UNDERSTANDING AND TROUBLESHOOTING WASTEWATER PUMPING SYSTEM HYDRAULICS

OWEA Plant Operations and Laboratory Workshop

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Columbus, OH

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PRIME AE Group

OBJECTIVES

- Understand Pumping Systems
- Gain knowledge to identify potential solutions for improving pump system capacity, increasing asset life, and thus decreasing costs
- Share your own experiences

AGENDA

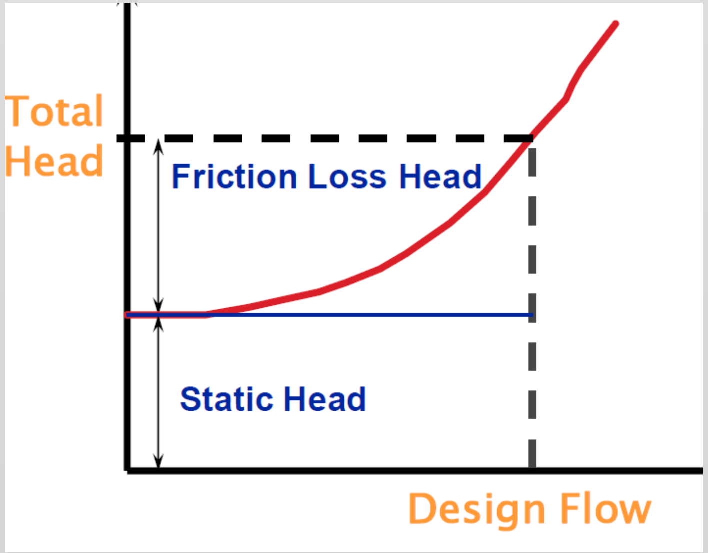
- Elements of a Pumping System
- Developing and Understanding System Curves
- Hydraulic Transients
- Cavitation
- Pump curves
- Pump System Design and Analysis

ELEMENTS OF A PUMPING SYSTEM

- Convey a fluid that can’t be conveyed by gravity
- System network – pipes, fittings, valves
- Hydraulic Control Points (intake elevations, high
- points, discharge elevations)
- Pump
- Motor
- Valves
- Instrumentation
- Controls

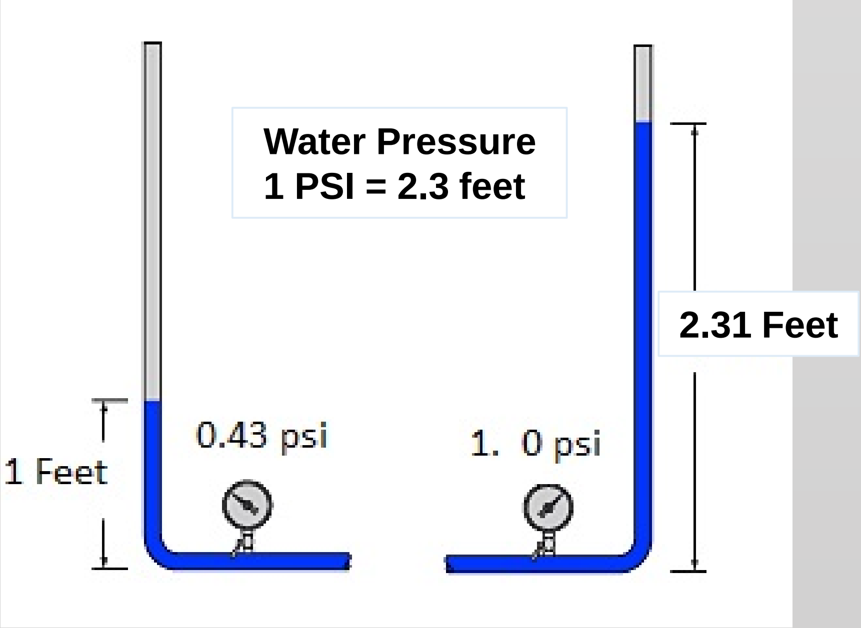
DEVELOPING AND UNDERSTANDING SYSTEM CURVES

- Developing System Curves is one of the most important components of selecting the correct pumps.
- What is a System Curve? A System Curve is a graphical representation of the relationship between flow and head in a fixed hydraulic network.
  - Static Head: The difference in elevation or pressure between the inlet water level and the effluent water level
  - Friction Loss Head: The amount of energy required to overcome resistance in the pipes, valves and fittings.
  - Total Dynamic Head: The total energy required to move the fluid from the suction to the discharge point. It is the **sum of Total Static Head and Friction Head**.



DEVELOPING AND UNDERSTANDING SYSTEM CURVES - HEAD

- What is Head?
- Is Head the same as Pressure? It is not the same, but we can use pressure to calculate head.
- **Head** is the height of a column of fluid and it is measured in feet of liquid column or simply indicated in feet (ft). Head is fluid independent.
  Pressure is weight applied to an area. It is fluid dependent and is affected by the specific gravity of the liquid.



DEVELOPING AND UNDERSTANDING SYSTEM CURVES – FRICTION LOSS

- Friction losses are dependent upon the flowrate through the system and primarily attributed to the system friction. This includes friction of the liquid flowing through the pipe and fittings, as well as the friction internal to the fluid
- Total Friction Loss = Major Losses + Minor Losses
  - Major Losses = Friction Loss through Pipe (Hazen-Williams Equation)

Hazen-Williams Equation:

$$h_f = \frac{3.02 \times (V/C)^{1.85} \times L}{D^{1.17}}$$

h_f = headloss (ft)
V = velocity (ft/s)
C = friction factor
L = pipe length (ft)
D = pipe diameter (ft)

HAZEN WILLIAM DESIGN COEFFICIENTS (C)		
PIPE MATERIAL	C_{WATER}	$C_{WASTEWATER}$
DI – unlined	80-120	80-110
DI – cement lined	100-140	100-130
Steel – unlined	110-130	110-130
Steel – cement lined	120-145	120-140
PVC	135-150	130-145
CPP	130-140	120-130

Table 1 - Source: Hydraulic Design Handbook by Mays

DEVELOPING AND UNDERSTANDING SYSTEM CURVES – MINOR LOSSES

- Total Friction Loss = Major Losses + Minor Losses
  - Minor Losses = Friction Loss Through Fittings, Valves, and are calculated using the equation below. K values vary based on geometry.

Entrance	Bellmouth	0.005
	Rounded	0.25
	Sharp-Edged	0.5
	Projecting	0.8
Exits		1.0
90° Bend		0.25
45° Bend		0.18
Tee, line flow		0.30
Tee, branch flow		0.75
Cross, line flow		0.50
Cross, branch flow		0.75
Wye, 45°		0.50

Ball		0.04
Check Valves	Ball	0.9-1.7
	Rubber flapper (v < ft/s)	2.0
	Rubber flapper (v > ft/s)	1.1
	Swing	0.6-2.2
Gate	Double Disc	0.1-0.2
	Resilient seat	0.3
Knife Gate	Metal seat	0.2
	Resilient seat	0.3
Eccentric Plug	Rectangular (80%) opening	1.0
	Full bore opening	0.5

Table 2 – K Values, Source: Pumping Station Design

DEVELOPING AND UNDERSTANDING SYSTEM CURVES – FORCE MAINS

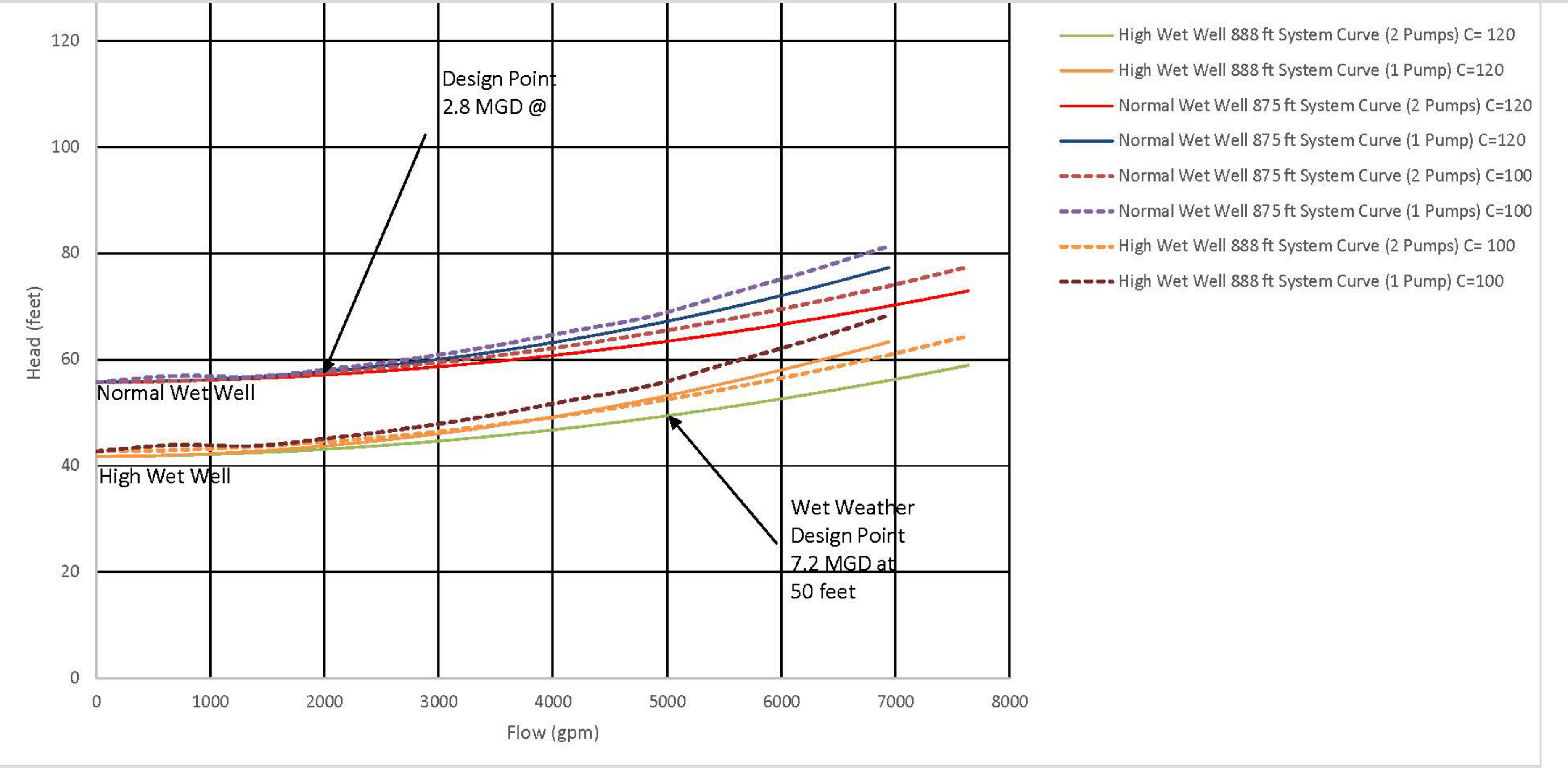
- Common Wastewater Force Main Materials
  - Ductile Iron Pipe (cement lined or polyethylene lined)
  - Concrete (cylinder pipe)
  - PVC, Polyethylene, or Fiberglass
- Hazen-Williams Friction Factors
  - C values change over time.
  - Design for range of C values anticipated over life of station
  - Typical Range for Ductile Iron Pipe:
    - Design for C = 120 (Ten State Standards)
    - Anticipated Range C = 100 (old pipe) to C = 140 (new pipe)
  - Typical Range for PVC, Polyethylene, or Fiberglass
    - Design for C = 140
    - Anticipated Range C = 130 to 150

DEVELOPING AND UNDERSTANDING SYSTEM CURVES – FORCE MAINS

- Recommended Force Main Velocities
  - Design for range of 2.0 to 8.0 ft/s
  - Avoid velocities less than 2.0 ft/s to minimize solids and grit deposition
  - Velocities should exceed 3.5 ft/s daily to resuspend settled solids and grit
  - Avoid velocities greater than 8.0 ft/s to mitigate excessive head/power requirements and to avoid high surge pressures on loss of power condition
- Avoid high points that are higher than the hydraulic grade line
  - Location where "column separation" occurs
  - Location where pipe corrosion likely to occur
  - Potential odor source
- Minimize number of intermediate high points
  - Each high point requires an air and vacuum valve, which requires maintenance!

DEVELOPING AND UNDERSTANDING SYSTEM CURVES – SYSTEM CURVES

- System curves should be generated for the range of conditions
  - High and low wet well levels
  - C values when pipe is new and at end of design life
  - One pump running and multiple pumps running



HYDRAULIC TRANSIENTS (SURGE/WATER HAMMER)

- Causes of Transients
  - Uncontrolled pump shutdown or startup (power failure)
  - Valve Malfunction or operator error
  - Specialty valve operation (check, air release, pressure reducing, pressure relief)
  - Pipe rupture
- Hydraulic transients are the result of sudden changes in flow or velocity that create large pressure fluctuations that can break pipelines, cause check valve slam, cause pipe vibrations, or result in column separation within the force main

HYDRAULIC TRANSIENTS (SURGE/WATER HAMMER)

- Piping systems should be analyzed for hydraulic transients when any two of the following conditions are met:
  - High total discharge head conditions, above 50 ft
  - High pipe velocities, above 5 ft/s
  - Force main profile with intermediate high points higher than the hydraulic grade line
  - Force main profile that results in steep gradients (greater than 34 ft over short lengths)
  - Check valve or isolation valve closure less than the critical time ($t_c = 2L/a$)

- Control of Hydraulic Transients
  - Pipe Material Selection
  - Air and vacuum valves
  - Cushioned Swing Check Valve
  - Surge Relieve Valves
  - Pump Control Valves
  - Surge Tanks

CAVITATION

- The shock of the imploding bubbles on the surface of the vane produces a gradual erosion and pitting which damages the impeller.

CAVITATION

- Three effects of pump cavitation are:
  - Degraded pump performance resulting in a fluctuating flow rate and discharge pressure
  - Excessive pump vibration
  - Destructive to pump internal components (damage to pump impeller, bearings, wearing rings, and seals)
- There are three indications that a centrifugal pump is cavitating.
  - Noise
  - Fluctuating discharge pressure and flow
  - Fluctuating pump motor current

CAVITATION

- Steps that can be taken to stop pump cavitation include:
  - Increase the pressure at the suction of the pump.
  - Reduce the temperature of the liquid being pumped.
  - Reduce head losses in the pump suction piping.
  - Reduce the flow rate through the pump.(reduce $NPSH_R$)
  - Reduce the speed of the pump impeller. (reduce $NPSH_R$)
- The net positive suction head available must be greater than the net positive suction head required.

$$NPSH_A > NPSH_R$$

NET POSITIVE SUCTION HEAD (NPSH)

- A pump will only perform properly if it is supplied with a steady flow of liquid at the suction flange with sufficient pressure to provide adequate net positive suction head (NPSH)
- Failure to provide adequate NPSH can lead to noisy pump operation, random axial load oscillations, premature bearing failure and cavitation
- NPSH Required is specific for individual pump types and sized and must be provided by the pump manufacturer
- NPSH Available should exceed NPSH Required by a margin of 50% or greater. NPSH margin should never be less then 5 feet.

NPSH Available = $H_{spa} + H_{ss} – H_{fs} – H_{vpa} – H_{vol}$ where…

H_{spa} = Surface pressure on the liquid (usually atmospheric pressure, 14.7 psig or 33.9 ft)

H_{ss} = Static Suction Head or Lift

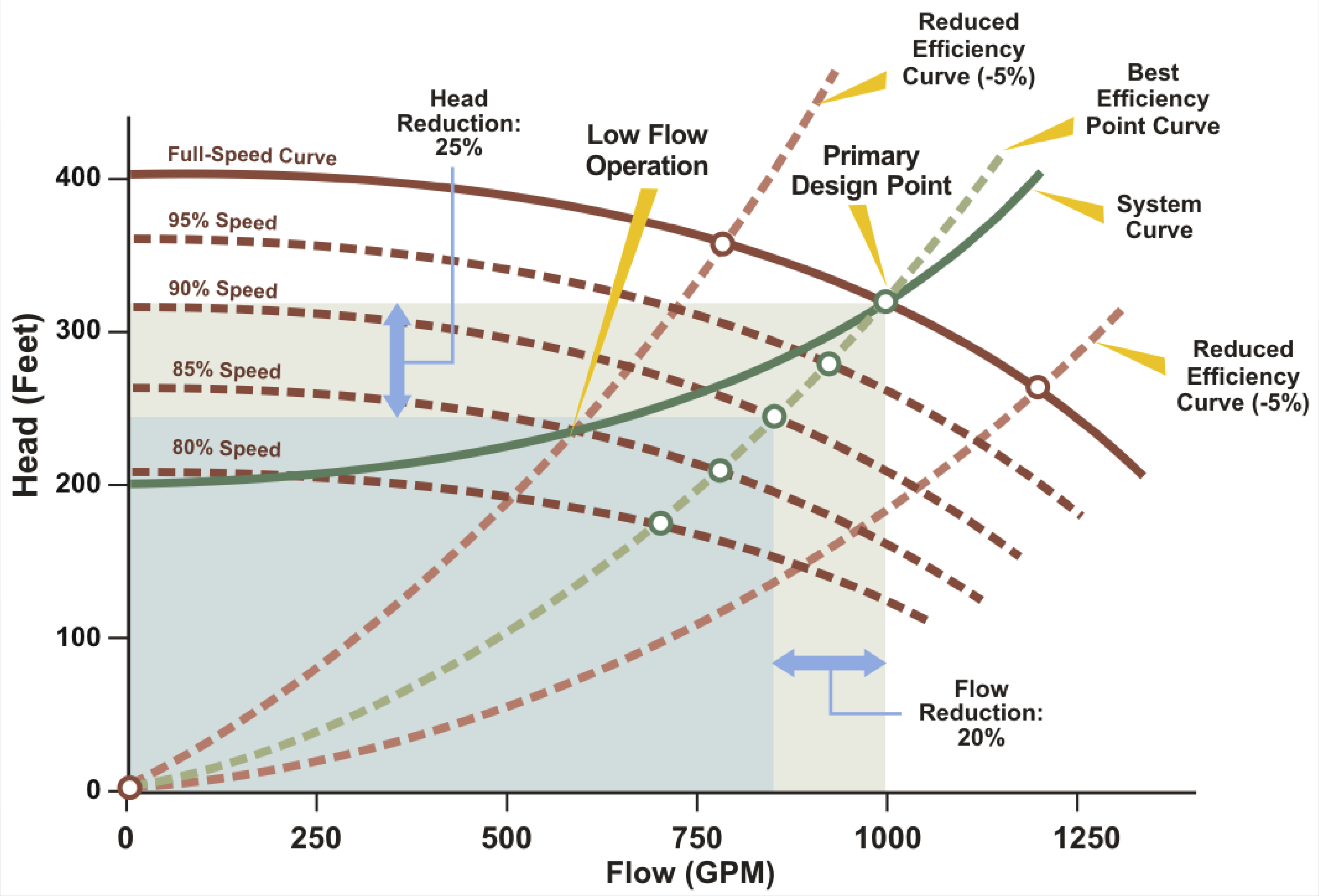
H_{fs} = Suction Friction Head (friction loss in suction piping)

H_{vpa} = Vapor pressure of the liquid (usually 0.8 ft for water @ 70 ^{o}F)

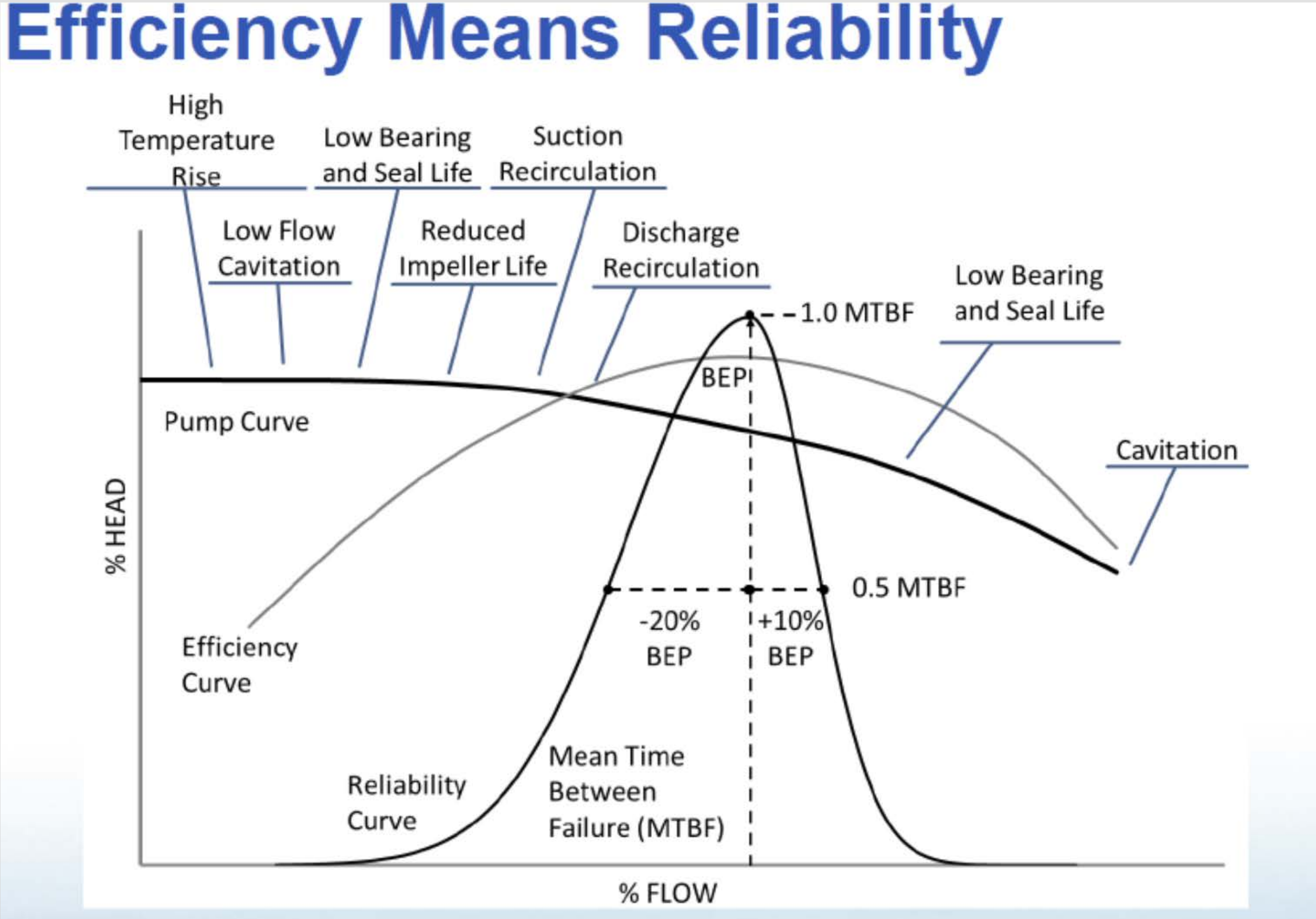
H_{vol} = Partial pressure of dissolved gases such as air in water (customarily ignored)

SELECTING A PUMP

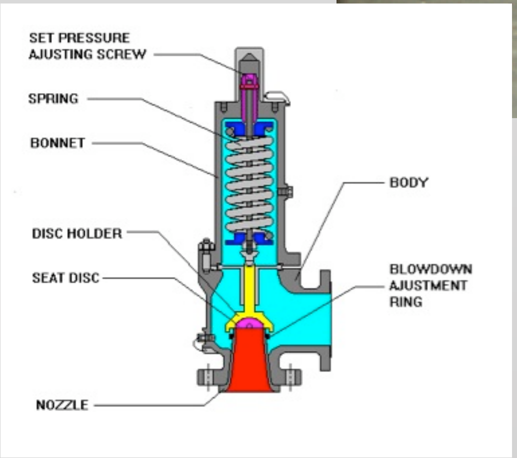
SELECTING A PUMP



SELECTING A PUMP



QUESTIONS ?



Hardened fats, oils and grease clogged a larger sewer pipe.

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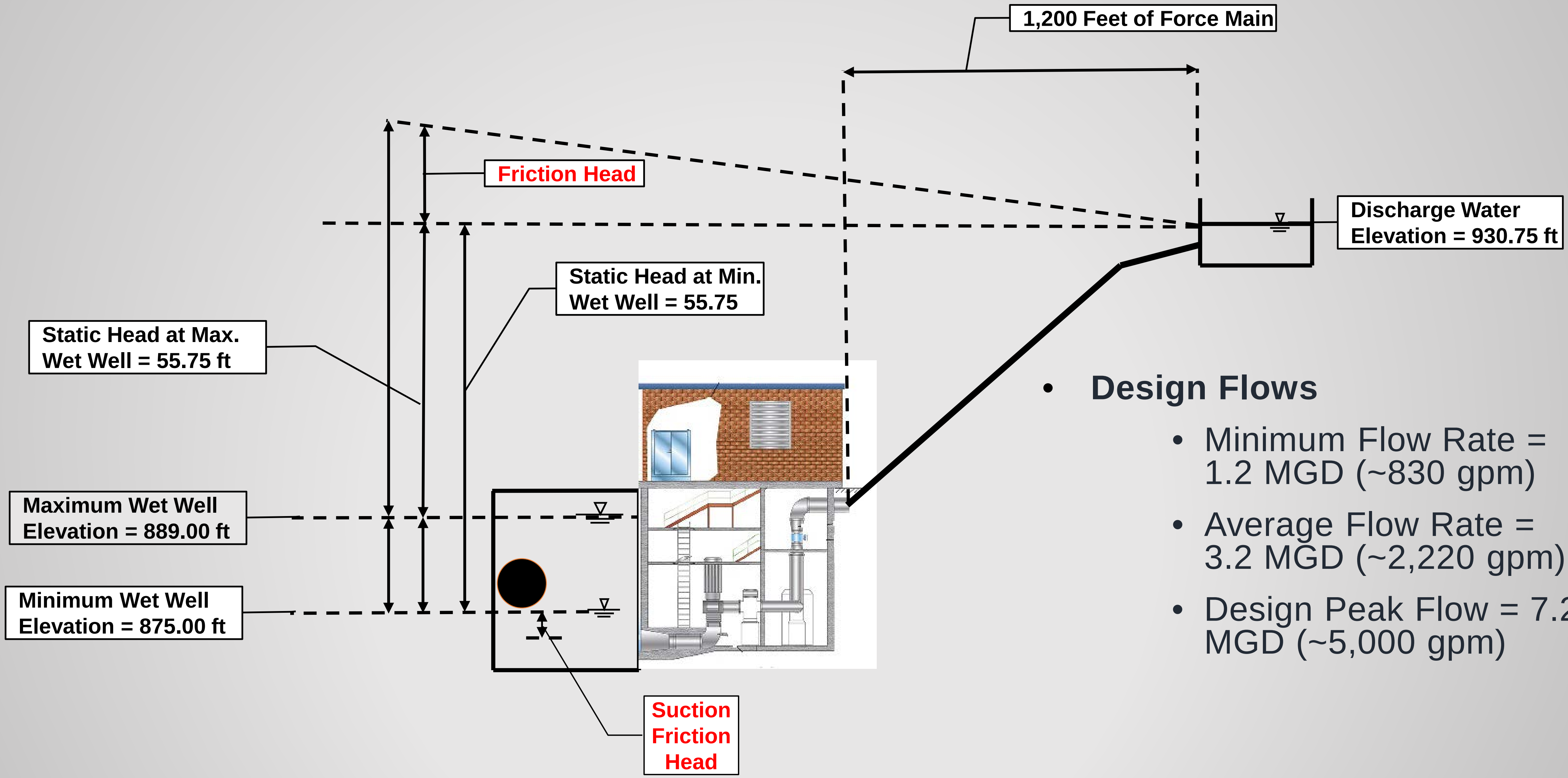
CASE 1 – WWTP INFLUENT PUMP STATION

CASE 1 – NEW INFLUENT PUMP STATION

- Treatment Plant Influent Pump Station Pump Replacement
  - Current Flows
    - Minimum Flow Rate = 1.2 MGD (~830 gpm)
    - Average Flow Rate = 3.2 MGD (~2,220 gpm)
    - Maximum Flow Rate = 8.0 MGD (~5,550 gpm)
    - Design Peak Flow = 7.2 MGD (~5,000 gpm)
      - Sewer has storage capacity 800,000 gallons (550 gpm at 24 hours)

- Planned Flows in 1970
  - Minimum Flow Rate = 4.0 MGD (~2,780 gpm)
  - Average Flow Rate = 12 MGD (~8,330 gpm)
  - Maximum Flow Rate = 28 MGD (20,820 gpm)
- Pump Station Site
  - 72-inch Pipe Invert = 875.00
- Headworks Site
  - 1,200 feet away
  - Discharge Water Level Elevation = 930.75

Pump System Schematic



- **Design Flows**
  - Minimum Flow Rate = 1.2 MGD (~830 gpm)
  - Average Flow Rate = 3.2 MGD (~2,220 gpm)
  - Design Peak Flow = 7.2 MGD (~5,000 gpm)

DEVELOPING THE PUMPING SYSTEM CURVES – PIPE SIZING

- Design Flows
  - Minimum Flow Rate = 1.2 MGD (~830 gpm)
  - Average Flow Rate = 3.2 MGD (~2,220 gpm)
  - Design Peak Flow = 7.2 MGD (~5,000 gpm)

SYSTEM CURVE CALCULATIONS

Pump Station Hydraulics

FLOW RATE	10.00	mgd	=	6940 gpm	=	15.47	cfs
DYNAMIC HEAD	**25.61**	ft					

ELEVATION DATA

PUMP DISCHARGE WS ELEVATION	**930.75**	ft	STATIC HEAD ON PUMPS =	42.75	ft
WS ELEVATION AT WET WELL	**888.00**	ft			
PIPE DIAMETER varies	inches	D			
FM Length	1,200.00 feet				

FORCE MAIN 1 CALCULATIONS

	Description	Quantity	Units	K Value	C Value	Q (cfs)	A (sf)	V (ft/sec)	(V^2/2g) (ft)	Headloss (ft)	Elevation (ft)
	Pump Discharge Channel WS El.										**930.75**
	20.70 " Exit Loss	1.0	EA	1.0		15.470	2.34	6.62	0.680	0.680	931.43
	20.00 " Magmeter	1	EA	0.05		15.470	2.18	7.09	0.781	0.039	931.47
	20.70 " 90 deg bend	3	EA	0.39		15.470	2.34	6.62	0.680	0.796	932.27
	20.70 " 45 deg bend	2	EA	0.25		15.470	2.34	6.62	0.680	0.340	932.61
	20.70 " 22.5 deg bend	0	EA	0.15		15.470	2.34	6.62	0.680	0.000	932.61
	20.70 " 11.25 deg bend	0	EA	0.07		15.470	2.34	6.62	0.680	0.000	932.61
	20.70 " Pipe from header to exit	1200	LF		100	15.470	2.34	6.62	0.680	12.635	945.24
	24.86 " x 20" Y	1	EA	0.60		15.470	3.37	4.59	0.327	0.196	945.44
	24.86 " 90 deg bend	2	EA	0.39		15.470	3.37	4.59	0.327	0.255	945.69
	24.86 " Tees	1	EA	0.78		15.470	3.37	4.59	0.327	0.255	945.95
	24.86 " Pipe from header to exit	32	LF		100	15.470	3.37	4.59	0.327	0.138	946.09
	24.86 " to 18 Conc Reducer	1	EA	0.20		15.470	3.37	4.59	0.327	0.065	946.01
	18.62 " Pipe from Entr to Header	18	LF		100	15.470	1.89	8.18	1.039	0.317	946.33
											15.6
					# pumps	1					
	18.62 " Y Branch	1	EA	0.39		15.470	1.89	8.18	1.039	0.405	946.74
	18.62 " to 14 Conc Reducer elb	1	EA	0.25		15.470	1.89	8.18	1.039	0.260	947.00
	14.46 " Pipe from pump to Header	6	LF		100	15.470	1.14	13.57	2.857	0.362	947.36
	14.46 " Plug Valves	1	EA	1.00		15.470	1.14	13.57	2.857	2.857	950.21
	14.46 " Check Valve	1	EA	1.30		15.470	1.14	13.57	2.857	3.715	953.93
	14.46 " to 10 Conc Reducer elb	1	EA	0.25		15.470	1.14	13.57	2.857	0.714	954.64
	10.34 " Pipe from Entr to pump	2	LF		100	15.470	0.58	26.53	10.928	0.617	955.26
	18.68 " to 10 Conc Reducer elb	1	EA	0.25		15.470	1.90	8.13	1.026	0.256	955.52
	18.68 " Plug Valves	1	EA	1.00		15.470	1.90	8.13	1.026	1.026	956.54
	18.68 " Pipe from Entr to pump	10	LF		100	15.470	1.90	8.13	1.026	0.174	956.72
	18.68 " Entrance Loss	1	EA	0.05		15.470	1.90	8.13	1.026	0.051	956.77
											10.0

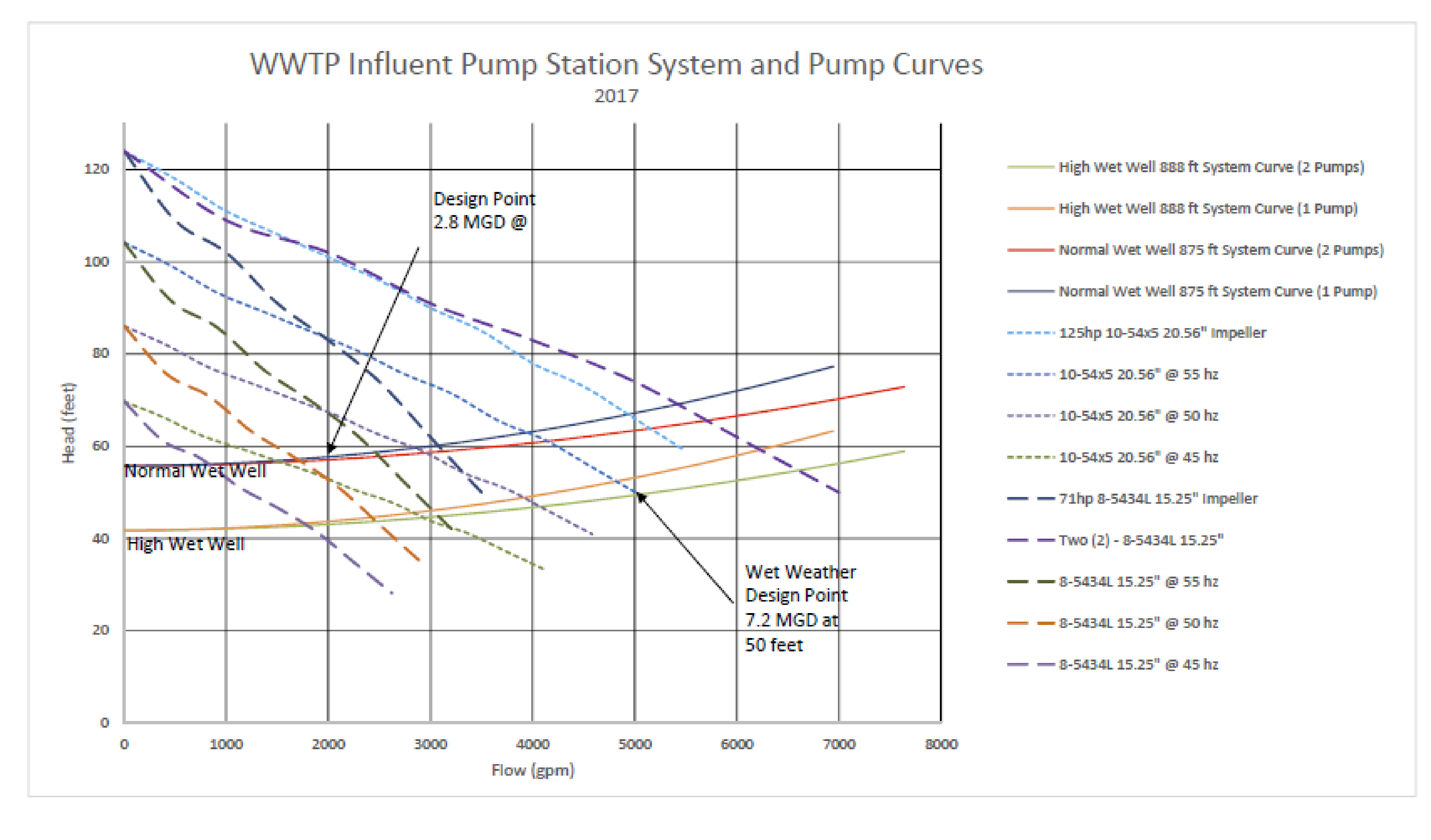
SYSTEM CURVE CALCULATIONS

1 pumps running C =100

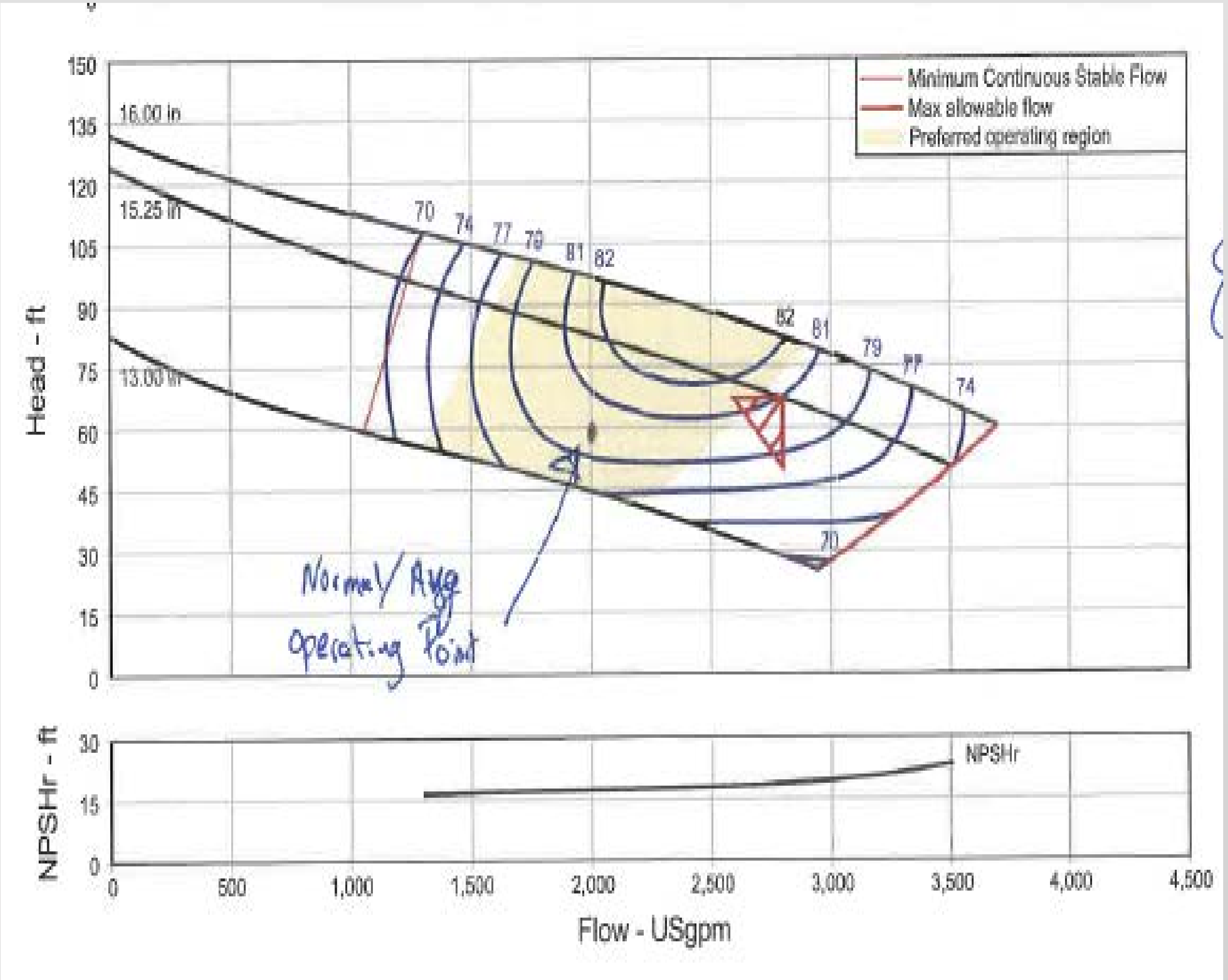
				20-inch	24-inch
Flow	**Flow**	**Dynamic**	**TDH**	**Velocity**	**Velocity**
MGD	**GPM**	**feet**	**feet**	**ft/sec**	**ft/sec**
0	0	0.00	42.75	0	0
1	694.44	1.18	43.93	0.66	0.46
2	1388.88	1.02	43.77	1.32	1.92
3	2083.32	2.56	45.31	1.99	1.39
4	2777.76	4.43	47.18	2.65	1.84
5	3472.2	6.79	49.54	3.31	2.29
6	4166.64	9.62	52.37	3.97	2.75
7	4861.08	12.39	55.14	4.63	3.21
8	5555.52	16.7	59.45	5.3	3.67
9	6249.96	20.93	63.68	5.96	4.13
10	6944.4	25.61	68.36	6.62	4.59

CASE 1

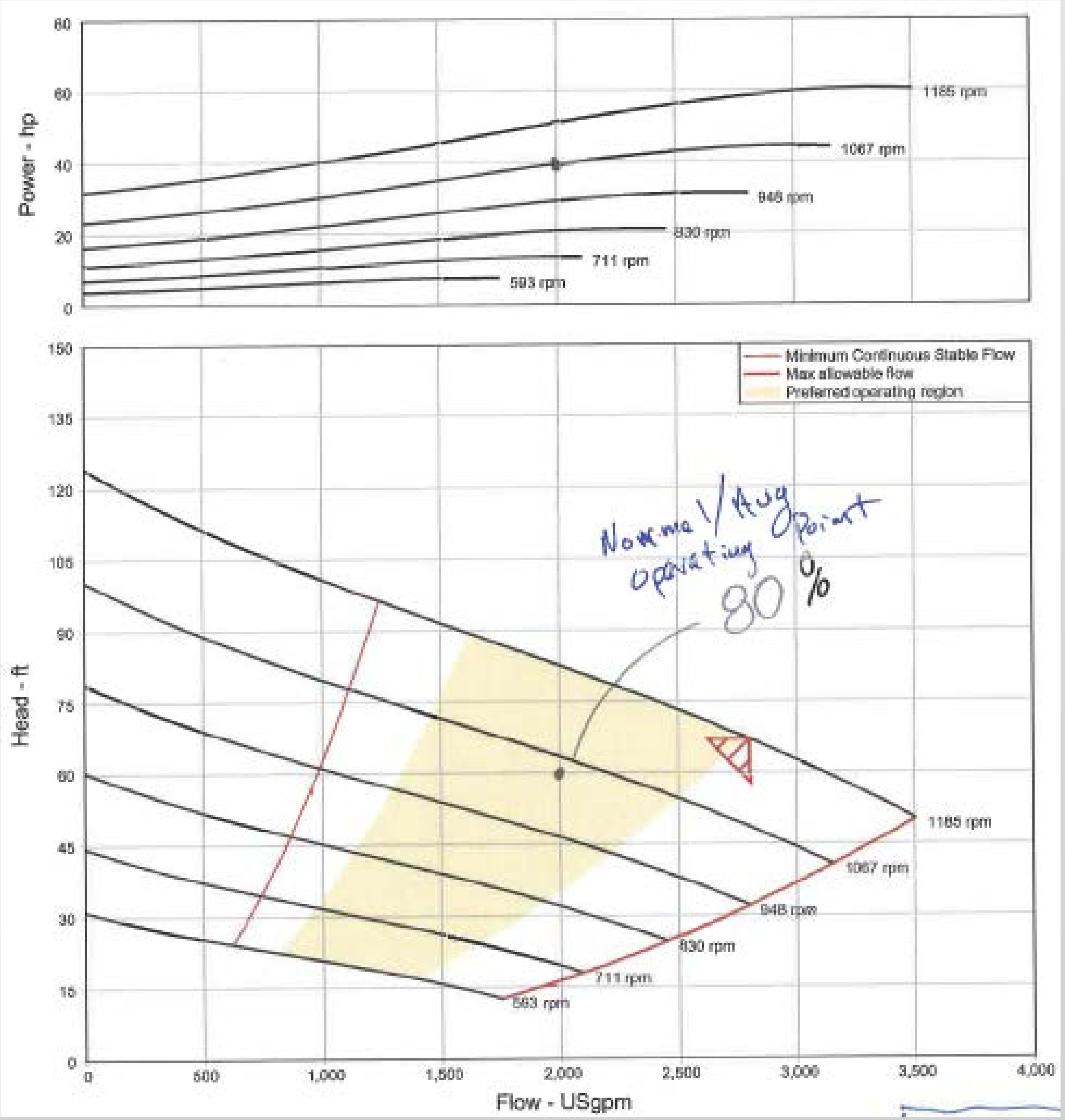
- Current Flows
  - Minimum Flow Rate = 1.2 MGD (~830 gpm)
  - Average Flow Rate = 3.2 MGD (~2,220 gpm)
  - Design Peak Flow = 7.2 MGD (~5,000 gpm)



8 INCH PUMP

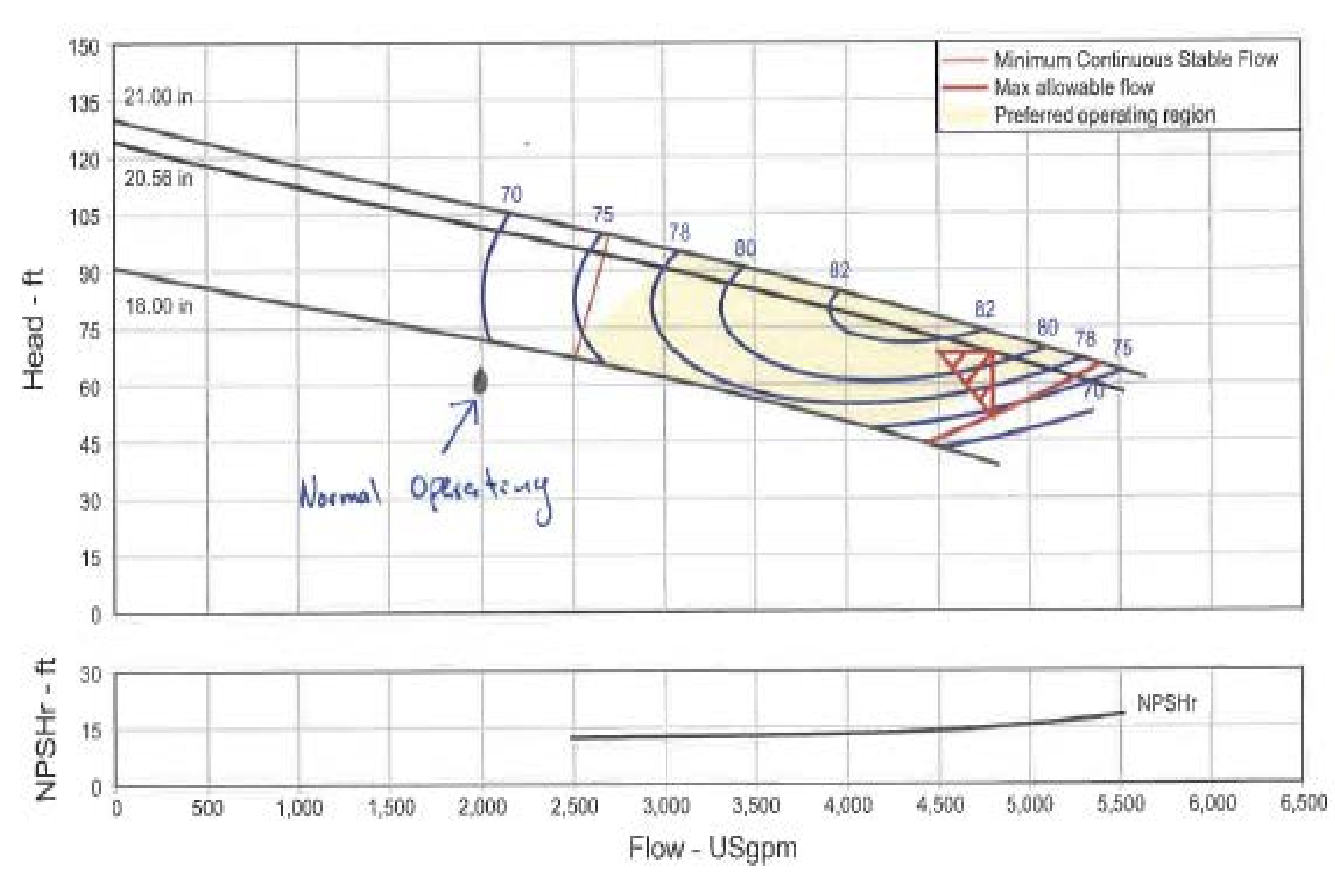


Minimum Continuous Stable Flow
Max allowable flow
Preferred operating region
16.00 in
15.25 in
13.00 in
Head - ft
NPSHr - ft
NPSHr
Flow - USgpm
Normal/Avg Operating Point

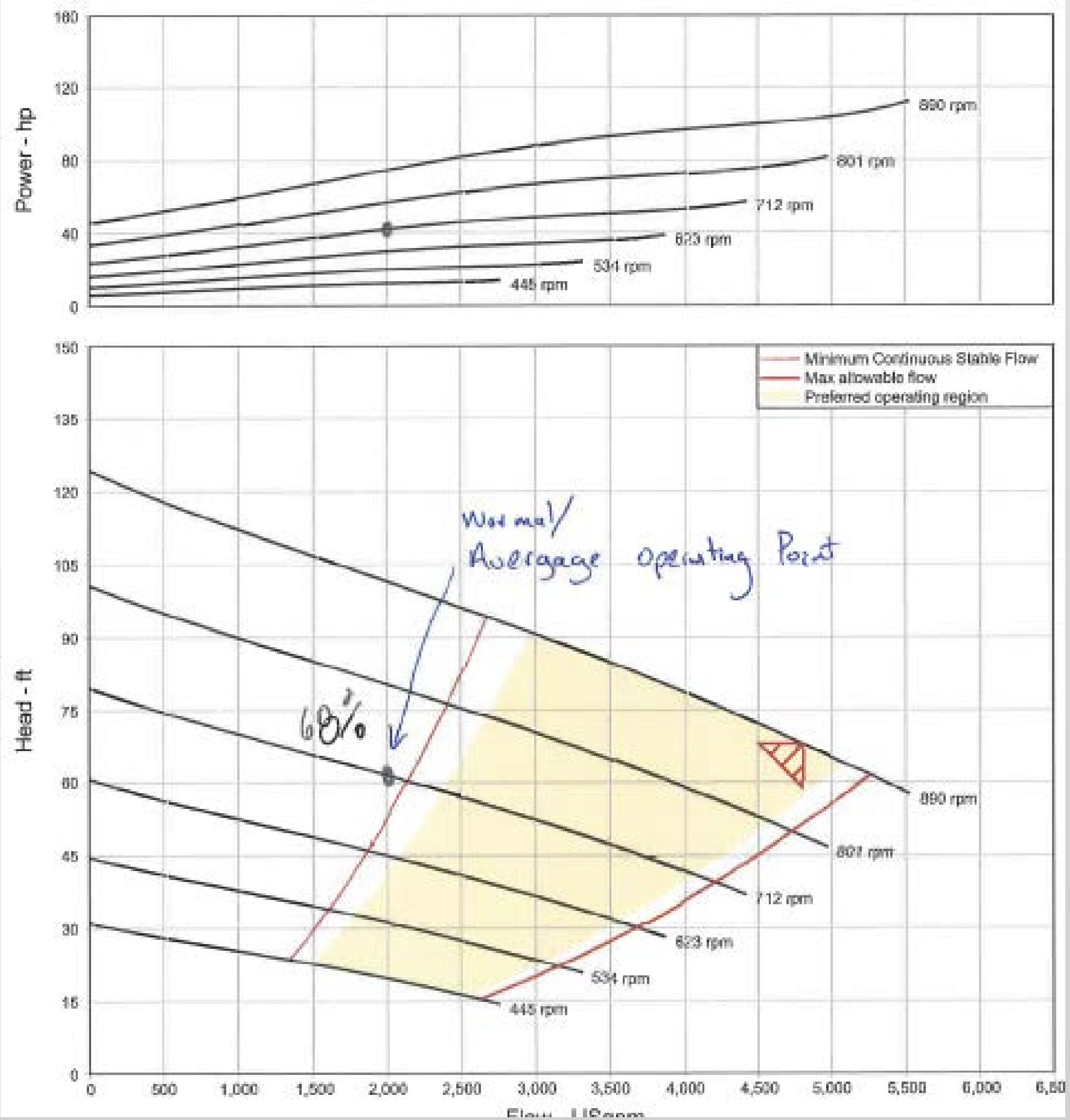


Power - hp
1185 rpm
1067 rpm
948 rpm
830 rpm
711 rpm
593 rpm
Minimum Continuous Stable Flow
Max allowable flow
Preferred operating region
Head - ft
Flow - USgpm
Normal/Avg Operating Point
80 %

10 INCH PUMP



Minimum Continuous Stable Flow
Max allowable flow
Preferred operating region
21.00 in
20.56 in
18.00 in
70
75
78
80
82
82
80
78
75
70
Head - ft
NPSHr - ft
NPSHr
Normal Operating
Flow - USgpm



Power - hp
890 rpm
801 rpm
712 rpm
623 rpm
534 rpm
445 rpm
Minimum Continuous Stable Flow
Max allowable flow
Preferred operating region
Head - ft
Normal/
Averagage Operating Point
68%

ENERGY SAVINGS

Design Point =	2000 gpm @ 58 feet	
Cost per KWh =	$0.10	
	Annual Energy Usage (KWh)	Annual Cost
71 HP 8-5434L 15.25" Impeller	169,000	$16,900.00
125 HP 10-54x5 20.56" Impeller	202,000	$20,200.00

OUTSIDE BEP – ITEMS OF CONCERN

DISCUSSION ITEMS/ QUESTIONS?