Flow Rating Analysis for Pump Stations G-207 and G-208
Brighton Seminole Indian Reservation

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Executive Summary

Rating analyses of pump stations G-207 and G-208 were carried out using the conventional case 8 model. At each station, the model equation was fit to the station performance curve that depicts the TSH vs. discharge relationship. Flows computed with each equation agree with those obtained from the respective performance curve to within 2.5%. In contrast, flows computed with the existing rating equations deviated from the performance curves by as much as 11%. Existing flow measurements at both pump stations were determined to be inadequate for curve fitting purposes due to their wide confidence intervals along with the limited range of static heads over which they were acquired. However, the data obtained at G-207 did appear to partially substantiate the new rating equation for this station. On the other hand, measured flows at G-208 did not substantiate the respective rating equation to any extent. These data are suspect since their values are well below the design discharge rate.

Although the new rating equations should result in more accurate flow computations than those afforded by the exiting equations, it is recommended that they be compared with additional flow rates measured over a wider range of static heads. In the event that the new flow measurements are consistent with existing data, it is recommended that a detailed engineering review of each station be conducted to identify mechanical problems and evaluate current pump performance.

An impact analysis of the new rating equations was performed for the period of record spanning January 1, 2000 through April 29, 2007. Average differences between discharge rates computed with the existing and new rating equations were 8 - 9 % for G-207 and 5 - 7 % for G-208. It is recommended that the entire time series of discharge rates for each structure be recomputed with the new rating equations and reloaded into DBHYDRO.

Acknowledgements

The investigator wishes to thank Ms Kim Johnson and Ms Christine Rock for their assistance in locating and acquiring the archived plans and specifications from off-site storage. Appreciation is also expressed to Raul Pellegrino for his assistance in evaluating the pump performance data and to Hua Li for his peer review of this report.

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Introduction

Pump stations G-207 and G-208 are located in Glades County, immediately downstream of spillways S-71 and S-72, respectively. The functional purpose of G-207 is to back pump water from the reach of C-41 located downstream of S-71 to the reach located immediately upstream of the spillway so as to maintain target stages within the Brighton Seminole Indian reservation. Similarly, G-208 back pumps water from C-40 downstream of S-72 to the reach located upstream of this spillway. Each is equipped with a 48-inch diameter, vertical axial-flow pump powered by an electric motor.

Objectives and Scope

The primary purposes of the rating analyses conducted in this study are to improve the accuracy of flow computations and assess possible systematic errors in the measured flow data. The existing rating equations were formulated according to the case 1 model (see, for example, Ansar and Alexis, 2003) which has no engineering basis. In contrast, the new hydraulic rating equations are based on the improved case 8 model (Imru, 2003).

Station Design

Both pumps have a design rating of 60,000 GPM at 18 feet of TDH and are of model number NW348x48. The design pump speed is 334 RPM while the design motor speed is 1185 RPM. Elevation and plan views of pump station G-207 and its discharge piping are provided in figure 1 while pump station details are shown in figure 2. The corresponding pump station specifications and piping configuration of G-208 are similar. Each pump discharges directly to a long steel force main that has a submerged outlet with a flap gate. Table 1 provides the hydraulic properties of the force mains.

The only pump performance curves found in the project files pertained to a standard pump prototype manufactured by the same corporation. They did not appear to reflect the actual pump prototype installed (or a model thereof). However, tabulated data acquired from a performance test conducted by MWI Corporation on a model of the installed prototype were obtained and are shown in table 2. Although no certified performance curve associated with these data was available, discussions with Construction and Engineering department staff led to the conclusion that the model performance data should be used in this rating analysis instead of the standard pump prototype performance curves provided by the manufacturer.

Existing Rating Equations

The existing rating equation is the same for both pump stations. As indicated previously, they are based on the case 1 model that can be stated as:

$$Q = C_0 + C_1H + C_2H^2 + C_3H^3 \quad \text{...} \quad (1)$$

where

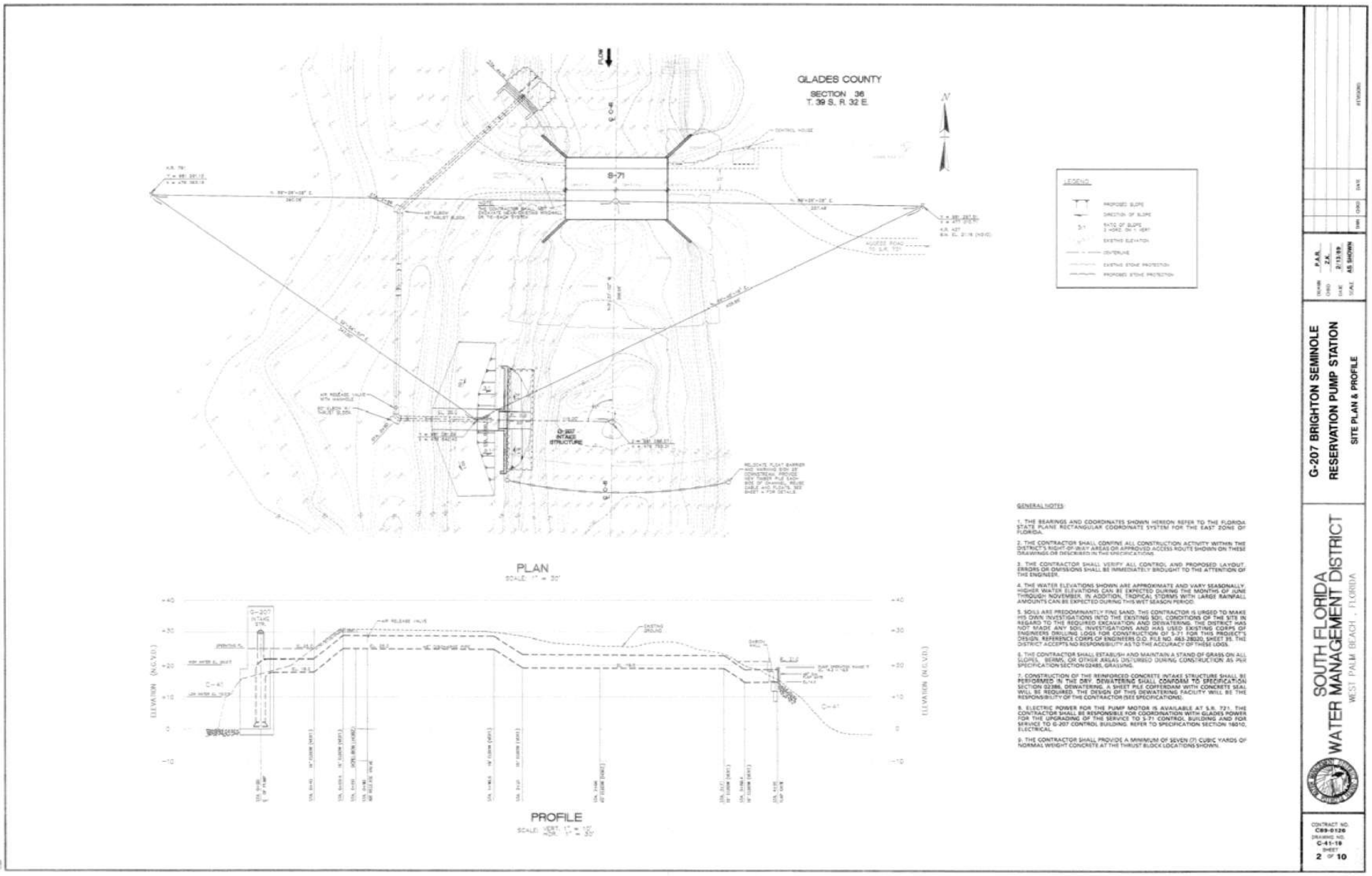


Figure 1. Elevation and plan views of G-207 and its discharge piping

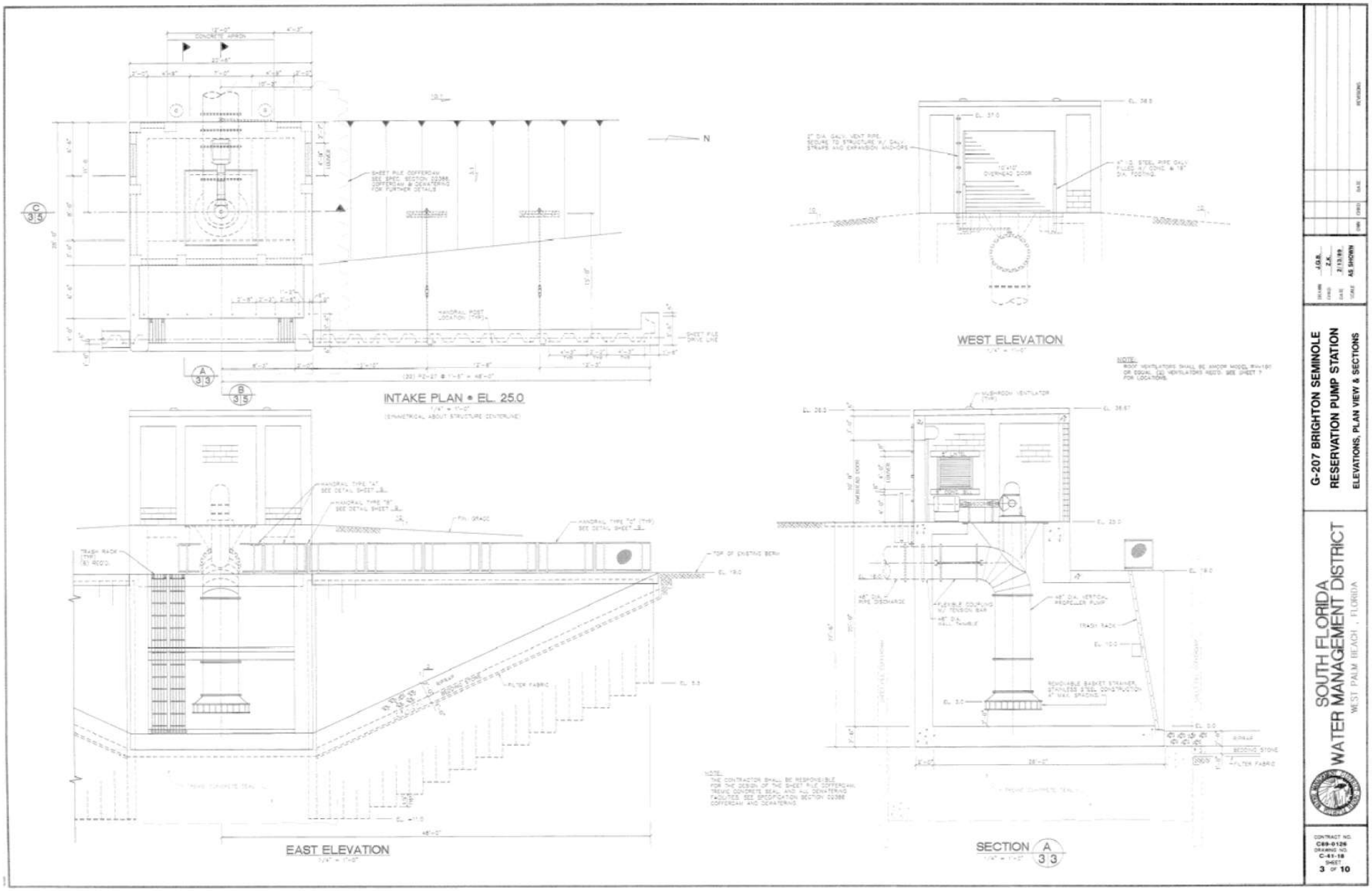


Figure 2. Elevation and plan views of pump station details

Table 1. Hydraulic properties of the discharge piping

Discharge Pipe Dimensions		
Dimension	*Value*	*Source*
O.D. (in)	48	Design Specifications
Wall Thickness (in)	0.375	Design Specifications
Length (ft)	407 (G-207); 342 (G-208)	Shop drawings

Local Head Loss Data				
Item	*Number*	K_{min}	K_{max}	*Source*
$15^0 \pm$ mitered bnd	6	0.042	0.062	Hydr Inst (1990)
$45^0 \pm$ mitered bnd	3 (G-207); 2 (G-208)	0.236	0.32	Hydr Inst (1990)
Submerged Exit	1	1	1	

Friction Head Loss Data		
Parameter	*Value*	*Source*
ε_{min} (ft)	0.00015	Hydr Inst (1990), Table 27
ε_{max} (ft)	0.0013	Sanks(1989), Table B-5

Table 2. Pump Performance Test Data

TDH (ft)	*Q (GPM)*
23.2	49,727
22.2	52,744
21.4	58,310
20.3	59,621
19.5	62,159
18.4	63,390
17.6	66,947
16.5	68,092
15.8	72,489
14.7	74,591
13.6	75,620
12.1	77,636
10.0	79,602

Q = The discharge rate (cfs)
H = the total static head across the pump station (ft)
C_0, C_1, C_2, and C_3 are constant parameters to be determined through regression analysis.

While the form of equation (1) is convenient for curve fitting to stream flow or pump performance data, its lack of an engineering basis can render the resultant model unreliable outside of the flow and head ranges used to determine the parameters. For G-207 and G-208, the values of C_0, C_1, C_2, and C_3 were previously determined to be 170.014, -1.414, 0.18 and -0.0144, respectively. Unfortunately, no documentation supporting the determination of these values could be found.

Current Rating Analysis

The procedure implemented here for developing the rating curves reflects the standard procedure presented by Imru and Wang (2004). Previous applications of this procedure to other pump station rating analyses are explained in detail by Wilsnack and Li (2006). The model rating equation applied to G-207 and G-208 is the standard case 8 model:

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

In equation 2, Q is the discharge at a pump or engine speed of N RPM, H is the TSH, N_O is the design engine or pump speed, and A, B and C are coefficients 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.

Tables 3 contain the measured flow data along with their estimated ranges of uncertainty. For each measurement, the uncertainty range was taken to be the sum of the 95% confidence interval of the measurement along with a 2% systematic error. The limited static head range associated with these measurements along with the wide error bands precluded the direct use of these data in the rating analysis. Hence, the objective was to fit equation (2) to the *pump station* performance curves (i.e. the static head versus discharge relationships). These were obtained as usual from the manufacturer's pump performance data by subtracting the head losses associated with a given discharge rate from the corresponding value of TDH. The results are shown in figures 3 along with the measured flows. Several pump station performance curves were computed to evaluate the effects of uncertainties in the head loss calculations. The supporting calculations are provided in appendix B. It can be seen that there are some small errors and scatter in the pump performance data. Further refinement of these data by the pump manufacturer is recommended.

Using the PROC NLIN procedure of SAS, equation (2) was fit to each of the curves in figures 5 depicting average head losses. The resultant coefficients are shown in table 4. Comparisons between the rating equations and the performance curves are given in tables 5. It can be seen that the maximum absolute error is 2.5% for the new ratings. In contrast, errors in flows computed by

Table 3a. Measured discharges at G-207

TSH (ft)	Quality Flag	Unit Q (cfs)		
		lower uncertainty	Estimated	upper uncertainty
6.98	G	54.60	59.50	64.40
7.52	P	110.58	127.33	144.08
7.9	P	80.70	130.78	180.86
7.52	P	157.45	179.78	202.11
7.62	P	108.40	145.55	182.70
8.73	P	106.93	125.8	144.67

Table 3b. Measured discharges at G-208

TSH (ft)	Quality Flag	Unit Q (cfs)		
		lower uncertainty	Estimated	upper uncertainty
7.14	G	86.29	94.90	103.51
6.72	P	84.59	92.26	99.94
7.27	P	83.54	94.23	104.91
7.8	P	90.57	112.19	133.80
7.68	P	93.09	99.72	106.36
9.26	P	117.42	123.63	129.83

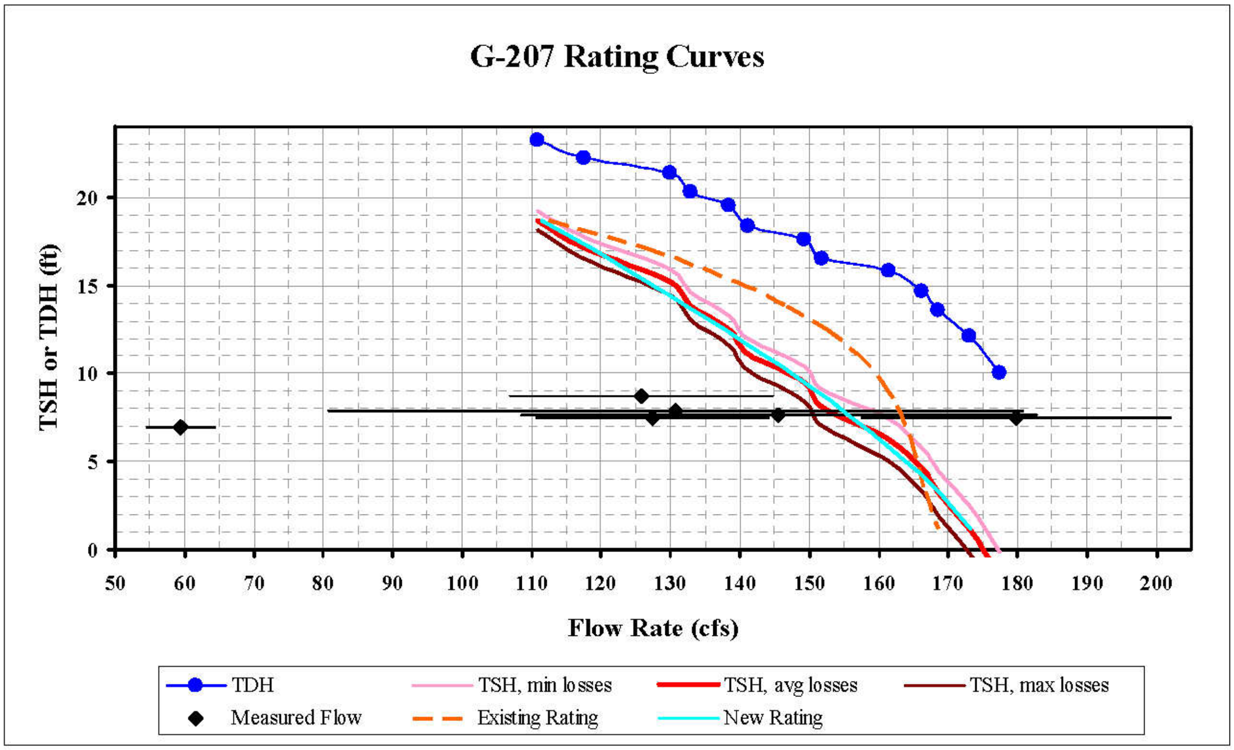


Figure 3a. Performance and rating curves along with measured flows for G-207

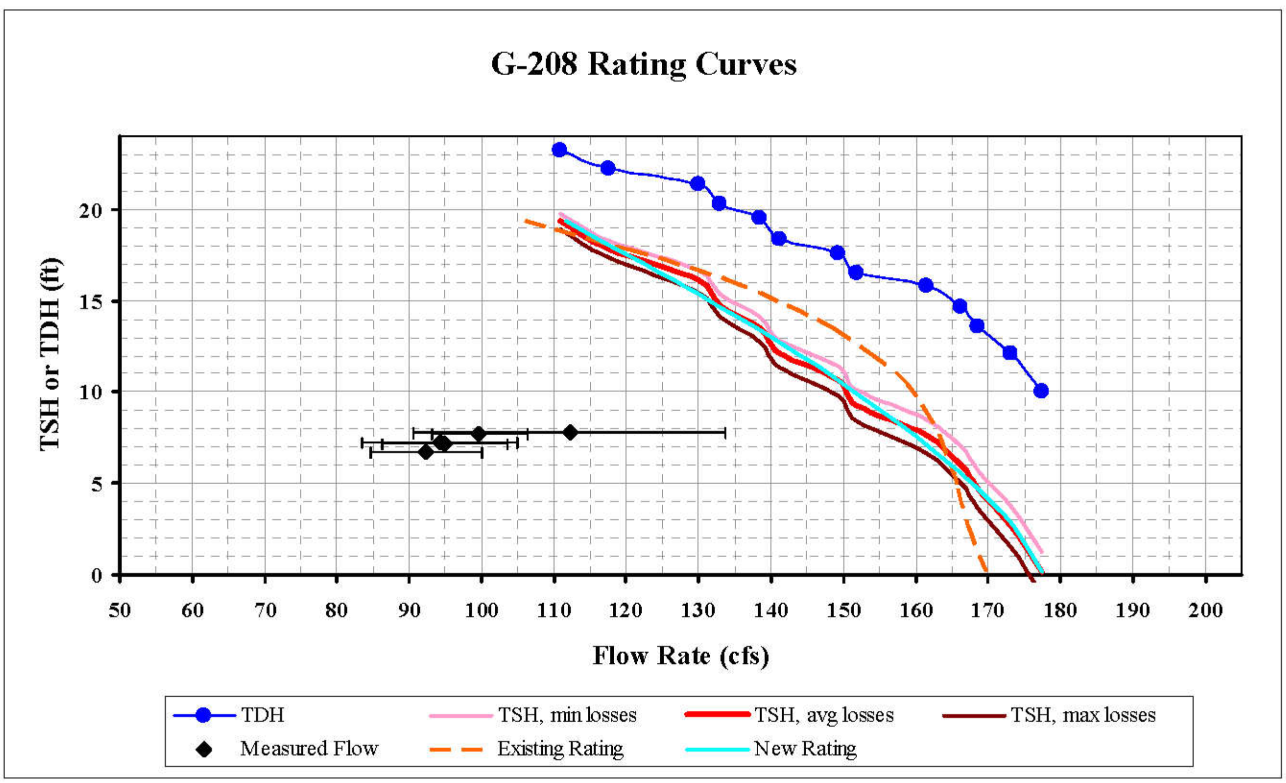


Figure 3b. Performance and rating curves along with measured flows for G-208

Table 4. Values of the new rating equation parameters

Parameter		G-207	G-208
A	*lower limit, approx. 95% C.I.*	171.0	174.5
	estimated value	174.9	177.5
	upper limit, approx. 95% C.I	178.8	180.5
B	*lower limit, approx. 95% C.I.*	-2.145	-1.534
	estimated value	-1.286	-0.983
	upper limit, approx. 95% C.I	-0.427	-0.431
C	*lower limit, approx. 95% C.I.*	1.112	1.236
	estimated value	1.331	1.420
	upper limit, approx. 95% C.I	1.549	1.605

Table 5a. Differences between computed and performance curve flows for G-207

Pump Station Performance Curve	Existing Rating (case 1)		Revised Rating (case 8)	
	Discharge (cfs)	% Error	Discharge (cfs)	% Error
110.81	112.39	1.43	111.52	0.64
117.53	126.17	7.35	118.45	0.79
129.93	139.41	7.29	126.69	-2.50
132.85	146.73	10.45	132.42	-0.33
138.51	152.39	10.02	137.87	-0.46
141.25	156.78	10.99	143.21	1.38
149.18	160.53	7.61	149.26	0.05
151.73	162.73	7.25	154.10	1.56
161.53	164.67	1.94	160.06	-0.91
166.21	165.90	-0.19	165.03	-0.71
168.51	166.83	-1.00	168.74	0.14
173.00	168.56	-2.56	173.28	0.16

the existing rating equations can be as much as 11%.

The results shown in figures 5 suggest that some systematic error exists either in the measured flows or in the actual pump performance. The problem appears to be more pronounced at G-208. However, at G-207 there is some overlap between the measured data and the range of performance curves. At either site, it is clearly evident that these data are inadequate for rating purposes due to their wide uncertainty intervals and excessive scatter. It is recommended that additional discharges under a variety of static heads be measured using an alternative stream flow gauging technique, if possible. If it turns out that these additional data are consistent with existing measurements, the pump station performance is suspect and a comprehensive mechanical evaluation of the pump station should be performed.

Table 5b. Differences between computed and performance curve flows for G-208

Pump Station Performance Curve	Existing Rating (case 1)		Revised Rating (case 8)	
	Discharge (cfs)	% Error	Discharge (cfs)	% Error
110.81	105.91	-4.42	111.57	0.69
117.53	120.20	2.27	118.62	0.93
129.93	133.85	3.01	126.68	-2.50
132.85	142.08	6.94	132.58	-0.21
138.51	148.41	7.14	138.01	-0.36
141.25	153.62	8.76	143.46	1.56
149.18	158.05	5.95	149.34	0.11
151.73	160.89	6.03	154.25	1.66
161.53	163.32	1.11	159.91	-1.00
166.21	164.86	-0.81	164.85	-0.82
168.51	165.84	-1.58	168.63	0.08
173.00	167.20	-3.35	173.41	0.24

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 and are plotted in figures 4. Associated with these head losses are estimated minimum and maximum static heads of 3.5 and 8.0 feet NGVD, respectively, at pump station G-207 while the corresponding static heads at G-208 are 5.5 and 8.0 feet, NGVD. These static heads are based on project specifications and/or measured stages. At each station, the system performance curve based on average head losses reflects a static head equal to the average of the minimum and maximum values.

Figure 4a. System curves and operational conditions for G-207

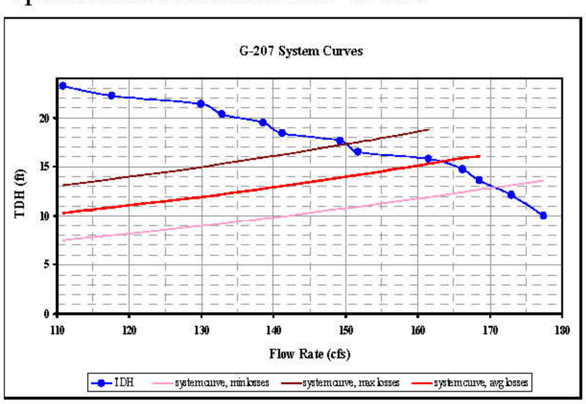
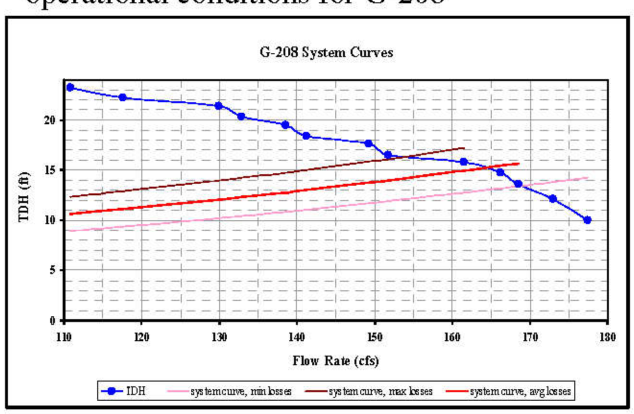


Figure 4b. System curves and operational conditions for G-208



At G-207, discharges can range from about 150 to 170 cfs. This implies a velocity range of 12.5 ft/s to about 14 ft/s within the force main. Likewise, at G-208 discharges can range from about 153 to about 168 cfs, corresponding to a velocity range of about 12.5 – 14 ft/s.

Stream Gauging Data Needs

As mentioned previously, the stream gauging data need to be improved in regards to both accuracy and the range of static heads where discharges occur. Moreover, these pump stations typically operate only during droughts when the static head across the pump station is about 7 – 9 feet. Hence, special operations may have to be arranged. If this is possible, it is recommended that at least 4 measurements be obtained within each of the static head ranges of 0 – 4 feet and 4 – 7 feet.

Impact Analysis

A comparison between flows computed by the old and new rating equations was made for G-207 using mean daily flows computed over the period of record spanning January 1, 2000 through April 29, 2007. Mean daily flows resulting from the revised rating equation averaged about 9% lower than the mean daily flows stored in DBHYDRO. Additionally, a comparison between computed flows was made using break-point stage and pump speed data acquired over periods of record where the pump station was frequently operated. These time windows include December 1, 2000 through May 31, 2001 and October 1, 2006 through April 22, 2007. Again, the revised rating equation yielded discharge rates during the 2001 drought that averaged about 9% lower than those produced by the current rating equation. Similarly, during the 2007 drought, the revised discharges averaged about 8% lower. These results only reflect instances when pumping occurred.

Similar comparisons between flows computed by the old and new rating equations were made for G-208. At this structure, mean daily flows resulting from the revised rating equation averaged about 7 % lower than the mean daily flows stored in DBHYDRO. Furthermore, the revised rating equation yielded break point flows during the 2001 drought that averaged about 6% lower than those produced by the current rating equation. Similarly, during the 2007 drought, the revised discharges averaged about 5 % lower. As was the case for G-207, these results only reflect instances when pumping occurred.

Summary and Conclusions

Rating analyses of pump stations G-207 and G-208 were carried out using the conventional case 8 model. At each station, the model equation was fit to the station performance curve that depicts the TSH vs. discharge relationship. Flows computed with each equation agree with those obtained from the respective performance curve to within 2.5%. In contrast, flows computed with the existing rating equations deviated from the performance curves by as much as 11%. Existing flow measurements at both pump stations were determined to be inadequate for curve fitting purposes due to their wide confidence intervals along with the limited range of static heads over which they were acquired. However, the data obtained at G-207 did appear to partially substantiate the new rating equation for this station. On the other hand, measured flows at G-208 did not substantiate the respective rating equation to any extent. These data are suspect since their values are well below the design discharge rate.

Although the new rating equations should result in more accurate flow computations than those afforded by the exiting equations, it is recommended that they be compared with additional flow rates measured over a wider range of static heads. In the event that the new flow measurements are consistent with existing data, it is recommended that a detailed engineering review of each station be conducted to identify mechanical problems and evaluate current pump performance.

An impact analysis of the new rating equations was performed for the period of record spanning January 1, 2000 through April 29, 2007. Average differences between discharge rates computed with the existing and new rating equations were 8 - 9 % for G-207 and 5 - 7 % for G-208. It is recommended that the entire time series of discharge rates for each structure be recomputed with the new rating equations and reloaded into DBHYDRO.

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Appendix A. Head Loss Calculations

Table A1. Minimum head loss calculations at G-207

334 RPM						Swamee & Jain(1976)		
TDH (ft)	**Q(GPM)**	**Q(cfs)**	**V(ft/s)**	**N_R**	**$V^2/2g$ (ft)**	**f**	**$h_l = f(L/D)V^2/2g$**	**$h_m = \Sigma K_m V^2/$**
23.20	49727.15	110.81	9.10	3.58E+06	1.29	0.01105	1.47	2.52
22.20	52743.61	117.53	9.65	3.80E+06	1.45	0.01101	1.65	2.84
21.40	58310.25	129.93	10.67	4.20E+06	1.77	0.01094	2.00	3.47
20.30	59620.76	132.85	10.91	4.30E+06	1.85	0.01092	2.09	3.62
19.50	62158.94	138.51	11.38	4.48E+06	2.01	0.01090	2.26	3.94
18.40	63389.93	141.25	11.60	4.57E+06	2.09	0.01088	2.35	4.10
17.60	66947.23	149.18	12.25	4.82E+06	2.33	0.01085	2.61	4.57
16.50	68091.71	151.73	12.46	4.91E+06	2.41	0.01084	2.70	4.73
15.80	72489.16	161.53	13.27	5.22E+06	2.73	0.01080	3.05	5.36
14.70	74590.73	166.21	13.65	5.37E+06	2.89	0.01079	3.23	5.67
13.60	75619.61	168.51	13.84	5.45E+06	2.97	0.01078	3.31	5.83
12.10	77636.49	173.00	14.21	5.59E+06	3.13	0.01076	3.49	6.14
10.00	79602.28	177.38	14.57	5.74E+06	3.30	0.01075	3.66	6.46

Table A2. Maximum head loss calculations at G-207

334 RPM						Swamee & Jain(1976)		
TDH (ft)	**Q(GPM)**	**Q(cfs)**	**V(ft/s)**	**N_R**	**$V^2/2g$ (ft)**	**f**	**$h_l = f(L/D)V^2/2g$**	**$h_m = \Sigma K_m V^2/$**
23.20	49727.15	110.81	9.10	3.58E+06	1.29	0.01558	2.07	3.00
22.20	52743.61	117.53	9.65	3.80E+06	1.45	0.01557	2.33	3.37
21.40	58310.25	129.93	10.67	4.20E+06	1.77	0.01555	2.84	4.12
20.30	59620.76	132.85	10.91	4.30E+06	1.85	0.01555	2.97	4.31
19.50	62158.94	138.51	11.38	4.48E+06	2.01	0.01554	3.23	4.69
18.40	63389.93	141.25	11.60	4.57E+06	2.09	0.01553	3.36	4.87
17.60	66947.23	149.18	12.25	4.82E+06	2.33	0.01552	3.74	5.44
16.50	68091.71	151.73	12.46	4.91E+06	2.41	0.01552	3.87	5.62
15.80	72489.16	161.53	13.27	5.22E+06	2.73	0.01551	4.38	6.37
14.70	74590.73	166.21	13.65	5.37E+06	2.89	0.01551	4.64	6.75
13.60	75619.61	168.51	13.84	5.45E+06	2.97	0.01550	4.77	6.93
12.10	77636.49	173.00	14.21	5.59E+06	3.13	0.01550	5.02	7.31
10.00	79602.28	177.38	14.57	5.74E+06	3.30	0.01550	5.28	7.68

Table A3. Minimum head loss calculations at G-208

334 RPM						Swamee & Jain(1976)		
TDH (ft)	Q(GPM)	Q(cfs)	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma K_m V^2/$
23.20	49727.15	110.81	9.10	3.58E+06	1.29	0.01105	1.23	2.22
22.20	52743.61	117.53	9.65	3.80E+06	1.45	0.01101	1.38	2.49
21.40	58310.25	129.93	10.67	4.20E+06	1.77	0.01094	1.68	3.05
20.30	59620.76	132.85	10.91	4.30E+06	1.85	0.01092	1.75	3.19
19.50	62158.94	138.51	11.38	4.48E+06	2.01	0.01090	1.90	3.46
18.40	63389.93	141.25	11.60	4.57E+06	2.09	0.01088	1.98	3.60
17.60	66947.23	149.18	12.25	4.82E+06	2.33	0.01085	2.20	4.02
16.50	68091.71	151.73	12.46	4.91E+06	2.41	0.01084	2.27	4.16
15.80	72489.16	161.53	13.27	5.22E+06	2.73	0.01080	2.56	4.71
14.70	74590.73	166.21	13.65	5.37E+06	2.89	0.01079	2.71	4.99
13.60	75619.61	168.51	13.84	5.45E+06	2.97	0.01078	2.78	5.13
12.10	77636.49	173.00	14.21	5.59E+06	3.13	0.01076	2.93	5.40
10.00	79602.28	177.38	14.57	5.74E+06	3.30	0.01075	3.08	5.68

Table A4. Maximum head loss calculations at G-208

334 RPM						Swamee & Jain(1976)		
TDH (ft)	Q(GPM)	Q(cfs)	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma K_m V^2/$
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19.50	62158.94	138.51	11.38	4.48E+06	2.01	0.01554	2.71	4.04
18.40	63389.93	141.25	11.60	4.57E+06	2.09	0.01553	2.82	4.20
17.60	66947.23	149.18	12.25	4.82E+06	2.33	0.01552	3.14	4.69
16.50	68091.71	151.73	12.46	4.91E+06	2.41	0.01552	3.25	4.85
15.80	72489.16	161.53	13.27	5.22E+06	2.73	0.01551	3.68	5.50
14.70	74590.73	166.21	13.65	5.37E+06	2.89	0.01551	3.90	5.82
13.60	75619.61	168.51	13.84	5.45E+06	2.97	0.01550	4.00	5.98
12.10	77636.49	173.00	14.21	5.59E+06	3.13	0.01550	4.22	6.31
10.00	79602.28	177.38	14.57	5.74E+06	3.30	0.01550	4.44	6.63