FLOW RATING ANALYSIS FOR PUMP STATION S199

By
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May 2012

SFWMD-HIST-025

Hydro Data Management Section
Operation & Infrastructure Bureau
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ACKNOWLEDGEMENT

The authors wish to express their appreciation to Jorge Jaramillo and Chris Bauer for collecting the pump performance curve and pump design information for this rating analysis.

DEFINITIONS

Acronyms

AARE	Average absolute relative error
ARE	Absolute relative error
HW	Head water
TW	Tail water
SFWMD	South Florida Water Management District
TDH	Total dynamic head
TSH	Total static head

EXECUTIVE SUMMARY

Pump Station S199 consists of three identical electric pumps each with capacity of 75 cfs. This report summarizes a flow rating analysis for the pumps at Pump Station S199 based on the TSH vs. discharge relationship obtained from the pump performance tests with the calibration using the two flow measurements. The developed rating equation will be used to compute flow through the pump station.

1.0 INTRODUCTION

1.1 Background

Pump Station S199 is one of key components of the southern section of the C-111 Spreader Canal Phase 1 Project, which is located in southern Miami-Dade County in an area bounded by Everglades National Park, the Florida City-Homestead area, and Manatee. The main south components include Pump Station S-199, the Aerojet Canal Extension, the weirs and plugs on a portion of the Aerojet Canal, ten plugs in the C-110 Canal, a plug in the L-31E Canal, and a water control structure S-198.

Pump Station S199 is located on the west side of the C-111 Canal, south of Ingraham Highway and north of the S-177 gate structure with an excavated inlet canal connecting S-199 to the C-111 Canal, as shown in **Figure 1**. The pump station has three identical electric pumps, each with a design capacity of 75 cfs. It was constructed to pump water from C-111 and raise the water elevation in the Aerojet Canal to create a hydraulic mound in the vicinity of this Canal and minimize groundwater flow from Taylor Slough to the east.

Figure 1. Location of Pump Station S199

1.2 Objectives and Scope

We will conduct a rating analysis to develop a flow rating equation for Pump Station S199 to compute flow through the pump station.

2.0 STATION DESIGN

Pump Station S199 houses three identical electric pumps with pump serial number SN10018, SN10018, and SN10020, each with design capacity of 75 cfs. **Figure 2** illustrates the plan view of the pump station, and **Figure 3** the profile view of the pump station.

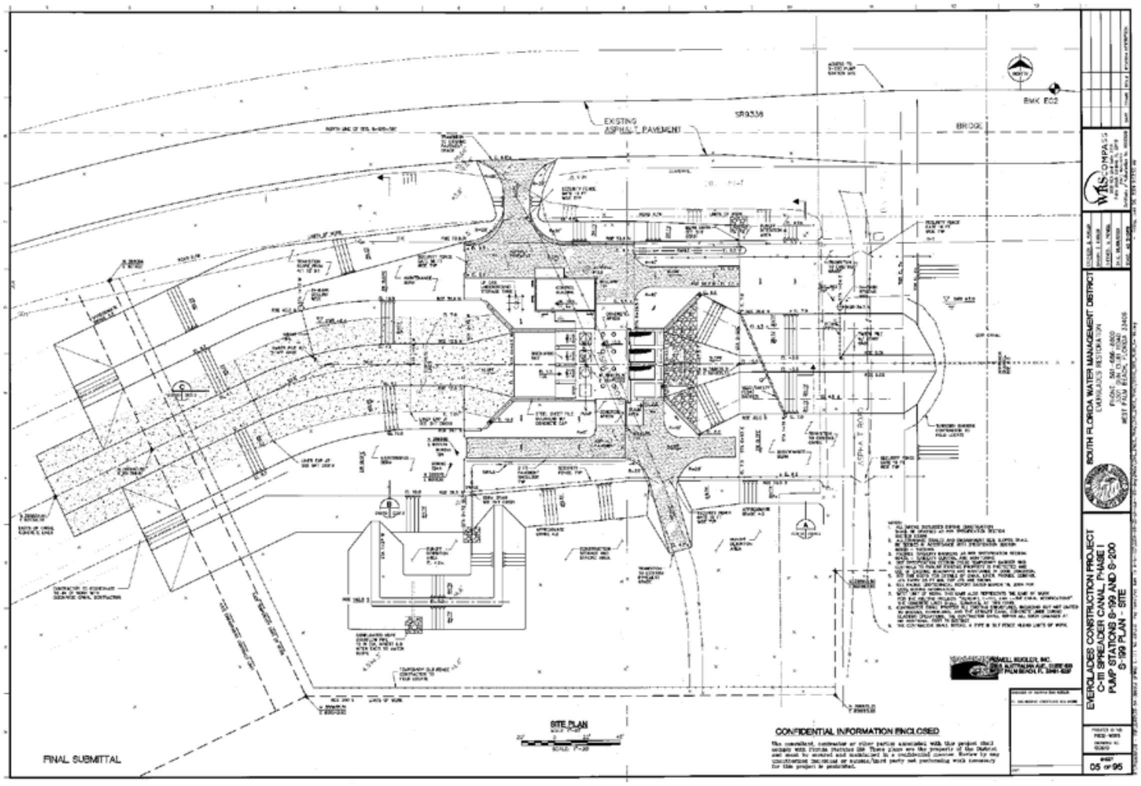

Figure 2. Plan view of Pump Station S199

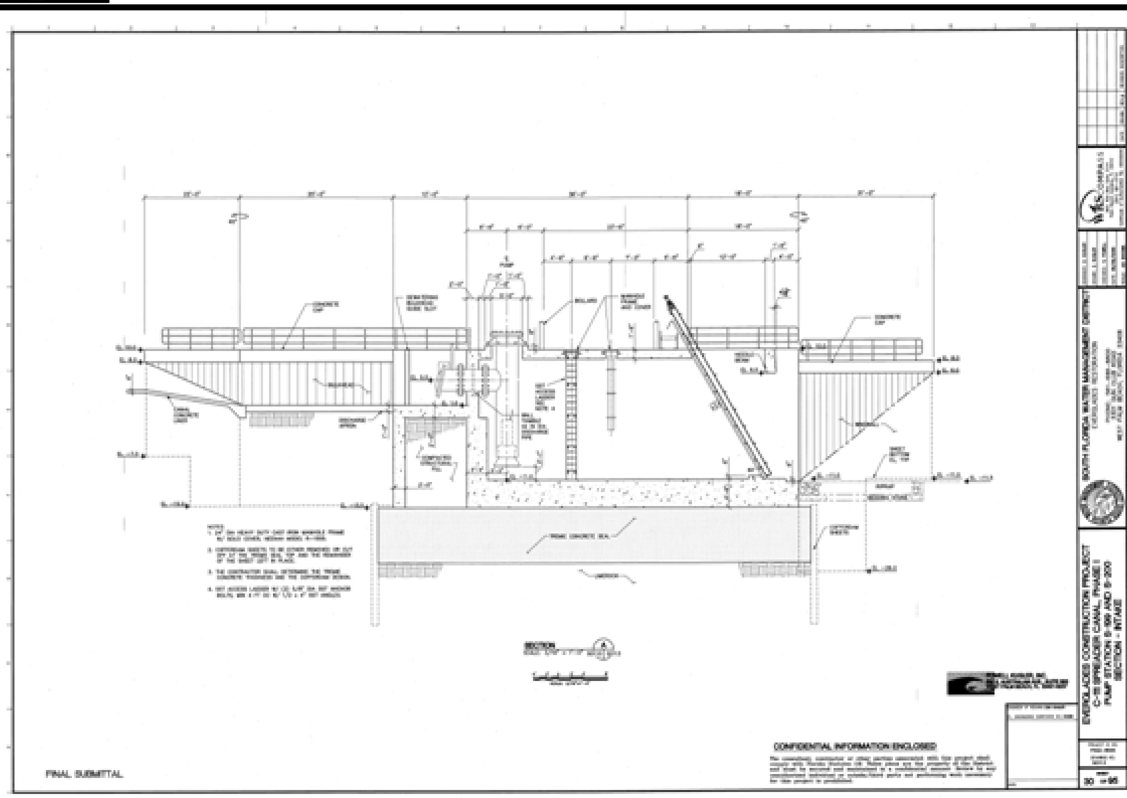

Figure 3. Profile view of Pump Station S199

Table 1. Description for Pump Station S199

ITEM	Description
Number of pumps	3
Design pump capacity	75 cfs
Engine motor horsepower	200 Hp
Design engine speed	588 rpm
Pump impeller speed	588 rpm
Propeller Diameter	30 in
Discharge pipe diameter	42 in

2.1. Pump Performance Test

The manufacturer conducted pump performance tests on these three pumps. The total dynamic head (TDH) computations of these pumps are given in Appendix A through C (MWI Corporation, 2011). **Table 2** below presents the total static head (TSH) versus discharge values that were extracted from Appendix A through C.

Table 2. TSH and Discharge Relationship

Pump Serial No.	Test Point	Pressure Gauge Height (in)	Static Pressure (psi)	TSH (ft)	Flow (gpm)	Flow (cfs)
SN 10018	1	28.5	6.10	16.45	32465	72.33
	2	28.5	5.00	13.91	33952	75.65
	3	28.5	4.00	11.60	35144	78.30
	4	28.5	3.00	9.30	36069	80.36
	5	28.5	1.90	6.76	36523	81.38
	6	28.5	1.00	4.68	38068	84.82
	7	28.5	0.00	2.38	38712	86.25
SN10019	1	28.0	6.20	16.64	31953	71.19
	2	28.0	5.00	13.87	33709	75.11
	3	28.0	4.10	11.79	34909	77.78
	4	28.0	2.90	9.02	35840	79.85
	5	28.0	1.90	6.72	37193	82.87
	6	28.0	0.90	4.41	38068	84.82
	7	28.0	0.00	2.33	38924	86.73
SN10020	1	26.0	6.20	16.47	32465	72.33
	2	26.0	5.10	13.93	33952	75.65
	3	26.0	3.80	10.93	35378	78.82
	4	26.0	3.00	9.09	36297	80.87
	5	26.0	1.90	6.55	37193	82.87
	6	26.0	1.00	4.47	38068	84.82
	7	26.0	-0.10	1.94	38924	86.73

3.0 STREAM FLOW DATA

We conducted flow measurement at Pump Station S199 using Acoustic Doppler Current Profiler (ADCP) on March 7, 2012, and at Pump Station S200 on February 23, 2012. We can borrow the measured flows at S200 to calibrate the flow rating for S199 since the two stations have identical pump station design and identical pumps. **Table 3** summarizes the flow measurement, including the HW and TW stage, number of pumps in operation, engine speed, average discharge, and measurement quality tag. The quality of each flow measurement has been evaluated and assigned quality tag or qualitative accuracy qualifier by our stream gauging staff. There are six categories of qualifiers are used: “excellent (E)”, “good (G)”, “fair (F)”, “poor (P)”, “bad (B)”, and “Not processed (N).

Table 3. Summary of Flow Measurements

Date	HW Stage (ft, NGVD)	TW Stage (ft, NGVD)	# of Units	Avg Engine Speed (rpm)	Avg Discharge (cfs)	Device	Quality Tag
2/23/2012	3.10	8.70	3	588	225.56	ADCP	G
3/7/2012	2.26	7.80	3	588	224.48	ADCP	G

4.0 RATING ANALYSIS

We will develop a Case 8 flow rating equation for Pump Station S199 based on the TSH vs. discharge relationship obtained from the pump performance tests. Case 8 rating equation is developed by dimensional analysis and the pump affinity laws. Case 8 rating is the conventional rating equation representing all the possible cases, as documented in Damisse (2001) and Imru and Wang (2003). Equation below shows the Case 8 flow rating equation.

$$Q = A\left(\frac{N}{No}\right) + BH^{C}\left(\frac{No}{N}\right)^{2C-1} \quad (1)$$

$$H = \max\{CL, TW\} - HW \quad (2)$$

Where

Q: Discharge in cfs;
H: Total static head (TSH);
N: Pump engine speed in rpm;
No: Design pump engine speed in rpm (= 588 rpm);
A, *B* and *C*: Regression coefficients determined through regression analysis (A > 0, B < 0, and C > 1.0).
CL: Discharge pipe outlet centerline elevation;
TW: Tailwater elevation;
HW: Headwater elevation.

For an electric pump with constant speed, $N = N_o$, and Equation (1) becomes

$$Q = A + BH^{C} \quad (3)$$

We conducted rating analysis by nonlinear regression analysis based on the TSH vs. discharge values in **Table 2**. **Figure 4** shows comparison between measured flows and computed flows from the new rating. It illustrates that the developed rating curve fits the tested data well, but it is far away from the measured flows. **Table 4** presents the average absolute relative error (AARE) between measured and computed flows and AARE is 11.7%. This indicates that given a TSH, the rating might overestimate flow through the pump station by 12%. Hence, the developed rating based on the tested data cannot represent real flow capacity of the pumps.

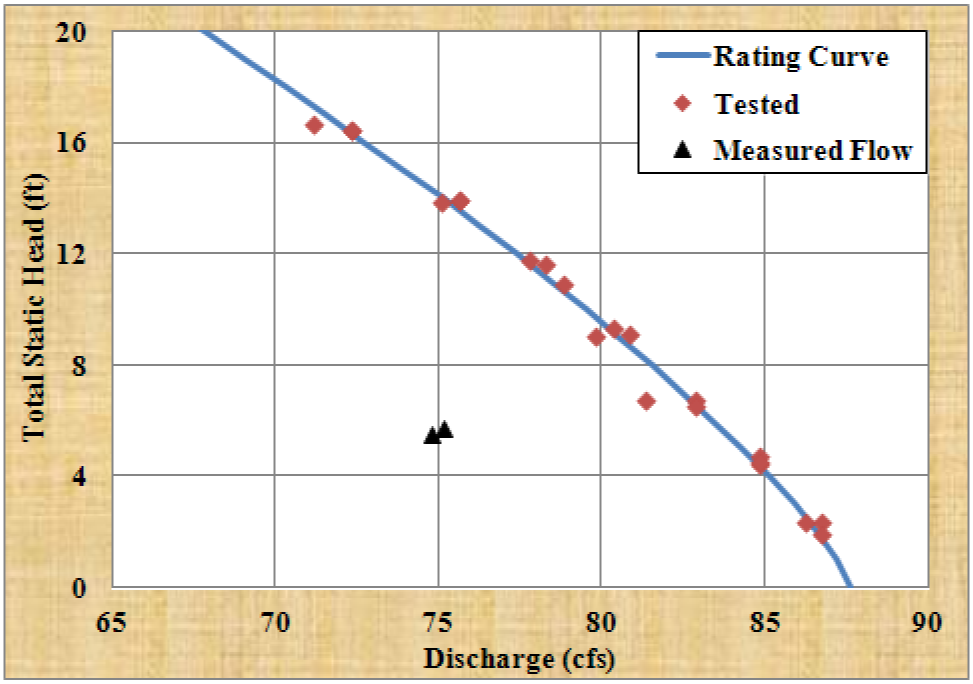

Figure 4. Comparison between measured flows and developed rating

Table 4. Comparison between Measured and Computed Flows

Date	HW Stage (ft, NGVD)	TW Stage (ft, NGVD)	Avg Discharge (cfs)	Computed Flow (cfs)	ARE (%)
2/23/2012	3.10	8.70	75.2	83.7	11.3
3/7/2012	2.26	7.80	74.8	83.8	12.0
AARE (%)					**11.7**

Each of the three pumps at Pump Station S199 has design capacity of 75 cfs. Our measured flow rates were close to design capacity of the pump station when all three pumps were running. Quality of the flow measurements are good and reliable based on our engineering judgment. In order to calculate flow with reasonable accuracy, we need to shift the developed rating curve close to the measured flows. We shifted the developed rating curve using Eq. (1) by giving lower engine speed, i.e., N = 530 rpm and got the shifted curve which is in parallel with the original one. **Table 5 presents** TSH vs. discharge values from the shifted rating. We then conducted non-linear regression analysis on the shifted TSH vs. discharge in **Table 5** to estimate rating coefficients in Equation (3). **Table 6** provides the flow rating equation coefficients of Eq. (3).

Table 5. TSH and Discharge from Shifted Rating Curve

Total Static Head (ft)	Discharge (cfs)
0.0	79.439
0.5	79.238
1.0	78.950
1.5	78.615
2.0	78.245
3.0	77.428
4.0	76.527
5.0	75.558
6.0	74.532
7.0	73.455
8.0	72.333
9.0	71.170
10.0	69.969
11.0	68.733
12.0	67.464
13.0	66.165

Table 6. Flow Rating Coefficients for Pump Station S199

Rating Coefficient	Estimate	Approximate Lower 95% Confidence Limit	Approximate Upper 95% Confidence Limit
A	79.4386	79.4382	79.4389
B	-0.4889	-0.4890	-0.4887
C	1.2871	1.2870	1.2872

Figure 5 illustrates the developed rating curve for the pumps at Pump Station S199. The diagram illustrate that the rating curve from the developed rating equation well fits both the shifted data and measured flows. **Table 7** presents the relative errors between tested and calculated flows, and the AARE between tested and calculated flows is 0.3%. These results indicate that the developed rating can represent the relationship between total static head and discharge of the pump station.

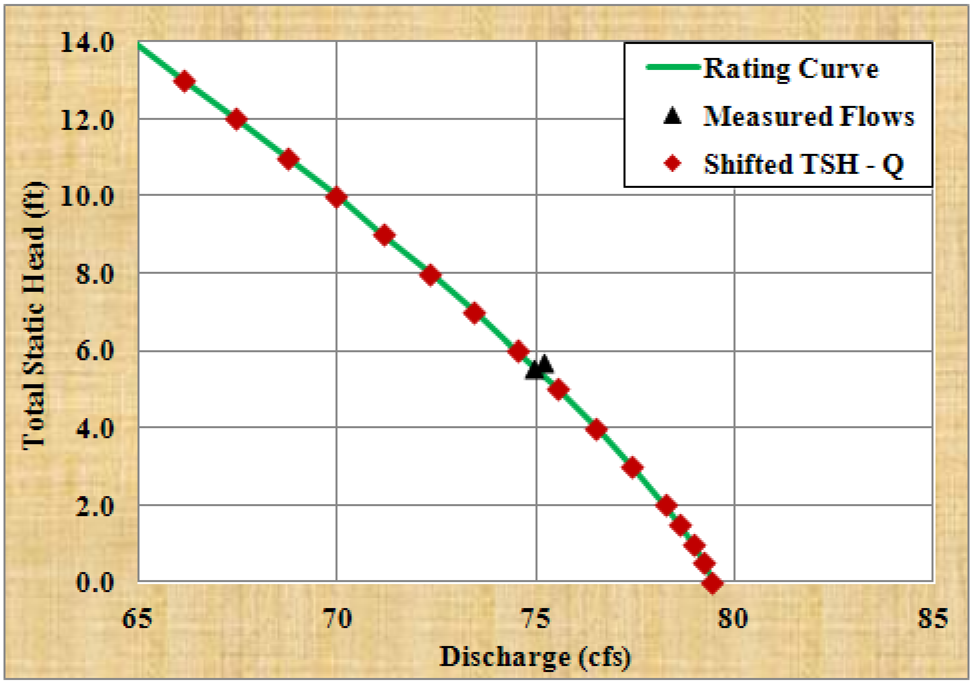

Figure 5. Rating Curve for Pump Station S199

Table 7. Comparison between Measured and Computed Flows

Date	HW Stage (ft, NGVD)	TW Stage (ft, NGVD)	Avg Discharge (cfs)	Computed Flow (cfs)	ARE (%)
2/23/2012	3.10	8.70	75.2	74.9	0.4
3/7/2012	2.26	7.80	74.8	75.0	0.2
AARE (%)					**0.3**

4.0 CONCLUDING REMARKS

We conducted rating analysis for Pump Station S199 based on the TSH vs. discharge relationship obtained from the pump performance tests. We then adjusted the rating based on the measured flows. **Table 6** presents the coefficients of the flow rating equation for Pump Station S199. The rating can be used to compute flow through the pump station for now. However, it needs to be further calibrated, and to be potentially improved based on more flow measurements in the future.

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Damisse, E. 2001. Flow rating development for G335 Pump Station in STA-2. Hydrologic Data Management Division, South Florida Water Management District, West Palm Beach, Florida.

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

MWI Corporation, 2011. South Florida Water Management District S-199 & S-200 Pump Stations: Full Size Pump Performance Test, MWI JOB # 10021, Deerfield Beach, Florida.

Appendix A. SN 10018 TDH calculation

Test date	14-Jan-11	pressure gauge height	28.5
Pump Model Description	SEA330	motor full load current (FLA)	328
Pump Serial No	10018	friction k value (pipe)	0.05
Water pump speed	588 rpm	friction k value (for motor region)	4.49
Test pipe ID	41.5 inches	friction k value (for discharge elbow)	0.78

Test Point	pump speed (rpm)	Static Pressure (psi)	Venturi reading ("$H_2$0)	electric power into motor (amps)	electric power into motor (kWs)
1		6.1	32.0	328	168
2		5.0	35.0	317	162
3		4.0	37.5	306	155
4		3.0	39.5	297	146
5		1.9	40.5	286	139
6		1.0	44.0	275	130
7		0.0	45.5	264	121

Vel (ft/sec)	Hv (ft)	pipe pipe friction Hf (ft)	motor region friction Hf (ft)	disch elbow friction Hf (ft)	**Flow (gpm)**	**TDH (ft)**	WHP
7.70	0.92	0.05	4.13	0.72	**32465**	**22.3**	182.5
8.05	1.01	0.05	4.52	0.79	**33952**	**20.3**	173.8
8.34	1.08	0.05	4.84	0.84	**35144**	**18.4**	163.5
8.56	1.14	0.06	5.10	0.89	**36069**	**16.5**	150.1
8.66	1.17	0.06	5.23	0.91	**36523**	**14.1**	130.3
9.03	1.27	0.06	5.68	0.99	**38068**	**12.7**	121.9
9.18	1.31	0.07	5.88	1.02	**38712**	**10.6**	104.1

Appendix B. SN 10019 TDH calculation

Test date	14-Jan-11	pressure gauge height	28
Pump Model Description	SEA330	motor full load current (FLA)	328
Pump Serial No	10019	friction k value (pipe)	0.05
Water pump speed	588 rpm	friction k value (for motor region)	4.49
Test pipe ID	41.5 inches	friction k value (for discharge elbow)	0.78

Test Point	pump speed (rpm)	Static Pressure (psi)	Venturi reading ("$H_2$0)	electric power into motor (amps)	electric power into motor (kWs)
1		6.2	31.0	328	168
2		5.0	34.5	312	158
3		4.1	37.0	306	151
4		2.9	39.0	292	144
5		1.9	42.0	282	136
6		0.9	44.0	273	127
7		0.0	46.0	259	118

Vel (ft/sec)	Hv (ft)	pipe pipe friction Hf (ft)	motor region friction Hf (ft)	disch elbow friction Hf (ft)	**Flow (gpm)**	**TDH (ft)**	WHP
7.58	0.89	0.04	4.00	0.70	**31953**	**22.2**	178.8
8.00	0.99	0.05	4.46	0.77	**33709**	**20.1**	171.4
8.28	1.06	0.05	4.78	0.83	**34909**	**18.5**	163.3
8.50	1.12	0.06	5.04	0.88	**35840**	**16.1**	145.8
8.82	1.21	0.06	5.43	0.94	**37193**	**14.4**	134.8
9.03	1.27	0.06	5.68	0.99	**38068**	**12.4**	119.3
9.23	1.32	0.07	5.94	1.03	**38924**	**10.7**	105.2

Appendix C. SN 10020 TDH calculation

Test date	21-Jan-11		
Pump Model Description	SEA330		
Pump Serial No	10020		
Water pump speed	588	rpm	
Test pipe ID	41.5	inches	

pressure gauge height	26
motor full load current (FLA)	328
friction k value (pipe)	0.05
friction k value (for motor region)	4.49
friction k value (for discharge elbow)	0.78

Test Point	pump speed (rpm)	Static Pressure (psi)	Venturi reading ("$H_2$0)	electric power into motor (amps)	(kWs)
1		6.2	32.0	336	175
2		5.1	35.0	328	166
3		3.8	38.0	312	158
4		3.0	40.0	304	152
5		1.9	42.0	293	146
6		1.0	44.0	283	136
7		-0.1	46.0	269	126

Vel (ft/sec)	Hv (ft)	pipe pipe friction Hf (ft)	motor region friction Hf (ft)	disch elbow friction Hf (ft)	**Flow (gpm)**	**TDH (ft)**	WHP
7.70	0.92	0.05	4.13	0.72	**32465**	**22.2**	181.8
8.05	1.01	0.05	4.52	0.79	**33952**	**20.3**	174.0
8.39	1.09	0.05	4.91	0.85	**35378**	**17.8**	159.4
8.61	1.15	0.06	5.17	0.90	**36297**	**16.4**	150.0
8.82	1.21	0.06	5.43	0.94	**37193**	**14.2**	133.2
9.03	1.27	0.06	5.68	0.99	**38068**	**12.5**	119.9
9.23	1.32	0.07	5.94	1.03	**38924**	**10.3**	101.2