LARSON CONSULTING

3192 LUCAS CIRCLE
LAFAYETTE, CA 94549
(925) 360-6600
JLarson@LarsCon.com

NOV 2006

November 10, 2006

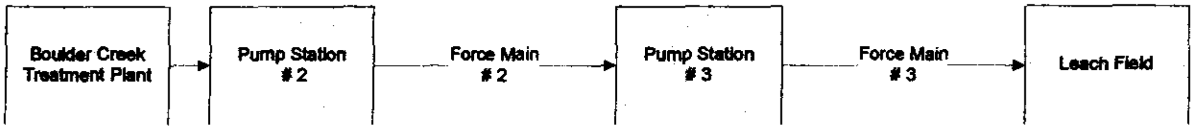
Ms. Rachèl Lather, PE
Department of Public Works
Santa Cruz County
701 Ocean Street, Room 410
Santa Cruz, CA 95060

Dear Ms. Lather,

RE: ENGINEERING EVALUATION OF TREATED EFFLUENT FORCE MAIN FAILURES, COUNTY SERVICE AREA NO. 7, BOULDER CREEK GOLF AND COUNTRY CLUB

The Sanitation Division of Santa Cruz County Public Works Department manages, operates, and maintains the wastewater system serving the residents of the Boulder Creek Golf and Country Club (County Service Area No. 7). The wastewater system consists of a sewer system, five wastewater pump stations, a package treatment plant, and a treated effluent disposal system. The treated effluent from the treatment plant is conveyed to a leach field via two pump stations and two force mains. The treated effluent system is shown schematically on Figure 1. The effluent disposal system conveys an average flow of 42,000 gallons per day.

Figure 1: Schematic Diagram of Effluent Disposal System



The two treated effluent force mains have experienced failures over the past two years (there were also earlier failures that were not included in the scope of this evaluation). The recent failures are summarized on Table 1.

The purpose of this engineering evaluation is to determine the causes of the force main failures and to recommend appropriate action to reduce the frequency or eliminate future force main failures. This evaluation was limited in scope, based on As-Built drawings, site visits, and verbal information. This work is preliminary in nature and the results are not intended to present information for use in the design of facilities.

FORCE MAIN NO. 2

Force Main No. 2 runs from Pump Station No. 2 at the treatment plant to the wet well of Pump Station No. 3. It is approximately 3,760 feet long and it is constructed of 4 inch PVC pipe. During my visit to the site, the static pressure at Pump Station No. 2 was 8 feet and the dynamic pressure was 53 feet. This indicates that Force Main No. 2 operates at low pressure. The estimated flow averages 35 gpm (velocity < 1 fps). Failure of the force main due to high operating pressures, surge, and/or fatigue is unlikely.

Table 1: Recent Force Main Failures

Date	Force Main	Volume Spilled, gallons
4/24/04	# 2	150
3/31/05	# 2	56,000
5/19/05	# 3	400
7/13/05	# 3	Unknown
10/31/05	# 3	655

The two failures on 4/24/04 and 3/31/05 were located near the intersection of State Highway 236 and Lucille's Court. Failure of the force main at this location is likely the result of damage by others during the repair/installation of the guard rail at the bridge approach. Locating and marking the location of the force main in response to notification of planned excavation is the best way to prevent this type of failure in the future.

FORCE MAIN NO. 3

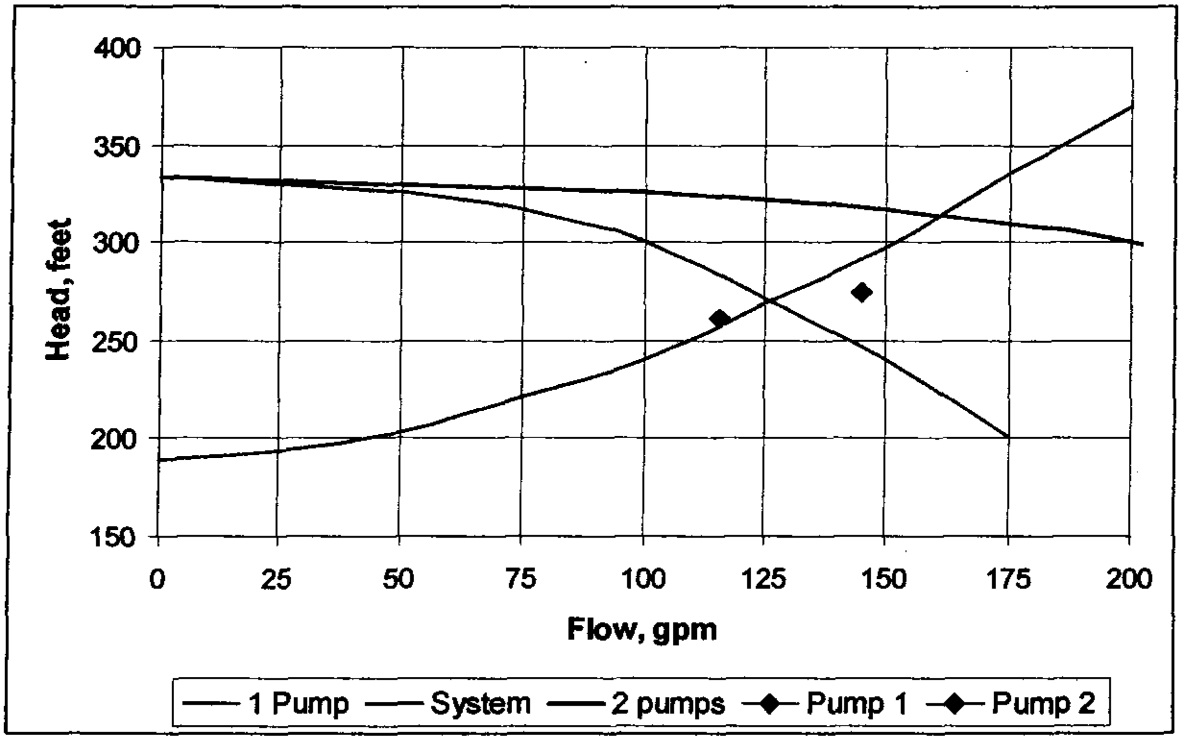
Force Main No. 3 runs between Pump Station No. 3 and the leach field above the west end of Fern Rock Way. It was installed in 1984, is approximately 2,610 feet long, and is constructed of 4 inch PVC pipe. The As-Built drawings indicate that Class 200 pipe was installed from 18 feet outside Pump Station No. 3 to the upper end of Fern Rock Way. The first 18 feet of the force main is shown to be ductile iron pipe.

The static pressure at Pump Station No. 3 could not be measured due the presence of a check valve in the force main downstream of the pump station. The static pressure is estimated to be 190 feet based on the system elevations. The results of a pump test conducted on October 11, 2006 are shown on Table 2. The data from the pump test is shown on the pump station-force main system curve on Figure 2. The difference in flows between the two pumps suggests that they have different impellors. The manufacturer's pump curve is included as Enclosure 1.

Table 2: Pump Station #3 Operating Data

Parameter	Value
Static Pressure, psi	ND
Dynamic Pressure, psi	
Pump 1	113
Pump 2	119
Both Pumps	144
Flow Rate, gpm	
Pump 1	116
Pump 2	145
Note: ND = No Data	

Figure 2: Pump Station-Force Main System Curve



The three failures in this force main all occurred in the portion of Fern Rock Way that is located directly above Pump Station No. 3. According the County Staff there were two pipe wall failures and one pipe coupling failure. The failures occurred in the portion of the pipe operating at the highest pressure. The location and the description of the failures suggest that they may have been caused by high operating pressures and/or fatigue. There were no photographs or pipe samples available to confirm the nature of the failures.

The range of operating pressures and the location of the force main failures is an important consideration. The force main in Fern Rock Way appears to be approximately 20 feet above the elevation of the pumps. The operating pressures that were measured during the pump test have been mathematically corrected for the elevation change in Table 3. It is important to note that the PVC portion of the force main is subjected to higher pressures than shown in Table 3. The surge pressures were estimated, assuming quick closing check valves:

$$P_{surge} = V\,(3{,}960Et/(Et+30{,}000D_{inside}))^{0.5}$$

Where: P_{surge} = Surge pressure, psi
V = Velocity, fps
E = Modulus of Elasticity (420,000 for PVC), psi
t = Pipe wall thickness, inches
D_{inside} = Inside diameter of pipe, inches

Table 3: Estimated Operating Pressures in Force Main No. 3 Near Failure Locations

Flow Condition	Flow, gpm	Velocity, fps	Estimated Operating Pressure, psi	Estimated Surge Pressure, psi	Estimated Maximum Operating Pressure, psi
Static (no flow)	0	0	48 – 9 = 39[1] 84 – 9 = 75[2]	0	39 84
Pump #1 Operating	116	2.6	113 – 9 = 104	43	147
Pump #2 Operating	145	3.7	119 – 9 = 110	61	171
Both Pumps Operating	160	4.2	144 – 9 = 135	70	205

Notes:

1. Assumes check valve at STA 19+75 holds.
2. Assumes check valve at STA 19+75 leaks.

The impact of surge pressures during the operation of Force Main No. 3 appears to have been considered in the original design. Two check valves were included: one just upstream of the pump station and one at STA 19+75 with a surge relief valve. Pipe joints upstream of the check valve at STA 19+75 are shown on the As-Built drawings as being restrained.

The rated working pressure for Class 200 (SDR 21) PVC pipe is 200 psi; however, the Plastic Pipe Institute recommends de-rating the pipe for long term applications in order to account for damage during handling and installation and to avoid failure due to fatigue over long term operation (Systems Engineering Data for Thermoplastic Piping, included as Enclosure 2). This information was not available at the time of the original design. The recommended service factor is 0.4 applied to the Hydrostatic Design Stress. Using this service factor, the allowable working pressure is calculated:

$$P = 2S/(R-1)$$

Where:

P = Allowable operating pressure, psi

S = Hydrostatic design stress, psi. S = 1,600 for PVC pipe with a 0.4 service factor.

R = Ratio of pipe diameter to wall thickness or DR. DR = 21 for Class 200 PVC.

The resulting allowable working pressure for SDR 21 PVC pipe is 160 psi. It appears that this value is routinely exceeded when Pump 2 or both pumps are operating (common during wet weather flow conditions according to County Staff). The most likely cause of the force main failures in Fern Rock Way appears to be the result of long term operation (over 22 years) with surge pressures that exceed the allowable working pressure each time the pumps cycle. The situation may be exacerbated by damage to the outside wall of the pipe that occurred during installation; point loads and/or deep scratches to the pipe wall would increase the stress at those locations.

There are two alternative courses of action that can be taken to reduce the potential for future force main failures. They involve reducing the maximum operating pressures through surge pressure reduction or replacement of the portion of the force main subjected to pressures above the allowable operating pressure. The two actions are discussed in detail below.

ALTERNATIVE 1: SURGE PRESSURE REDUCTION

This alternative would consist of the installation of a hydro-pneumatic surge tank. The location of the tank would be just upstream of the check valve in the force main near the pump station.

The application of slow closing check valves or a surge relief valve was also considered to reduce the surge pressure; however, that would require modification to the piping and/or pumps. In addition, the ability of a pressure relief valve to operate in time to relieve the pressure surge is in question. The assured operation and cost of the surge tank option make it more attractive.

The planning level cost estimate (+30%/-30%) for this alternative, using a 600 gallon hydro-pneumatic tank with a rubber bladder installed on a concrete pad and connected to the force main with 4 inch valves and piping is $95,000 (July 2007).

This alternative does not address the condition of the portion of the force main that has been subjected to high pressures and may be at risk of failure in the future.

ALTERNATIVE 2: PARTIAL FORCE MAIN REPLACEMENT

This alternative would consist of replacing the portion of the force main that has been operated at pressures in excess of 160 psi. The alternative is based on replacement with a parallel 4 inch diameter ductile iron pipe using direct excavation. Lining was considered; however, the liner would be limited to a 3 inch HDPE pipe. This would significantly decrease the capacity of the force main.

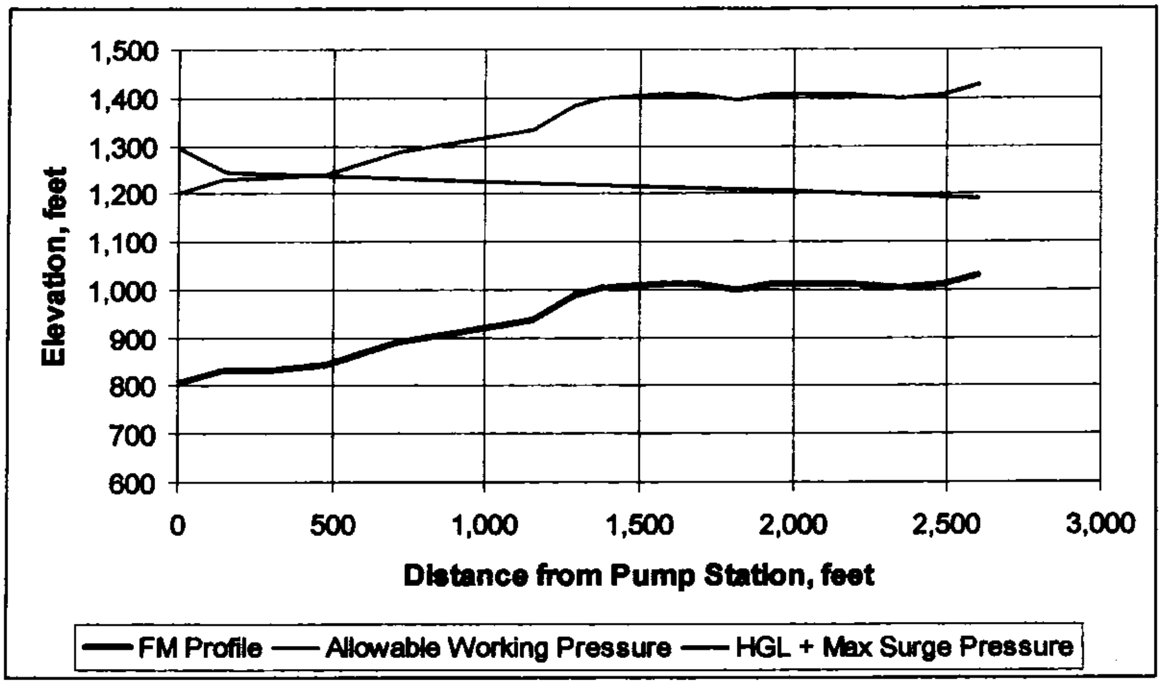
The quantity of pipe requiring replacement was estimated based on Figure 3. Figure 3 shows the force main profile, the hydraulic grade line plus the maximum surge pressure, and the allowable working pressure. The point where the hydraulic grade line plus the maximum surge pressure falls below the allowable working pressure is the limit of the pipe requiring replacement. The quantity of pipe requiring replacement is estimated to be 700 feet (500 feet from Figure 3 plus an additional 200 feet).

The planning level cost estimate for this alternative, using 4 inch pressure class 350 plastic lined ductile iron pipe installed in a polyethylene bag with paving restoration (assumes curb to curb repaving of Fern Rock Way in vicinity of prior force main repairs), is $200,000 (July 2007 midpoint of construction) including design and construction administration costs.

SUMMARY

The probable cause of the Force Main No. 3 failures is high operating pressures in excess of the allowable working pressure caused by pressure surges associated with pump shut down (end of cycle and power failure). There are two alternatives that would minimize future failures: installation of a hydro-pneumatic surge tank or replacement of approximately 700 feet of the force main with a material (Class 350 ductile iron pipe) that can handle the high pressures. The alternatives differ in cost. The lowest cost alternative would be to install the hydro-pneumatic surge tank; however, this alternative does not address any latent problems with the existing force main. The decision to select this alternative should be made with the understanding that it includes a risk of future force main failures. The partial replacement alternative, while more expensive, would substantially eliminate the risk of future force main failures associated with pressure surge and pipe material fatigue.

Figure 3: Graphical Estimate of Pipe Replacement Requirement



Please let me know if you have any questions or need any additional information on this matter.

Sincerely,

REGISTERED PROFESSIONAL ENGINEER
JOHN A LARSON
M-16403
EXP 12/31/07
MECHANICAL
STATE OF CALIFORNIA

Enclosures

	ROUTE DATA	COPY	ATT.
1	**DIRECTOR**	✓	
2	**ASST. DIR. SPEC. SVCS.**	✓	
	RECYCLING/SOLID WASTE		
	LANDFILL OPERATIONS		
	WATER CON/FLOOD CONT.		
	STORM WATER MANG.		
	CONSTRUCT.ENG.		
3	SANITATION ENG.	✓	
	WATER & WASTEWATER		
	ASST. DIR. TRANSPORT.		
	ROAD OPS.ENG.		
	PERMITS/ENCROACH.		
	DRAINAGE OPERATIONS		
	RD.MAINT.OPERATIONS		
	RDA ENG.		
	ROAD DESIGN ENG.		
	SURVEY/DEVELOPMT.		
	TRANSP/RD.PLANNING		
	ASST. DIR. ADMIN. SVCS.		
	REAL PROPERTY/FLEET		
	CSA/PRGM ADMIN.		
	SAFETY OFFICER/LIVE OAK P.		
	PERSONNEL/MIS		

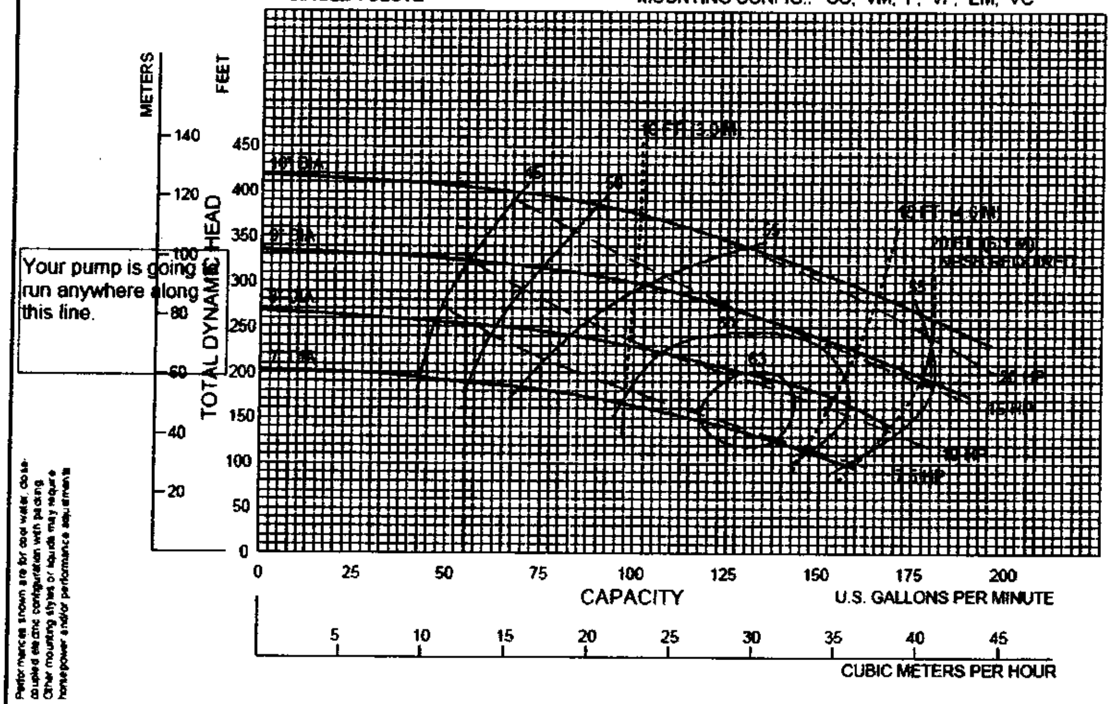
Enclosure 1: Factory Pump Curve for Pump Station No. 3

Feet x .305 = Meters
Inches x 25.4 = Millimeters
GPM x .227 = Cubic Meters/Hour
GPM x 3.785 = Liters/Minute
HP x .746 = KW

Speed	Impeller Dia.	Style	Solids Dia.	N_S	Suction	Discharge	No. vanes
3550	VARIOUS	ENCLOSED	.28"	600	2.0"	1.25"	6

SINGLE VOLUTE

MOUNTING CONFIG.: CC, VM, F, VF, EM, VC



Your pump is going to run anywhere along this line.

Performances shown are for cool water, close-coupled electric configuration with packing. Other mounting styles or liquids may require horsepower and/or performance adjustments.

6/11/00

Cornell Pump Company • Portland, Oregon

1.25Y - 3600 RPM

SYSTEMS ENGINEERING DATA FOR THERMOPLASTIC PIPING

INTRODUCTION

In the engineering of thermoplastic piping systems, it is necessary to have not only a working knowledge of piping design but also an awareness of a number of the unique properties of thermoplastics.

In addition to chemical resistance, important factors to be considered in designing piping systems employing thermoplastics are:

1. Pressure ratings.
2. Water hammer.
3. Temperature-Pressure relationships.
4. Friction-loss characteristics.
5. Dimensional and Weight data.

These factors are considered in detail in this section.

PRESSURE RATINGS OF THERMOPLASTICS

DETERMINING PRESSURE-STRESS-PIPE RELATIONSHIPS

ISO EQUATION

Circumferential stress is the largest stress present in any pressurized piping system. It is this factor that determines the pressure that a section of pipe can withstand. The relation-ship of stress, pressure and pipe dimensions is described by the ISO (for International Standardization Organization) Equation. In various forms this equation is:

$$P = \frac{2S}{R-1} = \frac{2St}{D_o-t} \qquad \frac{2S}{P} = \left(\frac{D_o}{t}\right) - 1$$

$$\frac{2S}{P} = R - 1 \qquad S = \frac{P(R-1)}{2}$$

Where:

P = Internal Pressure, psi
S = Circumferential Stress, psi
t = Wall thickness, in.
D_o = Outside Pipe diameter, in.
$R = D_o/t$

LONG-TERM STRENGTH

To determine the long-term strength of thermoplastic pipe, lengths of pipe are capped at both ends (see Figure 1) and subjected to various internal pressures, to produce circumferential stresses that will produce failure in from 10 to 10,000 hours. The test is run according to ASTM D 1598 — Standard Test for Time-to-Failure of Plastic Pipe Under Long-Term Hydrostatic Pressure.

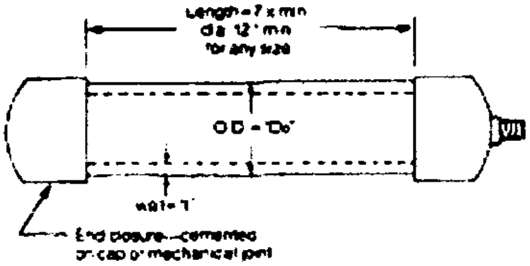
The resulting failure points are used in a statistical analysis (outlined in ASTM D-2837; see page 6) to determine the characteristic regression curve that represents the stress/time-to-failure relationship for the particular thermoplastic pipe compound under test. This curve is represented by the equation: $\text{Log} = a + b \log S$

Where:

a and b are constants describing the slope and intercept of the curve, and T and S are time-to-failure and stress, respectively.

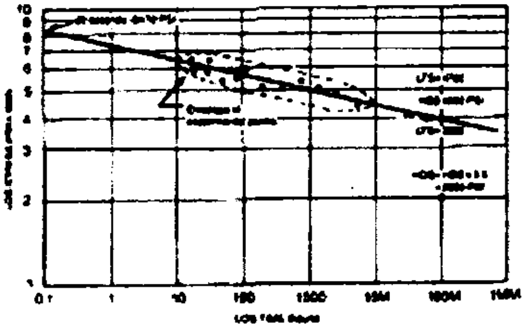
The regression curve may be plotted on a log-log paper, as shown in Figure 2, and extrapolated from 10,000 to 100,000 hours (11.4 years). The stress at 100,000 hours is known as the Long Term Hydrostatic Strength (LTHS) for that particular thermoplastic compound. From this (LTHS) the Hydrostatic Design Stress (HDS) is determined by applying the service factor multiplier, as described below.

FIGURE 1
LONG-TERM STRENGTH TEST PER ASTM D1 598



Pipe test specimen per ASTM D 1598 for "Time-to-Failure of Plastic Pipe Under Long-Term Hydrostatic Pressure"

FIGURE 2
REGRESSION CURVE—STRESS/TIME-TO-FAILURE FOR PVC TYPE I



SERVICE FACTOR

The Plastics Pipe Institute (PPI) has determined that a service (design) factor of one-half the Hydrostatic Design Basis would provide an adequate safety margin for use with water to ensure useful plastic-pipe service for a long period of time. While not stated in the standards, it is generally understood within the industry that this "long period of time" is minimum of 50 years.

SYSTEMS ENGINEERING DATA FOR THERMOPLASTIC PIPING

Accordingly, the standards for plastic pipe, using the 0.5 service factor, required that the pressure rating of the pipe be based upon this Hydrostatic Design Stress, again calculated with the ISO equation.

While early experience indicated that this service factor, or multiplier, of 0.5 provided adequate safety for many if not most uses, some experts felt that a more conservative service factor of 0.4 would better compensate for water hammer pressure surges, as well as for slight manufacturing variations and damage suffered during installation.

The PPI has issued a policy statement officially recommending this 0.4 service factor. This is equivalent to recommending that the pressure rating of the pipe should equal 1.25 times the system design pressure for any particular installation. Based upon this policy, many thousands of miles of thermoplastic pipe have been installed in the United States without failure.

It is best to consider the actual surge conditions, as outlined later in this section. In addition, substantial reductions in working pressure are advisable when handling aggressive chemical solutions and in high-temperature service.

Numerical relationships for service factors and design stresses of PVC are shown in Table I-A below.

SERVICE FACTORS AND HYDROSTATIC DESIGN STRESS (HDS)*

SERVICE FACTOR	HDS
0.5	2000 psi (13.8 MPa)
0.4	1600 psi (11 MPa)

*Material: PVC Type 1 & CPVC

TEMPERATURE-PRESSURE AND MODULUS RELATIONSHIPS

Temperature Derating.

Pressure ratings for thermoplastic pipe are generally determined in a water medium at room temperature (73°F). As the system temperature increases, the thermoplastic pipe becomes more ductile, increases in impact strength and decreases in tensile strength. The pressure ratings of thermoplastic pipe must therefore be decreased accordingly.

The effects of temperature have been exhaustively studied and correction (derating) factors developed for each thermoplastic piping compound. To determine the maximum operating pressure at any given temperature, multiply the pressure rating at ambient shown in Table 1 by the temperature correction factor for that material shown in Table 2. Attention must also be given to the pressure rating of the joining technique i.e. Threaded system normally reduces pressure capabilities, substantially.

TABLE 1

MAXIMUM OPERATING PRESSURES (PSI) AT 73°F AMBIENT
BASED UPON A SERVICE FACTOR OF .5

NOMINAL SIZE	PVC & CPVC SCHEDULE 40 SOLVENT WELD	PVC & CPVC SCHEDULE 80		POLYPROPYLENE*(PP)			POLYVINYLIDENE FLUORIDE (PVDF)			
					PROLINE SDR		SUPER PROLINE SDR		SCHEDULE 80	
		SOLVENT WELD	THREADED	*PRO-SEAL	11	32	11	32	SOCKET FUSION	THREADED
1/4	780	1130	—	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3/8	620	920		N/A	N/A	N/A	N/A	N/A	N/A	N/A
1/2	600	850	420	150	160	45	230	N/A	975	290
3/4	480	690	340	150	160	45	230	N/A	790	235
1	450	630	320	150	160	45	230	N/A	725	215
1-1/4	370	520	260	N/A	160	45	230	N/A	660	180
1 1/2	330	470	240	150	160	45	230	N/A	540	160
2	280	400	200	150	160	45	230	N/A	465	135
2-1/2	300	425	210**	N/A	160	45	N/A	160	N/A	N/R
3	260	375	190**	N/A	160	45	N/A	160	410	N/R
4	220	324	160**	N/A	160	45	N/A	160	370	N/R
6	180	280	N/R	N/A	160	45	N/A	160	N/A	N/R
8	160	250	N/R	N/A	160	45	N/A	160	N/A	N/A
10	140	230	N/R	N/A	160	45	N/A	160	N/A	N/A
12	130	230	N/R	N/A	160	45	N/A	160	N/A	N/A

--- = Data not available at printing, N/R = Not Recommended, N/A = Not Available (not manufactured)

* Threaded Polypropylene is not recommended for pressure applications and Fuseal drainage systems are not pressure rated.

**For threaded joints properly backwelded

NOTE: The pressure ratings in this chart are based on water and are for pipe and fittings only. Systems that include valves, flanges, or other weaker items will require derating the entire system.

SYSTEMS ENGINEERING DATA
FOR THERMOPLASTIC PIPING

WATER HAMMER

Surge pressures due to water hammer are a major factor contributing to pipe failure in liquid transmission systems. A column of moving fluid within a pipeline, owing to its mass and velocity, contains stored energy. Since liquids are essentially incompressible, this energy cannot be absorbed by the fluid when a valve is suddenly closed. The result is a high momentary pressure surge, usually called water hammer. The five factors that determine the severity of water hammer are:

1. Velocity (The primary factor in excessive water hammer: see discussion of "Velocity" and "Safety Factor" on page 62).
2. Modulus of elasticity of material of which the pipe is made.
3. Inside diameter of pipe.
4. Wall thickness of pipe.
5. Valve closing time.

Maximum pressure surges caused by water hammer can be calculated by using the equation below. This surge pressure should be added to the existing line pressure to arrive at a maximum operating pressure figure.

$$P_s = V\left(\frac{E\,t\,3960}{E\,t + 3 \times 10^5\,D_i}\right)^{1/2}$$

Where:

P_s = Surge Pressure, in psi
V = Liquid Velocity, in ft. per sec.
D_i = Inside Diameter of Pipe, in.
E = Modulus of Elasticity of Pipe Material, psi
t = Wall Thickness of Pipe, in.

Calculated surge pressure, which assumes instantaneous valve closure, can be calculated for any material using the values for E (Modulus of Elasticity) found in the properties chart, pages 13-14. Here are the most commonly used surge pressure tables for IPS pipe sizes.

Table 20 - SURGE PRESSURE, Ps IN PSI AT 73°F

WATER VELOCITY (FT/SEC)	NOMINAL PIPE SIZE											
	1/2	3/4	1	1-1/4	1-1/2	2	3	4	6	8	10	12
SCHEDULE 40 PVC & CPVC												
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	40.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SCHEDULE 80 PVC & CPVC												
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	41.0	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SCHEDULE 80 POYLPROPYLENE												
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SCHEDULE 80 PVDF												
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SUPER PROLINE												
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PROLINE PRO 150												
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
PROLINE PRO 45												
1	-	-	-	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7.1
2	-	-	-	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14.1
3	-	-	-	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	21.1
4	-	-	-	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	-	-	-	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	-	-	-	-	-	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

NOTE: For sizes larger than 12", call your Corr Tech representative.

CORR TECH

SYSTEMS ENGINEERING DATA
FOR THERMOPLASTIC PIPING

WATER HAMMER (continued)

However, to keep water hammer pressures within reasonable limits, it is common practice to design valves for closure times considerably greater than 2L/C.

$$T_c > \frac{2L}{C}$$

Where:
Tc - Valve Closure time, sec.
L - Length of Pipe run, ft.
C - Sonic Velocity of the Pressure Wave - 4720 ft. sec.

Another formula which closely predicts water hammer effects is:

$$p = a\frac{v}{144g}$$

Which is based on the elastic wave theory. In this text, we have further simplified the equation to:

$$p = Cv$$

Where:
p - maximum surge pressure, psi
v - fluid velocity in feet per second
C - surge wave constant for water at 73°F

It should be noted that the surge pressure (water hammer) calculated here is a maximum pressure rise for any fluid velocity, such as would be expected from the instant closing of a valve. It would therefore yield a somewhat conservative figure for use with slow closing actuated valves, etc.

For fluids heavier than water, the following correction should be made to the surge wave constant C.

$$C' = \frac{(S.G. - 1)\,C}{2} + C$$

Where:
C' - Corrected Surge Wave Constant
S.G. - Specific Gravity or Liquid

For example, for a liquid with a specific gravity of 1.2 in 2" Schedule 80 PVC pipe, from Table 43 - 24.2

$$C' = \frac{(1.2 - 1)}{2}(24.2) + 24.2$$

$$C' = 2.42 + 24.2$$

$$C' = 26.6$$

Table 21 - Surge Wave Correction for Specific Gravity

PIPE SIZE (IN.)	PVC		CPVC		POLY-PROPYLENE	KYNAR (PVDF)
	SCH 40	SCH 80	SCH 40	SCH 80	SCH 80	SCH 80
1/4	31.3	34.7	33.2	37.3		
3/8	29.3	32.7	31.0	34.7	—	—
1/2	28.7	31.7	30.3	33.7	25.9	26.3
3/4	26.3	29.8	27.8	31.6	23.1	25.2
1	25.7	29.2	27.0	30.7	21.7	24.0
1-1/4	23.2	27.0	24.5	28.6	19.8	—
1-1/2	22.0	25.8	23.2	27.3	18.8	20.6
2	20.2	24.2	21.3	25.3	17.3	19.0
2-1/2	21.1	24.7	22.2	26.0	—	
3	19.5	23.2	20.6	24.5	19.6	
4	17.8	21.6	18.8	22.9	15.4	
6	15.7	20.2	16.8	21.3		
8	14.8	19.8	15.8	19.8		
10	14.0	18.3	15.1	19.3		
12	13.7	18.0	14.7	19.2		
14	13.4	17.9	14.4	19.2		

Proper design when laying out a piping system will eliminate the possibility of water hammer damage.

The following suggestions will help in avoiding problems:

1) In a plastic piping system, a fluid velocity not exceeding 5ft/sec. will minimize water hammer effects, even with quickly closing valves, such as solenoid valves.
2) Using actuated valves which have a specific closing time will eliminate the possibility of someone inadvertently slamming a valve open or closed too quickly. With pneumatic and air-spring actuators, it may be necessary to place a valve in the air line to slow down the valve operation cycle.
3) If possible, when starting a pump, partially close the valve in the discharge line to minimize the volume of liquid which is rapidly accelerating through the system. Once the pump is up to speed and the line completely full, the valve may be opened.
4) A check valve installed near a pump in the discharge line will keep the line full and help prevent excessive water hammer during pump start-up.

VELOCITY

Thermoplastic piping systems have been installed that have successfully handled water velocities in excess of 10 ft/sec. Thermoplastic pipe is not subject to erosion caused by high velocities and turbulent flow, and in this respect is superior to metal piping systems, particularly where corrosive or chemically aggressive fluids are involved. The Plastics Pipe Institute has issued the following policy statement on water velocity: The maximum safe water velocity in a thermoplastic piping system depends on the specific details of the system and the operating conditions. **In general, 5 feet per second is considered to be safe.** Higher velocities may be used in cases where the operating characteristics of valves and pumps are known so that sudden changes in flow velocity can be controlled. The total pressure in the system at any time (operating plus surge or water hammer) should not exceed 150 percent of the pressure rating of the system.

SAFETY FACTOR

As the duration of pressure surges due to water hammer is extremely short - seconds, or more likely, fractions of a second - in determining the safety factor the maximum fiber stress due to total internal pressure must be compared to some very short-term strength value. Referring to Figure 2, shown on page 15, it will be seen that the failure stress for very short time periods is very high when compared to the hydrostatic design stress. The calculation of safety factor may thus be based very conservatively on the 20-second strength value given in Figure 2, shown on page 15 - 8470 psi for PVC Type 1.

A sample calculation is shown below, based upon the listed criteria:

Pipe - 1-1/4" Schedule 80 PVC
O.D. - 1.660; Wall - 0.191
HDS - 2000 psi

The calculated surge pressure for 1-1/4" Schedule 80 PVC pipe at a velocity of 1 ft/sec is 26.2 psi/ft/sec.