Flow Rating Analysis for Pump Station S-332C
IOP Emergency Pump Station, C-111 Basin

Technical Publication ERA # 449

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Executive Summary

A rating analysis of S-332C was carried out using the conventional case 8 model. The model equation was fit to the performance curve that depicts the TSH vs discharge relationship for each installed pump type. Flows computed with each equation agree with those obtained from its respective performance curve to within 0.2%. Furthermore, errors in computed flows resulting from uncertainties in computed head losses were estimated to be about 2% or less.

Despite these favorable results, it is recommended that the rating equations be compared with measured flows. Because of the hydraulic conditions at the downstream end of the discharge piping, it is suggested that an ADFM be used to monitor discharges. Furthermore, if feasible, it is recommended that head losses within the discharge piping be measured under a variety of discharges in order to evaluate pipe roughness under field conditions.

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Introduction

Pump station S-332C is a component of Alternative 7R for the Interim Operational Plan (IOP) within the C-111 basin. Its functional purposes are similar to those of S-332B in that it transfers water from the C-111 borrow canal to a detention basin located within the eastern ENP. It is equipped with 5 vertical, axial-flow pumps manufactured by the MWI / Couch company and mounted on an outdoor platform. Four are driven by Catepillar model 3406E diesel engines with a nominal design speed of 1800 RPM. The fifth is driven by an electric US Motors engine with a nominal speed of 1800 RPM. The discharge pipes for all pumps extend approximately one half a mile into the ENP and terminate at the associated detention reservoir.

Objectives and Scope

The primary purpose of the rating analyses conducted in this study is to enable flows through S-332C to be estimated using measured head water elevations, tail water elevations and pump engine speeds. A secondary objective is to estimate the range of expected pipeline velocities in order to help ensure that the most appropriate flow measurement equipment is used. The hydraulic rating equations are based on pump performance characteristics, hydraulic properties of the pump station piping and appurtenances, and sound engineering principles. Since S-332C is relatively new and has not yet been acquired by the District, no flow measurements were available for calibrating the rating equations.

Station Design

The diesel engine-driven pumps are of model number NW342x48 with an impeller diameter of 42 inches and a design speed of 404 RPM. The electric engine-driven pump is of model number NW330x48 with an impeller diameter of 30 inches and a design speed of 620 RPM. A conceptual cross section of a diesel engine-driven pump along with its discharge conduit is shown in figure 1. The corresponding cross section for the electric engine-driven pump is similar. Figure 2 provides detailed plan and profile views of the discharge piping that connects the pump station with the detention reservoir. Each pump discharges directly to about 60 feet of steel pipe that is connected at its downstream end to about one half mile of CMP. Each of these conduits terminates in a concrete outlet structure that is open to the reservoir (figure 3). Table 1 contains the relevant specifications of the station piping and appurtenances while figures 4 contain the pump performance curves. The Darcy-Weisbach friction factor values for the CMP were derived from the estimated range of Manning's n values shown in figure B-3 of HDS 5 (FHWA, 1985). Appendix A contains the associated calculations. These friction values appear to agree with those provided by FHWA (1980).

Rating Analysis

The procedure implemented here for developing the rating curves reflects the standard procedure presented by Imru and Wang (2004). Previous applications of this procedure to other pump

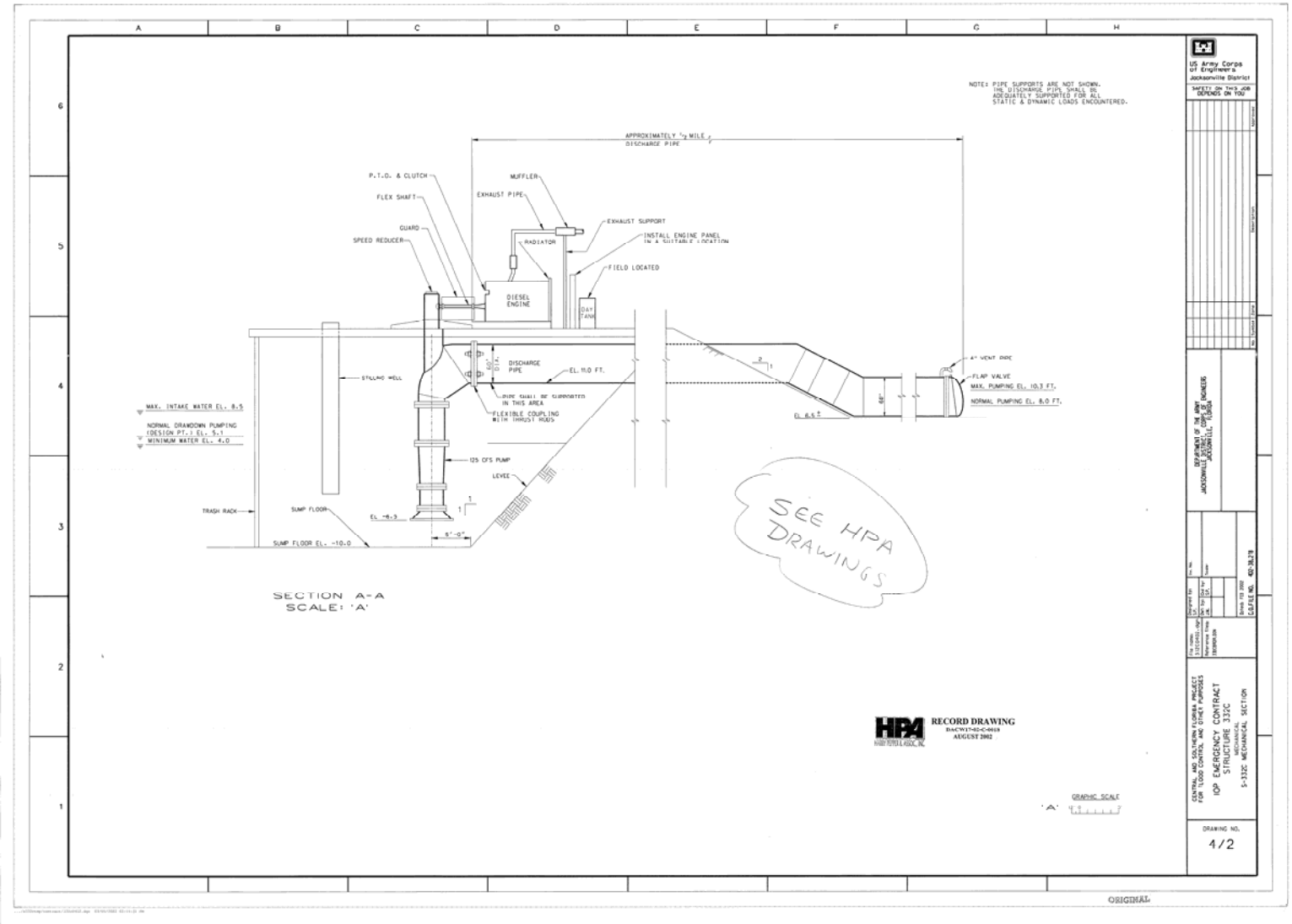

Figure 1. Conceptual cross section of S-332C pumps and discharge piping

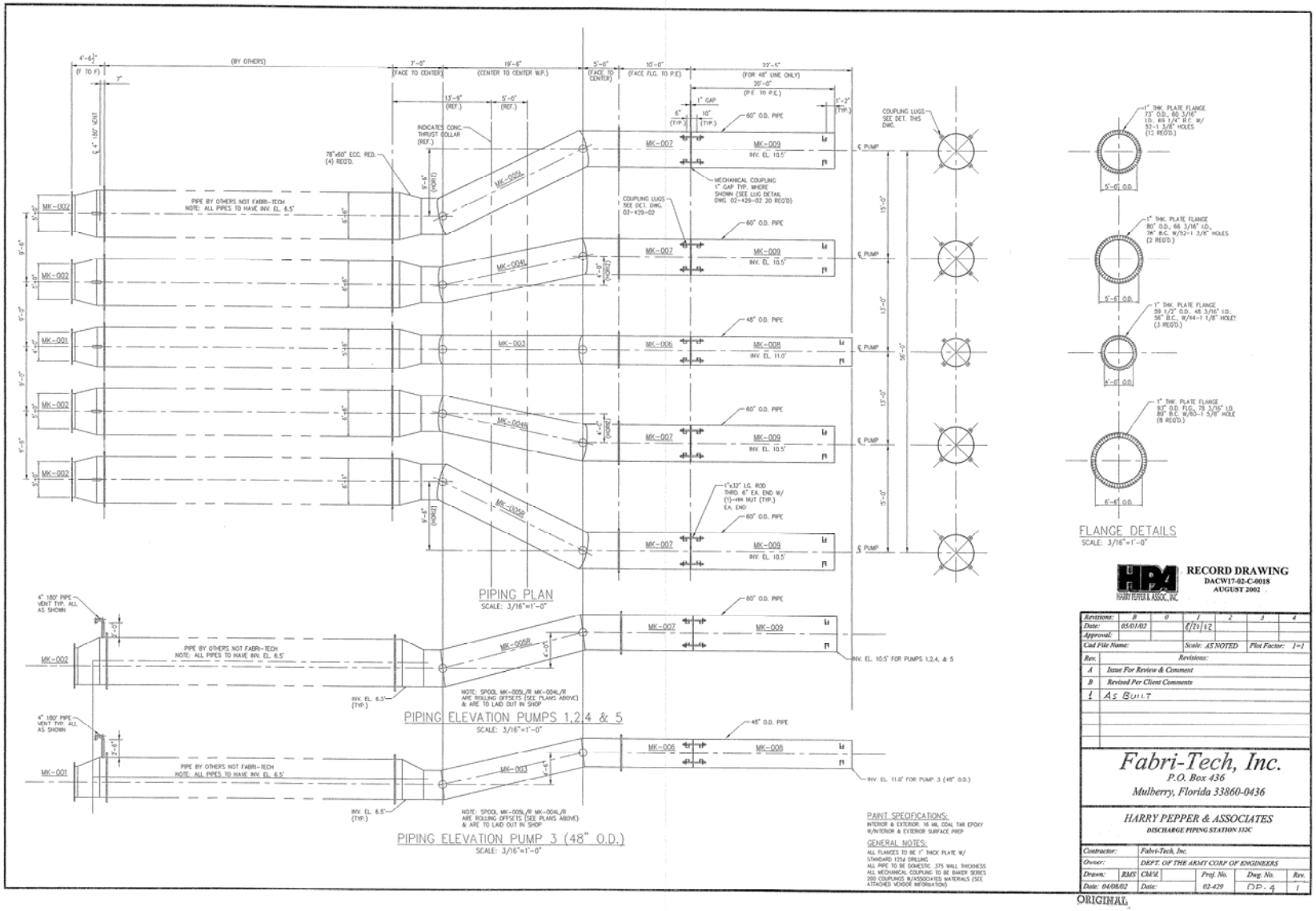

Figure 2. Plan and profile views of the discharge conduits

Figure 3. S-332C outlet structure at the detention reservoir

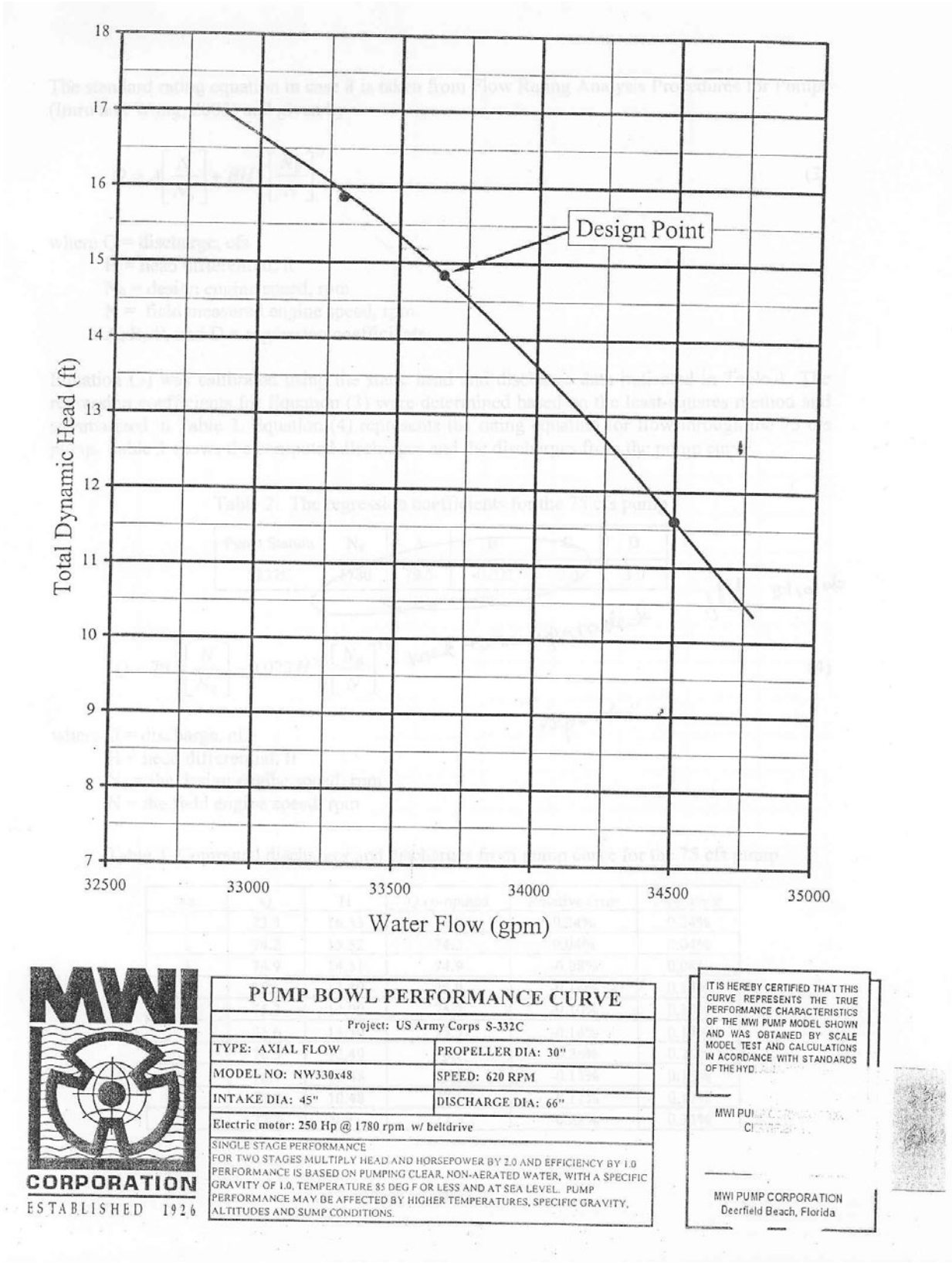

Figure 4a. Pump performance curves for the electric motor-driven pump

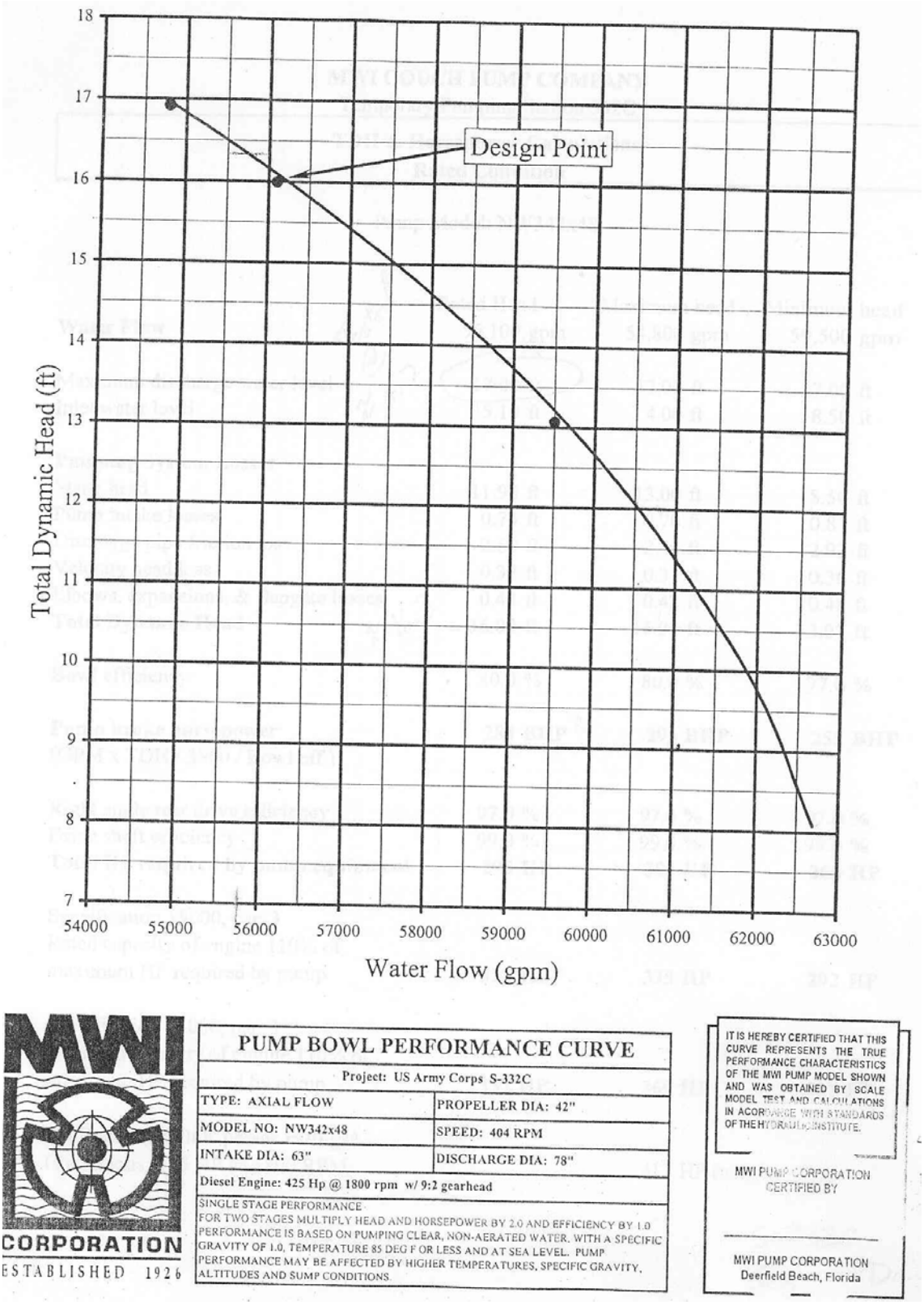

Figure 4b. Pump performance curves for the diesel engine-driven pump

Table 1. Hydraulic properties of S-332C discharge piping

Pipe	Parameter	Diesel Pumps			Electric Pump			*Source*
STEEL	length (ft)	62			62			*record dwgs*
	O.D. (in)	60			48			*record dwgs*
	wall thickn (in)	0.375			0.375			*Sanks (1989)*
	I.D. (ft)	4.9375			3.9375			----------
	Area (sqft)	19.15			12.18			----------
	ε (min) (ft)	0.00015			0.00015			*Hyd Inst (1990)*
	ε (max) (ft)	0.0006			0.0006			*Sanks (1989), C=130*
		#	K_{min}	K_{max}	#	K_{min}	K_{max}	
	25° miter bnd	2	0.066	0.154	0	0.066	0.154	*Hyd Inst (1990)*
	12.5^o miter bnd	2	0.042	0.062	2	0.042	0.062	*Hyd Inst (1990)*
	enlgr @ us end	1	0.19	0.57	0	0	0	*Hyd Inst (1990)*
	enlgr @ ds end	1	0.45	1.35	1	0.45	1.35	*Hyd Inst (1990)*
CMP	length (ft)	2050			2050			*record dwgs*
	I.D. (ft)	6.5			5.5			*record dwgs*
	Area (sqft)	33.18			23.76			----------
	f (min)	0.052	(fully turbulent)		0.055	(fully turbulent)		*HDS 5, fig B3; see calcs*
	f (max)	0.078	(fully turbulent)		0.082	(fully turbulent)		
		#	K_{min}	K_{max}	#	K_{min}	K_{max}	
	reducr @ ds end	1	0.02	0.04	1	0.02	0.04	*Sanks (1989)*
	exit	1	1	1	1	1	1	----------

station rating analyses are explained in detail by Wilsnack and Li (2006). The model rating equation applied to S-332C is the standard case 8 model:

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

Where Q is the discharge at a speed of N RPM, H is the TSH, N_O is the design engine or pump speed, and A, B and C are coefficients to be determined through regression. The form of this expression was determined through dimensional analysis and is based on the pump affinity laws. For pumps driven by electric motors, N_O = N so the ratios involving these parameters are eliminated.

As indicated previously, there are no discharge measurements available, so the objective was to fit equation (1) to the *pump station* performance curves (i.e. the static head versus discharge relationships). These were obtained as usual from the manufacturer's pump performance curves by subtracting the head losses associated with a given discharge rate from the corresponding value of TDH. The results are shown in figures 5. Several pump station performance curves were computed to evaluate the effects of uncertainties in the head loss calculations. The supporting calculations are provided in appendix B. Using the PROC NLIN procedure of SAS, equation (1) was fit to each of the curves in figures 5 depicting average head losses. The resultant coefficients

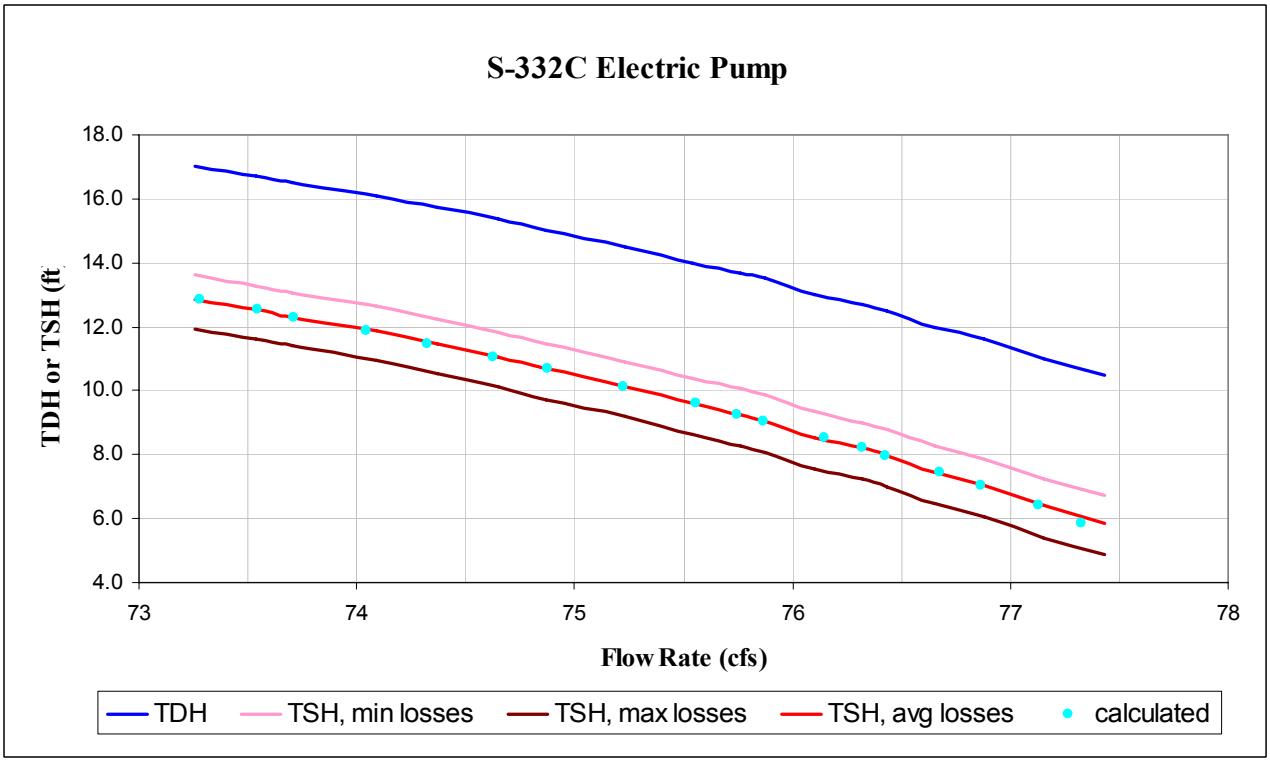

Figure 5a. Pump performance curves for the electric motor-driven pump

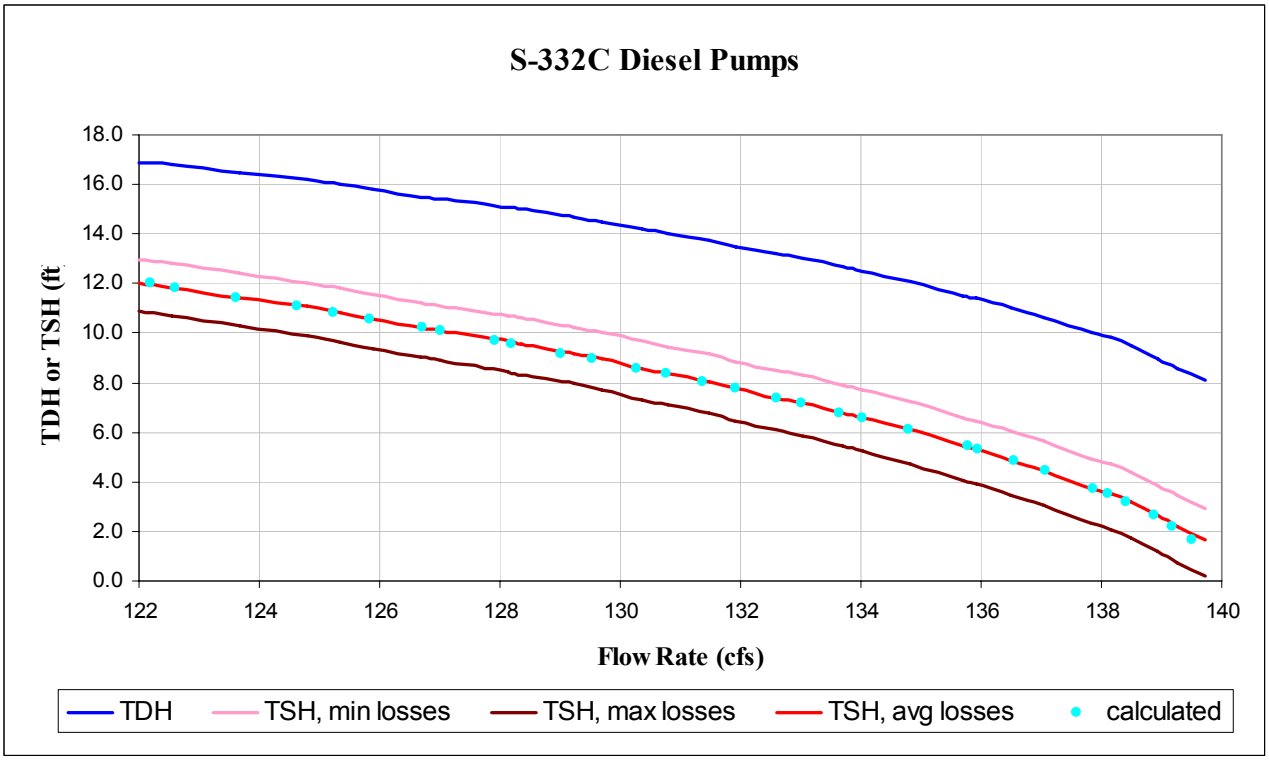

Figure 5b. Pump performance curves for the diesel engine-driven pump

are provided in table 2 while computed flow rates are shown in figures 5. It should also be noted that the pump station performance curves shown in figures 5 indicate that the uncertainty in flow rate due to uncertainties in computed head losses is less than about 2% of the flow rate.

Table 2. Values of the rating equation parameters for the S-332 pumps

Parameter		Electric Pump	Diesel Pump
A	*lower limit, approx. 95% C.I.*	78.177	139.9
	estimated value	78.380	140.0
	upper limit, approx. 95% C.I	78.583	140.2
B	*lower limit, approx. 95% C.I.*	-0.0416	-0.213
	estimated value	-0.0298	-0.195
	upper limit, approx. 95% C.I	-0.0179	-0.176
C	*lower limit, approx. 95% C.I.*	1.871	1.781
	estimated value	2.014	1.818
	upper limit, approx. 95% C.I	2.156	1.855

Discharge and Velocity Ranges

In order to estimate the expected range of operating conditions, system performance curves were computed for the expected minimum and maximum head losses and are plotted in figures 6. Associated with these head losses are estimated minimum, average and maximum static heads of 1, 2.9 and 5.4 feet NGVD, respectively. These static heads were based on information provided in the record drawings and the Interim Operational Plan under storm conditions.

Within the estimated range of static heads, it is evident that discharges through the 78-inch CMP could range from about 134 cfs to somewhere around 140 cfs, although the upper limit cannot be accurately estimated due to the upper discharge limit of the pump performance curve. According to figure 6b, the diesel engine-driven pumps will most likely operate at a discharge rate of about 139 cfs. This is approximately 11% higher than the design discharge rate of 125 cfs. The corresponding velocity is 4.2 ft/s. Similarly, figure 6a suggests that discharges through the 66-inch CMP will be at least 77 cfs while the upper limit cannot be determined. Furthermore, the expected operating point for the electric engine-driven pump cannot be determined due to the upper discharge limit of the pump performance curve. Apparently, this pump will discharge at a rate somewhat greater the rated value of 75 cfs. Hence, the pump station operating characteristics shown in figures 6 indicate that the pumps will operate at points near the extreme right ends of their performance curves.

Stream Gauging Data Needs

Given the absence of any discharge measurements, the flow data needs can be easily summarized as given in table 3 (Hua Li, personal communication). In order to obtain data over all the static head ranges shown, it is possible that some of the flow measurements will have to be obtained during designated pre or post storm conditions.

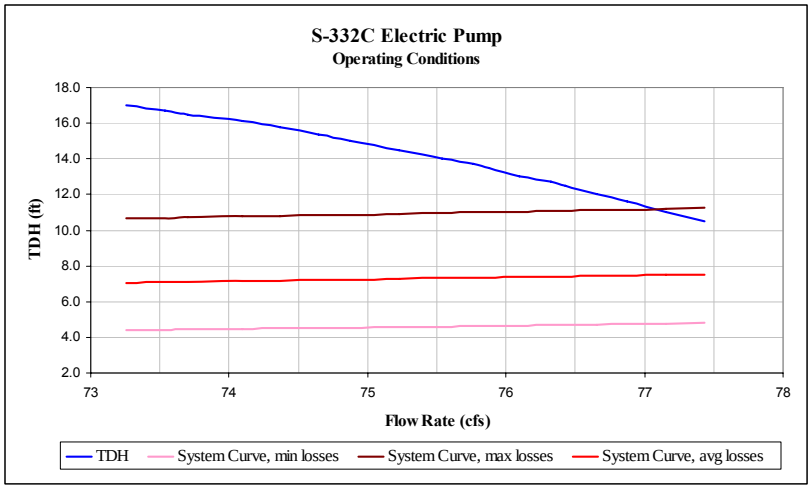

Figure 6a. Operating conditions for the electric motor-driven pump

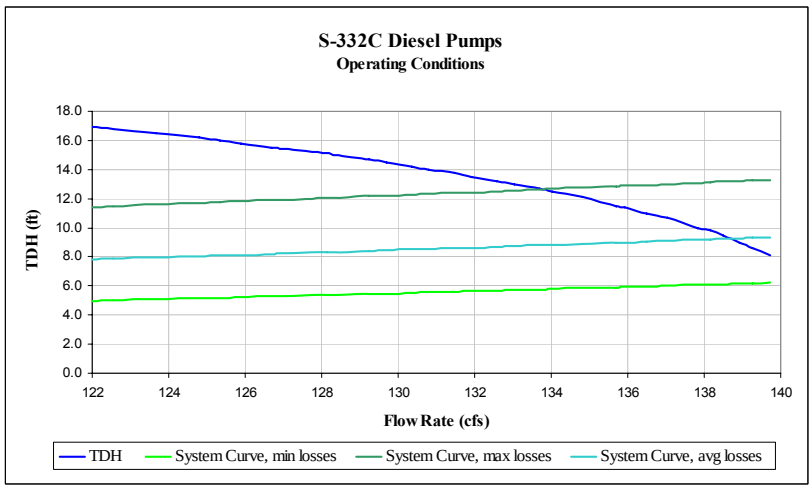

Figure 6b. Operating conditions for the diesel engine-driven pump

Summary and Conclusions

A rating analysis of S-332C was carried out using the conventional case 8 model. The model equation was fit to the performance curve that depicts the TSH vs discharge relationship for each installed pump type. Flows computed with each equation agree with those obtained from its respective performance curve to within 0.2%. Furthermore, errors in computed flows resulting from uncertainties in computed head losses were estimated to be about 2% or less.

Despite these favorable results, it is recommended that the rating equations be compared with measured flows. Because of the hydraulic conditions at the downstream end of the discharge piping, it is suggested that an ADFM be used to monitor discharges. Furthermore, if feasible, it is recommended that head losses within the discharge piping be measured under a variety of discharges in order to evaluate pipe roughness under field conditions.

Table 3. Stream gauging needs for pump station S-332C.

Unit	TSH (ft)	RPM			
		900 - 1200	*1200 - 1500*	*1500 - 1800*	*1800*
Diesel (1,2,4,5)	0~4	*5*	*5*	*5*	
	4~8	*5*	*5*	*5*	
	8~12	*5*	*5*	*5*	
Electric (3)	0~3				*5*
	3~6				*5*
	6~9				*5*

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Appendix A. Estimation of Friction Factors for CMP

South Florida Water Management District
OPERATIONS & HYDRO DATA MANAGEMENT DIVISION

Calculations

Form #0230
Rev.11/97

Project: S-332C RATING ANALYSIS — Sheet No. 1 of 1
Subject: ESTIMATE RANGE OF DARCY-WEISBACH f — Job No. / Program Code:
Engineer: WILSNACK — Date: 3/26/07 Checked By:

$$S_{DW} = \left(\frac{f}{D}\right)\frac{V^2}{2g} \qquad S_M = \frac{185.03}{D^{4/3}} n^2 \left(\frac{V^2}{2g}\right)$$

$$\frac{f}{D}\left(\frac{V^2}{2g}\right) = \frac{185.03}{D^{4/3}} n^2 \left(\frac{V^2}{2g}\right)$$

$$\boxed{f = 185.03 \frac{n^2}{D^{1/3}}}$$

FROM FIGURE B-3 OF HDS 5, THE EXPECTED RANGE OF n CAN BE TAKEN AS $0.023 \leq n \leq 0.028$.

THUS, CAN WRITE

	n=0.023	n=0.028
66" ϕ	f=0.055	f=0.082
78" ϕ	f=0.052	f=0.078

CHECK TYPE OF FLOW:

FOR Q ≈ 75 CFS THRU THE 66" ϕ CMP, $V = \frac{Q}{A} = 3.16$ FT/S. FOR 125 CFS THRU THE 78" CMP, V = 2.26 FT/S. THESE RESULT IN N_R VALUES OF $1.5 - 2\ (\times 10^6)$. ACCORDING TO THE MOODY DIAGRAM, FLOW IS WHOLLY TURBULENT THRU A ROUGH PIPE, SO f CAN BE ASSUMED CONSTANT.

Appendix B. Head Loss Calculations

Table B1a. Minimum head losses associated with the diesel engine-driven pumps

Pump Performance @ 404 RPM			Steel Pipe						CMP							
						Swamee & Jain(1976)						fully turbulent, rough pipe				
TDH (ft)	Q(gpm)	Q(cfs)	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma KV^2/2g$	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma KV^2/2g$	Total Head Loss (ft)	Static Head (ft)
16.90	54750	122.00	6.37	3.15E+06	0.63	0.01091	0.09	0.22	3.68	2.39E+06	0.21	0.05200	3.44	0.22	3.97	12.93
16.80	55000	122.56	6.40	3.16E+06	0.64	0.01091	0.09	0.22	3.69	2.40E+06	0.21	0.05200	3.47	0.22	4.01	12.79
16.50	55500	123.67	6.46	3.19E+06	0.65	0.01090	0.09	0.23	3.73	2.42E+06	0.22	0.05200	3.54	0.23	4.08	12.42
16.20	56000	124.79	6.52	3.22E+06	0.66	0.01089	0.09	0.23	3.76	2.44E+06	0.22	0.05200	3.60	0.23	4.15	12.05
16.00	56250	125.34	6.55	3.23E+06	0.67	0.01089	0.09	0.23	3.78	2.46E+06	0.22	0.05200	3.63	0.23	4.19	11.81
15.80	56500	125.90	6.58	3.25E+06	0.67	0.01089	0.09	0.23	3.79	2.47E+06	0.22	0.05200	3.67	0.24	4.23	11.57
15.50	56850	126.68	6.62	3.27E+06	0.68	0.01088	0.09	0.24	3.82	2.48E+06	0.23	0.05200	3.71	0.24	4.28	11.22
15.40	57000	127.02	6.63	3.28E+06	0.68	0.01088	0.09	0.24	3.83	2.49E+06	0.23	0.05200	3.73	0.24	4.30	11.10
15.10	57500	128.13	6.69	3.30E+06	0.70	0.01087	0.09	0.24	3.86	2.51E+06	0.23	0.05200	3.80	0.24	4.38	10.72
15.00	57600	128.35	6.70	3.31E+06	0.70	0.01087	0.10	0.24	3.87	2.51E+06	0.23	0.05200	3.81	0.25	4.39	10.61
14.70	58000	129.24	6.75	3.33E+06	0.71	0.01086	0.10	0.25	3.89	2.53E+06	0.24	0.05200	3.86	0.25	4.46	10.24
14.50	58200	129.69	6.77	3.34E+06	0.71	0.01086	0.10	0.25	3.91	2.54E+06	0.24	0.05200	3.89	0.25	4.49	10.01
14.20	58500	130.36	6.81	3.36E+06	0.72	0.01086	0.10	0.25	3.93	2.55E+06	0.24	0.05200	3.93	0.25	4.53	9.67
14.00	58700	130.80	6.83	3.37E+06	0.72	0.01085	0.10	0.25	3.94	2.56E+06	0.24	0.05200	3.96	0.26	4.56	9.44
13.75	59000	131.47	6.87	3.39E+06	0.73	0.01085	0.10	0.26	3.96	2.58E+06	0.24	0.05200	4.00	0.26	4.61	9.14
13.50	59200	131.92	6.89	3.40E+06	0.74	0.01085	0.10	0.26	3.98	2.58E+06	0.25	0.05200	4.02	0.26	4.64	8.86
13.20	59500	132.59	6.92	3.42E+06	0.74	0.01084	0.10	0.26	4.00	2.60E+06	0.25	0.05200	4.07	0.26	4.69	8.51
13.00	59700	133.03	6.95	3.43E+06	0.75	0.01084	0.10	0.26	4.01	2.61E+06	0.25	0.05200	4.09	0.26	4.72	8.28
12.70	60000	133.70	6.98	3.45E+06	0.76	0.01083	0.10	0.26	4.03	2.62E+06	0.25	0.05200	4.13	0.27	4.77	7.93
12.50	60150	134.03	7.00	3.46E+06	0.76	0.01083	0.10	0.27	4.04	2.63E+06	0.25	0.05200	4.15	0.27	4.79	7.71
12.10	60500	134.81	7.04	3.48E+06	0.77	0.01083	0.10	0.27	4.06	2.64E+06	0.26	0.05200	4.20	0.27	4.85	7.25
11.50	60900	135.71	7.09	3.50E+06	0.78	0.01082	0.11	0.27	4.09	2.66E+06	0.26	0.05200	4.26	0.27	4.91	6.59
11.40	61000	135.93	7.10	3.51E+06	0.78	0.01082	0.11	0.27	4.10	2.66E+06	0.26	0.05200	4.27	0.28	4.93	6.47
11.00	61250	136.49	7.13	3.52E+06	0.79	0.01082	0.11	0.28	4.11	2.67E+06	0.26	0.05200	4.31	0.28	4.97	6.03
10.65	61500	137.04	7.16	3.53E+06	0.80	0.01081	0.11	0.28	4.13	2.68E+06	0.26	0.05200	4.34	0.28	5.01	5.64
10.00	61850	137.82	7.20	3.55E+06	0.80	0.01081	0.11	0.28	4.15	2.70E+06	0.27	0.05200	4.39	0.28	5.07	4.93
9.80	62000	138.16	7.22	3.56E+06	0.81	0.01081	0.11	0.28	4.16	2.71E+06	0.27	0.05200	4.41	0.28	5.09	4.71
9.50	62150	138.49	7.23	3.57E+06	0.81	0.01080	0.11	0.28	4.17	2.71E+06	0.27	0.05200	4.44	0.29	5.12	4.38
9.00	62350	138.94	7.26	3.58E+06	0.82	0.01080	0.11	0.29	4.19	2.72E+06	0.27	0.05200	4.46	0.29	5.15	3.85
8.60	62500	139.27	7.27	3.59E+06	0.82	0.01080	0.11	0.29	4.20	2.73E+06	0.27	0.05200	4.49	0.29	5.17	3.43
8.10	62700	139.72	7.30	3.60E+06	0.83	0.01080	0.11	0.29	4.21	2.74E+06	0.28	0.05200	4.51	0.29	5.21	2.89

Table B1b. Minimum head losses associated with the electric engine-driven pumps

Pump Performance @ 620 RPM			Steel Pipe						CMP							
						Swamee & Jain(1976)						fully turbulent, rough pipe				
TDH (ft)	Q(gpm)	Q(cfs)	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma KV^2/2g$	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma KV^2/2g$	Total Head Loss (ft)	Static Head (ft)
17.00	32875	73.26	6.02	2.37E+06	0.56	0.01141	0.10	0.11	3.08	1.70E+06	0.15	0.05500	3.03	0.16	3.39	13.61
16.70	33000	73.54	6.04	2.38E+06	0.57	0.01140	0.10	0.11	3.10	1.70E+06	0.15	0.05500	3.05	0.16	3.42	13.28
16.50	33075	73.70	6.05	2.38E+06	0.57	0.01140	0.10	0.11	3.10	1.71E+06	0.15	0.05500	3.06	0.16	3.43	13.07
16.10	33250	74.09	6.08	2.40E+06	0.57	0.01140	0.10	0.11	3.12	1.72E+06	0.15	0.05500	3.10	0.16	3.47	12.63
15.75	33375	74.37	6.11	2.40E+06	0.58	0.01139	0.10	0.11	3.13	1.72E+06	0.15	0.05500	3.12	0.16	3.50	12.25
15.35	33500	74.65	6.13	2.41E+06	0.58	0.01139	0.10	0.11	3.14	1.73E+06	0.15	0.05500	3.14	0.16	3.52	11.83
15.00	33600	74.87	6.15	2.42E+06	0.59	0.01139	0.11	0.11	3.15	1.73E+06	0.15	0.05500	3.16	0.17	3.54	11.46
14.50	33760	75.23	6.18	2.43E+06	0.59	0.01138	0.11	0.11	3.17	1.74E+06	0.16	0.05500	3.19	0.17	3.58	10.92
14.00	33900	75.54	6.20	2.44E+06	0.60	0.01138	0.11	0.11	3.18	1.75E+06	0.16	0.05500	3.22	0.17	3.61	10.39
13.70	34000	75.76	6.22	2.45E+06	0.60	0.01137	0.11	0.11	3.19	1.75E+06	0.16	0.05500	3.24	0.17	3.63	10.07
13.50	34050	75.87	6.23	2.45E+06	0.60	0.01137	0.11	0.12	3.19	1.76E+06	0.16	0.05500	3.25	0.17	3.64	9.86
13.00	34150	76.10	6.25	2.46E+06	0.61	0.01137	0.11	0.12	3.20	1.76E+06	0.16	0.05500	3.27	0.17	3.66	9.34
12.70	34250	76.32	6.27	2.47E+06	0.61	0.01137	0.11	0.12	3.21	1.77E+06	0.16	0.05500	3.28	0.17	3.68	9.02
12.50	34300	76.43	6.28	2.47E+06	0.61	0.01137	0.11	0.12	3.22	1.77E+06	0.16	0.05500	3.29	0.17	3.69	8.81
12.00	34400	76.65	6.30	2.48E+06	0.62	0.01136	0.11	0.12	3.23	1.77E+06	0.16	0.05500	3.31	0.17	3.71	8.29
11.60	34500	76.88	6.31	2.49E+06	0.62	0.01136	0.11	0.12	3.24	1.78E+06	0.16	0.05500	3.33	0.17	3.74	7.86
11.00	34625	77.16	6.34	2.49E+06	0.62	0.01136	0.11	0.12	3.25	1.79E+06	0.16	0.05500	3.36	0.18	3.76	7.24
10.50	34750	77.43	6.36	2.50E+06	0.63	0.01135	0.11	0.12	3.26	1.79E+06	0.16	0.05500	3.38	0.18	3.79	6.71

Table B2a. Maximum head losses associated with the diesel engine-driven pumps

Pump Performance @ 404 RPM			Steel Pipe						CMP							
						Swamee & Jain(1976)						fully turbulent, rough pipe				
TDH (ft)	Q(gpm)	Q(cfs)	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma KV^2/2g$	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma KV^2/2g$	Total Head Loss (ft)	Static Head (ft)
16.90	54750	122.00	6.37	3.15E+06	0.63	0.01299	0.10	0.52	3.68	2.39E+06	0.21	0.07800	5.16	0.23	6.02	10.88
16.80	55000	122.56	6.40	3.16E+06	0.64	0.01299	0.10	0.53	3.69	2.40E+06	0.21	0.07800	5.21	0.24	6.08	10.72
16.50	55500	123.67	6.46	3.19E+06	0.65	0.01298	0.11	0.54	3.73	2.42E+06	0.22	0.07800	5.31	0.24	6.19	10.31
16.20	56000	124.79	6.52	3.22E+06	0.66	0.01298	0.11	0.55	3.76	2.44E+06	0.22	0.07800	5.40	0.24	6.30	9.90
16.00	56250	125.34	6.55	3.23E+06	0.67	0.01298	0.11	0.55	3.78	2.46E+06	0.22	0.07800	5.45	0.25	6.36	9.64
15.80	56500	125.90	6.58	3.25E+06	0.67	0.01297	0.11	0.56	3.79	2.47E+06	0.22	0.07800	5.50	0.25	6.41	9.39
15.50	56850	126.68	6.62	3.27E+06	0.68	0.01297	0.11	0.56	3.82	2.48E+06	0.23	0.07800	5.57	0.25	6.49	9.01
15.40	57000	127.02	6.63	3.28E+06	0.68	0.01297	0.11	0.57	3.83	2.49E+06	0.23	0.07800	5.60	0.25	6.53	8.87
15.10	57500	128.13	6.69	3.30E+06	0.70	0.01297	0.11	0.58	3.86	2.51E+06	0.23	0.07800	5.70	0.26	6.64	8.46
15.00	57600	128.35	6.70	3.31E+06	0.70	0.01296	0.11	0.58	3.87	2.51E+06	0.23	0.07800	5.72	0.26	6.67	8.33
14.70	58000	129.24	6.75	3.33E+06	0.71	0.01296	0.12	0.59	3.89	2.53E+06	0.24	0.07800	5.79	0.26	6.76	7.94
14.50	58200	129.69	6.77	3.34E+06	0.71	0.01296	0.12	0.59	3.91	2.54E+06	0.24	0.07800	5.83	0.26	6.81	7.69
14.20	58500	130.36	6.81	3.36E+06	0.72	0.01296	0.12	0.60	3.93	2.55E+06	0.24	0.07800	5.90	0.27	6.88	7.32
14.00	58700	130.80	6.83	3.37E+06	0.72	0.01296	0.12	0.60	3.94	2.56E+06	0.24	0.07800	5.94	0.27	6.92	7.08
13.75	59000	131.47	6.87	3.39E+06	0.73	0.01295	0.12	0.61	3.96	2.58E+06	0.24	0.07800	6.00	0.27	6.99	6.76
13.50	59200	131.92	6.89	3.40E+06	0.74	0.01295	0.12	0.61	3.98	2.58E+06	0.25	0.07800	6.04	0.27	7.04	6.46
13.20	59500	132.59	6.92	3.42E+06	0.74	0.01295	0.12	0.62	4.00	2.60E+06	0.25	0.07800	6.10	0.28	7.11	6.09
13.00	59700	133.03	6.95	3.43E+06	0.75	0.01295	0.12	0.62	4.01	2.61E+06	0.25	0.07800	6.14	0.28	7.16	5.84
12.70	60000	133.70	6.98	3.45E+06	0.76	0.01295	0.12	0.63	4.03	2.62E+06	0.25	0.07800	6.20	0.28	7.23	5.47
12.50	60150	134.03	7.00	3.46E+06	0.76	0.01295	0.12	0.63	4.04	2.63E+06	0.25	0.07800	6.23	0.28	7.27	5.23
12.10	60500	134.81	7.04	3.48E+06	0.77	0.01294	0.13	0.64	4.06	2.64E+06	0.26	0.07800	6.30	0.29	7.35	4.75
11.50	60900	135.71	7.09	3.50E+06	0.78	0.01294	0.13	0.65	4.09	2.66E+06	0.26	0.07800	6.39	0.29	7.45	4.05
11.40	61000	135.93	7.10	3.51E+06	0.78	0.01294	0.13	0.65	4.10	2.66E+06	0.26	0.07800	6.41	0.29	7.48	3.92
11.00	61250	136.49	7.13	3.52E+06	0.79	0.01294	0.13	0.65	4.11	2.67E+06	0.26	0.07800	6.46	0.29	7.54	3.46
10.65	61500	137.04	7.16	3.53E+06	0.80	0.01294	0.13	0.66	4.13	2.68E+06	0.26	0.07800	6.52	0.30	7.60	3.05
10.00	61850	137.82	7.20	3.55E+06	0.80	0.01293	0.13	0.67	4.15	2.70E+06	0.27	0.07800	6.59	0.30	7.69	2.31
9.80	62000	138.16	7.22	3.56E+06	0.81	0.01293	0.13	0.67	4.16	2.71E+06	0.27	0.07800	6.62	0.30	7.72	2.08
9.50	62150	138.49	7.23	3.57E+06	0.81	0.01293	0.13	0.67	4.17	2.71E+06	0.27	0.07800	6.65	0.30	7.76	1.74
9.00	62350	138.94	7.26	3.58E+06	0.82	0.01293	0.13	0.68	4.19	2.72E+06	0.27	0.07800	6.70	0.30	7.81	1.19
8.60	62500	139.27	7.27	3.59E+06	0.82	0.01293	0.13	0.68	4.20	2.73E+06	0.27	0.07800	6.73	0.30	7.85	0.75
8.10	62700	139.72	7.30	3.60E+06	0.83	0.01293	0.13	0.69	4.21	2.74E+06	0.28	0.07800	6.77	0.31	7.90	0.20

Table B2b. Maximum head losses associated with the electric engine-driven pumps

Pump Performance @ 620 RPM			Steel Pipe						CMP							
						Swamee & Jain(1976)						fully turbulent, rough pipe				
TDH (ft)	Q(gpm)	Q(cfs)	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma KV^2/2g$	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma KV^2/2g$	Total Head Loss (ft)	Static Head (ft)
17.00	32875	73.26	6.02	2.37E+06	0.56	0.01361	0.12	0.25	3.08	1.70E+06	0.15	0.08200	4.51	0.17	5.05	11.95
16.70	33000	73.54	6.04	2.38E+06	0.57	0.01360	0.12	0.25	3.10	1.70E+06	0.15	0.08200	4.55	0.17	5.09	11.61
16.50	33075	73.70	6.05	2.38E+06	0.57	0.01360	0.12	0.25	3.10	1.71E+06	0.15	0.08200	4.57	0.17	5.11	11.39
16.10	33250	74.09	6.08	2.40E+06	0.57	0.01360	0.12	0.26	3.12	1.72E+06	0.15	0.08200	4.62	0.17	5.17	10.93
15.75	33375	74.37	6.11	2.40E+06	0.58	0.01360	0.12	0.26	3.13	1.72E+06	0.15	0.08200	4.65	0.17	5.21	10.54
15.35	33500	74.65	6.13	2.41E+06	0.58	0.01360	0.12	0.26	3.14	1.73E+06	0.15	0.08200	4.69	0.18	5.25	10.10
15.00	33600	74.87	6.15	2.42E+06	0.59	0.01360	0.13	0.26	3.15	1.73E+06	0.15	0.08200	4.71	0.18	5.28	9.72
14.50	33760	75.23	6.18	2.43E+06	0.59	0.01359	0.13	0.26	3.17	1.74E+06	0.16	0.08200	4.76	0.18	5.33	9.17
14.00	33900	75.54	6.20	2.44E+06	0.60	0.01359	0.13	0.27	3.18	1.75E+06	0.16	0.08200	4.80	0.18	5.37	8.63
13.70	34000	75.76	6.22	2.45E+06	0.60	0.01359	0.13	0.27	3.19	1.75E+06	0.16	0.08200	4.83	0.18	5.40	8.30
13.50	34050	75.87	6.23	2.45E+06	0.60	0.01359	0.13	0.27	3.19	1.76E+06	0.16	0.08200	4.84	0.18	5.42	8.08
13.00	34150	76.10	6.25	2.46E+06	0.61	0.01359	0.13	0.27	3.20	1.76E+06	0.16	0.08200	4.87	0.18	5.45	7.55
12.70	34250	76.32	6.27	2.47E+06	0.61	0.01359	0.13	0.27	3.21	1.77E+06	0.16	0.08200	4.90	0.18	5.48	7.22
12.50	34300	76.43	6.28	2.47E+06	0.61	0.01358	0.13	0.27	3.22	1.77E+06	0.16	0.08200	4.91	0.18	5.50	7.00
12.00	34400	76.65	6.30	2.48E+06	0.62	0.01358	0.13	0.27	3.23	1.77E+06	0.16	0.08200	4.94	0.18	5.53	6.47
11.60	34500	76.88	6.31	2.49E+06	0.62	0.01358	0.13	0.28	3.24	1.78E+06	0.16	0.08200	4.97	0.19	5.56	6.04
11.00	34625	77.16	6.34	2.49E+06	0.62	0.01358	0.13	0.28	3.25	1.79E+06	0.16	0.08200	5.01	0.19	5.60	5.40
10.50	34750	77.43	6.36	2.50E+06	0.63	0.01358	0.13	0.28	3.26	1.79E+06	0.16	0.08200	5.04	0.19	5.64	4.86

Table B3a. Average head losses associated with the diesel engine-driven pumps

Pump Performance @ 404 RPM			Steel Pipe						CMP							
						Swamee & Jain(1976)						fully turbulent, rough pipe				
TDH (ft)	Q(gpm)	Q(cfs)	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma KV^2/2g$	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma KV^2/2g$	Total Head Loss (ft)	Static Head (ft)
16.90	54750	122.00	6.37	3.15E+06	0.63	0.01191	0.09	0.37	3.68	2.39E+06	0.21	0.06369	4.22	0.23	4.91	11.99
16.80	55000	122.56	6.40	3.16E+06	0.64	0.01190	0.10	0.37	3.69	2.40E+06	0.21	0.06369	4.25	0.23	4.95	11.85
16.50	55500	123.67	6.46	3.19E+06	0.65	0.01190	0.10	0.38	3.73	2.42E+06	0.22	0.06369	4.33	0.23	5.04	11.46
16.20	56000	124.79	6.52	3.22E+06	0.66	0.01189	0.10	0.39	3.76	2.44E+06	0.22	0.06369	4.41	0.24	5.14	11.06
16.00	56250	125.34	6.55	3.23E+06	0.67	0.01189	0.10	0.39	3.78	2.46E+06	0.22	0.06369	4.45	0.24	5.18	10.82
15.80	56500	125.90	6.58	3.25E+06	0.67	0.01188	0.10	0.40	3.79	2.47E+06	0.22	0.06369	4.49	0.24	5.23	10.57
15.50	56850	126.68	6.62	3.27E+06	0.68	0.01188	0.10	0.40	3.82	2.48E+06	0.23	0.06369	4.55	0.25	5.29	10.21
15.40	57000	127.02	6.63	3.28E+06	0.68	0.01188	0.10	0.40	3.83	2.49E+06	0.23	0.06369	4.57	0.25	5.32	10.08
15.10	57500	128.13	6.69	3.30E+06	0.70	0.01187	0.10	0.41	3.86	2.51E+06	0.23	0.06369	4.65	0.25	5.41	9.69
15.00	57600	128.35	6.70	3.31E+06	0.70	0.01187	0.10	0.41	3.87	2.51E+06	0.23	0.06369	4.67	0.25	5.43	9.57
14.70	58000	129.24	6.75	3.33E+06	0.71	0.01187	0.11	0.42	3.89	2.53E+06	0.24	0.06369	4.73	0.26	5.51	9.19
14.50	58200	129.69	6.77	3.34E+06	0.71	0.01186	0.11	0.42	3.91	2.54E+06	0.24	0.06369	4.76	0.26	5.55	8.95
14.20	58500	130.36	6.81	3.36E+06	0.72	0.01186	0.11	0.42	3.93	2.55E+06	0.24	0.06369	4.81	0.26	5.60	8.60
14.00	58700	130.80	6.83	3.37E+06	0.72	0.01186	0.11	0.43	3.94	2.56E+06	0.24	0.06369	4.85	0.26	5.64	8.36
13.75	59000	131.47	6.87	3.39E+06	0.73	0.01185	0.11	0.43	3.96	2.58E+06	0.24	0.06369	4.90	0.26	5.70	8.05
13.50	59200	131.92	6.89	3.40E+06	0.74	0.01185	0.11	0.43	3.98	2.58E+06	0.25	0.06369	4.93	0.27	5.74	7.76
13.20	59500	132.59	6.92	3.42E+06	0.74	0.01185	0.11	0.44	4.00	2.60E+06	0.25	0.06369	4.98	0.27	5.80	7.40
13.00	59700	133.03	6.95	3.43E+06	0.75	0.01185	0.11	0.44	4.01	2.61E+06	0.25	0.06369	5.01	0.27	5.84	7.16
12.70	60000	133.70	6.98	3.45E+06	0.76	0.01184	0.11	0.45	4.03	2.62E+06	0.25	0.06369	5.06	0.27	5.90	6.80
12.50	60150	134.03	7.00	3.46E+06	0.76	0.01184	0.11	0.45	4.04	2.63E+06	0.25	0.06369	5.09	0.28	5.93	6.57
12.10	60500	134.81	7.04	3.48E+06	0.77	0.01184	0.11	0.45	4.06	2.64E+06	0.26	0.06369	5.15	0.28	5.99	6.11
11.50	60900	135.71	7.09	3.50E+06	0.78	0.01183	0.12	0.46	4.09	2.66E+06	0.26	0.06369	5.22	0.28	6.07	5.43
11.40	61000	135.93	7.10	3.51E+06	0.78	0.01183	0.12	0.46	4.10	2.66E+06	0.26	0.06369	5.23	0.28	6.09	5.31
11.00	61250	136.49	7.13	3.52E+06	0.79	0.01183	0.12	0.46	4.11	2.67E+06	0.26	0.06369	5.28	0.29	6.14	4.86
10.65	61500	137.04	7.16	3.53E+06	0.80	0.01183	0.12	0.47	4.13	2.68E+06	0.26	0.06369	5.32	0.29	6.19	4.46
10.00	61850	137.82	7.20	3.55E+06	0.80	0.01182	0.12	0.47	4.15	2.70E+06	0.27	0.06369	5.38	0.29	6.26	3.74
9.80	62000	138.16	7.22	3.56E+06	0.81	0.01182	0.12	0.48	4.16	2.71E+06	0.27	0.06369	5.41	0.29	6.30	3.50
9.50	62150	138.49	7.23	3.57E+06	0.81	0.01182	0.12	0.48	4.17	2.71E+06	0.27	0.06369	5.43	0.29	6.33	3.17
9.00	62350	138.94	7.26	3.58E+06	0.82	0.01182	0.12	0.48	4.19	2.72E+06	0.27	0.06369	5.47	0.30	6.37	2.63
8.60	62500	139.27	7.27	3.59E+06	0.82	0.01182	0.12	0.48	4.20	2.73E+06	0.27	0.06369	5.49	0.30	6.40	2.20
8.10	62700	139.72	7.30	3.60E+06	0.83	0.01181	0.12	0.49	4.21	2.74E+06	0.28	0.06369	5.53	0.30	6.44	1.66

Table B3b. Average head losses associated with the electric engine-driven pumps

Pump Performance @ 620 RPM			Steel Pipe						CMP							
						Swamee & Jain(1976)						fully turbulent, rough pipe				
TDH (ft)	Q(gpm)	Q(cfs)	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma KV^2/2g$	V(ft/s)	N_R	$V^2/2g$ (ft)	f	$h_l = f(L/D)V^2/2g$	$h_m = \Sigma KV^2/2g$	Total Head Loss (ft)	Static Head (ft)
17.00	32875	73.26	6.02	2.37E+06	0.56	0.01246	0.11	0.18	3.08	1.70E+06	0.15	0.06716	3.70	0.16	4.15	12.85
16.70	33000	73.54	6.04	2.38E+06	0.57	0.01245	0.11	0.18	3.10	1.70E+06	0.15	0.06716	3.72	0.16	4.18	12.52
16.50	33075	73.70	6.05	2.38E+06	0.57	0.01245	0.11	0.18	3.10	1.71E+06	0.15	0.06716	3.74	0.17	4.20	12.30
16.10	33250	74.09	6.08	2.40E+06	0.57	0.01245	0.11	0.18	3.12	1.72E+06	0.15	0.06716	3.78	0.17	4.24	11.86
15.75	33375	74.37	6.11	2.40E+06	0.58	0.01245	0.11	0.18	3.13	1.72E+06	0.15	0.06716	3.81	0.17	4.27	11.48
15.35	33500	74.65	6.13	2.41E+06	0.58	0.01244	0.11	0.19	3.14	1.73E+06	0.15	0.06716	3.84	0.17	4.31	11.04
15.00	33600	74.87	6.15	2.42E+06	0.59	0.01244	0.12	0.19	3.15	1.73E+06	0.15	0.06716	3.86	0.17	4.33	10.67
14.50	33760	75.23	6.18	2.43E+06	0.59	0.01244	0.12	0.19	3.17	1.74E+06	0.16	0.06716	3.90	0.17	4.37	10.13
14.00	33900	75.54	6.20	2.44E+06	0.60	0.01243	0.12	0.19	3.18	1.75E+06	0.16	0.06716	3.93	0.17	4.41	9.59
13.70	34000	75.76	6.22	2.45E+06	0.60	0.01243	0.12	0.19	3.19	1.75E+06	0.16	0.06716	3.95	0.17	4.44	9.26
13.50	34050	75.87	6.23	2.45E+06	0.60	0.01243	0.12	0.19	3.19	1.76E+06	0.16	0.06716	3.96	0.18	4.45	9.05
13.00	34150	76.10	6.25	2.46E+06	0.61	0.01243	0.12	0.19	3.20	1.76E+06	0.16	0.06716	3.99	0.18	4.48	8.52
12.70	34250	76.32	6.27	2.47E+06	0.61	0.01243	0.12	0.19	3.21	1.77E+06	0.16	0.06716	4.01	0.18	4.50	8.20
12.50	34300	76.43	6.28	2.47E+06	0.61	0.01243	0.12	0.19	3.22	1.77E+06	0.16	0.06716	4.02	0.18	4.51	7.99
12.00	34400	76.65	6.30	2.48E+06	0.62	0.01242	0.12	0.20	3.23	1.77E+06	0.16	0.06716	4.05	0.18	4.54	7.46
11.60	34500	76.88	6.31	2.49E+06	0.62	0.01242	0.12	0.20	3.24	1.78E+06	0.16	0.06716	4.07	0.18	4.57	7.03
11.00	34625	77.16	6.34	2.49E+06	0.62	0.01242	0.12	0.20	3.25	1.79E+06	0.16	0.06716	4.10	0.18	4.60	6.40
10.50	34750	77.43	6.36	2.50E+06	0.63	0.01242	0.12	0.20	3.26	1.79E+06	0.16	0.06716	4.13	0.18	4.63	5.87