Flow Rating Analysis for Pump Station G-337
Stormwater Treatment Area 2

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Executive Summary

A rating analysis of G-337 was carried out using the conventional case 8 model. A new rating equation depicting the TSH versus Q relationship was developed for each of the three pumps. Since no reliable flow measurements were available at this site, each rating equation was based on the respective factory test performance results along with estimated system head losses. Discharges computed with the three rating equations were generally within 5% of the discharges obtained from the performance curves. Exceptions to this, however, occurred at a few points along the performance curves for pumps 2 and 3. It is believed that the larger discrepancies are primarily due to measurement errors inherent to the factory pump performance test results. In contrast, discharges computed with the existing rating equation were almost always 10% greater than the corresponding discharges obtained from the performance curves. Hence, the revised rating equations are considered to be a significant improvement over the existing rating equation.

An impact analysis was carried out to evaluate the need to recompute historical flows through G-337. Mean daily flows computed with the new equations over the entire period of record were compared with the mean daily flows currently stored in DBHYDRO. The average difference is about 14%. The reloading of historical flows into DBHYDRO is therefore recommended.

Acknowledgements

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Table of Contents

List of Figures

List of Tables

Introduction

Stormwater Treatment Area 2 (STA-2) is a major structural component of the Everglades Construction Project mandated by the 1994 Everglades Forever Act. It is generally situated on the former Brown's Farm Wildlife Management Area and surrounding lands. It is located immediately west of Water Conservation Area 2A (figure 1). STA-2 provides a total effective treatment area of 6,430 acres to treat stormwater runoff originating from the portions of the Hillsboro Canal and Ocean Canal drainage basins located upstream of the S-6 Pump Station.

Also shown in figure 1 is the location of pump station G-337. The purpose of this pump station is to reduce seepage from STA 2 to privately owned lands located adjacent to the impoundment. This is accomplished by pumping seepage collected in the outer perimeter canal back into the interior supply canal of the STA.

G-337 has three vertical axial, 42-inch diameter centrifugal pumps driven by electric-powered motors. These pumps were originally obtained from pump station G-250, an inflow structure for the former ENR facility. They were subsequently refurbished and adapted to G-337.

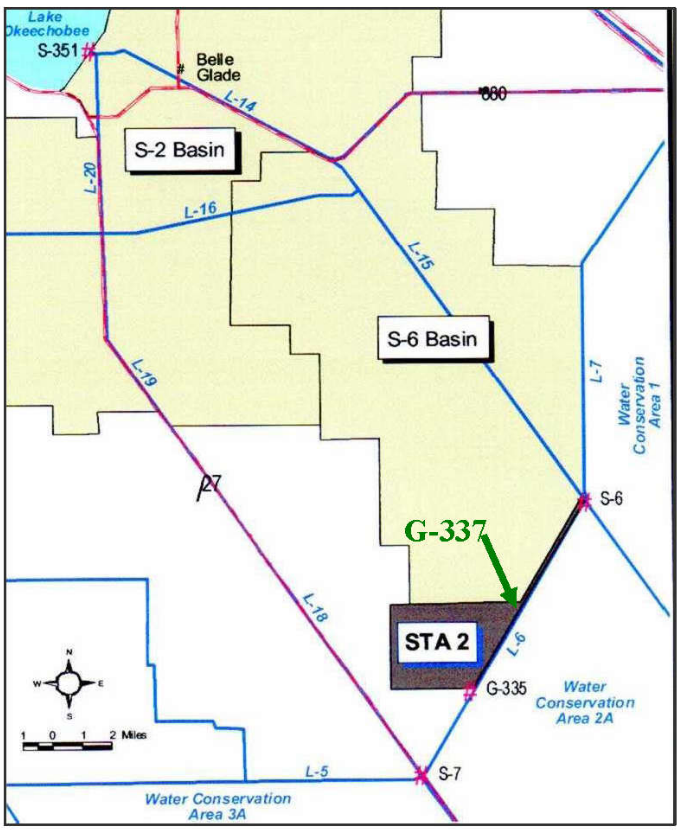

Figure 1. Location of STA 2 and G-337 (reprinted from Sutron Corp., 2005)

Objectives and Scope

The purpose of the rating analyses conducted in this study is to enable flows through G-337 to be estimated using measured head water elevations, tail water elevations and pump engine speeds. The rating equations are based on pump performance characteristics, the hydraulic properties of the pump station piping, and engineering principles. Due to the difficulties involved with obtaining accurate stream flow measurements at this site, no measurements were available for calibrating the rating equation.

Station Design

Various cross sectional views of the pump station design are shown in figure 2 while figure 3 shows the design profiles of the discharge pipe, the intake chamber and the outlet structure. Table 1 contains the hydraulic properties of the station piping and table 2 lists the performance data acquired for each of the pumps during the factory performance tests (MWI Couch Pump Company, 1998).

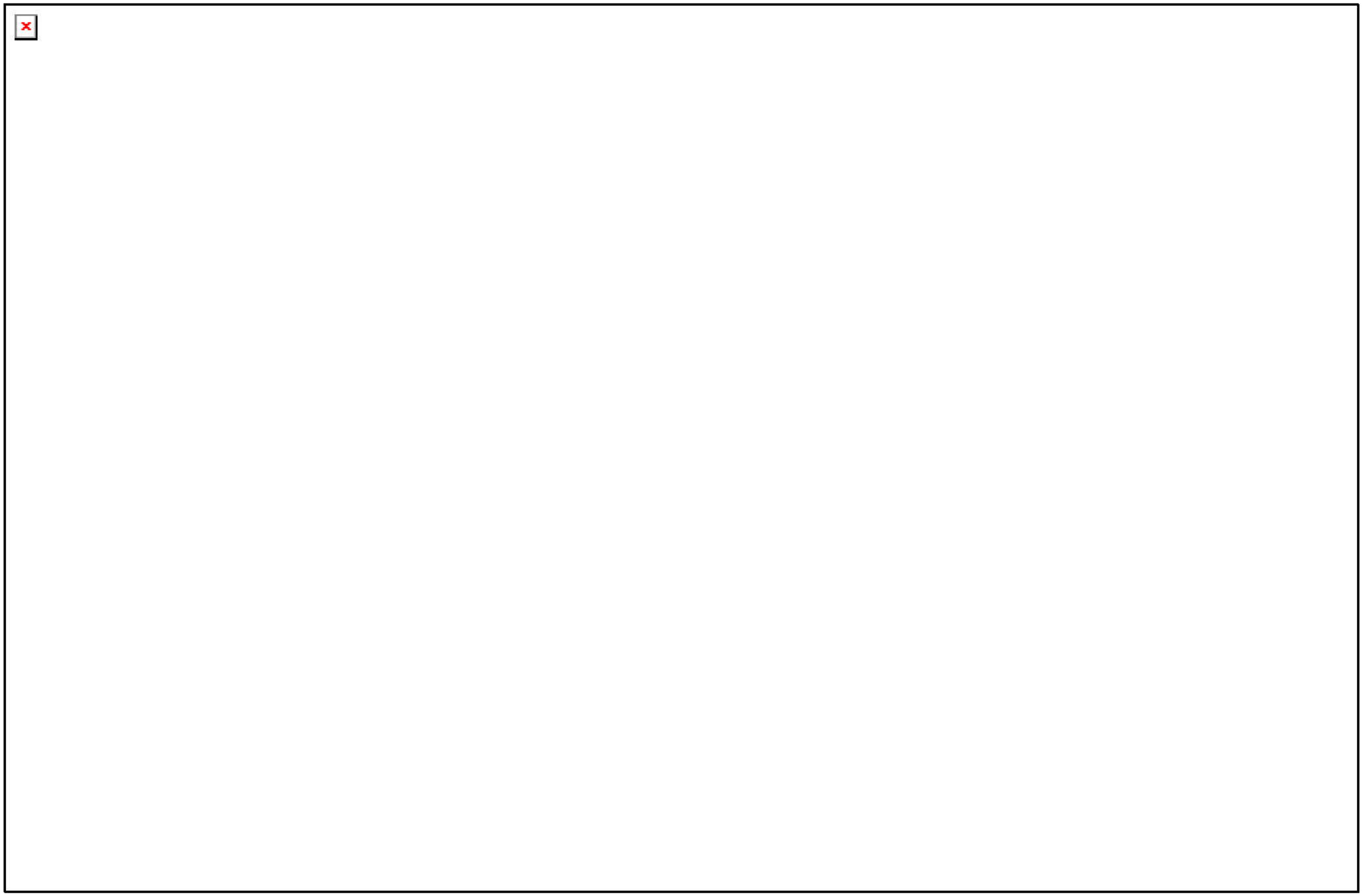

Figure 2. Design of G-337

Figure 3. Design profiles of the discharge pipe, the intake chamber and outlet structure

Table 1. Hydraulic properties of the discharge pipe

Property	Dimension	Source
OD	42 in.	*record dwgs*
Wall Thickness	0.375 in.	*proj specs*
Length	70 ft	*record dwgs*
ε_{min}	0.00015 ft	*Hyd Inst (1990)*
ε_{max}	0.0013 ft	*Sanks (1989)*

Note that the pump speeds shown in table 2 vary somewhat from the design speed of 347 RPM. 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.

Table 2. Pump performance test results

Test Point #	Serial # 6727 - Pump 3			Serial # 6722 - Pump 2			Serial # 6724 - Pump 1		
	Pump Speed (RPM)	TDH	Q (gpm)	Pump Speed (RPM)	TDH	Q (gpm)	Pump Speed (RPM)	TDH	Q (gpm)
1	337.8	14.57	17,317	325	13.25	20,813	340.6	13.67	22,356
2	339.6	14.35	20,813	329	13.29	21,598	341.1	12.89	25,815
3	340.4	13.84	22,356	330	12.30	24,490	341.9	12.37	29,434
4	341.0	13.39	25,161	332	11.89	25,815	342.4	11.68	32,139
5	342.1	12.29	29,994	331	11.85	26,452	342.7	11.32	35,112
6	342.3	11.58	32,654	333	11.67	30,545	343.0	10.17	38,290
7	342.9	11.00	36,961	334	11.27	34,634	343.5	8.74	41,625
8	343.3	10.38	37,852	338	10.38	38,290	343.9	8.25	42,418
9	343.6	9.47	38,722	337	8.41	41,625			
10	344.1	8.73	39,992						

Rating Analysis

New Rating Equation

The procedure implemented here for developing the rating curves reflects the standard procedure presented by Imru and Wang (2004). The model rating equation is the standard Case 8 model:

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

where Q is the discharge at N RPM, H is the total static head (TSH), N_O is the design engine or pump speed, and A, B and C are coefficients to be determined through regression. The TSH versus Q relationship for each pump was determined by subtracting the head losses through the discharge pipe from each point on the pump performance curve (appendix A). This results in a *pump station* performance curve for each pump. Figures 4 display these curves for the three pumps along with the associated pump performance curves constructed from the data in table 2. Computed for each pump were several pump station performance curves reflecting the estimated range of pipe hydraulic roughness shown in table 1. It is readily evident that the performance curves are insensitive to pipe roughness within the estimated range.

The SAS nonlinear regression procedure NLIN was used to fit equation 1 to each of the pump station performance curves. The resultant parameters are provided in table 3. The computed pump station performance curves based on the rating equations are also shown in figures 4.

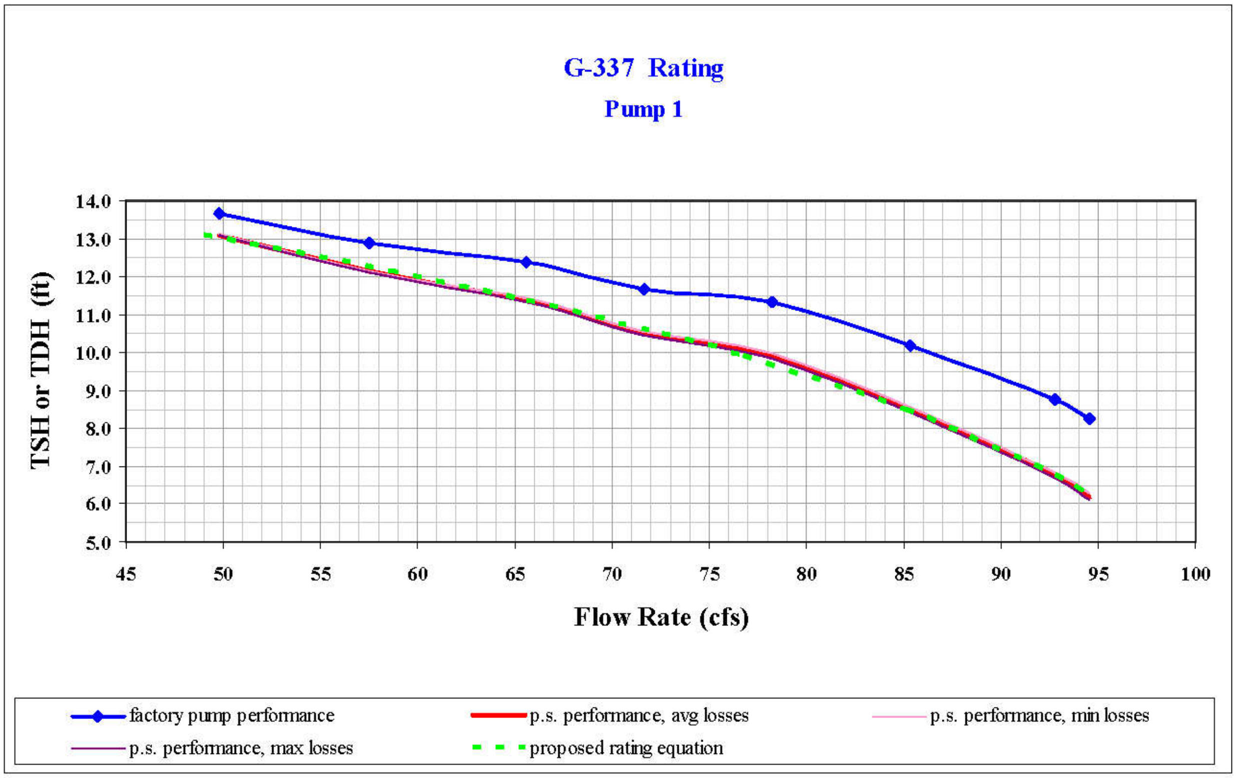

Figure 4a. Performance curves for pump # 1

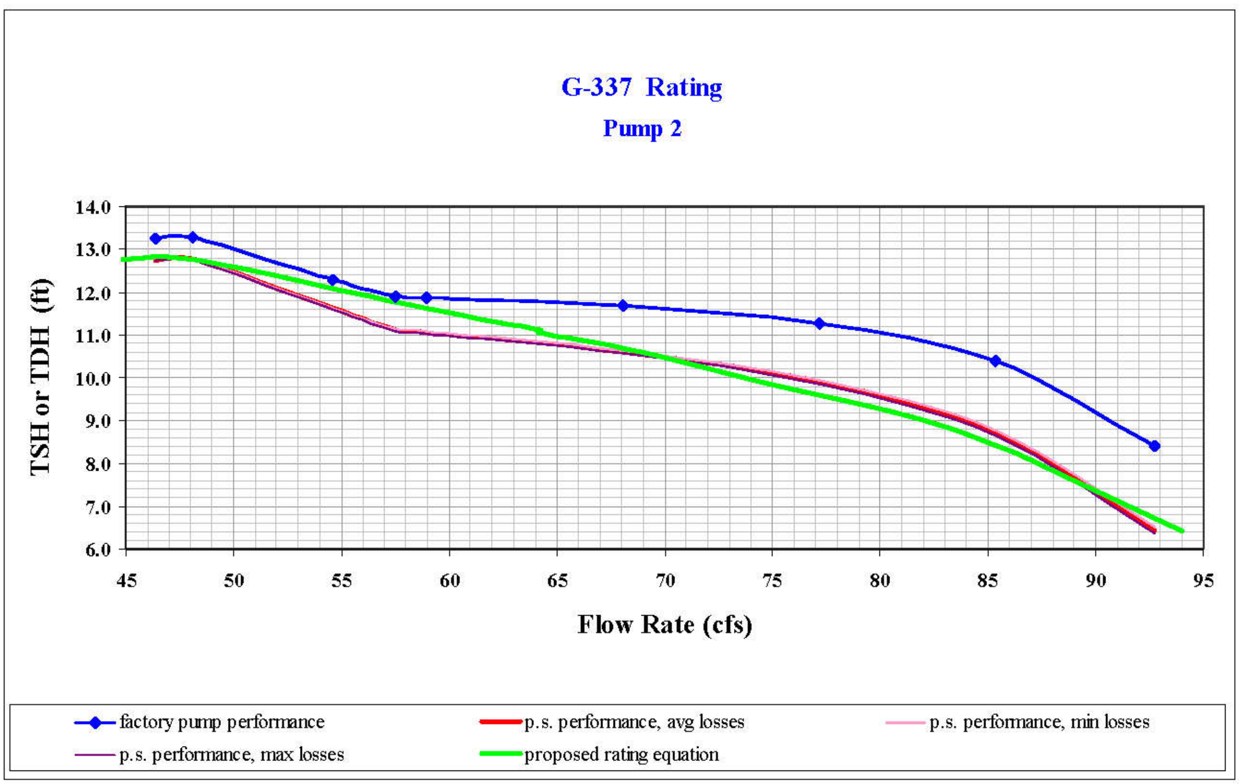

Figure 4b. Performance curves for pump # 2

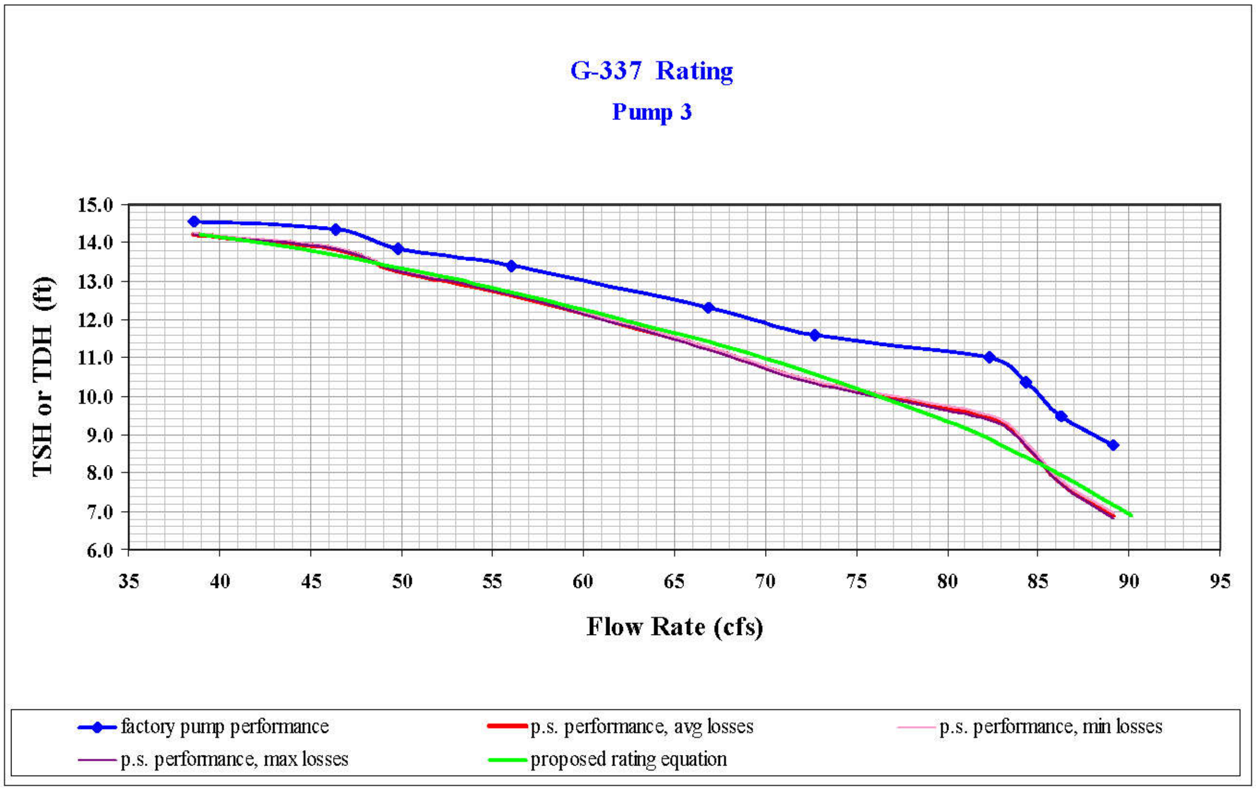

Figure 4c. Performance curves for pump # 3

The performance curves shown in figures 4 cannot be directly compared since they were operated at different speeds during the individual factory performance tests. To circumvent this difficulty, each of the pump station performance curves was recomputed after adjusting the factory test points to the design speed of 347 RPM. This was accomplished by applying the following affinity laws (see, for example, Sanks, 1989) to each pair of TDH and Q values:

Table 3. Values of A, B and C in equation 1

Parameter	Pump Number		
	1	*2*	*3*
A	103.4	108.5	98.76
B	-0.076	-0.18	-0.046
C	2.51	2.18	2.64

$$\frac{Q}{Q_o} = \frac{N}{N_o} \qquad (2a)$$

$$\frac{H}{H_o} = \left(\frac{N}{N_o}\right)^2 \qquad (2b)$$

The adjusted performance curves are compared in figure 5. Given these results along with the age of the pumps, it is advisable that only one pump be operated at a time while taking stream flow measurements.

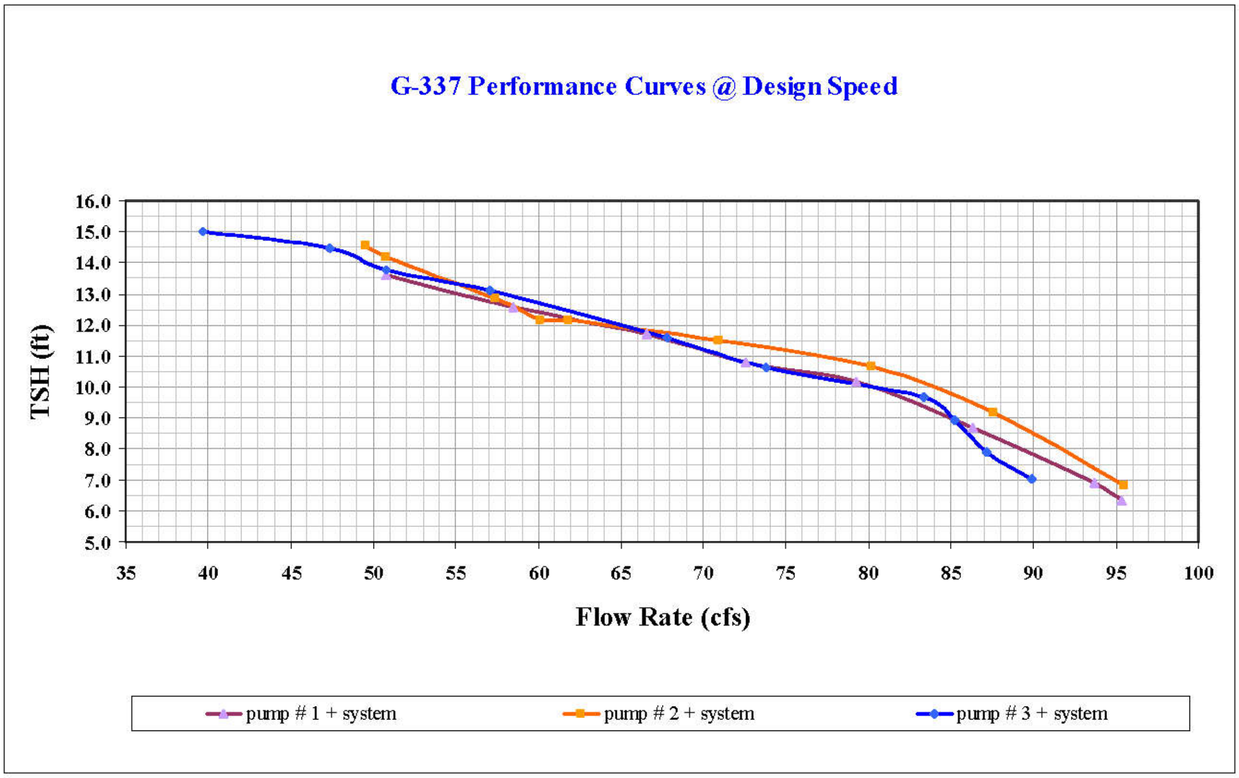

Figure 5. Comparison of G-337 performance curves

Existing Rating Equation

The equation currently used to compute flows through G-337 is based on the Case 5 model (see, for example, Ansar and Alexis, 2003) and can be stated as follows:

$$Q = C_o + C_1 H + C_2 H^2 \quad \text{.......................................} \quad (3)$$

Specified in DBHYDRO for each pump in G-337 are $C_o = 99.51$, $C_1 = 0.60$ and $C_2 = -0.26$. Unfortunately, no records or information explaining the basis of these coefficients could be located. Hence, their accuracy is questionable. Since N is not a parameter in equation 3, design speed is assumed.

Comparison of Rating Equations

Equations 1 and 3 were compared at design speed to each of the pump station performance curves. Tables 4 summarize these comparisons. It is apparent that the new rating equations replicate the performance curves significantly better than the existing equation. For pump # 1, the new rating equation computes flows to within 2% of the performance curve. In contrast, at a few of the test points for pumps 2 and 3, the proposed ratings did not agree well with the

Table 4a. Comparison of existing and proposed rating equations for pump # 1

Discharge (cfs) from PS Performance Curve	TSH (ft) from PS Performance Curve	Existing Rating (case 5)		Revised Rating (case 8)	
		Discharge (cfs)	% Error	Discharge (cfs)	% Error
50.75	13.59	43.90	-13.49	49.92	-1.63
58.52	12.55	51.54	-11.92	59.66	1.95
66.57	11.72	57.21	-14.05	66.57	0.00
72.58	10.78	63.20	-12.93	73.54	1.32
79.22	10.16	66.92	-15.54	77.68	-1.95
86.32	8.69	74.90	-13.23	86.02	-0.34
93.70	6.90	83.16	-11.25	93.69	-0.02
95.37	6.30	85.53	-10.33	95.65	0.29

Table 4b. Comparison of existing and proposed rating equations for pump #2

Discharge (cfs) from PS Performance Curve	TSH (ft) from PS Performance Curve	Existing Rating (case 5)		Revised Rating (case 8)	
		Discharge (cfs)	% Error	Discharge (cfs)	% Error
49.52	14.54	36.51	-26.27	47.43	-4.22
50.76	14.19	39.30	-22.58	50.58	-0.36
57.38	12.84	49.47	-13.78	61.91	7.89
60.12	12.15	54.29	-9.71	67.16	11.70
61.79	12.14	54.37	-12.01	67.25	8.83
70.93	11.51	58.58	-17.41	71.77	1.20
80.18	10.68	63.80	-20.43	77.29	-3.60
87.59	9.17	72.41	-17.34	86.11	-1.69
95.51	6.82	83.50	-12.58	96.78	1.33

Table 4c. Comparison of existing and proposed rating equations for pump #3

Discharge (cfs) from PS Performance Curve	TSH (ft) from PS Performance Curve	Existing Rating (case 5)		Revised Rating (case 8)	
		Discharge (cfs)	% Error	Discharge (cfs)	% Error
39.64	15.01	32.64	-17.66	34.78	-12.27
47.39	14.46	37.11	-21.68	40.90	-13.69
50.78	13.78	42.43	-16.44	48.00	-5.48
57.05	13.11	47.48	-16.78	54.54	-4.40
67.79	11.58	58.10	-14.30	67.63	-0.25
73.76	10.64	64.03	-13.20	74.47	0.96
83.35	9.66	69.73	-16.33	80.72	-3.15
85.26	8.93	73.68	-13.58	84.80	-0.53
87.14	7.91	78.71	-9.68	89.69	2.93
89.87	7.02	82.66	-8.02	93.25	3.77

performance curves (see also figures 4), where discrepancies were as high as 11.7% for pump 2 and 13.7% for pump 3. However, the rough shapes of the pump performance curves shown in figures 4b and 4c suggest that some of the factory test results are tainted by measurement errors. Nonetheless, at most of the test points, the proposed rating equations agree with the respective performance curves to within 5%. On the other hand, absolute differences between flows computed with the existing rating equation and each of the pump station performance curves are usually greater than 10% for all three pumps.

Discharge and Velocity Ranges

The expected range of operating conditions for each pump can be estimated by reading from figure 5 the expected range of discharges corresponding to the expected range of static heads over which pumping would typically occur (about 5 – 8 feet). As an alternative, conventional system performance curves were computed for minimum, average and maximum head losses. These losses were based on minimum, average and maximum static heads of 4.68, 7 and 8.03 feet NGVD, respectively. These system curves along with the respective pump performance curves are plotted in figures 6. It is evident that each of the pumps will operate near the lower

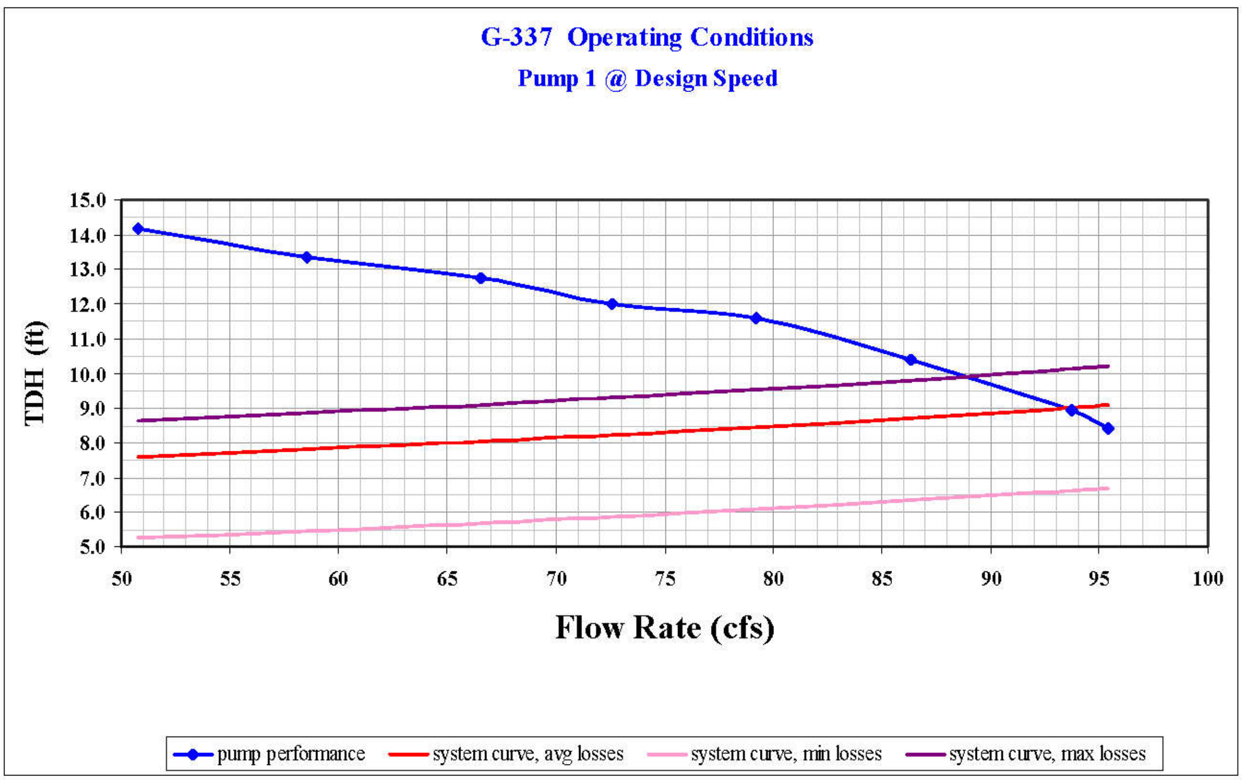

Figure 6a. Operating conditions for pump # 1

end of their performance curves at discharges of about 90 – 95 cfs. This corresponds to a velocity range of 9.7 – 10.24 ft/s. Hence, any flow measuring device installed within any of the discharge pipes should be suitable for a velocity of about 10 ft/s.

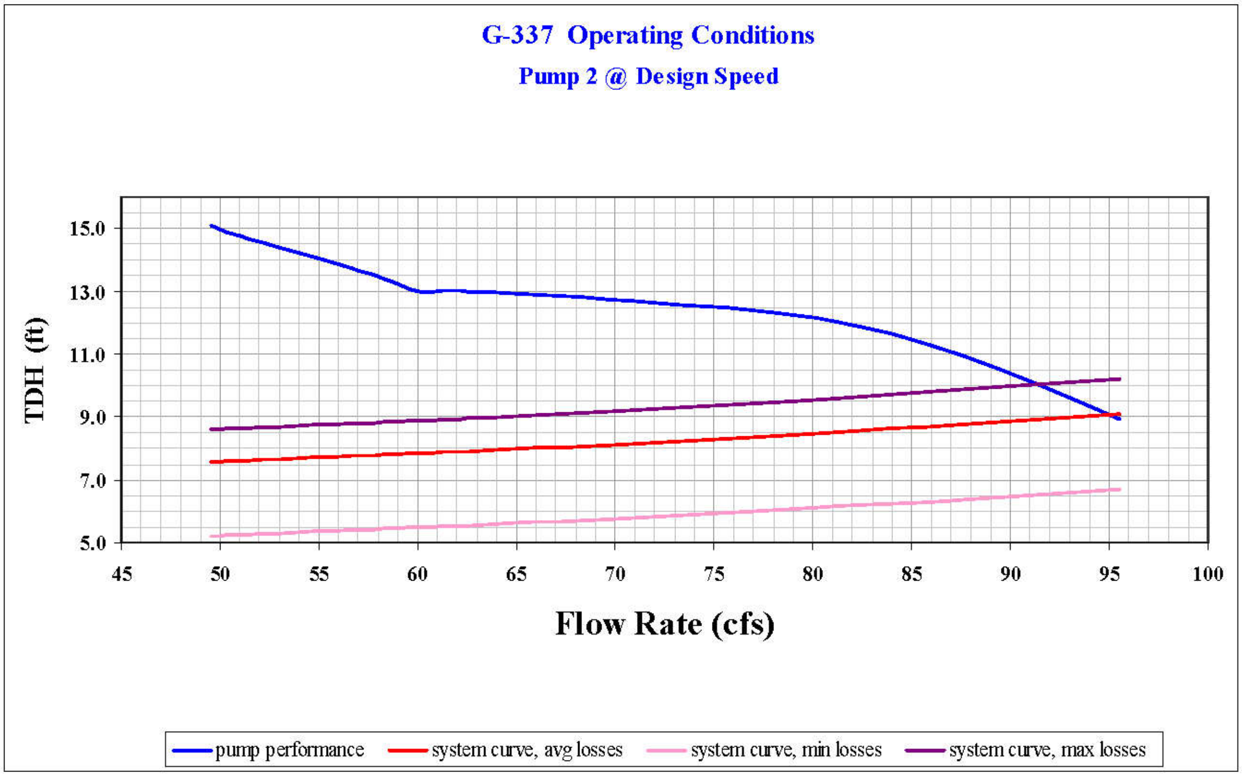

Figure 6b. Operating conditions for pump # 2

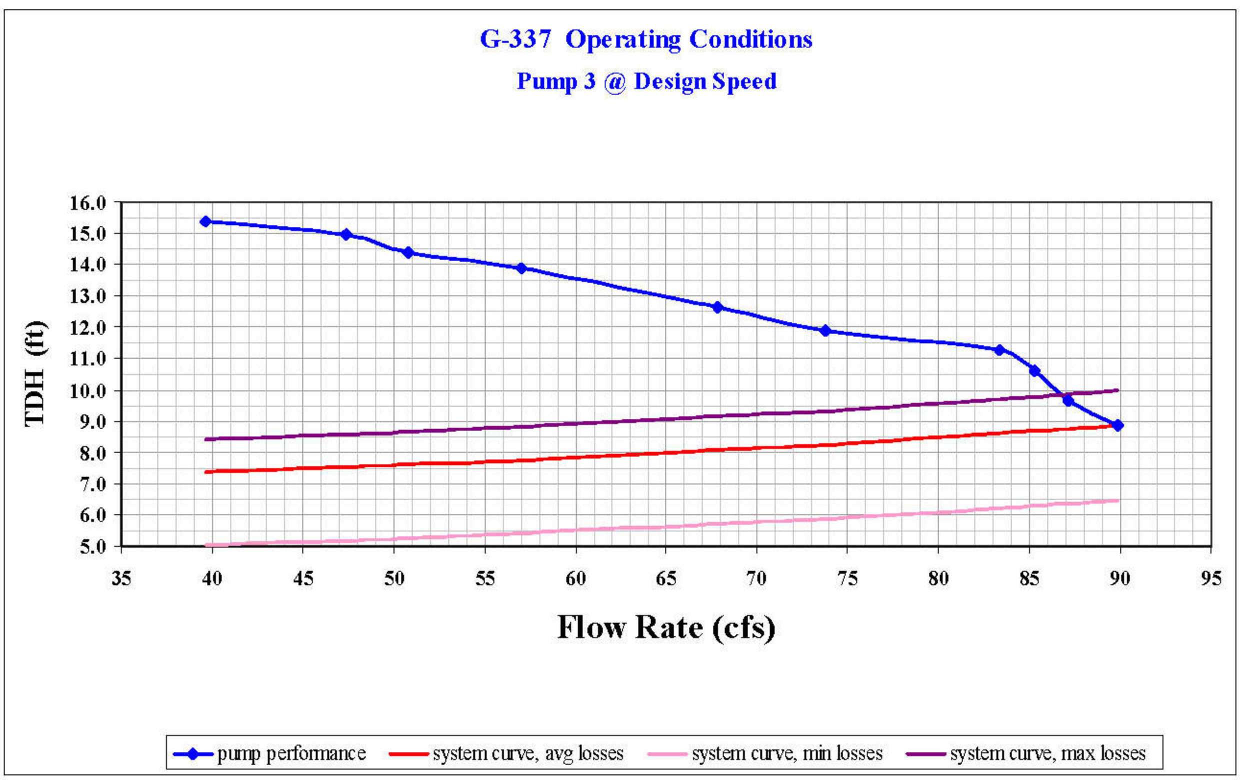

Figure 6c. Operating conditions for pump # 3

Impact Analysis

Given the differences between the proposed and existing ratings, an impact analysis over the entire period of record for G-337 was conducted in order to assess the need for recomputing historical flows. Mean daily flows through G-337 were computed with both the new and existing rating equations over the period of record spanning October 16, 2001 through July 24, 2007. For the days when pumping occurred, the difference in mean daily flow averaged about 14%. Consequently, the reloading of historical flows into DBHYDRO is recommended.

Stream Gauging Needs

Given the absence of any reliable flow data at G-337, stream gauging measurements are needed throughout the entire range of static head that is anticipated to occur under field conditions. This is summarized for all pumps in table 5.

Table 5. Required stream gauging data

Static Head Range (ft)	# of Measurements
4 - 6	5
6 - 8	5
8 - 9	5

Summary and Conclusions

A rating analysis of G-337 was carried out using the conventional case 8 model. A new rating equation depicting the TSH versus Q relationship was developed for each of the three pumps. Since no reliable flow measurements were available at this site, each rating equation was based on the respective factory test performance results along with estimated system head losses. Discharges computed with the three rating equations were generally within 5% of the discharges obtained from the respective performance curves. Exceptions to this, however, occurred at a few points along the performance curves for pumps 2 and 3. It is believed that this is primarily due to measurement errors inherent to the factory pump performance test results. In contrast, discharges computed with the existing rating equation were usually 10% lower than the corresponding discharges obtained from the performance curves. Hence, the revised rating equations are considered to be a significant improvement over the existing rating equation.

An impact analysis was carried out to evaluate the need to recompute historical flows through G-337. Mean daily flows computed with the new equations over the entire period of record were compared with the mean daily flows currently stored in DBHYDRO. The average difference is about 14%. The reloading of historical flows into DBHYDRO is therefore recommended.

References

Ansar, M., and A. Alexis, 2003, Atlas of Flow Computations at District Hydraulic Structures. Hydrology and Hydraulics Division, South Florida Water Management District, West Palm Beach, Florida. 78 pp.

Hydraulic Institute. 1990. *Engineering Data Book, Second Edition*. Hydraulic Institute, Cleveland, Ohio.

Imru, M. and Y. Wang. 2004. Flow Rating Development for New Pump Stations. Technical

Publication EMA # 419, South Florida Water Management District, West Palm Beach, Florida, 44 pp.

MWI Couch Pump Company. 1998. Factory Test Report, G-337 Seepage Pump Station: Job # 98118 for SFWMD. MWI Couch Pump Company, Grant, Florida, 16 pp.

Sanks, R. L. 1989. *Pumping Station Design.* Butterworth Publishers, Stoneham, MA.

Sutron Corporation. 2005. STA-2 2-D Hydraulic Modeling (Linked Cells Model) : Task 1.8 Final Report. South Florida Water Management District, West Palm Beach, Florida, 94 pp.

Appendix A. Performance Curve Calculations

Table A1. Performance curve calculations for pump # 1 at test speeds and average losses

RPM Varies						Swamee & Jain(1976)				
TDH (ft)	Q(GPM)	Q(cfs)	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma K_m V^2/2g$	Total Head Loss (ft)	TSH(FT)
13.67	22,356	49.82	5.37	1.85E+06	0.45	0.01400	0.13	0.45	0.57	13.10
12.89	25,815	57.52	6.20	2.13E+06	0.60	0.01390	0.17	0.60	0.77	12.12
12.37	29,434	65.59	7.07	2.43E+06	0.78	0.01382	0.22	0.78	0.99	11.38
11.68	32,139	71.62	7.72	2.65E+06	0.92	0.01377	0.26	0.92	1.18	10.50
11.32	35,112	78.24	8.43	2.90E+06	1.10	0.01372	0.31	1.10	1.41	9.91
10.17	38,290	85.32	9.19	3.16E+06	1.31	0.01368	0.37	1.31	1.68	8.49
8.74	41,625	92.75	9.99	3.44E+06	1.55	0.01364	0.43	1.55	1.98	6.76
8.25	42,418	94.52	10.18	3.50E+06	1.61	0.01363	0.45	1.61	2.06	6.19

Table A2. Performance curve calculations for pump # 2 at test speeds and average losses

RPM Varies						Swamee & Jain(1976)				
TDH (ft)	Q(GPM)	Q(cfs)	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma K_m V^2/2g$	Total Head Loss (ft)	TSH(FT)
13.25	20,813	46.38	5.00	1.72E+06	0.39	0.01405	0.11	0.39	0.50	12.75
13.29	21,598	48.13	5.19	1.78E+06	0.42	0.01403	0.12	0.42	0.54	12.75
12.30	24,490	54.57	5.88	2.02E+06	0.54	0.01394	0.15	0.54	0.69	11.61
11.89	25,815	57.52	6.20	2.13E+06	0.60	0.01390	0.17	0.60	0.77	11.12
11.85	26,452	58.94	6.35	2.18E+06	0.63	0.01389	0.18	0.63	0.80	11.05
11.67	30,545	68.06	7.33	2.52E+06	0.84	0.01380	0.23	0.84	1.07	10.60
11.27	34,634	77.18	8.32	2.86E+06	1.07	0.01373	0.30	1.07	1.37	9.90
10.38	38,290	85.32	9.19	3.16E+06	1.31	0.01368	0.37	1.31	1.68	8.70
8.41	41,625	92.75	9.99	3.44E+06	1.55	0.01364	0.43	1.55	1.98	6.43

Table A3. Performance curve calculations for pump # 3 at test speeds and average losses

RPM Varies						Swamee & Jain(1976)				
TDH (ft)	Q(GPM)	Q(cfs)	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma K_m V^2/2g$	Total Head Loss (ft)	TSH(FT)
14.57	17,317	38.59	4.16	1.43E+06	0.27	0.01420	0.08	0.27	0.35	14.22
14.35	20,813	46.38	5.00	1.72E+06	0.39	0.01405	0.11	0.39	0.50	13.85
13.84	22,356	49.82	5.37	1.85E+06	0.45	0.01400	0.13	0.45	0.57	13.27
13.39	25,161	56.07	6.04	2.08E+06	0.57	0.01392	0.16	0.57	0.73	12.66
12.29	29,994	66.84	7.20	2.48E+06	0.81	0.01381	0.23	0.81	1.03	11.26
11.58	32,654	72.76	7.84	2.70E+06	0.95	0.01376	0.27	0.95	1.22	10.36
11.00	36,961	82.36	8.87	3.05E+06	1.22	0.01370	0.34	1.22	1.56	9.44
10.38	37,852	84.35	9.09	3.12E+06	1.28	0.01369	0.36	1.28	1.64	8.74
9.47	38,722	86.29	9.30	3.20E+06	1.34	0.01367	0.37	1.34	1.72	7.75
8.73	39,992	89.12	9.60	3.30E+06	1.43	0.01366	0.40	1.43	1.83	6.90

Table A4. Performance curve calculations for pump # 1 at design speed and average losses

347 RPM						Swamee & Jain(1976)				
TDH (ft)	Q(GPM)	Q(cfs)	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$hl = f(L/D)V^2/2g$	$h_m = \Sigma K_m V^2/2g$	Total Head Loss (ft)	System TDH (FT)
14.19	22,776	50.75	5.47	1.88E+06	0.46	0.01399	0.13	0.46	0.60	7.60
13.34	26,262	58.52	6.31	2.17E+06	0.62	0.01389	0.17	0.62	0.79	7.79
12.74	29,873	66.57	7.17	2.47E+06	0.80	0.01381	0.22	0.80	1.02	8.02
12.00	32,571	72.58	7.82	2.69E+06	0.95	0.01376	0.27	0.95	1.22	8.22
11.61	35,553	79.22	8.54	2.93E+06	1.13	0.01372	0.32	1.13	1.45	8.45
10.41	38,737	86.32	9.30	3.20E+06	1.34	0.01367	0.37	1.34	1.72	8.72
8.92	42,049	93.70	10.10	3.47E+06	1.58	0.01363	0.44	1.58	2.02	9.02
8.40	42,800	95.37	10.28	3.53E+06	1.64	0.01363	0.46	1.64	2.09	9.09

Table A5. Performance curve calculations for pump # 2 at design speed and average losses

347 RPM						Swamee & Jain(1976)				
TDH (ft)	Q(GPM)	Q(cfs)	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma K_m V^2/2g$	Total Head Loss (ft)	System TDH (FT)
15.10	22,222	49.52	5.34	1.83E+06	0.44	0.01401	0.13	0.44	0.57	7.57
14.78	22,780	50.76	5.47	1.88E+06	0.46	0.01399	0.13	0.46	0.60	7.60
13.60	25,752	57.38	6.18	2.13E+06	0.59	0.01391	0.17	0.59	0.76	7.76
12.99	26,981	60.12	6.48	2.23E+06	0.65	0.01388	0.18	0.65	0.84	7.84
13.02	27,731	61.79	6.66	2.29E+06	0.69	0.01386	0.19	0.69	0.88	7.88
12.67	31,829	70.93	7.64	2.63E+06	0.91	0.01378	0.25	0.91	1.16	8.16
12.16	35,982	80.18	8.64	2.97E+06	1.16	0.01371	0.32	1.16	1.48	8.48
10.94	39,310	87.59	9.44	3.24E+06	1.38	0.01367	0.38	1.38	1.77	8.77
8.92	42,860	95.51	10.29	3.54E+06	1.64	0.01363	0.46	1.64	2.10	9.10

Table A6. Performance curve calculations for pump # 3 at design speed and average losses

347 RPM						Swamee & Jain(1976)				
TDH (ft)	Q(GPM)	Q(cfs)	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma K_m V^2/2g$	Total Head Loss (ft)	System TDH (FT)
15.37	17,789	39.64	4.27	1.47E+06	0.28	0.01418	0.08	0.28	0.37	7.37
14.98	21,267	47.39	5.11	1.76E+06	0.40	0.01404	0.12	0.40	0.52	7.52
14.38	22,789	50.78	5.47	1.88E+06	0.46	0.01399	0.13	0.46	0.60	7.60
13.87	25,604	57.05	6.15	2.11E+06	0.59	0.01391	0.17	0.59	0.75	7.75
12.64	30,424	67.79	7.30	2.51E+06	0.83	0.01380	0.23	0.83	1.06	8.06
11.90	33,102	73.76	7.95	2.73E+06	0.98	0.01376	0.27	0.98	1.26	8.26
11.26	37,403	83.35	8.98	3.09E+06	1.25	0.01369	0.35	1.25	1.60	8.60
10.60	38,260	85.26	9.19	3.16E+06	1.31	0.01368	0.37	1.31	1.68	8.68
9.66	39,105	87.14	9.39	3.23E+06	1.37	0.01367	0.38	1.37	1.75	8.75
8.88	40,329	89.87	9.68	3.33E+06	1.46	0.01365	0.40	1.46	1.86	8.86