 7:26	126.9	7.70	4.58	0.0	60.9	0.0	0.0	0.0
48	9/28/2012 7:27	128.3	7.85	4.76	0.0	61.4	0.0	0.0	0.0
49	9/28/2012 7:28	129.0	8.03	4.77	0.0	61.6	0.0	0.0	0.0
50	9/28/2012 7:29	130.5	8.32	4.82	0.0	63.3	0.0	0.0	0.0
51	9/28/2012 7:30	131.1	8.60	4.87	0.0	65.4	0.0	0.0	0.0
52	9/28/2012 7:31	131.9	9.01	5.08	0.0	66.2	0.0	0.0	0.0
53	9/28/2012 7:32	132.3	9.27	5.09	0.0	67.8	0.0	0.0	0.0
54	9/28/2012 7:33	131.9	9.53	5.33	0.0	68.1	0.0	0.0	0.0

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
55	9/28/2012 7:34	131.6	9.65	5.17	0.0	68.2	0.0	0.0	0.0
56	9/28/2012 7:35	130.9	9.65	5.17	0.0	68.6	0.0	0.0	0.0
57	9/28/2012 7:36	131.0	9.87	5.33	0.0	69.8	0.0	0.0	0.0
58	9/28/2012 7:37	131.0	10.01	5.50	0.0	70.5	0.0	0.0	0.0
59	9/28/2012 7:38	130.6	10.09	5.47	0.0	70.7	0.0	0.0	0.0
60	9/28/2012 7:39	130.8	10.20	5.43	0.0	70.8	0.0	0.0	0.0
61	9/28/2012 7:40	130.8	10.30	5.56	0.0	71.6	0.0	0.0	0.0
62	9/28/2012 7:41	130.8	10.43	5.55	0.0	72.1	0.0	0.0	0.0
63	9/28/2012 7:42	130.2	10.37	5.39	0.0	72.6	0.0	0.0	0.0
64	9/28/2012 7:43	129.2	10.29	5.42	0.0	71.8	0.0	0.0	0.0
65	9/28/2012 7:44	128.5	10.24	5.34	0.0	71.1	0.0	0.0	0.0
66	9/28/2012 7:45	128.0	10.14	5.37	0.0	71.1	0.0	0.0	0.0
67	9/28/2012 7:46	128.0	10.17	5.42	0.0	71.3	0.0	0.0	0.0
68	9/28/2012 7:47	128.2	10.12	5.47	0.0	70.9	0.0	0.0	0.0
69	9/28/2012 7:48	128.7	10.24	5.39	0.0	71.7	0.0	0.0	0.0
70	9/28/2012 7:49	129.1	10.34	5.45	0.0	72.6	0.0	0.0	0.0
71	9/28/2012 7:50	129.4	10.41	5.49	0.0	72.3	0.0	0.0	0.0
72	9/28/2012 7:51	128.8	10.42	5.40	0.0	72.3	0.0	0.0	0.0
73	9/28/2012 7:52	128.2	10.40	5.47	0.0	72.1	0.0	0.0	0.0
74	9/28/2012 7:53	127.9	10.30	5.45	0.0	71.6	0.0	0.0	0.0
75	9/28/2012 7:54	127.8	10.23	5.45	0.0	72.1	0.0	0.0	0.0
76	9/28/2012 7:55	128.2	10.32	5.55	0.0	72.5	0.0	0.0	0.0
77	9/28/2012 7:56	128.7	10.37	5.43	0.0	72.4	0.0	0.0	0.0
78	9/28/2012 7:57	129.6	10.52	5.49	0.0	73.9	0.0	0.0	0.0
79	9/28/2012 7:58	130.1	10.73	5.59	0.0	74.0	0.0	0.0	0.0
80	9/28/2012 7:59	130.7	11.03	5.62	0.0	75.3	0.0	0.0	0.0
81	9/28/2012 8:00	130.8	11.17	5.83	0.0	76.4	0.0	0.0	0.0
82	9/28/2012 8:01	130.5	11.33	5.93	0.0	76.6	0.0	0.0	0.0
83	9/28/2012 8:02	129.8	11.22	5.90	0.0	75.7	0.0	0.0	0.0
84	9/28/2012 8:03	129.3	11.23	5.67	0.0	75.6	0.0	0.0	0.0
85	9/28/2012 8:04	129.5	11.30	5.81	0.0	76.9	0.0	0.0	0.0
86	9/28/2012 8:05	129.7	11.35	5.74	0.0	77.3	0.0	0.0	0.0
87	9/28/2012 8:06	130.2	11.48	5.96	0.0	78.2	0.0	0.0	0.0
88	9/28/2012 8:07	130.3	11.80	5.93	0.0	77.9	0.0	0.0	0.0
89	9/28/2012 8:08	130.6	11.91	6.00	0.0	79.5	0.0	0.0	0.0
90	9/28/2012 8:09	130.1	11.94	5.99	0.0	79.3	0.0	0.0	0.0
91	9/28/2012 8:10	129.4	11.78	5.96	0.0	78.8	0.0	0.0	0.0
92	9/28/2012 8:11	128.9	11.77	5.93	0.0	78.4	0.0	0.0	0.0
93	9/28/2012 8:12	128.4	11.74	5.94	0.0	78.5	0.0	0.0	0.0
94	9/28/2012 8:13	127.9	11.68	5.94	0.0	78.0	0.0	0.0	0.0
95	9/28/2012 8:14	127.7	11.64	5.84	0.0	78.6	0.0	0.0	0.0
96	9/28/2012 8:15	128.0	11.72	5.86	0.0	78.5	0.0	0.0	0.0
97	9/28/2012 8:16	128.5	11.72	5.86	0.0	78.8	0.0	0.0	0.0
98	9/28/2012 8:17	129.1	11.83	5.90	0.0	79.4	0.0	0.0	0.0
99	9/28/2012 8:18	129.6	11.92	6.06	0.0	79.9	0.0	0.0	0.0
100	9/28/2012 8:19	129.3	12.02	6.06	0.0	80.2	0.0	0.0	0.0
101	9/28/2012 8:20	128.9	12.01	6.18	0.0	79.5	0.0	0.0	0.0
102	9/28/2012 8:21	128.5	11.86	6.00	0.0	79.0	0.0	0.0	0.0
103	9/28/2012 8:22	128.5	11.99	6.09	0.0	80.1	0.0	0.0	0.0
104	9/28/2012 8:23	128.6	11.99	6.18	0.0	79.8	0.0	0.0	0.0
105	9/28/2012 8:24	129.2	12.01	6.10	0.0	80.3	0.0	0.0	0.0
106	9/28/2012 8:25	129.7	12.21	6.12	0.0	81.7	0.0	0.0	0.0
107	9/28/2012 8:26	129.9	12.31	6.27	0.0	82.4	0.0	0.0	0.0
108	9/28/2012 8:27	130.9	12.55	6.28	0.0	83.5	0.0	0.0	0.0
109	9/28/2012 8:28	131.0	12.80	6.57	0.0	83.5	0.0	0.0	0.0
110	9/28/2012 8:29	130.6	12.91	6.52	0.0	84.1	0.0	0.0	0.0
111	9/28/2012 8:30	130.2	12.90	6.40	0.0	84.4	0.0	0.0	0.0

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
112	9/28/2012 8:31	129.4	12.85	6.37	0.0	84.6	0.0	0.0	0.0
113	9/28/2012 8:32	129.3	12.74	6.38	0.0	84.3	0.0	0.0	0.0
114	9/28/2012 8:33	128.9	12.88	6.38	0.0	84.4	0.0	0.0	0.0
115	9/28/2012 8:34	128.9	12.93	6.49	0.0	84.2	0.0	0.0	0.0
116	9/28/2012 8:35	129.2	12.96	6.47	0.0	84.5	0.0	0.0	0.0
117	9/28/2012 8:36	129.6	13.06	6.56	0.0	85.9	0.0	0.0	0.0
118	9/28/2012 8:37	129.9	13.28	6.69	0.0	86.2	0.0	0.0	0.0
119	9/28/2012 8:38	129.7	13.22	6.62	0.0	85.7	0.0	0.0	0.0
120	9/28/2012 8:39	129.2	13.16	6.57	0.0	85.5	0.0	0.0	0.0
121	9/28/2012 8:40	127.8	13.17	6.72	0.0	85.1	0.0	0.0	0.0
122	9/28/2012 8:41	127.7	12.94	6.47	0.0	85.1	0.0	0.0	0.0
123	9/28/2012 8:42	126.9	12.86	6.43	0.0	84.2	0.0	0.0	0.0
124	9/28/2012 8:43	126.9	12.75	6.40	0.0	83.7	0.0	0.0	0.0
125	9/28/2012 8:44	127.5	12.90	6.43	0.0	84.5	0.0	0.0	0.0
126	9/28/2012 8:45	127.9	13.01	6.59	0.0	84.4	0.0	0.0	0.0
127	9/28/2012 8:46	128.8	13.06	6.37	0.0	85.4	0.0	0.0	0.0
128	9/28/2012 8:47	129.2	13.08	6.54	0.0	85.6	0.0	0.0	0.0
129	9/28/2012 8:48	129.4	13.26	6.66	0.0	86.7	0.0	0.0	0.0
130	9/28/2012 8:49	128.8	13.24	6.60	0.0	86.2	0.0	0.0	0.0
131	9/28/2012 8:50	128.2	13.22	6.41	0.0	85.3	0.0	0.0	0.0
132	9/28/2012 8:51	128.1	13.12	6.43	0.0	85.6	0.0	0.0	0.0
133	9/28/2012 8:52	128.2	13.13	6.57	0.0	85.5	0.0	0.0	0.0
134	9/28/2012 8:53	128.4	13.30	6.69	0.0	86.2	0.0	0.0	0.0
135	9/28/2012 8:54	129.1	13.30	6.65	0.0	86.5	0.0	0.0	0.0
136	9/28/2012 8:55	129.6	13.55	6.90	0.0	87.7	0.0	0.0	0.0
137	9/28/2012 8:56	130.2	13.65	6.78	0.0	87.8	0.0	0.0	0.0
138	9/28/2012 8:57	130.8	13.91	7.00	0.0	89.2	0.0	0.0	0.0
139	9/28/2012 8:58	131.0	14.09	7.06	0.0	90.2	0.0	0.0	0.0
140	9/28/2012 8:59	130.4	14.04	6.98	0.0	89.8	0.0	0.0	0.0
141	9/28/2012 9:00	129.6	13.96	6.76	0.0	89.8	0.0	0.0	0.0
142	9/28/2012 9:01	127.9	13.77	6.87	0.0	88.2	0.0	0.0	0.0
143	9/28/2012 9:02	127.2	13.62	6.62	0.0	87.1	0.0	0.0	0.0
144	9/28/2012 9:03	126.9	13.50	6.72	0.0	87.6	0.0	0.0	0.0
145	9/28/2012 9:04	127.8	13.55	6.81	0.0	88.4	0.0	0.0	0.0
146	9/28/2012 9:05	127.7	13.65	6.90	0.0	87.9	0.0	0.0	0.0
147	9/28/2012 9:06	128.4	13.68	6.87	0.0	88.7	0.0	0.0	0.0
148	9/28/2012 9:07	128.7	13.74	6.79	0.0	88.1	0.0	0.0	0.0
149	9/28/2012 9:08	129.3	13.91	7.00	0.0	89.4	0.0	0.0	0.0
150	9/28/2012 9:09	128.9	13.85	6.85	0.0	89.4	0.0	0.0	0.0
151	9/28/2012 9:10	128.4	13.89	6.79	0.0	88.9	0.0	0.0	0.0
152	9/28/2012 9:11	127.8	13.73	6.82	0.0	89.0	0.0	0.0	0.0
153	9/28/2012 9:12	127.6	13.68	6.69	0.0	88.1	0.0	0.0	0.0
154	9/28/2012 9:13	127.4	13.73	6.79	0.0	88.6	0.0	0.0	0.0
155	9/28/2012 9:14	128.0	13.71	6.87	0.0	89.0	0.0	0.0	0.0
156	9/28/2012 9:15	128.4	13.84	6.90	0.0	89.0	0.0	0.0	0.0
157	9/28/2012 9:16	129.1	13.98	7.04	0.0	89.7	0.0	0.0	0.0
158	9/28/2012 9:17	129.6	14.06	6.95	0.0	90.6	0.0	0.0	0.0
159	9/28/2012 9:18	130.3	14.20	7.16	0.0	91.3	0.0	0.0	0.0
160	9/28/2012 9:19	130.9	14.43	7.29	0.0	92.2	0.0	0.0	0.0
161	9/28/2012 9:20	130.6	14.49	7.31	0.0	92.3	0.0	0.0	0.0
162	9/28/2012 9:21	129.7	14.50	7.23	0.0	92.5	0.0	0.0	0.0
163	9/28/2012 9:22	128.5	14.39	7.12	0.0	91.3	0.0	0.0	0.0
164	9/28/2012 9:23	127.8	14.32	7.00	0.0	91.2	0.0	0.0	0.0
165	9/28/2012 9:24	127.7	14.18	6.95	0.0	91.5	0.0	0.0	0.0
166	9/28/2012 9:25	127.7	14.29	7.23	0.0	91.1	0.0	0.0	0.0
167	9/28/2012 9:26	128.0	14.28	7.15	0.0	91.1	0.0	0.0	0.0
168	9/28/2012 9:27	128.8	14.35	7.23	0.0	92.6	0.0	0.0	0.0

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
169	9/28/2012 9:28	129.1	14.44	7.16	0.0	91.9	0.0	0.0	0.0
170	9/28/2012 9:29	129.1	14.56	7.29	0.0	92.2	0.0	0.0	0.0
171	9/28/2012 9:30	129.4	14.52	7.25	0.0	92.2	0.0	0.0	0.0
172	9/28/2012 9:31	128.8	14.56	7.29	0.0	92.5	0.0	0.0	0.0
173	9/28/2012 9:32	127.2	14.34	7.12	0.0	91.7	0.0	0.0	0.0
174	9/28/2012 9:33	126.5	14.18	7.34	0.0	90.5	0.0	0.0	0.0
175	9/28/2012 9:34	126.3	14.11	6.98	0.0	89.6	0.0	0.0	0.0
176	9/28/2012 9:35	126.6	13.95	6.84	0.0	89.9	0.0	0.0	0.0
177	9/28/2012 9:36	127.0	14.05	7.10	0.0	90.8	0.0	0.0	0.0
178	9/28/2012 9:37	126.9	14.12	7.06	0.0	89.8	0.0	0.0	0.0
179	9/28/2012 9:38	127.5	14.09	7.13	0.0	90.1	0.0	0.0	0.0
180	9/28/2012 9:39	128.2	14.21	6.91	0.0	91.0	0.0	0.0	0.0
181	9/28/2012 9:40	128.9	14.35	7.19	0.0	91.6	0.0	0.0	0.0
182	9/28/2012 9:41	129.4	14.32	7.28	0.0	92.4	0.0	0.0	0.0
183	9/28/2012 9:42	129.2	14.45	7.23	0.0	92.1	0.0	0.0	0.0
184	9/28/2012 9:43	128.1	14.28	7.09	0.0	91.9	0.0	0.0	0.0
185	9/28/2012 9:44	127.4	14.22	7.06	0.0	90.9	0.0	0.0	0.0
186	9/28/2012 9:45	127.5	14.13	7.04	0.0	90.9	0.0	0.0	0.0
187	9/28/2012 9:46	127.5	14.21	7.25	0.0	90.2	0.0	0.0	0.0
188	9/28/2012 9:47	128.0	14.22	7.17	0.0	90.9	0.0	0.0	0.0
189	9/28/2012 9:48	128.3	14.28	7.15	0.0	91.4	0.0	0.0	0.0
190	9/28/2012 9:49	129.2	14.32	7.15	0.0	92.7	0.0	0.0	0.0
191	9/28/2012 9:50	129.1	14.44	7.26	0.0	92.7	0.0	0.0	0.0
192	9/28/2012 9:51	129.7	14.62	7.16	0.0	93.1	0.0	0.0	0.0
193	9/28/2012 9:52	130.1	14.73	7.34	0.0	93.7	0.0	0.0	0.0
194	9/28/2012 9:53	129.7	14.79	7.42	0.0	94.4	0.0	0.0	0.0
195	9/28/2012 9:54	128.6	14.68	7.32	0.0	93.6	0.0	0.0	0.0
196	9/28/2012 9:55	127.4	14.49	7.16	0.0	92.5	0.0	0.0	0.0
197	9/28/2012 9:56	126.4	14.35	7.03	0.0	91.3	0.0	0.0	0.0
198	9/28/2012 9:57	126.6	14.31	7.07	0.0	91.8	0.0	0.0	0.0
199	9/28/2012 9:58	126.8	14.27	7.10	0.0	91.0	0.0	0.0	0.0
200	9/28/2012 9:59	127.2	14.31	6.95	0.0	91.5	0.0	0.0	0.0
201	9/28/2012 10:00	127.5	14.26	7.12	0.0	91.5	0.0	0.0	0.0
202	9/28/2012 10:01	128.2	14.34	7.16	0.0	92.4	0.0	0.0	0.0
203	9/28/2012 10:02	128.8	14.50	6.90	0.0	92.7	0.0	0.0	0.0
204	9/28/2012 10:03	129.0	14.54	7.26	0.0	92.8	0.0	0.0	0.0
205	9/28/2012 10:04	128.8	14.55	7.20	0.0	92.8	0.0	0.0	0.0
206	9/28/2012 10:05	127.8	14.39	6.95	0.0	92.3	0.0	0.0	0.0
207	9/28/2012 10:06	127.2	14.31	7.06	0.0	92.2	0.0	0.0	0.0
208	9/28/2012 10:07	126.9	14.28	7.12	0.0	91.0	0.0	0.0	0.0
209	9/28/2012 10:08	127.1	14.26	7.03	0.0	91.3	0.0	0.0	0.0
210	9/28/2012 10:09	127.7	14.33	7.04	0.0	91.2	0.0	0.0	0.0
211	9/28/2012 10:10	128.0	14.43	7.15	0.0	92.4	0.0	0.0	0.0
212	9/28/2012 10:11	128.2	14.61	7.35	0.0	92.0	0.0	0.0	0.0
213	9/28/2012 10:12	129.5	14.51	7.23	0.0	93.6	0.0	0.0	0.0
214	9/28/2012 10:13	129.1	14.68	7.19	0.0	93.3	0.0	0.0	0.0
215	9/28/2012 10:14	129.9	14.87	7.67	0.0	94.3	0.0	0.0	0.0
216	9/28/2012 10:15	129.3	14.88	7.23	0.0	93.8	0.0	0.0	0.0
217	9/28/2012 10:16	128.9	14.67	7.38	0.0	93.9	0.0	0.0	0.0
218	9/28/2012 10:17	127.2	14.61	7.29	0.0	93.1	0.0	0.0	0.0
219	9/28/2012 10:18	126.2	14.31	7.16	0.0	91.8	0.0	0.0	0.0
220	9/28/2012 10:19	126.7	14.26	7.13	0.0	91.7	0.0	0.0	0.0
221	9/28/2012 10:20	127.0	14.38	7.17	0.0	92.2	0.0	0.0	0.0
222	9/28/2012 10:21	126.9	14.40	7.17	0.0	91.5	0.0	0.0	0.0
223	9/28/2012 10:22	127.6	14.45	7.25	0.0	92.8	0.0	0.0	0.0
224	9/28/2012 10:23	128.2	14.54	7.41	0.0	92.5	0.0	0.0	0.0
225	9/28/2012 10:24	128.7	14.54	7.15	0.0	93.5	0.0	0.0	0.0

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
226	9/28/2012 10:25	128.3	14.66	7.25	0.0	92.3	0.0	0.0	0.0
227	9/28/2012 10:26	127.7	14.45	7.16	0.0	93.0	0.0	0.0	0.0
228	9/28/2012 10:27	126.9	14.40	7.19	0.0	91.1	0.0	0.0	0.0
229	9/28/2012 10:28	126.6	14.27	7.01	0.0	91.0	0.0	0.0	0.0
230	9/28/2012 10:29	126.9	14.22	7.07	0.0	92.0	0.0	0.0	0.0
231	9/28/2012 10:30	126.8	14.31	6.97	0.0	91.5	0.0	0.0	0.0
232	9/28/2012 10:31	127.8	14.34	7.34	0.0	91.9	0.0	0.0	0.0
233	9/28/2012 10:32	128.0	14.33	7.17	0.0	92.2	0.0	0.0	0.0
234	9/28/2012 10:33	128.6	14.55	7.20	0.0	92.5	0.0	0.0	0.0
235	9/28/2012 10:34	129.0	14.54	7.41	0.0	92.8	0.0	0.0	0.0
236	9/28/2012 10:35	129.7	14.74	7.35	0.0	93.7	0.0	0.0	0.0
237	9/28/2012 10:36	129.1	14.76	7.26	0.0	93.4	0.0	0.0	0.0
238	9/28/2012 10:37	128.2	14.62	7.34	0.0	93.0	0.0	0.0	0.0
239	9/28/2012 10:38	127.6	14.51	7.28	0.0	92.5	0.0	0.0	0.0
240	9/28/2012 10:39	126.6	14.38	7.15	0.0	91.5	0.0	0.0	0.0
241	9/28/2012 10:40	126.8	14.33	7.10	0.0	91.1	0.0	0.0	0.0
242	9/28/2012 10:41	126.9	14.32	6.94	0.0	91.2	0.0	0.0	0.0
243	9/28/2012 10:42	127.2	14.37	7.23	0.0	91.2	0.0	0.0	0.0
244	9/28/2012 10:43	127.7	14.39	7.20	0.0	91.8	0.0	0.0	0.0
245	9/28/2012 10:44	128.0	14.39	7.09	0.0	92.1	0.0	0.0	0.0
246	9/28/2012 10:45	129.0	14.66	7.26	0.0	93.0	0.0	0.0	0.0
247	9/28/2012 10:46	128.6	14.56	7.34	0.0	92.9	0.0	0.0	0.0
248	9/28/2012 10:47	128.0	14.61	6.91	0.0	92.6	0.0	0.0	0.0
249	9/28/2012 10:48	127.7	14.43	7.26	0.0	91.9	0.0	0.0	0.0
250	9/28/2012 10:49	127.1	14.31	7.19	0.0	91.2	0.0	0.0	0.0
251	9/28/2012 10:50	127.2	14.31	7.10	0.0	91.2	0.0	0.0	0.0
252	9/28/2012 10:51	127.7	14.24	7.03	0.0	91.5	0.0	0.0	0.0
253	9/28/2012 10:52	127.8	14.35	7.15	0.0	91.9	0.0	0.0	0.0
254	9/28/2012 10:53	128.6	14.49	7.10	0.0	92.7	0.0	0.0	0.0
255	9/28/2012 10:54	128.8	14.51	7.25	0.0	92.8	0.0	0.0	0.0
256	9/28/2012 10:55	129.6	14.70	7.19	0.0	93.4	0.0	0.0	0.0
257	9/28/2012 10:56	129.6	14.74	7.48	0.0	93.9	0.0	0.0	0.0
258	9/28/2012 10:57	129.0	14.71	7.06	0.0	94.7	0.0	0.0	0.0
259	9/28/2012 10:58	128.7	14.71	7.48	0.0	93.2	0.0	0.0	0.0
260	9/28/2012 10:59	127.5	14.50	7.12	0.0	93.1	0.0	0.0	0.0
261	9/28/2012 11:00	127.5	14.52	7.25	0.0	93.1	0.0	0.0	0.0
262	9/28/2012 11:01	127.5	14.48	7.29	0.0	92.9	0.0	0.0	0.0
263	9/28/2012 11:02	127.1	14.44	7.01	0.0	92.5	0.0	0.0	0.0
264	9/28/2012 11:03	127.8	14.46	7.19	0.0	93.2	0.0	0.0	0.0
265	9/28/2012 11:04	128.5	14.59	7.42	0.0	92.9	0.0	0.0	0.0
266	9/28/2012 11:05	128.9	14.61	7.42	0.0	93.4	0.0	0.0	0.0
267	9/28/2012 11:06	129.1	14.82	7.32	0.0	93.9	0.0	0.0	0.0
268	9/28/2012 11:07	128.0	14.66	7.39	0.0	93.5	0.0	0.0	0.0
269	9/28/2012 11:08	127.4	14.59	7.25	0.0	93.4	0.0	0.0	0.0
270	9/28/2012 11:09	126.4	14.27	7.00	0.0	91.8	0.0	0.0	0.0
271	9/28/2012 11:10	127.1	14.33	7.20	0.0	92.3	0.0	0.0	0.0
272	9/28/2012 11:11	126.8	14.27	6.91	0.0	91.5	0.0	0.0	0.0
273	9/28/2012 11:12	126.7	14.16	7.20	0.0	91.5	0.0	0.0	0.0
274	9/28/2012 11:13	127.3	14.23	7.12	0.0	91.2	0.0	0.0	0.0
275	9/28/2012 11:14	127.5	14.35	7.19	0.0	91.9	0.0	0.0	0.0
276	9/28/2012 11:15	127.9	14.32	6.95	0.0	92.3	0.0	0.0	0.0
277	9/28/2012 11:16	128.8	14.48	7.19	0.0	93.9	0.0	0.0	0.0
278	9/28/2012 11:17	128.2	14.38	7.17	0.0	92.7	0.0	0.0	0.0
279	9/28/2012 11:18	127.1	14.28	7.06	0.0	91.7	0.0	0.0	0.0
280	9/28/2012 11:19	126.9	14.17	7.04	0.0	91.8	0.0	0.0	0.0
281	9/28/2012 11:20	126.4	14.06	6.91	0.0	91.0	0.0	0.0	0.0
282	9/28/2012 11:21	126.1	14.00	6.97	0.0	90.4	0.0	0.0	0.0

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
283	9/28/2012 11:22	126.8	14.09	7.01	0.0	90.5	0.0	0.0	0.0
284	9/28/2012 11:23	127.4	14.04	7.00	0.0	90.6	0.0	0.0	0.0
285	9/28/2012 11:24	127.5	14.12	6.97	0.0	90.8	0.0	0.0	0.0
286	9/28/2012 11:25	128.3	14.28	6.98	0.0	91.5	0.0	0.0	0.0
287	9/28/2012 11:26	129.0	14.35	7.10	0.0	91.6	0.0	0.0	0.0
288	9/28/2012 11:27	128.6	14.26	6.98	0.0	91.6	0.0	0.0	0.0
289	9/28/2012 11:28	128.3	14.28	7.16	0.0	91.8	0.0	0.0	0.0
290	9/28/2012 11:29	127.4	14.11	6.82	0.0	91.3	0.0	0.0	0.0
291	9/28/2012 11:30	127.1	14.11	7.13	0.0	91.1	0.0	0.0	0.0
292	9/28/2012 11:31	127.4	14.11	6.91	0.0	91.0	0.0	0.0	0.0
293	9/28/2012 11:32	127.5	14.13	6.98	0.0	91.2	0.0	0.0	0.0
294	9/28/2012 11:33	127.9	14.15	7.01	0.0	90.8	0.0	0.0	0.0
295	9/28/2012 11:34	128.4	14.21	7.17	0.0	92.1	0.0	0.0	0.0
296	9/28/2012 11:35	128.6	14.21	7.04	0.0	92.2	0.0	0.0	0.0
297	9/28/2012 11:36	129.4	14.39	7.12	0.0	92.4	0.0	0.0	0.0
298	9/28/2012 11:37	129.4	14.42	7.16	0.0	92.9	0.0	0.0	0.0
299	9/28/2012 11:38	128.2	14.38	7.15	0.0	92.4	0.0	0.0	0.0
300	9/28/2012 11:39	127.7	14.22	7.03	0.0	91.7	0.0	0.0	0.0
301	9/28/2012 11:40	127.1	14.18	7.01	0.0	91.6	0.0	0.0	0.0
302	9/28/2012 11:41	127.4	14.06	7.10	0.0	91.2	0.0	0.0	0.0
303	9/28/2012 11:42	126.9	14.06	7.00	0.0	90.8	0.0	0.0	0.0
304	9/28/2012 11:43	127.6	14.18	7.03	0.0	91.0	0.0	0.0	0.0
305	9/28/2012 11:44	127.6	14.09	7.06	0.0	90.9	0.0	0.0	0.0
306	9/28/2012 11:45	128.2	14.22	7.19	0.0	91.5	0.0	0.0	0.0
307	9/28/2012 11:46	129.0	14.37	7.32	0.0	93.0	0.0	0.0	0.0
308	9/28/2012 11:47	129.1	14.42	7.23	0.0	92.8	0.0	0.0	0.0
309	9/28/2012 11:48	128.7	14.34	7.19	0.0	92.3	0.0	0.0	0.0
310	9/28/2012 11:49	127.7	14.26	7.10	0.0	91.7	0.0	0.0	0.0
311	9/28/2012 11:50	127.1	14.17	6.97	0.0	90.7	0.0	0.0	0.0
312	9/28/2012 11:51	127.0	14.10	7.13	0.0	91.4	0.0	0.0	0.0
313	9/28/2012 11:52	127.4	14.16	7.07	0.0	91.9	0.0	0.0	0.0
314	9/28/2012 11:53	127.3	14.12	7.15	0.0	91.3	0.0	0.0	0.0
315	9/28/2012 11:54	127.4	14.05	6.81	0.0	91.5	0.0	0.0	0.0
316	9/28/2012 11:55	127.8	14.17	7.09	0.0	91.7	0.0	0.0	0.0
317	9/28/2012 11:56	128.6	14.28	7.25	0.0	92.0	0.0	0.0	0.0
318	9/28/2012 11:57	128.2	14.34	6.91	0.0	91.5	0.0	0.0	0.0
319	9/28/2012 11:58	127.5	14.12	7.04	0.0	90.8	0.0	0.0	0.0

Steady Low Flow – Air Valves Open

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
0	12/20/2012 8:03	148.4	8.02	5.99	62.9	0.0	0.0	0.0	0.0
1	12/20/2012 8:04	145.6	7.25	6.44	60.9	0.0	0.0	0.0	0.0
2	12/20/2012 8:05	142.4	6.93	6.98	61.0	0.0	0.0	0.0	0.0
3	12/20/2012 8:06	139.7	7.48	7.39	64.1	0.0	0.0	0.0	0.0
4	12/20/2012 8:07	136.4	7.15	7.91	63.9	0.0	0.0	0.0	0.0
5	12/20/2012 8:08	135.7	7.04	8.05	64.0	0.0	0.0	0.0	0.0
6	12/20/2012 8:09	132.9	7.42	8.82	67.1	0.0	0.0	0.0	0.0
7	12/20/2012 8:10	131.8	7.26	9.21	66.9	0.0	0.0	0.0	0.0
8	12/20/2012 8:11	131.8	7.26	9.21	66.9	0.0	0.0	0.0	0.0
9	12/20/2012 8:12	130.5	7.17	10.54	69.0	0.0	0.0	0.0	0.0
10	12/20/2012 8:13	130.4	7.19	11.23	70.0	0.0	0.0	0.0	0.0
11	12/20/2012 8:14	130.8	7.30	11.56	71.0	0.0	0.0	0.0	0.0
12	12/20/2012 8:15	131.3	7.08	12.11	71.1	0.0	0.0	0.0	0.0
13	12/20/2012 8:16	131.6	7.20	12.61	72.2	0.0	0.0	0.0	0.0
14	12/20/2012 8:17	133.1	6.98	13.91	73.0	0.0	0.0	0.0	0.0
15	12/20/2012 8:18	133.1	6.98	13.91	73.0	0.0	0.0	0.0	0.0
16	12/20/2012 8:19	134.7	7.21	15.48	76.2	0.0	0.0	0.0	0.0
17	12/20/2012 8:20	135.1	7.11	15.72	76.1	0.0	0.0	0.0	0.0
18	12/20/2012 8:21	137.2	7.27	16.82	78.1	0.0	0.0	0.0	0.0
19	12/20/2012 8:22	137.8	7.21	16.98	78.2	0.0	0.0	0.0	0.0
20	12/20/2012 8:23	140.7	7.10	17.30	77.9	0.0	0.0	0.0	0.0
21	12/20/2012 8:24	143.4	7.08	17.36	78.0	0.0	0.0	0.0	0.0
22	12/20/2012 8:25	146.2	7.39	17.59	79.1	0.0	0.0	0.0	0.0
23	12/20/2012 8:26	149.5	7.32	17.72	79.1	0.0	0.0	0.0	0.0
24	12/20/2012 8:27	152.3	7.88	17.93	81.1	0.0	0.0	0.0	0.0
25	12/20/2012 8:28	155.3	7.89	18.10	81.0	0.0	0.0	0.0	0.0
26	12/20/2012 8:29	157.9	7.92	18.21	81.1	0.0	0.0	0.0	0.0
27	12/20/2012 8:30	159.7	7.92	18.27	81.0	0.0	0.0	0.0	0.0
28	12/20/2012 8:31	160.9	7.94	18.37	81.0	0.0	0.0	0.0	0.0
29	12/20/2012 8:32	161.7	7.88	18.41	80.9	0.0	0.0	0.0	0.0
30	12/20/2012 8:33	162.0	7.86	18.49	81.2	0.0	0.0	0.0	0.0
31	12/20/2012 8:34	162.4	7.86	18.49	81.0	0.0	0.0	0.0	0.0
32	12/20/2012 8:35	162.8	7.88	18.43	81.0	0.0	0.0	0.0	0.0
33	12/20/2012 8:36	163.3	7.86	18.54	81.0	0.0	0.0	0.0	0.0
34	12/20/2012 8:37	163.7	7.83	18.59	81.1	0.0	0.0	0.0	0.0
35	12/20/2012 8:38	164.2	7.82	18.66	81.0	0.0	0.0	0.0	0.0
36	12/20/2012 8:39	164.5	7.83	18.65	81.2	0.0	0.0	0.0	0.0
37	12/20/2012 8:40	165.2	7.86	18.71	81.0	0.0	0.0	0.0	0.0
38	12/20/2012 8:41	165.6	7.81	18.73	81.1	0.0	0.0	0.0	0.0
39	12/20/2012 8:42	166.2	7.83	18.72	81.0	0.0	0.0	0.0	0.0
40	12/20/2012 8:43	166.6	7.86	18.75	81.1	0.0	0.0	0.0	0.0
41	12/20/2012 8:44	166.9	7.88	18.76	81.0	0.0	0.0	0.0	0.0
42	12/20/2012 8:45	167.5	7.88	18.76	81.1	0.0	0.0	0.0	0.0
43	12/20/2012 8:46	168.1	7.92	18.69	81.0	0.0	0.0	0.0	0.0
44	12/20/2012 8:47	168.3	7.87	18.75	80.9	0.0	0.0	0.0	0.0
45	12/20/2012 8:48	169.0	7.85	18.73	81.2	0.0	0.0	0.0	0.0
46	12/20/2012 8:49	169.5	7.86	18.75	81.1	0.0	0.0	0.0	0.0
47	12/20/2012 8:50	170.3	7.86	18.85	81.0	0.0	0.0	0.0	0.0
48	12/20/2012 8:51	170.4	7.87	18.81	81.1	0.0	0.0	0.0	0.0
49	12/20/2012 8:52	171.3	7.93	18.78	81.0	0.0	0.0	0.0	0.0
50	12/20/2012 8:53	171.7	7.91	18.73	81.0	0.0	0.0	0.0	0.0
51	12/20/2012 8:54	172.1	7.92	18.81	81.1	0.0	0.0	0.0	0.0
52	12/20/2012 8:55	172.6	6.82	18.59	76.1	0.0	0.0	0.0	0.0
53	12/20/2012 8:56	173.6	7.11	18.60	78.1	0.0	0.0	0.0	0.0
54	12/20/2012 8:57	173.8	7.69	18.69	80.1	0.0	0.0	0.0	0.0
55	12/20/2012 8:58	174.1	7.70	18.68	80.0	0.0	0.0	0.0	0.0

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
56	12/20/2012 8:59	174.9	7.74	18.71	79.9	0.0	0.0	0.0	0.0
57	12/20/2012 9:00	175.5	7.76	18.72	80.2	0.0	0.0	0.0	0.0
58	12/20/2012 9:01	176.1	7.76	18.65	80.0	0.0	0.0	0.0	0.0
59	12/20/2012 9:02	176.8	7.78	18.72	80.1	0.0	0.0	0.0	0.0
60	12/20/2012 9:03	177.4	7.80	18.63	80.2	0.0	0.0	0.0	0.0
61	12/20/2012 9:04	178.1	7.80	18.63	80.0	0.0	0.0	0.0	0.0
62	12/20/2012 9:05	178.8	7.77	18.69	80.1	0.0	0.0	0.0	0.0
63	12/20/2012 9:06	179.3	7.81	18.69	80.1	0.0	0.0	0.0	0.0
64	12/20/2012 9:07	180.0	7.83	18.66	79.9	0.0	0.0	0.0	0.0
65	12/20/2012 9:08	180.8	7.78	18.69	80.1	0.0	0.0	0.0	0.0
66	12/20/2012 9:09	181.6	7.78	18.65	80.0	0.0	0.0	0.0	0.0
67	12/20/2012 9:10	182.4	7.83	18.65	80.2	0.0	0.0	0.0	0.0
68	12/20/2012 9:11	183.2	7.86	18.68	80.1	0.0	0.0	0.0	0.0
69	12/20/2012 9:12	184.3	7.82	18.71	80.1	0.0	0.0	0.0	0.0
70	12/20/2012 9:13	184.8	7.86	18.69	80.0	0.0	0.0	0.0	0.0
71	12/20/2012 9:14	185.8	7.86	18.69	80.1	0.0	0.0	0.0	0.0
72	12/20/2012 9:15	186.2	7.86	18.68	80.1	0.0	0.0	0.0	0.0
73	12/20/2012 9:16	187.2	7.91	18.71	80.0	0.0	0.0	0.0	0.0
74	12/20/2012 9:17	188.0	7.85	18.71	80.1	0.0	0.0	0.0	0.0
75	12/20/2012 9:18	188.5	7.88	18.66	80.2	0.0	0.0	0.0	0.0
76	12/20/2012 9:19	189.3	7.92	18.69	80.1	0.0	0.0	0.0	0.0
77	12/20/2012 9:20	190.1	7.92	18.71	80.0	0.0	0.0	0.0	0.0
78	12/20/2012 9:21	190.7	7.94	18.72	80.1	0.0	0.0	0.0	0.0
79	12/20/2012 9:22	191.4	7.97	18.68	80.1	0.0	0.0	0.0	0.0
80	12/20/2012 9:23	192.1	7.98	18.72	80.1	0.0	0.0	0.0	0.0
81	12/20/2012 9:24	193.0	7.96	18.68	80.1	0.0	0.0	0.0	0.0
82	12/20/2012 9:25	193.6	7.97	18.71	80.2	0.0	0.0	0.0	0.0
83	12/20/2012 9:26	193.8	7.98	18.60	80.1	0.0	0.0	0.0	0.0

Steady Low Flow – Air Valves Closed

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
0	10/19/2012 13:32	149.3	7.32	5.45	60.0	0.0	0.0	0.0	0.0
1	10/19/2012 13:33	154.6	7.78	4.93	60.1	0.0	0.0	0.0	0.0
2	10/19/2012 13:34	159.0	7.91	4.95	60.0	0.0	0.0	0.0	0.0
3	10/19/2012 13:35	161.2	7.58	4.83	58.0	0.0	0.0	0.0	0.0
4	10/19/2012 13:36	162.9	7.21	4.54	56.0	0.0	0.0	0.0	0.0
5	10/19/2012 13:37	163.6	7.20	4.58	56.0	0.0	0.0	0.0	0.0
6	10/19/2012 13:38	164.0	7.24	4.57	56.0	0.0	0.0	0.0	0.0
7	10/19/2012 13:39	164.1	7.82	4.83	56.0	0.0	0.0	0.0	0.0
8	10/19/2012 13:40	163.4	7.99	4.92	59.9	0.0	0.0	0.0	0.0
9	10/19/2012 13:41	162.3	7.65	4.57	58.1	0.0	0.0	0.0	0.0
10	10/19/2012 13:42	161.2	7.63	4.64	58.0	0.0	0.0	0.0	0.0
11	10/19/2012 13:43	160.1	7.59	4.68	57.9	0.0	0.0	0.0	0.0
12	10/19/2012 13:44	159.4	7.54	4.68	58.0	0.0	0.0	0.0	0.0
13	10/19/2012 13:45	157.9	7.55	4.61	57.9	0.0	0.0	0.0	0.0
14	10/19/2012 13:46	156.9	7.55	4.63	58.0	0.0	0.0	0.0	0.0
15	10/19/2012 13:47	154.9	7.50	4.58	58.0	0.0	0.0	0.0	0.0
16	10/19/2012 13:48	153.2	7.44	4.57	58.0	0.0	0.0	0.0	0.0
17	10/19/2012 13:49	149.8	7.46	4.52	57.9	0.0	0.0	0.0	0.0
18	10/19/2012 13:50	148.2	7.39	4.55	58.1	0.0	0.0	0.0	0.0
19	10/19/2012 13:51	144.8	7.38	4.46	58.0	0.0	0.0	0.0	0.0
20	10/19/2012 13:52	141.6	7.38	4.35	58.1	0.0	0.0	0.0	0.0
21	10/19/2012 13:53	138.8	7.28	4.36	57.9	0.0	0.0	0.0	0.0
22	10/19/2012 13:54	136.0	7.26	4.38	58.1	0.0	0.0	0.0	0.0
23	10/19/2012 13:55	132.7	7.20	4.33	58.0	0.0	0.0	0.0	0.0
24	10/19/2012 13:56	129.1	7.13	4.33	57.9	0.0	0.0	0.0	0.0
25	10/19/2012 13:57	125.6	7.10	4.36	58.0	0.0	0.0	0.0	0.0
26	10/19/2012 13:58	122.1	7.42	4.52	60.1	0.0	0.0	0.0	0.0
27	10/19/2012 13:59	118.3	7.38	4.43	60.0	0.0	0.0	0.0	0.0
28	10/19/2012 14:00	115.6	7.37	4.39	60.0	0.0	0.0	0.0	0.0
29	10/19/2012 14:01	111.9	7.37	4.33	60.0	0.0	0.0	0.0	0.0
30	10/19/2012 14:02	110.8	7.30	4.41	60.0	0.0	0.0	0.0	0.0
31	10/19/2012 14:03	112.3	7.35	4.43	60.0	0.0	0.0	0.0	0.0
32	10/19/2012 14:04	114.2	7.39	4.42	60.1	0.0	0.0	0.0	0.0
33	10/19/2012 14:05	117.1	7.46	4.41	60.0	0.0	0.0	0.0	0.0
34	10/19/2012 14:06	122.9	7.49	4.54	60.0	0.0	0.0	0.0	0.0
35	10/19/2012 14:07	130.2	7.63	4.51	60.0	0.0	0.0	0.0	0.0
36	10/19/2012 14:08	136.8	7.75	4.48	60.1	0.0	0.0	0.0	0.0
37	10/19/2012 14:09	140.7	7.74	4.51	60.1	0.0	0.0	0.0	0.0
38	10/19/2012 14:10	149.2	7.52	4.30	57.9	0.0	0.0	0.0	0.0
39	10/19/2012 14:11	156.1	7.50	4.41	58.0	0.0	0.0	0.0	0.0
40	10/19/2012 14:12	163.0	7.75	4.48	58.0	0.0	0.0	0.0	0.0
41	10/19/2012 14:13	166.9	7.37	4.21	56.0	0.0	0.0	0.0	0.0
42	10/19/2012 14:14	170.0	7.37	4.30	56.0	0.0	0.0	0.0	0.0
43	10/19/2012 14:15	173.1	7.43	4.39	56.1	0.0	0.0	0.0	0.0
44	10/19/2012 14:16	175.6	7.46	4.41	56.0	0.0	0.0	0.0	0.0
45	10/19/2012 14:17	177.1	7.48	4.36	55.9	0.0	0.0	0.0	0.0
46	10/19/2012 14:18	178.8	7.47	4.36	55.9	0.0	0.0	0.0	0.0
47	10/19/2012 14:19	180.4	7.52	4.39	56.0	0.0	0.0	0.0	0.0
48	10/19/2012 14:20	181.6	7.55	4.45	56.0	0.0	0.0	0.0	0.0
49	10/19/2012 14:21	182.5	7.55	4.39	55.9	0.0	0.0	0.0	0.0
50	10/19/2012 14:22	182.7	7.53	4.41	56.0	0.0	0.0	0.0	0.0
51	10/19/2012 14:23	183.3	7.57	4.36	56.0	0.0	0.0	0.0	0.0
52	10/19/2012 14:24	184.2	7.58	4.35	56.1	0.0	0.0	0.0	0.0
53	10/19/2012 14:25	184.8	7.50	4.33	56.1	0.0	0.0	0.0	0.0
54	10/19/2012 14:26	185.3	7.60	4.33	56.0	0.0	0.0	0.0	0.0
55	10/19/2012 14:27	185.9	7.63	4.39	56.1	0.0	0.0	0.0	0.0

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
56	10/19/2012 14:28	186.9	7.58	4.36	56.0	0.0	0.0	0.0	0.0
57	10/19/2012 14:29	187.6	7.61	4.39	56.1	0.0	0.0	0.0	0.0
58	10/19/2012 14:30	188.0	7.65	4.39	56.0	0.0	0.0	0.0	0.0
59	10/19/2012 14:31	188.2	7.63	4.33	56.0	0.0	0.0	0.0	0.0
60	10/19/2012 14:32	186.9	7.61	4.36	56.0	0.0	0.0	0.0	0.0
61	10/19/2012 14:33	184.8	7.60	4.33	55.9	0.0	0.0	0.0	0.0
62	10/19/2012 14:34	182.9	7.58	4.29	55.9	0.0	0.0	0.0	0.0
63	10/19/2012 14:35	181.7	7.48	4.32	56.1	0.0	0.0	0.0	0.0
64	10/19/2012 14:36	180.9	7.54	4.36	55.9	0.0	0.0	0.0	0.0
65	10/19/2012 14:37	180.7	7.55	4.30	55.9	0.0	0.0	0.0	0.0
66	10/19/2012 14:38	180.2	7.54	4.35	55.9	0.0	0.0	0.0	0.0
67	10/19/2012 14:39	179.8	7.47	4.27	55.9	0.0	0.0	0.0	0.0
68	10/19/2012 14:40	179.3	7.54	4.33	56.2	0.0	0.0	0.0	0.0
69	10/19/2012 14:41	178.9	7.48	4.29	56.1	0.0	0.0	0.0	0.0
70	10/19/2012 14:42	178.5	7.47	4.29	55.9	0.0	0.0	0.0	0.0
71	10/19/2012 14:43	178.2	7.44	4.30	56.0	0.0	0.0	0.0	0.0
72	10/19/2012 14:44	177.7	7.44	4.30	56.1	0.0	0.0	0.0	0.0
73	10/19/2012 14:45	177.2	7.47	4.32	56.0	0.0	0.0	0.0	0.0
74	10/19/2012 14:46	176.7	7.44	4.29	56.0	0.0	0.0	0.0	0.0
75	10/19/2012 14:47	176.4	7.48	4.26	56.0	0.0	0.0	0.0	0.0
76	10/19/2012 14:48	176.1	7.44	4.24	56.0	0.0	0.0	0.0	0.0

Steady High Flow – Air Valves Open

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
0	12/20/2012 9:49	186.4	39.24	32.61	99.0	93.9	99.1	98.9	98.8
1	12/20/2012 9:50	178.3	44.00	27.12	99.2	87.9	99.1	99.0	98.8
2	12/20/2012 9:51	172.5	38.65	27.64	99.2	0.0	99.1	98.9	98.9
3	12/20/2012 9:52	164.4	41.91	24.35	93.1	0.0	99.2	99.0	98.7
4	12/20/2012 9:53	157.0	36.23	26.94	88.1	0.0	99.1	99.0	98.7
5	12/20/2012 9:54	148.5	36.23	26.78	88.1	0.0	99.1	99.0	98.9
6	12/20/2012 9:55	140.4	36.64	26.81	91.0	0.0	99.1	99.0	98.7
7	12/20/2012 9:56	133.0	36.28	27.07	93.1	0.0	99.2	98.8	98.7
8	12/20/2012 9:57	126.6	36.32	27.36	95.1	0.0	99.3	98.9	98.9
9	12/20/2012 9:58	121.1	37.15	27.15	95.0	0.0	99.1	99.1	98.7
10	12/20/2012 9:59	116.7	36.97	27.04	95.1	0.0	99.2	98.9	98.8
11	12/20/2012 10:00	104.8	35.98	26.93	95.0	0.0	99.0	98.9	98.9
12	12/20/2012 10:01	97.4	41.99	27.28	99.1	0.0	99.1	98.9	99.0
13	12/20/2012 10:02	81.1	36.93	26.71	99.1	0.0	99.1	98.9	98.9

Steady High Flow – Air Valves Closed

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharg e Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
0	10/19/2012 15:34	167.3	37.72	25.68	99.3	98.9	99.0	84.9	0.0
1	10/19/2012 15:35	165.5	38.53	25.81	99.0	99.0	99.2	88.0	0.0
2	10/19/2012 15:36	164.3	38.31	25.80	99.1	99.1	99.1	88.0	0.0
3	10/19/2012 15:37	162.7	38.38	25.67	99.1	99.0	99.3	87.0	0.0
4	10/19/2012 15:38	160.6	38.36	25.61	99.3	99.0	99.1	87.0	0.0
5	10/19/2012 15:39	158.2	38.37	25.47	99.0	98.9	99.2	86.9	0.0
6	10/19/2012 15:40	156.4	38.33	25.45	99.1	99.0	99.3	87.0	0.0
7	10/19/2012 15:41	154.8	38.35	25.42	99.0	99.0	99.1	86.8	0.0
8	10/19/2012 15:42	153.9	38.21	25.47	99.3	98.9	99.0	86.9	0.0
9	10/19/2012 15:43	153.2	38.15	25.45	99.3	98.9	99.2	87.0	0.0
10	10/19/2012 15:44	151.4	37.87	25.45	99.1	98.9	99.3	86.9	0.0
11	10/19/2012 15:45	149.3	37.87	25.39	99.0	98.9	99.3	87.0	0.0
12	10/19/2012 15:46	146.8	37.78	25.27	99.1	99.0	99.2	87.0	0.0
13	10/19/2012 15:47	143.1	38.05	25.23	99.1	99.1	99.2	87.9	0.0
14	10/19/2012 15:48	138.0	37.66	25.02	99.2	98.9	99.2	88.0	0.0
15	10/19/2012 15:49	131.8	37.70	25.06	99.0	99.0	99.2	88.0	0.0
16	10/19/2012 15:50	124.1	38.05	24.90	99.2	99.1	99.2	87.9	0.0
17	10/19/2012 15:51	113.1	37.97	24.68	99.1	99.0	99.1	88.0	0.0

Low to High Flow Test – Air Valves Open

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
0	10/5/2012 8:49	242.4	7.36	4.39	50.0	0.0	0.0	0.0	0.0
1	10/5/2012 8:50	240.1	7.28	4.45	50.0	0.0	0.0	0.0	0.0
2	10/5/2012 8:51	239.6	7.46	4.77	52.1	0.0	0.0	0.0	0.0
3	10/5/2012 8:52	239.4	7.72	4.57	52.1	0.0	0.0	0.0	0.0
4	10/5/2012 8:53	239.9	7.69	4.57	52.1	0.0	0.0	0.0	0.0
5	10/5/2012 8:54	240.7	7.71	4.61	53.1	0.0	0.0	0.0	0.0
6	10/5/2012 8:55	241.1	8.63	5.28	57.0	0.0	0.0	0.0	0.0
7	10/5/2012 8:56	241.0	9.20	5.47	60.1	0.0	0.0	0.0	0.0
8	10/5/2012 8:57	240.5	9.42	5.09	63.2	0.0	0.0	0.0	0.0
9	10/5/2012 8:58	239.9	10.21	5.34	64.1	0.0	0.0	0.0	0.0
10	10/5/2012 8:59	239.2	10.48	5.75	66.1	0.0	0.0	0.0	0.0
11	10/5/2012 9:00	238.4	10.98	5.75	68.0	0.0	0.0	0.0	0.0
12	10/5/2012 9:01	237.6	11.26	5.80	69.0	0.0	0.0	0.0	0.0
13	10/5/2012 9:02	236.9	11.24	5.72	68.9	0.0	0.0	0.0	0.0
14	10/5/2012 9:03	236.4	11.56	6.35	71.9	0.0	0.0	0.0	0.0
15	10/5/2012 9:04	235.4	12.56	6.18	75.9	0.0	0.0	0.0	0.0
16	10/5/2012 9:05	233.9	12.49	6.21	76.2	0.0	0.0	0.0	0.0
17	10/5/2012 9:06	233.5	12.89	6.62	78.9	0.0	0.0	0.0	0.0
18	10/5/2012 9:07	232.6	13.32	6.98	81.0	0.0	0.0	0.0	0.0
19	10/5/2012 9:08	231.5	13.54	6.68	82.1	0.0	0.0	0.0	0.0
20	10/5/2012 9:09	230.1	14.34	7.91	88.0	0.0	0.0	0.0	0.0
21	10/5/2012 9:10	227.8	15.05	7.39	89.9	0.0	0.0	0.0	0.0
22	10/5/2012 9:11	226.1	14.98	7.35	90.3	0.0	0.0	0.0	0.0
23	10/5/2012 9:12	224.8	15.66	9.21	93.9	0.0	0.0	0.0	0.0
24	10/5/2012 9:13	222.9	16.67	8.13	98.9	0.0	0.0	0.0	0.0
25	10/5/2012 9:14	221.4	16.65	8.21	99.5	0.0	0.0	0.0	0.0
26	10/5/2012 9:15	219.9	16.63	8.26	99.2	0.0	0.0	0.0	0.0
27	10/5/2012 9:16	219.1	16.65	8.19	99.4	0.0	0.0	0.0	0.0
28	10/5/2012 9:17	218.4	16.61	8.11	99.4	0.0	0.0	0.0	0.0
29	10/5/2012 9:18	218.2	16.60	8.21	98.9	0.0	0.0	0.0	0.0
30	10/5/2012 9:19	218.9	13.89	5.97	79.9	0.0	0.0	0.0	0.0
31	10/5/2012 9:20	220.9	13.16	6.59	80.1	0.0	0.0	0.0	0.0
32	10/5/2012 9:21	222.2	13.19	6.56	80.0	0.0	0.0	0.0	0.0
33	10/5/2012 9:22	223.8	12.19	6.50	55.9	49.9	0.0	0.0	0.0
34	10/5/2012 9:23	224.7	13.68	8.48	55.9	62.0	0.0	0.0	0.0
35	10/5/2012 9:24	222.7	18.35	9.71	70.1	70.0	0.0	0.0	0.0
36	10/5/2012 9:25	218.4	19.80	10.12	71.0	75.0	0.0	0.0	0.0
37	10/5/2012 9:26	214.7	19.75	9.94	71.1	74.8	0.0	0.0	0.0
38	10/5/2012 9:27	211.9	21.29	13.81	79.2	79.7	0.0	0.0	0.0
39	10/5/2012 9:28	207.9	23.18	13.28	90.0	79.9	0.0	0.0	0.0
40	10/5/2012 9:29	203.1	23.44	12.68	95.1	79.9	0.0	0.0	0.0
41	10/5/2012 9:30	198.4	24.63	13.59	98.2	79.8	0.0	0.0	0.0
42	10/5/2012 9:31	193.6	26.28	15.06	97.9	90.0	0.0	0.0	0.0
43	10/5/2012 9:32	187.7	27.05	17.52	98.3	99.0	0.0	0.0	0.0
44	10/5/2012 9:33	181.1	27.71	16.24	99.4	99.0	0.0	0.0	0.0
45	10/5/2012 9:34	176.8	27.78	16.26	99.2	98.8	0.0	0.0	0.0
46	10/5/2012 9:35	173.2	20.31	9.83	75.2	75.0	0.0	0.0	0.0
47	10/5/2012 9:36	177.2	16.54	9.62	60.0	59.9	60.1	0.0	0.0
48	10/5/2012 9:37	180.2	23.22	14.28	70.0	79.9	75.0	0.0	0.0
49	10/5/2012 9:38	177.7	27.69	17.65	99.2	79.9	75.1	0.0	0.0
50	10/5/2012 9:39	173.0	29.04	17.27	99.0	82.8	75.1	0.0	0.0
51	10/5/2012 9:40	169.2	30.51	19.92	99.2	95.0	75.1	0.0	0.0
52	10/5/2012 9:41	165.1	33.28	23.72	99.0	98.9	99.3	0.0	0.0
53	10/5/2012 9:42	159.0	34.49	22.78	99.2	98.9	99.2	0.0	0.0
54	10/5/2012 9:43	152.7	33.47	18.56	99.2	99.2	80.1	0.0	0.0

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
55	10/5/2012 9:44	151.1	26.69	14.95	80.0	79.9	80.0	0.0	0.0
56	10/5/2012 9:45	150.9	25.93	14.18	80.0	79.9	75.2	0.0	0.0
57	10/5/2012 9:46	151.1	25.38	13.83	80.1	74.9	75.0	0.0	0.0
58	10/5/2012 9:47	151.0	27.52	16.63	80.0	74.9	75.1	74.9	0.0
59	10/5/2012 9:48	148.9	29.35	18.49	80.1	74.8	75.1	92.1	0.0
60	10/5/2012 9:49	144.9	30.53	20.16	80.0	74.9	82.1	99.3	0.0
61	10/5/2012 9:50	139.3	32.88	22.15	90.0	81.9	82.1	99.1	0.0
62	10/5/2012 9:51	132.1	34.79	26.25	99.1	98.9	82.1	99.2	0.0
63	10/5/2012 9:52	122.2	37.61	26.81	99.2	99.0	96.2	99.3	0.0
64	10/5/2012 9:53	106.7	38.10	26.81	99.2	99.0	99.2	99.3	0.0

Low to High Flow Test – Air Valves Closed

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
0	10/5/2012 11:18	244.0	6.43	5.31	49.9	0.0	0.0	0.0	0.0
1	10/5/2012 11:19	243.2	7.26	4.17	0.0	0.0	0.0	0.0	0.0
2	10/5/2012 11:20	244.5	6.99	4.79	0.0	50.9	0.0	0.0	0.0
3	10/5/2012 11:21	245.5	7.58	4.57	0.0	50.9	0.0	0.0	0.0
4	10/5/2012 11:22	246.7	7.64	4.55	0.0	51.0	0.0	0.0	0.0
5	10/5/2012 11:23	247.6	8.30	4.92	0.0	54.9	0.0	0.0	0.0
6	10/5/2012 11:24	232.7	9.24	6.54	0.0	65.8	0.0	0.0	0.0
7	10/5/2012 11:25	233.6	11.22	6.62	0.0	69.8	0.0	0.0	0.0
8	10/5/2012 11:26	233.6	12.57	6.30	0.0	75.8	0.0	0.0	0.0
9	10/5/2012 11:27	229.2	13.80	7.95	0.0	84.1	0.0	0.0	0.0
10	10/5/2012 11:28	248.5	15.29	7.86	0.0	91.0	0.0	0.0	0.0
11	10/5/2012 11:29	248.1	16.63	9.06	0.0	98.9	0.0	0.0	0.0
12	10/5/2012 11:30	246.6	19.15	10.76	0.0	99.0	50.1	0.0	0.0
13	10/5/2012 11:31	244.6	19.92	10.18	0.0	98.9	50.1	0.0	0.0
14	10/5/2012 11:32	242.5	19.91	10.24	0.0	98.9	50.1	0.0	0.0
15	10/5/2012 11:33	240.1	22.56	12.87	0.0	98.8	66.1	0.0	0.0
16	10/5/2012 11:34	236.6	24.55	13.77	0.0	98.7	76.2	0.0	0.0
17	10/5/2012 11:35	232.1	25.97	14.95	0.0	98.9	85.2	0.0	0.0
18	10/5/2012 11:36	227.6	27.42	16.43	0.0	98.9	95.1	0.0	0.0
19	10/5/2012 11:37	222.2	29.80	18.71	0.0	99.1	99.3	59.9	0.0
20	10/5/2012 11:38	216.6	30.15	18.59	0.0	98.9	99.3	60.0	0.0
21	10/5/2012 11:39	210.9	31.68	20.29	0.0	98.7	99.3	74.9	0.0
22	10/5/2012 11:40	205.3	31.74	20.10	0.0	99.1	99.2	75.0	0.0
23	10/5/2012 11:41	199.8	31.55	20.13	0.0	98.9	99.1	76.0	0.0
24	10/5/2012 11:42	194.5	31.75	20.63	0.0	99.0	99.2	78.9	0.0
25	10/5/2012 11:43	190.2	33.41	21.97	0.0	98.9	99.2	89.9	0.0
26	10/5/2012 11:44	185.1	35.11	25.47	0.0	99.0	99.3	99.4	69.1
27	10/5/2012 11:45	179.4	37.78	27.28	0.0	98.8	99.1	99.4	90.9
28	10/5/2012 11:46	174.1	38.93	28.23	0.0	99.0	99.1	99.1	99.2
29	10/5/2012 11:47	168.8	38.76	28.01	0.0	99.0	99.1	99.2	99.2
30	10/5/2012 11:48	164.4	38.94	27.91	0.0	98.9	99.1	99.2	99.3
31	10/5/2012 11:49	160.9	39.07	27.78	0.0	98.9	99.2	99.3	99.2
32	10/5/2012 11:50	159.0	39.25	27.78	0.0	98.9	99.2	99.3	99.2
33	10/5/2012 11:51	155.0	38.86	27.79	0.0	99.1	99.2	99.2	99.1
34	10/5/2012 11:52	153.1	38.75	27.51	0.0	98.9	99.2	99.2	99.1
35	10/5/2012 11:53	149.6	38.79	27.48	0.0	98.9	99.2	99.3	99.2
36	10/5/2012 11:54	146.0	38.64	27.42	0.0	99.0	99.3	99.3	99.0
37	10/5/2012 11:55	143.2	38.49	27.48	0.0	99.0	99.2	99.2	99.3
38	10/5/2012 11:56	140.1	38.74	27.31	0.0	98.9	99.2	99.4	99.3
39	10/5/2012 11:57	136.6	39.02	27.22	0.0	98.9	99.2	99.2	99.1

High to Low Flow – Air Valves Open

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
0	12/20/2012 11:01	134.4	38.10	26.18	0.0	98.8	99.2	92.9	99.0
1	12/20/2012 11:02	129.8	37.09	25.43	0.0	99.0	99.1	87.9	98.8
2	12/20/2012 11:03	123.7	36.10	24.86	0.0	98.9	99.1	81.5	98.8
3	12/20/2012 11:04	115.7	35.50	23.86	0.0	98.8	99.0	72.3	98.9
4	12/20/2012 11:05	105.6	33.28	21.30	0.0	99.1	99.2	57.8	98.9
5	12/20/2012 11:06	96.8	34.00	21.37	0.0	98.9	99.1	0.0	99.0
6	12/20/2012 11:07	89.0	32.02	19.25	0.0	98.9	99.2	0.0	88.8
7	12/20/2012 11:08	90.7	25.44	11.58	0.0	99.0	85.1	0.0	0.0
8	12/20/2012 11:09	104.7	22.34	14.59	0.0	98.8	80.1	0.0	0.0
9	12/20/2012 11:10	116.2	25.17	17.69	0.0	98.9	99.2	0.0	0.0
10	12/20/2012 11:11	124.9	25.29	17.52	0.0	98.9	99.2	0.0	0.0
11	12/20/2012 11:12	129.0	24.17	18.06	0.0	98.7	94.1	0.0	0.0
12	12/20/2012 11:13	132.1	24.87	16.79	0.0	98.9	92.7	0.0	0.0
13	12/20/2012 11:14	137.3	22.60	15.19	0.0	98.8	81.9	0.0	0.0
14	12/20/2012 11:15	143.9	19.71	14.24	0.0	98.8	69.1	0.0	0.0
15	12/20/2012 11:16	150.1	22.06	15.34	0.0	98.8	79.0	0.0	0.0
16	12/20/2012 11:17	156.5	19.12	12.87	0.0	98.9	63.1	0.0	0.0
17	12/20/2012 11:18	162.6	18.58	13.97	0.0	98.9	63.1	0.0	0.0
18	12/20/2012 11:19	164.7	20.04	13.75	0.0	99.1	69.1	0.0	0.0
19	12/20/2012 11:20	166.3	16.43	8.20	0.0	98.7	0.0	0.0	0.0
20	12/20/2012 11:21	168.6	15.94	8.80	0.0	97.8	0.0	0.0	0.0
21	12/20/2012 11:22	171.2	14.76	7.76	0.0	92.7	0.0	0.0	0.0
22	12/20/2012 11:23	172.8	13.91	7.25	0.0	87.9	0.0	0.0	0.0
23	12/20/2012 11:24	175.2	12.74	6.54	0.0	82.1	0.0	0.0	0.0
24	12/20/2012 11:25	177.8	11.46	6.09	0.0	74.8	0.0	0.0	0.0
25	12/20/2012 11:26	180.4	10.45	6.03	0.0	70.0	0.0	0.0	0.0
26	12/20/2012 11:27	183.6	10.36	5.97	0.0	70.0	0.0	0.0	0.0
27	12/20/2012 11:28	186.3	10.09	5.89	0.0	67.8	0.0	0.0	0.0
28	12/20/2012 11:29	189.3	9.16	5.43	0.0	58.9	0.0	0.0	0.0
29	12/20/2012 11:30	193.2	7.35	4.84	0.0	53.9	0.0	0.0	0.0

High to Low Flow – Air Valves Closed

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
0	12/20/2012 12:33	160.6	37.60	27.04	98.9	98.9	99.2	0.0	91.8
1	12/20/2012 12:34	144.5	36.64	25.20	99.4	98.9	98.9	0.0	84.8
2	12/20/2012 12:35	130.8	35.68	22.91	99.1	98.9	99.2	0.0	67.7
3	12/20/2012 12:36	120.8	34.33	22.08	99.0	98.9	99.2	0.0	59.9
4	12/20/2012 12:37	112.1	36.06	24.00	99.1	98.9	99.3	0.0	78.0
5	12/20/2012 12:38	100.7	34.29	21.24	99.1	99.0	99.2	0.0	0.0
6	12/20/2012 12:39	96.5	31.31	17.89	90.2	98.9	85.1	0.0	0.0
7	12/20/2012 12:40	99.3	29.51	17.94	94.1	98.9	80.1	0.0	0.0
8	12/20/2012 12:41	105.0	28.93	16.79	94.0	98.9	70.2	0.0	0.0
9	12/20/2012 12:42	113.6	28.30	15.63	94.2	98.7	60.0	0.0	0.0
10	12/20/2012 12:43	122.4	27.69	15.64	94.1	99.0	58.0	0.0	0.0
11	12/20/2012 12:44	125.7	25.90	14.66	94.0	98.9	0.0	0.0	0.0
12	12/20/2012 12:45	128.9	24.81	14.54	88.1	99.0	0.0	0.0	0.0
13	12/20/2012 12:46	133.6	23.91	15.15	88.1	98.9	0.0	0.0	0.0
14	12/20/2012 12:47	136.9	22.97	14.30	81.0	98.6	0.0	0.0	0.0
15	12/20/2012 12:48	141.3	22.18	13.43	76.1	98.7	0.0	0.0	0.0
16	12/20/2012 12:49	145.5	20.24	12.29	67.0	99.0	0.0	0.0	0.0
17	12/20/2012 12:50	150.5	20.63	11.80	67.0	98.8	0.0	0.0	0.0
18	12/20/2012 12:51	153.6	19.68	10.65	60.0	98.8	0.0	0.0	0.0
19	12/20/2012 12:52	156.4	18.79	9.90	54.0	98.9	0.0	0.0	0.0
20	12/20/2012 12:53	159.7	15.65	7.51	0.0	98.8	0.0	0.0	0.0
21	12/20/2012 12:54	162.5	15.76	8.36	0.0	98.7	0.0	0.0	0.0
22	12/20/2012 12:55	163.0	15.78	8.10	0.0	99.0	0.0	0.0	0.0
23	12/20/2012 12:56	164.1	14.01	7.16	0.0	90.1	0.0	0.0	0.0
24	12/20/2012 12:57	165.0	13.51	6.90	0.0	86.9	0.0	0.0	0.0
25	12/20/2012 12:58	165.6	12.41	6.24	0.0	80.8	0.0	0.0	0.0
26	12/20/2012 12:59	166.7	11.12	5.80	0.0	75.0	0.0	0.0	0.0
27	12/20/2012 13:00	167.8	10.92	6.35	0.0	75.0	0.0	0.0	0.0
28	12/20/2012 13:01	168.3	9.62	5.58	0.0	67.9	0.0	0.0	0.0
29	12/20/2012 13:02	169.0	8.52	3.41	0.0	56.6	0.0	0.0	0.0
30	12/20/2012 13:03	170.0	7.35	4.84	0.0	56.9	0.0	0.0	0.0

October 12th Compressed Air Test

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
0	10/12/2012 11:59	231.2	7.48	16.13	0.0	74.9	0.0	0.0	0.0
1	10/12/2012 12:00	229.1	7.72	16.86	0.0	75.0	0.0	0.0	0.0
2	10/12/2012 12:01	228.7	7.58	17.18	0.0	74.9	0.0	0.0	0.0
3	10/12/2012 12:02	228.8	7.44	17.59	0.0	75.0	0.0	0.0	0.0
4	10/12/2012 12:03	229.3	7.32	17.83	0.0	74.8	0.0	0.0	0.0
5	10/12/2012 12:04	229.9	8.59	18.28	0.0	81.0	0.0	0.0	0.0
6	10/12/2012 12:05	230.4	8.76	18.60	0.0	80.9	0.0	0.0	0.0
7	10/12/2012 12:06	231.5	8.68	18.79	0.0	80.8	0.0	0.0	0.0
8	10/12/2012 12:07	232.0	10.10	19.17	0.0	85.9	0.0	0.0	0.0
9	10/12/2012 12:08	232.2	11.07	19.54	0.0	89.9	0.0	0.0	0.0
10	10/12/2012 12:09	231.4	12.02	19.91	0.0	94.0	0.0	0.0	0.0
11	10/12/2012 12:10	230.7	12.91	20.33	0.0	97.8	0.0	0.0	0.0
12	10/12/2012 12:11	229.7	13.16	20.71	0.0	99.3	0.0	0.0	0.0
13	10/12/2012 12:12	228.7	16.45	21.50	0.0	99.0	0.0	0.0	69.9
14	10/12/2012 12:13	224.7	21.88	13.68	0.0	99.1	0.0	0.0	69.9
15	10/12/2012 12:14	217.1	26.55	7.41	0.0	99.0	0.0	0.0	69.8
16	10/12/2012 12:15	210.1	25.64	4.32	0.0	99.0	0.0	0.0	49.9
17	10/12/2012 12:16	209.4	18.43	2.69	0.0	59.5	0.0	0.0	49.9
18	10/12/2012 12:17	213.0	16.75	3.97	0.0	59.9	0.0	0.0	49.7
19	10/12/2012 12:18	217.9	16.61	4.04	0.0	60.0	0.0	0.0	49.9
20	10/12/2012 12:19	222.4	16.65	4.13	0.0	60.0	0.0	0.0	49.8
21	10/12/2012 12:20	227.1	16.73	4.13	0.0	59.9	0.0	0.0	49.8
22	10/12/2012 12:21	230.7	16.87	4.05	0.0	59.9	0.0	0.0	49.8
23	10/12/2012 12:22	233.5	16.99	4.08	0.0	59.9	0.0	0.0	49.9
24	10/12/2012 12:23	235.7	16.65	4.57	0.0	59.9	0.0	0.0	49.9
25	10/12/2012 12:24	237.4	16.01	5.39	0.0	59.9	0.0	0.0	49.8
26	10/12/2012 12:25	239.6	14.66	6.62	0.0	59.9	0.0	0.0	49.8
27	10/12/2012 12:26	240.5	15.92	9.11	0.0	59.9	0.0	0.0	64.8
28	10/12/2012 12:27	241.5	15.75	12.01	0.0	59.9	0.0	0.0	75.9
29	10/12/2012 12:28	244.4	14.11	18.82	0.0	69.9	0.0	0.0	79.8
30	10/12/2012 12:29	247.4	15.40	20.55	0.0	79.8	0.0	0.0	79.9
31	10/12/2012 12:30	247.2	18.42	21.37	0.0	89.9	0.0	0.0	79.9
32	10/12/2012 12:31	246.9	19.47	22.21	0.0	90.0	0.0	0.0	85.9
33	10/12/2012 12:32	247.6	19.47	22.28	0.0	89.9	0.0	0.0	86.0
34	10/12/2012 12:33	248.5	20.34	22.98	0.0	94.9	0.0	0.0	90.9
35	10/12/2012 12:34	248.1	21.57	23.56	0.0	94.9	0.0	0.0	91.0
36	10/12/2012 12:35	248.9	21.35	23.20	0.0	94.9	0.0	0.0	90.9
37	10/12/2012 12:36	248.9	23.68	24.99	0.0	98.9	0.0	0.0	99.3
38	10/12/2012 12:37	248.8	23.87	24.76	0.0	99.0	0.0	0.0	99.1
39	10/12/2012 12:38	248.7	23.96	24.71	0.0	99.2	0.0	0.0	99.1
40	10/12/2012 12:39	248.7	26.81	26.94	0.0	99.0	0.0	75.0	99.2
41	10/12/2012 12:40	248.9	22.67	24.49	0.0	80.3	0.0	74.9	99.2
42	10/12/2012 12:41	247.1	26.72	26.95	0.0	99.0	0.0	74.8	99.2
43	10/12/2012 12:42	245.5	27.31	26.78	0.0	98.9	0.0	75.0	99.2
44	10/12/2012 12:43	244.0	27.91	25.45	0.0	98.9	0.0	75.0	99.3
45	10/12/2012 12:44	240.8	30.78	23.03	0.0	99.0	0.0	81.0	99.1
46	10/12/2012 12:45	235.5	31.74	24.74	0.0	98.8	0.0	90.0	99.1
47	10/12/2012 12:46	232.6	33.99	25.09	0.0	98.9	0.0	96.0	99.2
48	10/12/2012 12:47	227.5	34.24	25.36	0.0	98.8	0.0	99.2	99.3
49	10/12/2012 12:48	222.7	34.00	24.99	0.0	99.0	0.0	99.2	99.2
50	10/12/2012 12:49	218.2	33.95	24.86	0.0	98.9	0.0	99.2	99.2
51	10/12/2012 12:50	215.0	29.81	20.60	0.0	69.9	35.4	99.2	99.1
52	10/12/2012 12:51	210.8	32.07	23.48	0.0	69.9	75.1	99.1	99.4
53	10/12/2012 12:52	205.0	33.79	25.58	0.0	84.9	75.1	99.3	99.2
54	10/12/2012 12:53	197.9	35.64	26.73	0.0	92.9	85.1	99.3	99.2

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
55	10/12/2012 12:54	190.4	36.60	26.72	0.0	92.9	90.2	99.3	99.2
56	10/12/2012 12:55	181.4	37.03	26.57	0.0	92.9	90.1	99.3	99.2
57	10/12/2012 12:56	174.1	37.09	26.66	0.0	92.9	90.1	99.2	99.1
58	10/12/2012 12:57	168.8	36.50	26.49	0.0	92.9	90.1	99.2	99.3
59	10/12/2012 12:58	165.0	34.71	24.80	0.0	84.9	85.1	99.3	99.3

October 19th Compressed Air Test

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
0	10/19/2012 9:10	212.5	2.97	11.12	0.0	0.0	50.1	0.0	0.0
1	10/19/2012 9:11	213.6	2.78	11.98	0.0	0.0	50.2	0.0	0.0
2	10/19/2012 9:12	215.2	2.73	12.36	0.0	0.0	50.2	0.0	0.0
3	10/19/2012 9:13	217.5	2.68	12.58	0.0	0.0	50.1	0.0	0.0
4	10/19/2012 9:14	220.7	2.72	12.83	0.0	0.0	50.2	0.0	0.0
5	10/19/2012 9:15	224.4	3.35	13.09	0.0	0.0	54.1	0.0	0.0
6	10/19/2012 9:16	227.3	3.30	13.46	0.0	0.0	54.1	0.0	0.0
7	10/19/2012 9:17	230.7	4.10	13.84	0.0	0.0	58.1	0.0	0.0
8	10/19/2012 9:18	233.3	7.32	14.44	0.0	0.0	70.1	0.0	0.0
9	10/19/2012 9:19	233.9	8.24	15.32	0.0	0.0	73.9	0.0	0.0
10	10/19/2012 9:20	234.0	9.04	16.24	0.0	0.0	78.0	0.0	0.0
11	10/19/2012 9:21	234.0	9.70	17.12	0.0	0.0	81.9	0.0	0.0
12	10/19/2012 9:22	234.0	10.56	17.80	0.0	0.0	86.2	0.0	0.0
13	10/19/2012 9:23	234.1	11.80	18.38	0.0	0.0	90.1	0.0	0.0
14	10/19/2012 9:24	233.7	11.61	18.76	0.0	0.0	90.1	0.0	0.0
15	10/19/2012 9:25	233.8	12.52	19.22	0.0	0.0	94.1	0.0	0.0
16	10/19/2012 9:26	233.6	12.45	19.51	0.0	0.0	94.0	0.0	0.0
17	10/19/2012 9:27	233.3	13.89	20.00	0.0	0.0	98.2	0.0	0.0
18	10/19/2012 9:28	233.5	14.65	20.24	0.0	0.0	99.2	27.3	0.0
19	10/19/2012 9:29	233.2	14.84	20.52	0.0	0.0	99.2	0.0	0.0
20	10/19/2012 9:30	232.9	15.48	21.80	0.0	0.0	99.1	0.0	63.8
21	10/19/2012 9:31	231.3	16.54	20.46	0.0	0.0	99.1	0.0	63.8
22	10/19/2012 9:32	228.9	25.06	8.38	0.0	0.0	99.2	0.0	67.9
23	10/19/2012 9:33	221.4	27.61	6.56	0.0	0.0	99.3	0.0	71.8
24	10/19/2012 9:34	214.5	21.97	3.44	0.0	0.0	60.1	0.0	71.8
25	10/19/2012 9:35	213.7	16.69	3.80	0.0	0.0	60.0	0.0	49.9
26	10/19/2012 9:36	215.3	17.15	4.10	0.0	0.0	65.1	0.0	49.8
27	10/19/2012 9:37	216.1	17.98	4.32	0.0	0.0	70.3	0.0	49.9
28	10/19/2012 9:38	216.6	18.14	4.36	0.0	0.0	70.3	0.0	49.8
29	10/19/2012 9:39	217.0	18.63	4.57	0.0	0.0	74.0	0.0	49.8
30	10/19/2012 9:40	217.3	18.52	4.84	0.0	0.0	74.3	0.0	49.9
31	10/19/2012 9:41	(null)	18.52	4.84	(null)	(null)	74.3	0.0	49.9
32	10/19/2012 9:42	218.8	16.88	8.35	0.0	0.0	82.1	0.0	49.9
33	10/19/2012 9:43	220.6	16.16	10.60	0.0	0.0	86.0	0.0	49.8
34	10/19/2012 9:44	223.2	14.35	14.73	0.0	0.0	90.3	0.0	49.8
35	10/19/2012 9:45	227.4	12.21	19.51	0.0	0.0	94.1	0.0	48.8
36	10/19/2012 9:46	229.4	22.57	25.17	99.0	0.0	99.1	0.0	0.0
37	10/19/2012 9:47	225.8	23.56	24.49	99.1	0.0	99.3	0.0	0.0
38	10/19/2012 9:48	223.0	23.56	24.55	99.2	0.0	99.1	0.0	0.0
39	10/19/2012 9:49	221.3	23.58	24.52	99.0	54.9	99.4	0.0	0.0
40	10/19/2012 9:50	220.0	23.80	24.08	99.3	0.0	99.2	0.0	49.8
41	10/19/2012 9:51	217.9	26.31	23.42	99.2	0.0	99.1	0.0	64.7
42	10/19/2012 9:52	214.8	27.85	21.84	99.0	0.0	99.1	0.0	64.9
43	10/19/2012 9:53	211.3	29.21	22.50	99.3	0.0	99.1	0.0	72.9
44	10/19/2012 9:54	209.0	29.45	22.12	99.4	0.0	99.2	0.0	72.8
45	10/19/2012 9:55	208.3	29.37	28.39	99.2	84.9	99.2	0.0	0.0
46	10/19/2012 9:56	207.2	28.25	21.27	99.2	98.9	0.0	65.0	0.0
47	10/19/2012 9:57	206.1	29.25	21.53	99.1	98.9	0.0	69.0	0.0
48	10/19/2012 9:58	204.8	30.10	21.31	99.0	99.0	0.0	72.9	0.0
49	10/19/2012 9:59	204.5	27.78	24.05	99.1	99.0	0.0	77.2	0.0
50	10/19/2012 10:00	202.0	30.21	21.86	99.3	98.9	0.0	76.9	0.0
51	10/19/2012 10:01	197.7	31.84	21.12	99.0	99.0	0.0	81.0	0.0
52	10/19/2012 10:02	194.2	31.14	22.78	99.1	99.0	0.0	85.0	0.0
53	10/19/2012 10:03	190.8	33.21	23.10	99.1	99.1	0.0	92.8	0.0
54	10/19/2012 10:04	187.1	33.57	23.94	99.1	99.0	0.0	97.0	0.0

Duration (minutes)	Date / Time	Wetwell Level (in)	Discharge Flow (mgd)	Discharge Pressure (psi)	Pump 1 Speed (%)	Pump 2 Speed (%)	Pump 3 Speed (%)	Pump 4 Speed (%)	Pump 5 Speed (%)
55	10/19/2012 10:05	184.4	33.46	23.85	99.3	98.9	0.0	97.0	0.0
56	10/19/2012 10:06	180.8	34.31	23.94	99.1	98.9	0.0	99.2	0.0
57	10/19/2012 10:07	177.9	34.89	25.05	99.0	98.9	0.0	99.3	63.9
58	10/19/2012 10:08	175.2	35.50	25.43	99.1	98.9	0.0	99.4	72.0
59	10/19/2012 10:09	172.7	36.25	26.43	99.1	99.0	0.0	99.3	79.8
60	10/19/2012 10:10	169.5	37.69	27.45	99.3	99.0	0.0	99.5	91.7
61	10/19/2012 10:11	166.6	37.36	28.04	99.3	99.0	0.0	99.2	95.8
62	10/19/2012 10:12	163.5	38.76	28.30	99.3	99.0	0.0	99.3	99.4
63	10/19/2012 10:13	162.7	38.60	28.21	99.2	98.9	0.0	99.4	99.2
64	10/19/2012 10:14	157.7	38.16	28.13	99.1	99.0	0.0	99.4	99.2
65	10/19/2012 10:15	154.5	38.60	28.04	99.1	99.0	0.0	99.3	99.1

APPENDIX C

HYDRAULIC CALCULATIONS

October 12th Field Test Effective Flow Area Calculations

Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)
7.58	8.59	10.1	11.07	12.02	12.91	13.16
Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)
5264	5965	7013	7687	8347	8965	9138
Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)
12	13	16	17	19	20	20

Diameter (in)	Diameter (in)	Diameter (in)
36.8	36	28
Area (ft^2)	Area (ft^2)	Area (ft^2)
7.4	7.1	4.3
Velocity (fps)	Velocity (fps)	Velocity (fps)
8.3	8.6	14.3

HDPE C= 120
Steel C= 100

Red Dia (in) @ 7.58 mgd	Red Dia (in) @ 8.59 mgd	Red Dia (in) @ 10.1mgd	Red Dia (in) @ 11.07 mgd	Red Dia (in) @ 12.02 mgd	Red Dia (in) @ 12.91mgd	Red Dia (in) @ 13.16 mgd
20.19	20.85	21.95	22.58	23.3	23.88	23.94
Red Area (ft^2)	Red Area (ft^2)	Red Area (ft^2)	Red Area (ft^2)	Red Area (ft^2)	Red Area (ft^2)	Red Area (ft^2)
2.2	2.4	2.6	2.8	3.0	3.1	3.1
Red Vel (fps)	Red Vel (fps)	Red Vel (fps)	Red Vel (fps)	Red Vel (fps)	Red Vel (fps)	Red Vel (fps)
5.3	5.6	6.0	6.2	6.3	6.4	6.5
% Full Flow Ar	% Full Flow A	% Full Flow Are	% Full Flow Are	% Full Flow Are	% Full Flow Are	% Full Flow Are
30%	32%	36%	38%	40%	42%	42%

	Pressure Head @ 7.58 mgd (ft)	Pressure Head @ 8.59 mgd (ft)	Pressure Head @ 10.1 mgd (ft)	Pressure Head @ 11.07 mgd (ft)	Pressure Head @ 12.02 mgd (ft)	Pressure Head @ 12.91 mgd (ft)	Pressure Head @ 13.16 mgd (ft)
Field Test:	34.72	37.26	39.32	40.69	41.03	41.99	42.87
Hyd Calcs:	34.7	37.2	39.3	40.7	41.1	41.9	42.8

Segment 1: Full-Pipe Flow (36.8" HDPE)										
Type of Loss	**Location**	**Quantity**	**K (loss coeff)**	**hL (ft) at 7.58 mgd**	**hL (ft) at 8.59 mgd**	**hL (ft) at 10.1 mgd**	**hL (ft) at 11.07 mgd**	**hL (ft) at 12.02 mgd**	**hL (ft) at 12.91mgd**	**hL (ft) at 13.16 mgd**
Elevation	Plant No. 2 Vortex Structure	1		5.8	5.8	5.8	5.8	5.8	5.8	5.8
Exit	Plant No. 2 Vortex Structure	1	1	0.0	0.1	0.1	0.1	0.1	0.1	0.1
90 deg Bend	Sta. 75+70.36	1	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	75+70.36 to 75+50	20		0.0	0.0	0.0	0.0	0.0	0.0	0.0
58 deg Bend	Sta. 75+50	1	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18 deg Bend	Sta. 75+50	2	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45 deg Bend	Sta. 75+50	1	0.18	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	75+50 to 72+75	275		0.1	0.1	0.1	0.2	0.2	0.2	0.2
22.5 deg Bend	Sta. 72+75	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	72+75 to 72+65.41	9.6		0.0	0.0	0.0	0.0	0.0	0.0	0.0
51 deg Bend	Sta. 72+65.41	1	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	72+65.41 to 58+78.92	1386		0.4	0.5	0.6	0.8	0.9	1.0	1.1
90 deg Bend	Sta. 58+78.92	1	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	58+78.92 to 58+50	29		0.0	0.0	0.0	0.0	0.0	0.0	0.0
45 deg Bend	Sta. 58+50	2	0.18	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Segment 2: Decreased Pipe Flow from Air (36.8" HDPE)										
Type of Loss	**Location**	**Quantity**	**K (loss coeff)**	**hL (ft) at 7.58 mgd**	**hL (ft) at 8.59 mgd**	**hL (ft) at 10.1 mgd**	**hL (ft) at 11.07 mgd**	**hL (ft) at 12.02 mgd**	**hL (ft) at 12.91mgd**	**hL (ft) at 13.16 mgd**
Pipeline	58+50 to 57+98.84	51		0.3	0.3	0.3	0.3	0.3	0.3	0.3
11 deg Bend	Sta. 57+98.84	1	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	57+98.84 to 55+58.96	240		1.2	1.3	1.4	1.4	1.4	1.4	1.5
15 deg Bend	Sta. 55+58.96	1	0.08	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Pipeline	55+58.96 to 55+26.71	32		0.2	0.2	0.2	0.2	0.2	0.2	0.2
15 deg Bend	Sta. 55+26.71	1	0.08	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Pipeline	55+26.71 to 38+75.69	1651		8.4	9.1	9.5	9.8	9.8	9.9	10.2
43 deg Bend	Sta. 38+75.69	1	0.18	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pipeline	38+75.69 to 33+46.03	530		2.7	2.9	3.1	3.1	3.1	3.2	3.3
5 deg Bend	Sta. 33+46.03	1	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	33+46.03 to 27+49.94	596		3.0	3.3	3.4	3.5	3.5	3.6	3.7
12 deg Bend	Sta. 27+49.94	1	0.08	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Pipeline	27+49.94 to 24+83.99	266		1.4	1.5	1.5	1.6	1.6	1.6	1.6
20 deg Bend	Sta. 24+83.99	1	0.08	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Pipeline	24+83.99 to 22+66.88	217		1.1	1.2	1.3	1.3	1.3	1.3	1.3
18 deg Bend	St. 22+66.88	1	0.08	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Pipeline	22+66.88-10+00	1267		6.4	6.9	7.3	7.5	7.5	7.6	7.8
Pipeline	10+94 to 10+76.73	17.27		0.1	0.1	0.1	0.1	0.1	0.1	0.1
54 deg bend	Sta. 10+76.73	1	0.25	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Pipeline	10+76.73 to 10+25.94	50.79		0.3	0.3	0.3	0.3	0.3	0.3	0.3
50 deg bend	Sta. 10+25.94	1	0.25	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Pipeline	10+25.94 to 10+23.31	2.63		0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.5 deg Bend	Sta. 10+23.31	1	0.08	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Pipeline	10+23.31 to 10+14.25	9.06		0.0	0.0	0.1	0.1	0.1	0.1	0.1
22.5 deg Bend	Sta. 10+14.25	1	0.08	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Pipeline	10+14.25 to 10+00	14.25		0.1	0.1	0.1	0.1	0.1	0.1	0.1
Segment 3: Decreased Pipe Flow from Air (36" Steel)										
Type of Loss	**Location**	**Quantity**	**K (loss coeff)**	**hL (ft) at 7.58 mgd**	**hL (ft) at 8.59 mgd**	**hL (ft) at 10.1 mgd**	**hL (ft) at 11.07 mgd**	**hL (ft) at 12.02 mgd**	**hL (ft) at 12.91mgd**	**hL (ft) at 13.16 mgd**
36" Pipeline	BPPS	47		0.3	0.4	0.4	0.4	0.4	0.4	0.4
Plug Valves	BPPS	1	1	0.4	0.5	0.6	0.6	0.6	0.6	0.7
Tee	BPPS	1	0.3	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Plug Valves	BPPS	1	1	0.4	0.5	0.6	0.6	0.6	0.6	0.7
Expansion (28" to 36")	BPPS	1	0.8	0.3	0.4	0.4	0.5	0.5	0.5	0.5
28" Pipeline	BPPS	12		0.1	0.1	0.1	0.2	0.2	0.2	0.2
Contraction (28" to 36")	BPPS	1	0.28	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Plug Valves	BPPS	1	1	0.4	0.5	0.6	0.6	0.6	0.6	0.7
45 deg Bend	BPPS	1	0.18	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Wye	BPPS	1	0.5	0.2	0.2	0.3	0.3	0.3	0.3	0.3

October 19th Compressed Air Test Effective Flow Area Calculations

Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)
2.72	3.3	4.1	7.32	8.24	9.7	10.56	11.8	12.52	13.89	14.84	15.48
Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)
1889	2292	2847	5083	5722	6736	7333	8194	8694	9645	10305	10749
Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)
4	5	6	11	13	15	16	18	19	22	23	24

Diameter (in)	Diameter (in)	Diameter (in)
36.8	36	28
Area (ft^2)	Area (ft^2)	Area (ft^2)
7.4	7.1	4.3
Velocity (fps)	Velocity (fps)	Velocity (fps)
8.3	8.6	14.3

HDPE C= 120
Steel C= 100

Red Dia (in) @ 2.72 mgd	Red Dia (in) @ 3.3 mgd	Red Dia (in) @ 4.1mgd	Red Dia (in) @ 7.32 mgd	Red Dia (in) @ 8.24 mgd	Red Dia (in) @ 9.7mgd	Red Dia (in) @ 10.56 mgd	Red Dia (in) @ 11.8 mgd	Red Dia (in) @ 12.52 mgd	Red Dia (in) @ 13.89 mgd	Red Dia (in) @ 14.84 mgd	Red Dia (in) @ 15.48 mgd
14.77	15.67	16.92	20.98	21.59	22.3	22.83	23.85	24.24	25.17	25.85	25.97
Red Area (ft^2)	Red Area (ft^2)	Red Area (ft^2)	Red Area (ft^2)	Red Area (ft^2)	Red Area (ft^2)	Red Area (ft^2)	Red Area (ft^2)	Red Area (ft^2)	Red Area (ft^2)	Red Area (ft^2)	Red Area (ft^2)
1.2	1.3	1.6	2.4	2.5	2.7	2.8	3.1	3.2	3.5	3.6	3.7
Red Vel (fps)	Red Vel (fps)	Red Vel (fps)	Red Vel (fps)	Red Vel (fps)	Red Vel (fps)	Red Vel (fps)	Red Vel (fps)	Red Vel (fps)	Red Vel (fps)	Red Vel (fps)	Red Vel (fps)
3.5	3.8	4.1	4.7	5.0	5.5	5.8	5.9	6.0	6.2	6.3	6.5
% Full Flow Ar	% Full Flow Ar	% Full Flow Are	% Full Flow Are	% Full Flow Are	% Full Flow Are	% Full Flow Ar	% Full Flow Are	% Full Flow Are	% Full Flow Are	% Full Flow Are	% Full Flow Are
16%	18%	21%	33%	34%	37%	38%	42%	43%	47%	49%	50%

	Pressure Head @ 2.72 mgd (ft)	Pressure Head @ 3.3 mgd (ft)	Pressure Head @ 4.1 mgd (ft)	Pressure Head @ 7.32 mgd (ft)	Pressure Head @ 8.24 mgd (ft)	Pressure Head @ 9.7 mgd (ft)	Pressure Head @ 10.56 mgd (ft)	Pressure Head @ 11.8 mgd (ft)	Pressure Head @ 12.52 mgd (ft)	Pressure Head @ 13.89 mgd (ft)	Pressure Head @ 14.84 mgd (ft)	Pressure Head @ 15.48 mgd (ft)
Field Test:	24.67	26.13	27.00	28.39	30.42	34.58	36.15	37.49	39.43	41.24	42.43	45.39
Hyd Calcs:	24.7	26.2	27.0	28.4	30.5	34.6	36.1	37.4	39.5	41.3	42.4	45.4

Segment 1: Full-Pipe Flow (36.8" HDPE)

Type of Loss	Location	Quantity	K (loss coeff)	hL (ft) at 2.72 mgd	hL (ft) at 3.3 mgd	hL (ft) at 4.1 mgd	hL (ft) at 7.32 mgd	hL (ft) at 8.24 mgd	hL (ft) at 9.7mgd	hL (ft) at 10.56 mgd	hL (ft) at 11.8 mgd	hL (ft) at 12.52 mgd	hL (ft) at 13.89 mgd	hL (ft) at 14.84 mgd	hL (ft) at 15.48 mgd
Elevation	Plant No. 2 Vortex Structure	1		5.8	5.8	5.8	5.8	5.8	5.8	5.8	6.8	7.8	8.8	9.8	10.8
Exit	Plant No. 2 Vortex Structure	1	1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2
90 deg Bend	Sta. 75+70.36	1	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	75+70.36 to 75+50	20		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
58 deg Bend	Sta. 75+50	1	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18 deg Bend	Sta. 75+50	2	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45 deg Bend	Sta. 75+50	1	0.18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	75+50 to 72+75	275		0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3
22.5 deg Bend	Sta. 72+75	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	72+75 to 72+65.41	9.6		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
51 deg Bend	Sta. 72+65.41	1	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	72+65.41 to 58+78.92	1386		0.1	0.1	0.1	0.4	0.4	0.6	0.7	0.9	1.0	1.2	1.3	1.4
90 deg Bend	Sta. 58+78.92	1	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	58+78.92 to 58+50	29		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45 deg Bend	Sta. 58+50	2	0.18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1

Segment 2: Decreased Pipe Flow from Air (36.8" HDPE)

Type of Loss	Location	Quantity	K (loss coeff)	hL (ft) at 2.72 mgd	hL (ft) at 3.3 mgd	hL (ft) at 4.1 mgd	hL (ft) at 7.32 mgd	hL (ft) at 8.24 mgd	hL (ft) at 9.7mgd	hL (ft) at 10.56 mgd	hL (ft) at 11.8 mgd	hL (ft) at 12.52 mgd	hL (ft) at 13.89 mgd	hL (ft) at 14.84 mgd	hL (ft) at 15.48 mgd
Pipeline	58+50 to 57+98.84	51		0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
11 deg Bend	Sta. 57+98.84	1	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	57+98.84 to 55+58.96	240		0.8	0.9	0.9	0.9	1.0	1.2	1.2	1.2	1.3	1.3	1.3	1.3
15 deg Bend	Sta. 55+58.96	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Pipeline	55+58.96 to 55+26.71	32		0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
15 deg Bend	Sta. 55+26.71	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Pipeline	55+26.71 to 38+75.69	1651		5.8	6.2	6.4	6.5	7.1	8.2	8.5	8.5	8.7	8.8	8.7	9.2
43 deg Bend	Sta. 38+75.69	1	0.18	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pipeline	38+75.69 to 33+46.03	530		1.9	2.0	2.0	2.1	2.3	2.6	2.7	2.7	2.8	2.8	2.8	3.0
5 deg Bend	Sta. 33+46.03	1	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	33+46.03 to 27+49.94	596		2.1	2.2	2.3	2.4	2.6	3.0	3.1	3.1	3.2	3.2	3.2	3.3
12 deg Bend	Sta. 27+49.94	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Pipeline	27+49.94 to 24+83.99	266		0.9	1.0	1.0	1.1	1.1	1.3	1.4	1.4	1.4	1.4	1.4	1.5
20 deg Bend	Sta. 24+83.99	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Pipeline	24+83.99 to 22+66.88	217		0.8	0.8	0.8	0.9	0.9	1.1	1.1	1.1	1.1	1.2	1.1	1.2
18 deg Bend	St. 22+66.88	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Pipeline	22+66.88-10+00	1267		4.4	4.7	4.9	5.0	5.4	6.3	6.5	6.5	6.7	6.8	6.7	7.1
Pipeline	10+94 to 10+76.73	17.27		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
54 deg bend	Sta. 10+76.73	1	0.25	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Pipeline	10+76.73 to 10+25.94	50.79		0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3
50 deg bend	Sta. 10+25.94	1	0.25	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2
Pipeline	10+25.94 to 10+23.31	2.63		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.5 deg Bend	Sta. 10+23.31	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Pipeline	10+23.31 to 10+14.25	9.06		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
22.5 deg Bend	Sta. 10+14.25	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Pipeline	10+14.25 to 10+00	14.25		0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1

Segment 3: Decreased Pipe Flow from Air (36" Steel)

Type of Loss	Location	Quantity	K (loss coeff)	hL (ft) at 2.72 mgd	hL (ft) at 3.3 mgd	hL (ft) at 4.1 mgd	hL (ft) at 7.32 mgd	hL (ft) at 8.24 mgd	hL (ft) at 9.7mgd	hL (ft) at 10.56 mgd	hL (ft) at 11.8 mgd	hL (ft) at 12.52 mgd	hL (ft) at 13.89 mgd	hL (ft) at 14.84 mgd	hL (ft) at 15.48 mgd
36"Pipeline	BPPS	47		0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.3	0.4
Plug Valves	BPPS	1	1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.7
Tee	BPPS	1	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2
Plug Valves	BPPS	1	1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.7
Expansion (28" to 36")	BPPS	1	0.8	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.5	0.5
28" Pipeline	BPPS	12		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Contraction (28" to 36")	BPPS	1	0.28	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2
Plug Valves	BPPS	1	1	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.7
45 deg Bend	BPPS	1	0.18	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Wye	BPPS	1	0.5	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3

October 12th Field Test Hazen Williams Coefficient Calculations

Diameter (in)	Diameter (in)	Diameter (in)
36.8	36	28
Area (ft^2)	Area (ft^2)	Area (ft^2)
7.4	7.1	4.3
Velocity (fps)	Velocity (fps)	Velocity (fps)
8.3	8.6	14.3

Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)	Flow (mgd)
7.58	8.59	10.1	11.07	12.02	12.91	13.16
Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)	Flow (gpm)
5264	5965	7013	7687	8347	8965	9138
Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)	Flow (cfs)
12	13	16	17	19	20	20

HDPE C @ 7.58 mgd=	HDPE C @ 8.59 mgd=	HDPE C @ 10.1 mgd=	HDPE C @ 11.07 mgd=	HDPE C @ 12.02 mgd=	HDPE C @ 12.91 mgd=	HDPE C @ 13.16 mgd=
35	37	41	44	47	50	50

	Pressure Head @ 7.58 mgd (ft)	Pressure Head @ 8.59 mgd (ft)	Pressure Head @ 10.1 mgd (ft)	Pressure Head @ 11.07 mgd (ft)	Pressure Head @ 12.02 mgd (ft)	Pressure Head @ 12.91 mgd (ft)	Pressure Head @ 13.16 mgd (ft)
Field Test:	34.72	37.26	39.32	40.69	41.03	41.99	42.87
Hyd Calcs:	34.9	37.4	39.8	40.7	41.4	41.8	42.7

Segment 1: 36.8" HDPE										
Type of Loss	**Location**	**Quantity**	**K (loss coeff)**	**hL (ft) at 7.58 mgd**	**hL (ft) at 8.59 mgd**	**hL (ft) at 10.1 mgd**	**hL (ft) at 11.07 mgd**	**hL (ft) at 12.02 mgd**	**hL (ft) at 12.91mgd**	**hL (ft) at 13.16 mgd**
Elevation	Plant No. 2 Vortex Structure	1		5.8	5.8	5.8	5.8	5.8	5.8	5.8
Exit	Plant No. 2 Vortex Structure	1	1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
90 deg Bend	Sta. 75+70.36	1	0.25	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Pipeline	75+70.36 to 75+50	20		0.0	0.1	0.0	0.0	0.0	0.0	0.0
58 deg Bend	Sta. 75+50	1	0.25	0.3	0.3	0.3	0.3	0.3	0.3	0.3
18 deg Bend	Sta. 75+50	2	0.08	0.2	0.2	0.2	0.2	0.2	0.2	0.2
45 deg Bend	Sta. 75+50	1	0.18	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Pipeline	75+50 to 72+75	275		0.7	0.8	0.9	1.0	1.0	1.0	1.1
22.5 deg Bend	Sta. 72+75	1	0.08	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pipeline	72+75 to 72+65.41	9.6		0.0	0.0	0.0	0.0	0.0	0.0	0.0
51 deg Bend	Sta. 72+65.41	1	0.25	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Pipeline	72+65.41 to 58+78.92	1386		3.7	4.2	4.7	4.9	5.1	5.1	5.3
90 deg Bend	Sta. 58+78.92	1	0.25	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Pipeline	58+78.92 to 58+50	29		0.1	0.1	0.1	0.1	0.1	0.1	0.1
45 deg Bend	Sta. 58+50	2	0.18	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Pipeline	58+50 to 57+98.84	51		0.1	0.2	0.2	0.2	0.2	0.2	0.2
11 deg Bend	Sta. 57+98.84	1	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pipeline	57+98.84 to 55+58.96	240		0.6	0.7	0.8	0.8	0.9	0.9	0.9
15 deg Bend	Sta. 55+58.96	1	0.08	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pipeline	55+58.96 to 55+26.71	32		0.1	0.1	0.1	0.1	0.1	0.1	0.1
15 deg Bend	Sta. 55+26.71	1	0.08	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pipeline	55+26.71 to 38+75.69	1651		4.4	5.0	5.6	5.8	6.0	6.1	6.3
43 deg Bend	Sta. 38+75.69	1	0.18	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Pipeline	38+75.69 to 33+46.03	530		1.4	1.6	1.8	1.9	1.9	2.0	2.0
5 deg Bend	Sta. 33+46.03	1	0.05	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pipeline	33+46.03 to 27+49.94	596		1.6	1.8	2.0	2.1	2.2	2.2	2.3
12 deg Bend	Sta. 27+49.94	1	0.08	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pipeline	27+49.94 to 24+83.99	266		0.7	0.8	0.9	0.9	1.0	1.0	1.0
20 deg Bend	Sta. 24+83.99	1	0.08	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pipeline	24+83.99 to 22+66.88	217		0.6	0.7	0.7	0.8	0.8	0.8	0.8
18 deg Bend	St. 22+66.88	1	0.08	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pipeline	22+66.88-10+00	1267		3.4	3.9	4.3	4.5	4.6	4.7	4.9
Pipeline	10+94 to 10+76.73	17.27		0.0	0.1	0.1	0.1	0.1	0.1	0.1
54 deg bend	Sta. 10+76.73	1	0.25	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Pipeline	10+76.73 to 10+25.94	50.79		0.1	0.2	0.2	0.2	0.2	0.2	0.2
50 deg bend	Sta. 10+25.94	1	0.25	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Pipeline	10+25.94 to 10+23.31	2.63		0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.5 deg Bend	Sta. 10+23.31	1	0.08	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pipeline	10+23.31 to 10+14.25	9.06		0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.5 deg Bend	Sta. 10+14.25	1	0.08	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Pipeline	10+14.25 to 10+00	14.25		0.0	0.0	0.0	0.1	0.1	0.1	0.1

Segment 2: 36" Steel										
Type of Loss	**Location**	**Quantity**	**K (loss coeff)**	**hL (ft) at 7.58 mgd**	**hL (ft) at 8.59 mgd**	**hL (ft) at 10.1 mgd**	**hL (ft) at 11.07 mgd**	**hL (ft) at 12.02 mgd**	**hL (ft) at 12.91mgd**	**hL (ft) at 13.16 mgd**
36" Pipeline	BPPS	47		0.1	0.2	0.2	0.2	0.2	0.2	0.2
Plug Valves	BPPS	1	1	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Tee	BPPS	1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Plug Valves	BPPS	1	1	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Expansion (28" to 36")	BPPS	1	0.8	1.6	1.6	1.6	1.6	1.6	1.6	1.6
28" Pipeline	BPPS	12		0.0	0.0	0.0	0.0	0.0	0.0	0.1
Contraction (28" to 36")	BPPS	1	0.28	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Plug Valves	BPPS	1	1	1.2	1.2	1.2	1.2	1.2	1.2	1.2
45 deg Bend	BPPS	1	0.18	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Wye	BPPS	1	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6

October 19th Field Test Hazen Williams Coefficient Calculations

Diameter (in)	**Diameter (in)**	**Diameter (in)**
36.8	36	28
Area (ft^2)	**Area (ft^2)**	**Area (ft^2)**
7.4	7.1	4.3
Velocity (fps)	**Velocity (fps)**	**Velocity (fps)**
8.3	8.6	14.3

Flow (mgd)	**Flow (mgd)**	**Flow (mgd)**	**Flow (mgd)**	**Flow (mgd)**	**Flow (mgd)**	**Flow (mgd)**	**Flow (mgd)**	**Flow (mgd)**	**Flow (mgd)**	**Flow (mgd)**	**Flow (mgd)**
2.72	3.3	4.1	7.32	8.24	9.7	10.56	11.8	12.52	13.89	14.84	15.48
Flow (gpm)	**Flow (gpm)**	**Flow (gpm)**	**Flow (gpm)**	**Flow (gpm)**	**Flow (gpm)**	**Flow (gpm)**	**Flow (gpm)**	**Flow (gpm)**	**Flow (gpm)**	**Flow (gpm)**	**Flow (gpm)**
1889	2292	2847	5083	5722	6736	7333	8194	8694	9645	10305	10749
Flow (cfs)	**Flow (cfs)**	**Flow (cfs)**	**Flow (cfs)**	**Flow (cfs)**	**Flow (cfs)**	**Flow (cfs)**	**Flow (cfs)**	**Flow (cfs)**	**Flow (cfs)**	**Flow (cfs)**	**Flow (cfs)**
4	5	6	11	13	15	16	18	19	22	23	24

HDPE C @ 2.72 mgd=	HDPE C @ 3.3 mgd=	HDPE C @ 4.1 mgd=	HDPE C @ 7.32 mgd=	HDPE C @ 8.24 mgd=	HDPE C @ 9.7 mgd=	HDPE C @ 10.56 mgd=	HDPE C @ 11.8 mgd=	HDPE C @ 12.52 mgd=	HDPE C @ 13.89 mgd=	HDPE C @ 14.84 mgd=	HDPE C @ 15.48 mgd=
16.5	18.5	22	38	40	42	44	49	51	56	60	60

	Pressure Head @ 2.72 mgd (ft)	Pressure Head @ 3.3 mgd (ft)	Pressure Head @ 4.1 mgd (ft)	Pressure Head @ 7.32 mgd (ft)	Pressure Head @ 8.24 mgd (ft)	Pressure Head @ 9.7 mgd (ft)	Pressure Head @ 10.56 mgd (ft)	Pressure Head @ 11.8 mgd (ft)	Pressure Head @ 12.52 mgd (ft)	Pressure Head @ 13.89 mgd (ft)	Pressure Head @ 14.84 mgd (ft)	Pressure Head @ 15.48 mgd (ft)
Field Test:	24.67	26.13	27.00	28.39	30.42	34.58	36.15	37.49	39.43	41.24	42.43	45.39
Hyd Calcs:	24.4	26.3	27.5	28.5	30.6	34.9	36.6	37.8	39.7	41.3	42.2	45.3

Segment 1: 36.8" HDPE															
Type of Loss	**Location**	**Quantity**	**K (loss coeff)**	**hL (ft) at 2.72 mgd**	**hL (ft) at 3.3 mgd**	**hL (ft) at 4.1 mgd**	**hL (ft) at 7.32 mgd**	**hL (ft) at 8.24 mgd**	**hL (ft) at 9.7mgd**	**hL (ft) at 10.56 mgd**	**hL (ft) at 11.8 mgd**	**hL (ft) at 12.52 mgd**	**hL (ft) at 13.89 mgd**	**hL (ft) at 14.84 mgd**	**hL (ft) at 15.48 mgd**
Elevation	Plant No. 2 Vortex Structure	1		5.8	5.8	5.8	5.8	5.8	5.8	5.8	6.8	7.8	8.8	9.8	10.8
Exit	Plant No. 2 Vortex Structure	1	1	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.2	0.2
90 deg Bend	Sta. 75+70.36	1	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	75+70.36 to 75+50	20		0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
58 deg Bend	Sta. 75+50	1	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18 deg Bend	Sta. 75+50	2	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45 deg Bend	Sta. 75+50	1	0.18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	75+50 to 72+75	275		0.4	0.5	0.6	0.6	0.7	0.8	0.9	0.9	0.9	0.9	0.9	1.0
22.5 deg Bend	Sta. 72+75	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	72+75 to 72+65.41	9.6		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
51 deg Bend	Sta. 72+65.41	1	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	72+65.41 to 58+78.92	1386		2.2	2.6	2.8	3.0	3.4	4.2	4.5	4.5	4.7	4.8	4.7	5.1
90 deg Bend	Sta. 58+78.92	1	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	58+78.92 to 58+50	29		0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
45 deg Bend	Sta. 58+50	2	0.18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1
Pipeline	58+50 to 57+98.84	51		0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
11 deg Bend	Sta. 57+98.84	1	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	57+98.84 to 55+58.96	240		0.4	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.8	0.8	0.8	0.9
15 deg Bend	Sta. 55+58.96	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	55+58.96 to 55+26.71	32		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
15 deg Bend	Sta. 55+26.71	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	55+26.71 to 38+75.69	1651		2.7	3.1	3.3	3.6	4.0	5.0	5.3	5.4	5.6	5.7	5.7	6.1
43 deg Bend	Sta. 38+75.69	1	0.18	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	38+75.69 to 33+46.03	530		0.9	1.0	1.1	1.1	1.3	1.6	1.7	1.7	1.8	1.8	1.8	2.0
5 deg Bend	Sta. 33+46.03	1	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	33+46.03 to 27+49.94	596		1.0	1.1	1.2	1.3	1.5	1.8	1.9	1.9	2.0	2.1	2.0	2.2
12 deg Bend	Sta. 27+49.94	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	27+49.94 to 24+83.99	266		0.4	0.5	0.5	0.6	0.6	0.8	0.9	0.9	0.9	0.9	0.9	1.0
20 deg Bend	Sta. 24+83.99	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	24+83.99 to 22+66.88	217		0.4	0.4	0.4	0.5	0.5	0.7	0.7	0.7	0.7	0.7	0.7	0.8
18 deg Bend	St. 22+66.88	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	22+66.88-10+00	1267		2.0	2.4	2.6	2.7	3.1	3.8	4.1	4.1	4.3	4.4	4.3	4.7
Pipeline	10+94 to 10+76.73	17.27		0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1
54 deg bend	Sta. 10+76.73	1	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	10+76.73 to 10+25.94	50.79		0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
50 deg bend	Sta. 10+25.94	1	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	10+25.94 to 10+23.31	2.63		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.5 deg Bend	Sta. 10+23.31	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	10+23.31 to 10+14.25	9.06		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.5 deg Bend	Sta. 10+14.25	1	0.08	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pipeline	10+14.25 to 10+00	14.25		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Segment 2: 36" Steel															
Type of Loss	**Location**	**Quantity**	**K (loss coeff)**	**hL (ft) at 2.72 mgd**	**hL (ft) at 3.3 mgd**	**hL (ft) at 4.1 mgd**	**hL (ft) at 7.32 mgd**	**hL (ft) at 8.24 mgd**	**hL (ft) at 9.7mgd**	**hL (ft) at 10.56 mgd**	**hL (ft) at 11.8 mgd**	**hL (ft) at 12.52 mgd**	**hL (ft) at 13.89 mgd**	**hL (ft) at 14.84 mgd**	**hL (ft) at 15.48 mgd**
36"Pipeline	BPPS	47		0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Plug Valves	BPPS	1	1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Tee	BPPS	1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Plug Valves	BPPS	1	1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Expansion (28" to 36")	BPPS	1	0.8	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
28" Pipeline	BPPS	12		1.0	1.1	1.2	1.3	1.5	1.8	1.9	1.9	2.0	2.0	2.0	2.2
Contraction (28" to 36")	BPPS	1	0.28	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Plug Valves	BPPS	1	1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
45 deg Bend	BPPS	1	0.18	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Wye	BPPS	1	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

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