Flow Rating Analysis for Pump Station S-390

Taylor Creek/ Grassy Island Stormwater Treatment Area

Technical Publication OHDM # ERA-458

Hua Li
Mark Wilsnack

April 2007

Stream Gauging, Engineering & Hydraulic Support Unit
Operations & Hydro Data Management Division
South Florida Water Management District

Executive Summary

A rating analysis of S-390 was carried out using the conventional case 8 model. Four rating equations were developed since up to four pumps can be operating in parallel while discharging into a common force main. All four equations yield discharge rates that are within 2.1% of the discharges derived from the pump station rating curve under the expected range of static heads. Additionally, under the expected range of static heads, it was found that discharges can range from about 5.5 to 8.7 cfs with a single pump operating. With four pumps running simultaneously, the discharges can range from 20.5 to 32 cfs. Velocities within the force main can range from 1.7 to 2.8 ft/sec with one pump running and 6.5 to 10.2 ft/sec with four pumps operating. Given the uncertainties inherent to the hydraulic head loss calculations, it is recommended that the rating equations be calibrated with measured flows.

Acknowledgements

The authors wish to express appreciation to Rodrigo Musalem for arranging the field reconnaissance and providing the necessary construction drawings; to Lisa Kreiger of the Okeechobee service center for obtaining the pump performance data and providing useful information regarding the force main properties; and to Rich Virgil for sharing his expertise on pump station construction and pipe installation techniques.

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Introduction

The Taylor Creek / Grassy Island STA is one of the Critical Restoration Projects authorized by Congress through Section 528 of the 1996 Water Resources Development Act. The STA is located approximately 2 miles north of the city of Okeechobee, adjacent to Taylor Creek and immediately northwest of the U.S Highway 441 bridge that spans Taylor Creek (Figure 1). The southern end of this project is approximately 7 miles from the edge of Lake Okeechobee (Goforth, 2005).

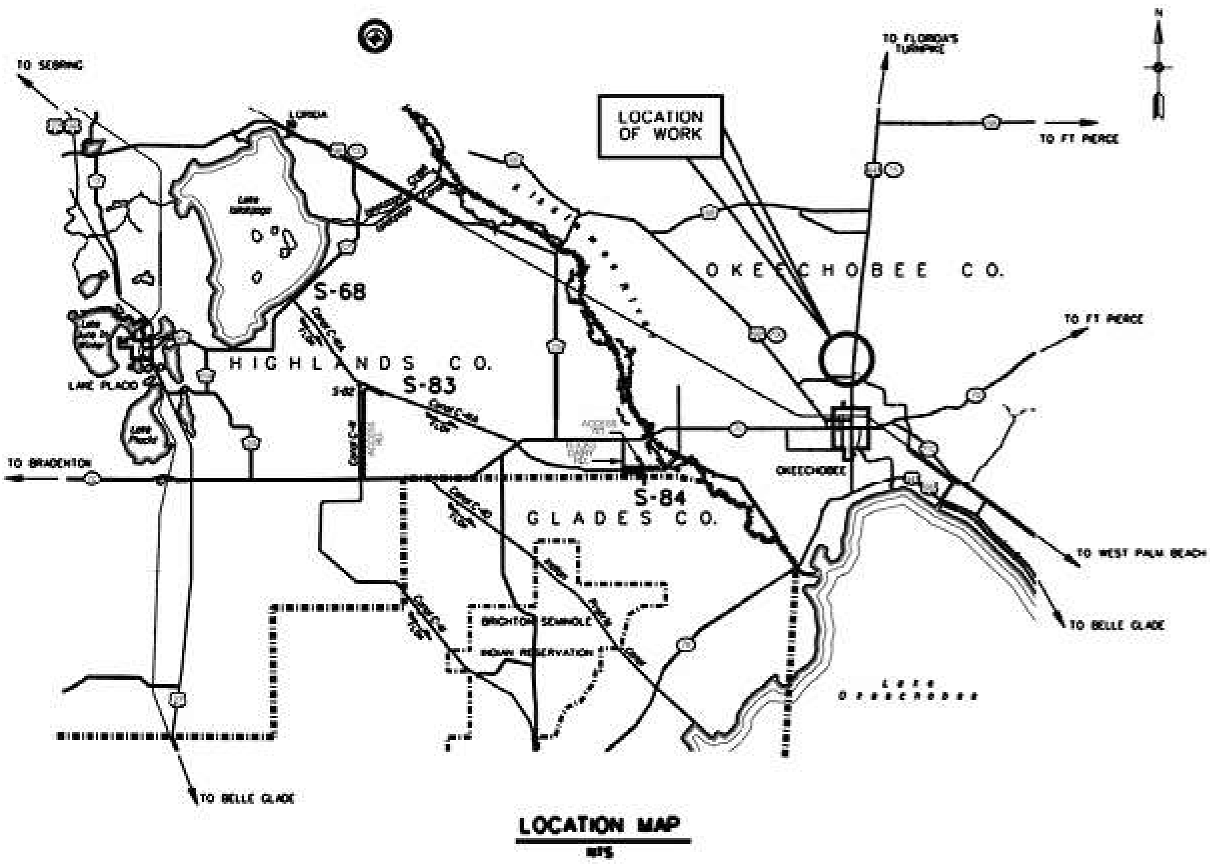

Figure 1. Taylor Creek / Grassy Island STA location map.

The goal of the Taylor Creek STA is to capture and reduce the mass of total phosphorus from the Taylor Creek Basin prior to discharge back into Taylor Creek and subsequently into Lake Okeechobee.

Objectives and Scope

The primary purpose of the rating analyses conducted in this study is to enable flows through S-390 to be estimated using measured head water elevations, tail water elevations and pump motor speeds. A secondary objective is to estimate the range of expected pipeline velocities in order to help ensure that the most appropriate flow measuring equipment is used. The hydraulic rating equations are based on pump performance characteristics, hydraulic properties of the pump station piping and appurtenances, and engineering principles. Since S-390 became operational only recently, the rating equations could not be calibrated to stream flow measurements since none were available at the time this rating analysis was conducted.

Station Design

The pump station has four (4) submersible 10-inch diameter centrifugal pumps with 14-horsepower electric motors. Each pump has a nominal discharge capacity of approximately 6 cfs pumping against a static head of 9 ft; however, friction and other energy losses within the piping system reduce the pump capacity. The discharge pipe of each pump is connected to a common 24-inch diameter, 116.3-ft long concrete pipe that conveys the P.S. discharges to the upstream end of Cell 1 (Figure 2). A cross section of the pump station wet well is shown in Figure 2. Other cross sectional and plan views of the pump station design are shown in figures 3 and 4, respectively. Figure 4 shows the design profile of the force main that connects the pump station with the deep zone trench at the upstream end of Cell 1. Unlike most SFWMD pump stations, all four of the pumps discharge into a common header that is directly connected to the force main. Table 1 contains the dimensions of the station piping while Table 2 lists the appurtenances located between each pump and the common header pipe. Listed also are the local head loss coefficients. Table 3 contains estimates of pipe roughness. The pump performance curves are shown in figure 5.

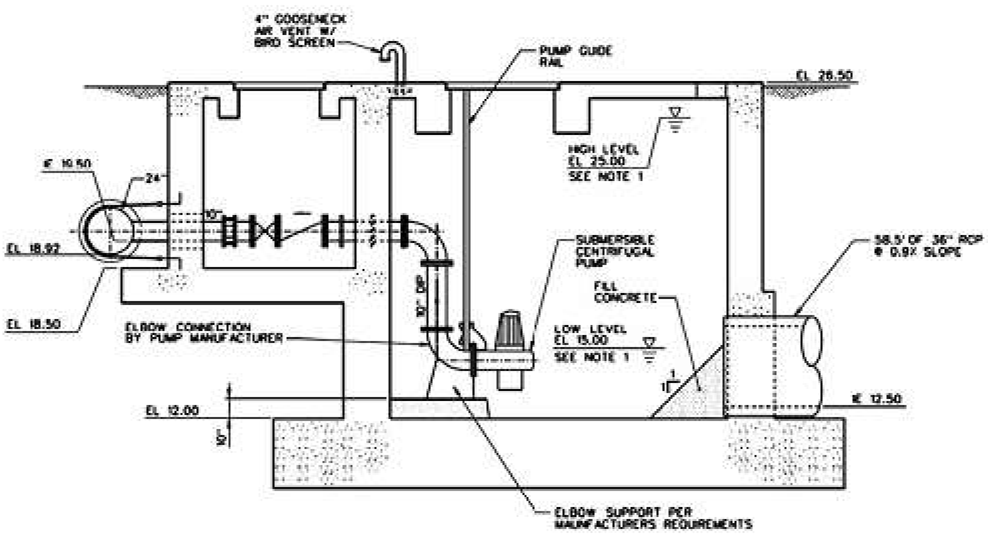

Figure 2. Schematic of pump station S-390 wet well.

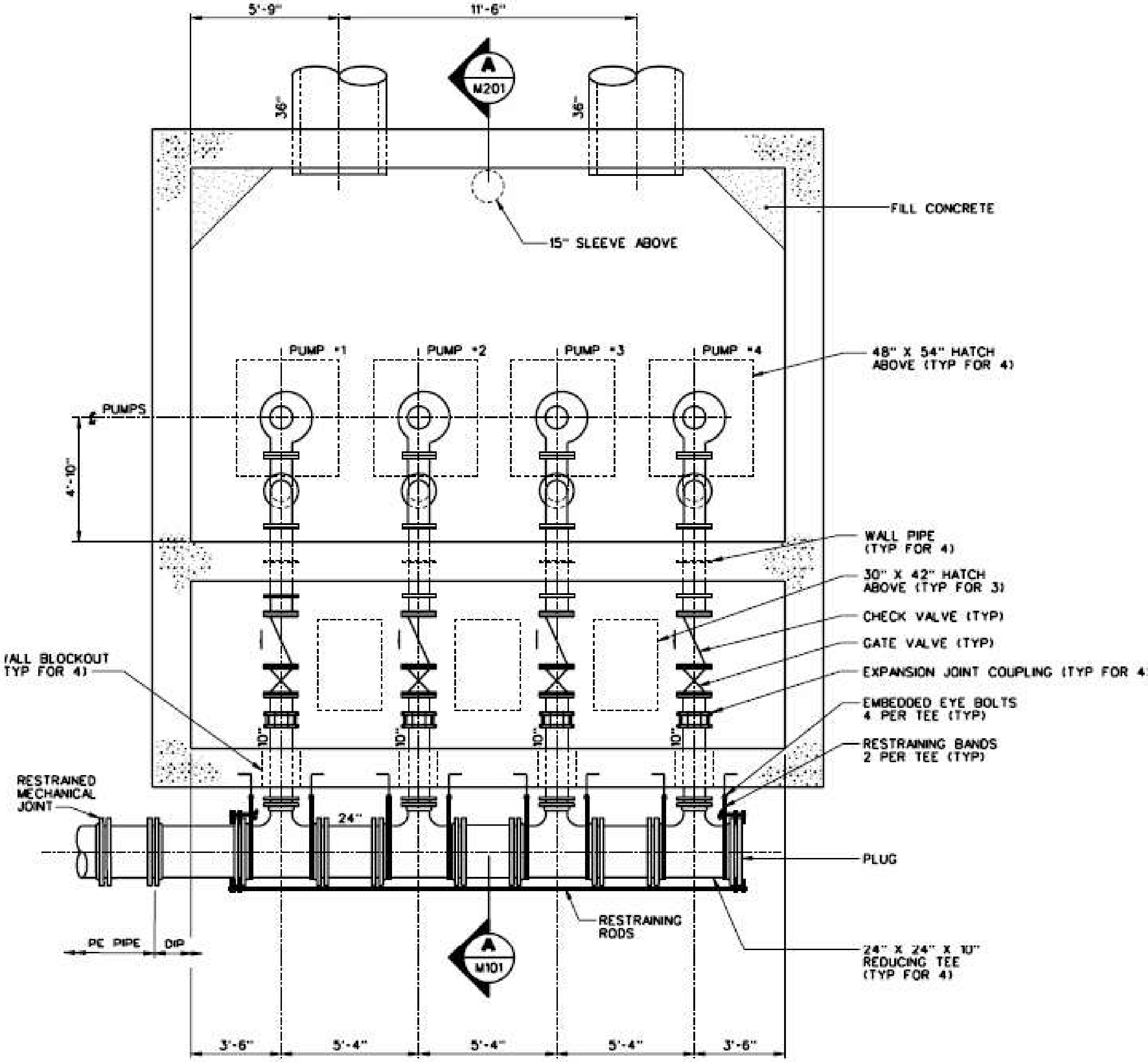

Figure 3. Plan views of the pump station.

At the time this rating analysis was carried out, no as-built drawings were available. Hence, construction drawings were used instead. It is therefore possible that corrections and revisions to this analysis may be necessary after the as-built drawings are obtained.

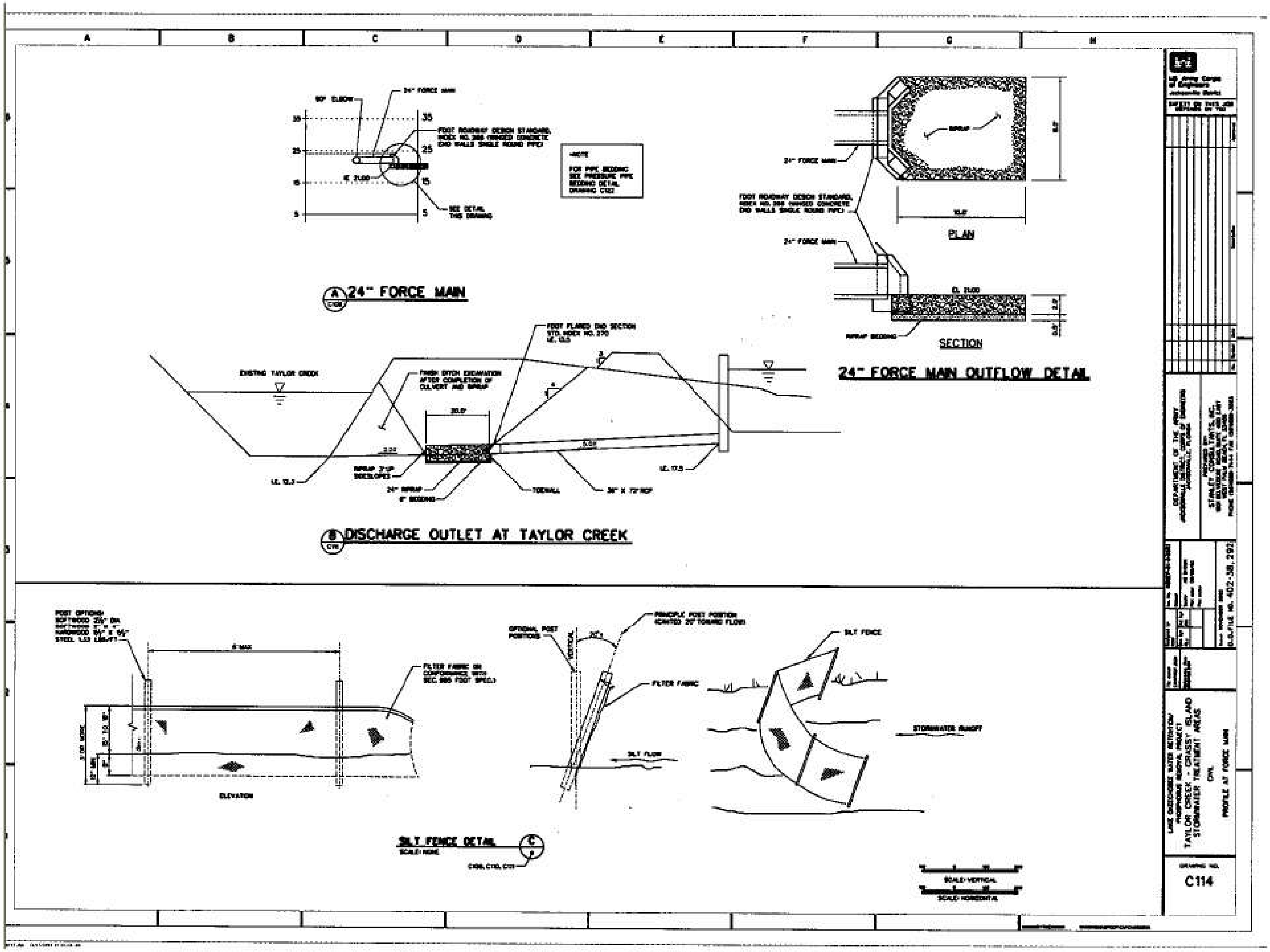

Figure 4. Profile of force main.

Table 1. Dimensions of station piping.

Local Discharge Pipe (DIP) Dimensions			
Pipe OD =	11.10	in	Sanks (1989)
Wall Thickness =	0.375	in	Sanks (1989)
Pipe ID =	10.22	in	Sanks (1989)
Pipe ID =	0.852	ft	
Pipe Length =	21.0	ft	*plans*
Area =	0.570	sq ft	Sanks (1989)
Motar Lining =	0.06	in	Sanks (1989)
Header and Conduit (Concrete) Dimensions			
Pipe OD =	29	in	*AWWA C301*
Wall Thickness =	2.49	in	*AWWA C301*
Pipe ID =	24.02	in	*AWWA C301*
Pipe ID =	2.001	ft	
Area =	3.15	sq ft	
Pipe Length (section 1,2,3) =	5.3	ft	*plans*
Pipe Length (section 4) =	116.3	ft	*plans*

* refer to figure 7 for pipe sections.

Table 2. Station appurtenances and local head loss coefficients.

Conduit	Local Losses Coefficients					
	Number		**K**	**min**	**max**	**sources**
Local Discharge Pipe	1	Check Valve	$K_{ck.valv}$ =	0.60	2.20	*Sanks 1989*
	2	90 Elbow	K_{elb} =	0.14	0.23	*Sanks 1989*
	1	GateValve	$K_{gt.valv}$ =	0.02	0.05	*Hydraulic Institute (1990)*
	1	Tee	K_{tee} =	0.26	0.54	*Hydraulic Institute (1990)*
		Total	ΣK_m =	1.16	3.25	
Header	1	Exit	K_{ext} =	1.00	1.00	*Hydraulic Institute (1990)*
	1	Tee	K_{tee} =	0.05	0.09	*Hydraulic Institute (1990)*

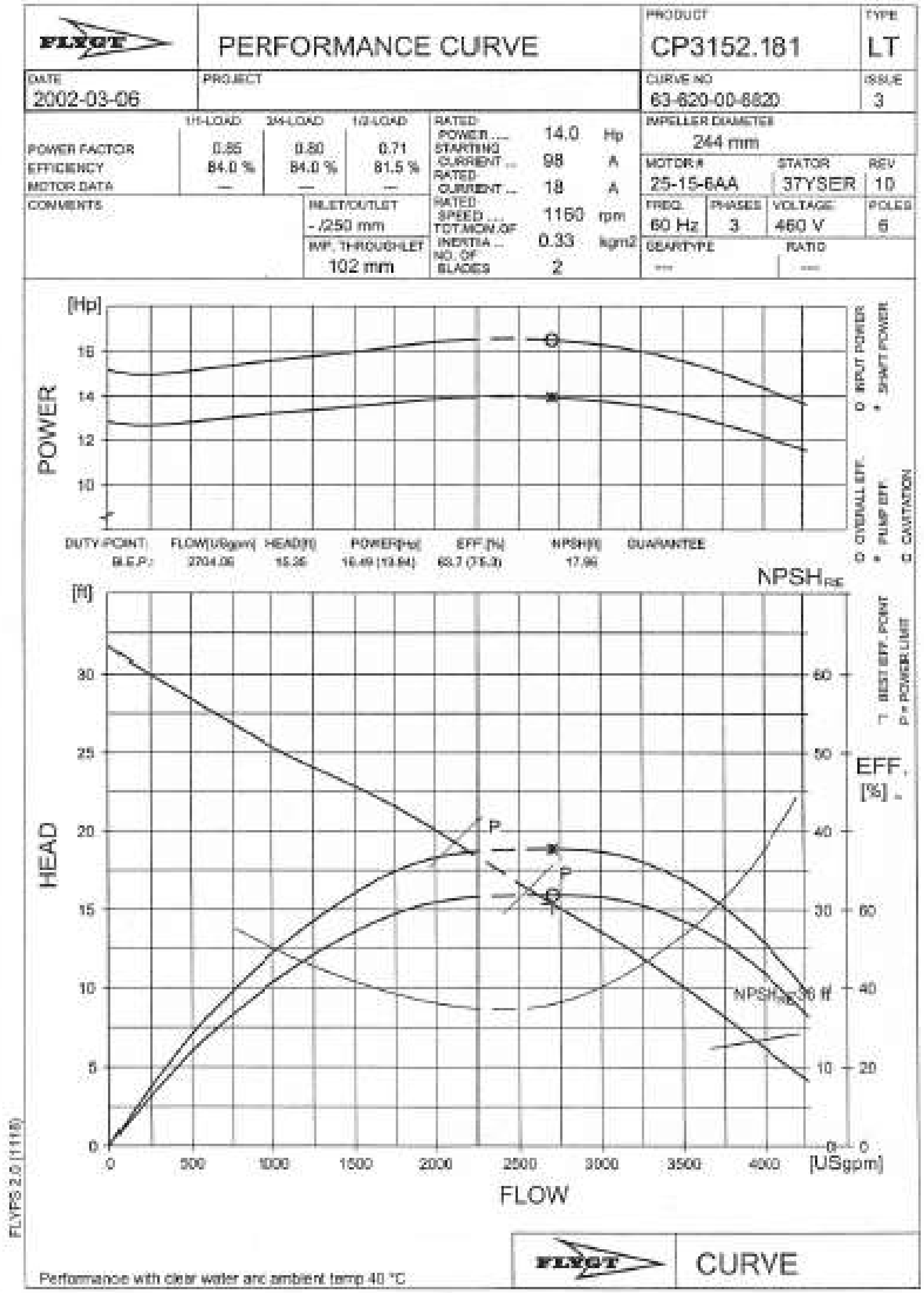

Figure 5. Pump performance curve.

Table 3. Roughness of station piping.

Concduit	Pipe Head Losses			Sources
DIP	ε =	0.000005	ft	*Flow Rating Analysis for Pump Station S-385 (Wilsnack, 2006)*
	ε =	0.0005	ft	*Flow Rating Analysis for Pump Station S-385 (Wilsnack, 2006)*
Concrete	ε =	0.001	ft	*Hydraulic Institute (1990)*
	ε =	0.01	ft	*Hydraulic Institute (1990)*

Methodology

The procedure implemented here for developing the rating curves reflects the standard procedure presented by Imru and Wang (2004). However, the station piping configuration for S-390 necessitates a more complicated analysis than is typically required. In particular, all four of the pump stations discharge into a common header pipe that is connected to the force main. This essentially constitutes a system where up to four pumps can be operating in parallel. Theoretically speaking, when more than one pump is operating, each pump cannot be rated individually. It still may be possible from a practical viewpoint to rate the pumps individually if the head losses through the force main are small or vary little over the expected range of flows. Unfortunately, given the long length of the force main, this would not be a good assumption. Hence, the pumps at S-390 will be rated either as a single pump in operation or as groups of two, three or four pumps operating in parallel.

Since no measured flow data exist at S-390, the approach for rating analysis essentially consists of the following steps:

1. Obtain the manufacturer's performance curve that depicts the relationship between total dynamic head (TDH) and flow rate.
2. Identify the pumps that will be operating in parallel.
3. Referring to Figure 7, start from the upstream-most operating pump, subtract from the performance curve all head losses between this pump and the point where the next pump discharge pipe connects to the common header.
4. Subtract from the performance curve of this second pump all head losses between the pump and the point where it connects to the common header. This will be the same location identified in step 3.
5. Add the modified performance curves obtained in step 3 and 4 together and deem it as the performance curve for one composite pump. Repeat step 3 until all pumps have been incorporated into the composite pump curve.
6. Subtract from the composite pump performance curve obtained in step 5 head losses incurred within the common force main located downstream of the last pump. This results in the relationship between pump station discharge and total static head (TSH) between the pump station wet well and the storage pond.
7. Fit the rating equation to the modified, composite performance curve determined in step 6.

8. Repeat steps 1~7 for other combinations of parallel pump operation that need to be considered.

This procedure will yield a total of four rating equations since one, two, three or four pumps can be operating simultaneously in parallel.

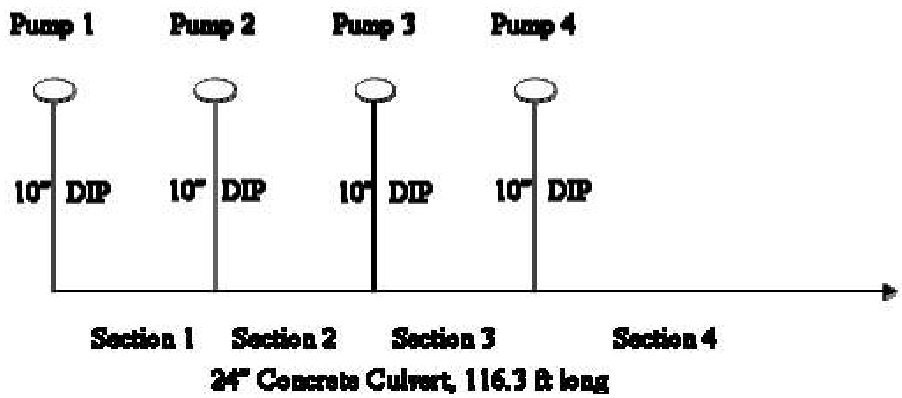

Figure 6. Schematic of the pump and piping configuration of S390.

Rating Analysis

The model rating equation applied to S-390 is the standard case 8 model (Imru and Wang, 2004):

$$Q = A\left(\frac{N}{N_O}\right) + BH^C\left(\frac{N_O}{N}\right)^{2C-1} \quad \text{...} (1)$$

where Q is the discharge at N RPM, H is the TSH, N_O is the design engine or pump speed, and A, B and C are constants to be determined through regression. The form of this expression was determined through dimensional analysis and is based on the pump affinity laws. For pumps driven by electric motors, $N_O = N$ so the ratios involving these parameters are eliminated.

Figure 7 depicts the TSH vs. flow relationship for one, two, three and four pumps operating in parallel. For comparative purposes, the TDH vs. flow relationship (i.e. the pump performance curve reflecting the number of pumps operating in parallel) is also shown for each pumping scenario. The associated head loss computations are provided in appendix A. Equation (1) was fit to each of the TSH vs. Q curves shown in figure 7. The resulting values of A, B and C are provided in Table 4. Tables 5, 6, 7 and 8 provide a comparison of each rating equation with its respective pump station performance curve. The highlighted rows in each table represent the approximate range of static heads expected in the field.

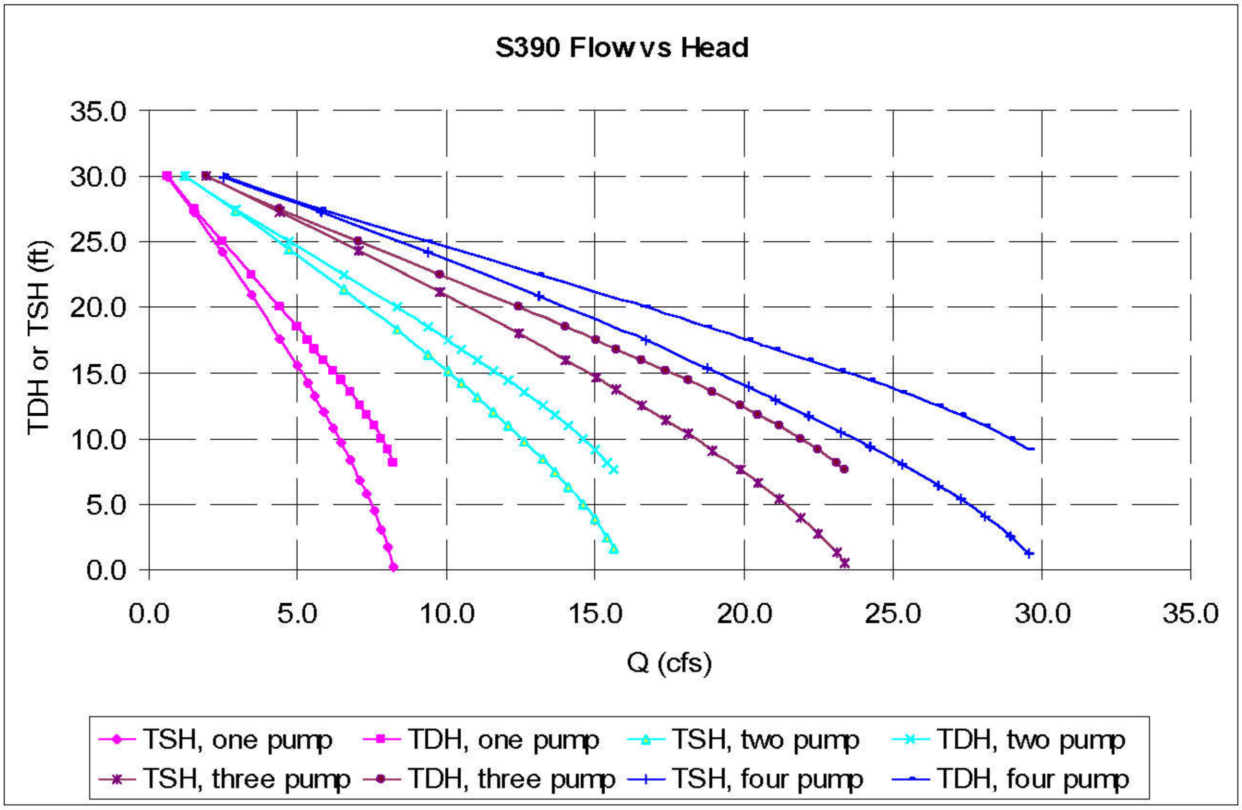

Figure 7. TSH/TDH vs. flow relationship for one, two, three and four pumps operating.

Table 4. Values of A, B and C in equation 1.

Regression Parameter	Number of Pumps in Operation			
	1	2	3	4
A	8.2242	15.9251	23.4528	29.9502
B	-0.0945	-0.1561	-0.2509	-0.2822
C	1.2899	1.3366	1.3094	1.3462

Discharge and Velocity Ranges

In order to estimate the expected range of operating conditions, system performance curves were computed for the expected, minimum and maximum head losses. These losses were based on minimum, average and maximum static heads of 1.5, 6.5 and 11.5 feet NGVD, respectively. The curves for a one-pump and four-pump operation are plotted in figures 8 and 9, respectively, along with the estimated range of pump station performance curves. The hatched area in each figure represents the estimated range of operating conditions. If a single pump is operating, it is evident that discharges could range from about 5.5 cfs to 8.7 cfs. This corresponds to a velocity range of 1.7 to 2.8 ft/s. Similarly, with all pumps operating, discharges could range from 20.5 cfs to 32 cfs. In this case velocities would range from 6.5 to 10.2 ft/s.

Table 5. Comparison of the regression equation and pump station performance curve for one pump operating.

TSH	Q (p.s. Perf. Curve)	Q (Regression)	% Error
29.96	0.56	0.64	14.42
27.27	1.39	1.51	8.08
24.26	2.52	2.45	-2.83
20.97	3.63	3.44	-5.38
17.64	4.51	4.39	-2.67
15.60	5.01	4.96	-1.16
14.20	5.35	5.33	-0.38
13.22	5.57	5.58	0.21
12.01	5.85	5.89	0.71
10.83	6.13	6.18	0.88
9.68	6.41	6.46	0.79
8.37	6.69	6.76	1.12
6.81	7.04	7.10	0.85
5.77	7.24	7.32	1.06
4.49	7.52	7.57	0.64
3.03	7.80	7.83	0.38
1.73	8.08	8.03	-0.56
0.16	8.36	8.22	-1.69

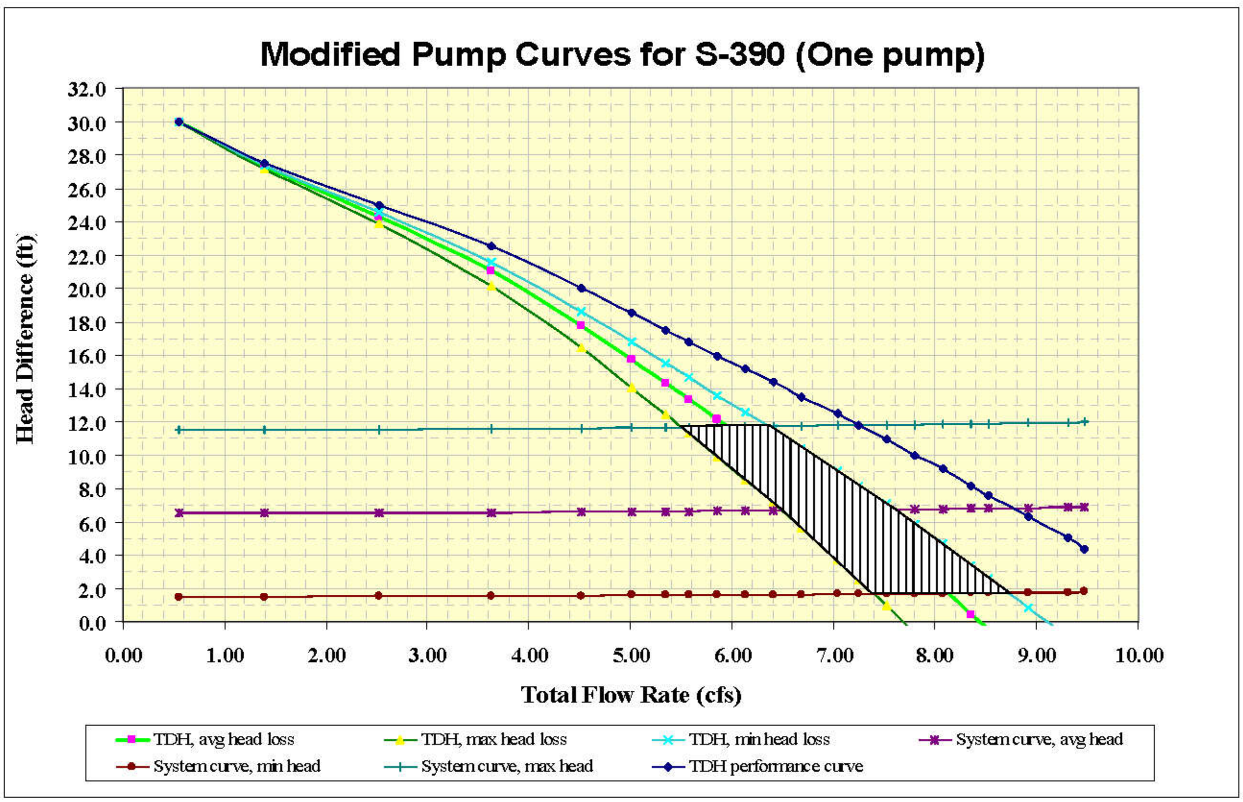

Figure 8. Pump performance curves and system curves with one pump operating.

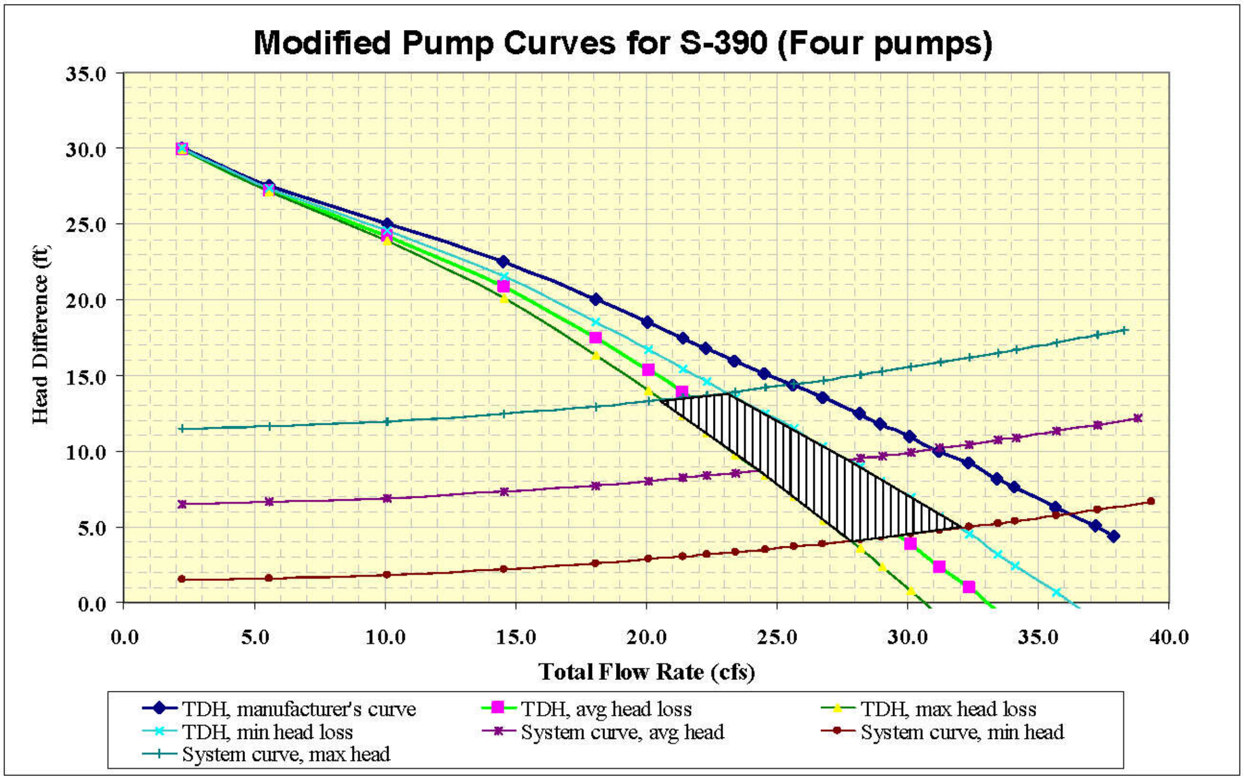

Figure 9. Pump performance curves and system curves with four pumps operating.

Table 6. Comparison of the regression equation and pump station performance curve for two pumps operating.

TSH	Q (p.s. Perf. Curve)	Q (Regression)	% Error
29.97	1.10	1.23	11.41
27.33	2.71	2.93	8.16
24.46	4.83	4.73	-2.17
21.39	6.93	6.56	-5.28
18.30	8.55	8.33	-2.63
16.41	9.46	9.36	-1.09
15.13	10.08	10.03	-0.47
14.23	10.48	10.50	0.21
13.12	10.95	11.06	0.93
12.05	11.43	11.58	1.34
11.01	12.01	12.07	0.54
9.81	12.44	12.62	1.42
8.42	13.20	13.23	0.27
7.47	13.45	13.63	1.33
6.32	14.04	14.09	0.32
5.01	14.44	14.58	0.99
3.85	15.09	14.98	-0.72
2.43	15.50	15.41	-0.57
1.65	15.82	15.62	-1.24

Table 7. Comparison of the regression equation and pump station performance curve for three pumps operating.

TSH	Q (p.s. Perf. Curve)	Q (Regression)	% Error
29.97	1.66	1.93	16.28
27.30	4.07	4.40	8.16
24.35	7.24	7.04	-2.72
21.17	10.39	9.79	-5.72
17.96	12.82	12.44	-2.97
15.99	14.18	13.99	-1.35
14.65	15.11	15.02	-0.65
13.71	15.71	15.72	0.06
12.55	16.43	16.56	0.83
11.43	17.14	17.36	1.28
10.34	18.00	18.11	0.60
9.08	18.67	18.95	1.48
7.60	19.79	19.88	0.47
6.60	20.19	20.48	1.47
5.39	21.06	21.17	0.53
4.01	21.67	21.91	1.11
2.78	22.63	22.50	-0.57
1.28	23.26	23.11	-0.66
0.46	23.73	23.36	-1.55

Table 8. Comparison of the regression equation and pump station performance curve for four pumps operating.

TSH	Q (p.s. Perf. Curve)	Q (Regression)	% Error
29.96	2.21	2.52	14.15
27.25	5.42	5.80	7.02
24.20	9.66	9.37	-2.99
20.85	13.85	13.11	-5.41
17.47	17.10	16.67	-2.50
15.39	18.93	18.76	-0.88
13.97	20.17	20.13	-0.19
12.97	20.96	21.06	0.47
11.73	21.93	22.18	1.16
10.53	22.90	23.24	1.50
9.35	24.03	24.23	0.81
8.01	24.94	25.31	1.46
6.41	26.41	26.51	0.36
5.35	26.97	27.26	1.05
4.04	28.12	28.10	-0.07
2.55	28.97	28.96	-0.04
1.21	30.21	29.58	-2.08

Table 9. Stream-gauging needs for Station S390.

		TSH	RPM	Number of measurements needed
S390	**One Pump in Operation**	0~4.5	1160	5
		4.5~8	1160	5
		8~11.5	1160	5
	Two Pumps in Operation	0~4.5	1160	5
		4.5~8	1160	5
		8~11.5	1160	5
	Three Pumps in Operation	0~4.5	1160	5
		4.5~8	1160	5
		8~11.5	1160	5
	Four Pumps in Operation	0~4.5	1160	5
		4.5~8	1160	5
		8~11.5	1160	5

Stream-gauging Needs

The stream-gauging needs for S390 are shown in Table 9. Because four rating equations were developed, the stream-gauging needs will be for four different cases as shown in Table 9.

Summary and Conclusions

A rating analysis of S-390 was carried out using the conventional case 8 model. Four rating equations were developed since up to four pumps can be operating in parallel and they discharge into a common force main. All four equations yield discharge rates that are within 2.1% of the discharges derived from the pump station rating curve under the expected range of static heads. Additionally, under the expected range of static heads, it was found that discharges can range from about 5.5 to 8.7 cfs with a single pump operating; with four pumps running simultaneously, the discharges can range from 20.5 to 32 cfs. Velocities within the force main can range from 1.7 to 2.8 ft/sec with one pump running and 6.5 to 10.2 ft/sec with four pumps operating.

Given the uncertainties inherent to the hydraulic head loss calculations, it is recommended that the rating equations be calibrated with measured flows. Furthermore, if feasible, it is recommended that head losses within the force main be measured under a variety of discharges in order to evaluate pipe roughness under field conditions.

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Appendix A. Head Loss Calculations

Table A1. Expected head losses with one pump operating (max loss)
Table A2. Expected head losses with one pump operating (min loss)

Table B1. Expected head losses with two pumps operating (max loss)
Table B2. Expected head losses with two pumps operating (min loss)

Table C1. Expected head losses with three pumps operating (max loss)
Table C2. Expected head losses with three pumps operating (min loss)

Table D1. Expected head losses with four pumps operating (max loss)
Table D2. Expected head losses with four pumps operating (min loss)

Table A1. Expected head losses with one pump operating (max loss)

PUMP 1 ONLY ON SKETCH

1160 RPM				10" DIP PIPE	24" PIPE
TDH(ft)	Q (GPM)	Q(cfs)	Static Head (ft)	10" Total Head Loss (ft)	24" IN Total Head Loss (ft)
30	250	0.56	29.94	0.06	0.00
27.5	625	1.39	27.14	0.35	0.01
25	1130	2.52	23.84	1.12	0.03
22.5	1630	3.63	20.10	2.34	0.07
20	2025	4.51	16.29	3.60	0.11
18.5	2250	5.01	13.92	4.44	0.13
17.5	2400	5.35	12.30	5.05	0.15
16.8	2500	5.57	11.15	5.48	0.16
15.95	2625	5.85	9.73	6.04	0.18
15.15	2750	6.13	8.32	6.63	0.20
14.4	2875	6.41	6.94	7.25	0.22
13.5	3000	6.69	5.37	7.89	0.23
12.5	3160	7.04	3.49	8.75	0.26
11.78	3250	7.24	2.25	9.26	0.28
10.97	3375	7.52	0.69	9.98	0.30
10	3500	7.80	-1.05	10.74	0.32
9.2	3625	8.08	-2.66	11.52	0.34
8.15	3750	8.36	-4.54	12.32	0.37
7.6	3825	8.52	-5.60	12.82	0.38
6.3	4000	8.91	-8.13	14.02	0.42
5.05	4175	9.30	-10.67	15.27	0.45
4.375	4250	9.47	-11.92	15.82	0.47

Table A2. Expected head losses with one pump operating (min loss)

PUMP 4 ONLY ON SKETCH

1160 RPM				10" DIP PIPE	
TDH(ft)	Q (GPM)	Q(cfs)	Static Head (ft)	10" Total Head Loss (ft)	24" Total Head Loss (ft)
30	250	0.56	29.97	0.02	0.00
27.5	625	1.39	27.35	0.14	0.01
25	1130	2.52	24.52	0.46	0.02
22.5	1630	3.63	21.52	0.93	0.04
20	2025	4.51	18.50	1.43	0.07
18.5	2250	5.01	16.66	1.76	0.08
17.5	2400	5.35	15.41	2.00	0.09
16.8	2500	5.57	14.53	2.17	0.10
15.95	2625	5.85	13.45	2.38	0.11
15.15	2750	6.13	12.41	2.61	0.12
14.4	2875	6.41	11.41	2.85	0.13
13.5	3000	6.69	10.25	3.10	0.15
12.5	3160	7.04	8.90	3.43	0.16
11.78	3250	7.24	7.98	3.63	0.17
10.97	3375	7.52	6.88	3.91	0.19
10	3500	7.80	5.60	4.20	0.20
9.2	3625	8.08	4.49	4.50	0.21
8.15	3750	8.36	3.11	4.81	0.23
7.6	3825	8.52	2.36	5.00	0.24
6.3	4000	8.91	0.58	5.46	0.26
5.05	4175	9.30	-1.18	5.94	0.28
4.375	4250	9.47	-2.07	6.16	0.29

Table B1. Expected head losses with two pumps operating (max loss)

PUMP 1 AND 2 ON SKETCH

1160 RPM			10" DIP PIPE	24" PIPE	
TDH(ft)	Q (GPM)	Q(cfs)	10" Total Head Loss (ft)	24" IN Total Head Loss (ft)	Static Head
30	250	0.56	0.06	0.01	29.94
27.5	625	1.39	0.35	0.04	27.11
25	1130	2.52	1.12	0.13	23.75
22.5	1630	3.63	2.34	0.27	19.90
20	2025	4.51	3.60	0.41	15.99
18.5	2250	5.01	4.44	0.51	13.55
17.5	2400	5.35	5.05	0.58	11.87
16.8	2500	5.57	5.48	0.63	10.69
15.95	2625	5.85	6.04	0.69	9.21
15.15	2750	6.13	6.63	0.76	7.76
14.4	2875	6.41	7.25	0.83	6.32
13.5	3000	6.69	7.89	0.90	4.71
12.5	3160	7.04	8.75	1.00	2.75
11.78	3250	7.24	9.26	1.06	1.46
10.97	3375	7.52	9.98	1.14	-0.16
10	3500	7.80	10.74	1.23	-1.96
9.2	3625	8.08	11.52	1.32	-3.63
8.15	3750	8.36	12.32	1.41	-5.58
7.6	3825	8.52	12.82	1.47	-6.69
6.3	4000	8.91	14.02	1.60	-9.32
5.05	4175	9.30	15.27	1.75	-11.97
4.375	4250	9.47	15.82	1.81	-13.26

Table B2. Expected head losses with two pumps operating (min loss)

PUMP 3 AND 4 ON SKETCH

1160 RPM			10" DIP PIPE	24" PIPE	
TDH(ft)	Q (GPM)	Q(cfs)	10" Total Head Loss (ft)	24" Total Head Loss (ft)	Static Head
30	250	0.56	0.02	0.00	29.97
27.5	625	1.39	0.14	0.03	27.33
25	1130	2.52	0.46	0.09	24.46
22.5	1630	3.63	0.93	0.17	21.39
20	2025	4.51	1.43	0.27	18.30
18.5	2250	5.01	1.76	0.33	16.41
17.5	2400	5.35	2.00	0.38	15.13
16.8	2500	5.57	2.17	0.41	14.23
15.95	2625	5.85	2.38	0.45	13.12
15.15	2750	6.13	2.61	0.49	12.05
14.4	2875	6.41	2.85	0.54	11.01
13.5	3000	6.69	3.10	0.58	9.81
12.5	3160	7.04	3.43	0.65	8.42
11.78	3250	7.24	3.63	0.69	7.47
10.97	3375	7.52	3.91	0.74	6.32
10	3500	7.80	4.20	0.79	5.01
9.2	3625	8.08	4.50	0.85	3.85
8.15	3750	8.36	4.81	0.91	2.43
7.6	3825	8.52	5.00	0.95	1.65
6.3	4000	8.91	5.46	1.04	-0.20
5.05	4175	9.30	5.94	1.13	-2.02
4.375	4250	9.47	6.16	1.18	-2.96

Table C1. Expected head losses with three pumps operating (max loss)

PUMP 1, 2 AND 3 ON SKETCH

			10" DIP PIPE	24" PIPE	
1160 RPM			10" Total Head Loss (ft)	24" IN Total Head Loss (ft)	Static Head
TDH(ft)	Q (GPM)	Q(cfs)			
30	250	0.56	0.06	0.01	29.93
27.5	625	1.39	0.35	0.08	27.07
25	1130	2.52	1.12	0.28	23.60
22.5	1630	3.63	2.34	0.58	19.59
20	2025	4.51	3.60	0.89	15.51
18.5	2250	5.01	4.44	1.10	12.96
17.5	2400	5.35	5.05	1.25	11.19
16.8	2500	5.57	5.48	1.36	9.96
15.95	2625	5.85	6.04	1.50	8.41
15.15	2750	6.13	6.63	1.64	6.87
14.4	2875	6.41	7.25	1.80	5.35
13.5	3000	6.69	7.89	1.96	3.65
12.5	3160	7.04	8.75	2.17	1.57
11.78	3250	7.24	9.26	2.30	0.22
10.97	3375	7.52	9.98	2.48	-1.49
10	3500	7.80	10.74	2.66	-3.40
9.2	3625	8.08	11.52	2.86	-5.17
8.15	3750	8.36	12.32	3.06	-7.23
7.6	3825	8.52	12.82	3.18	-8.40
6.3	4000	8.91	14.02	3.48	-11.20
5.05	4175	9.30	15.27	3.79	-14.01
4.375	4250	9.47	15.82	3.96	-15.40

Table C2. Expected head losses with three pumps operating (min loss)

PUMP 2, 3 AND 4 ON SKETCH

			10" DIP PIPE	24" PIPE	
1160 RPM			10" Total Head Loss (ft)	24" Total Head Loss (ft)	Static Head
TDH(ft)	Q (GPM)	Q(cfs)			
30	250	0.56	0.02	0.01	29.97
27.5	625	1.39	0.14	0.06	27.30
25	1130	2.52	0.46	0.19	24.35
22.5	1630	3.63	0.93	0.40	21.17
20	2025	4.51	1.43	0.61	17.96
18.5	2250	5.01	1.76	0.75	15.99
17.5	2400	5.35	2.00	0.85	14.65
16.8	2500	5.57	2.17	0.92	13.71
15.95	2625	5.85	2.38	1.02	12.55
15.15	2750	6.13	2.61	1.12	11.42
14.4	2875	6.41	2.85	1.22	10.33
13.5	3000	6.69	3.10	1.33	9.07
12.5	3160	7.04	3.43	1.47	7.59
11.78	3250	7.24	3.63	1.56	6.59
10.97	3375	7.52	3.91	1.68	5.38
10	3500	7.80	4.20	1.80	4.00
9.2	3625	8.08	4.50	1.93	2.77
8.15	3750	8.36	4.81	2.07	1.27
7.6	3825	8.52	5.00	2.15	0.44
6.3	4000	8.91	5.46	2.35	-1.52
5.05	4175	9.30	5.94	2.56	-3.46
4.375	4250	9.47	6.16	2.72	-4.50

Table D1. Expected head losses with four pumps operating (max loss)

PUMP 1, 2, 3 AND 4 ON SKETCH

1160 RPM			10" DIP PIPE	24" PIPE	
TDH(ft)	Q (GPM)	Q(cfs)	10" Total Head Loss (ft)	24" Total Head Loss (ft)	Static Head
30	250	0.56	0.06	0.02	29.92
27.5	625	1.39	0.35	0.15	27.01
25	1130	2.52	1.12	0.48	23.40
22.5	1630	3.63	2.34	0.99	19.17
20	2025	4.51	3.60	1.53	14.87
18.5	2250	5.01	4.44	1.89	12.17
17.5	2400	5.35	5.05	2.15	10.30
16.8	2500	5.57	5.48	2.33	8.99
15.95	2625	5.85	6.04	2.57	7.34
15.15	2750	6.13	6.63	2.82	5.70
14.4	2875	6.41	7.25	3.08	4.07
13.5	3000	6.69	7.89	3.36	2.25
12.5	3160	7.04	8.75	3.72	0.02
11.78	3250	7.24	9.26	3.94	-1.42
10.97	3375	7.52	9.98	4.25	-3.26
10	3500	7.80	10.74	4.57	-5.31
9.2	3625	8.08	11.52	4.90	-7.22
8.15	3750	8.36	12.32	5.25	-9.42
7.6	3825	8.52	12.82	5.46	-10.68
6.3	4000	8.91	14.02	5.97	-13.69
5.05	4175	9.30	15.27	6.50	-16.72
4.375	4250	9.47	15.82	6.85	-18.30

Table D2. Expected head losses with four pumps operating (min loss)

PUMP 1, 2, 3 AND 4 ON SKETCH

1160 RPM			10" DIP PIPE	24" PIPE	
TDH(ft)	Q (GPM)	Q(cfs)	10" Total Head Loss (ft)	24" Total Head Loss (ft)	Static Head
30	250	0.56	0.02	0.02	29.96
27.5	625	1.39	0.14	0.11	27.25
25	1130	2.52	0.46	0.34	24.20
22.5	1630	3.63	0.93	0.71	20.85
20	2025	4.51	1.43	1.09	17.47
18.5	2250	5.01	1.76	1.35	15.39
17.5	2400	5.35	2.00	1.53	13.97
16.8	2500	5.57	2.17	1.66	12.97
15.95	2625	5.85	2.38	1.83	11.73
15.15	2750	6.13	2.61	2.01	10.53
14.4	2875	6.41	2.85	2.20	9.35
13.5	3000	6.69	3.10	2.39	8.01
12.5	3160	7.04	3.43	2.65	6.41
11.78	3250	7.24	3.63	2.81	5.35
10.97	3375	7.52	3.91	3.02	4.04
10	3500	7.80	4.20	3.25	2.55
9.2	3625	8.08	4.50	3.49	1.21
8.15	3750	8.36	4.81	3.73	-0.39
7.6	3825	8.52	5.00	3.88	-1.28
6.3	4000	8.91	5.46	4.24	-3.41
5.05	4175	9.30	5.94	4.62	-5.51
4.375	4250	9.47	6.16	5.14	-6.92