TECHNICAL PUBLICATION
ERA # 436

RATING ANALYSES FOR PUMP STATIONS (S140, S331, S6, S7, S8)

Youchao Wang
Muluneh Imru

February, 2006

South Florida Water Management District
3301 Gun Club Road
West Palm Beach, FL 33406

EXECUTIVE SUMMARY

This document summarizes the results of flow rating analysis, model development and calibration for five pump stations - S140, S331, S6, S7, and S8. The existing flow rating equations for these pump stations are classified as Case 3. The new rating equations (Case 8) are developed based on the manufacturers' pump performance curves and the pump affinity laws, and calibrated using flow data obtained through streamgauging.

The new flow rating equations (16) through (20) have 100% of calculated discharges within ±15% of the measured discharges for each pump station. The averages of absolute relative errors are within 5% for the five pump stations for the new rating equations. The new flow rating equations presented here estimate flow better than the existing ones.

The new flow rating equations (16) through (20) are recommended for computing flow through the corresponding pumps for each pump station. It is recommended that two to three additional stream flow data be used every two years to investigate the performance of the new rating for each pump station. When the result of such an investigation warrants, a recalibration of the rating needs to be done using seven to twelve additional field measurements.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

OMD	Operations and Maintenance Department
Qmeas	Database table containing measured flow data
SQL	Structured Query Language
STA	Stormwater Treatment Area

ACKNOWLEDGEMENT

The authors would like to acknowledge Emile Damisse, Matahel Ansar, Gary Wu, and Garth Redfield for their review of the draft and valuable comments. Kathy Conner and Robin Campbell are gratefully acknowledged for assistance in coordinating the review and production of this document.

1. Introduction

The South Florida Water Management District (the District) is responsible for controlling and measuring flow at over 500 structures throughout South and Central Florida. The accuracy of flow data are needed to protect vital water resources such as the Everglades. There are over 60 major pump stations spread over the District's water management area moving large quantities of surface water to meet flood control and water supply needs.

Equations for estimating flow at pump stations in the District are classified into eight cases (Case 1 through Case 8). The existing flow rating equation for S140, S331, S6, S7, and S8 is classified as Case 3. The new rating equation (Case 8) is developed based on the manufacturer's pump performance curves and the pump affinity laws, and calibrated using flow data obtained through streamgauging (Imru and Wang, 2003). The purpose of this report is to develop a new flow rating equation that can improve flow calculations and reduce relative errors of pump flow data for each pump station.

2. Existing Flow Rating Equation

Pump stations S140, S331, S6, S7, and S8 are, for flow calculation purposes, classified as Case 3. In Case 3, discharge is obtained from an interpolation between an upper (Q_{upr}) and a lower (Q_{lwr}) discharges that are given by third-order polynomials. According to Otero (1995), the discharge in this case is given by:

$$Q = Q_{lwr} + \left(Q_{upr} - Q_{lwr}\right)\left(\frac{N - N_{lwr}}{N_{upr} - N_{lwr}}\right) \tag{1}$$

where, Q is the discharge at engine speed N; Q_{lwr} and Q_{upr} are the lower and upper discharges at engine speeds N_{lwr} and N_{upr}, respectively. Q_{lwr} and Q_{upr} are given by

$$Q_{lwr} = C_{10} + C_{11}.H_{lwr} + C_{12}.H_{lwr}^2 + C_{13}.H_{lwr}^3$$

$$Q_{upr} = C_{20} + C_{21}.H_{upr} + C_{22}.H_{upr}^2 + C_{23}.H_{upr}^3 \tag{2}$$

where, C_{10} through C_{13} and C_{20} through C_{23} are regression coefficients. H_{lwr} and H_{upr} are the heads corresponding to Q_{lwr} and Q_{upr}, respectively. H_{lwr} and H_{upr} are obtained from pump affinity laws as follows (Otero 1995):

$$H_{lwr} = H\left(\frac{N_{lwr}}{N}\right)^2$$

$$H_{upr} = H\left(\frac{N_{upr}}{N}\right)^2 \tag{3}$$

H is the head differential at engine speed N. The existing flow rating coefficients for the subject pump stations are given in Table 1.

Table 1. Flow coefficients for S140, S331, S6, S7, and S7 for the existing rating

Station	C_{10}	C_{11}	C_{12}	C_{13}	C_{20}	C_{21}	C_{22}	C_{23}	N_{lwr}	N_{upr}
S140_P	409.57	-19.07	-4.57	0	529.52	-12.45	-2.61	0	925	1200
S331_P	370.37	2.866	-20.01	0.78	487.16	-17.47	-1.74	-0.56	1400	1800
S6_P	791.64	84.20	-23.87	1.26	980.79	69.04	-19.35	1.06	613	700
S7_P	896.68	-8.06	-7.25	0	1022.09	-13.24	-4.40	0	640	720
S8_P	1119.37	-53.72	6.35	-1.05	1209.23	-33.13	-0.011	-0.24	646	707

3. New Flow Rating Equations

Pump characteristic curves are used in conjunction with the affinity laws to develop equations for quantifying discharge through the major pump stations of the District. The equations are then calibrated using field flow measurements to improve flow data accuracy.

Physical properties which have bearing on fluid discharge need to be considered when developing a new flow equation. The flow of a liquid through a pump may be described by a dimensionless relation containing relevant physical quantities including discharge Q, engine speed N, impeller diameter D, length L, head H, acceleration of gravity g, density ρ, and viscosity μ.

$$F\,(Q, N, D, L, gH\,, \rho, \mu) = 0 \tag{4}$$

Using the Buckingham π Theorem (Featherstone and Nalluri, 1982), based on the above function, the following dimensionless relation can be developed.

$$Q = ND^3\phi\left[\frac{D}{L}, \frac{N^2D^2}{gH}, \frac{\rho ND^2}{\mu}\right] \tag{5}$$

Considering that the performance of a specific prototype water pump is being investigated, all physical quantities other than Q, N, and H are assumed constant and are lumped into one coefficient A. On the basis of this assumption, the relation further reduces to the following.

$$Q = A\phi[H, N] \tag{6}$$

At the design engine speed the discharge is a function of the required head as can be observed from the pump performance curve provided by the manufacturer. For the design engine speed, i.e. where N is kept constant at design value, the above function can be written in the following form.

$$Q_0 = f(H) = A + BH_0{}^C \tag{7}$$

where Q_0 is the discharge (cfs) for a design engine speed; H_0 is head differential that corresponds to Q_0 (ft); and A and B are constant coefficients and C is a constant power.

The flow rate changes proportionally according to the pump affinity laws when the engine speed varies. The pump affinity laws assume no change in efficiency when engine speed changes and the relation between the change in discharge and the change in engine speed is given by

$$\frac{Q}{Q_0} = \frac{N}{N_0} \tag{8}$$

Substituting Equation (7) into Equation (8) and rearranging, we obtain Equation (9).

$$Q = \frac{N}{N_0}(A + BH_0{}^C) \tag{9}$$

H_0 can be written in terms of H using the following relation of the pump affinity laws.

$$H_0 = \left[\frac{N_0}{N}\right]^2 H \tag{10}$$

Substituting Equation (10) in Equation (9) and rearranging, we obtain Equation (11).

$$Q = A\left[\frac{N}{N_0}\right] + BH^C\left[\frac{N_0}{N}\right]^{2C-1} \tag{11}$$

where Q is the computed discharge (cfs); N is the field measured engine speed (rpm); N_0 is the design engine speed (rpm); H is the field measured head differential (ft); and A, B, and C are the calibration rating coefficients and exponent. It is worth noting here that speed (rpm) refers to the same part, i.e. either the engine speed if N_0 is related to engine speed, N must be engine speed, otherwise both N_0 and N must be impeller speed.

Equation (11) presents a model based on physical laws that can be used to estimate flow through variable speed pumps. This equation describes the relationship between discharge, head differential, and engine speed.

The available measurements and pump performance curves are used for flow rating calibration. The discharges at the rated engine speed were obtained from the field data using the pump affinity laws. The regression coefficients of Equation (7) are determined based on the least-squares method (Davis, 1986). According to the least-squares method, the deviation of the estimate from the measurement is $((A + BH_0^C) - Q_0)$, and the goal becomes one of finding a method such that

$$F = \sum_{i=1}^{n} \left(\left(A + BH_0^C \right) - Q_0 \right)^2 = \text{ minimum} \tag{12}$$

The expanded form of the above equation is given by

$$F = \sum_{i=1}^{n} \left(Q_0^2 - 2AQ_0 - 2BH_0^C Q_0 + A^2 + 2ABH_0^C + B^2 H_0^{2C} \right) \tag{13}$$

Mathematically F is minimized by setting its partial derivatives with respect to coefficients A, B, and C equal to zero. The partial derivatives were estimated individually; however, the results show that the three partial derivatives are similar as given below

$$\frac{\partial F}{\partial A} = \frac{\partial F}{\partial B} = \frac{\partial F}{\partial C} = \sum_{i=1}^{n} \left(2A + 2BH_0^C - 2Q_0 \right) = 0 \tag{14}$$

$$B = \frac{\sum_{i=1}^{n} Q_0 - nA}{\sum_{i=1}^{n} H_0^C} \tag{15}$$

where n is the total number of measurements.

A starting estimate for coefficient A would be: $A = \sum Q_0 / n$. For a parabolic equation, the coefficient A is between the design discharge and the discharge at zero lift. According to Damisse (2000) the coefficient C is more than one. Equation (15) can help to iteratively solve B for the given values of A and C. An iterative simulation helps to determine the optimum values of coefficients A, B, and C for the new rating equation.

4. Rating Analysis for S140

The structure S140 combines a pump station and a spillway. It is located in the alignment of Levee 28 approximately 42 miles south of Clewiston on the east edge of the Seminole Indian Reservation, in Broward Country, Florida. The pump station consists of three vertical pumps, each rated for 435 cfs at 4.1 ft static head (OMD 2002). Figure 1 shows the head-discharge relationship for flows through the pumps at S140 under laboratory conditions. Various pump speeds are represented by corresponding curves. The top curve represents 1200 rpm, the bottom curve represents 925 rpm and the curves in between are for 1000 and 1095 rpm as shown.

Field flow measurement records for S140 along with those for S331, S6, S7, and S8 are shown in Appendix B. Table 2 shows discharges calculated using the existing flow equation based on the headwater, tailwater, and engine speed obtained from the streamgauging database (Qmeas) tables. The last column in Table 2 indicates the estimated discharges (Q) from the existing equation for S140 corresponding to the available streamgauging data.

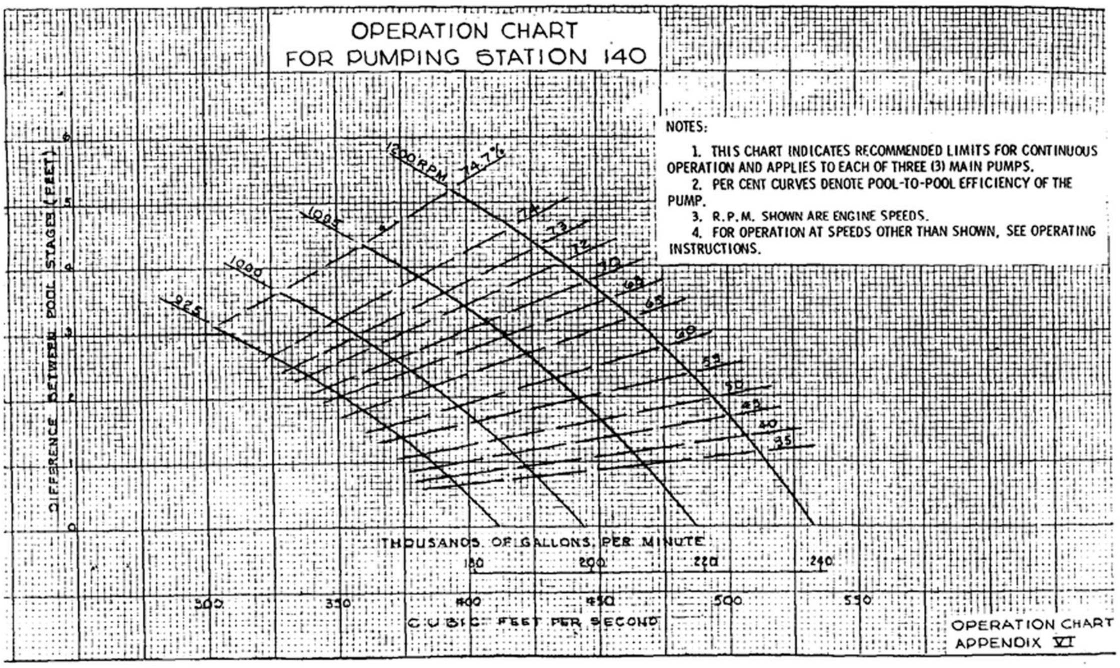

Figure 1. Performance curves for pumps at S140

Table 2. Existing flow estimation at S140 using streamgauging data

Date	HW	TW	N	H	H_{lwr}	H_{upr}	Q_{lwr}	Q_{upr}	Q computed
6-Sep-90	8.99	11.42	1200	2.43	1.44	2.43	373	484	484
12-Sep-90	8.86	11.32	1100	2.46	1.74	2.93	363	471	431
28-Sep-90	9.22	11.19	1200	1.97	1.17	1.97	381	495	495
1-Oct-90	9.02	11.29	1100	2.27	1.61	2.70	367	477	437
26-Jul-91	9.34	12.32	1200	2.98	1.77	2.98	361	469	469
14-Oct-91	9.16	11.66	1050	2.5	1.94	3.27	355	461	403
1-Oct-94	8.85	13.15	1150	4.3	2.78	4.68	321	414	397
4-Oct-94	8.91	13.16	1100	4.25	3.01	5.06	311	400	368
29-Jul-97	9.05	12.35	1200	3.3	1.96	3.30	355	460	460
29-Jul-97	8.93	12.32	1100	3.39	2.40	4.03	338	437	401
7-Oct-97	9.03	12.51	1200	3.48	2.07	3.48	351	455	455
7-Oct-97	8.86	12.46	1100	3.6	2.55	4.28	331	428	393
7-Oct-97	8.88	12.31	1200	3.43	2.04	3.43	352	456	456
8-Oct-99	9.02	12.82	1100	3.8	2.69	4.52	325	420	386
3-Nov-99	9.49	13.4	1100	3.91	2.76	4.65	322	415	381
27-Aug-04	9.19	12.35	1200	3.16	1.88	3.16	358	464	464

Equation (16) presents the new flow rating equation developed to estimate flow through each diesel pump at S140.

$$Q = 510\left[\frac{N}{N_0}\right] - 8.93H^{1.6}\left[\frac{N_0}{N}\right]^{2.2} \quad (16)$$

Equation (16) is valid when the headwater stage is lower than the tailwater, which is expected to be the most prevalent operating condition. The H term in the equation shall be ignored when the tailwater is lower than the headwater.

Figure 2 shows head-discharge relationships for S140 resulting from field measurements, the existing and the new rating equations. The continuous curve at the right end represents the pump performance curve at design engine speed 1200 rpm; the squares (red in color) represent field measurements; the triangles (green in color) represent flows computed using the existing rating equation, and the circles (dark in color) represent flows computed using the new calibrated equation.

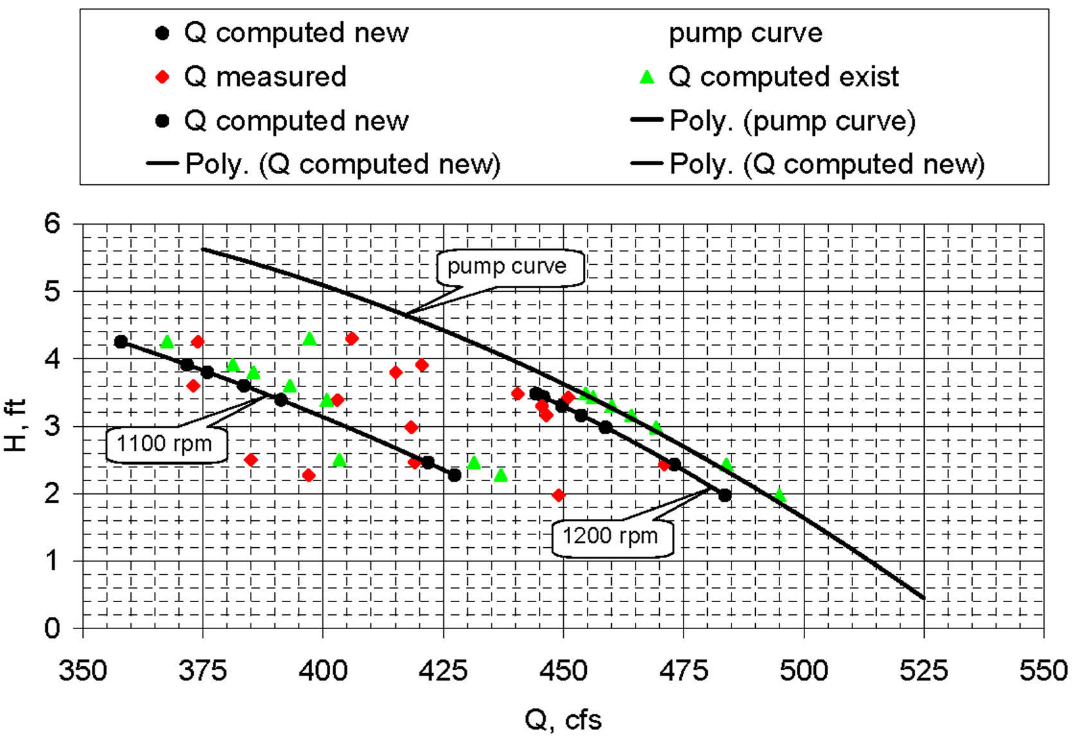

Figure 2. Head and discharge relationship for S140 resulting from field measurements, existing, and new rating equations

The relative errors of computed discharges using new and existing equations are calculated and shown in Table 3. As shown in Table 3, the average relative error for the new rating equation is 0.05%, with the relative errors ranging from -11.61% to 9.66%. For the existing rating equation, the average relative error is 2.44%, with the relative errors ranging from -9.34% to 12.18%. The average of absolute relative errors is 4.3% for the new rating equation and it is 5.05% for the existing rating equation.

Table 3. Relative errors of computed discharges using new and existing flow equations

Date	Q measured	New rating equation			Existing rating equation		
		Q computed	relative error	abs. error	Q computed	relative error	abs. error
6-Sep-90	471	473	0.43%	0.43%	483.9	2.73%	2.73%
12-Sep-90	419	422	0.68%	0.68%	431.4	2.96%	2.96%
28-Sep-90	449	484	7.70%	7.70%	494.9	10.22%	10.22%
1-Oct-90	397	427	7.65%	7.65%	437.0	10.07%	10.07%
26-Jul-91	418	459	9.66%	9.66%	469.3	12.18%	12.18%
14-Oct-91	385	394	2.43%	2.43%	403.4	4.78%	4.78%
1-Oct-94	406	388	-4.54%	4.54%	397.2	-2.17%	2.17%
4-Oct-94	374	358	-4.28%	4.28%	367.5	-1.73%	1.73%
29-Jul-97	446	450	0.94%	0.94%	460.0	3.27%	3.27%
29-Jul-97	403	391	-2.92%	2.92%	400.8	-0.55%	0.55%
7-Oct-97	441	444	0.87%	0.87%	454.6	3.21%	3.21%
7-Oct-97	373	384	2.83%	2.83%	393.1	5.39%	5.39%
7-Oct-97	451	446	-1.15%	1.15%	456.2	1.14%	1.14%
8-Oct-99	415	376	-9.44%	9.44%	385.5	-7.14%	7.14%
3-Nov-99	421	372	-11.61%	11.61%	381.2	-9.34%	9.34%
27-Aug-04	447	454	1.62%	1.62%	464.1	3.95%	3.95%
Average relative error			0.05%	4.30%		2.44%	5.05%
Minimum relative error			-11.61%	0.43%		-9.34%	0.55%
Maximum relative error			9.66%	11.61%		12.18%	12.18%
Standard deviation			5.79%	3.72%		5.84%	3.63%

5. Rating Analysis for S331

The structure S331 is a three-unit pump station located in L-31N borrow canal about 9 miles north of Homestead, Florida. The rated capacity is 387 cfs at 3.0 ft static head for each pump unit.

Field flow measurement records for S331 are shown in Appendix B. Table 4 shows discharges calculated using the existing flow equation based on the headwater, tailwater, and engine speed obtained from the streamgauging database (Qmeas) tables. The last column in Table 4 indicates the estimated discharges (Q) from the existing equation for S331 corresponding to the available streamgauging data.

Equation (17) presents the new model developed for estimating flow through each diesel pump.

$$Q = 430\left[\frac{N}{N_0}\right] - 12.97H^{1.2}\left[\frac{N_0}{N}\right]^{1.4} \tag{17}$$

Equation (17) is valid when the headwater stage is lower than the tailwater, which is expected to be the most prevalent operating condition. The H term in the equation shall be ignored when the tailwater is lower than the headwater.

Table 4. Existing flow estimation at S331 using streamgauging data

Date	HW	TW	N	H	H_{lwr}	H_{upr}	Q_{lwr}	Q_{upr}	$Q_{computed}$
3-Mar-83	3.69	5.64	1800	1.95	1.18	1.95	347	442	442
30-Sep-91	4.28	6.06	1600	1.78	1.36	2.25	339	433	386
4-Jun-97	4.12	5.05	1400	0.93	0.93	1.54	356	454	356
4-Jun-97	4.04	5.07	1600	1.03	0.79	1.30	361	460	410
4-Jun-97	3.92	5.07	1800	1.15	0.70	1.15	363	464	464
22-Apr-98	4.67	4.96	1800	0.29	0.18	0.29	370	482	482
6-May-98	4.64	4.96	1800	0.32	0.19	0.32	370	481	481
6-May-98	4.74	4.89	1720	0.15	0.10	0.16	370	484	461
14-Oct-98	4.41	5.08	1800	0.67	0.41	0.67	368	475	475
27-Oct-98	4.26	4.99	1800	0.73	0.44	0.73	368	473	473
6-Aug-04	4.1	5.02	1400	0.92	0.92	1.52	357	455	357
6-Sep-04	4.36	4.58	1400	0.22	0.22	0.36	370	481	370

Figure 3 shows a plot of computed discharges versus measured discharges for the existing and the new rating equations. The triangles (green in color) represent flows computed using the existing rating equation, and the circles (dark in color) represent flows computed using the new calibrated equation.

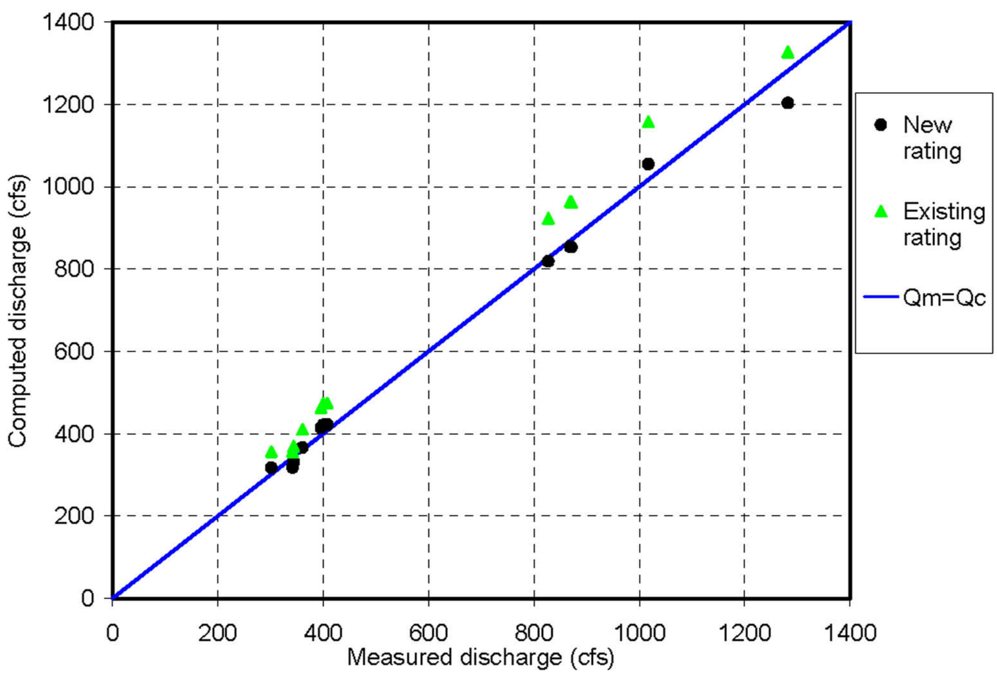

Figure 3. Computed and measured discharges for the existing and the new rating equations for S331

The relative errors of computed discharges using new and existing equations are calculated and shown in Table 5. As shown in Table 5, the average relative error for the new rating equation is 0.18%, with the relative errors ranging from -7.09% to 5.28%. For the existing rating equation, the average relative error is 12.14%, with the relative errors ranging from 3.51% to 18.32%. The average of absolute relative errors is 3.78% for the new rating equation and it is 12.14% for the existing rating equation.

Table 5. Relative errors of computed discharges using new and existing flow equations

Date	Q measured	New rating equation			Existing rating equation		
		Q computed	relative error	abs. error	Q computed	relative error	abs. error
3-Mar-83	427	401.1	-6.14%	6.14%	442.3	3.51%	3.51%
30-Sep-91	339	351.7	3.74%	3.74%	385.8	13.81%	13.81%
4-Jun-97	302	317.5	5.15%	5.15%	356.4	18.00%	18.00%
4-Jun-97	361	366.4	1.49%	1.49%	410.4	13.68%	13.68%
4-Jun-97	396	414.7	4.71%	4.71%	463.9	17.15%	17.15%
22-Apr-98	435	427.1	-1.71%	1.71%	481.9	10.92%	10.92%
6-May-98	436	426.7	-2.02%	2.02%	481.4	10.53%	10.53%
6-May-98	414	409.5	-0.97%	0.97%	461.5	11.60%	11.60%
14-Oct-98	408	422.0	3.43%	3.43%	474.5	16.30%	16.30%
27-Oct-98	400	421.1	5.28%	5.28%	473.3	18.32%	18.32%
6-Aug-04	342	317.8	-7.09%	7.09%	356.7	4.29%	4.29%
6-Sep-04	344	331.4	-3.65%	3.65%	370.0	7.57%	7.57%
Average relative error			0.18%	3.78%		12.14%	12.14%
Minimum relative error			-7.09%	0.97%		3.51%	3.51%
Maximum relative error			5.28%	7.09%		18.32%	18.32%
Standard deviation			4.40%	1.96%		5.06%	5.06%

6. Rating Analysis for S6

The structure S6 is a three unit pump station. S6 is located in the alignment of the Hillsboro Canal, at its intersection by Levee 6 and Levee 7, about 20 miles southeast of the town of Belle Glade, Florida. The rated engine speed for pumps at S6 was 514 rpm before repowering. After repowering was completed on May 20, 1991, the rated engine speed increased to 700 rpm. At this speed, each pump has a design capacity of 975 cfs at 8.3 ft static head. Experience indicates, however, that actual capacities obtainable are about 85 percent of those shown on the Operation Chart (OMD 2002).

Pump Station S6 delivers surplus water, via the Hillsboro Canal, from Lake Okeechobee and the agricultural area northwest of the pumping station, into Water Conservation Area 1 (WCA 1). Construction of Stormwater Treatment Area 2 (STA 2) in 2001, increased the effective service area of S6 and diverted the outflow from WCA 1 to WCA 2A.

Figure 4 shows the head-discharge relationship for flows through the pumps at S6 under laboratory conditions. Various pump speeds are represented by corresponding curves. For the engines in operation after May 1991, the top curve represents an engine speed of 706 rpm, the bottom curve represents an engine speed of 633 rpm and the curves in between are for engine speeds between 706 and 633 rpm.

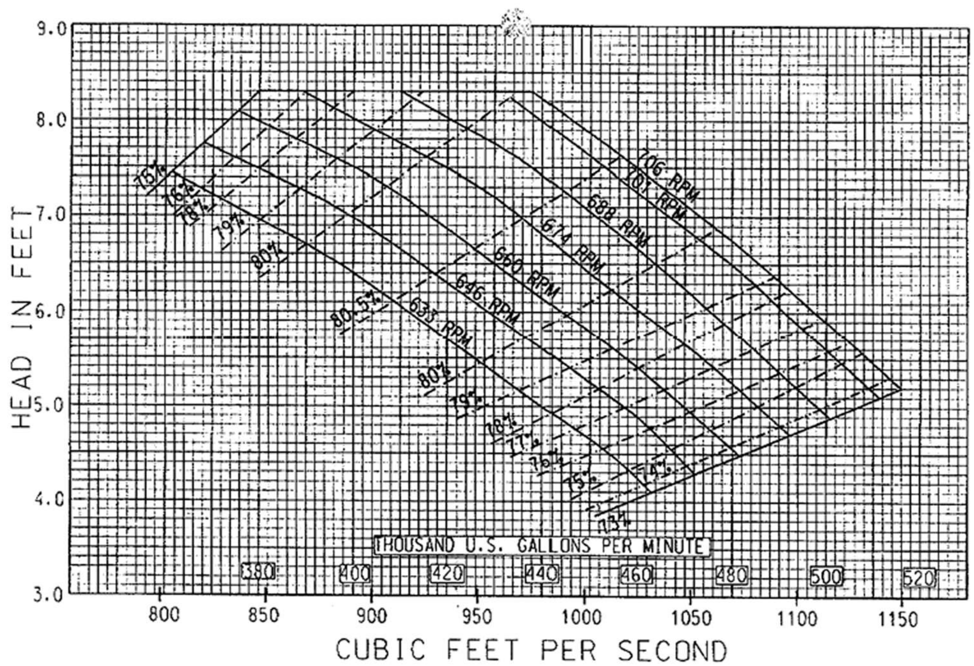

Figure 4. Performance curves for pumps at S6

Field flow measurement records for S6 are shown in Appendix B. Table 6 shows discharges calculated using the existing flow equation based on the headwater, tailwater, and engine speed obtained from the streamgauging database (Qmeas) tables. The last column in Table 6 indicates the estimated discharges (Q) from the existing equation for S6 corresponding to the available streamgauging data.

Table 6. Existing flow estimation at S6 using streamgauging data

Date	HW	TW	N	H	H_{lwr}	H_{upr}	Q_{lwr}	Q_{upr}	$Q_{computed}$
10-Jun-91	9.58	15.38	700	5.80	4.45	5.80	805	938	938
6-Feb-92	9.21	16.08	700	6.87	5.27	6.87	757	887	887
8-Jul-96	9.23	16.37	625	7.14	6.87	8.96	652	811	674
23-Jun-97	8.98	16.34	600	7.36	7.68	10.02	601	800	571
23-Jun-97	9.14	16.29	650	7.15	6.36	8.29	686	829	747
2-Dec-03	10.43	13.4	700	2.97	2.28	2.97	874	1043	1043
28-Jul-04	9.77	14.83	700	5.06	3.88	5.06	833	973	973
29-Oct-04	9.15	16.88	600	7.73	8.07	10.52	579	804	545
17-Jan-05	9.07	16	700	6.93	5.31	6.93	754	884	884

Equation (18) presents the new model developed for estimating flow through each diesel pump for S6.

$$Q = 1060\left[\frac{N}{N_0}\right] - 4.10H^2\left[\frac{N_0}{N}\right]^3 \qquad (18)$$

Equation (18) is valid when the headwater stage is lower than the tailwater, which is expected to be the most prevalent operating condition. The H term in the equation shall be ignored when the tailwater is lower than the headwater.

Figure 5 shows a plot of computed discharges versus measured discharges for the existing and the new rating equations. The triangles (green in color) represent flows computed using the existing rating equation, and the circles (dark in color) represent flows computed using the new calibrated equation.

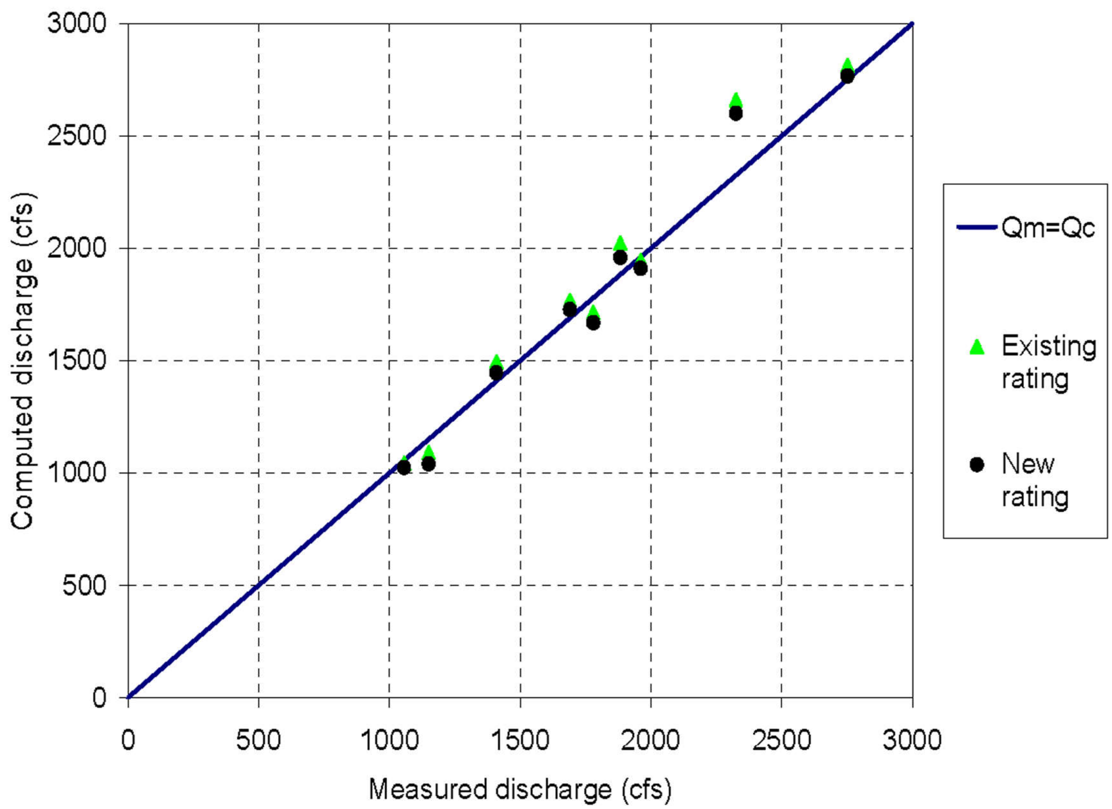

Figure 5. Computed and measured discharges for the existing and the new rating equations for S6

The relative errors of computed discharges using new and existing equations are calculated and shown in Table 7. As shown in Table 7, the average relative error for the new rating equation is -0.01%, with the relative errors ranging from -9.56% to 11.84%. For the existing rating equation, the average relative error is 2.65%, with the relative errors ranging from -5.21% to 14.42%. The average of absolute relative errors is 4.72% for the new rating equation and it is 5.06% for the existing rating equation.

Table 7. Relative errors of computed discharges using new and existing flow equations

Date	$Q_{measured}$	New rating equation			Existing rating equation		
		$Q_{computed}$	relative error	abs. error	$Q_{computed}$	relative error	abs. error
10-Jun-91	917	922.2	0.57%	0.57%	938	2.28%	2.28%
6-Feb-92	775	866.7	11.84%	11.84%	887	14.42%	14.42%
8-Jul-96	628	653.1	4.06%	4.06%	674	7.37%	7.37%
23-Jun-97	593	556.3	-6.19%	6.19%	571	-3.70%	3.70%
23-Jun-97	705	722.8	2.60%	2.60%	747	5.99%	5.99%
2-Dec-03	1056	1023.9	-3.01%	3.01%	1043	-1.19%	1.19%
28-Jul-04	980	955.2	-2.54%	2.54%	973	-0.76%	0.76%
29-Oct-04	575	520.0	-9.56%	9.56%	545	-5.21%	5.21%
17-Jan-05	845	863.3	2.17%	2.17%	884	4.61%	4.61%
Average relative error			-0.01%	4.72%		2.65%	5.06%
Minimum relative error			-9.56%	0.57%		-5.21%	0.76%
Maximum relative error			11.84%	11.84%		14.42%	14.42%
Standard deviation			6.26%	3.75%		6.17%	4.14%

7. Rating Analysis for S7

The structure S7 is a combination of pump station and spillway. S7 is located in the alignment of North New River Canal, at the intersection of Levees 5,6, and 18, about 26 miles south of the town of Belle Glade, Florida. The pump station consists of three 144 inch diameter horizontal pumps. The rated speed is 720 rpm for pumps at S7. At this speed each pump has a design capacity of 830 cfs with pool to pool heads of 5.3 ft (OMD 2002).

The station discharges drainage water, via the North New River Canal, from the agricultural area, into Water Conservation Area No. 2 (WCA 2), at a rate of 3/4 inch per day from the 125 square mile tributary drainage area (OMD 2002).

Figure 6 shows the head-discharge relationship for flows through the pumps at S7 under laboratory conditions. Various pump speeds are represented by corresponding curves. The top curve represents 720 rpm, the bottom curve represents 640 rpm and the curves in between are for 660, 680 and 700 rpm as shown.

Field flow measurement records for S7 are shown in Appendix B. Table 8 shows discharges calculated using the existing flow equation based on the headwater, tailwater, and engine speed obtained from the streamgauging database (Qmeas) tables. The last column in Table 8 indicates the estimated discharges (Q) from the existing equation for S7 corresponding to the available streamgauging data.

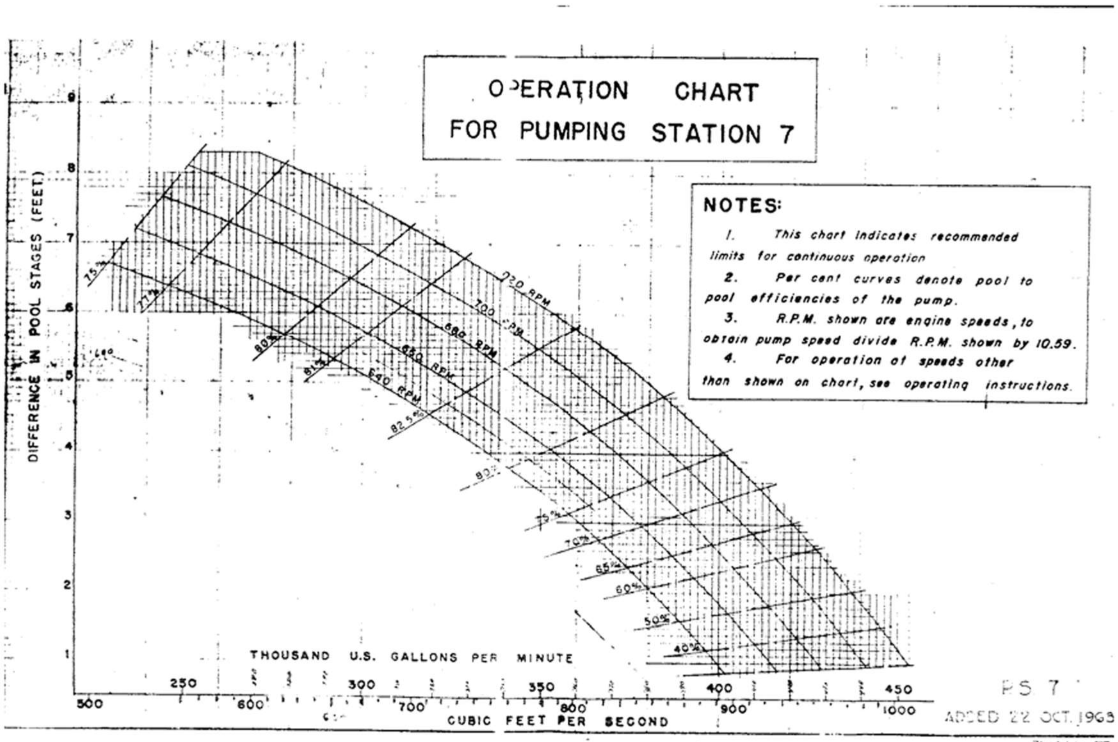

Figure 6. Performance curves for pumps at S7

Table 8. Existing flow estimation at S7 using streamgauging data

Date	HW	TW	N	H	H_{lwr}	H_{upr}	Q_{lwr}	Q_{upr}	$Q_{computed}$
17-Jul-90	10.76	11.88	600	1.12	1.27	1.61	875	989	817
12-Oct-90	11.74	13.17	720	1.43	1.13	1.43	878	994	994
16-Jan-91	11.86	13.28	650	1.42	1.38	1.74	872	986	886
17-Jan-91	11.64	13.37	700	1.73	1.45	1.83	870	983	955
17-Jan-91	11.66	13.41	700	1.75	1.46	1.85	869	982	954
19-Jun-91	10.24	13.03	700	2.79	2.33	2.95	838	945	918
12-Jul-91	10.04	13.8	720	3.76	2.97	3.76	809	910	910
15-Jul-91	9.2	14.28	720	5.08	4.01	5.08	748	841	841
30-Jul-91	9.08	13.82	720	4.74	3.75	4.74	765	860	860
6-Sep-91	9.62	13.6	720	3.98	3.14	3.98	800	900	900
10-Sep-91	9.15	13.37	640	4.22	4.22	5.34	734	826	734
2-Aug-94	9.21	13.36	650	4.15	4.02	5.09	747	841	759
7-Dec-94	10.24	15.93	660	5.69	5.35	6.77	646	731	667
10-Apr-96	9.88	13.12	600	3.24	3.69	4.67	768	864	720
10-Apr-96	9.78	13.1	600	3.32	3.78	4.78	763	858	715
8-Jul-96	10.98	14.55	680	3.57	3.16	4.00	799	899	849
16-May-03	10.25	12.48	720	2.23	1.76	2.23	860	971	971
16-May-03	10.07	12.62	720	2.55	2.01	2.55	851	960	960
29-May-03	10.08	12.45	720	2.37	1.87	2.37	856	966	966
30-Jul-04	10.5	12.95	720	2.45	1.94	2.45	854	963	963
15-Sep-04	10.58	14.66	720	4.08	3.22	4.08	795	895	895

Equation (19) presents the new model developed for estimating flow through each diesel pump for S7.

$$Q = 1040\left[\frac{N}{N_0}\right] - 12.37H^{1.6}\left[\frac{N_0}{N}\right]^{2.2} \tag{19}$$

Equation (19) is valid when the headwater stage is lower than the tailwater, which is expected to be the most prevalent operating condition. The H term in the equation shall be ignored when the tailwater is lower than the headwater.

Figure 7 shows a plot of computed discharges versus measured discharges for the existing and the new rating equations. The triangles (green in color) represent flows computed using the existing rating equation, and the circles (dark in color) represent flows computed using the new calibrated equation.

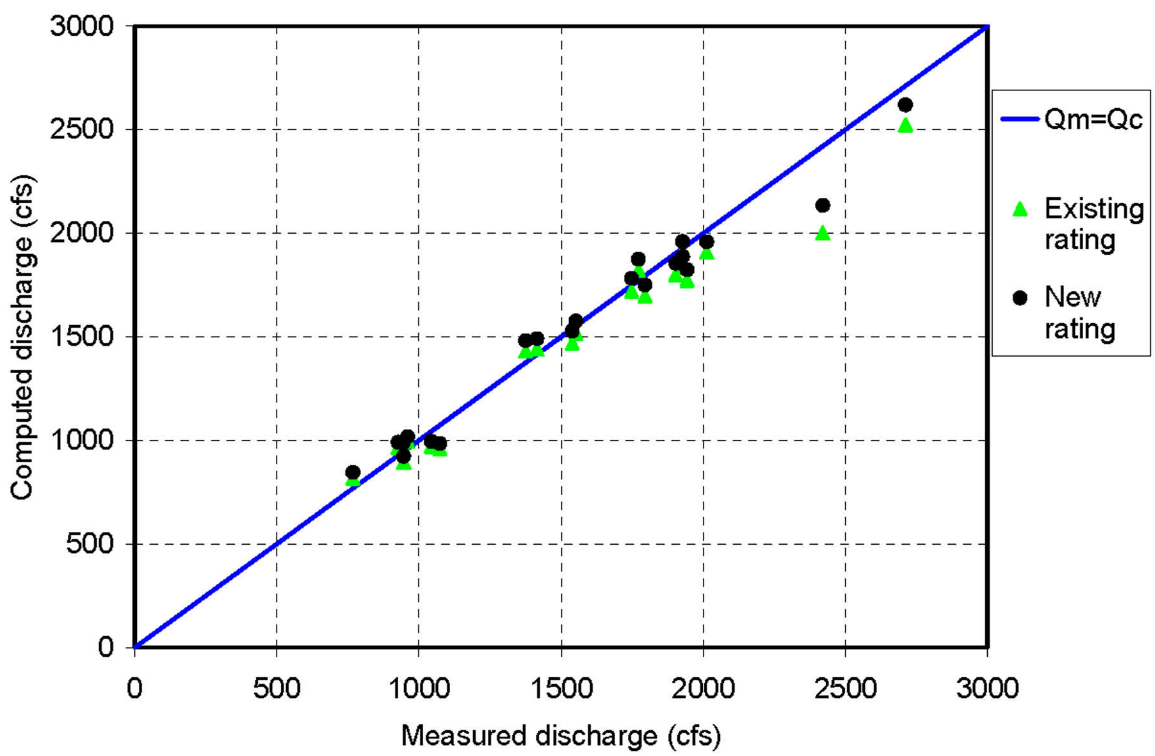

Figure 7. Computed and measured discharges for the existing and the new rating equations for S7

The relative errors of computed discharges using new and existing equations are calculated and shown in Table 9. As shown in Table 9, the average relative error for the new rating equation is 0.20%, with the relative errors ranging from -11.82% to 9.96%.

For the existing rating equation, the average relative error is -2.92%, with the relative errors ranging from -17.29% to 6.42%. The average of absolute relative errors is 4.71% for the new rating equation and it is 5.28% for the existing rating equation.

Table 9. Relative errors of computed discharges using new and existing flow equations

Date	$Q_{measured}$	New rating equation			Existing rating equation		
		$Q_{computed}$	relative error	abs. error	$Q_{computed}$	relative error	abs. error
17-Jul-90	768	845	9.96%	9.96%	817	6.4%	6.4%
10-Apr-96	708	745	5.36%	5.36%	720	1.8%	1.8%
10-Apr-96	688	741	7.73%	7.73%	715	4.0%	4.0%
10-Sep-91	770	764	-0.72%	0.72%	734	-4.7%	4.7%
16-Jan-91	972	912	-6.15%	6.15%	886	-8.8%	8.8%
2-Aug-94	776	788	1.53%	1.53%	759	-2.2%	2.2%
7-Dec-94	807	711	-11.82%	11.82%	667	-17.3%	17.3%
8-Jul-96	898	875	-2.54%	2.54%	849	-5.4%	5.4%
17-Jan-91	964	979	1.66%	1.66%	955	-0.9%	0.9%
17-Jan-91	1006	979	-2.70%	2.70%	954	-5.1%	5.1%
19-Jun-91	964	943	-2.16%	2.16%	918	-4.8%	4.8%
12-Oct-90	960	1018	6.05%	6.05%	994	3.6%	3.6%
12-Jul-91	886	937	5.76%	5.76%	910	2.7%	2.7%
15-Jul-91	904	873	-3.36%	3.36%	841	-6.9%	6.9%
30-Jul-91	874	891	1.98%	1.98%	860	-1.5%	1.5%
6-Sep-91	952	927	-2.55%	2.55%	900	-5.4%	5.4%
16-May-03	1043	995	-4.57%	4.57%	971	-6.9%	6.9%
16-May-03	1074	985	-8.32%	8.32%	960	-10.6%	10.6%
29-May-03	926	991	7.00%	7.00%	966	4.3%	4.3%
30-Jul-04	945	988	4.56%	4.56%	963	1.9%	1.9%
15-Sep-04	946	923	-2.47%	2.47%	895	-5.4%	5.4%
Average relative error			0.20%	4.71%		-2.92%	5.28%
Minimum relative error			-11.82%	0.72%		-17.29%	0.90%
Maximum relative error			9.96%	11.82%		6.42%	17.29%
Standard deviation			5.68%	3.00%		5.82%	3.68%

8. Rating Analysis for S8

The structure S8 is a combination of a pumping station and a gated spillway. S8 is located in the alignment of Miami Canal, at its intersection by Levees 4, 5, and 23, about 30 miles southwest of the town of Belle Glade, Florida. The pump station consists of four 152 inch diameter horizontal pumps, each rated for 1040 cfs at 4.5 ft static head (OMD 2002).

The purpose of the pump station is to discharge excess drainage water, via the Miami Canal, from the agricultural area north of the pumping station, into Water Conservation Area No. 3, at a rate of 3/4 inch per day from the 208 square mile tributary drainage area (OMD 2002).

Figure 8 shows the head-discharge relationship for flows through the pumps at S8 under laboratory conditions. Various pump speeds are represented by corresponding curves. The top curve represents 707 rpm, the bottom curve represents 646 rpm and the curves in between are for 666 and 687 rpm as shown.

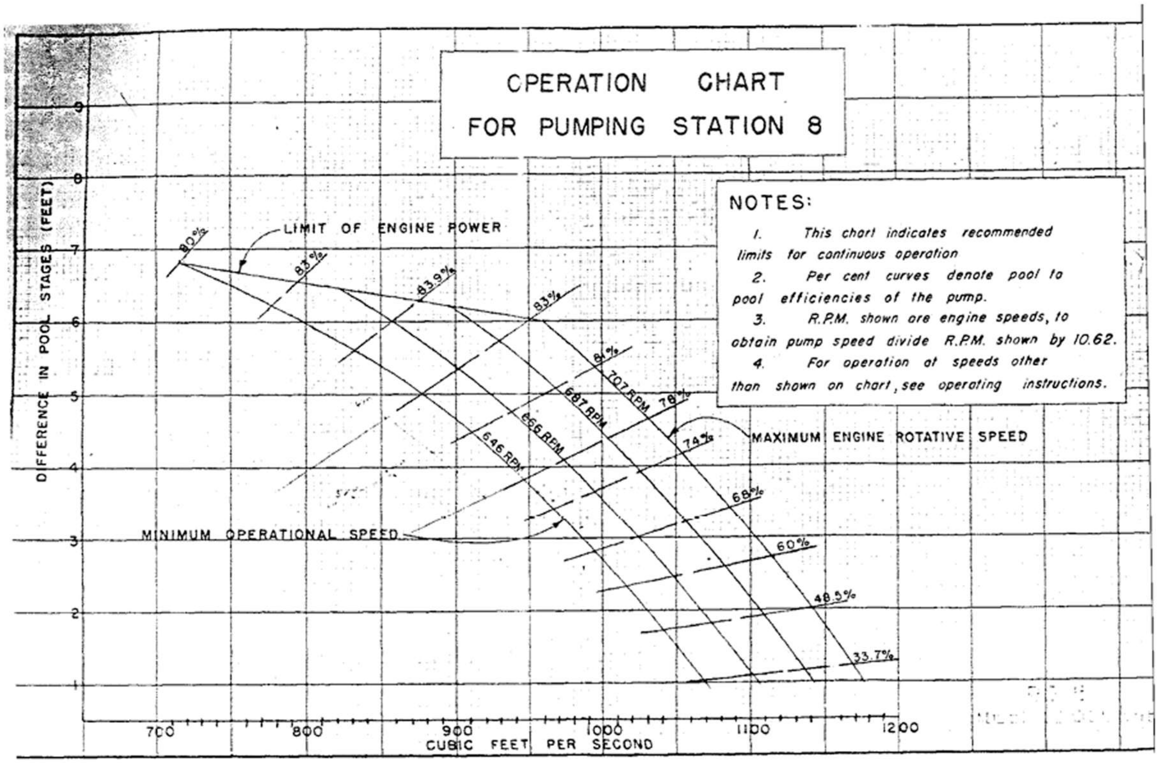

Figure 8. Performance curves for pumps at S8

Field flow measurement records for S8 are shown in Appendix B. Table 10 shows discharges calculated using the existing flow equation based on the headwater, tailwater, and engine speed obtained from the streamgauging database (Qmeas) tables. The last column in Table 10 indicates the estimated discharges (Q) from the existing equation for S8 corresponding to the available streamgauging data.

Table 10. Existing flow estimation at S8 using streamgauging data

Date	HW	TW	H	N	H_{lwr}	H_{upr}	Q_{lwr}	Q_{upr}	$Q_{computed}$
6-Jul-90	10.86	12.44	1.58	650	1.56	1.87	1047	1146	1053
6-Jul-90	10.69	12.46	1.77	650	1.75	2.09	1039	1138	1046
16-Jul-90	10.45	12.1	1.65	707	1.38	1.65	1055	1153	1153
16-Jul-90	10.61	12.09	1.48	707	1.24	1.48	1061	1159	1159
16-Aug-90	9.92	13.24	3.32	650	3.28	3.93	974	1065	980
9-Oct-90	10.22	12.69	2.47	680	2.23	2.67	1020	1116	1073
11-Oct-90	11.35	12.6	1.25	700	1.06	1.28	1068	1166	1155
12-Oct-90	10.52	13.52	3.00	700	2.55	3.06	1006	1101	1090
17-Jul-91	10.1	13.26	3.16	700	2.69	3.22	1000	1095	1084
27-Jul-91	9.62	13.29	3.67	700	3.13	3.74	981	1073	1062
4-Sep-91	9.45	13.19	3.74	680	3.38	4.04	970	1060	1020
19-Sep-91	9.2	12.9	3.70	580	4.59	5.50	905	988	814
29-Aug-94	10.38	13.34	2.96	650	2.92	3.50	990	1083	996
30-Aug-94	10.48	12.81	2.33	700	1.98	2.38	1030	1127	1116
1-Dec-94	9.15	13.64	4.49	700	3.82	4.58	948	1035	1025
30-May-96	9.96	14.08	4.12	650	4.07	4.87	935	1021	941
22-Jun-97	9.62	13.38	3.76	580	4.66	5.59	900	983	810
22-Jun-97	9.77	13.1	3.33	500	5.56	6.66	836	919	636
22-Jun-97	9.54	13.33	3.79	625	4.05	4.85	936	1022	907
19-Aug-97	10.07	13.69	3.62	680	3.27	3.91	975	1065	1025
19-Aug-97	10.2	13.7	3.50	650	3.46	4.14	966	1055	972
4-Jun-03	10.3	13.7	3.40	700	2.90	3.47	991	1084	1074
4-Jun-03	10.42	13.19	2.77	700	2.36	2.83	1014	1110	1099
4-Jun-03	10.46	13.05	2.59	700	2.21	2.64	1020	1117	1106
4-Jun-03	10.45	13.21	2.76	700	2.35	2.82	1015	1111	1100
29-Jul-04	9.99	13.74	3.75	680	3.38	4.05	969	1059	1019
3-Aug-04	9.82	14.3	4.48	650	4.43	5.30	915	999	920
13-Mar-05	9.5	13.5	4.00	650	3.95	4.73	941	1028	947

Equation (20) presents the new model developed for estimating flow through each diesel pump for S8.

$$Q = 1150\left[\frac{N}{N_0}\right] - 13.41H^{1.6}\left[\frac{N_0}{N}\right]^{2.2} \tag{20}$$

Equation (20) is valid when the headwater stage is lower than the tailwater, which is expected to be the most prevalent operating condition. The H term in the equation shall be ignored when the tailwater is lower than the headwater.

Figure 9 shows a plot of computed discharges versus measured discharges for the existing and the new rating equations. The triangles (green in color) represent flows computed using the existing rating equation, and the circles (dark in color) represent flows computed using the new calibrated equation.

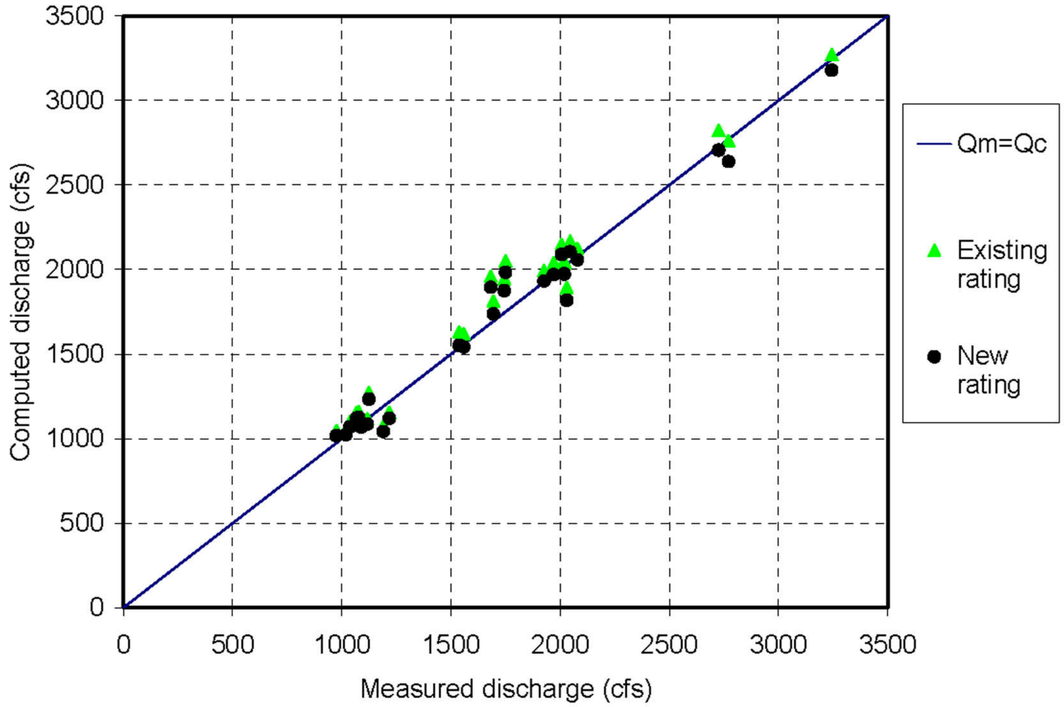

Figure 9. Computed and measured discharges for the existing and the new rating equations for S8

The relative errors of computed discharges using new and existing equations are calculated and shown in Table 11. As shown in Table 11, the average relative error for the new rating equation is 0.71%, with the relative errors ranging from -12.48% to 13.32%. For the existing rating equation, the average relative error is 4.18%, with the relative errors ranging from -9.76% to 17.18%. The average of absolute relative errors is 4.36% for the new rating equation and it is 5.76% for the existing rating equation.

Table 11. Relative errors of computed discharges using new and existing flow equations

Date	$Q_{measured}$	New rating equation			Existing rating equation		
		$Q_{computed}$	relative error	abs. error	$Q_{computed}$	relative error	abs. error
6-Jul-90	1019	1024	0.47%	0.47%	1053	3.38%	3.38%
6-Jul-90	976	1017	4.21%	4.21%	1046	7.14%	7.14%
16-Jul-90	1068	1120	4.88%	4.88%	1153	8.00%	8.00%
16-Jul-90	1077	1125	4.45%	4.45%	1159	7.65%	7.65%
16-Aug-90	841	947	12.63%	12.63%	980	16.56%	16.56%
9-Oct-90	1003	1044	4.09%	4.09%	1073	7.02%	7.02%
11-Oct-90	1218	1119	-8.13%	8.13%	1155	-5.16%	5.16%
12-Oct-90	1081	1059	-2.02%	2.02%	1090	0.85%	0.85%
17-Jul-91	1023	1052	2.91%	2.91%	1084	5.99%	5.99%
27-Jul-91	1039	1029	-0.98%	0.98%	1062	2.24%	2.24%
4-Sep-91	1009	986	-2.33%	2.33%	1020	1.09%	1.09%
19-Sep-91	769	775	0.88%	0.88%	814	5.98%	5.98%
29-Aug-94	963	966	0.28%	0.28%	996	3.46%	3.46%
30-Aug-94	1117	1086	-2.81%	2.81%	1116	-0.08%	0.08%
1-Dec-94	1009	987	-2.17%	2.17%	1025	1.57%	1.57%
30-May-96	909	902	-0.75%	0.75%	941	3.50%	3.50%
22-Jun-97	779	771	-1.04%	1.04%	810	3.98%	3.98%
22-Jun-97	562	616	9.67%	9.67%	636	13.19%	13.19%
22-Jun-97	847	868	2.52%	2.52%	907	7.03%	7.03%
19-Aug-97	875	992	13.32%	13.32%	1025	17.18%	17.18%
19-Aug-97	872	938	7.55%	7.55%	972	11.49%	11.49%
4-Jun-03	1190	1041	-12.48%	12.48%	1074	-9.76%	9.76%
4-Jun-03	1088	1069	-1.78%	1.78%	1099	1.03%	1.03%
4-Jun-03	1092	1076	-1.49%	1.49%	1106	1.30%	1.30%
4-Jun-03	1037	1069	3.09%	3.09%	1100	6.04%	6.04%
29-Jul-04	985	985	0.00%	0.00%	1019	3.50%	3.50%
3-Aug-04	923	880	-4.74%	4.74%	920	-0.34%	0.34%
13-Mar-05	1015	909	-10.44%	10.44%	947	-6.71%	6.71%
Average relative error			0.71%	4.36%		4.18%	5.76%
Minimum relative error			-12.48%	0.00%		-9.76%	0.08%
Maximum relative error			13.32%	13.32%		17.18%	17.18%
Standard deviation			5.96%	4.05%		6.11%	4.60%

9. Summary of Rating Analyses

The new flow rating analyses results for five pump stations are summarized in Table 12. The percentages of data within selected error ranges from the measured discharges are calculated and summarized in Table 13 for five pump stations.

An assessment of impact of the new rating equations on historical data was performed for each pump station for the period from January through December in 2004. The average of the monthly percent changes between the existing and the new flow rating equations is within 5% for S140, S6, S7, and S8 and it is 12% for S331.

Table 12. Summary of the new flow rating analyses results for five pump stations

No.	Pump Station	Unit No.	Power source	Design flow (cfs)	Design head (ft)	Pump diameter (ft)	Case No.	engine speed (N_0*)	A	B	C	D=2C-1	Abs. error
1	S140_P	1 2 3	diesel	435	4.1	9.17	8	1200	510	-8.93	1.6	2.2	4.30%
2	S331_P	1 2 3	diesel	387	3.0	8.0	8	1800	430	-12.97	1.2	1.4	3.78%
3	S6_P	1 2 3	diesel	975	8.3	11.25	8	700	1060	-4.1	2	3	4.72%
4	S7_P	1 2 3	diesel	830	5.3	12.0	8	720	1040	-12.37	1.6	2.2	4.71%
5	S8_P	1 2 3 4	diesel	1040	4.5	12.67	8	707	1150	-13.41	1.6	2.2	4.36%

Table 13. Percentages of data within selected error ranges from the measured discharges

Criterion on absolute relative error	S140		S331		S6		S7		S8	
	New rating	Existing rating	New rating	Existing rating	New rating	Existing rating	New rating	Existing rating	New rating	Existing rating
Percentage of data within 5% of measured discharge	69%	63%	67%	17%	67%	56%	57%	52%	75%	43%
Percentage of data within 10% of measured discharge	94%	81%	100%	25%	89%	89%	95%	90%	86%	86%
Percentage of data within 15% of measured discharge	100%	100%	100%	67%	100%	100%	100%	90%	100%	93%

10. Conclusion

The existing rating equation for S140 has 63% of calculated flows within 5% of measured discharges, 81% within 10%, and 100% within 15%. However, the new flow rating equation gives 69% of calculated flows within 5% of the measured discharges, 94% within 10%, and 100% within 15%.

For pump station S331, the existing rating equation has 17% of calculated flows within 5% of measured discharges, 25% within 10%, and 67% within 15%. However, the new flow rating equation gives 67% of calculated flows within 5% of the measured discharges, 100% within 10%, and 100% within 15%.

The existing rating equation has 56% of calculated flows within 5% of measured discharges, 89% within 10%, and 100% within 15% for pump station S6. However, the new flow rating equation gives 67% of calculated flows within 5% of the measured discharges, 89% within 10%, and 100% within 15%.

The existing rating equation for S7 has 52% of calculated flows within 5% of measured discharges, 90% within 10%, and 90% within 15%. However, the new flow rating equation gives 57% of calculated flows within 5% of the measured discharges, 95% within 10%, and 100% within 15%.

For pump station S8, the existing rating equation has 43% of calculated flows within 5% of measured discharges, 86% within 10%, and 93% within 15%. However, the new flow rating equation gives 75% of calculated flows within 5% of the measured discharges, 86% within 10%, and 100% within 15%.

An assessment of impact of the new flow rating equations on historical data shows that the average of the monthly percent changes between the existing and the new flow rating equations is in 5% for S140, S6, S7, and S8 and the average percent change is 12% for S331. At the time of this rating analysis, the historical data do not need to change for S140, S6, S7, and S8. It needs further investigation for S331 on whether to change the historical data or not.

11. Recommendation

The new flow rating equations (16) through (20) are recommended for computing flow through pumps. It is recommended that two to three additional stream flow data be used every two years to investigate the performance of the new rating for each pump station. When the result of such an investigation warrants, a recalibration of the rating needs to be done using seven to twelve additional field measurements.

References

Damisse, E., 2000, Flow Rating Development for G335 Pump Station in STA-2, Hydrology and Hydraulics Division, South Florida Water Management District, West Palm Beach, Florida.

Davis, J. C., 1986, Statistics and Data Analysis in Geology, John Wiley & Sons, Inc.

Featherstone, N.E. & C. Nalluri, 1982, Civil Engineering Hydraulics, Granada Publishing, London

Imru, M., and Y., Wang, 2003, Flow Rating Analysis Procedures for Pumps, Technical Publication EMA #413, Hydrology and Hydraulics Division, South Florida Water Management District, West Palm Beach, Florida.

Operations and Maintenance Department/OMD/, Structure Book, Intranet.
http://iweb/iwebB501/omd/division/omdops/structure_books/sb-index.htm
South Florida Water Management District, West Palm Beach, Florida.

Otero, J. (1995). "Computation of flow through water control structures." Technical Publication No. 95-03. Hydrology and Hydraulics Division, South Florida Water Management District, West Palm Beach, Florida.

APPENDIX

APPENDIX A

SQL scripts for pump station S140

```
set pagesize 2500
set linesize 200
column Time format a6 word_wrapped
select distinct x.station, x.meas_date, to_char(x.meas_date, 'HH24:MI') Time, x.hw_avg
HW, x.tw_avg TW, z.npump Units, x.Discharge Q, x.Discharge_type DisT, y.oper_nr
Pump#, r.case_no case, r.pumpdia pumpdia, y.reading N, r.rpm_noflow Nnoflow,
r.pump_type type, r.unit_no unit
from qm_main x, qm_operations y, dm_pump z, dm_pump_unit r
where x.station=z.station
and x.station=r.station
and y.oper_nr=r.unit_no
and y.reading>0
and x.Discharge_type='PUMP'
and x.q_meas_id = y.q_meas_id
and x.station = 'S140_P'
order by meas_date, time
/
```

SQL scripts for pump station S331

```
set pagesize 2500
set linesize 200
column Time format a6 word_wrapped
select distinct x.station, x.meas_date, to_char(x.meas_date, 'HH24:MI') Time, x.hw_avg
HW, x.tw_avg TW, z.npump Units, x.Discharge Q, x.Discharge_type DisT, y.oper_nr
Pump#, r.case_no case, r.pumpdia pumpdia, y.reading N, r.rpm_noflow Nnoflow,
r.pump_type type, r.unit_no unit
from qm_main x, qm_operations y, dm_pump z, dm_pump_unit r
where x.station=z.station
and x.station=r.station
and y.oper_nr=r.unit_no
and y.reading>0
and x.Discharge_type='PUMP'
and x.q_meas_id = y.q_meas_id
and x.station = 'S331_P'
order by meas_date, time
/
```

SQL scripts for pump station S6

```
set pagesize 2500
set linesize 200
column Time format a6 word_wrapped
select  distinct x.station, x.meas_date,  to_char(x.meas_date, 'HH24:MI') Time, x.hw_avg
HW, x.tw_avg TW, z.npump Units, x.Discharge Q, x.Discharge_type DisT, y.oper_nr
Pump#, r.case_no case, r.pumpdia pumpdia, y.reading N, r.rpm_noflow Nnoflow,
r.pump_type type, r.unit_no unit
from qm_main x, qm_operations y, dm_pump z, dm_pump_unit r
where x.station=z.station
and x.station=r.station
and y.oper_nr=r.unit_no
and y.reading>0
and x.Discharge_type='PUMP'
and x.q_meas_id = y.q_meas_id
and x.station = 'S6_P'
order by meas_date, time
/
```

SQL scripts for pump station S7

```
set pagesize 2500
set linesize 200
column Time format a6 word_wrapped
select  distinct x.station, x.meas_date,  to_char(x.meas_date, 'HH24:MI') Time, x.hw_avg
HW, x.tw_avg TW, z.npump Units, x.Discharge Q, x.Discharge_type DisT, y.oper_nr
Pump#, r.case_no case, r.pumpdia pumpdia, y.reading N, r.rpm_noflow Nnoflow,
r.pump_type type, r.unit_no unit
from qm_main x, qm_operations y, dm_pump z, dm_pump_unit r
where x.station=z.station
and x.station=r.station
and y.oper_nr=r.unit_no
and y.reading>0
and x.Discharge_type='PUMP'
and x.q_meas_id = y.q_meas_id
and x.station = 'S7_P'
order by meas_date, time
/
```

SQL scripts for pump station S8

```
set pagesize 2500
set linesize 200
column Time format a6 word_wrapped
select  distinct x.station, x.meas_date,  to_char(x.meas_date, 'HH24:MI') Time, x.hw_avg
HW, x.tw_avg TW, z.npump Units, x.Discharge Q, x.Discharge_type DisT, y.oper_nr
Pump#, r.case_no case, r.pumpdia pumpdia, y.reading N, r.rpm_noflow Nnoflow,
r.pump_type type, r.unit_no unit
from qm_main x, qm_operations y, dm_pump z, dm_pump_unit r
where x.station=z.station
and x.station=r.station
and y.oper_nr=r.unit_no
and y.reading>0
and x.Discharge_type='PUMP'
and x.q_meas_id = y.q_meas_id
and x.station = 'S8_P'
order by meas_date, time
/
```

APPENDIX B

Available measurements for pumps at pump station S140

MEAS_DATE	TIME	HW	TW	Q	PUMP#	N
6-Sep-90	12:40	8.99	11.42	471	3	1204
12-Sep-90	13:08	8.86	11.32	419	2	1100
28-Sep-90	12:35	9.22	11.19	449	1	1196
1-Oct-90	12:55	9.02	11.29	397	1	1097
26-Jul-91	11:22	9.34	12.32	1255	1	1196
26-Jul-91	11:22	9.34	12.32	1255	2	1197
26-Jul-91	11:22	9.34	12.32	1255	3	1151
14-Oct-91	13:38	9.16	11.66	385	1	1050
1-Oct-94	10:00	8.85	13.15	812	1	1150
1-Oct-94	10:00	8.85	13.15	812	2	1150
4-Oct-94	11:50	8.91	13.16	748	1	1100
4-Oct-94	11:50	8.91	13.16	748	3	1100
29-Jul-97	10:53	9.05	12.35	891	1	1198
29-Jul-97	10:53	9.05	12.35	891	3	1199
29-Jul-97	11:40	8.93	12.32	806	1	1111
29-Jul-97	11:40	8.93	12.32	806	3	1100
7-Oct-97	10:36	9.03	12.51	881	2	1183
7-Oct-97	10:36	9.03	12.51	881	3	1201
7-Oct-97	11:39	8.86	12.46	746	2	1088
7-Oct-97	11:39	8.86	12.46	746	3	1091
7-Oct-97	13:00	8.88	12.31	451	2	1187
8-Oct-99	0:00	9.02	12.82	830.3	1	1100
8-Oct-99	0:00	9.02	12.82	830.3	3	1100
3-Nov-99	14:13	9.49	13.4	841	2	1116
3-Nov-99	14:13	9.49	13.4	841	3	1099
27-Aug-04	14:11	9.19	12.35	893	1	1200
27-Aug-04	14:11	9.19	12.35	893	2	1200

Available measurements for pumps at pump station S331

MEAS_DATE	TIME	HW	TW	Q	PUMP#	N
3-Mar-83	10:10	3.69	5.64	1282	1	1800
3-Mar-83	10:10	3.69	5.64	1282	2	1800
3-Mar-83	10:10	3.69	5.64	1282	3	1800
4-Jun-97	10:45	4.12	5.05	302	1	1400
27-Oct-98	11:19	4.26	4.99	400	2	1800
4-Jun-97	11:40	4.04	5.07	361	1	1600
4-Jun-97	12:43	3.92	5.07	396	1	1800
30-Sep-91	14:50	4.28	6.06	1017	1	1600
30-Sep-91	14:50	4.28	6.06	1017	2	1600
30-Sep-91	14:50	4.28	6.06	1017	3	1600
6-Feb-01	15:40	4.48	4.07	368	2	1400
6-Aug-04	11:02	4.1	5.02	342	1	1400
6-Sep-04	22:42	4.36	4.58	344	1	1400

Available measurements for pumps at pump station S6

MEAS_DATE	TIME	HW	TW	Q	PUMP#	N
10-Jun-91	13:15	9.58	15.38	2751	1	700
10-Jun-91	13:15	9.58	15.38	2751	2	700
10-Jun-91	13:15	9.58	15.38	2751	3	700
6-Feb-92	13:25	9.21	16.08	2325	1	693
6-Feb-92	13:25	9.21	16.08	2325	2	698
6-Feb-92	13:25	9.21	16.08	2325	3	696
25-Feb-92	13:15	9.29	15.64	1670.1	1	550
25-Feb-92	13:15	9.29	15.64	1670.1	2	550
25-Feb-92	13:15	9.29	15.64	1670.1	3	550
10-Jul-92	12:37	9.45	15.65	520	1	1
10-Jul-92	12:37	9.45	15.65	520	2	1
10-Jul-92	12:37	9.45	15.65	520	3	500
14-Jul-92	12:00	9.7	15.49	461	1	1
14-Jul-92	12:00	9.7	15.49	461	2	499
14-Jul-92	12:00	9.7	15.49	461	3	0
16-Jul-92	11:06	9.55	15.37	496	1	501
16-Jul-92	11:06	9.55	15.37	496	2	1
16-Jul-92	11:06	9.55	15.37	496	3	1
8-Jul-96	11:19	9.23	16.37	1883	1	624
8-Jul-96	11:19	9.23	16.37	1883	2	626
8-Jul-96	11:19	9.23	16.37	1883	3	622
23-Jun-97	11:19	8.98	16.34	1779	1	600
23-Jun-97	11:19	8.98	16.34	1779	2	600
23-Jun-97	11:19	8.98	16.34	1779	3	600
23-Jun-97	12:28	9.14	16.29	1409	2	650
23-Jun-97	12:28	9.14	16.29	1409	3	650
23-Jun-97	13:40	9.11	16.3	1362	2	675
23-Jun-97	13:40	9.11	16.3	1362	3	675
2-Dec-03	9:37	10.43	13.4	1055.6	2	700
28-Jul-04	10:11	9.77	14.83	1960	2	700
28-Jul-04	10:11	9.77	14.83	1960	3	700
29-Oct-04	11:31	9.15	16.88	1150	1	600
29-Oct-04	11:31	9.15	16.88	1150	2	600
17-Jan-05	13:48	9.07	16	1690	2	700
17-Jan-05	13:48	9.07	16	1690	3	700

Available measurements for pumps at pump station S7

DATE	TIME	HW	TW	Q	N	UNIT
17-Jul-90	13:05	10.76	11.88	768	600	1
20-Aug-90	12:25	10.06	13.25	1337	720	2
20-Aug-90	12:25	10.06	13.25	1337	720	3
10-Oct-90	14:40	11.45	13.1	1021	750	1
12-Oct-90	13:10	11.74	13.17	960	720	3
16-Jan-91	15:45	11.86	13.28	1943	650	2
16-Jan-91	15:45	11.86	13.28	1943	650	3
17-Jan-91	9:02	11.64	13.37	1927	460	1
17-Jan-91	9:02	11.64	13.37	1927	700	2
17-Jan-91	9:02	11.64	13.37	1927	700	3
17-Jan-91	13:15	11.66	13.41	2012	460	1
17-Jan-91	13:15	11.66	13.41	2012	700	2
17-Jan-91	13:15	11.66	13.41	2012	700	3
19-Jun-91	13:45	10.24	13.03	1928	700	2
19-Jun-91	13:45	10.24	13.03	1928	700	3
12-Jul-91	13:40	10.04	13.8	1772	720	1
12-Jul-91	13:40	10.04	13.8	1772	720	3
15-Jul-91	12:35	9.2	14.28	2711	720	1
15-Jul-91	12:35	9.2	14.28	2711	720	2
15-Jul-91	12:35	9.2	14.28	2711	720	3
30-Jul-91	13:05	9.08	13.82	1747	720	2
30-Jul-91	13:05	9.08	13.82	1747	720	3
6-Sep-91	12:49	9.62	13.6	1903	720	1
6-Sep-91	12:49	9.62	13.6	1903	720	3
10-Sep-91	12:45	9.15	13.37	1539	640	2
10-Sep-91	12:45	9.15	13.37	1539	640	3
2-Aug-94	12:55	9.21	13.36	1552	650	1
2-Aug-94	12:55	9.21	13.36	1552	650	2
7-Dec-94	11:50	10.24	15.93	2420	660	1
7-Dec-94	11:50	10.24	15.93	2420	660	2
7-Dec-94	11:50	10.24	15.93	2420	660	3
10-Apr-96	11:55	9.88	13.12	1415	600	1
10-Apr-96	11:55	9.88	13.12	1415	600	2
10-Apr-96	12:31	9.78	13.1	1375	600	1
10-Apr-96	12:31	9.78	13.1	1375	600	2
8-Jul-96	13:53	10.98	14.55	1795	680	1
8-Jul-96	13:53	10.98	14.55	1795	680	2
16-May-03	10:34	10.25	12.48	1043	720	3
16-May-03	11:49	10.07	12.62	1074	720	1
29-May-03	12:04	10.08	12.45	926	720	1
30-Jul-04	11:19	10.5	12.95	945	720	1
15-Sep-04	17:00	10.58	14.66	946	720	1

Available measurements for pumps at pump station S8

MEAS_DATE	TIME	HW	TW	Q	PUMP#	N
29-Jun-90	13:13	10.77	13.17	1396	2	600
29-Jun-90	13:13	10.77	13.17	1396	3	600
6-Jul-90	13:45	10.86	12.44	1019	4	650
6-Jul-90	15:30	10.69	12.46	976	4	650
16-Jul-90	12:15	10.45	12.1	1068	3	707
16-Jul-90	14:30	10.61	12.09	1077	3	707
16-Aug-90	14:22	9.92	13.24	1682	2	650
16-Aug-90	14:22	9.92	13.24	1682	3	650
9-Oct-90	13:30	10.22	12.69	2006	3	680
9-Oct-90	13:30	10.22	12.69	2006	4	680
11-Oct-90	14:00	11.35	12.6	1218	4	700
12-Oct-90	11:00	10.52	13.52	3243	2	700
12-Oct-90	11:00	10.52	13.52	3243	3	700
12-Oct-90	11:00	10.52	13.52	3243	4	700
16-Jan-91	15:58	9.63	13.98	3021	2	680
16-Jan-91	15:58	9.63	13.98	3021	3	700
16-Jan-91	15:58	9.63	13.98	3021	4	700
17-Jul-91	14:05	10.58	13.72	2045	1	704
17-Jul-91	14:05	10.58	13.72	2045	2	706
27-Jul-91	12:05	10.14	13.75	2078	1	706
27-Jul-91	12:05	10.14	13.75	2078	2	704
27-Jul-91	12:05	10.14	13.75	2078	3	1
4-Sep-91	14:16	10.02	13.73	2018	1	3
4-Sep-91	14:16	10.02	13.73	2018	2	684
4-Sep-91	14:16	10.02	13.73	2018	3	679
4-Sep-91	14:16	10.02	13.73	2018	4	0
19-Sep-91	14:38	9.75	13.41	1537	1	3
19-Sep-91	14:38	9.75	13.41	1537	2	584
19-Sep-91	14:38	9.75	13.41	1537	3	582
15-Jun-92	14:28	9.43	14.35	3680	1	689
15-Jun-92	14:28	9.43	14.35	3680	2	687
15-Jun-92	14:28	9.43	14.35	3680	3	690
15-Jun-92	14:28	9.43	14.35	3680	4	673
29-Aug-94	14:30	10.62	13.58	1926	1	648
29-Aug-94	14:30	10.62	13.58	1926	2	646
30-Aug-94	11:25	10.73	12.99	1117	1	708
1-Dec-94	13:15	9.4	13.83	2018	3	692
1-Dec-94	13:15	9.4	13.83	2018	4	694
30-May-96	11:23	10.18	14.27	2726	1	649
30-May-96	11:23	10.18	14.27	2726	2	650
30-May-96	11:23	10.18	14.27	2726	3	653

Available measurements for pumps at pump station S8

MEAS_DATE	TIME	HW	TW	Q	PUMP#	N
22-Jun-97	15:07	9.62	13.38	1558	1	580
22-Jun-97	15:07	9.62	13.38	1558	2	580
22-Jun-97	15:43	9.77	13.1	1124	1	500
22-Jun-97	15:43	9.77	13.1	1124	2	500
22-Jun-97	16:17	9.54	13.33	1694	1	625
22-Jun-97	16:17	9.54	13.33	1694	2	626
19-Aug-97	9:00	10.07	13.69	1750.1	1	680
19-Aug-97	9:00	10.07	13.69	1750.1	4	680
19-Aug-97	11:10	10.2	13.7	1743.4	1	650
19-Aug-97	11:10	10.2	13.7	1743.4	4	650
4-Jun-03	10:08	10.49	13.31	1190	4	704
4-Jun-03	10:45	10.39	13.21	1088	3	700
4-Jun-03	12:02	10.48	13.05	1092	1	709
4-Jun-03	12:59	10.54	13.07	1037	2	702
29-Jul-04	10:19	9.99	13.74	1970	2	680
29-Jul-04	10:19	9.99	13.74	1970	3	680
3-Aug-04	15:46	9.82	14.3	2770	2	650
3-Aug-04	15:46	9.82	14.3	2770	3	650
3-Aug-04	15:46	9.82	14.3	2770	4	650
13-Mar-05	9:11	9.5	13.5	2030	1	650
13-Mar-05	9:11	9.5	13.5	2030	3	650