APPENDIX I

Design Calculations

Sizing a Submersible Pump for Groundwater Extraction Wells

To calculate the total dynamic head (TDH), total head losses through pipe and fittings need to be evaluated. The total head losses are calculated by combining the minor losses through pipe fittings with the head loss through pressurized pipe.

Head loss (h_f) through pipe for turbulent flow conditions (N_{Re}>2,000) is calculated by the Hazen-Williams equation:

$$\mathbf{h_f = \frac{10.44*L*(F)^{1.85}}{(C)^{1.85}(d)^{4.8655}}}$$

Where;
L = Length of pipe (feet)
F = Flow rate in gpm
C = Hazen-Williams coefficient (unit less; appropriate value obtained from literature)
d = Diameter of pipe (inches)
N_{Re}= Reynolds number (dimensionless quantity)

Friction losses through fittings (or minor losses) are calculated by applying Darcy's equation:

$$\mathbf{h_L = \frac{f*L*V^2}{2*D*g_c}}$$

Alternatively, a loss coefficient "K" can be used. This loss coefficient, when multiplied by the velocity head, will give the head loss in feet. The method is used to calculate entrance and exit losses. Using "K" values (from Crane Manual, Appendix A, pages A-26 to A-29), minor losses are estimated by:

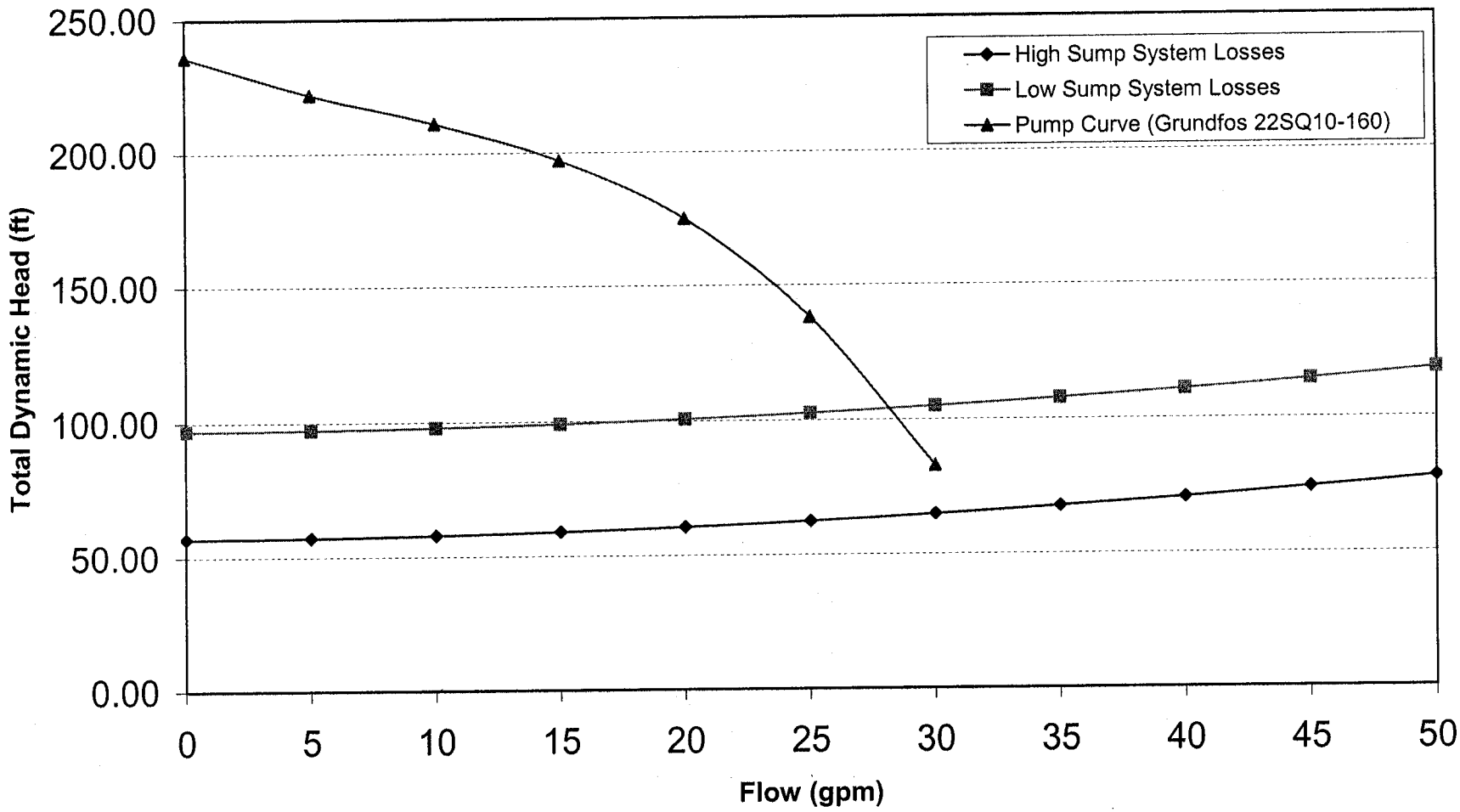
$$\mathbf{h_m = 0.5*K*\ V^2/g}$$

Where;
L = Equivalent length of pipe (feet)
f = Friction factor (obtained from Moody friction factor chart)
D = Diameter of fitting
g_c = Gravitational constant (32.2 ft/s^2)
V = velocity head (ft/sec)
K = loss coefficient (dimensionless)

The TDH is obtained by the adding the total static head and the sum of head losses through pipe and fittings. A system losses curve is developed by plotting the total dynamic head at different flow rates against the pump curve (as obtained from the pump manufacturer), which also shows TDH at different flow rates.

The point of intersection of both the above mentioned curves is the optimum operational flow rate and TDH for the selected pump.

Source Area
System Loss Curve



Source Area
Head Loss Calculations

High groundwater level =	-60
Low groundwater level =	-100
Pipe level =	-3
Static head at high water level =	57
Static head at low water level =	97

From Crane, Appendix A, pages A-26 to A-29

K_1 =	0.34	entrance (expansion)	K_6 =	0.057	ball valve
K_2 =	9.66	check valve	K_7 =	0.57	90 degree bend
K_3 =	0.57	90 degree bend	K_8 =	0.57	90 degree bend
K_4 =	0.057	ball valve	K_9 =	1	exit to EQ tank
K_5 =	6.46	globe valve (throttled)			

g (ft/s2)= 32.2
Minor losses (hm) = 1/2 K V^2 / g

Length of pressurized pipe (ft) =	200
Flow (gpm) =	variable
Friction Coefficient =	150
Pipe Diameter (inches) =	1.913
Pipe Diameter (feet) =	0.159

HIGH WATER

Flow [cfs]	Flow [gpm]	Area [ft]	Velocity [ft/s]	h_m1 [ft]	h_m2 [ft]	h_m3 [ft]	h_m4 [ft]	h_m5 [ft]	h_m6 [ft]	h_m7 [ft]	h_m8 [ft]	h_m9 [ft]	hp [ft]	hs [ft]	TDH [ft]
0.00	0	0.01996	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	57	57.00
0.01	5	0.01996	0.56	0.002	0.047	0.003	0.000	0.031	0.000	0.003	0.003	0.005	0.165	57	57.26
0.02	10	0.01996	1.12	0.007	0.187	0.011	0.001	0.125	0.001	0.011	0.011	0.019	0.593	57	57.97
0.03	15	0.01996	1.67	0.015	0.421	0.025	0.002	0.281	0.002	0.025	0.025	0.044	1.256	57	59.10
0.04	20	0.01996	2.23	0.026	0.748	0.044	0.004	0.500	0.004	0.044	0.044	0.077	2.139	57	60.63
0.06	25	0.01996	2.79	0.041	1.168	0.069	0.007	0.781	0.007	0.069	0.069	0.121	3.232	57	62.56
0.07	30	0.01996	3.35	0.059	1.682	0.099	0.010	1.125	0.010	0.099	0.099	0.174	4.528	57	64.89
0.08	35	0.01996	3.91	0.081	2.290	0.135	0.014	1.531	0.014	0.135	0.135	0.237	6.023	57	67.59
0.09	40	0.01996	4.46	0.105	2.990	0.176	0.018	2.000	0.018	0.176	0.176	0.310	7.711	57	70.68
0.10	45	0.01996	5.02	0.133	3.785	0.223	0.022	2.531	0.022	0.223	0.223	0.392	9.588	57	74.14
0.11	50	0.01996	5.58	0.164	4.672	0.276	0.028	3.125	0.028	0.276	0.276	0.484	11.651	57	77.98

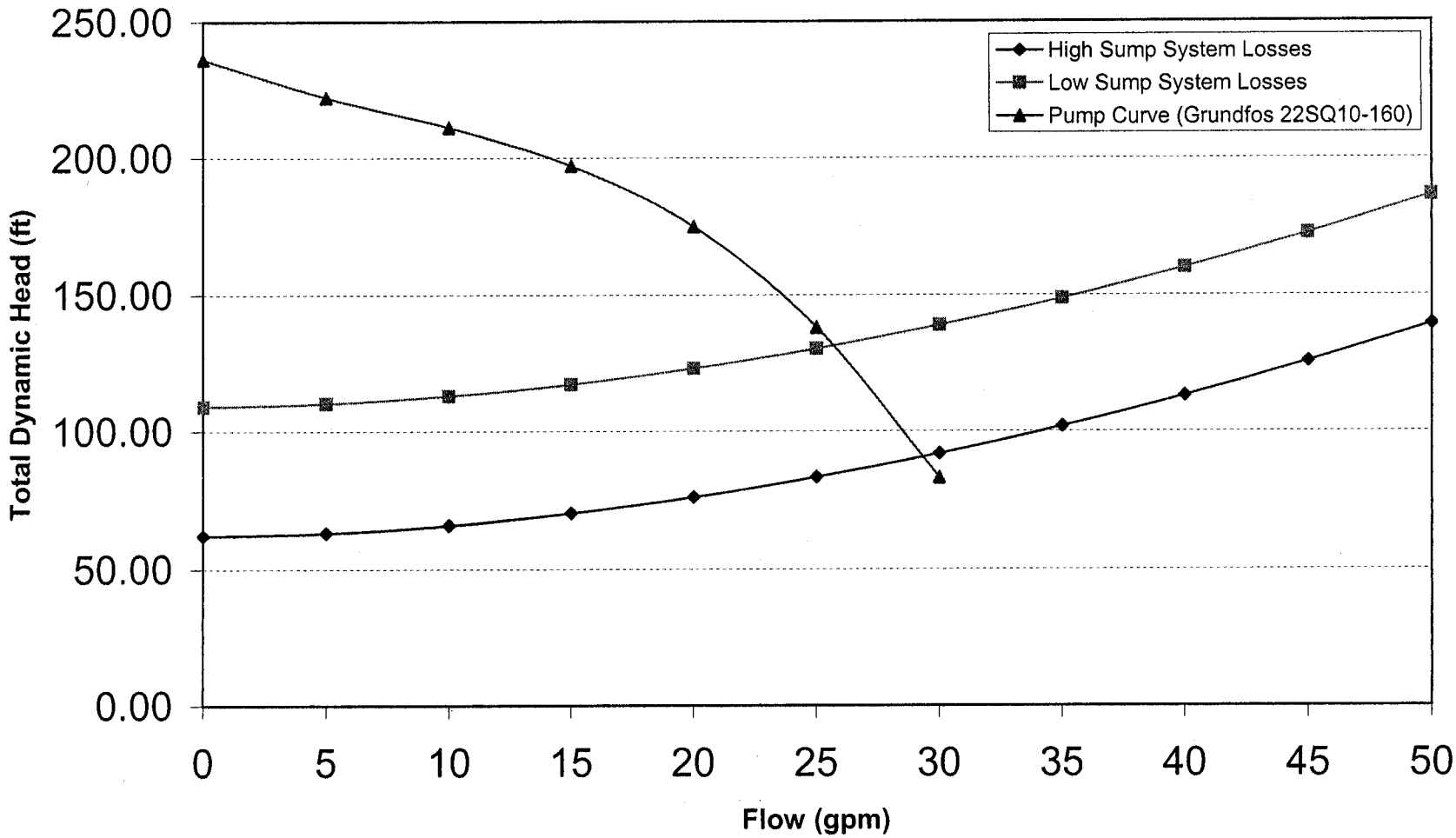
LOW WATER

Flow [cfs]	Flow [gpm]	Area [ft]	Velocity [ft/s]	h_m1 [ft]	h_m2 [ft]	h_m3 [ft]	h_m4 [ft]	h_m5 [ft]	h_m6 [ft]	h_m7 [ft]	h_m8 [ft]	h_m9 [ft]	hp [ft]	hs [ft]	TDH [ft]
0.00	0	0.01996	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	97	97.00
0.01	5	0.01996	0.56	0.002	0.047	0.003	0.000	0.031	0.000	0.003	0.003	0.005	0.165	97	97.26
0.02	10	0.01996	1.12	0.007	0.187	0.011	0.001	0.125	0.001	0.011	0.011	0.019	0.593	97	97.97
0.03	15	0.01996	1.67	0.015	0.421	0.025	0.002	0.281	0.002	0.025	0.025	0.044	1.256	97	99.10
0.04	20	0.01996	2.23	0.026	0.748	0.044	0.004	0.500	0.004	0.044	0.044	0.077	2.139	97	100.63
0.06	25	0.01996	2.79	0.041	1.168	0.069	0.007	0.781	0.007	0.069	0.069	0.121	3.232	97	102.56
0.07	30	0.01996	3.35	0.059	1.682	0.099	0.010	1.125	0.010	0.099	0.099	0.174	4.528	97	104.89
0.08	35	0.01996	3.91	0.081	2.290	0.135	0.014	1.531	0.014	0.135	0.135	0.237	6.023	97	107.59
0.09	40	0.01996	4.46	0.105	2.990	0.176	0.018	2.000	0.018	0.176	0.176	0.310	7.711	97	110.68
0.10	45	0.01996	5.02	0.133	3.785	0.223	0.022	2.531	0.022	0.223	0.223	0.392	9.588	97	114.14
0.11	50	0.01996	5.58	0.164	4.672	0.276	0.028	3.125	0.028	0.276	0.276	0.484	11.651	97	117.98

PUMP CURVE - Grundfos 22SQ10-160

Flow [gpm]	Head [ft]
0	236
5	222
10	211
15	197
20	175
25	138
30	83

Downgradient Pump System Loss Curve



Downgradient Pump
Head Loss Calculations

High groundwater level = -65
Low groundwater level = -112
Pipe level = -3
Static head at high water level = 62
Static head at low water level = 109
From Crane, Appendix A, pages A-26 to A-29

K_1 =	0.34	entrance (expansion)	K_9 =	0.304	45 degree bend
K_2 =	9.66	check valve	K_{10} =	0.57	90 degree bend
K_3 =	0.57	90 degree bend	K_{11} =	0.304	45 degree bend
K_4 =	0.057	ball valve	K_{12} =	0.57	90 degree bend
K_5 =	6.46	globe valve (throttled)	K_{13} =	0.304	45 degree bend
K_6 =	0.057	ball valve	K_{14} =	0.13	22.5 degree mitre bend
K_7 =	1.14	tee (through branch)	K_{15} =	0.38	tee (through run)
K_8 =	0.57	90 degree bend			

g (ft/s2)= 32.2
Minor losses (hm) = 1/2 K V^2 / g

Length of pressurized pipe (ft) = 1150
Flow (gpm) = variable
Friction Coefficient = 150
Pipe Diameter (inches) = 1.913
Pipe Diameter (feet) = 0.159

HIGH WATER

Flow [cfs]	Flow [gpm]	Area [ft]	Velocity [ft/s]	h_m1 [ft]	h_m2 [ft]	h_m3 [ft]	h_m4 [ft]	h_m5 [ft]	h_m6 [ft]	h_m7 [ft]	h_m8 [ft]	h_m9 [ft]	h_m10 [ft]	h_m11 [ft]	h_m12 [ft]	h_m13 [ft]	h_m14 [ft]	h_m15 [ft]	h_p [ft]	h_s [ft]	TDH [ft]
0.00	0	0.01996	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	62	62.00
0.01	5	0.01996	0.56	0.002	0.047	0.003	0.000	0.031	0.000	0.006	0.003	0.001	0.003	0.001	0.003	0.001	0.001	0.002	0.946	62	63.05
0.02	10	0.01996	1.12	0.007	0.187	0.011	0.001	0.125	0.001	0.022	0.011	0.006	0.011	0.006	0.011	0.006	0.003	0.007	3.411	62	65.83
0.03	15	0.01996	1.67	0.015	0.421	0.025	0.002	0.281	0.002	0.050	0.025	0.013	0.025	0.013	0.025	0.013	0.006	0.017	7.223	62	70.16
0.04	20	0.01996	2.23	0.026	0.748	0.044	0.004	0.500	0.004	0.088	0.044	0.024	0.044	0.024	0.044	0.024	0.010	0.029	12.298	62	75.96
0.06	25	0.01996	2.79	0.041	1.168	0.069	0.007	0.781	0.007	0.138	0.069	0.037	0.069	0.037	0.069	0.037	0.016	0.046	18.584	62	83.17
0.07	30	0.01996	3.35	0.059	1.682	0.099	0.010	1.125	0.010	0.199	0.099	0.053	0.099	0.053	0.099	0.053	0.023	0.066	26.039	62	91.77
0.08	35	0.01996	3.91	0.081	2.290	0.135	0.014	1.531	0.014	0.270	0.135	0.072	0.135	0.072	0.135	0.072	0.031	0.090	34.631	62	101.71
0.09	40	0.01996	4.46	0.105	2.990	0.176	0.018	2.000	0.018	0.353	0.176	0.094	0.176	0.094	0.176	0.094	0.040	0.118	44.336	62	112.97
0.10	45	0.01996	5.02	0.133	3.785	0.223	0.022	2.531	0.022	0.447	0.223	0.119	0.223	0.119	0.223	0.119	0.051	0.149	55.130	62	125.52
0.11	50	0.01996	5.58	0.164	4.672	0.276	0.028	3.125	0.028	0.551	0.276	0.147	0.276	0.147	0.276	0.147	0.063	0.184	66.995	62	139.35

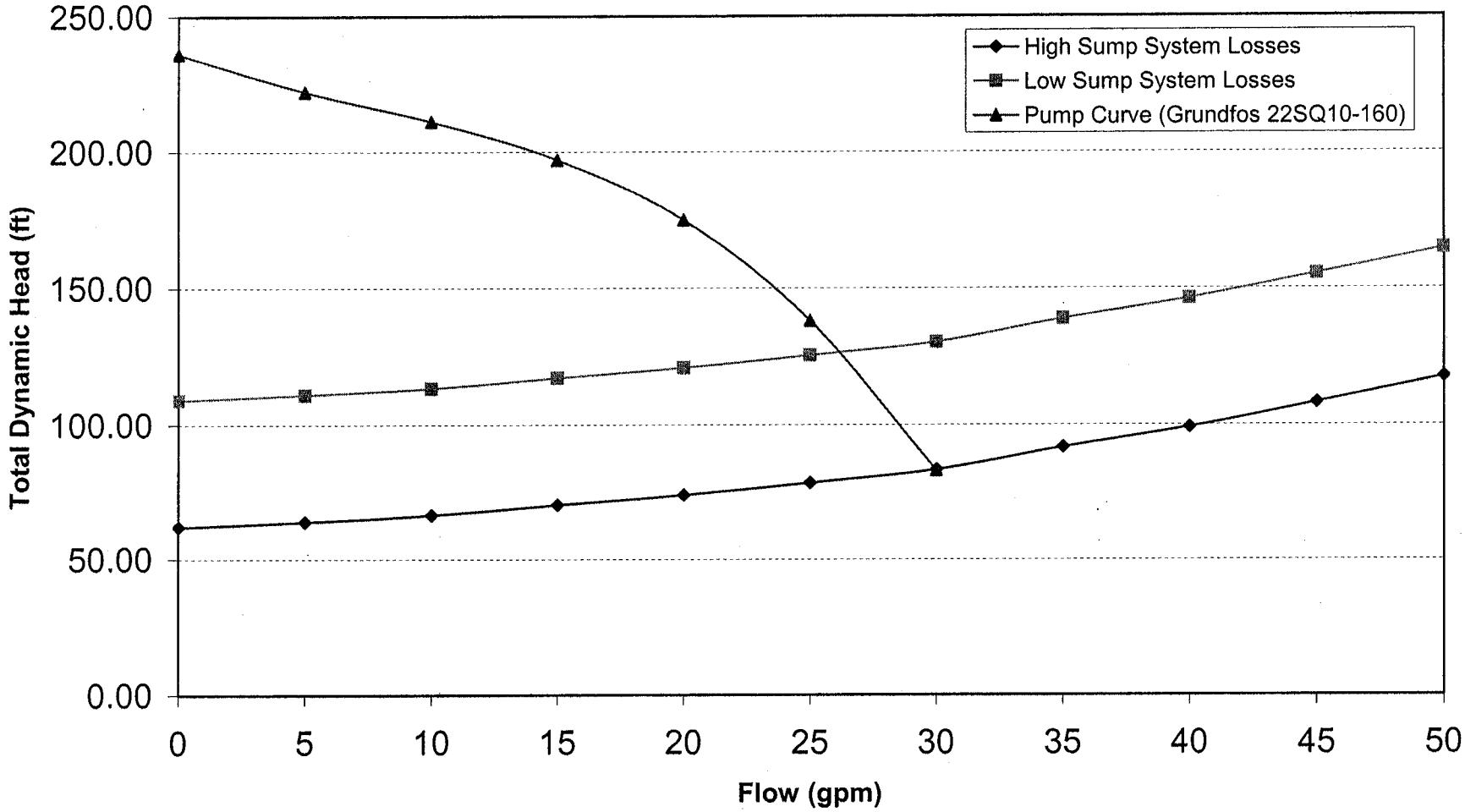
LOW WATER

Flow [cfs]	Flow [gpm]	Area [ft]	Velocity [ft/s]	h_m1 [ft]	h_m2 [ft]	h_m3 [ft]	h_m4 [ft]	h_m5 [ft]	h_m6 [ft]	h_m7 [ft]	h_m8 [ft]	h_m9 [ft]	h_m10 [ft]	h_m11 [ft]	h_m12 [ft]	h_m13 [ft]	h_m14 [ft]	h_m15 [ft]	hp [ft]	hs [ft]	TDH [ft]
0.00	0	0.01996	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	109	109.00
0.01	5	0.01996	0.56	0.002	0.047	0.003	0.000	0.031	0.000	0.006	0.003	0.001	0.003	0.001	0.003	0.001	0.001	0.002	0.946	109	110.05
0.02	10	0.01996	1.12	0.007	0.187	0.011	0.001	0.125	0.001	0.022	0.011	0.006	0.011	0.006	0.011	0.006	0.003	0.007	3.411	109	112.83
0.03	15	0.01996	1.67	0.015	0.421	0.025	0.002	0.281	0.002	0.050	0.025	0.013	0.025	0.013	0.025	0.013	0.006	0.017	7.223	109	117.16
0.04	20	0.01996	2.23	0.026	0.748	0.044	0.004	0.500	0.004	0.088	0.044	0.024	0.044	0.024	0.044	0.024	0.010	0.029	12.298	109	122.96
0.06	25	0.01996	2.79	0.041	1.168	0.069	0.007	0.781	0.007	0.138	0.069	0.037	0.069	0.037	0.069	0.037	0.016	0.046	18.584	109	130.17
0.07	30	0.01996	3.35	0.059	1.682	0.099	0.010	1.125	0.010	0.199	0.099	0.053	0.099	0.053	0.099	0.053	0.023	0.066	26.039	109	138.77
0.08	35	0.01996	3.91	0.081	2.290	0.135	0.014	1.531	0.014	0.270	0.135	0.072	0.135	0.072	0.135	0.072	0.031	0.090	34.631	109	148.71
0.09	40	0.01996	4.46	0.105	2.990	0.176	0.018	2.000	0.018	0.353	0.176	0.094	0.176	0.094	0.176	0.094	0.040	0.118	44.336	109	159.97
0.10	45	0.01996	5.02	0.133	3.785	0.223	0.022	2.531	0.022	0.447	0.223	0.119	0.223	0.119	0.223	0.119	0.051	0.149	55.130	109	172.52
0.11	50	0.01996	5.58	0.164	4.672	0.276	0.028	3.125	0.028	0.551	0.276	0.147	0.276	0.147	0.276	0.147	0.063	0.184	66.995	109	186.35

PUMP CURVE - Grundfos 22SQ10-160

Flow [gpm]	Head [ft]
0	236
5	222
10	211
15	197
20	175
25	138
30	83

Groundwater Injection System Loss Curve



Injection Wells
Head Loss Calculations

High groundwater level =	-65
Low groundwater level =	-112
Pipe level =	-3
Static head at high water level =	62
Static head at low water level =	109

From Crane, Appendix A, pages A-26 to A-29

K_1 =	0.34	entrance (expansion)	K_7 =	0.57	90 degree bend
K_2 =	9.66	check valve	K_8 =	0.57	90 degree bend
K_3 =	0.57	90 degree bend	K_9 =	1	entrance to EQ tank
K_4 =	0.057	ball valve	K_{10} =	0.78	5 exits from vessels
K_5 =	6.46	globe valve (throttled)	K_{11} =	1	4 entrances
K_6 =	0.057	ball valve	K_{12} =	9.66	check valve

g (ft/s2)= 32.2

Minor losses (hm) = 1/2 K V^2 / g

Carbon/Resin Vessels (ΔP) =	3.6	psi @ 25 gpm, see Baker Filtration cutsheet [hm13]
Length of pressurized pipe (ft) =	500	
Flow (gpm) =	variable	
Friction Coefficient =	150	
Pipe Diameter (inches) =	1.913	
Pipe Diameter (feet) =	0.159	

HIGH WATER

Flow [cfs]	Flow [gpm]	Area [ft]	Velocity [ft/s]	h_m1 [ft]	h_m2 [ft]	h_m3 [ft]	h_m4 [ft]	h_m5 [ft]	h_m6 [ft]	h_m7 [ft]	h_m8 [ft]	h_m9 [ft]	h_m10 [ft]	h_m11 [ft]	h_m12 [ft]	h_m13 [ft]	hp [ft]	hs [ft]	TDH [ft]
0.00	0	0.01996	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	62	62.00
0.01	5	0.01996	0.56	0.002	0.047	0.003	0.000	0.031	0.000	0.003	0.003	0.005	0.004	0.005	0.047	1.386	0.411	62	63.95
0.02	10	0.01996	1.12	0.007	0.187	0.011	0.001	0.125	0.001	0.011	0.011	0.019	0.015	0.019	0.187	2.310	1.483	62	66.39
0.03	15	0.01996	1.67	0.015	0.421	0.025	0.002	0.281	0.002	0.025	0.025	0.044	0.034	0.044	0.421	3.696	3.140	62	70.17
0.04	20	0.01996	2.23	0.026	0.748	0.044	0.004	0.500	0.004	0.044	0.044	0.077	0.060	0.077	0.748	4.158	5.347	62	73.88
0.06	25	0.01996	2.79	0.041	1.168	0.069	0.007	0.781	0.007	0.069	0.069	0.121	0.094	0.121	1.168	4.620	8.080	62	78.42
0.07	30	0.01996	3.35	0.059	1.682	0.099	0.010	1.125	0.010	0.099	0.099	0.174	0.136	0.174	1.682	4.620	11.321	62	83.29
0.08	35	0.01996	3.91	0.081	2.290	0.135	0.014	1.531	0.014	0.135	0.135	0.237	0.185	0.237	2.290	7.392	15.057	62	91.73
0.09	40	0.01996	4.46	0.105	2.990	0.176	0.018	2.000	0.018	0.176	0.176	0.310	0.241	0.310	2.990	8.316	19.277	62	99.10
0.10	45	0.01996	5.02	0.133	3.785	0.223	0.022	2.531	0.022	0.223	0.223	0.392	0.306	0.392	3.785	10.164	23.970	62	108.17
0.11	50	0.01996	5.58	0.164	4.672	0.276	0.028	3.125	0.028	0.276	0.276	0.484	0.377	0.484	4.672	11.550	29.128	62	117.54

LOW WATER

Flow [cfs]	Flow [gpm]	Area [ft]	Velocity [ft/s]	h_m1 [ft]	h_m2 [ft]	h_m3 [ft]	h_m4 [ft]	h_m5 [ft]	h_m6 [ft]	h_m7 [ft]	h_m8 [ft]	h_m9 [ft]	h_m10 [ft]	h_m11 [ft]	h_m12 [ft]	h_m13 [ft]	hp [ft]	hs [ft]	TDH [ft]
0.00	0	0.01996	0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	109	109.00
0.01	5	0.01996	0.56	0.002	0.047	0.003	0.000	0.031	0.000	0.003	0.003	0.005	0.004	0.005	0.047	1.386	0.411	109	110.95
0.02	10	0.01996	1.12	0.007	0.187	0.011	0.001	0.125	0.001	0.011	0.011	0.019	0.015	0.019	0.187	2.310	1.483	109	113.39
0.03	15	0.01996	1.67	0.015	0.421	0.025	0.002	0.281	0.002	0.025	0.025	0.044	0.034	0.044	0.421	3.696	3.140	109	117.17
0.04	20	0.01996	2.23	0.026	0.748	0.044	0.004	0.500	0.004	0.044	0.044	0.077	0.060	0.077	0.748	4.158	5.347	109	120.88
0.06	25	0.01996	2.79	0.041	1.168	0.069	0.007	0.781	0.007	0.069	0.069	0.121	0.094	0.121	1.168	4.620	8.080	109	125.42
0.07	30	0.01996	3.35	0.059	1.682	0.099	0.010	1.125	0.010	0.099	0.099	0.174	0.136	0.174	1.682	4.620	11.321	109	130.29
0.08	35	0.01996	3.91	0.081	2.290	0.135	0.014	1.531	0.014	0.135	0.135	0.237	0.185	0.237	2.290	7.392	15.057	109	138.73
0.09	40	0.01996	4.46	0.105	2.990	0.176	0.018	2.000	0.018	0.176	0.176	0.310	0.241	0.310	2.990	8.316	19.277	109	146.10
0.10	45	0.01996	5.02	0.133	3.785	0.223	0.022	2.531	0.022	0.223	0.223	0.392	0.306	0.392	3.785	10.164	23.970	109	155.17
0.11	50	0.01996	5.58	0.164	4.672	0.276	0.028	3.125	0.028	0.276	0.276	0.484	0.377	0.484	4.672	11.550	29.128	109	164.54

PUMP CURVE - Grundfos 22SQ10-160

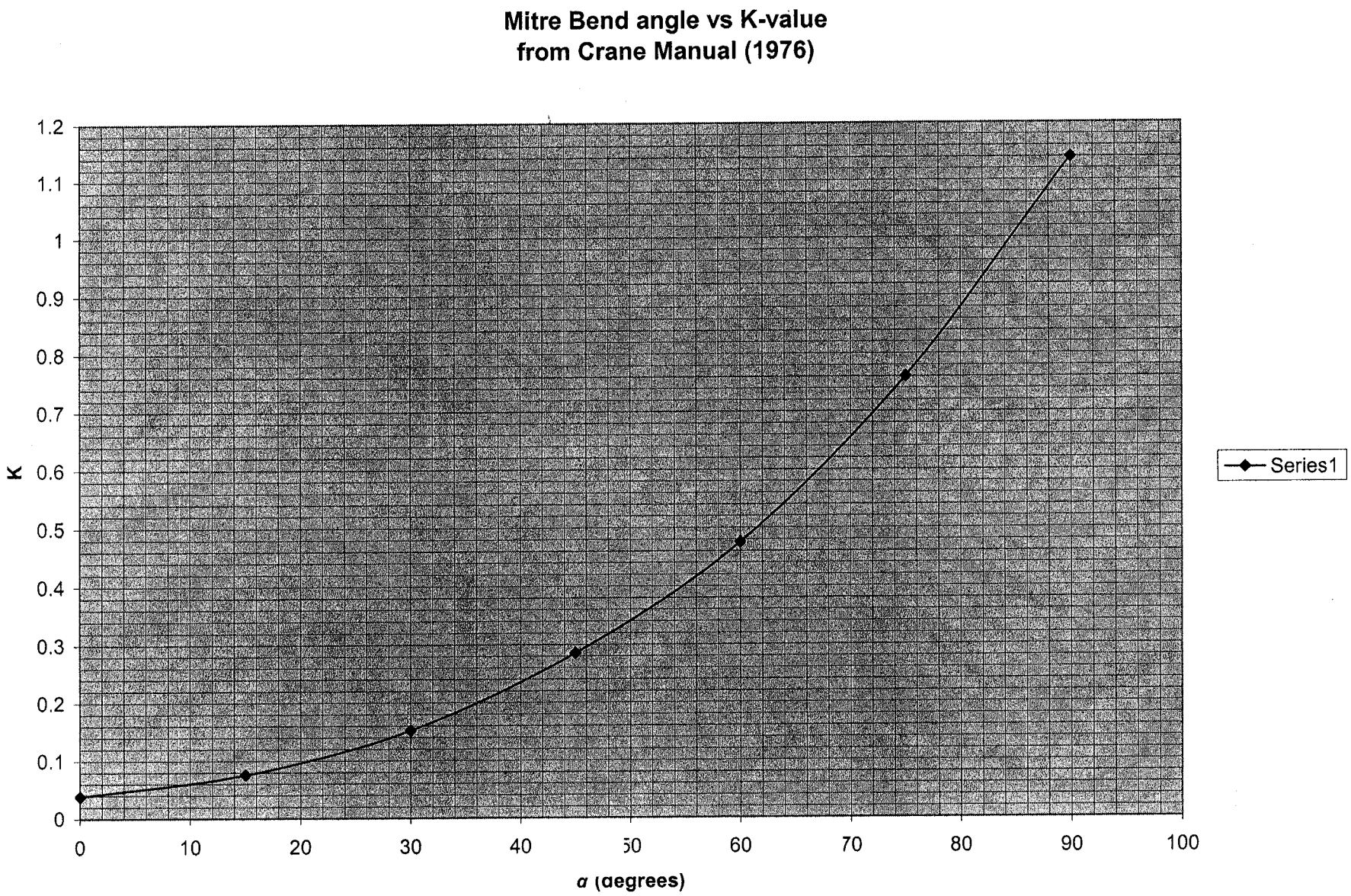
Flow [gpm]	Head [ft]
0	236
5	222
10	211
15	197
20	175
25	138
30	83

Parameter	Value	Unit
Flow	0.16	cfs
Flow	70	gpm
Area	0.01995984	feet
Velocity	7.81	feet/sec
hm- expansion	0.322	feet of H_2O
hm- check valve	9.158	feet of H_2O
hm-90 degree bend	0.540	feet of H_2O
hp- linear pipe	54.281	feet of H_2O
hm-90 degree bend	0.540	feet of H_2O
hm-90 degree bend	0.540	feet of H_2O
hm- check valve	9.158	feet of H_2O
Total Head Loss	74.54	feet of H_2O
Total Head Loss	32.27	psig *

*2.31 feet of head/ psig of pressure

Exit Pressure from hiPOx unit = 7 to 10 psig

Postive pressure via into injection wells = 0.49 to 3.49 psig (+ve)


Mitre Bend angle vs K-value
from Crane Manual (1976)
K
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
α (degrees)
Series1