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RATING ANALYSIS FOR PUMP STATION S9

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Executive Summary

This document summarizes the results of a rating analysis, model development and calibration for flow through S9, which is a three-unit pump station located in Broward County, about 20 miles west of Hollywood, Florida.

Field flow measurements showed that the pumps at S9 deliver lower discharges than 960 cfs per unit when operating at full capacity under design conditions. The existing model estimates flow within 5% of the measurements under design conditions. Depending on the headwater and tailwater combinations, it slightly overestimates or underestimates the flows as compared to the field measurements. Overall the measurements and the computed flows for S9 pumps agree reasonably well. The average error relative to field measurements is in the order of 7.5%, which is satisfactory. Operations and Maintenance Department (OMD) raised concerns regarding flow data accuracy for S9, which was the basis for this rating analysis and calibration study.

For standardization of pump flow calculation methods, a new model has been developed and calibrated for the estimation of flow through the pumps at S9. The equation developed and calibrated here is based on the pump affinity laws and related principles of hydraulics. Based on available field measurements, the new equation estimates flow within 10% of measured values for all conditions and within 5% of measured values for conditions close to the design capacity. The overall average relative error is 1.32%, which is a significant improvement over the existing rating (with a relative error of 7.5%). On the basis of the improvement shown in the analysis, it is recommended to implement the new equation developed in this study to compute flow through the pumps at S9.

The accuracy of the calibrated equations will be verified using additional stream flow data. When 10 or more additional measurements are available, the flow equations can be re-evaluated further if necessary.

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RATING ANALYSIS FOR PUMP STATION S9

1. Introduction

The structure S9 is a three-unit pump station located in Broward County, Florida (Fig.1), at the end of Canal 11 in the alignment of Levee 37, about 0.5 mile west of U.S. Highway 27 and about 20 miles west of Hollywood, Florida (OMD 1987). The pump station consists of reinforced concrete and concrete block superstructure. It has three Nordberg 122-inch diameter vertical lift pumps each rated at 960 cfs with a 10.4-ft head. Each pump unit is driven by a Caterpillar diesel engine connected to the pump through a single reduction helical gear transmission manufactured by the Philadelphia Gear Works. The main pump does not normally require priming. The station gets power from three Detroit Diesel, Model 6-71, 75 kW AC generators and a 30 kW unit. For general service and maintenance, a Wright 10-ton manually operated overhead bridge is available.

The pumps at S9 deliver excess water from Davie agricultural area west of S13A to Water Conservation Area 3 (WCA3) via the South New River Canal. The station also pumps seepage water from under Levee 33 and Levee 37 back into WCA3.

This report summarizes the rating analysis performed for S9. Section 2 of this report describes the objective and scope of this work. Section 3 discusses the existing flow model used to estimate discharge through S9 pumps. Flow measurement and rating development are treated in Section 4 and Section 5 respectively. Sections 6 and 7 discuss new model calibration and input parameters. Conclusions and recommendations are given in Section 8 and Section 9, respectively.

2. Objective and Scope

The diesel-powered units of the pump station operate at variable speeds. Information from the Operations & Maintenance Department indicated that the flows computed using the equations in the FLOW program seemed to underestimate the discharge during Hurricane Irene in October 2001, when the pumps operated at full capacity. The objective of this discharge rating analysis is to look into possibilities for improving flow data accuracy for this pump station. This rating analysis makes use of the principles of energy conservation, and the pump affinity laws, which account for variability in the speed of the diesel pumps. The discharge rating presented in this report gives a mathematical description of the variation of discharge with changes in head and pump speed.

The rating analysis for S9 is based on flow data obtained through streamgauging. This analysis provides estimates of flow computation error in relation to field measurements for the existing equation as well as for the new model calibrated with field data. The least square method is used to calibrate the new model.

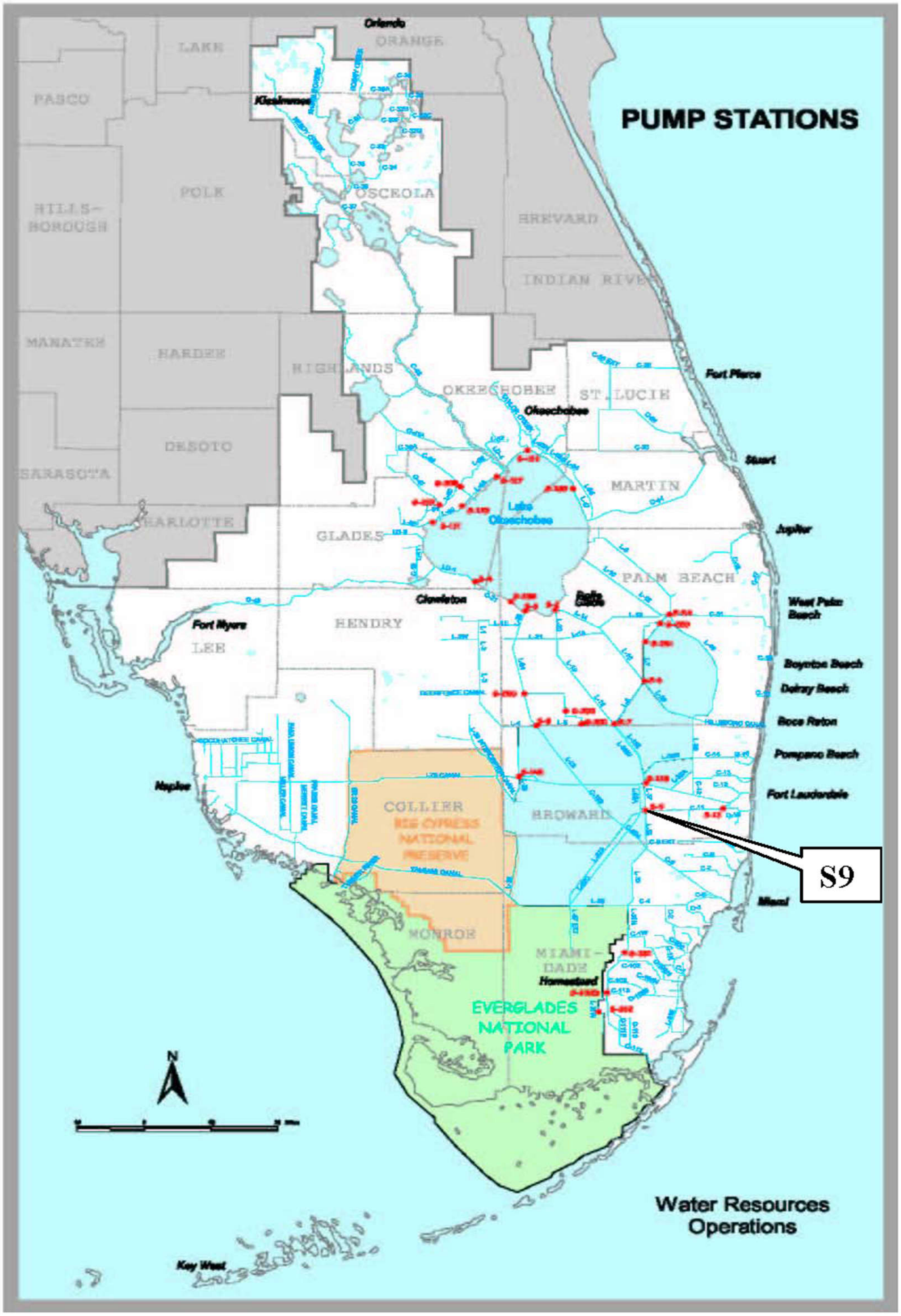

FIGURE 1 LOCATION MAP

3. Existing Flow Model and Parameters used for S9

Pumps at S9 are, for flow calculation purposes, classified as Case 4, making use of the flow equations for Case 2, where a two-variable polynomial is used to model the flow. However, the flow is computed using two sets of coefficients (Version 1 and Version 2). Version 1 coefficients are used to calculate flow through S9 for the period after 1989, i.e. after the engines were replaced, while Version 2 coefficients are used for the period before that. The flow coefficients in this case are summarized in Table A1 (Appendix).

The existing flow estimation procedure involves a third-order model (Eq. 1) with two independent variables (Otero, 1995).

$$Q = C_0 + C_1 \cdot X + C_2 \cdot Y + C_3 \cdot X^2 + C_4 \cdot XY + C_5 \cdot Y^2 + C_6 \cdot X^3 + C_7 \cdot YX^2 + C_8 \cdot XY^2 + C_9 \cdot Y^3 \quad (1)$$

Q is the discharge in cfs; C_0 is a constant and C_1 through C_9 are regression coefficients. X is the dimensionless ratio of the head H in feet and the head factor Hfact (maximum possible head), i.e., X = H/Hfact. H is the head difference between headwater and tailwater. Y is a dimensionless engine speed parameter given by Y = (N-Nmin)/Nfact; where, N is the engine speed in rpm. Nfact is the engine speed factor, Nfact = Nmax-Nmin; Nmin and Nmax are, respectively, the minimum and maximum engine speed.

4. Stream Flow Measurements and Existing Rating

There are about forty measurements of stream flow for this station in the streamgauging records. All of the forty data points are considered in this rating analysis. The streamgauging data for S9 pumps are shown in Figure 2.

Figure 2 represents flow measurements by triangles when engine speed and stage are at field value. The circles represent the values when the field data are adjusted to the rated engine speed of 733 rpm using the pump affinity laws.

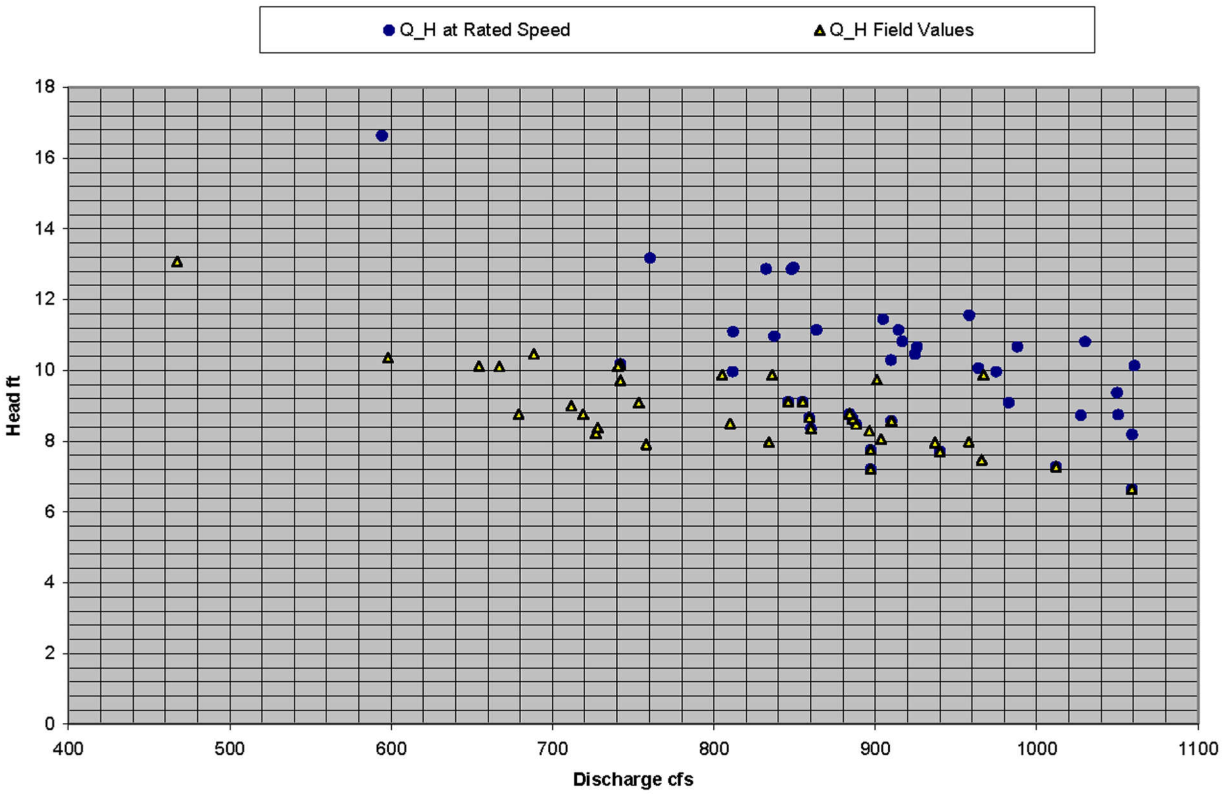

FIGURE 2 STREAM FLOW MEASUREMENTS FOR S9 PUMPS

Table 1 shows sample measurements of discharge through the pumps at S9 and corresponding values obtained using the existing flow equations. The results shown in the table were obtained using Qverify (an in-house software application for verifying discharge ratings).

The relative errors (computed relative to measured) in discharge vary from –19.53% to +4.34%. All data points show relative errors under 20%. About 40% of the computed data are within 5% of the measured values while 50% are within 10% and 85% are within 15%. Thus the existing rating performs very well as compared to field measurements. With the availability of forty data points obtained from field measurements, it is worth looking into possibilities of improving the accuracy of computed flow data as requested by OMD.

Table 1 Comparison of measured and computed discharges

Discharge Rating Errors for S9_P								
Record Number	Date	Time	Head Water	Tail Water	Head Difference	Measured Discharge	Computed Discharge	Relative Error
			ft	ft	ft	cfs	cfs	
1	29-May-90	12:14	1.25	7.9	6.65	1059	930	-12.18%
2	30-May-90	12:48	0.63	7.91	7.28	1012	903.834	-10.69%
3	27-Jul-90	14:30	0.24	8.6	8.36	860	856.875	-0.36%
4	11-Sep-90	14:20	0.56	9.19	8.63	886	844.816	-4.65%
5	14-Sep-90	13:00	0.44	9.02	8.58	910	847.056	-6.92%
6	14-Sep-90	14:37	0.35	9.02	8.67	859	843.021	-1.86%
7	18-Sep-90	14:55	0.17	8.94	8.77	884	838.523	-5.14%
8	27-Sep-90	14:10	0.34	8.82	8.48	888	851.528	-4.11%
9	23-May-91	12:55	1.01	8.76	7.75	1794	1767.364	-1.48%
10	23-May-91	15:35	0.91	8.62	7.71	940	885.417	-5.81%
11	7-Aug-91	13:35	0.54	10.72	10.18	742	774.199	4.34%
12	22-Oct-91	17:40	3.14	10.35	7.21	897	906.793	1.09%
13	22-Jun-94	14:40	0.98	10.1	9.12	846	822.695	-2.75%
14	23-Jun-94	14:40	0.98	10.1	9.12	855	822.695	-3.78%
15	13-Mar-96	12:05	1.63	10.01	8.38	728	685.718	-5.81%
16	13-Mar-96	13:44	1.63	9.85	8.22	727	692.802	-4.70%
17	13-Jun-96	12:14	1.46	10.22	8.76	679	668.76	-1.51%
18	13-Jun-96	13:34	1.46	10.22	8.76	719	668.76	-6.99%
19	15-Jun-97	10:40	0.96	10.84	9.88	1934	1563.537	-19.16%
20	15-Jun-97	11:40	1.11	10.84	9.73	1802	1450.014	-19.53%
21	15-Jun-97	14:29	2.52	10.58	8.06	1807	1515.021	-16.16%
22	15-Jun-97	15:05	2.61	10.58	7.97	1668	1407.587	-15.61%
23	22-Jun-97	9:10	0.78	10.89	10.11	1334	1215.148	-8.91%
24	22-Jun-97	10:22	0.95	10.83	9.88	805	781.769	-2.89%
25	22-Jun-97	11:42	1.14	10.86	9.72	742	704.272	-5.08%
26	15-Jan-98	13:37	0.97	10.84	9.87	836	718.654	-14.04%
27	1-May-98	10:11	0.82	9.91	9.09	1507	1307.814	-13.22%
28	6-Nov-98	10:20	0.79	11.25	10.46	1377	1220.311	-11.38%
29	26-Feb-99	11:10	2.58	10.05	7.47	966	824.966	-14.60%
30	30-Apr-99	11:16	1.12	9.1	7.98	1916	1606.109	-16.17%
31	30-Apr-99	12:07	1.1	9.06	7.96	937	803.924	-14.20%
32	21-May-99	14:01	1.23	9.14	7.91	758	706.416	-6.81%
33	2-Jun-99	10:38	0.94	9.44	8.5	2430	2041.146	-16.00%
34	8-Jun-99	11:48	1.43	9.72	8.29	2689	2368.512	-11.92%
35	17-Jun-99	12:23	0.87	9.87	9	1423	1315.937	-7.52%
36	24-Aug-99	12:35	1	11.12	10.12	1481	1414.603	-4.48%
37	24-Aug-99	13:15	1.02	11.14	10.12	1309	1214.235	-7.24%
38	26-Aug-99	11:13	0.73	11.09	10.36	1196	1192.375	-0.30%
39	3-Nov-99	11:45	0.35	13.43	13.08	934.7	951.597	1.81%
40	25-Jun-01	10:50	0.72	8.94	8.22	1453	1403.546	-3.40%
				Minimum Error				-19.53%
				Maximum Error				4.34%

5. Rating Equation Development

The pump characteristic curves supplied by the manufacturer were used in conjunction with the principles of energy and mass conservation, and the pump affinity laws to develop the model for estimating flow through the pumps at S9. Figure 3 shows the head-discharge relationship for flows through the pumps at S9 under laboratory conditions. Various pump speeds are represented by corresponding curves. For the engines in operation after 1989, the top curve represents an engine speed of 733 rpm, the bottom curve represents an engine speed of 660 rpm and the curves in between are for engine speeds between 733 and 660 rpm. For the old engines, i.e. prior to 1989, the top curve represents 400 rpm, the bottom curve represents 360 rpm and the curves in between are for 370, 380 and 390 rpm as shown

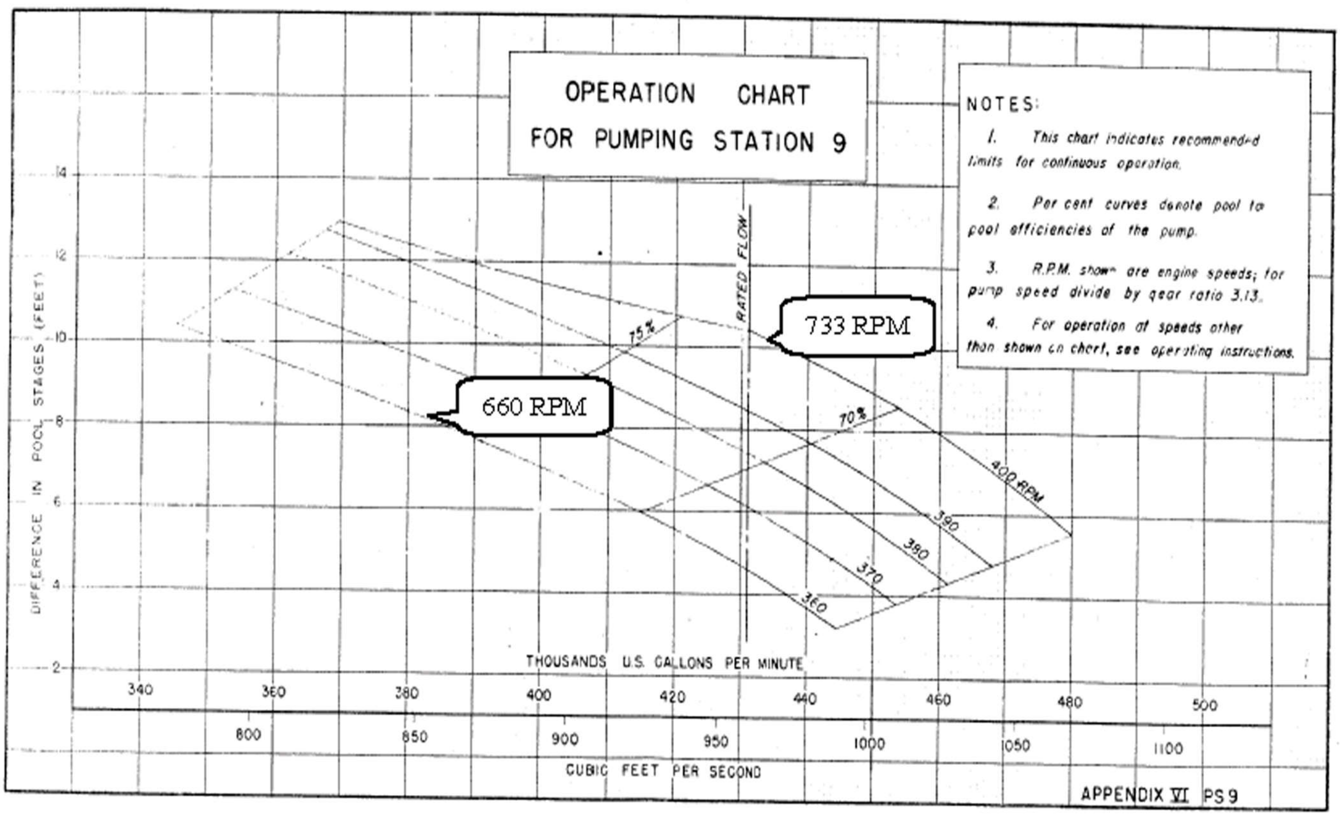

Figure 3 Manufacturer's pump curves for S9

From the energy conservation principle we can note that velocity is a function of the head differential. Discharge through a constant cross section (such as a pump flow section), which is directly proportional to velocity is a function of the head. The absolute value of the hydraulic head differential (H) is used in all subsequent equations. On the basis of this concept Eq. 2 is valid for all Q and H values for the rated pump speed.

$$Q_o = f(H) = A + BH_0^{\,C} \tag{2}$$

In Eq. (2), Q_o (variable) denotes discharge for a reference pump speed, H_0 (variable) is head differential that corresponds to Q_o, B is a proportionality coefficient, and C is an exponent assumed constant.

When the pump speed varies, the flow rate is affected proportionally according to the pump affinity laws. The pump affinity laws assume no appreciable change in efficiency when engine speeds change, and relate change in discharge with change in pump speed according to Eq. 3.

$$\frac{Q}{Q_o} = \frac{N}{N_o} \tag{3}$$

Substituting Eq. (2) into Eq. (3) and rearranging, we obtain Eq. (4).

$$Q = \frac{N}{N_0}(A + BH_0^{\,C}) \tag{4}$$

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

$$H_0 = \left[\frac{N_0}{N}\right]^2 H \tag{5}$$

Substituting Eq. (5) in Eq. (4) and rearranging, we obtain Eq. (6).

$$Q = A\left[\frac{N}{N_0}\right] + BH^c\left[\frac{N_0}{N}\right]^{2c-1} \tag{6}$$

Equation (6) is a model based on physical laws that can be used to estimate flow through variable speed pumps. For S9, this model was calibrated using field data obtained through streamgauging.

6. Calibration of the Model

The pump characteristic curves supplied by the manufacturer (Fig. 2) suggest that the head-discharge function could be monotonically decreasing in the range shown, which is consistent with the model, developed from the energy equation and the pump affinity laws. Based on the pump curves, the energy equation and the pump affinity laws, the discharge estimation model was developed (Equation 6). This equation was calibrated (Eq. 7), using streamgauging data, in such a way that it can use static head (head difference between headwater and tailwater) as an input variable.

Figure 4 shows the plot of the curve resulting from the calibration of Equation 6 using head and discharge values from the pump manufacturer's curve. The calibration results (coefficients and exponents) were then applied to the equation developed using the pump affinity laws and subsequently compared to the field measurements.

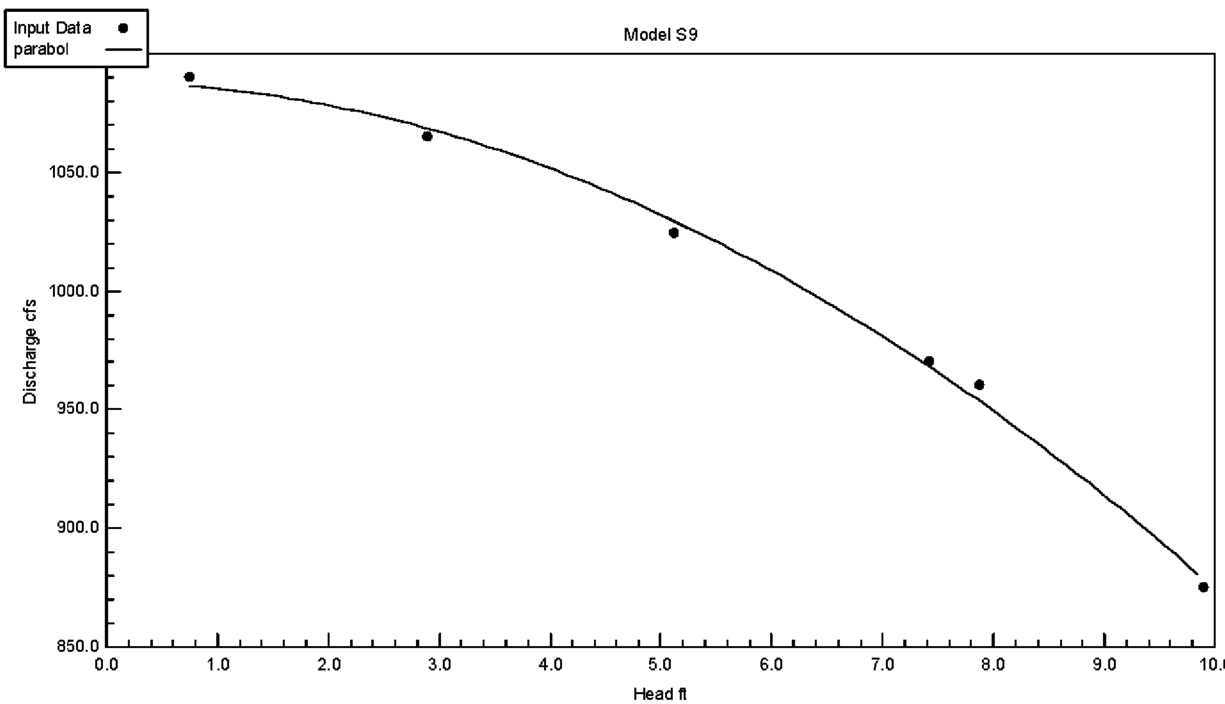

Figure 4 Manufacturer's pump curve at 733 rpm, adjusted for losses (static head) and developed into an equation

Figure 5 shows head-discharge relationships from measurements and computations. The continuous curve represents the manufacturer's curve at 733 rpm, square symbols (red in color) represent field measurements, light crosses (cyan in color) represent computed values using existing model, dark (dark-blue in color) circles represent flows computed using the new calibrated model. Field measurements as well as calculated values indicate that the actual field performance of the pump is slightly lower than what the manufacturer's curve suggests. This is an expected scenario if the manufacturer's curves are based on model test results under laboratory settings. There may also be reduction in performance due to aging.

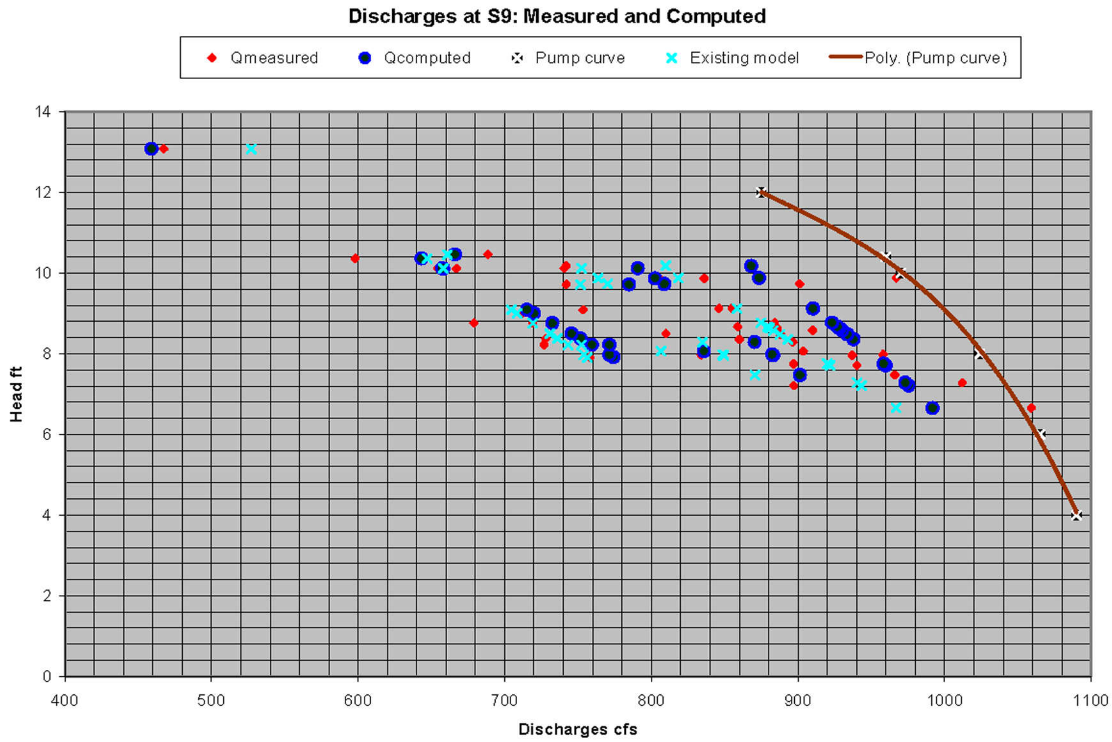

Figure 5 Flow data for S9 resulting from field measurements, existing model, new model (Qcomputed), and 733-rpm theoretical curve

The rating equation developed in this study will be further refined if necessary. When additional stream flow measurements are available, the accuracy of the rating will be evaluated. If the evaluation results in relative errors greater than 10% based on good streamgauging data, the equations will be re-calibrated. If the re-calibration results in significantly better flow computation accuracy, the newly calibrated equations will be adopted to generate instantaneous and daily flow data.

Table 2 shows the values of coefficients and powers resulting from the calibration using available streamgauging data. The values of the coefficient B are negative as long as the headwater is lower than the tailwater. This is consistent with the concept that pump discharge is higher when assisted by gravity and lower when working against a positive static head.

Table 2 New pump equation coefficients and exponents for S9

Unit	A	B	C	D=2C-1
1	1088	-2.44	1.94	2.88
2	1088	-2.44	1.94	2.88
3	1088	-2.44	1.94	2.88

A regression of discharge on the head differential was performed for the S9 pumps on the basis of streamgauging data and the model developed in this study. The regression gave a very good fit with $R^2 = 0.996$ (Table A3). Equation (7) is for estimating flow through each diesel pump.

$$Q = 1088\left[\frac{N}{No}\right] - 2.44H^{1.94}\left[\frac{No}{N}\right]^{2.88} \qquad (7)$$

Equation (7) is valid when the headwater stage is not above the tailwater, which is expected to be the most prevalent operating condition. In the event that the upstream elevation exceeds the tailwater, the head differential assists the flow. The tailwater is not expected to fall below the headwater elevation. A more extensive investigation with field flow measurements will be required to quantitatively determine how much gravity flow assists the pump flow if there is pumping while the tailwater is below the headwater level.

7. Input Parameters

The elevation midway between the invert and the crown at the outflow (exit) point is the "outlet center". The outlet center is the lower limit of the tailwater stage. If the tailwater elevation (TWE) is below the outlet center at the exit point, the outlet center elevation is used in determining the head differential. The head differential is the absolute value of the difference between headwater and tailwater stages, where the minimum value for tailwater stage is the outlet center elevation. The value of H is determined from Eq. (8) and is used to determine Q in Equations (2), (4), (5), (6), and (7).

$$H = ABS(HWE - \max(TWE, Outlet\,center)) \qquad (8)$$

Equation (8) means that the head (H) is the absolute value of the difference between the headwater elevation and the tailwater elevation where the minimum value of the tailwater elevation is the outlet center.

8. Conclusions

Field measurements of flow through S9 did not confirm the design pump capacity of 960 cfs per unit indicated in the structure books (OMD 1987). The measurements show that the pumps at S9 deliver lower discharges than 960 cfs per unit when operating at full capacity under design conditions. The existing model estimates flow within 5% of the measurements under design conditions. Depending on the headwater and tailwater combinations, it slightly overestimates or underestimates the flows as compared to the field measurements. Overall the measurements and the computed flows for S9 pumps agree reasonably well. The average error relative to field measurements is in the order of 7.5%, which is satisfactory.

There is room for improvement in terms of reducing errors. The number of parameters can be reduced. The coefficients can be reduced from nine for the existing equation, to three for a new physically based one. The existing polynomial was presumably developed using regression to determine the nine coefficients, which may not provide for reliability of estimates for values other than those used in the calibration.

For standardization of pump flow calculation methods, using more physically based equations, a new model has been developed and calibrated for the estimation of flow through the pumps at S9. The calibration of the model for S9 resulted in Eq. (7) for normal operating conditions.

The equation developed and calibrated here is based on physical laws and principles of hydraulics. The pump affinity laws have been used with field flow measurements to calibrate the model and arrive at pump station-specific flow equations. Based on available field measurements, which were used in the calibration, the new equation estimates flow within 10% of measured values for all conditions and within 5% of measured values for conditions close to the design capacity. The overall average relative error is 1.32% (Table A2).

The accuracy of the calibrated equations will be verified using stream flow data. When 10 or more additional measurements are available, the flow equations can be refined further if necessary.

9. Recommendations

The existing flow estimation equation used for pumps at S9 performs satisfactorily as far as flow data accuracy is concerned. There is room for improvement and a desire (in Hydrology and Hydraulics Division) to standardize and reduce the number and type of equations used to compute flow through pumps. The equations developed and calibrated in this study are recommended for the estimation of flow through S9 pumps.

Telemetric data are available for S9 stages starting from April 2001. It is recommended that the new flow model be used effective immediately in conjunction with telemetry stage and pump operation data.

The number of pumps operating at the same time influences the discharge efficiency of each pump. The impact is not so significant as to affect the overall accuracy of the discharge rating. To determine the effect of simultaneous operation on the efficiency of each pump, a lot of data sets will be needed under the same operating conditions while varying the number of pumps in operation. Such data sets will help determine correction factors for multiple pumps working at the same time. This aspect can be considered when attempting to further refine the flow equation developed and calibrated.

It is imperative that more stream flow data be collected to verify the flow equations developed for S9. About ten additional flow measurements of good quality will also help to further improve the accuracy of flow computation for S9 pumps.

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Appendix

Table A1. Existing flow coefficients for S9 pumps

Version 1 (For period after1989/replacement of engine)

Pump Station	UNIT_NO	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	Hfact	Nfact	Nmin	C_p	PUMP TYPE
S9_P	1	5613.63	-941.07	-16678	-699.27	1858.45	18714.6	363.683	-106.34	-972.59	-6514.4	14	310	100	.90	V
	2	5613.63	-941.07	-16678	-699.27	1858.45	18714.6	363.683	-106.34	-972.59	-6514.4	14	310	100	.90	V
	3	5613.63	-941.07	-16678	-699.27	1858.45	18714.6	363.683	-106.34	-972.59	-6514.4	14	310	100	.90	V

Version 2 (For period prior to 1989)

Pump Station	UNIT_NO	C_0	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	Hfact	Nfact	Nmin	C_p	PUMP TYPE
S9_P	1	-9432.4	-8111.3	37492.7	1298.43	15299	-44708	-96.108	-1543	-7204.2	17817.4	14	310	100	.90	V
	2	-9432.4	-8111.3	37492.7	1298.43	15299	-44708	-96.108	-1543	-7204.2	17817.4	14	310	100	.90	V
	3	-9432.4	-8111.3	37492.7	1298.43	15299	-44708	-96.108	-1543	-7204.2	17817.4	14	310	100	.90	V

Table A2 Flow rating analysis for S9 pumps using existing and new models

Pump S9 Calibration

Existing Model
Q=Co+C1X+C2Y+C3X^2+C4XY+C5Y^2+C6X^3+C7YX^2+C8XY^2+C9Y^3

New Model (Quadratic2)
Q=C1H^C2*(No/N)^(2C2-1)+C3(N/No)

X=H/Hfact	Hfact	Nfact	Nmin
Y=(N-Nmin)/Nfact	14	633	100

Existing Model

C0	C1	C2	C3	C4	C5
5613.63	-941	-16678	-699.27	1858.45	18714.6
	C6	C7	C8	C9	
	364	-106.34	-972.59	-6514.4	

New Model

C1	C2	C3
-2.44	1.94	1088

HEADDIF	OPERATION VALUE	q	Existing Model Flow Values Qe	Error	X	Y	H(No/N)^2	q(No/N)=qo	Qc Curve	Qn New Model	Error
6.65	733	1059	967	-0.09	0.48	1.00	6.65	1059.00	991.69	992	-0.06
7.21	733	897	943	0.05	0.52	1.00	7.21	897.00	975.34	975	0.09
7.28	733	1012	940	-0.07	0.52	1.00	7.28	1012.00	973.20	973	-0.04
7.71	733	940	922	-0.02	0.55	1.00	7.71	940.00	959.69	960	0.02
7.75	733	897	920	0.03	0.55	1.00	7.75	897.00	958.39	958	0.07
7.47	700	966	871	-0.10	0.53	0.95	7.82	1011.54	956.04	901	-0.07
7.96	700	937	849	-0.09	0.57	0.95	8.34	981.17	938.73	883	-0.06
7.98	700	958	849	-0.11	0.57	0.95	8.36	1003.16	938.00	882	-0.08
8.36	733	860	893	0.04	0.60	1.00	8.36	860.00	937.87	938	0.09
8.48	733	888	888	0.00	0.61	1.00	8.48	888.00	933.66	934	0.05
8.58	733	910	883	-0.03	0.61	1.00	8.58	910.00	930.11	930	0.02
8.63	733	886	881	-0.01	0.62	1.00	8.63	886.00	928.32	928	0.05
8.67	733	859	879	0.02	0.62	1.00	8.67	859.00	926.88	927	0.08
8.29	700	896	835	-0.07	0.59	0.95	8.68	938.59	926.49	870	-0.03
8.06	680	904	807	-0.11	0.58	0.92	8.69	973.92	926.22	836	-0.08
8.77	733	884	875	-0.01	0.63	1.00	8.77	884.00	923.26	923	0.04
7.91	650	758	757	0.00	0.57	0.87	8.92	854.79	917.74	774	0.02
7.97	650	834	754	-0.10	0.57	0.87	8.99	940.50	915.23	771	-0.08
9.12	733	846	859	0.01	0.65	1.00	9.12	846.00	910.26	910	0.08
9.12	733	855	859	0.00	0.65	1.00	9.12	855.00	910.26	910	0.06
8.22	655	727	752	0.04	0.59	0.88	9.20	813.01	907.27	771	0.06
8.22	650	727	743	0.02	0.59	0.87	9.27	819.83	904.56	759	0.04
8.38	650	728	736	0.01	0.60	0.87	9.45	820.96	897.57	752	0.03
8.5	650	810	731	-0.10	0.61	0.87	9.59	913.43	892.25	746	-0.08
8.76	650	679	719	0.06	0.63	0.87	9.88	765.70	880.46	732	0.08
8.76	650	719	719	0.00	0.63	0.87	9.88	810.81	880.46	732	0.02

Pump S9 Calibration

Existing Model

$Q=Co+C1X+C2Y+C3X^2+C4XY+C5Y^2+C6X^3+C7YX^2+C8XY^2+C9Y^3$

New Model (Quadratic2)

$Q=C1H^{C2}*(No/N)^{(2C2-1)}+C3(N/No)$

	Hfact	Nfact	Nmin
X=H/Hfact			
Y=(N-Nmin)/Nfact	14	633	100

Existing Model

C0	C1	C2	C3	C4	C5
5613.63	-941	-16678	-699.27	1858.45	18714.6
	C6	C7	C8	C9	
	364	-106.34	-972.59	-6514.4	

New Model

C1	C2	C3
-2.44	1.94	1088

HEADDIF	OPERATION VALUE	q	Existing Model Flow Values Qe	Error	X	Y	H(No/N)^2	q(No/N)=qo	Qc Curve	Qn New Model	Error
9.88	730	805	818	0.02	0.71	1.00	9.92	808.31	878.75	873	0.09
9.88	730	967	818	-0.15	0.71	1.00	9.92	970.97	878.75	873	-0.10
9	650	712	708	0.00	0.64	0.87	10.15	802.35	869.29	720	0.01
10.18	733	742	810	0.09	0.73	1.00	10.18	742.00	868.00	868	0.17
9.73	700	901	770	-0.15	0.70	0.95	10.19	943.48	867.64	809	-0.10
9.09	650	754	704	-0.07	0.65	0.87	10.25	849.72	865.03	715	-0.05
9.72	690	742	751	0.01	0.69	0.93	10.33	788.24	861.85	785	0.06
9.87	700	836	764	-0.09	0.71	0.95	10.34	875.41	861.44	802	-0.04
10.12	700	741	752	0.02	0.72	0.95	10.60	775.41	850.18	791	0.07
10.11	650	667	658	-0.01	0.72	0.87	11.40	752.17	813.93	658	-0.01
10.12	650	655	658	0.01	0.72	0.87	11.41	738.07	813.41	657	0.00
10.46	660	689	661	-0.04	0.75	0.88	11.62	764.65	803.77	666	-0.03
10.36	650	598	647	0.08	0.74	0.87	11.68	674.36	800.63	643	0.08
13.08	650	467	527	0.13	0.93	0.87	14.75	527.03	636.29	459	-0.02
			Sum of Relative Errors		-0.69						0.53
			Average Relative Error (%)		-1.72						1.32

Table A3 New model regression result for S9 pumps

Results from project Datafit
DataFit version 6.1.10
Results from project "Untitled2"
Equation ID: parabol

Number of observations = 6
Number of missing observations = 0
Solver type: Nonlinear
Nonlinear iteration limit = 250
Diverging nonlinear iteration limit =10
Number of nonlinear iterations performed = 7
Residual tolerance = 0.0000000001

Sum of Residuals = -2.27373675443232E-12
Average Residual = -3.7895612573872E-13
Residual Sum of Squares (Absolute) = 114.245321006119
Residual Sum of Squares (Relative) = 114.245321006119
Standard Error of the Estimate = 6.17104315887567
Coefficient of Multiple Determination (R^2) = 0.9963126846
Proportion of Variance Explained = 99.63126846%
Adjusted coefficient of multiple determination (Ra^2) = 0.9938544744
Durbin-Watson statistic = 2.03864376139575

Regression Variable Results

Variable	Value	Standard Error	t-ratio	Prob(t)
a	-2.437263036	0.973868805	-2.502660547	0.0875
b	1.941824554	0.171501804	11.32247303	0.00148
c	1087.663049	5.814752686	187.0523319	0

68% Confidence Intervals

Variable	Value	68% (+/-)	Lower Limit	Upper Limit
a	-2.437263036	1.157832622	-3.595095657	-1.279430414
b	1.941824554	0.203898495	1.737926059	2.14572305
c	1087.663049	6.913159468	1080.74989	1094.576209

90% Confidence Intervals

Variable	Value	90% (+/-)	Lower Limit	Upper Limit
a	-2.437263036	2.291902845	-4.72916588	-0.145360191
b	1.941824554	0.403612346	1.538212208	2.345436901
c	1087.663049	13.68443897	1073.97861	1101.347488

95% Confidence Intervals

Variable	Value	95% (+/-)	Lower Limit	Upper Limit
a	-2.437263036	3.099240084	-5.536503119	0.661977048
b	1.941824554	0.545787342	1.396037212	2.487611897
c	1087.663049	18.50486895	1069.15818	1106.167918

99% Confidence Intervals

Variable	Value	99% (+/-)	Lower Limit	Upper Limit
a	-2.437263036	5.688270301	-8.125533336	3.251007265
b	1.941824554	1.001724889	0.940099665	2.943549444
c	1087.663049	33.96338896	1053.69966	1121.626438

Variance Analysis

Source	DF	Sum of Square:	Mean Square	F Ratio	Prob(F)
Regression	2	30869.08801	15434.54401	405.3000299	0.00022
Error	3	114.245321	38.08177367		
Total	5	30983.33333			

Table A4 Estimation of head loss for flow through pumps at S9

		Loss	hf =	(3.022*v^1.85*L)/C^1.85*D^1.165			(Hazen-Williams)	
Head-Discharge Curve								
Ht	H	Q	v	v^2/2g	section1	section2	section3	section4
2	-	1170	14.90	3.45	0.05	0.09	0.08	0.06
4	0.75	1090	13.89	2.99	0.05	0.08	0.07	0.05
6	2.90	1065	13.57	2.86	0.05	0.08	0.07	0.05
8	5.13	1024	13.04	2.64	0.04	0.07	0.06	0.05
10	7.43	970	12.36	2.37	0.04	0.07	0.06	0.04
10.4	7.88	960	12.23	2.32	0.04	0.06	0.05	0.04
12	9.90	875	11.15	1.93	0.03	0.05	0.05	0.04