Grundfos Technical Institute

Efficient Pump Selection & Control

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Grundfos Technical Institute
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Points on a Pump Performance Curve

Shut-Off Head
No flow performance, don't run here for more than a few minutes (Damage from heat buildup can occur)

Operating Point
This is where the pump is actually running, where the system curve intersects the performance curve

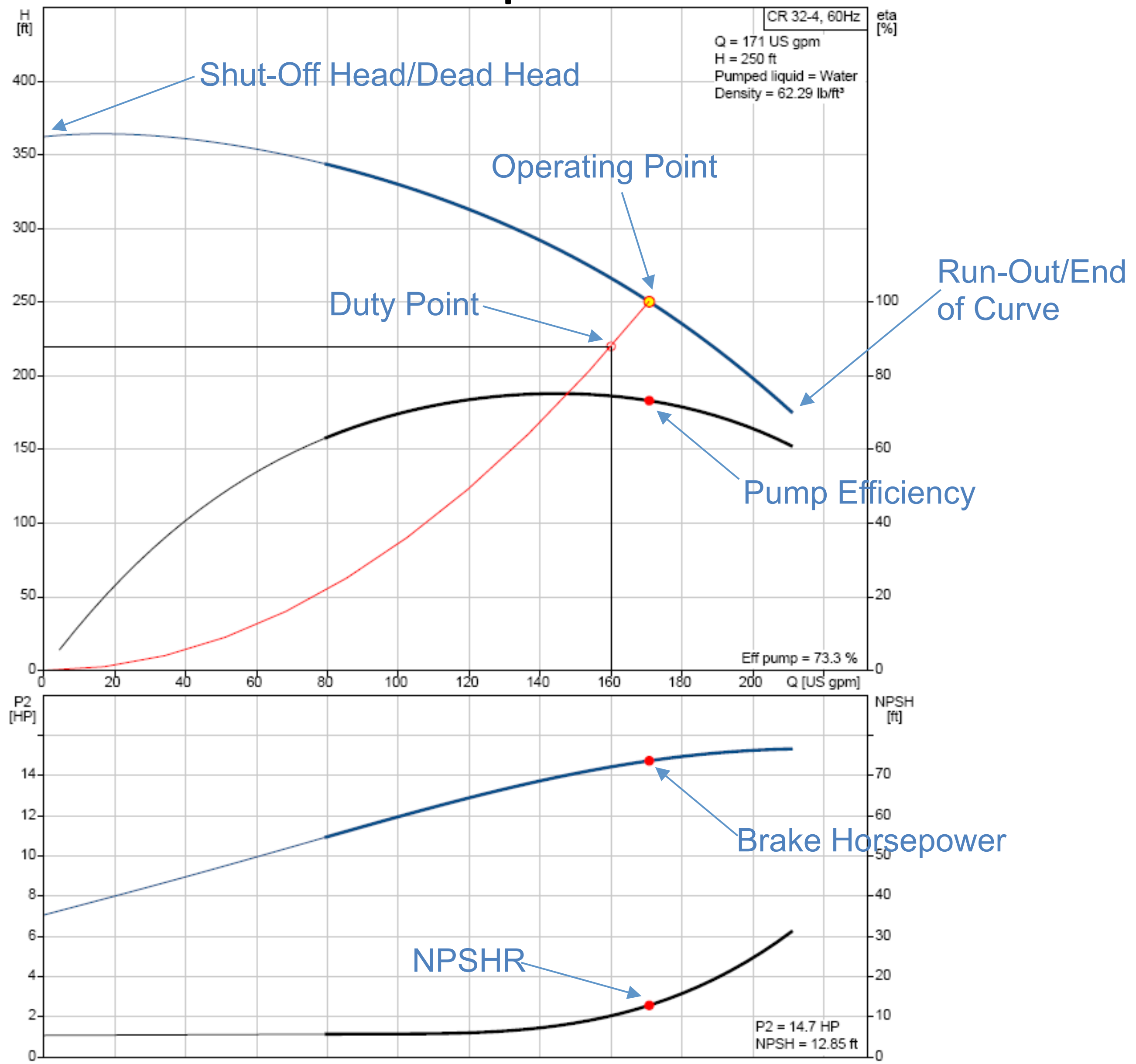
Duty Point
The design flow and head, this is what is required, usually based on calculations

Run Out/End of Curve
This is the maximum allowable flow rate for the pump.   Flows exceeding this should be avoided (Damage can occur)

Pump Efficiency
This is the pump hydraulic efficiency, does not typically include motor efficiency

Brake Horsepower
This is the horsepower required by the pump. Any point on this curve should be lower than the motor nameplate horsepower

NPSH
Net Positive Suction Head, the actual suction head of the system must be higher than this value. Very important in boiler feed systems and systems with flooded suction. Not so important for cold water from a pressurized source or hydronic heating/cool systems



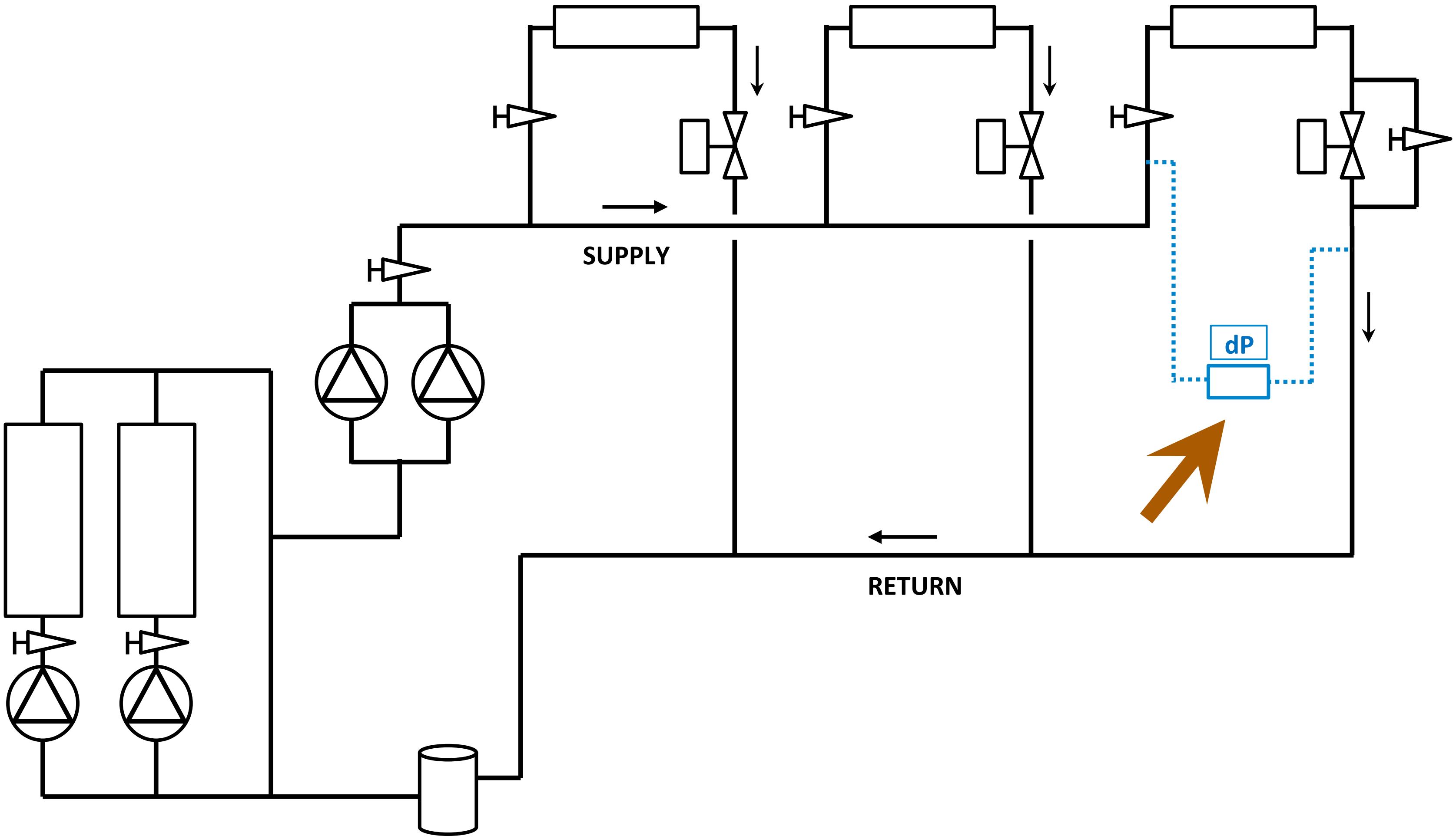
Two common variable flow pump applications

HVAC Circulation – Hot and/or Chilled Water

Water Supply – Pressure Boosting

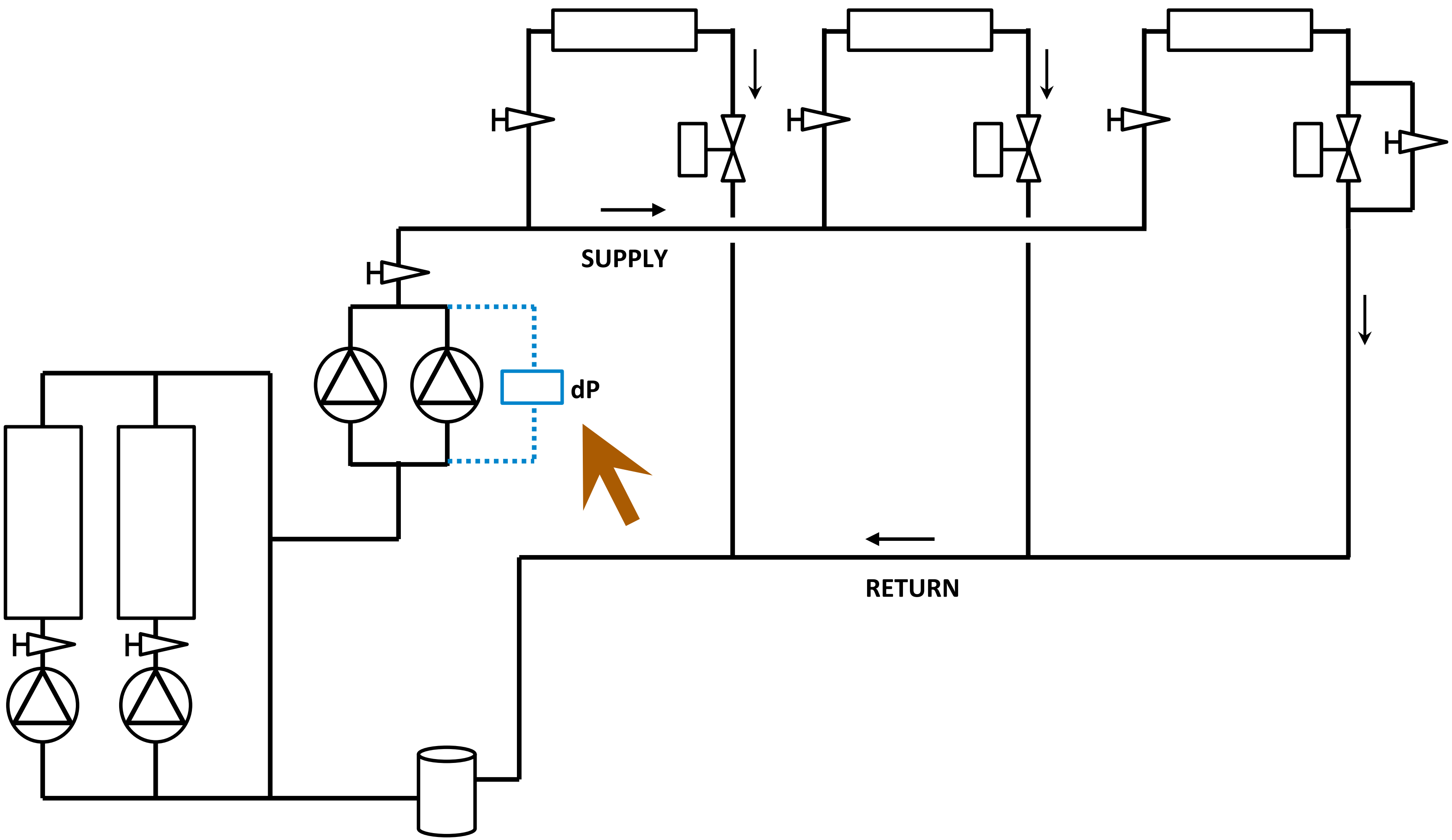
HVAC Circulation

Differential Pressure measured remotely

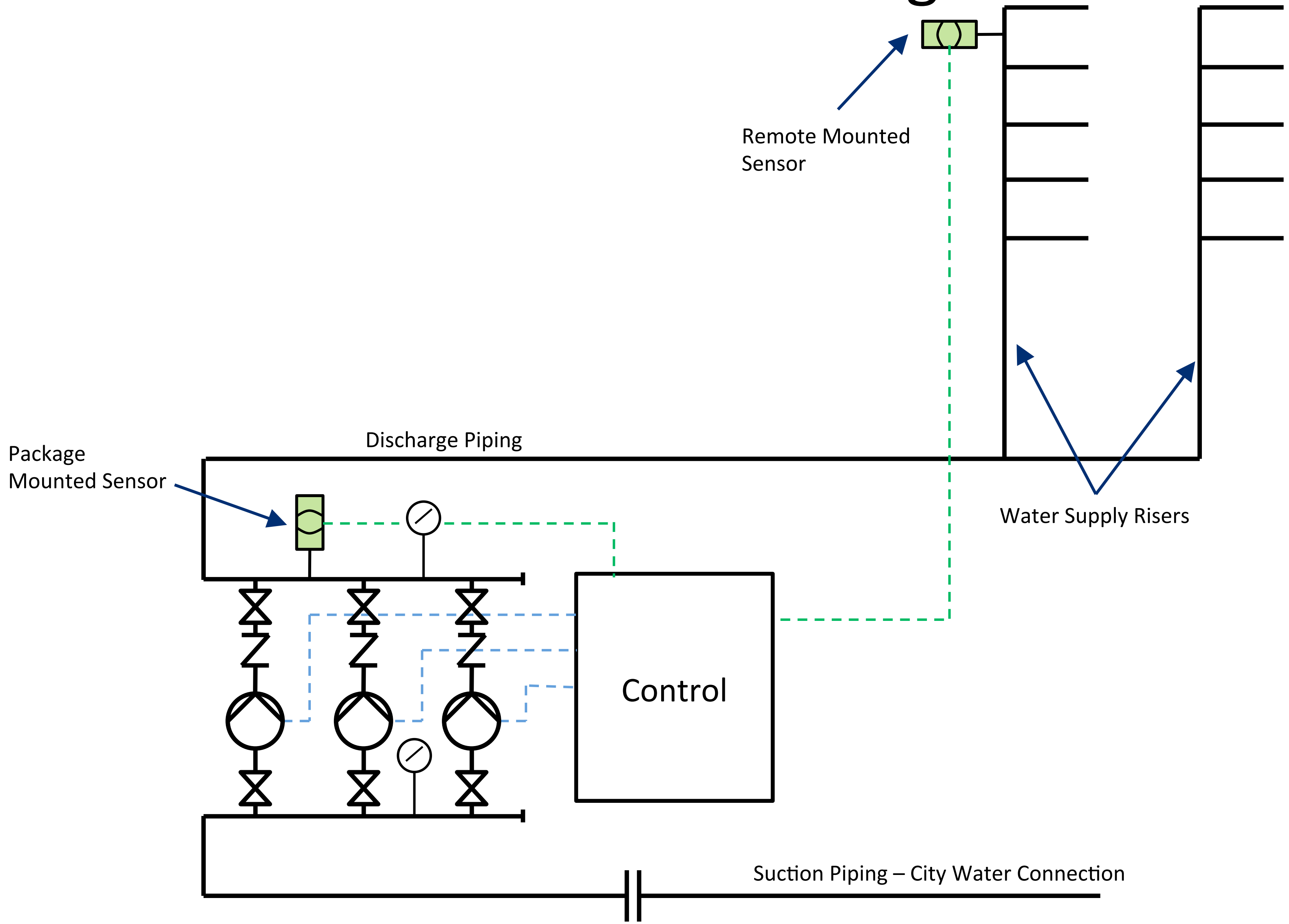


HVAC Circulation

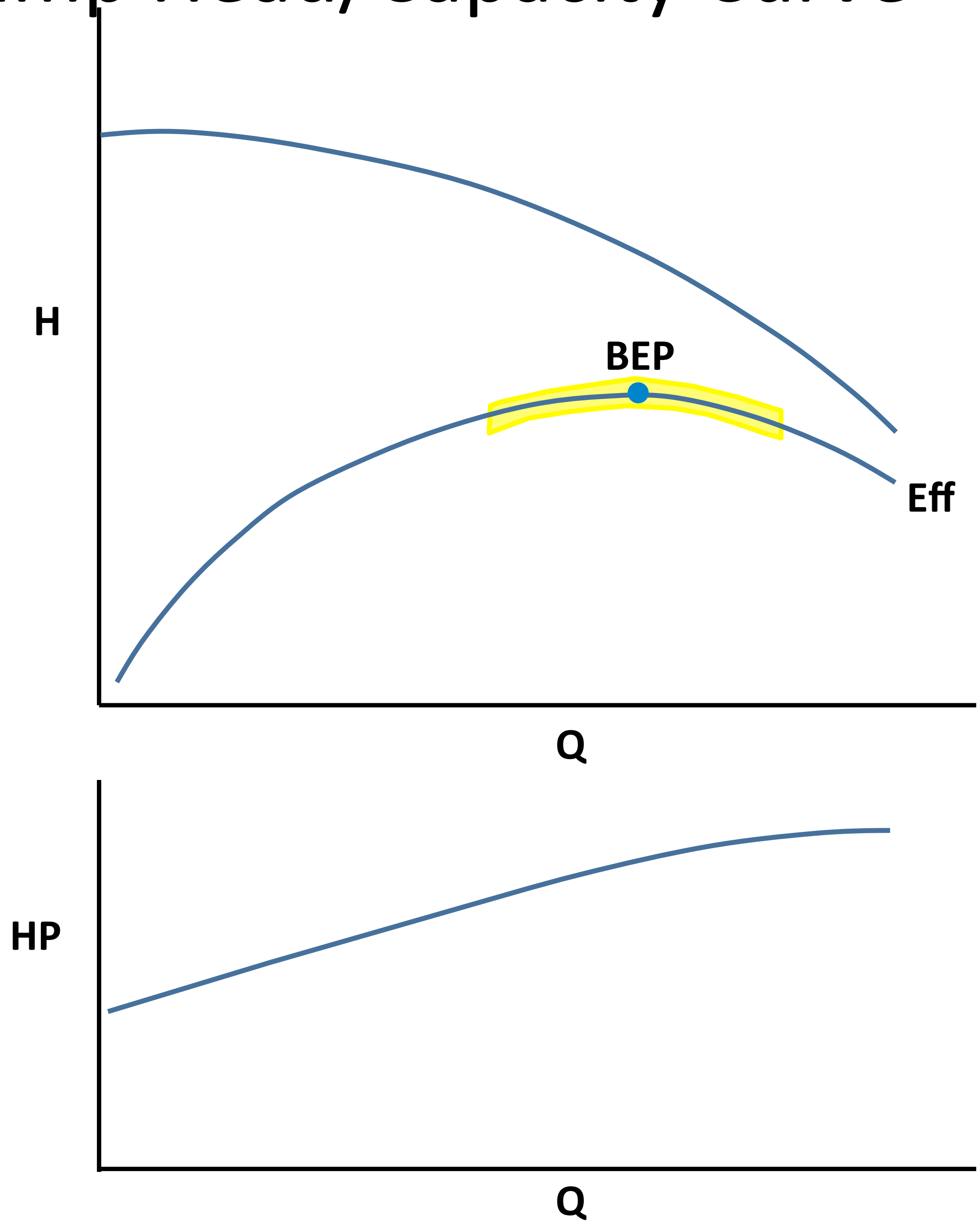
Differential Pressure measured across pumps



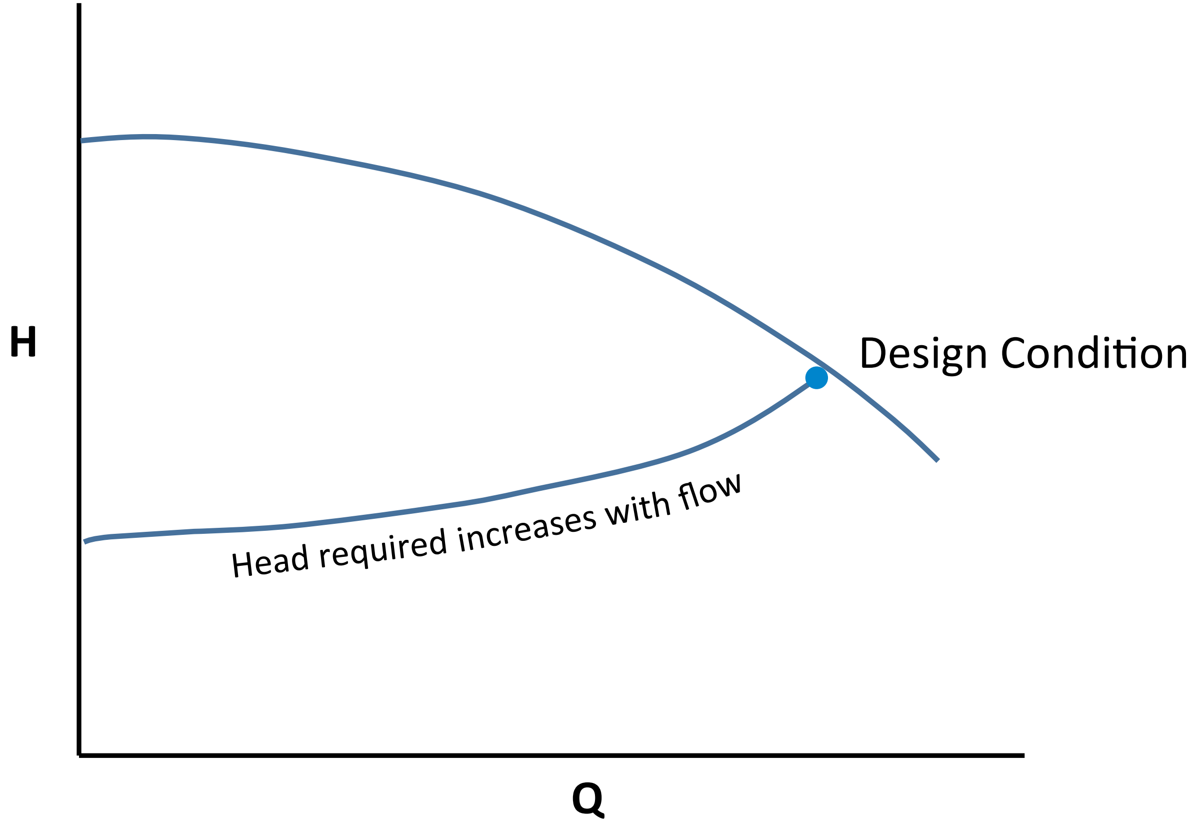
Pressure Boosting



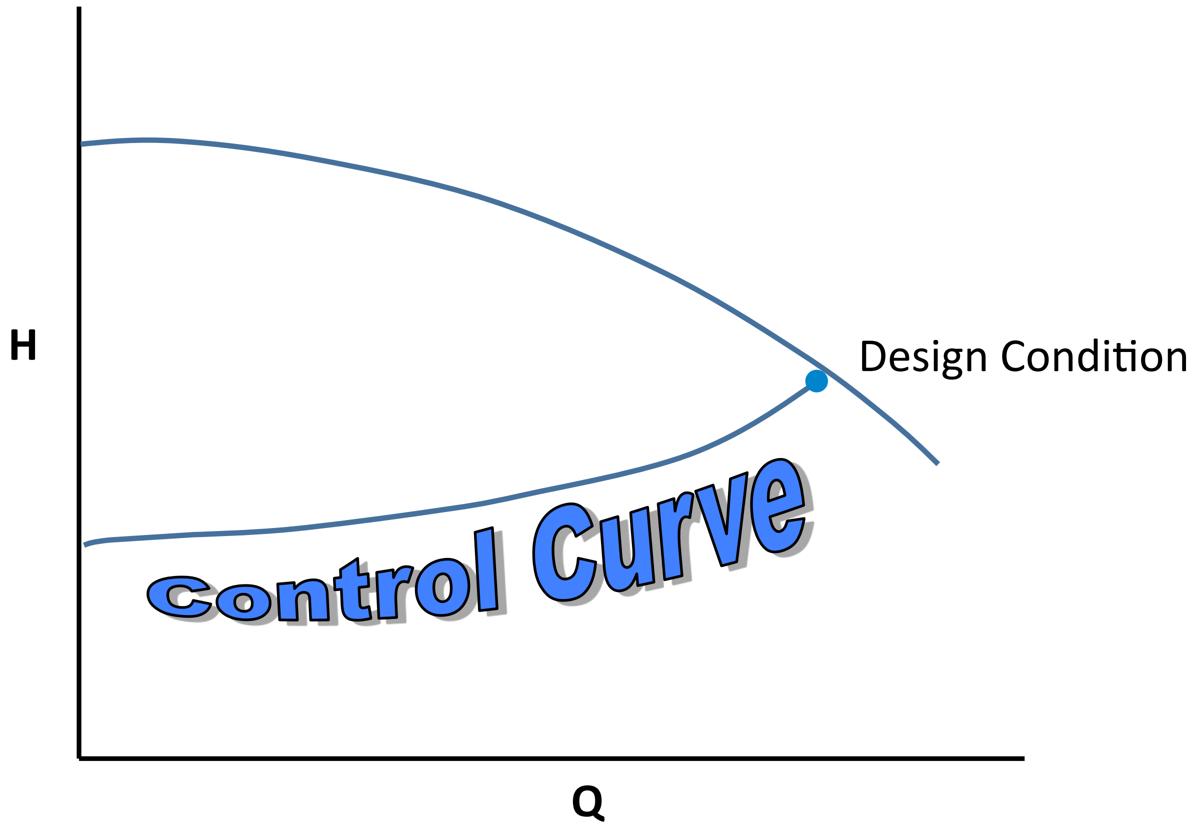
Pump Head/Capacity Curve



Pump Head/Capacity Curve



Pump Head/Capacity Curve



The Affinity Laws

for centrifugal pumps

Flow varies linearly with pump speed > $$\frac{GPM_1}{GPM_2} = \frac{RPM_1}{RPM_2}$$ > $$GPM_2 = GPM_1\left(\frac{RPM_2}{RPM_1}\right)$$

Head varies with the square of the pump speed > $$\frac{TDH_1}{TDH_2} = \left(\frac{RPM_1}{RPM_2}\right)^2$$ > $$TDH_2 = TDH_1\left(\frac{RPM_2}{RPM_1}\right)^2$$

Brake Horsepower varies with the cube of the pump speed > $$\frac{BHP_1}{BHP_2} = \left(\frac{RPM_1}{RPM_2}\right)^3$$ > $$BHP_2 = BHP_1\left(\frac{RPM_2}{RPM_1}\right)^3$$

When TDH_1, RPM_1 and TDH_2 are known:

$$RPM_2 = RPM_1\sqrt{\frac{TDH_2}{TDH_1}}$$

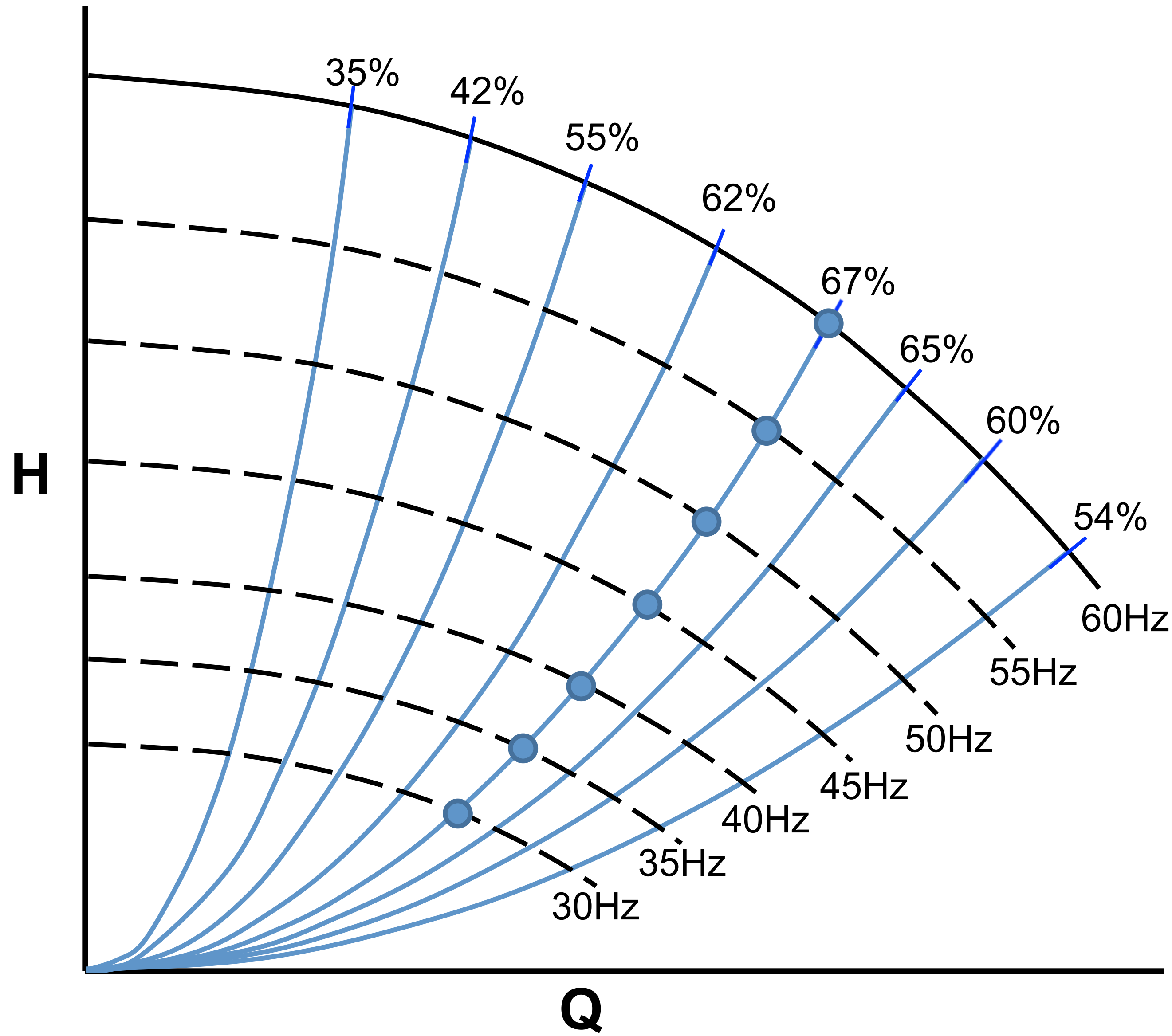
1 = Original condition (full speed)
2 = New condition (reduced speed)

What about efficiency?

Curves of constant efficiency with speed reductions

Remember…..the affinity laws assume constant pump efficiency.

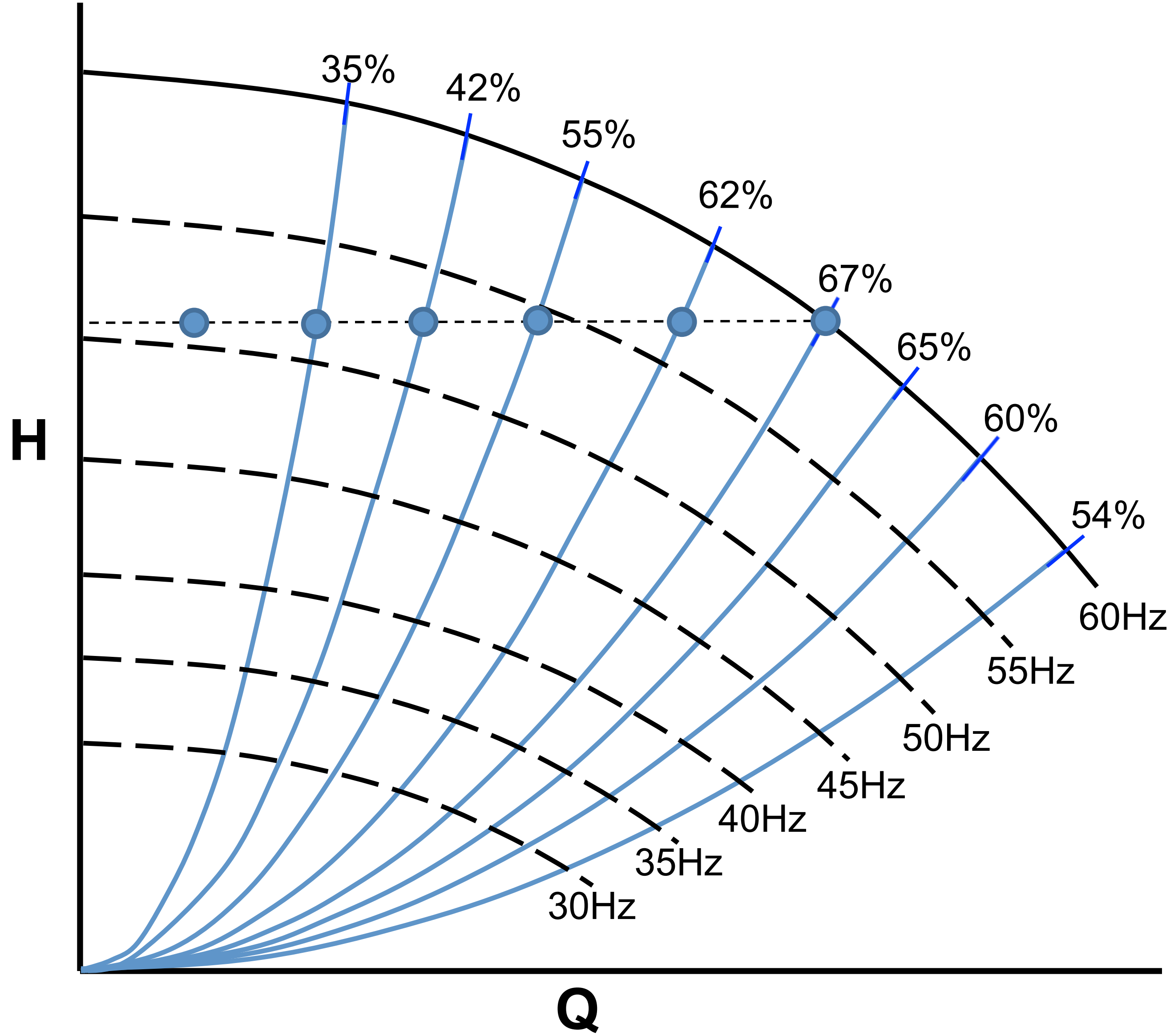
The pump can only run continuously at its **Best Efficiency** Point along a system or control curve that follows a curve of constant efficiency



Curves of constant efficiency with speed reductions

Constant Pressure:

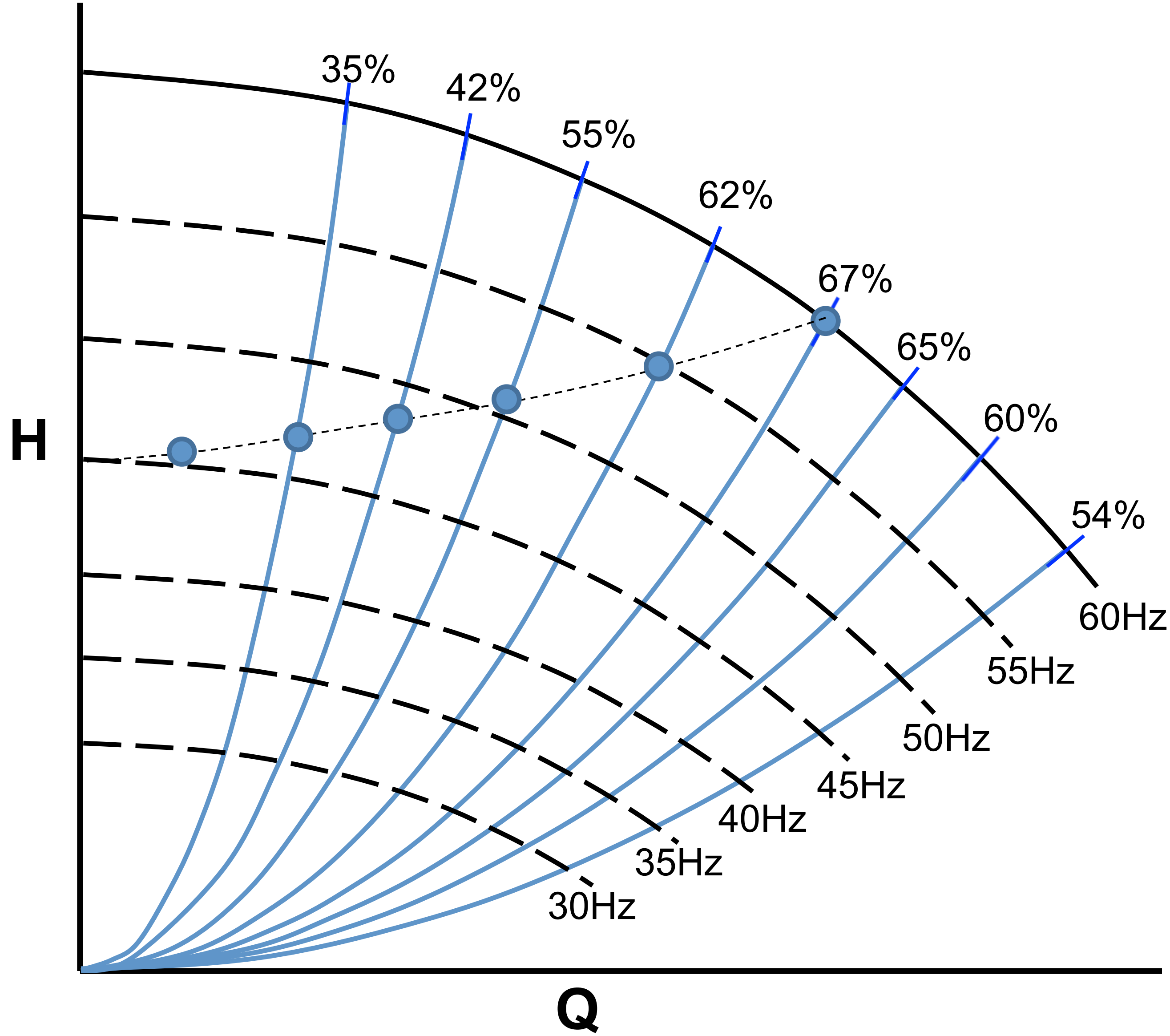
As flow reduces so does pump efficiency!



Curves of constant efficiency with speed reductions

Similarly with HVAC Circulation

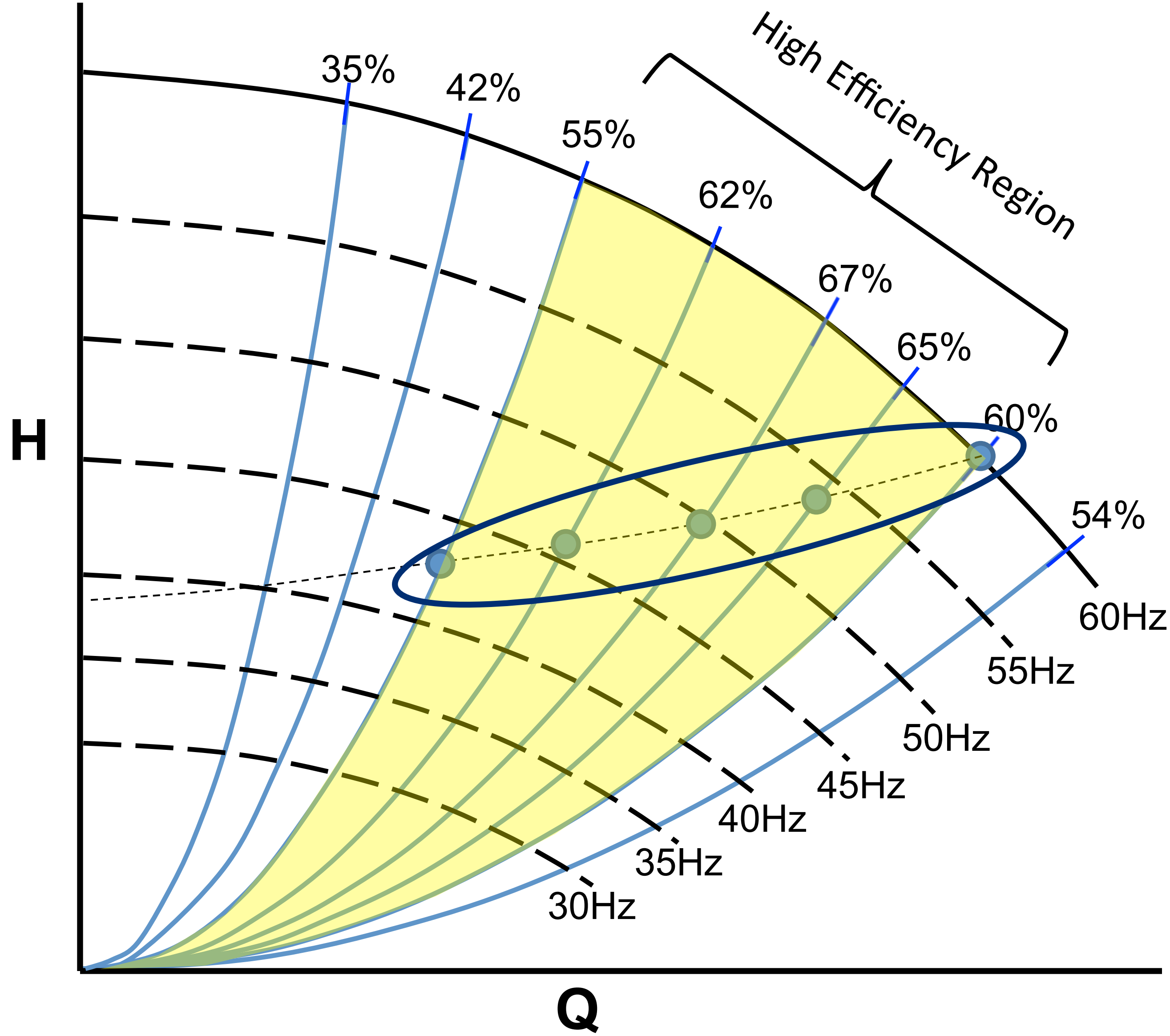
Efficiency also reduces with reducing flow



Curves of constant efficiency with speed reductions

When selecting pumps for variable flow

Select pumps based on a design flow that is to the **RIGHT** of the pumps best efficiency point.



Pump Selection Example

Design Flow: 1000 gpm
Design Head: 75 feet

Pump Selection Example

Design Flow: 1000 gpm
Design Head: 75 feet

Selection Tool Results:

Pump	Pump Speed [rpm]	Pump Efficiency [%]	NPSHr	Max. Power [bhp]	% Max. Diameter	Size [Suc/Dis]
Option 1	1750	83.16	9.25	26.7	97.60	6 x 5
Option 2	1750	82.94	8.39	25.5	81.24	6 x 5
Option 3	1750	80.03	12.7	24.7	81.24	5 x 4
Option 4	1750	78.09	27.2	24.2	92.69	5 x 4
Option 5	1750	83.71	10.1	24.8	89.80	6 x 5

Pump Selection Example

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Design Head: 75 feet

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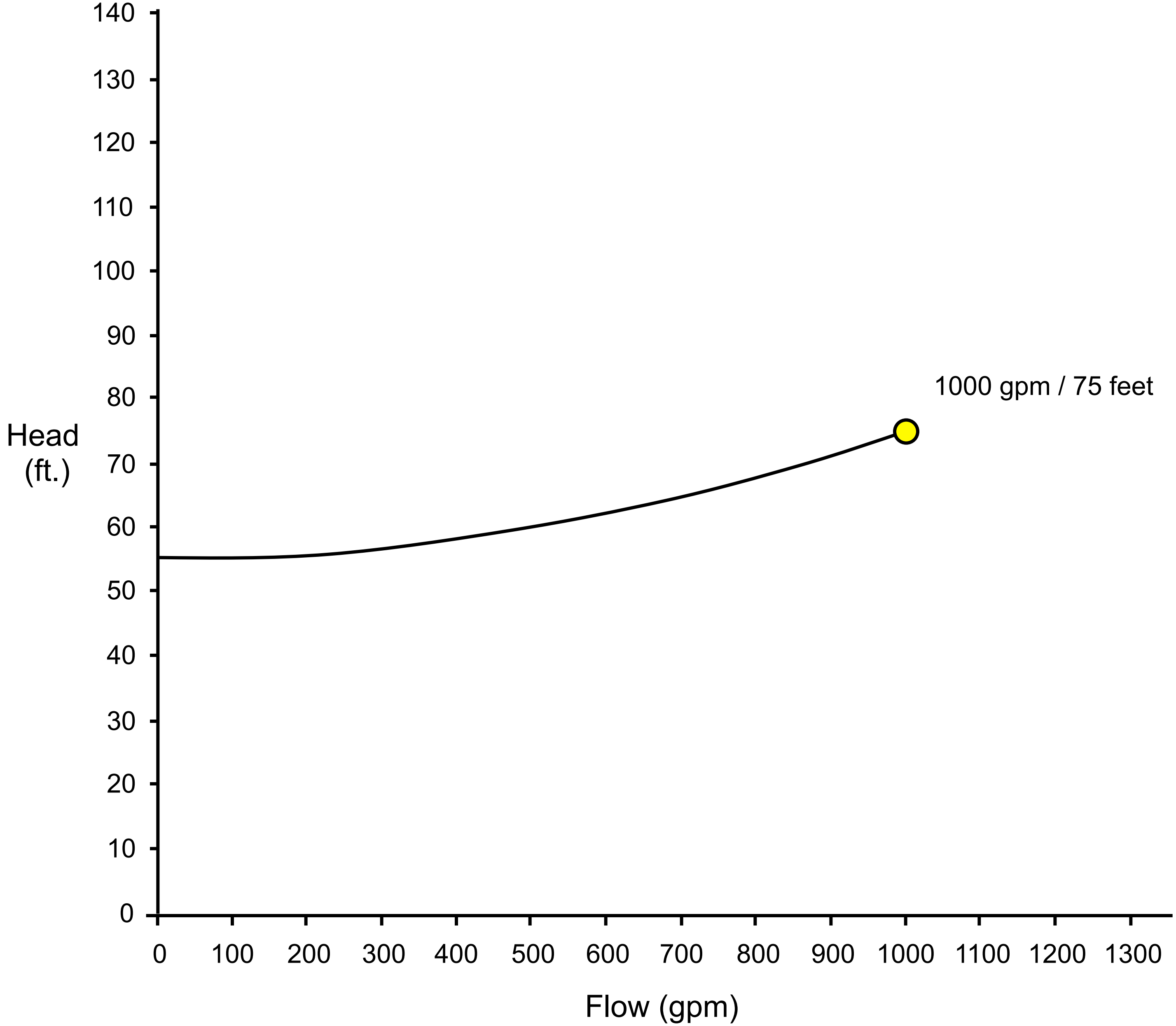
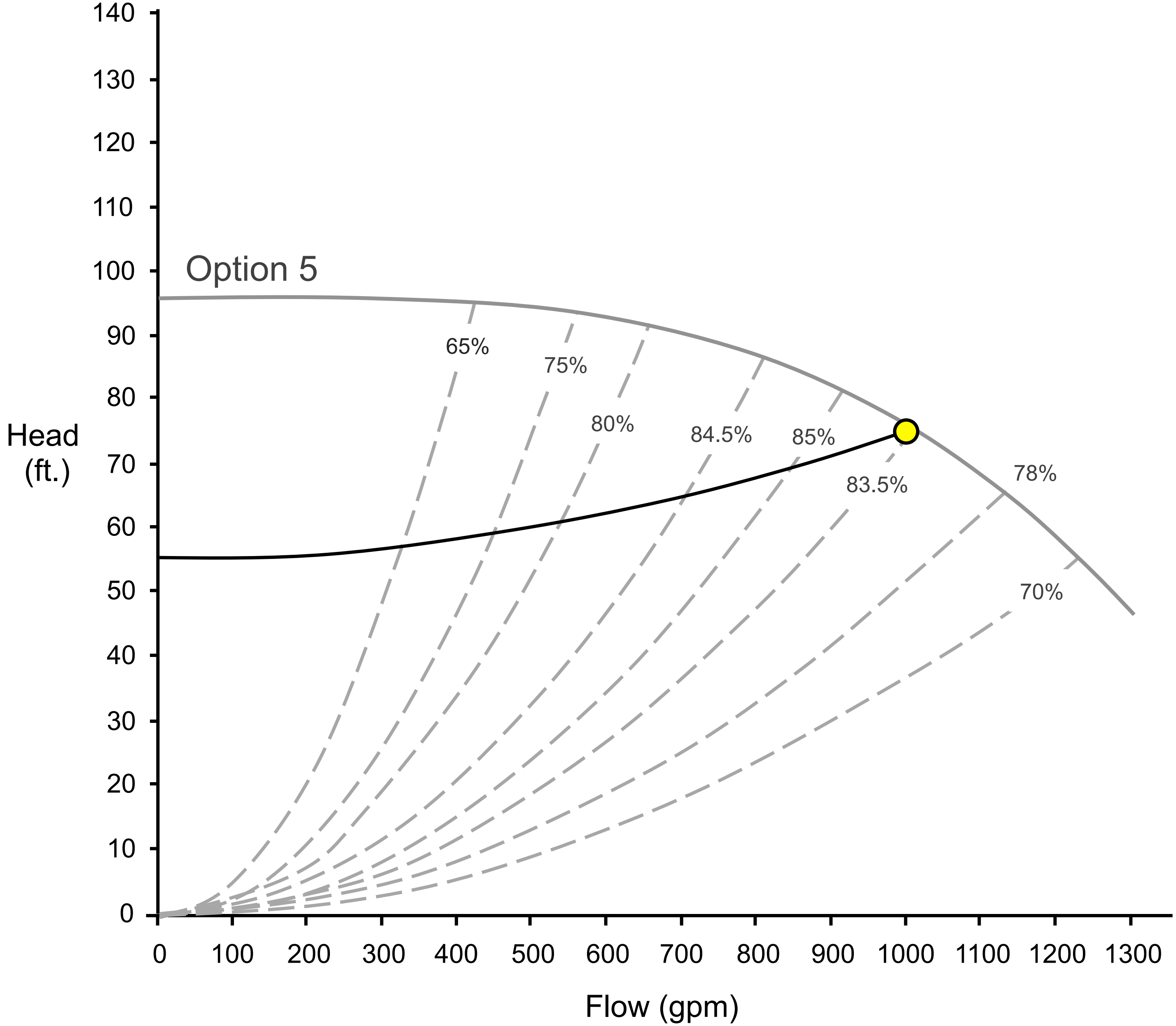
Option 5	1750	83.71	10.1	24.8	89.80	6 x 5

Option 5 = Highest efficiency, but is it the best choice for **variable** flow?

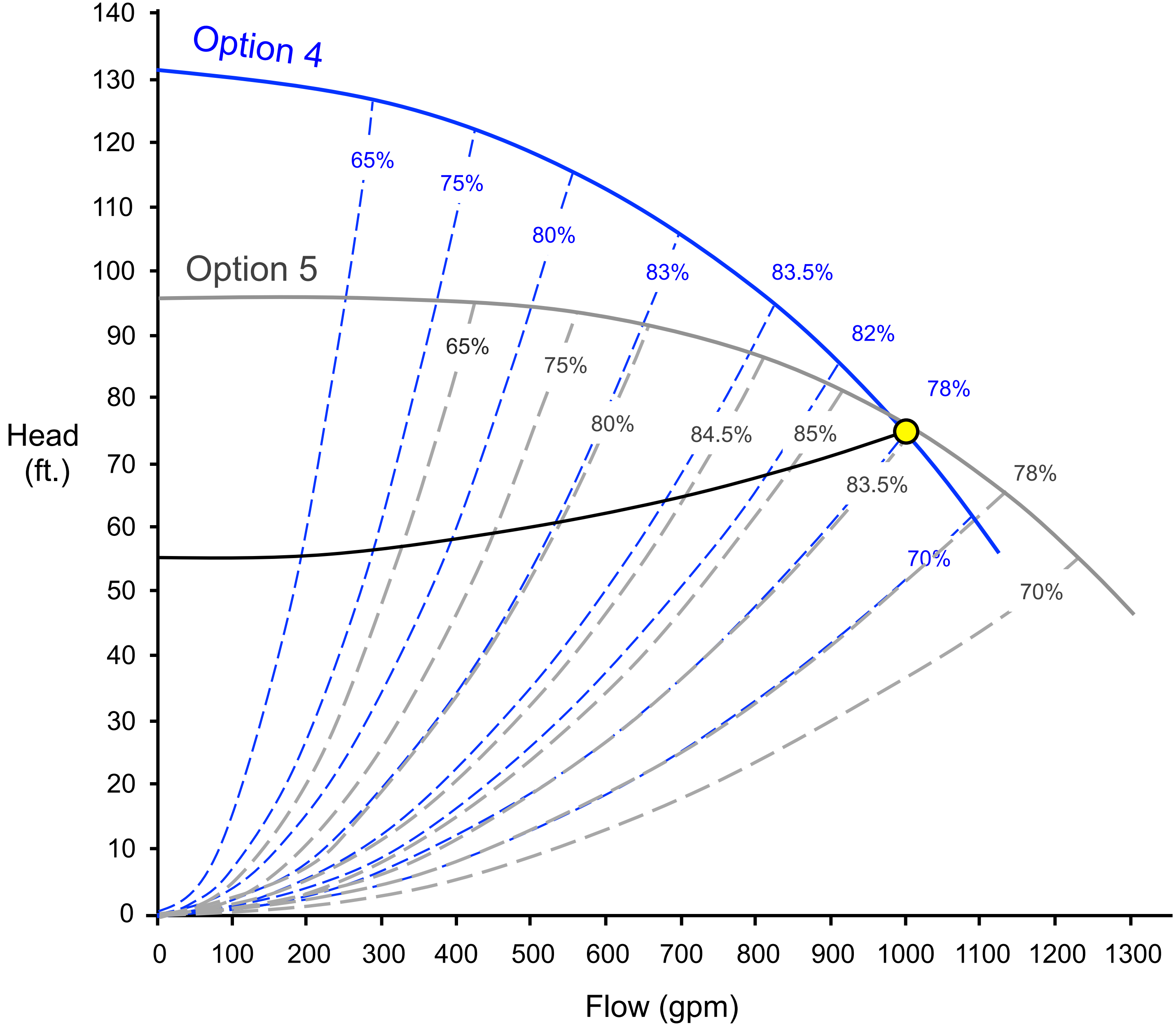
You must look at the pump curves as well as the control curve!



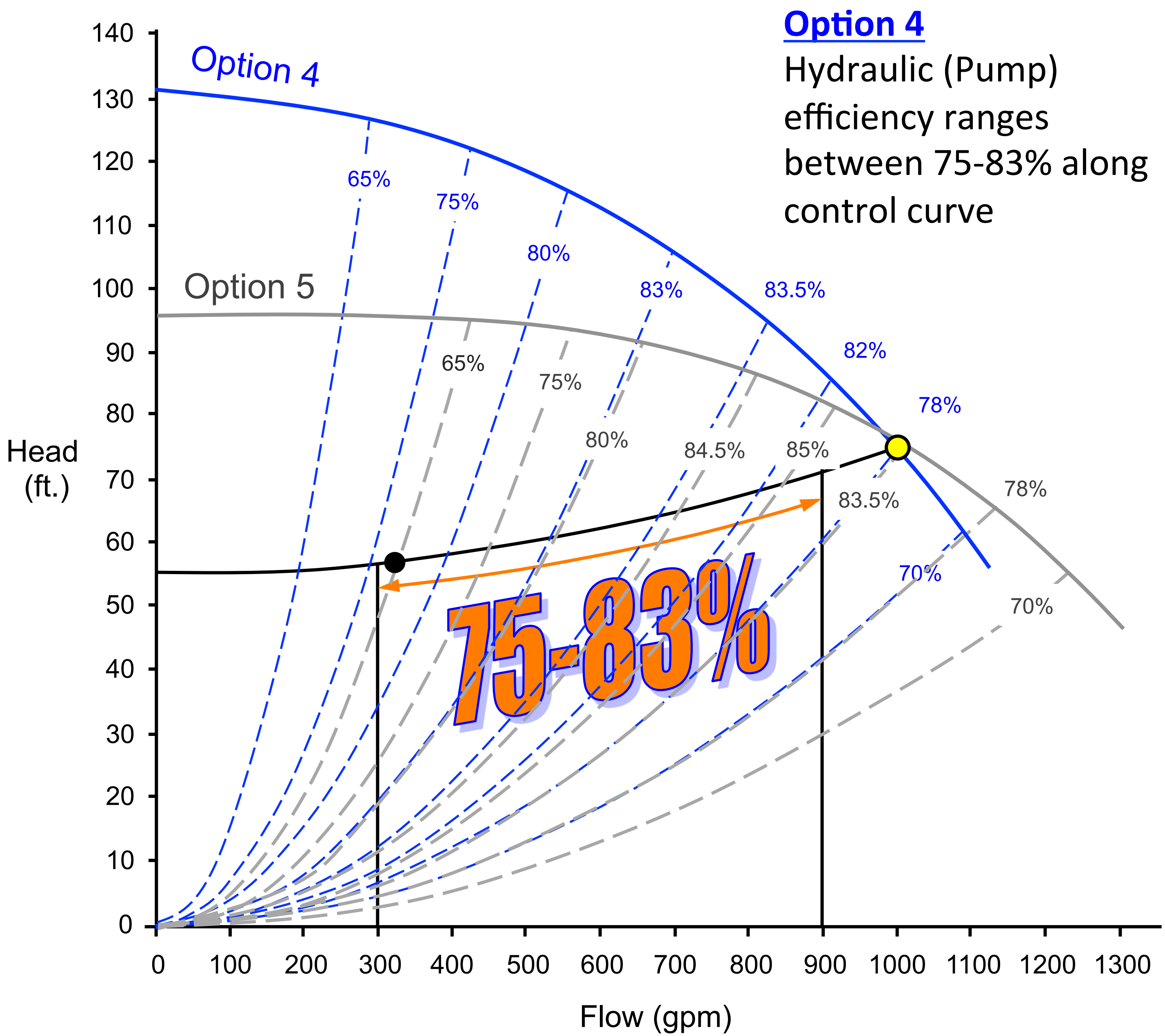
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
Head
(ft.)
1000 gpm / 75 feet
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Flow (gpm)



Option 5
Head (ft.)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
Flow (gpm)
65%
75%
80%
84.5%
85%
83.5%
78%
70%



Option 4
Option 5
Head (ft.)
Flow (gpm)
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
65%
75%
80%
83%
83.5%
82%
78%
70%
65%
75%
80%
84.5%
85%
83.5%
78%
70%



Option 4
Hydraulic (Pump) efficiency ranges between 75-83% along control curve
Option 4
Option 5
65%
75%
80%
83%
83.5%
82%
78%
70%
65%
75%
80%
84.5%
85%
83.5%
78%
70%
75-83%
Head (ft.)
Flow (gpm)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300

Enter Flow Profile - 5 Duty Points

Flow (GPM)	Required TDH, feet	Hours per Day	Hours per Yr
300.0	57	5.0	1,250
500.0	60	4.0	1,000
600.0	62	3.0	750
700.0	65	2.0	500
900.0	71	1.0	250
		15	3,750

Enter Flow Profile - 5 Duty Points

Flow (GPM)	Required TDH, feet	Hours per Day	Hours per Yr
300.0	57	5.0	1,250
500.0	60	4.0	1,000
600.0	62	3.0	750
700.0	65	2.0	500
900.0	71	1.0	250
		15	3,750

Brake Horsepower

Flow	Option 1	Option 2	Option 3	Option 4	Option 5
300	7.3	9.5	6.9	5.7	6.9
500	10.1	12.1	9.8	9.2	9.7
600	11.8	13.6	11.7	11.3	11.4
700	13.9	15.5	14.1	13.7	13.5
900	19.4	19.9	19.9	20.2	19.1

Efficiency

Flow	Option 1	Option 2	Option 3	Option 4	Option 5
300	59.1	45.3	62.8	75.8	62.6
500	75.4	62.6	77.1	82.6	78.5
600	79.6	69.0	80.2	83.6	82.4
700	82.1	74.2	81.6	83.4	84.5
900	83.4	81.1	81.1	80.3	84.7

Energy [kWh]

Flow	Option 1	Option 2	Option 3	Option 4	Option 5
300	7994.2	9978.5	7288.8	6322.3	7310.3
500	8473.2	10164.2	8357.4	7802.3	8212.9
600	7472.7	8611.7	7480.1	7183.3	7267.5
700	5860.5	6464.0	5929.2	5793.9	5715.7
900	4046.4	4165.6	4210.4	4274.1	4031.9
	33847.1	39384.0	33265.9	**31375.8**	32538.4

Pump	Pump Speed [rpm]	Pump Efficiency [%]	NPSHr	Max. Power [bhp]	% Max. Diameter	Size [Suc/Dis]
Option 1	1750	83.16	9.25	26.7	97.60	6 x 5
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Option 4 has the lowest energy consumption, yet the lowest efficiency at the design flow. How many hours do you really run at design flow, if ever…..

Multiple Pump Operation - Parallel

<u>Example:</u>

<u>Basic Requirements</u>

Design Flow: 350 gpm

Design TDH: 90 feet

Question:

Do we just select a 350 gpm pump with a head capacity of 90 feet and be done with it?

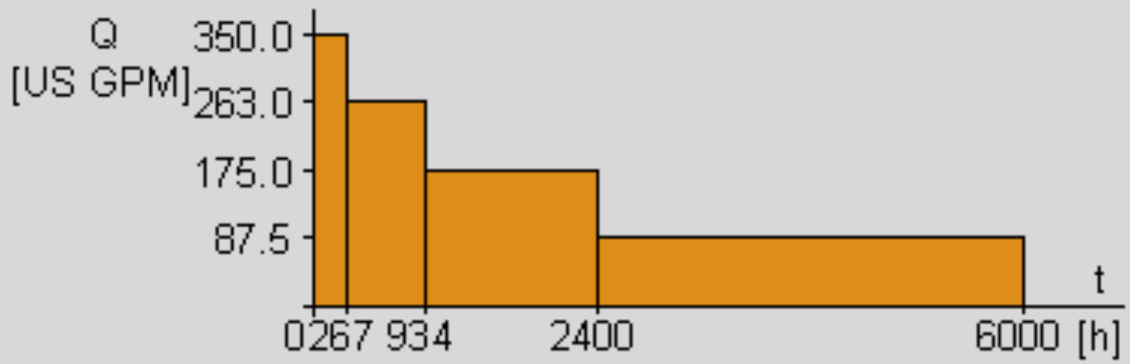
Load Profile

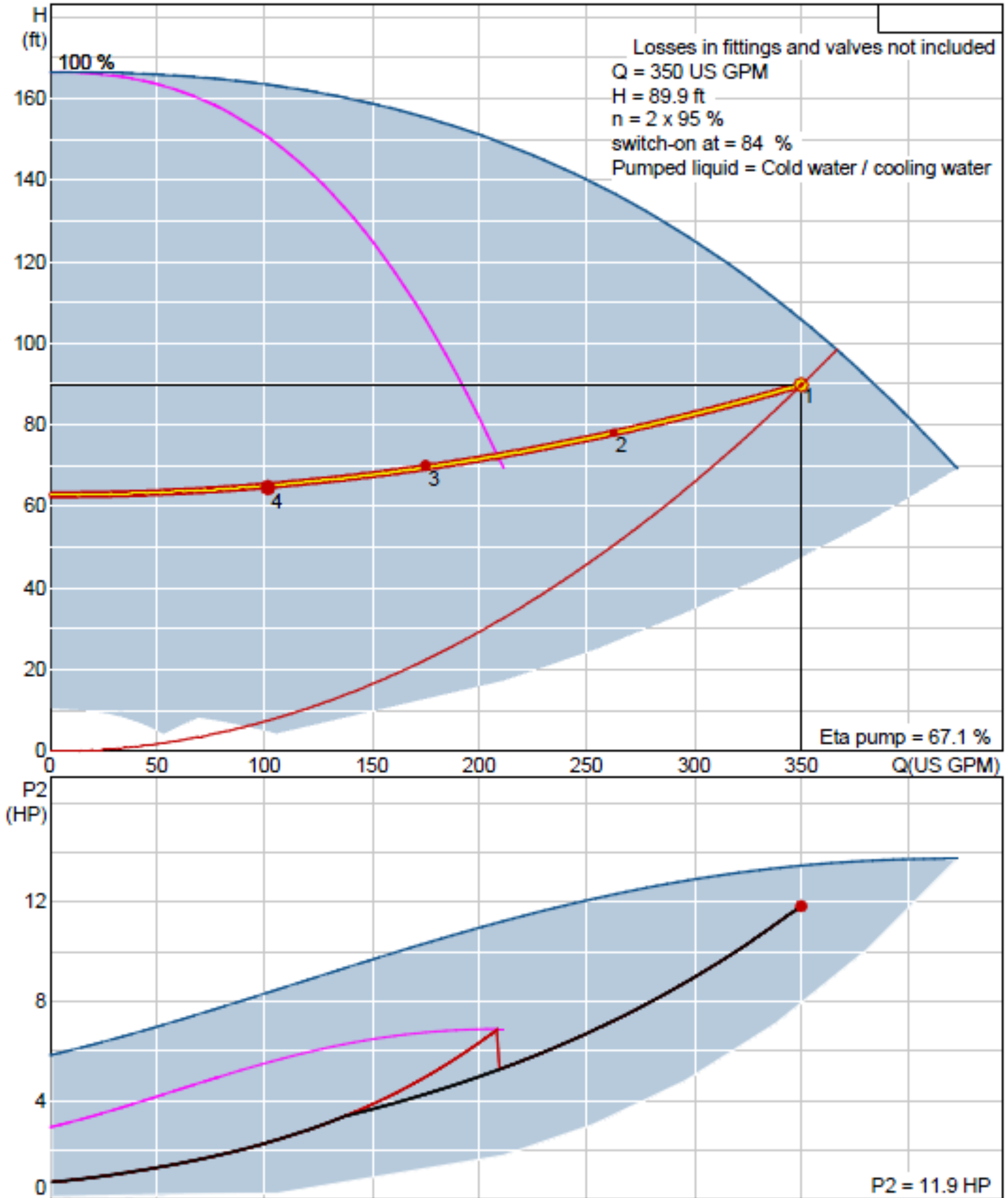
Edit Load Profile

Load profile: User profile

Yearly operation time: 250 days

Duty point	Flow		Q		Hours	
1	100	%	350	US GPM	267	h/a
2	75	%	263	US GPM	667	h/a
3	50	%	175	US GPM	1466	h/a
4	25	%	87.5	US GPM	3600	h/a





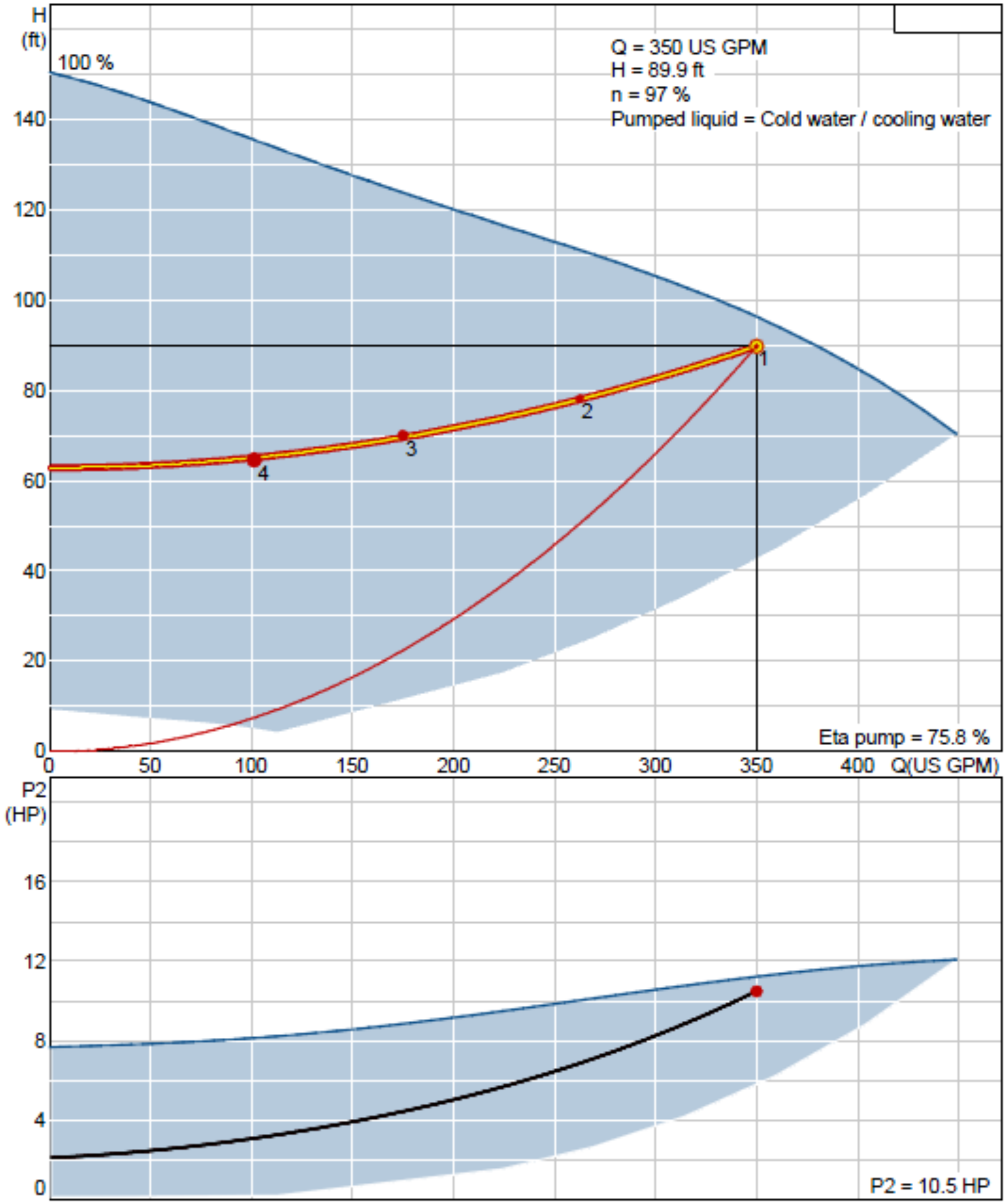
Two 50% pumps:

Design Flow: 350 gpm

Design TDH: 90 feet

Pumps: 2 x 7.5HP

BHP at Design: 11.9



One 100% Pump:

Design Flow: 350 gpm

Design TDH: 90 feet

Pumps: 1 x 15HP

BHP at Design: 10.5

Energy Consumption

1 x 15 HP Pump

Load Profile

	1	2	3	4	
Flow	100	75	50	29	%
Head	100	87	78	72	%
P1	9.57	6.28	4.36	3.26	kW
Time	267	667	1466	3600	h/Year
Energy consumption	2556	4190	6386	11725	kWh/Year

Total = 24,856 kWh/Year

2 x 7.5 HP Pumps

Load Profile

	1	2	3	4	
Flow	100	75	50	29	%
Head	100	87	78	72	%
P1	10.7	6.54	4.08	2.13	kW
Time	267	667	1466	3600	h/Year
Energy consumption	2868	4365	5982	7661	kWh/Year
Quantity	2	2	2	1	

Total = 20,877 kWh/Year

At 75-100% flow the single pump has a lower kW requirement (higher pump/motor efficiency). But pumps generally have higher running hours at lower flow rates therefore the two pump solution is a better choice overall due to the higher pump efficiency at flows less than 50%.

Parallel Connected Pumps - Pump Sequencing

Methods:

> Flow

> Current [Amps]

> Speed

> Demand [set-point not being reached]

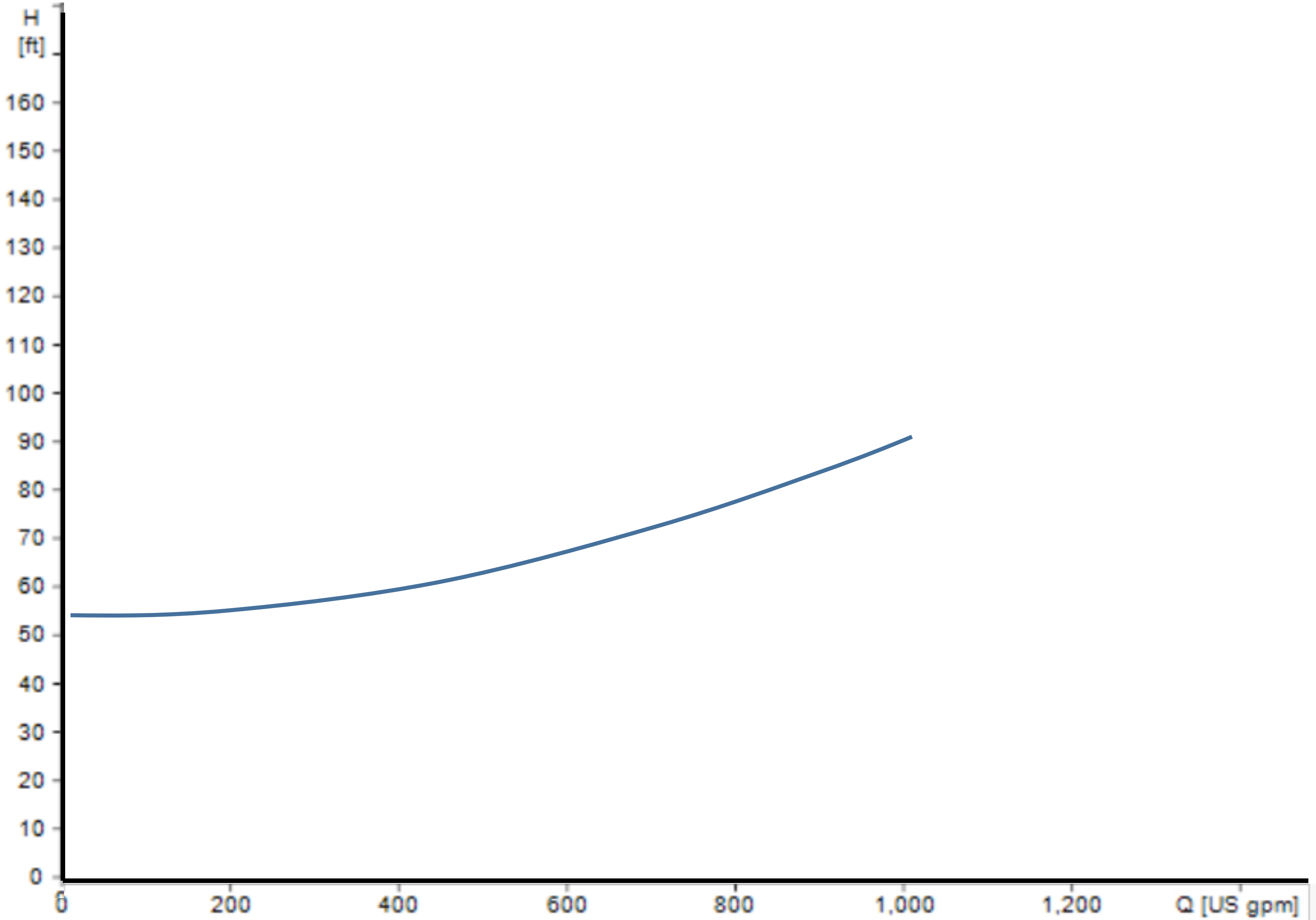
> Efficiency

Which is best?

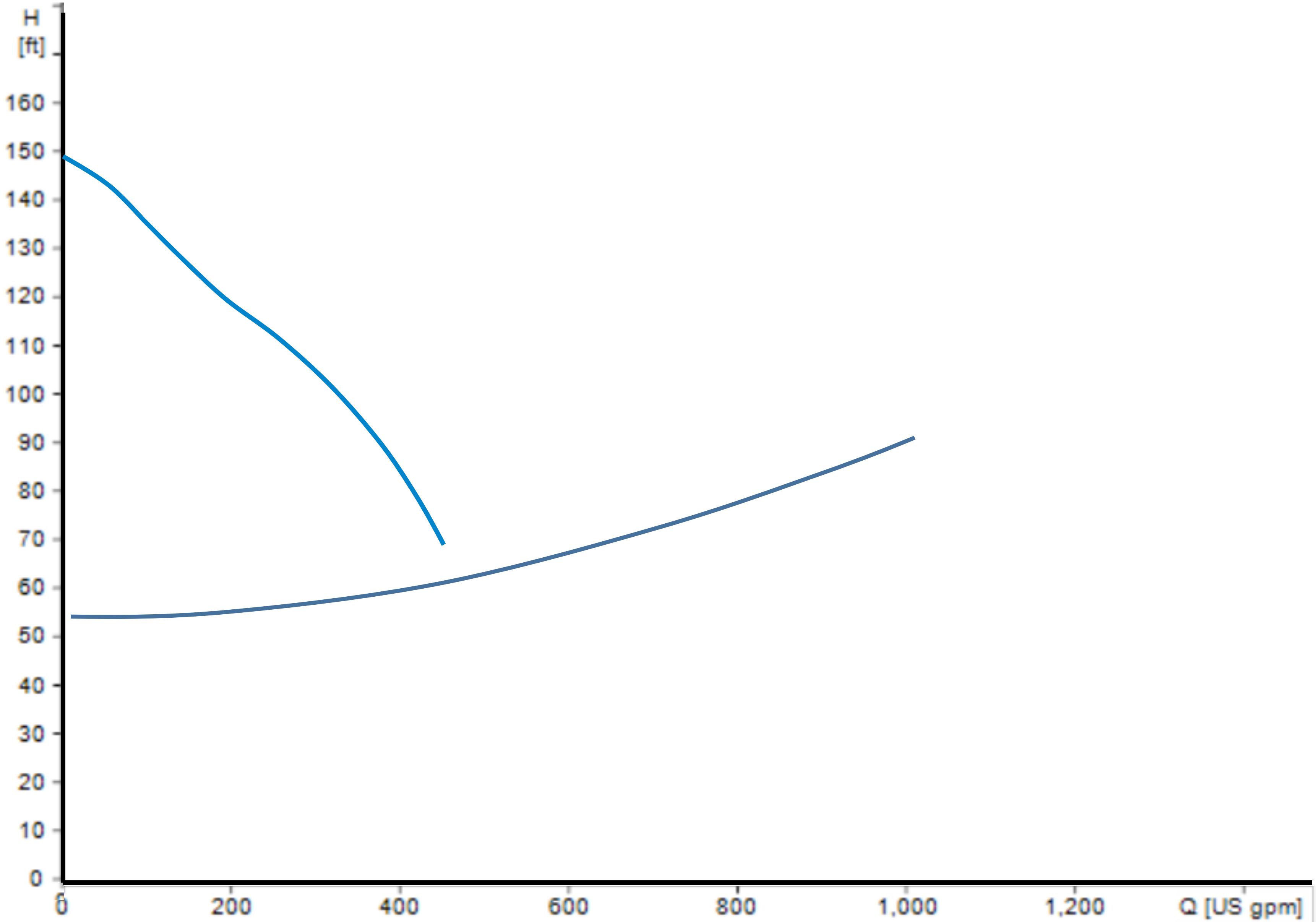
It depends ………….

on a lot of factors

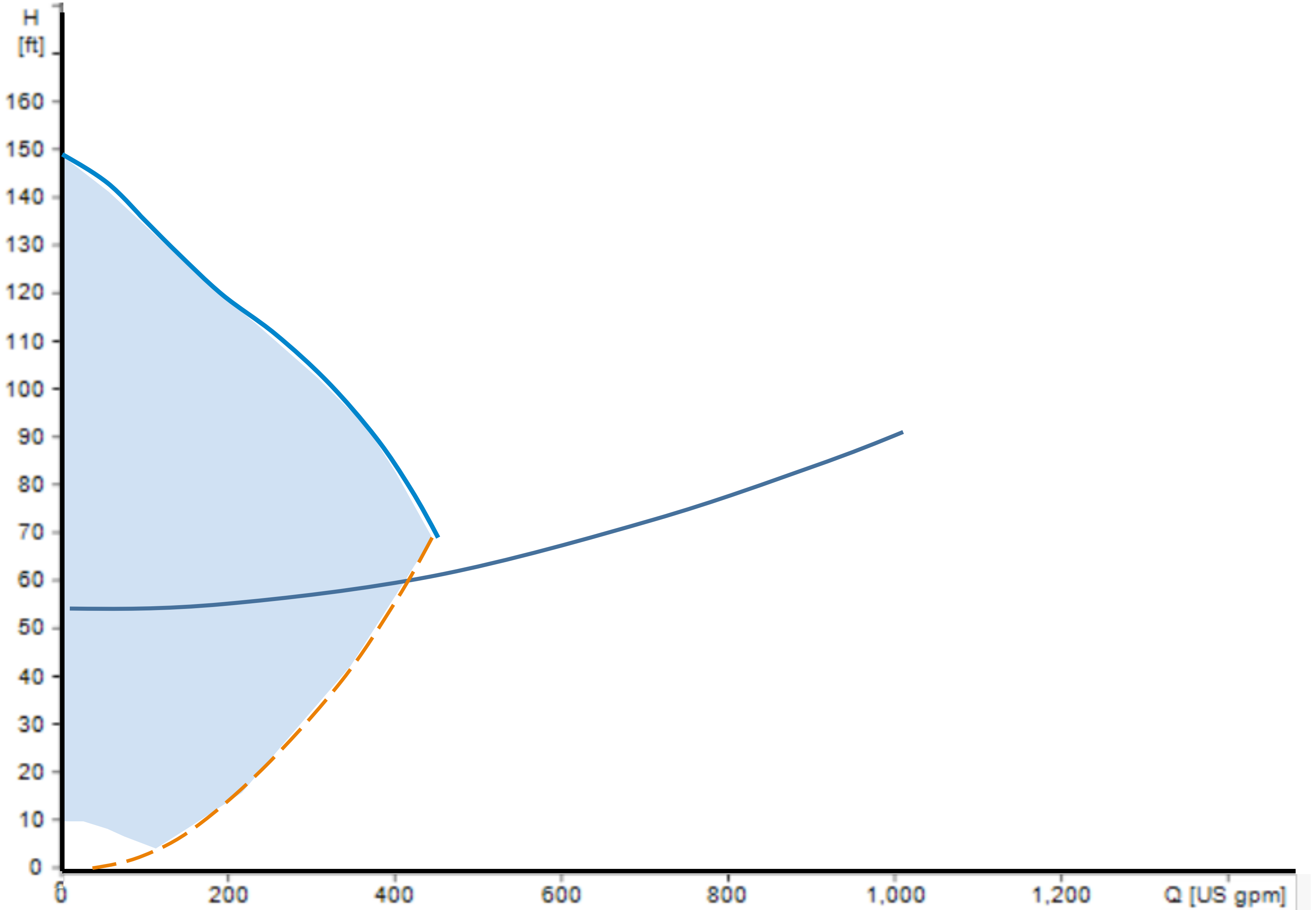
Parallel Connected Pumps - Flow Sequencing



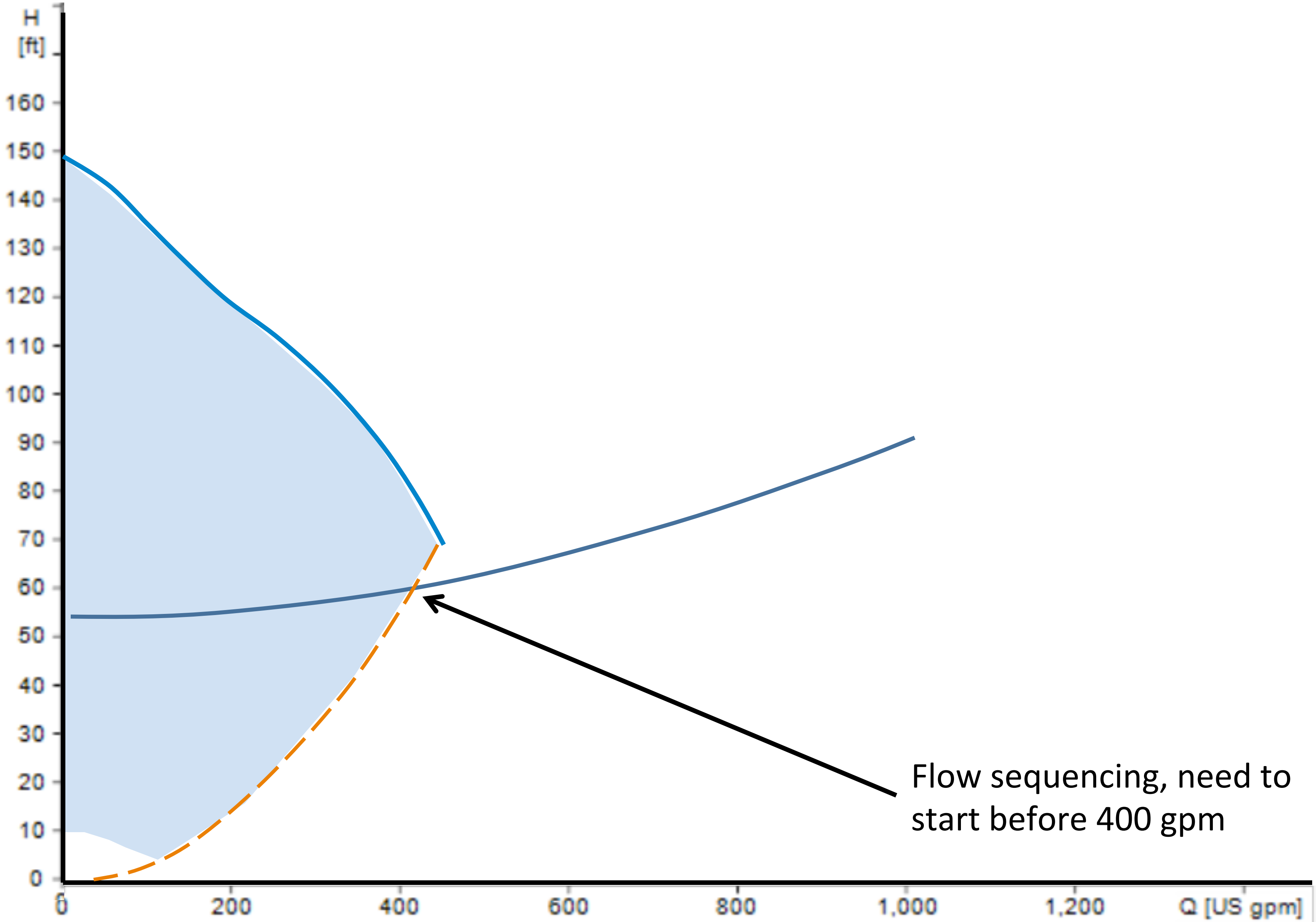
Parallel Connected Pumps - Flow Sequencing



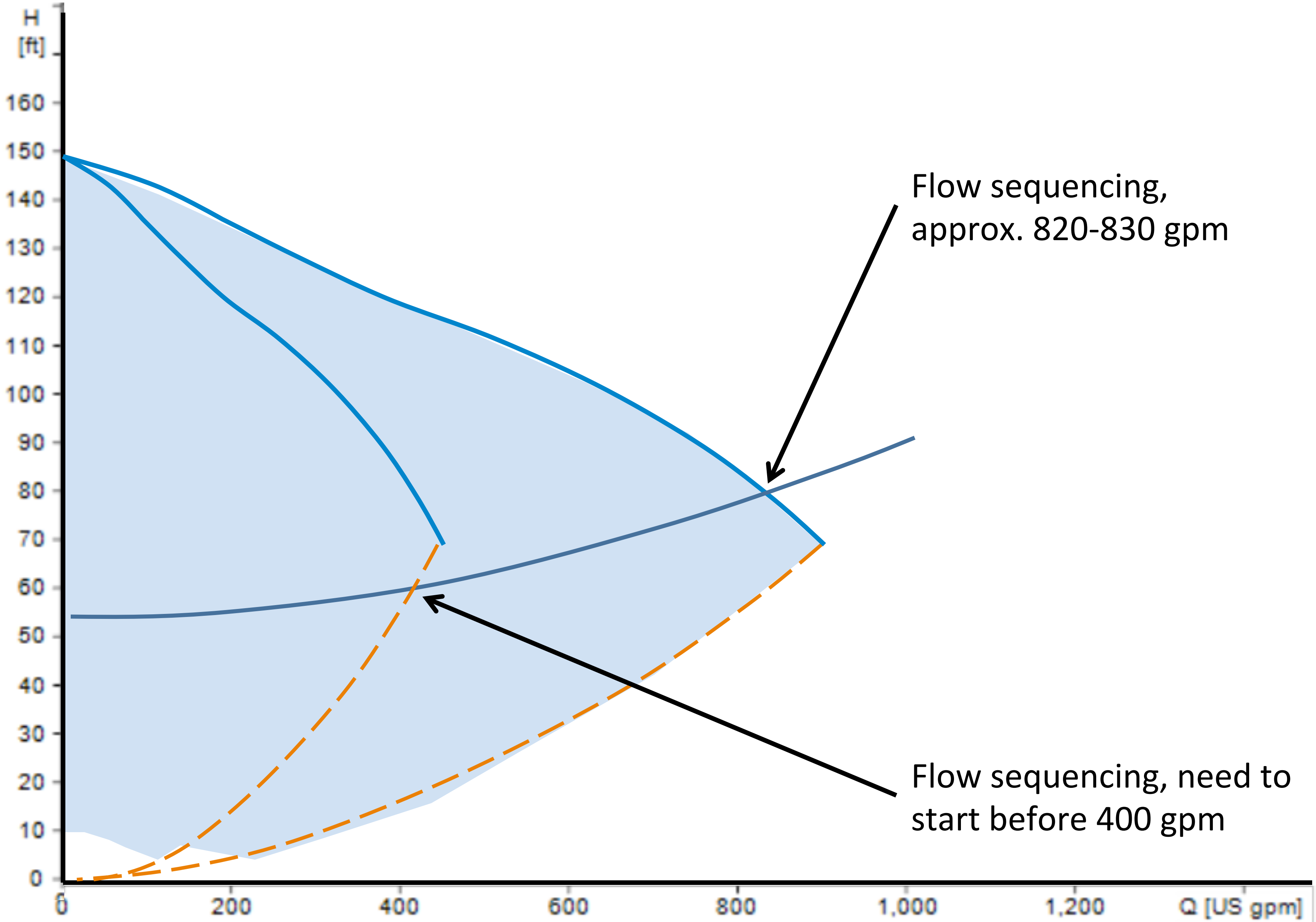
Parallel Connected Pumps - Flow Sequencing



Parallel Connected Pumps - Flow Sequencing



Parallel Connected Pumps - Flow Sequencing



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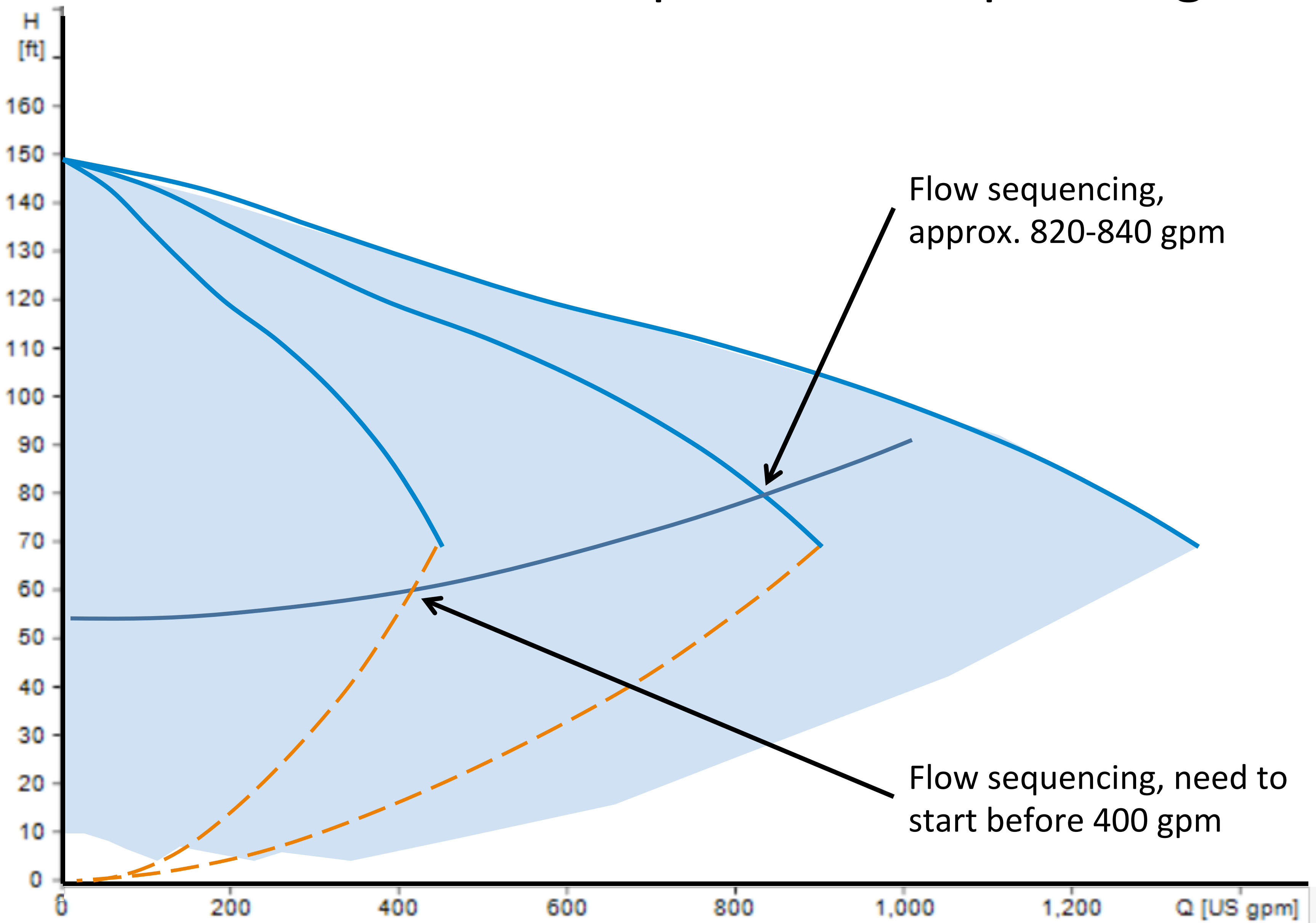
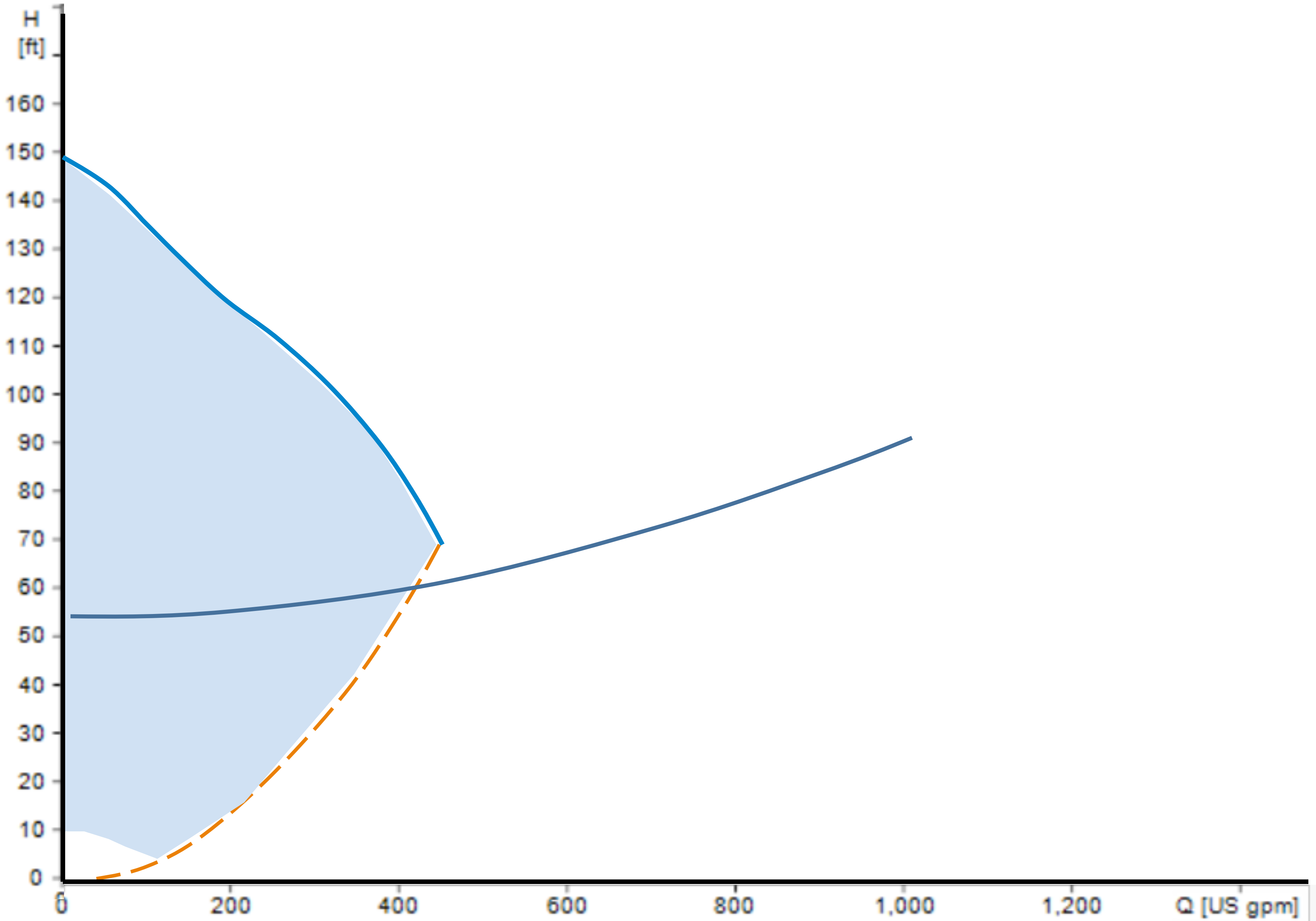
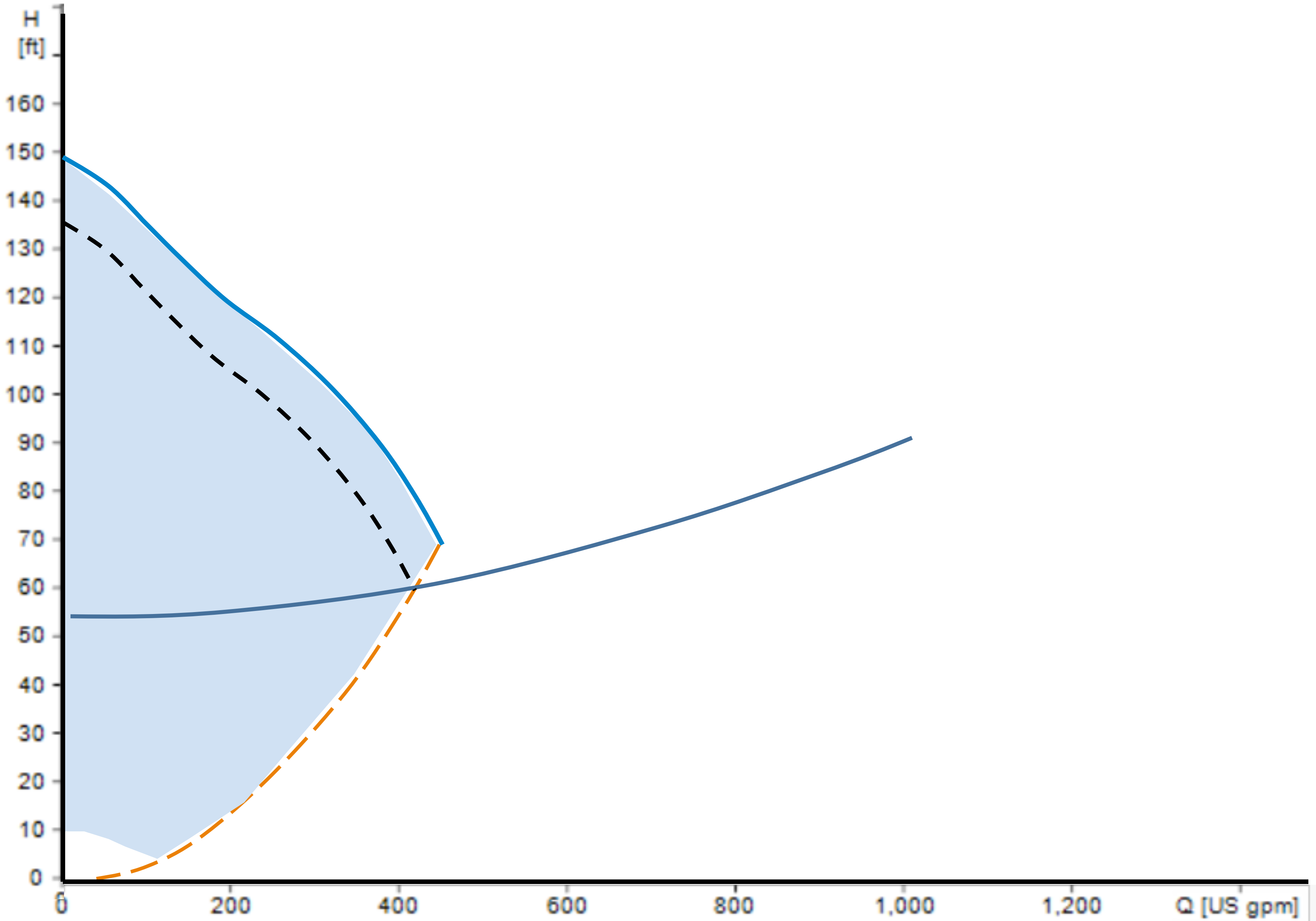


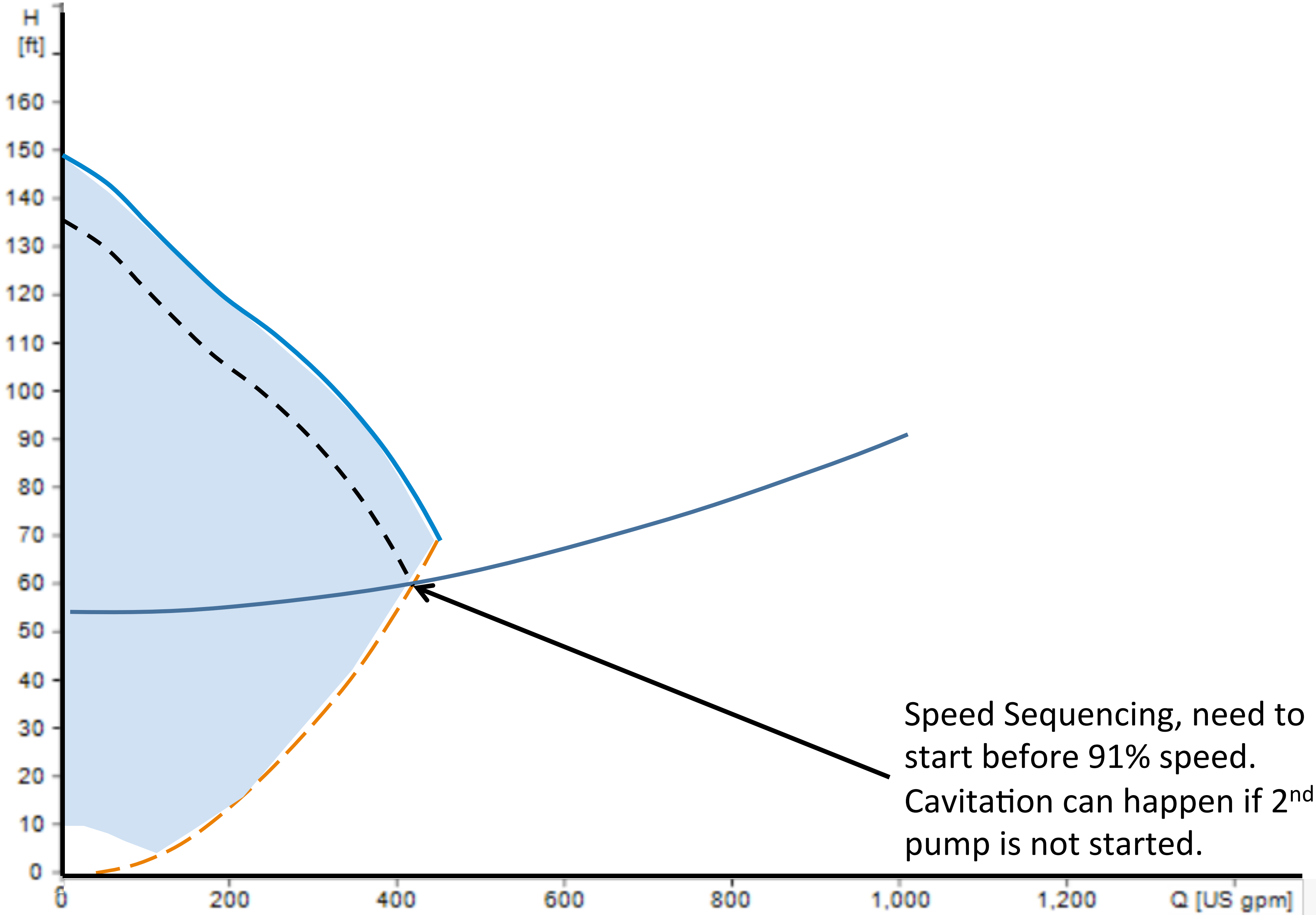
Parallel Connected Pumps – Speed Sequencing



Parallel Connected Pumps – Speed Sequencing

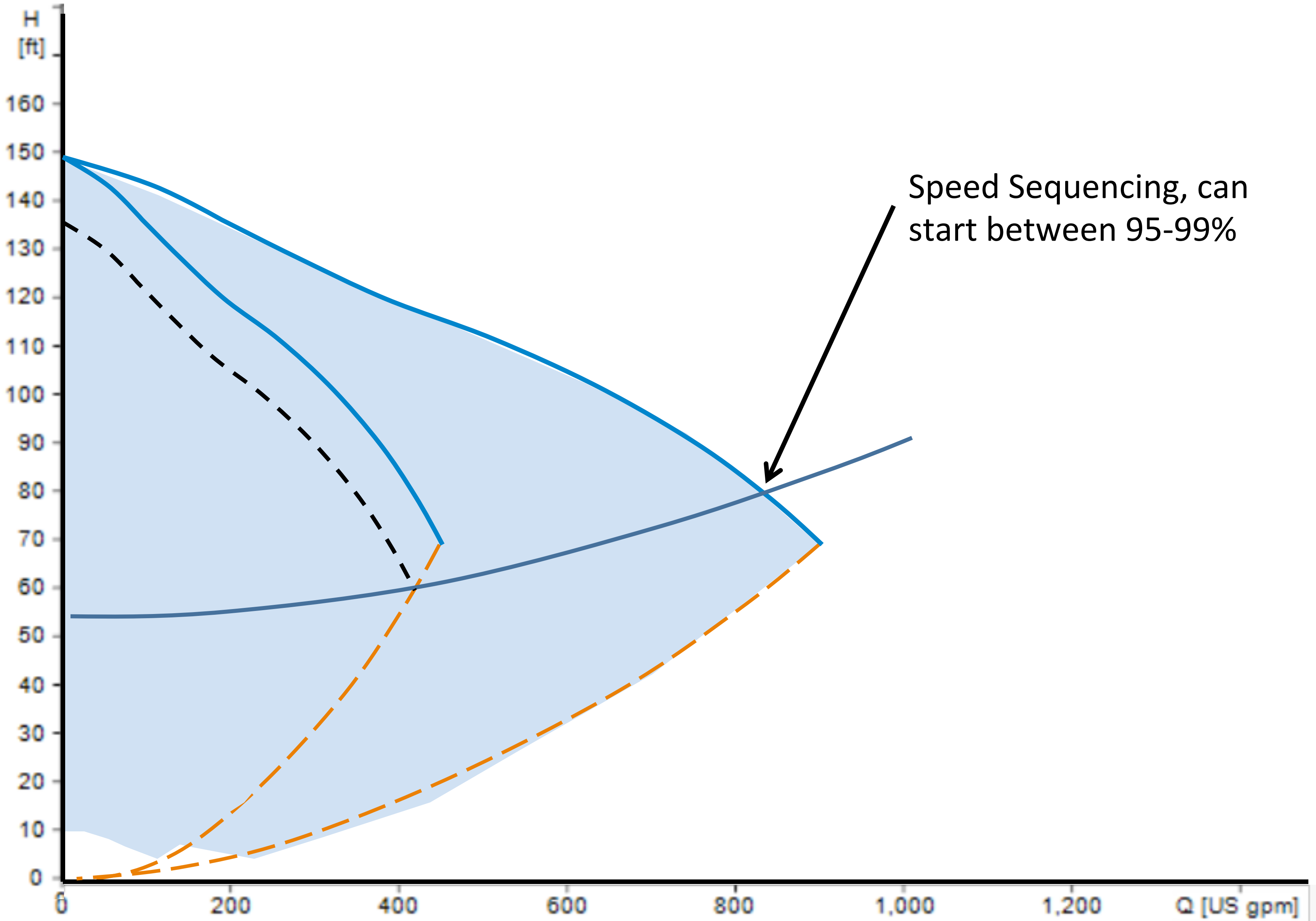


Parallel Connected Pumps – Speed Sequencing

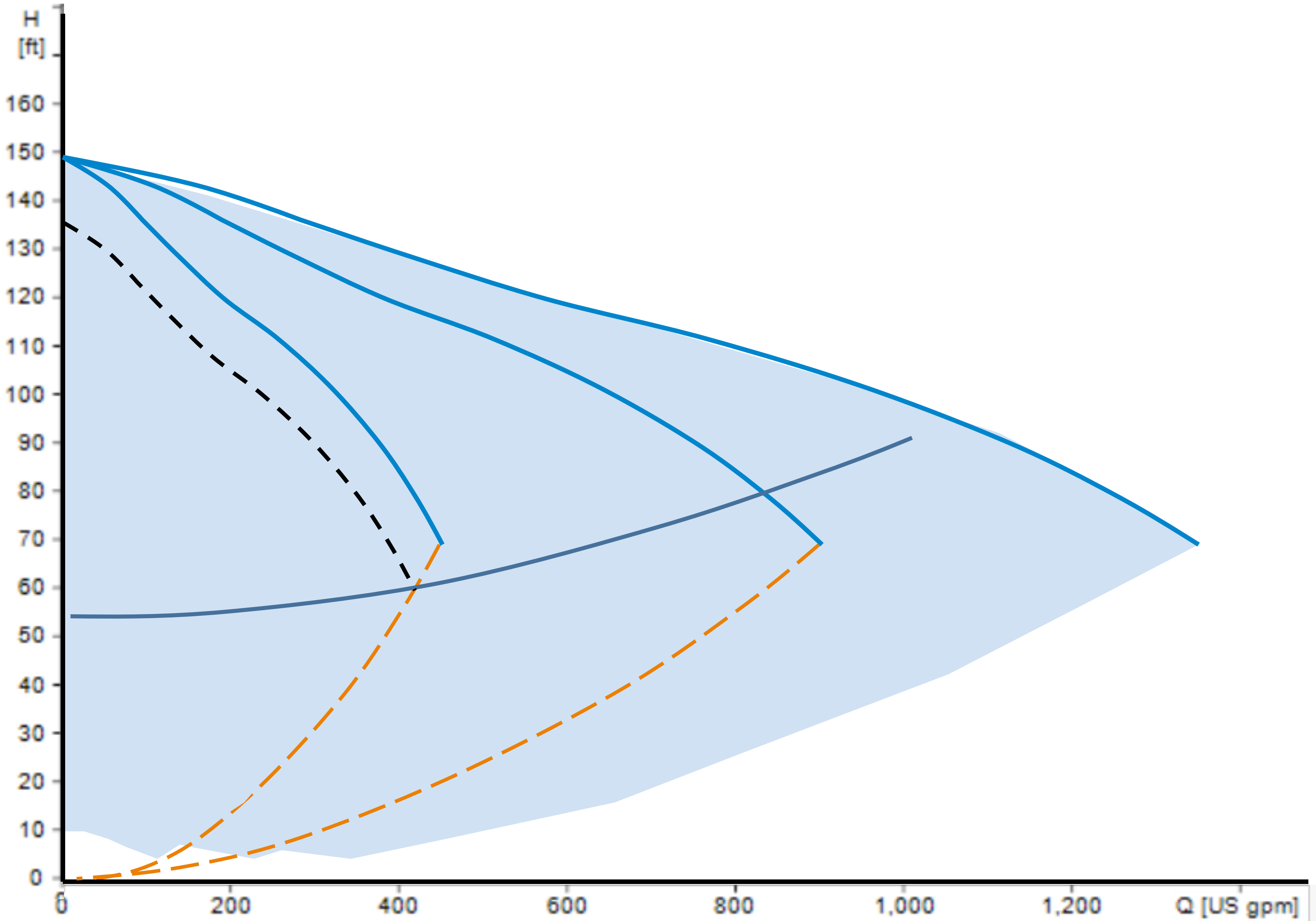


Speed Sequencing, need to start before 91% speed. Cavitation can happen if 2nd pump is not started.

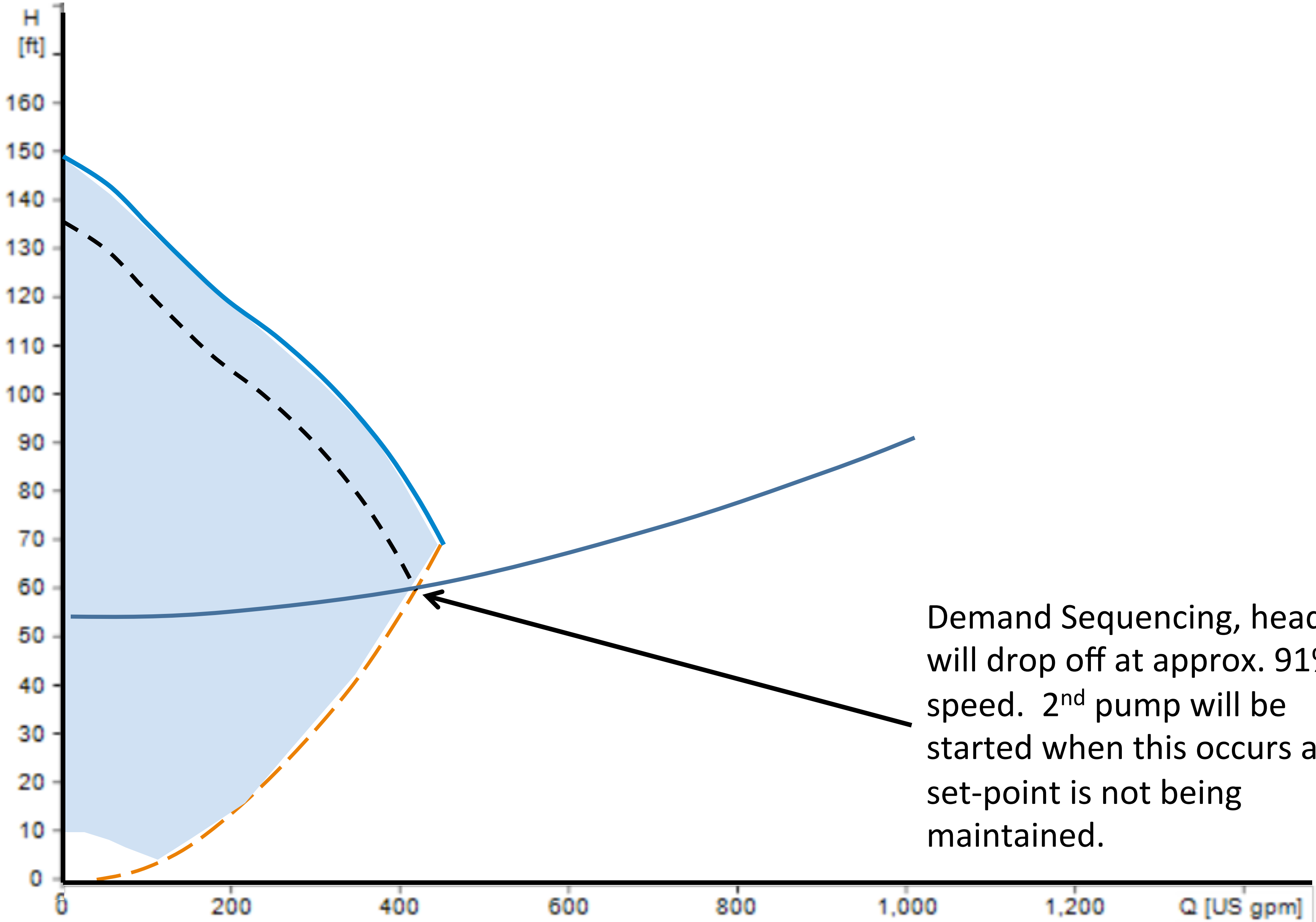
Parallel Connected Pumps – Speed Sequencing



Parallel Connected Pumps – Speed Sequencing

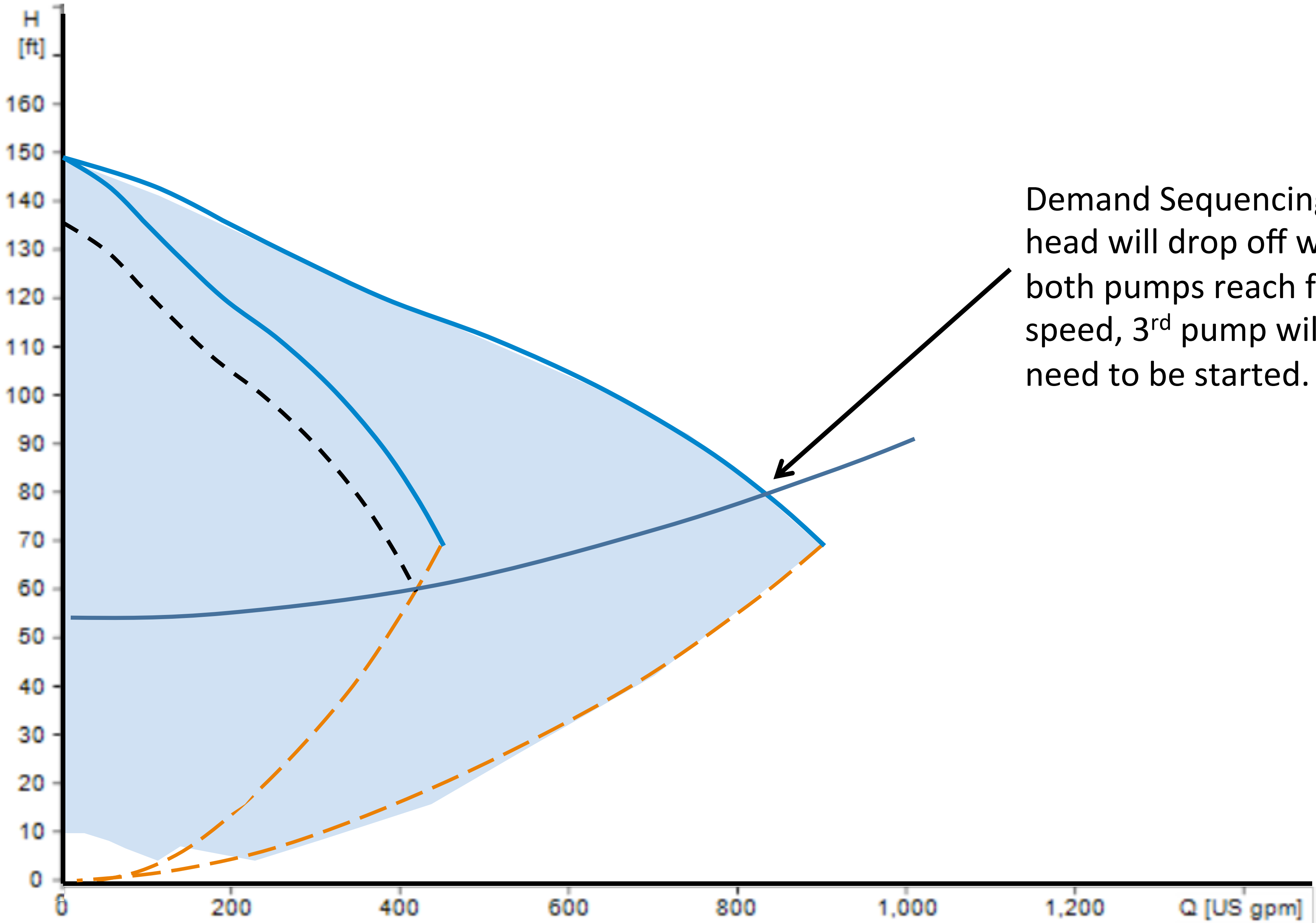


Parallel Connected Pumps – Demand Sequencing



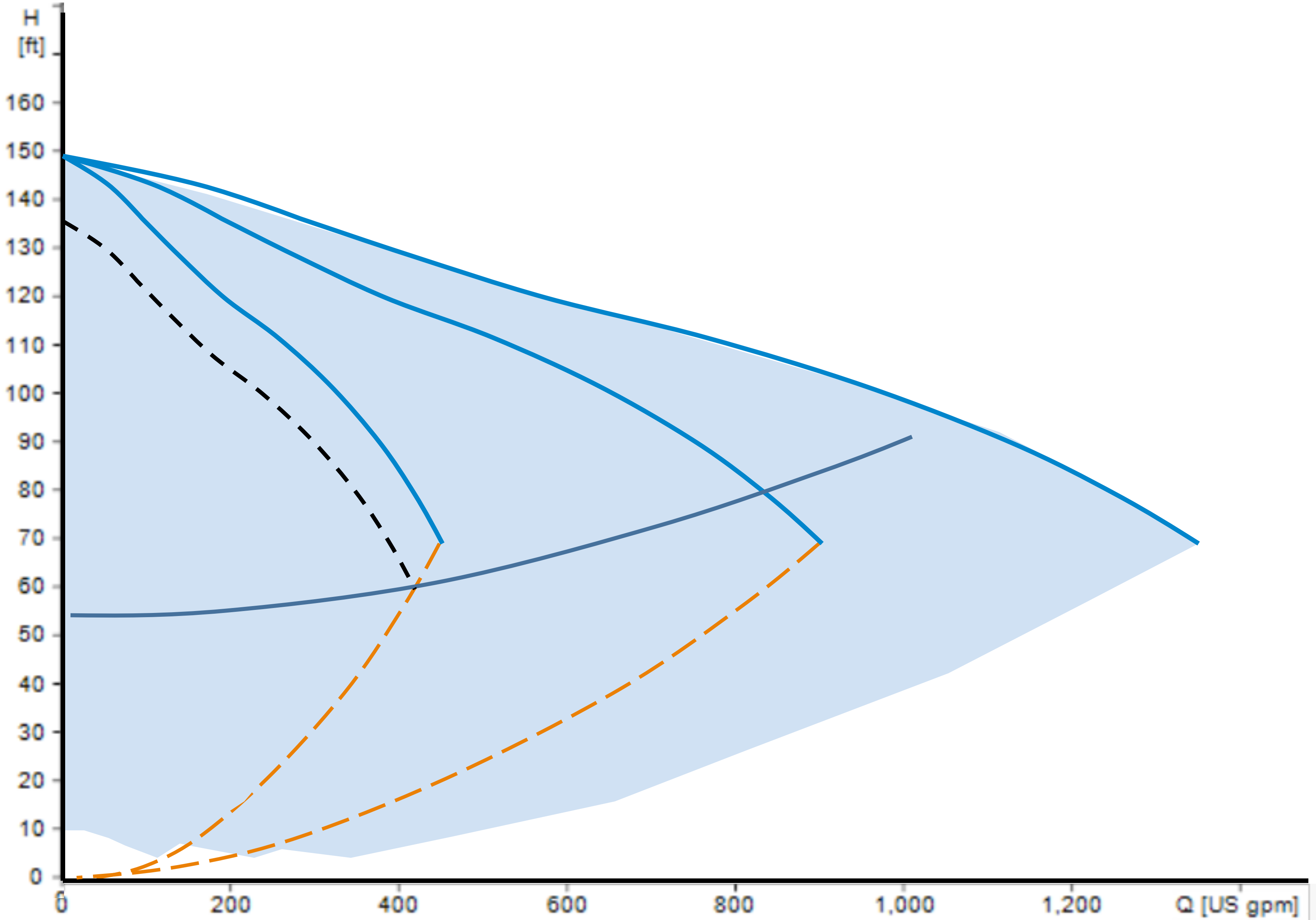
Demand Sequencing, head will drop off at approx. 91% speed. 2nd pump will be started when this occurs as set-point is not being maintained.

Parallel Connected Pumps – Demand Sequencing

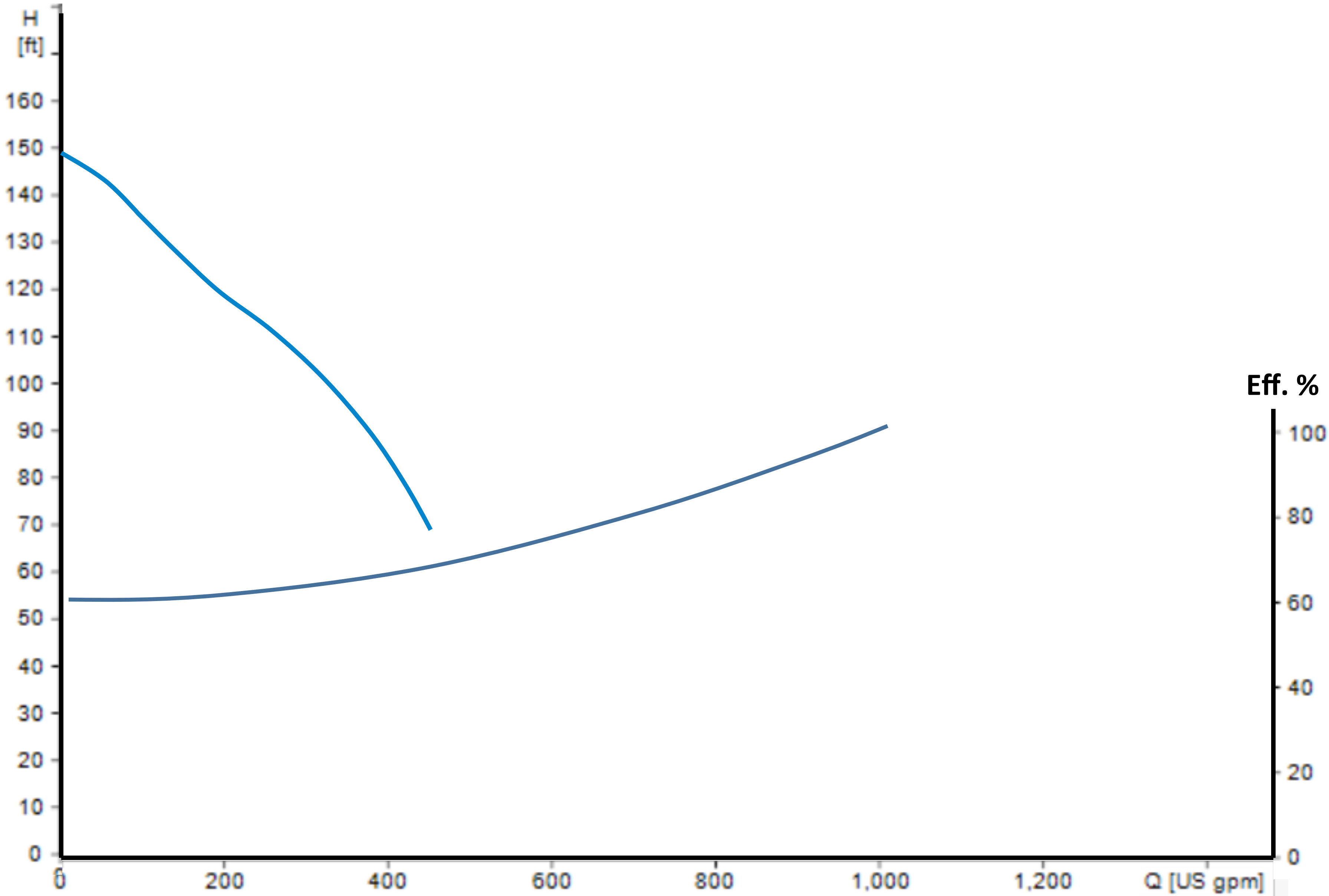


Demand Sequencing, head will drop off when both pumps reach full speed, 3rd pump will need to be started.

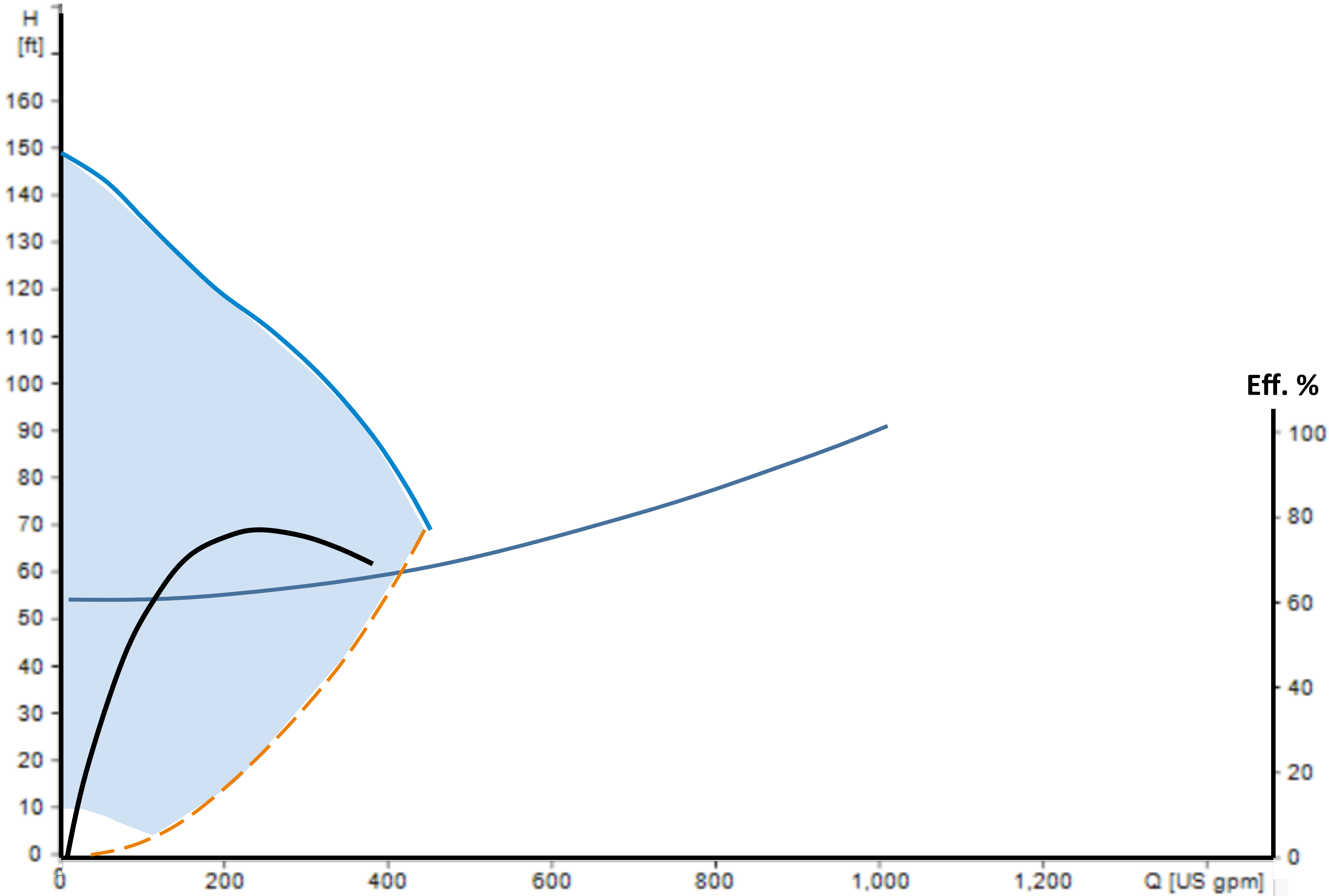
Parallel Connected Pumps – Demand Sequencing



Parallel Connected Pumps - Efficiency Sequencing



Parallel Connected Pumps - Efficiency Sequencing



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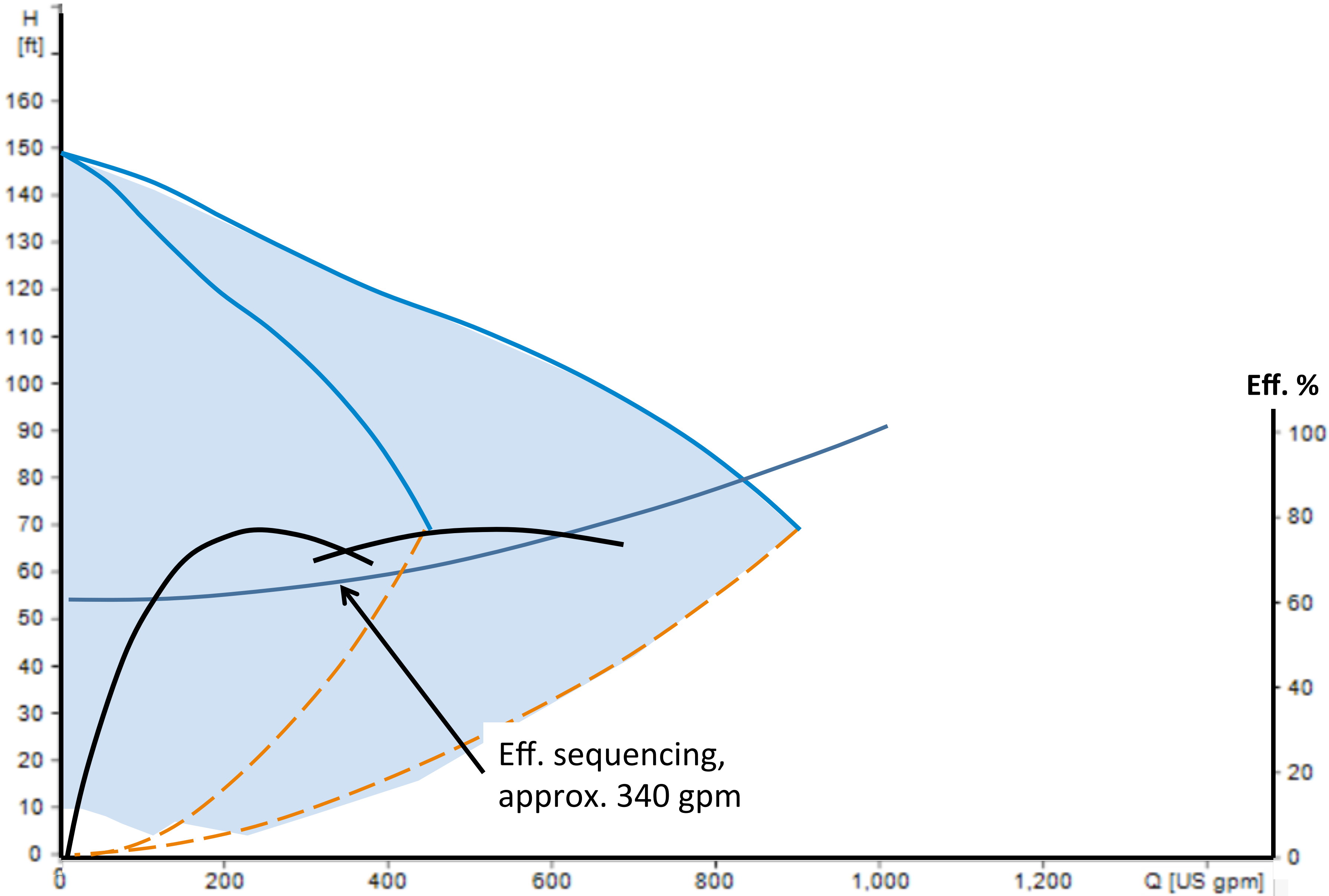
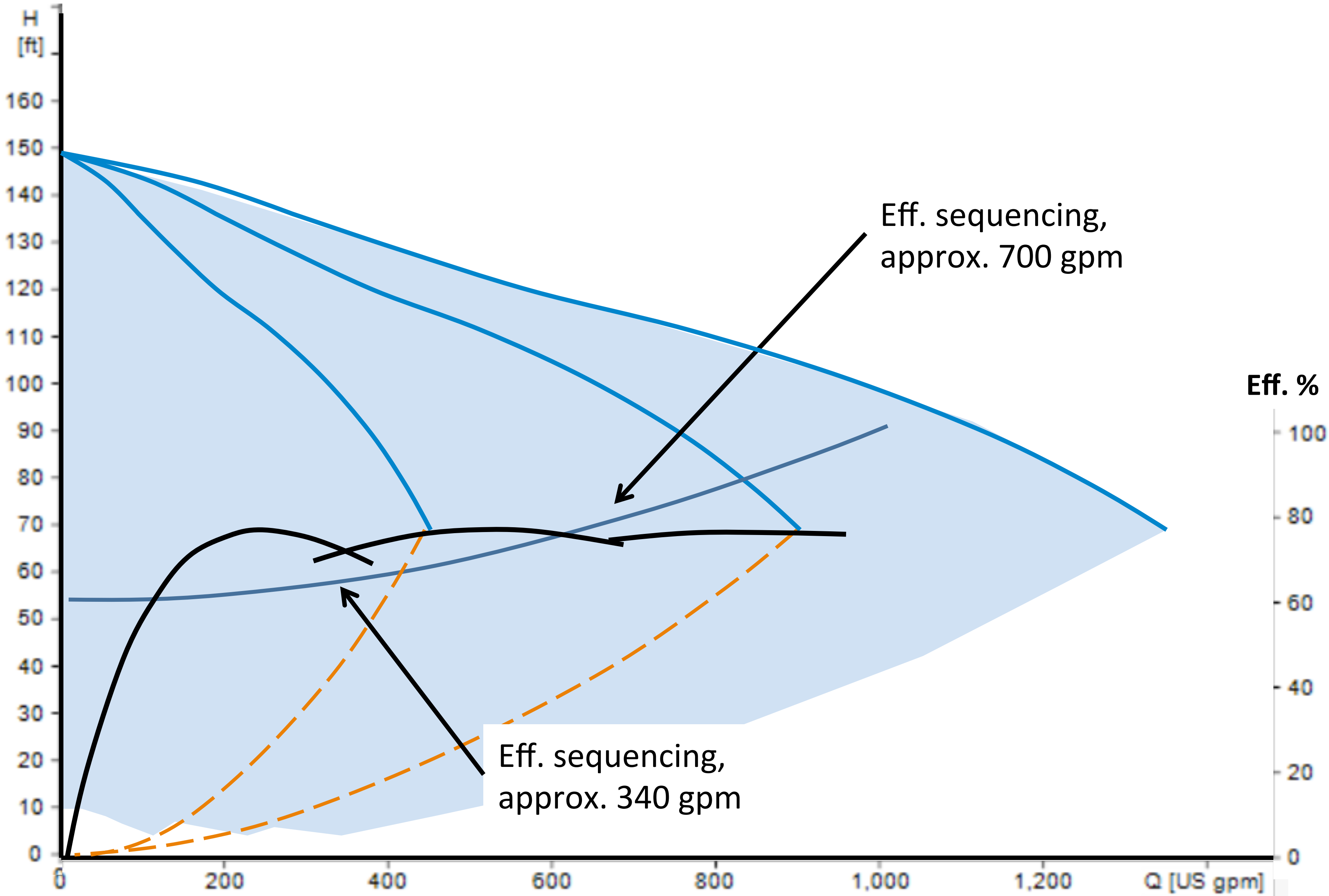


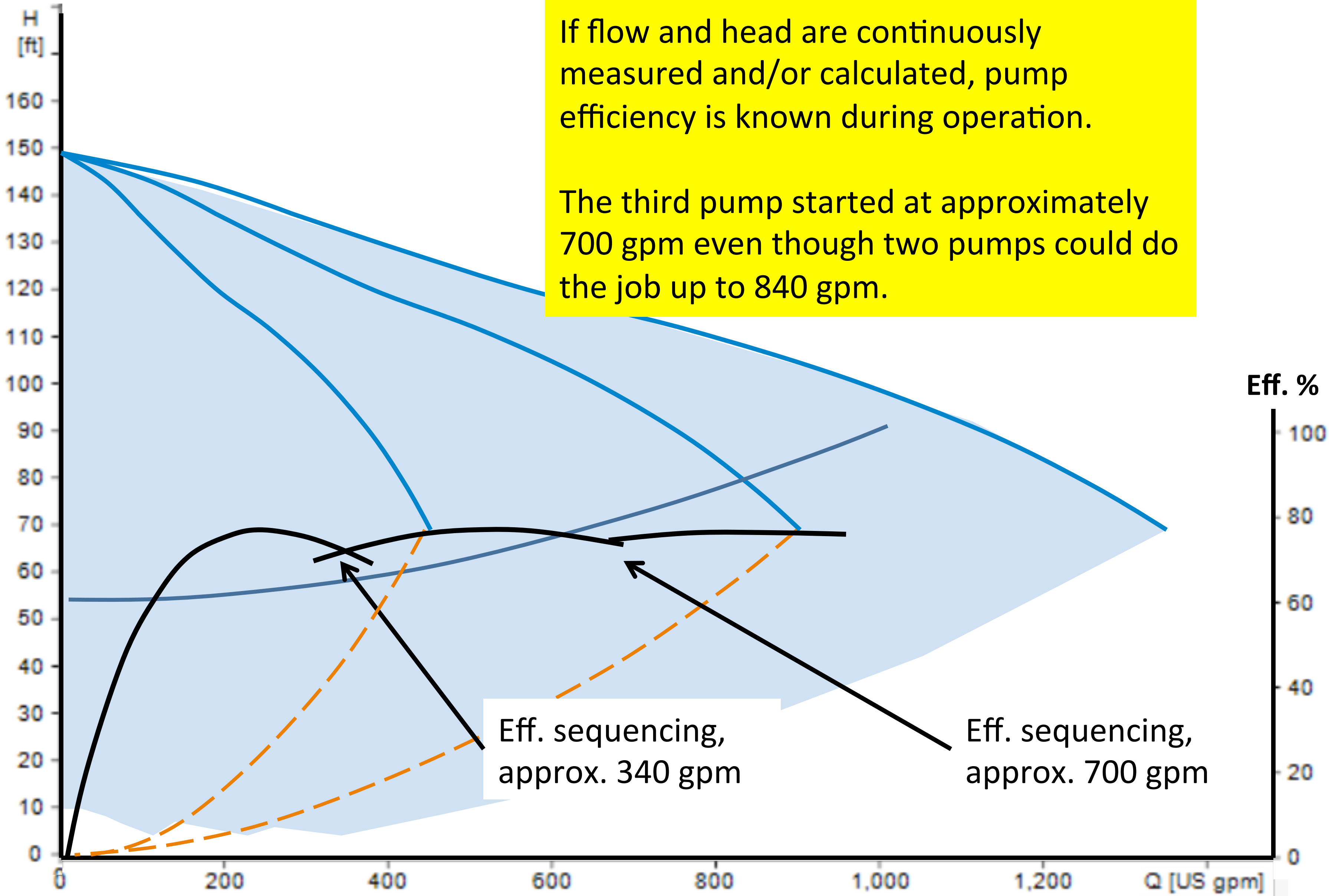
Parallel Connected Pumps - Efficiency Sequencing



Parallel Connected Pumps - Efficiency Sequencing

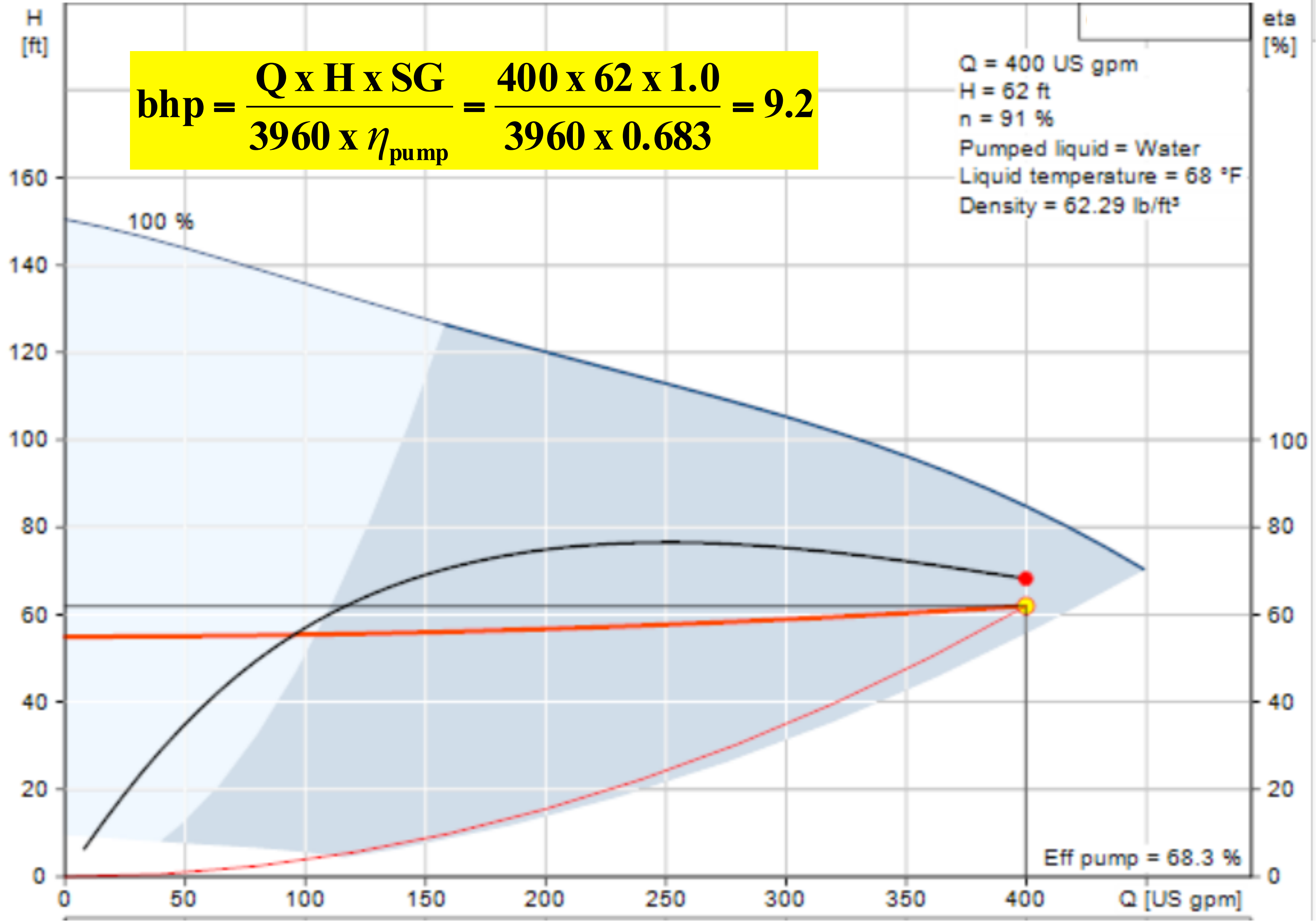
If flow and head are continuously measured and/or calculated, pump efficiency is known during operation.

The third pump started at approximately 700 gpm even though two pumps could do the job up to 840 gpm.



One pump – 400 gpm at 62 feet

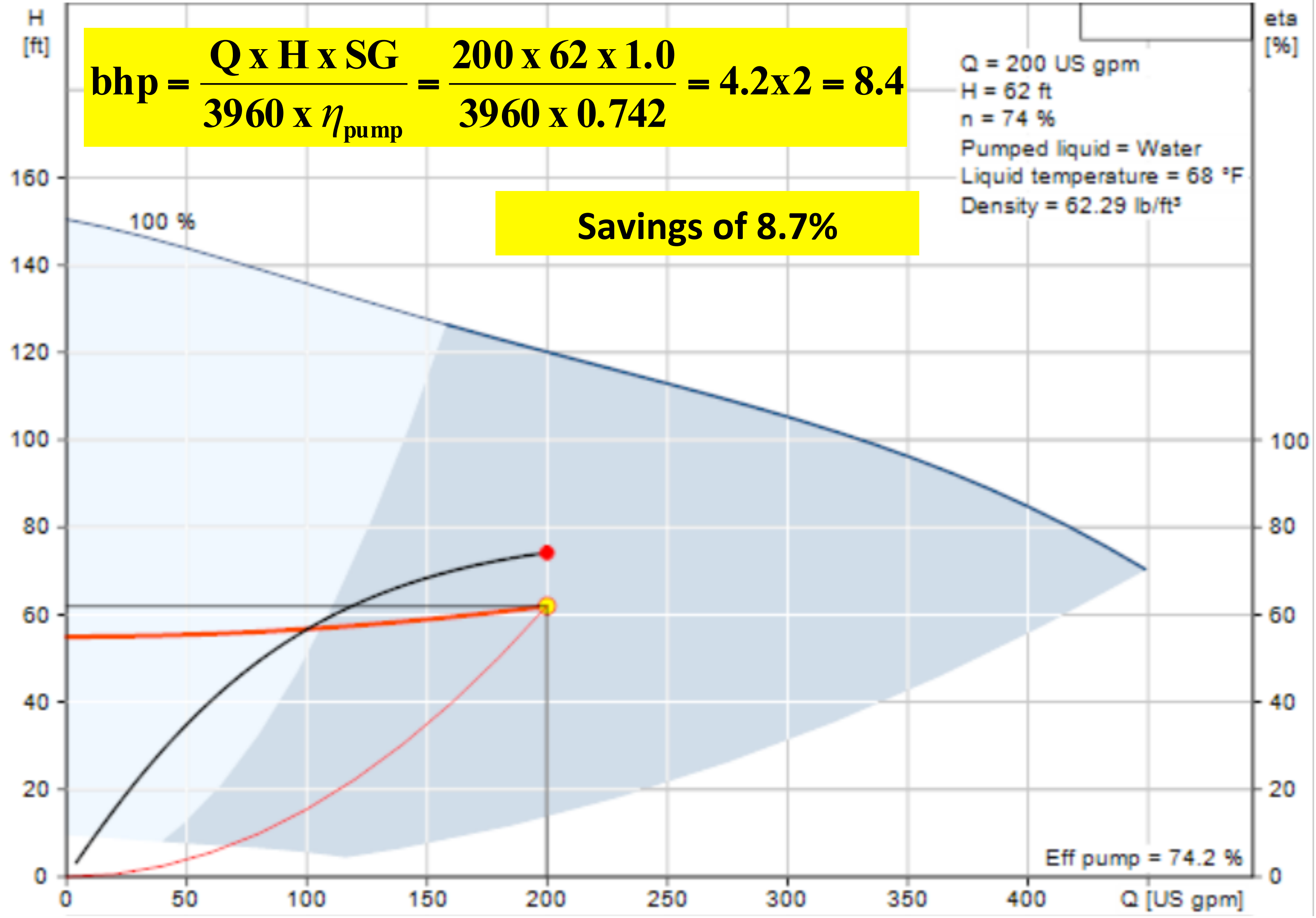
$$bhp = \frac{Q \times H \times SG}{3960 \times \eta_{pump}} = \frac{400 \times 62 \times 1.0}{3960 \times 0.683} = 9.2$$



One pump – 200 gpm at 62 feet

$$\text{bhp} = \frac{Q \times H \times SG}{3960 \times \eta_{pump}} = \frac{200 \times 62 \times 1.0}{3960 \times 0.742} = 4.2\text{x}2 = 8.4$$

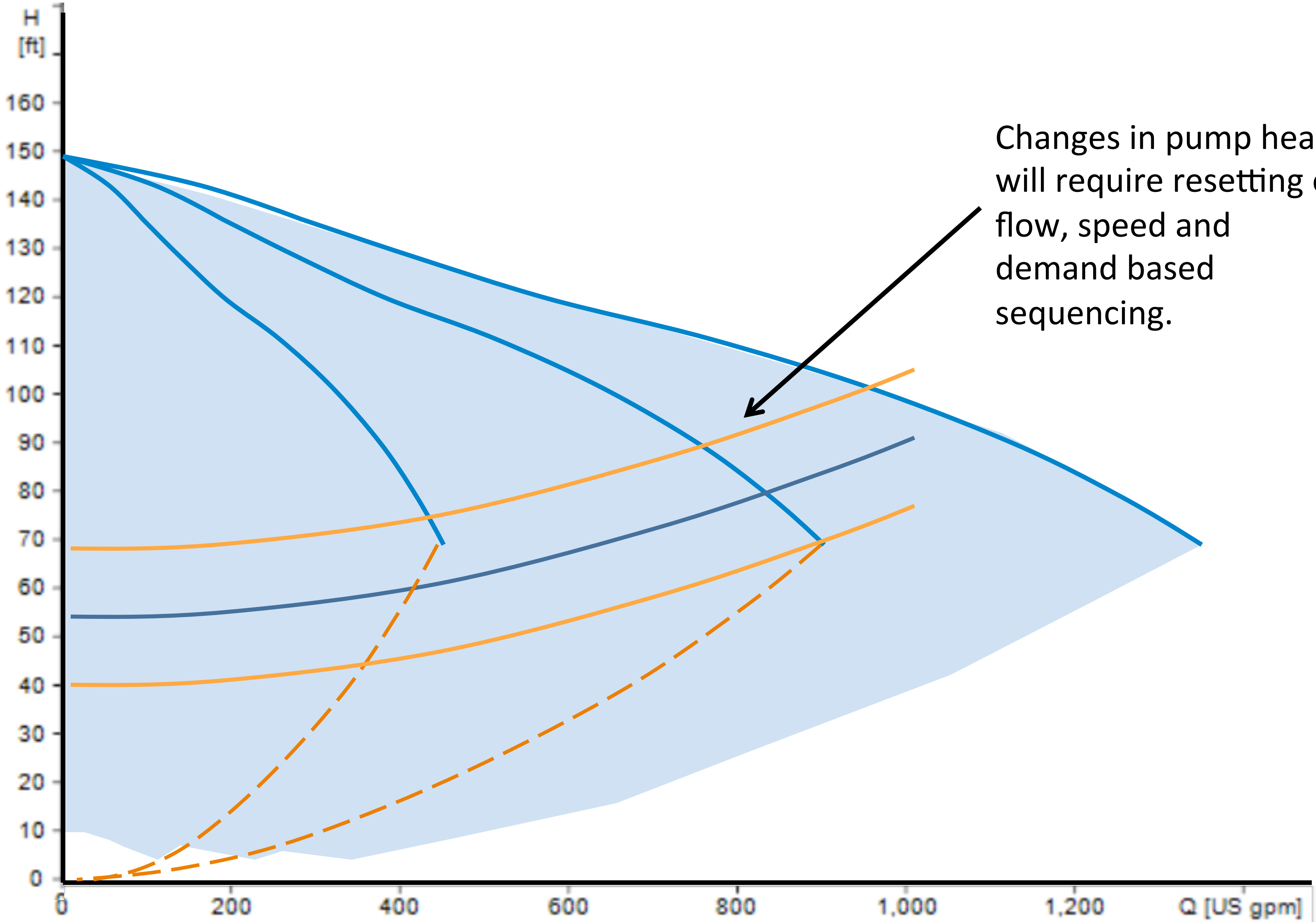
Savings of 8.7%



What if the required head changes?

Does that effect pump sequencing?

Parallel Connected Pumps - Flow Sequencing



Changes in pump head will require resetting of flow, speed and demand based sequencing.

Parallel Connected Pumps - Pump Sequencing

Most efficient: Stage on efficiency

> Total Efficiency (Electrical + Hydraulic)

> Hydraulic Efficiency

Parallel Connected Pumps - Pump Sequencing

Most efficient: Stage on efficiency

> Total Efficiency (Electrical + Hydraulic)

> Hydraulic Efficiency

Exception

> Limited suction head, must start additional pumps before flow gets too high

Examples: Boiler Feed, Cooling Tower, water supply from break tank

Grundfos Technical Institute

Thank you for your attention!

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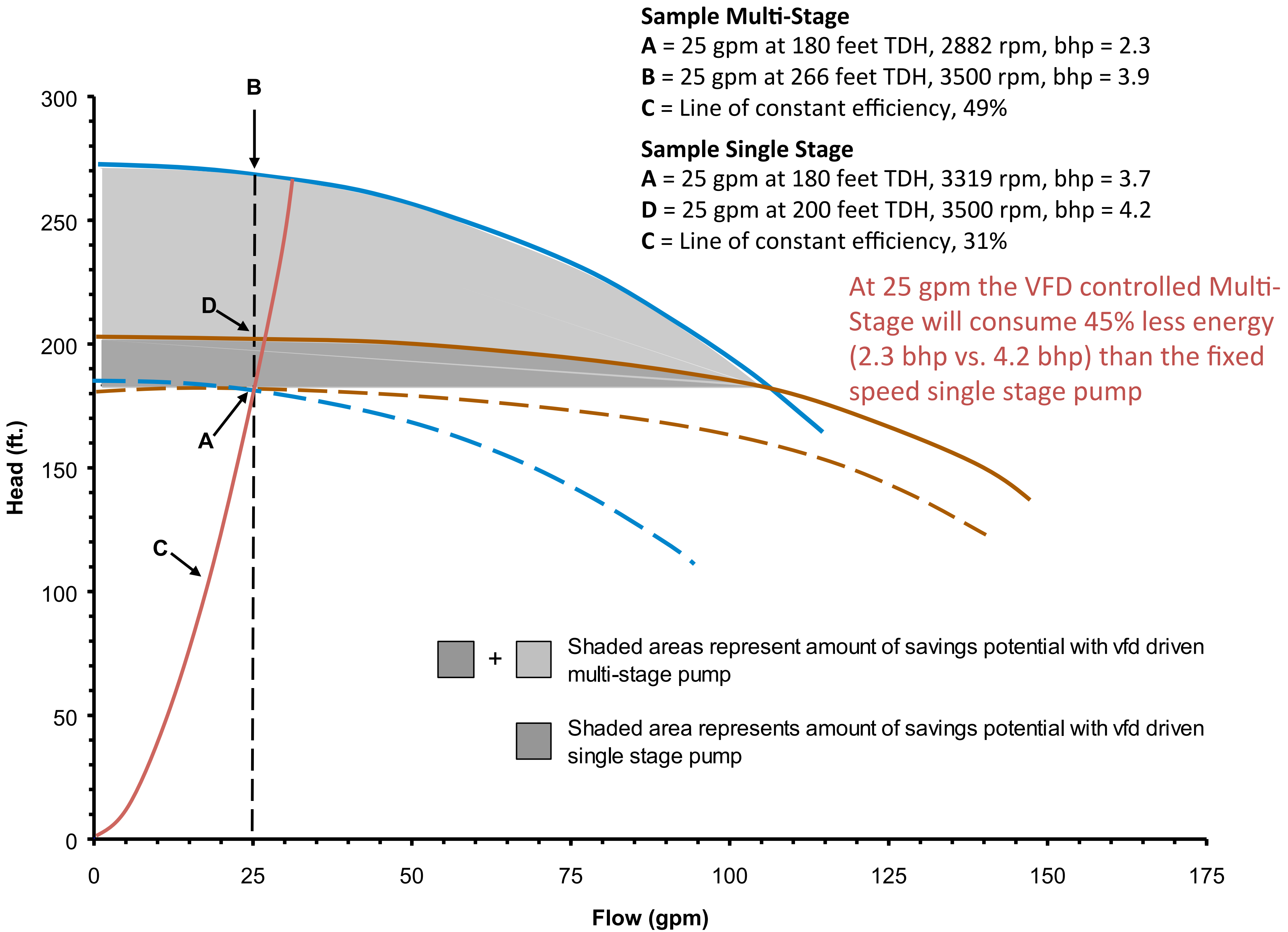
NOTE:

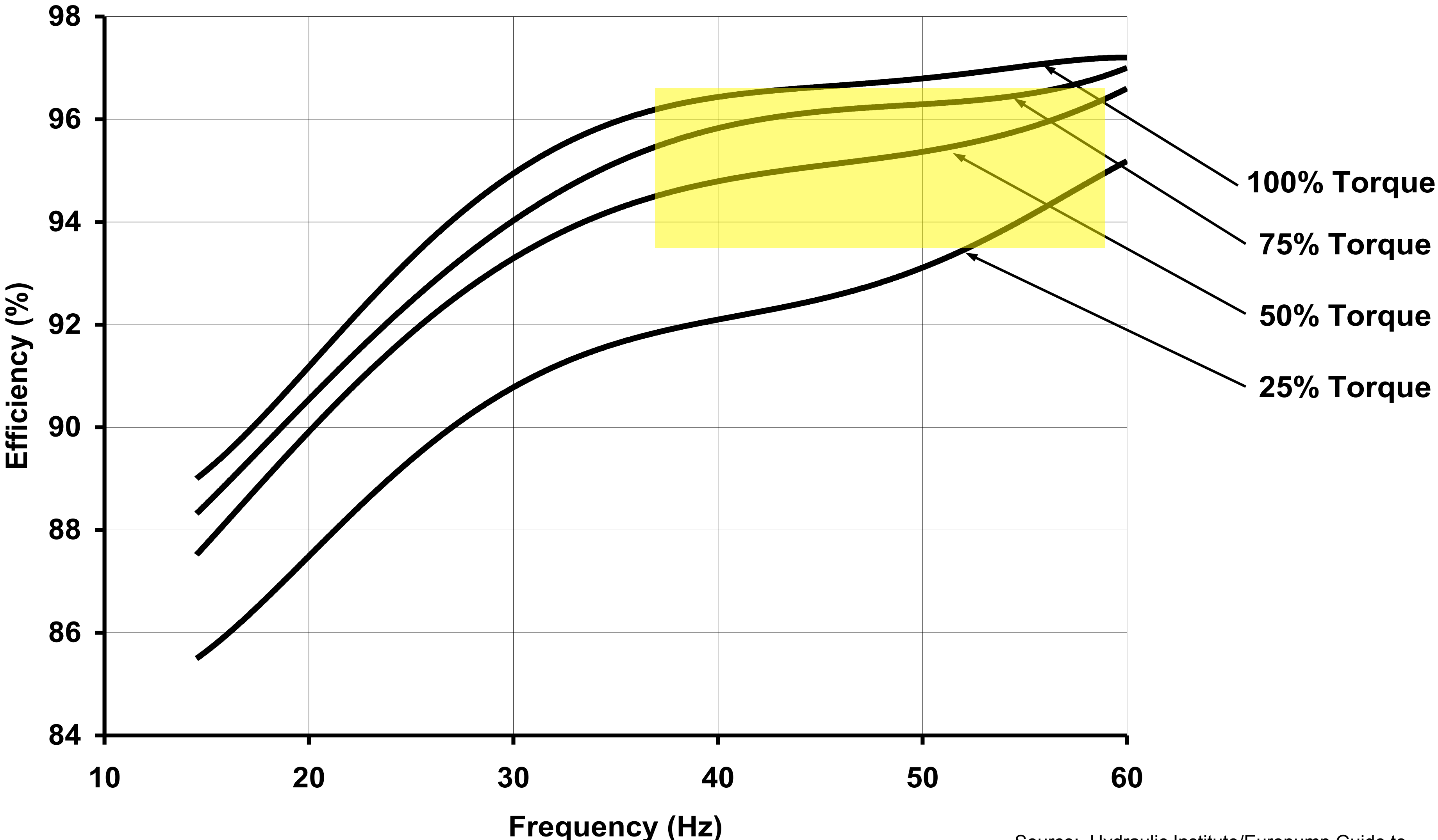
The following slides are not part of main slide deck but are left here just in case they can be used to help the Q&A session. If the presentation is made available to the viewers, these slide are to be **LEFT OUT.**

Misconception

Since variable head losses are such a small percentage of the total head in high rise building applications, variable frequency drives result in little or no energy savings.

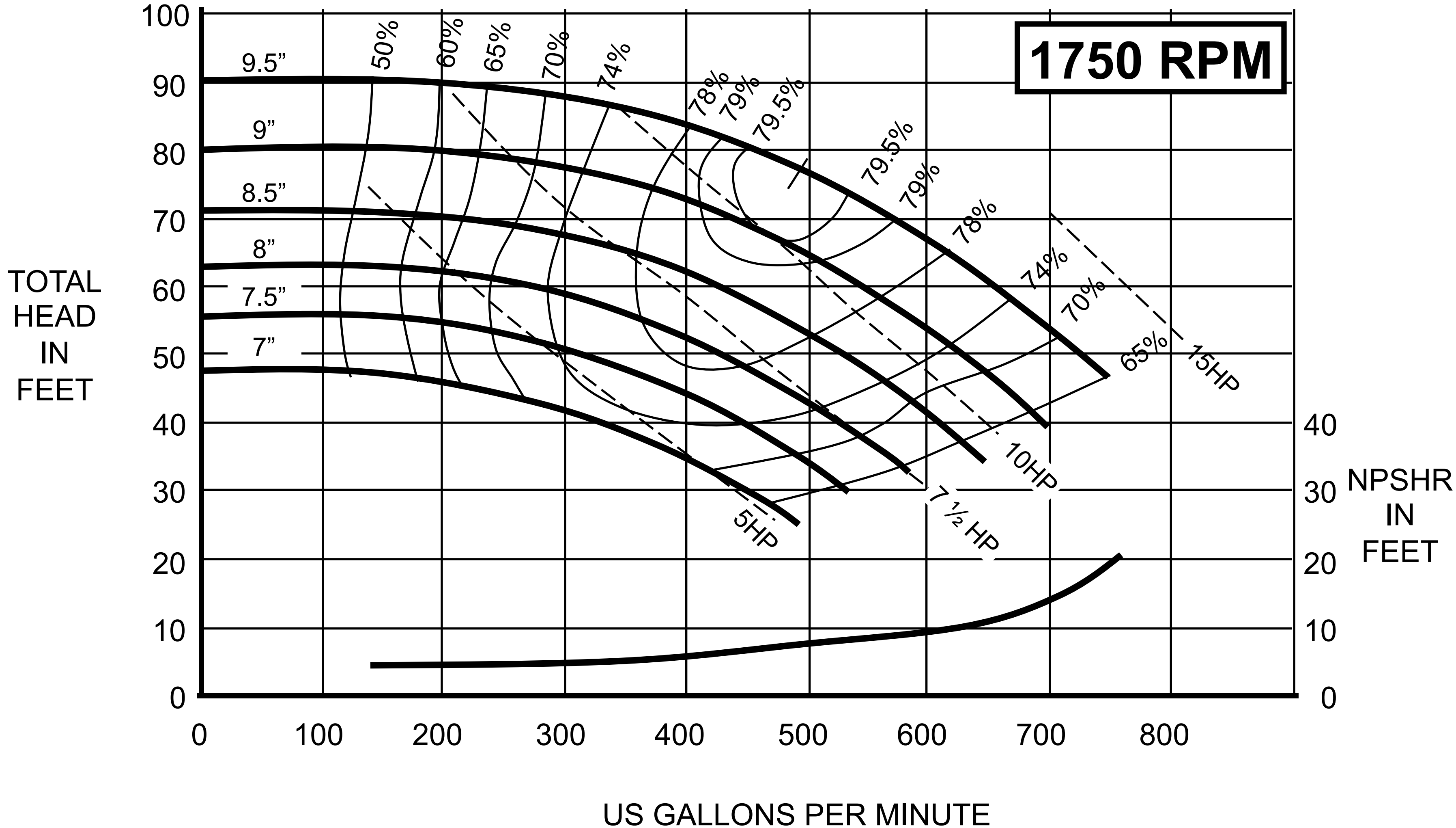

Sample Multi-Stage
A = 25 gpm at 180 feet TDH, 2882 rpm, bhp = 2.3
B = 25 gpm at 266 feet TDH, 3500 rpm, bhp = 3.9
C = Line of constant efficiency, 49%
Sample Single Stage
A = 25 gpm at 180 feet TDH, 3319 rpm, bhp = 3.7
D = 25 gpm at 200 feet TDH, 3500 rpm, bhp = 4.2
C = Line of constant efficiency, 31%
At 25 gpm the VFD controlled Multi-Stage will consume 45% less energy (2.3 bhp vs. 4.2 bhp) than the fixed speed single stage pump
B
D
A
C
Head (ft.)
0
50
100
150
200
250
300
Flow (gpm)
0
25
50
75
100
125
150
175
+
Shaded areas represent amount of savings potential with vfd driven multi-stage pump
Shaded area represents amount of savings potential with vfd driven single stage pump

Typical VFD Efficiency Curve

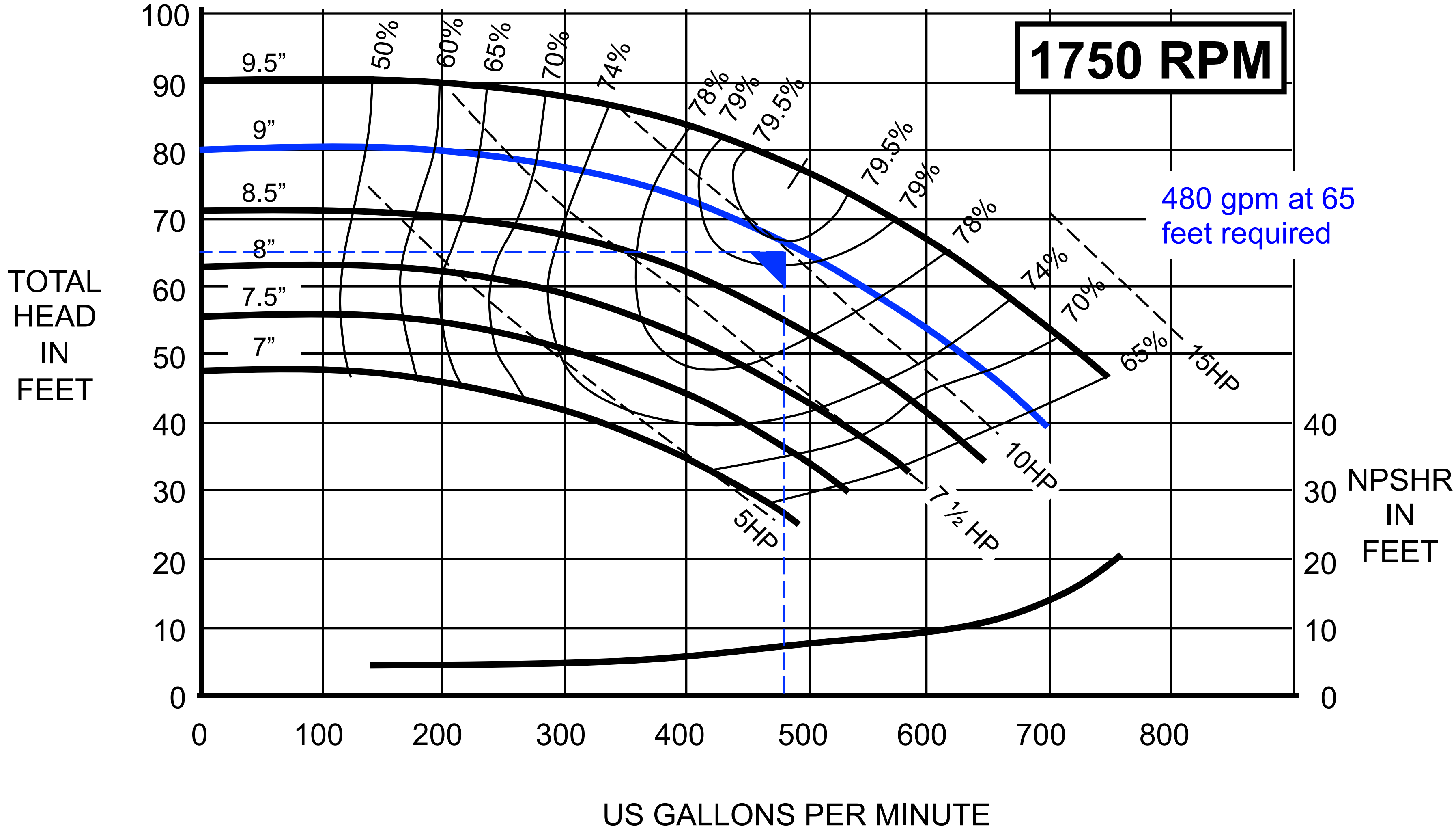


Source: Hydraulic Institute/Europump Guide to Life Cycle Costs

Typical Single Stage Pump Curve



Typical End Suction Pump Curve



Remember the Basics.....

Water horsepower (a.k.a. hydraulic horsepower)

$$P_3 = whp = \frac{Q \; x \; H \; x \; SG}{3960}$$

$Q = Flow \; in \; gpm$

$H = Head \; in \; feet$

$SG = Specific \; Gravity \; of \; liquid$

$\eta = Pump \; Efficiency \; (Greek \; symbol \; "eta")$

Brake horsepower (Pump Shaft)

$$P_2 = bhp = \frac{Q \; x \; H \; x \; SG}{3960 \; x \; \eta_{pump}}$$

Electric horsepower (Input Power)

$$P_1 = ehp = \frac{bhp}{\eta_{driver}}$$

$$\eta_{driver} = driver \; efficiency$$

$$P_1 \; [kW] = ehp = \frac{bhp \; x \; 0.746}{\eta_{motor} \; x \; \eta_{drive}}$$