Better Plants
U.S. DEPARTMENT OF ENERGY

WATER VIRTUAL IN-PLANT (VINPLT) TRAINING

Session 5

Today - Session 5: Pumps

We've already covered:

Energy Basics
Success Stories
Power Company Relations
KPIs
Source Selection
Energy Teams
Water Treatment
5Ls: Looping, Leaping, Leaking, Losing, Loading
Treasure Hunts

Thank You!

Sponsor:

Better Plants
U.S. DEPARTMENT OF ENERGY

Today's Agenda

	Homework Recap
	Pump Curves 101
	Break
	Pump Activity
	Pump Calculations
	Kahoot!
	Q&A

HOMEWORK RECAP

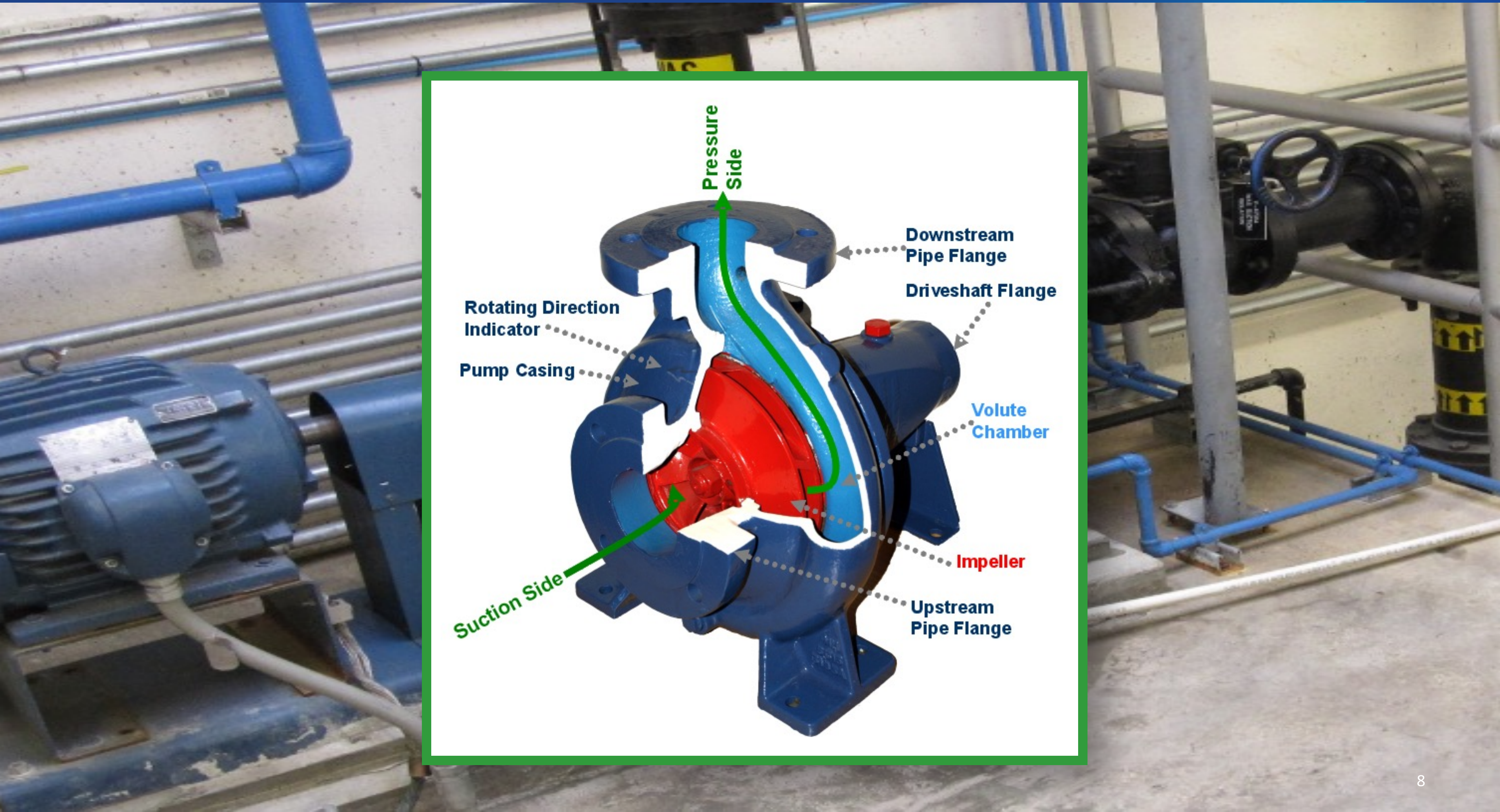
POLL

PUMP CURVES 101

Pumps and Efficiency

Where we answer the age-old question:

How come every pump in our plant is 30% bigger than it needs to be?!?!?

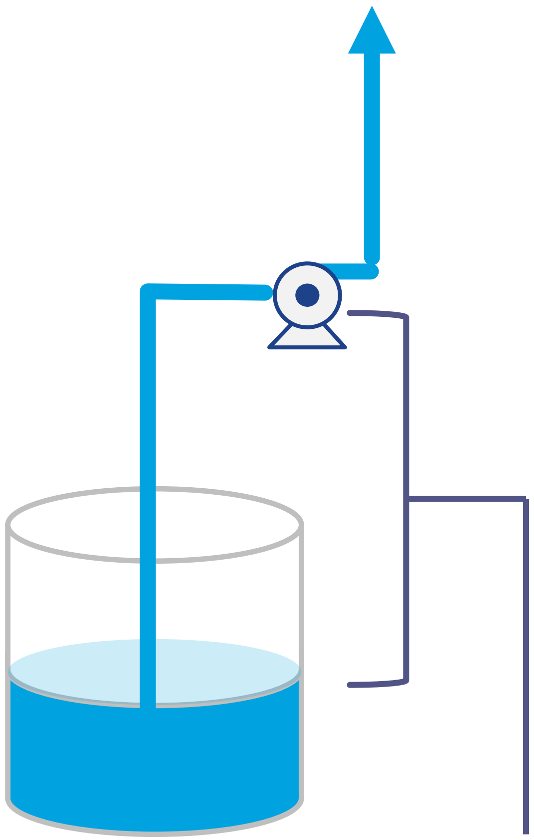


Pressure Side
Downstream Pipe Flange
Driveshaft Flange
Rotating Direction Indicator
Pump Casing
Volute Chamber
Impeller
Upstream Pipe Flange
Suction Side

Suction Lift (h_s)

When the supply is **below** the centerline of the pump.

Distance (in feet) from the centerline of the pump to the level of liquid to be pumped.



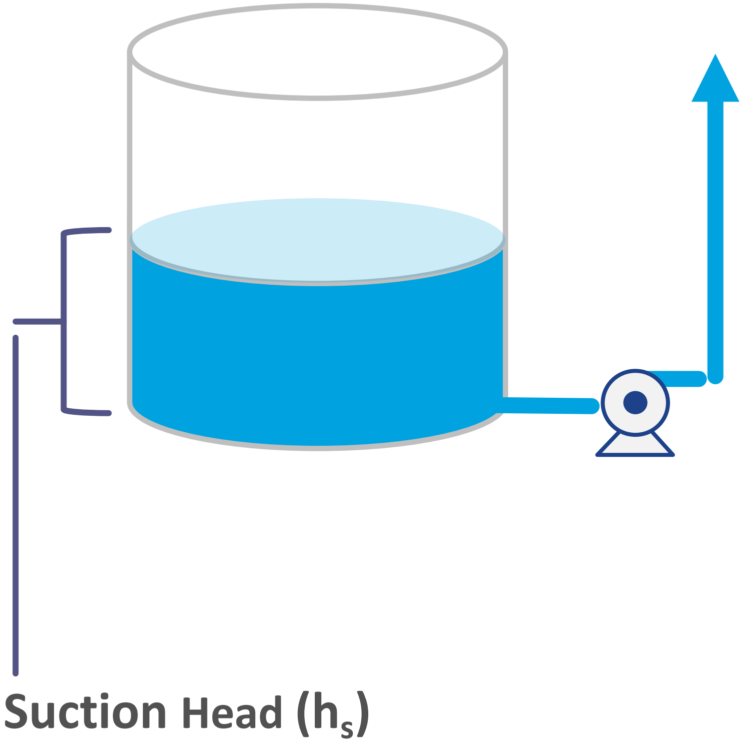
Suction Lift (h_s)

Suction Head (h_s)

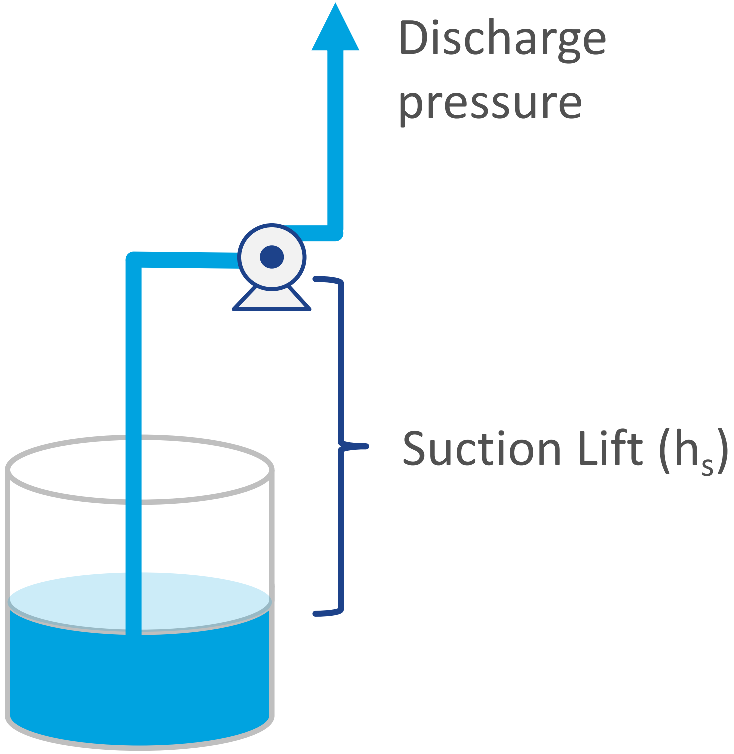
DEFINITION

When the supply is **above** the centerline of the pump.

Distance (in feet) from the centerline of the pump to the level of liquid to be pumped.



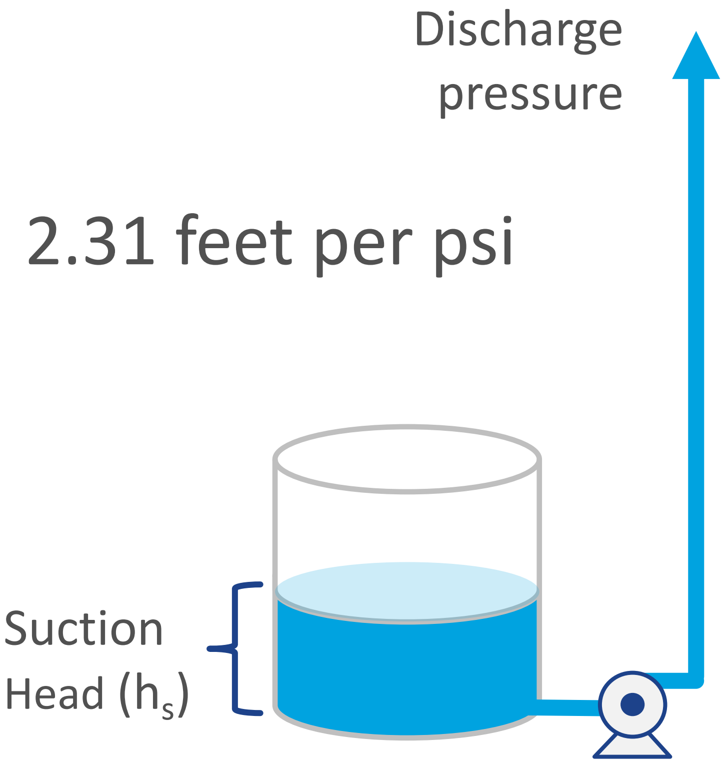
Total Head (H)



With Suction Lift

Discharge Pressure (ft) + h_s (ft)

2.31 feet per psi



With Suction Head

Discharge Pressure (ft) – h_s (ft)

Centrifugal Pump Power

DEFINITION

$$BHP = \frac{Q * H}{3960 * \eta}$$

Affinity Laws

Flow (Q) will change directly	When there is a change in speed (N) or diameter (D)

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2} \, or \, \frac{D_1}{D_2}$$

$$\frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2 \text{ or } \left(\frac{D_1}{D_2}\right)^2$$

$$\frac{BHP_1}{BHP_2} = \left(\frac{N_1}{N_2}\right)^3 \text{ or } \left(\frac{D_1}{D_2}\right)^3$$

Why does this matter?

N_1=100% and you can go down to 90% (N_2)

$$\frac{BHP_1}{BHP_2} = \left(\frac{N_1}{N_2}\right)^3 = \left(\frac{100}{90}\right)^3$$

Save 27% energy!

Centrifugal Pump Power

$$BHP = \frac{Q * H}{3960 * \eta}$$

How to save power?

- Decrease Flow
- Decrease Head
- Increase Efficiency

And because
Energy = Power x Time,
we can reduce energy by reducing runtime

Centrifugal Pump Motor Power

$$MotorPower(hp) = \frac{Power(BHP)}{\eta_{motor}}$$

$$MotorPower(kW) = MotorPower(hp) \cdot \frac{0.75kW}{hp}$$

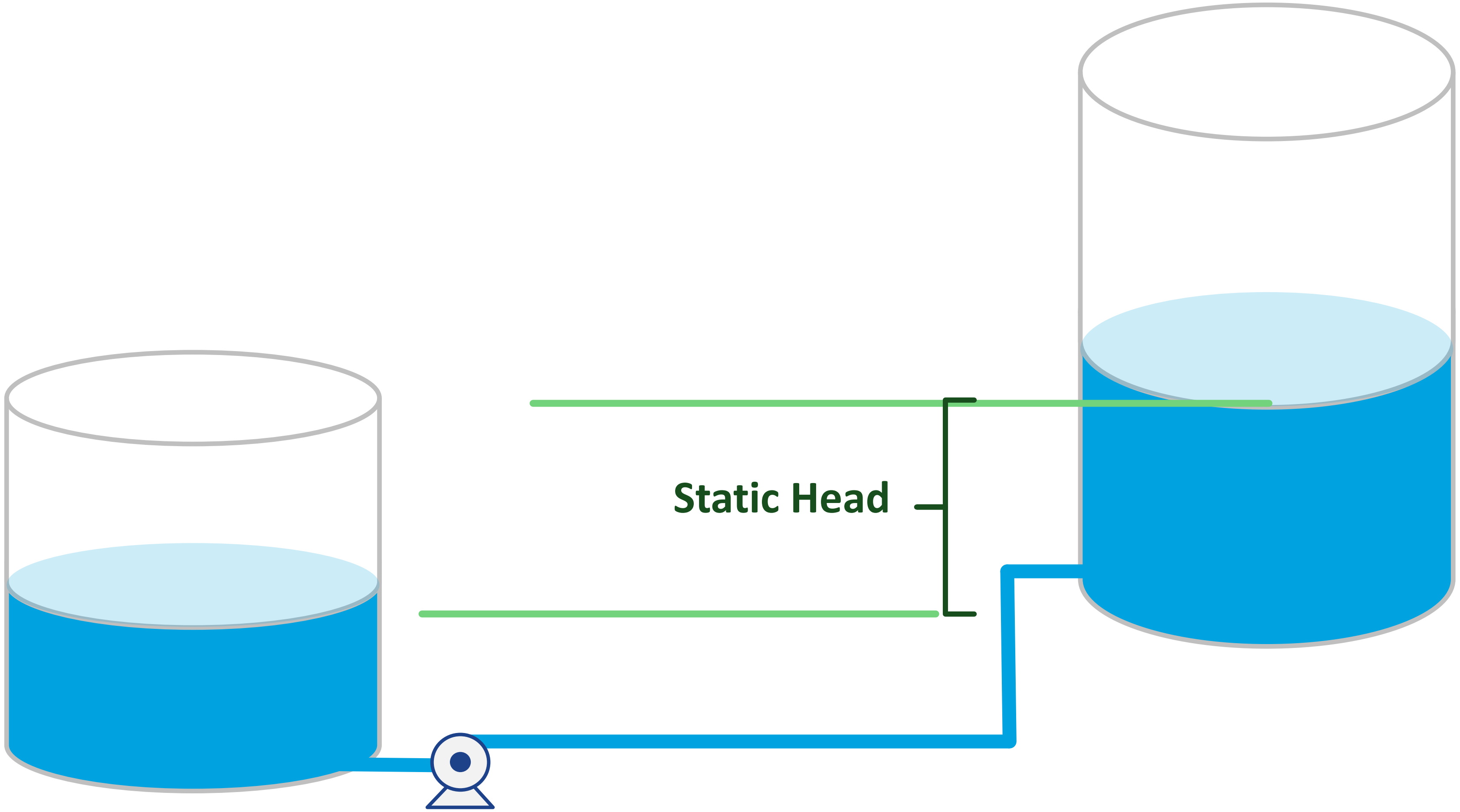
BHP	Brake Horsepower
η_{motor}	Motor Efficiency (%)

Centrifugal Pump Energy

Energy (kWh/yr)	Power (kW) **X** Annual Operating Hours (hours/yr)
Energy Cost ($/yr)	Energy (kWh/yr) **X** Electric Rate ($/kWh)

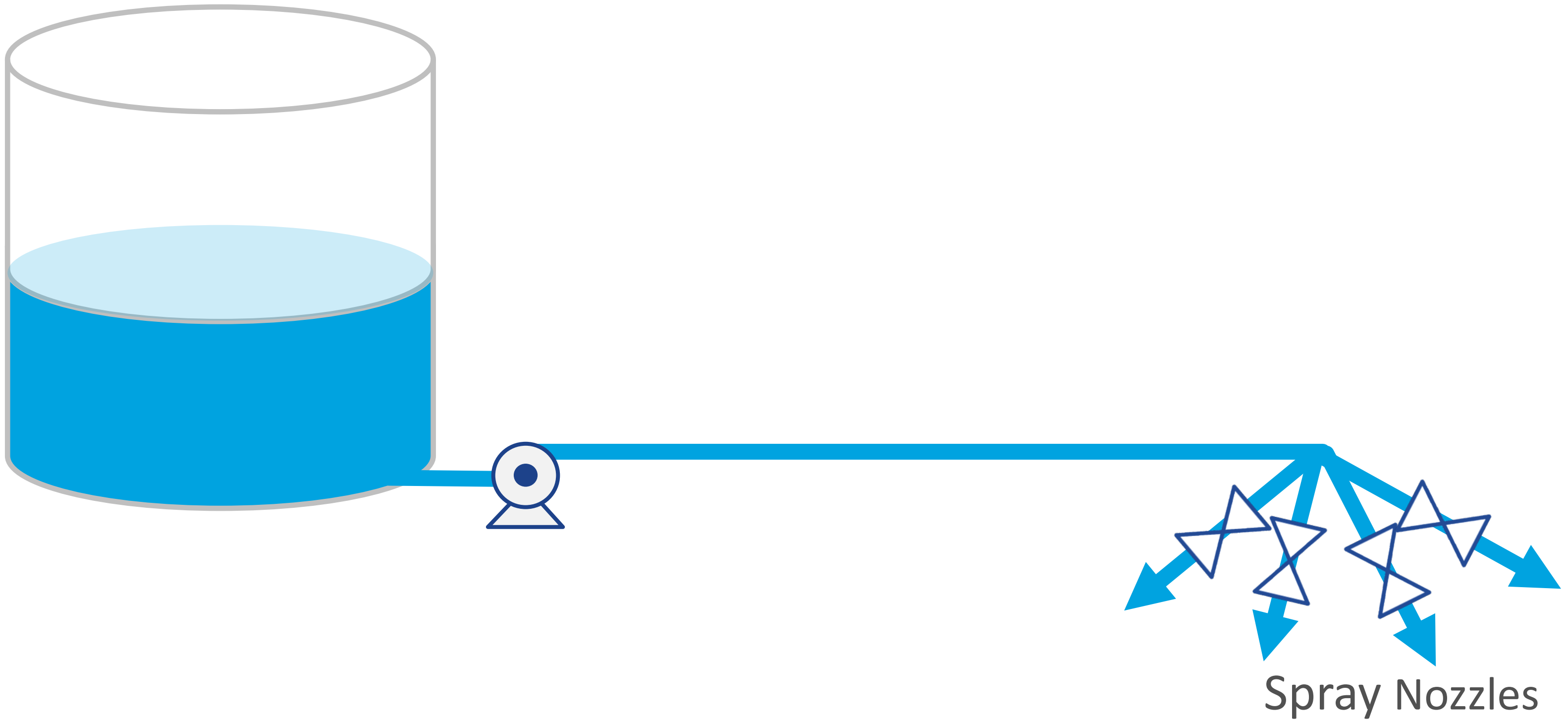
System Curves: Static Head

Ignoring pipeline friction, this is an example of purely static head.

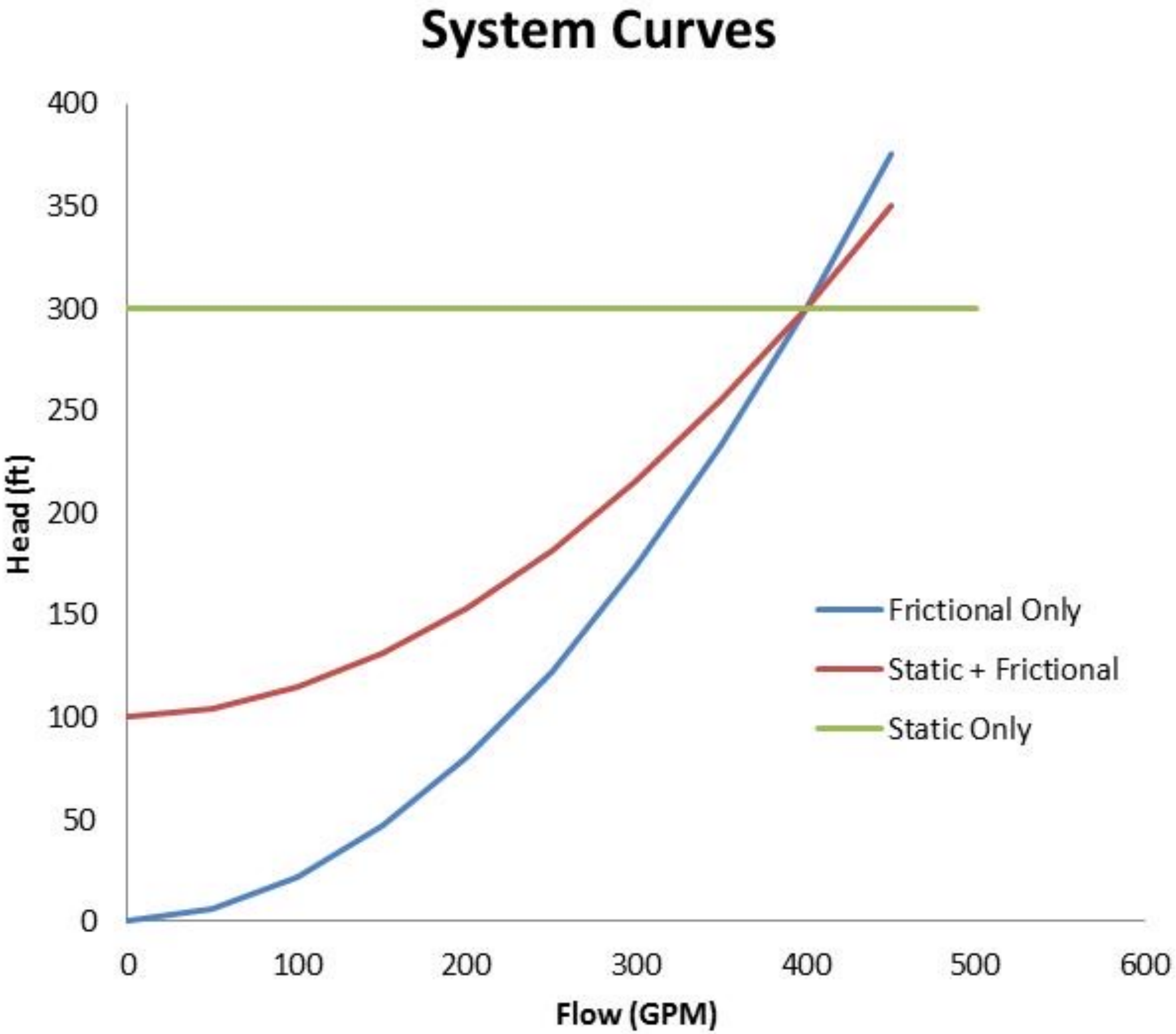


Pump Curves: Frictional Head

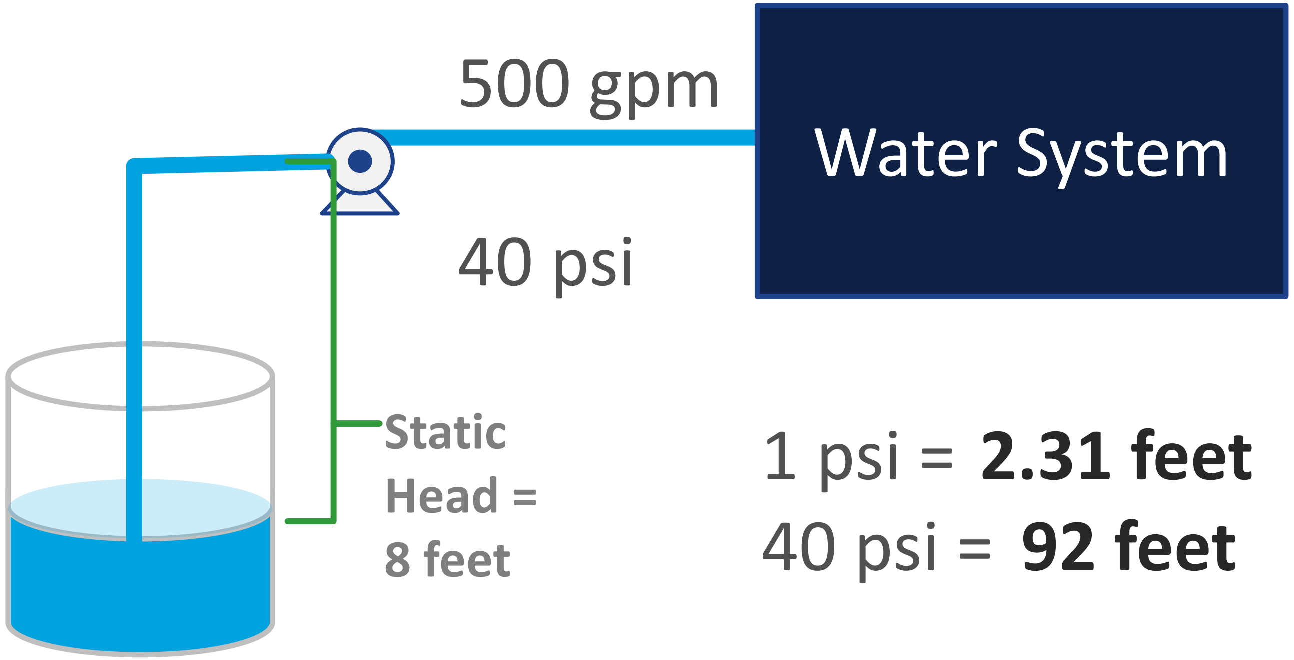
Assuming no elevation change,
this is an example of purely frictional head



Examples for Three Different Systems



Reading Pump Curves - Example



1 psi = **2.31 feet**

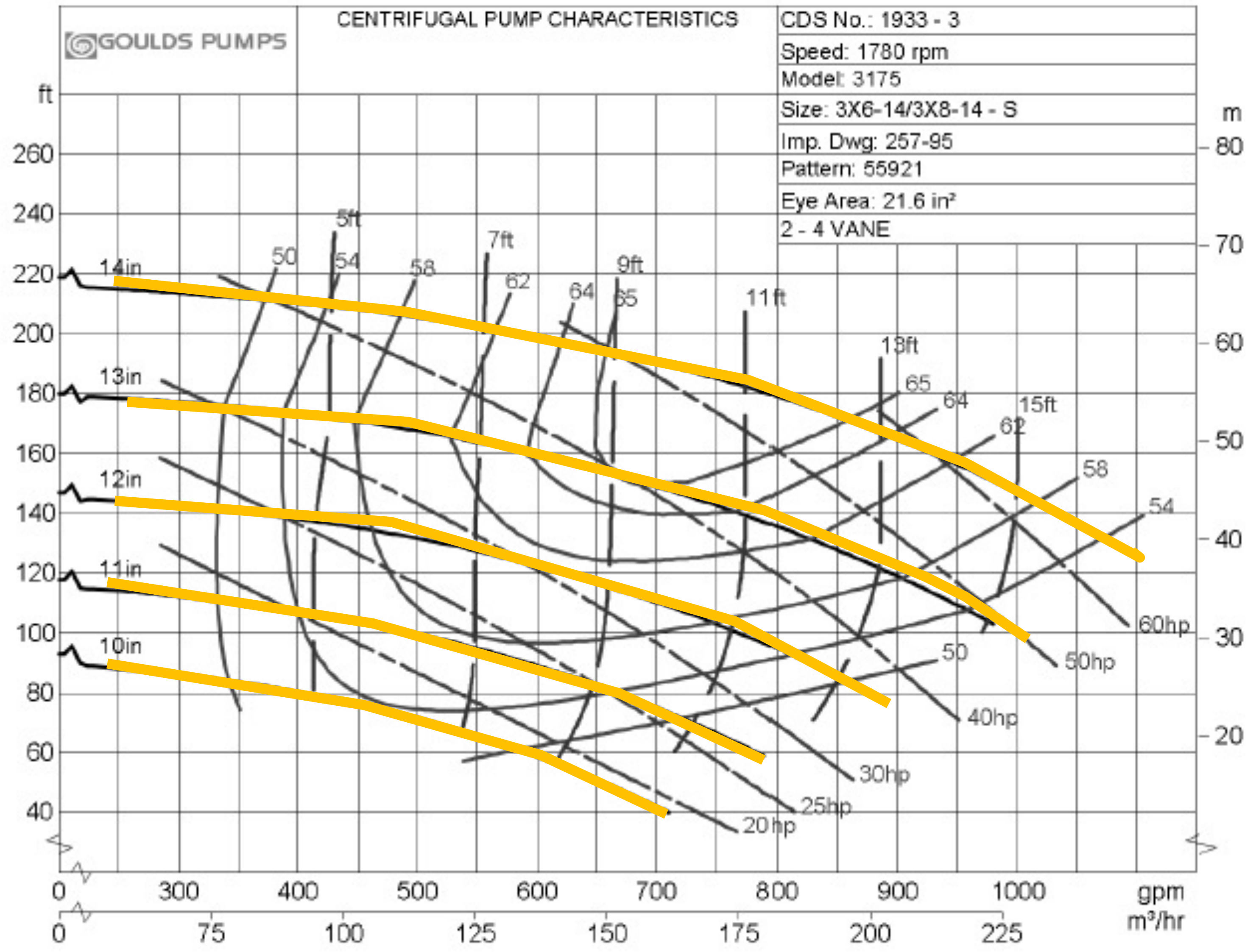
40 psi = **92 feet**

To Calculate Total Head (ft) With Suction Lift:

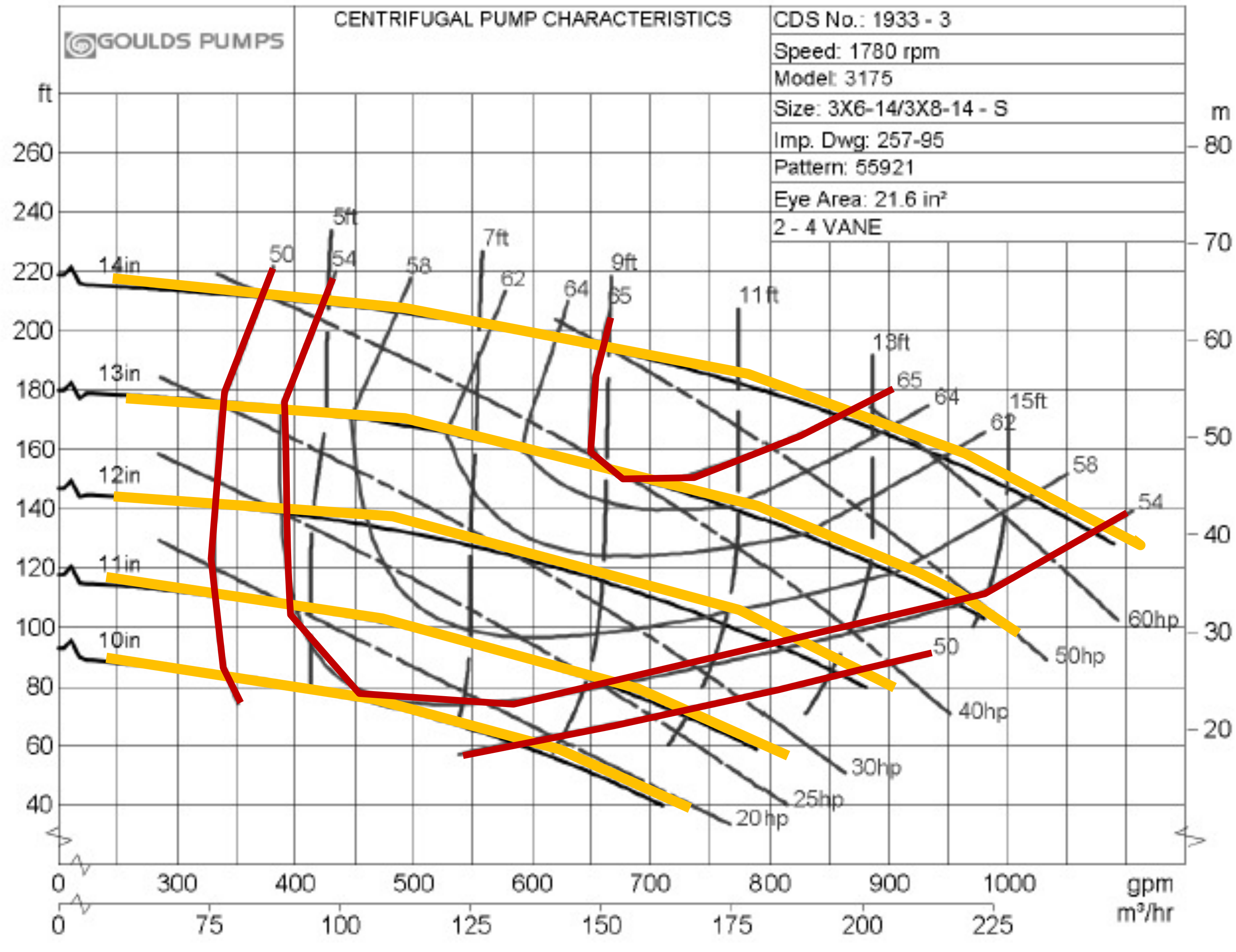
Discharge Pressure (ft) + Suction Head h_s (ft)

92 feet + 8 feet = 100 feet Total Head

Reading Pump Curves



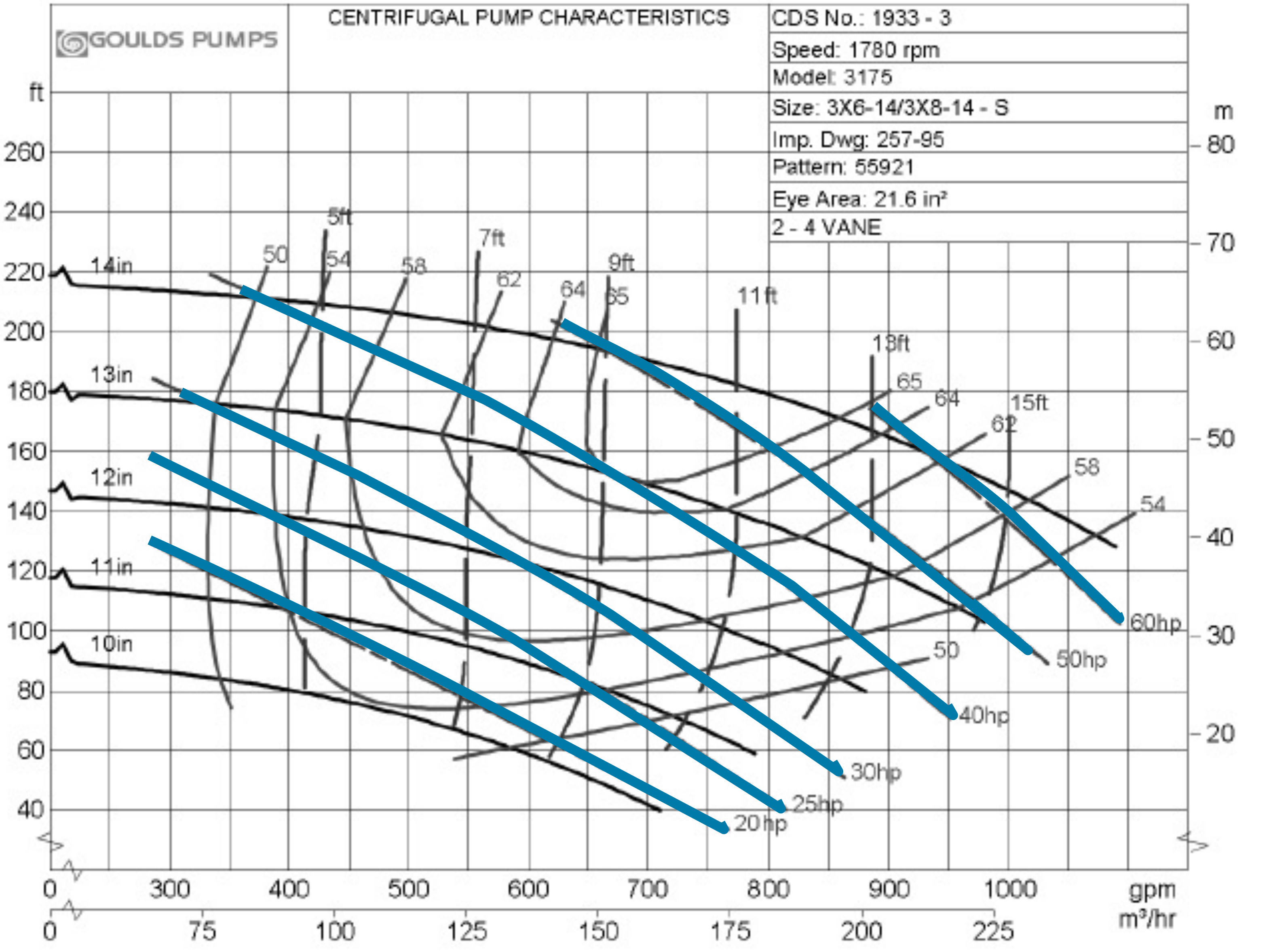
Reading Pump Curves



Better Plants
U.S. DEPARTMENT OF ENERGY

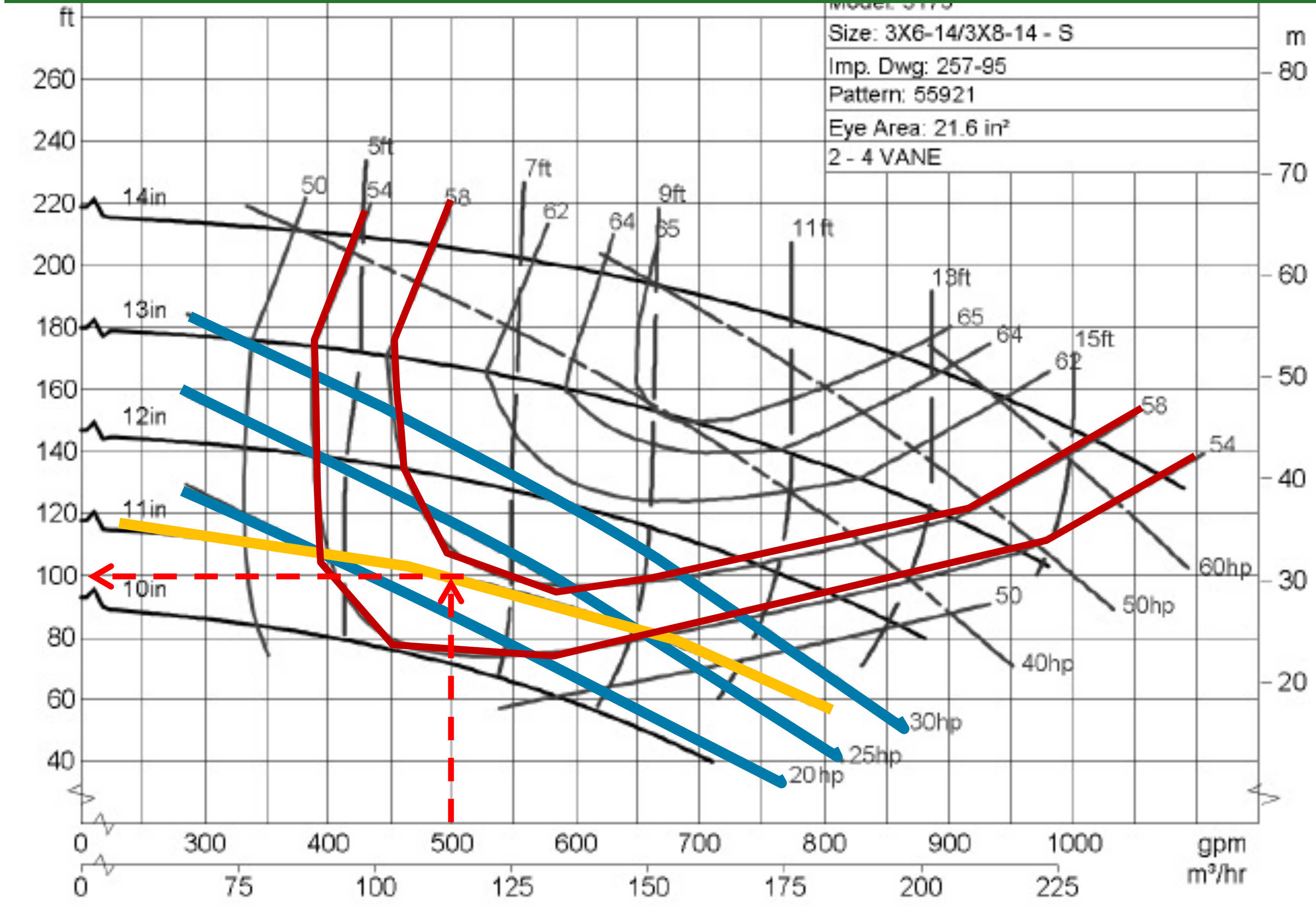
U.S. DEPARTMENT OF ENERGY

Reading Pump Curves



Reading Pump Curves

If the pump has a 11” impeller diameter, is pumping water, and is operating at 500 gpm, what are the other operating conditions (H, η, BHP)?



11” Impeller Diameter

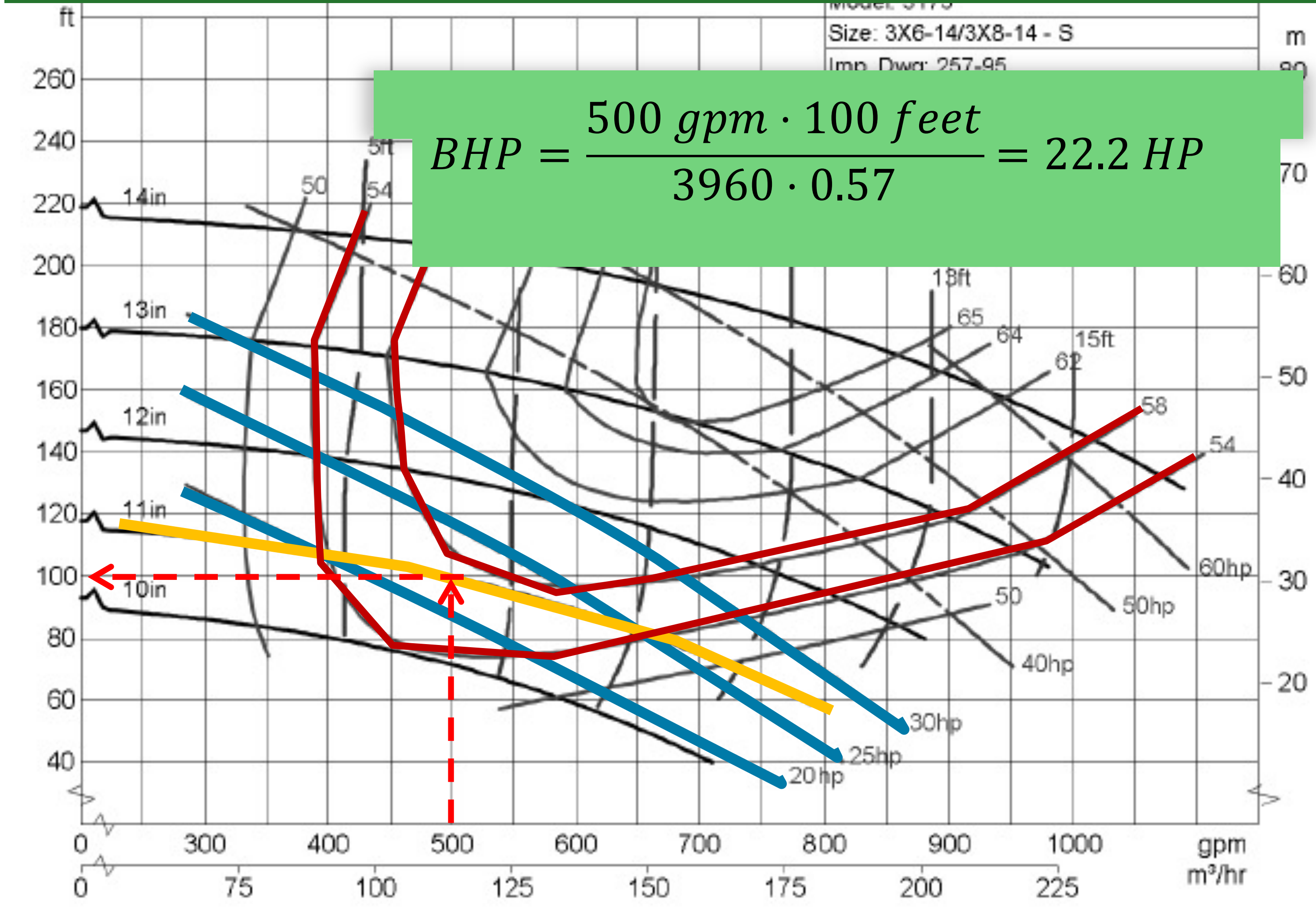
Q	500 GPM
H	100 Feet
η	57%

Reading Pump Curves

$$BHP = \frac{Q * H}{3960 * \eta}$$

If the pump has a 11” impeller diameter, is pumping water, and is operating at 500 gpm, what are the other operating conditions (H, η, BHP)?

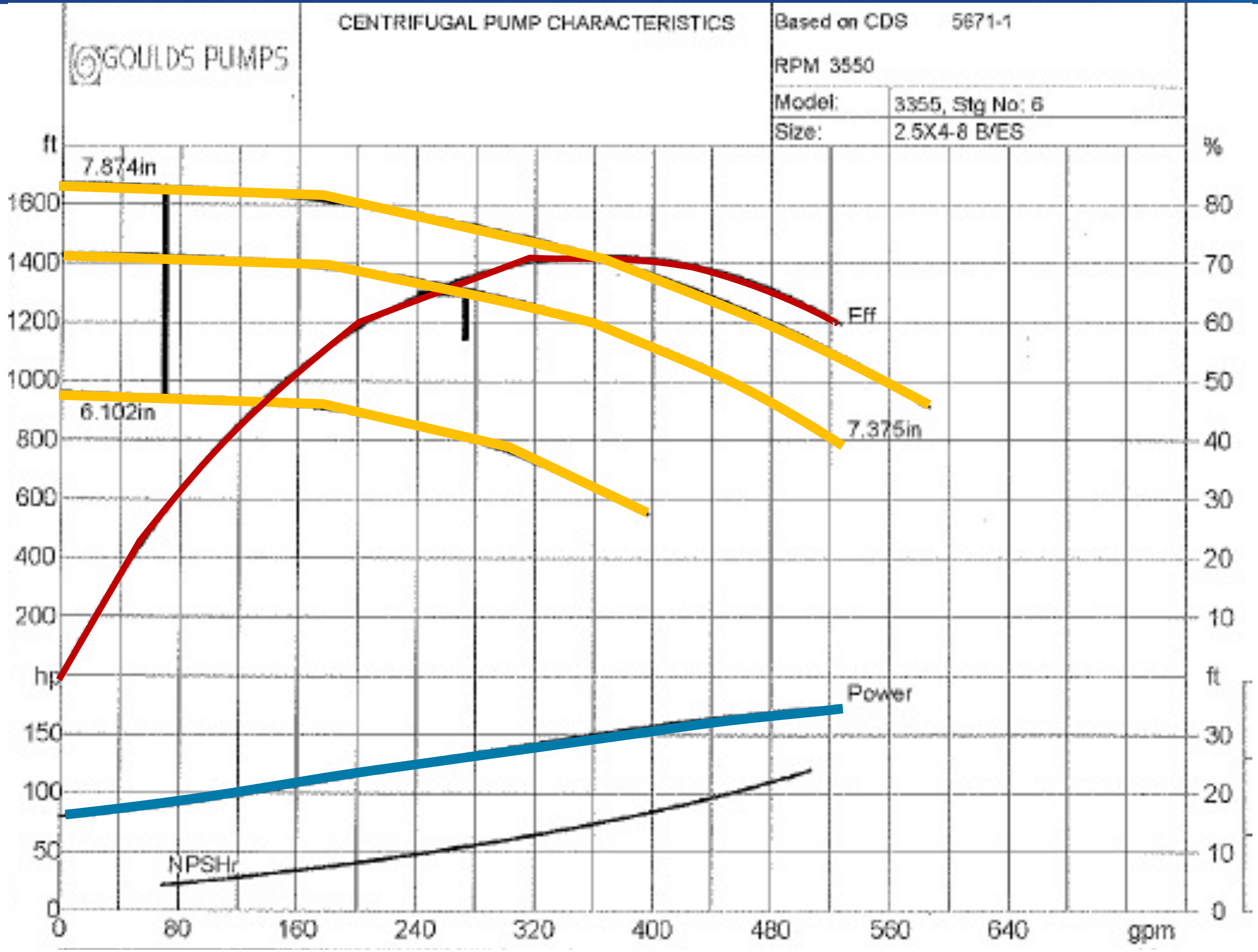
$$BHP = \frac{500\ gpm \cdot 100\ feet}{3960 \cdot 0.57} = 22.2\ HP$$



11” Impeller Diameter

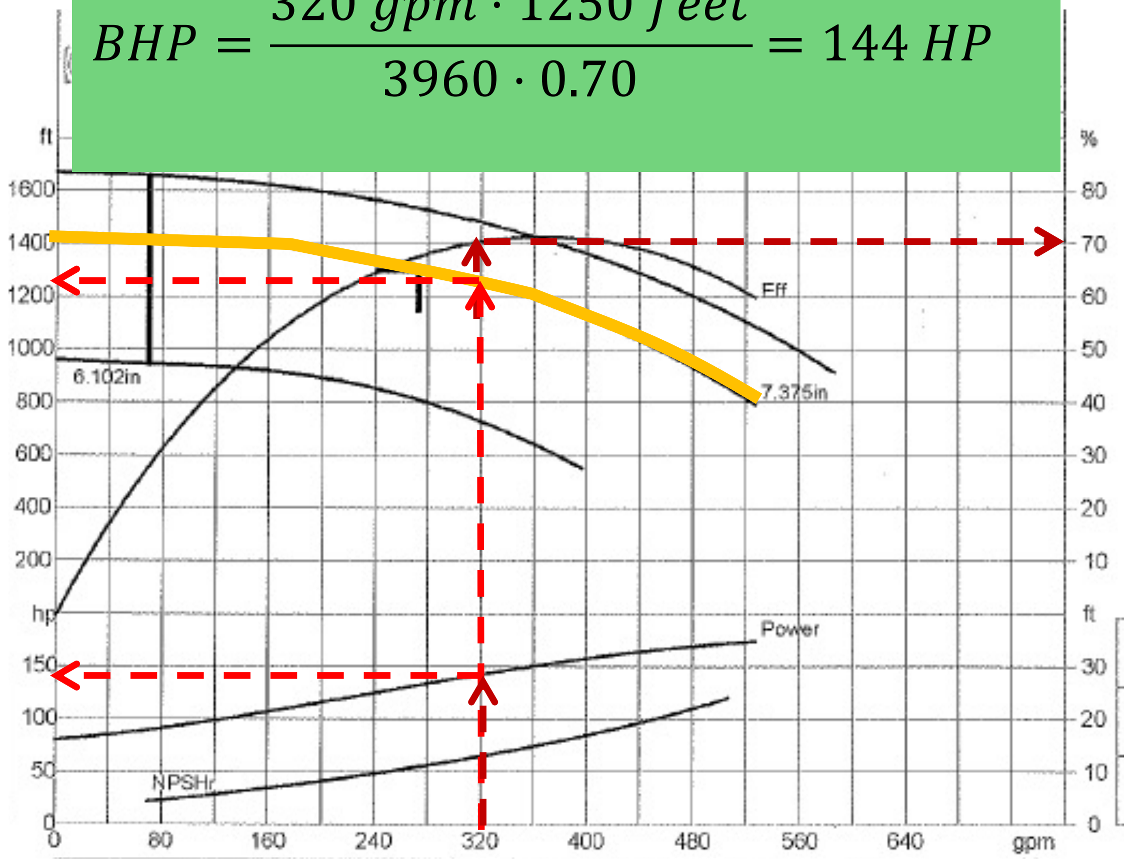
Q	500 GPM
H	100 Feet
η	57%

Reading Pump Curves Continued



Reading Pump Curves Continued

$$BHP = \frac{320\ gpm \cdot 1250\ feet}{3960 \cdot 0.70} = 144\ HP$$



H= 1250 ft

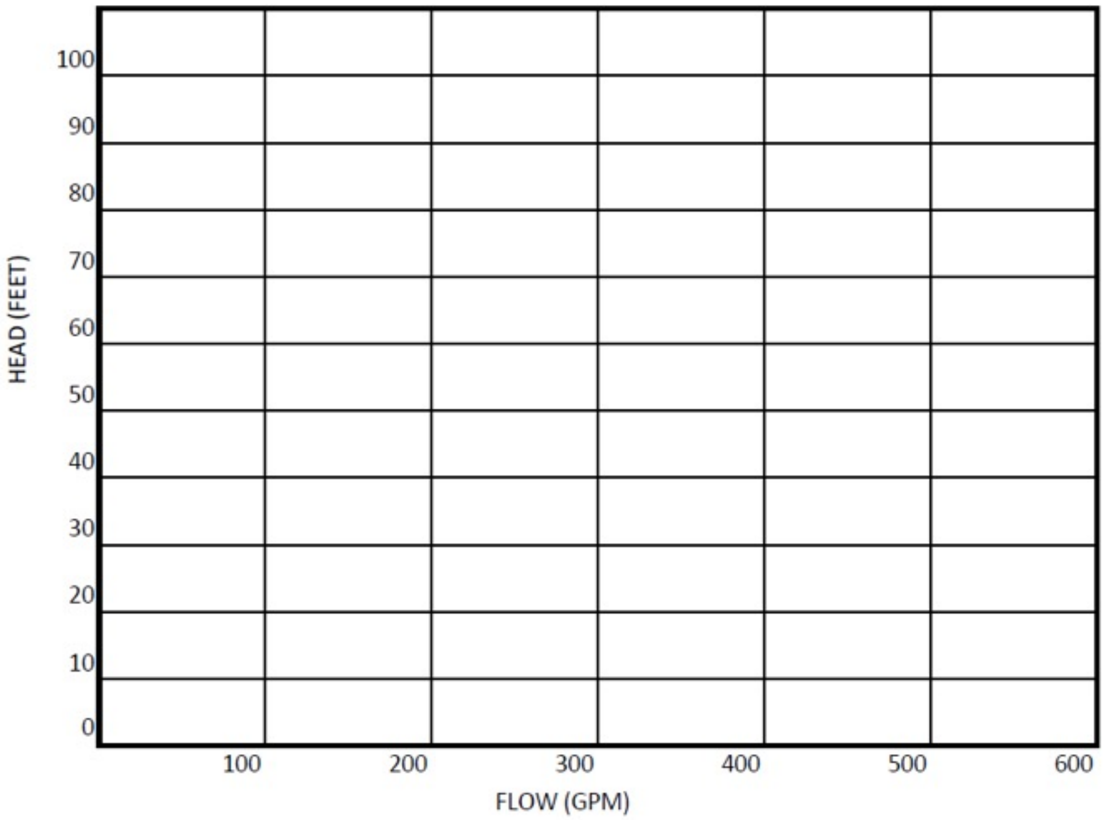
If the pump has a 7.375” impeller diameter (D), and is operating at 320 gpm, what are the other operating conditions (H, η, BHP)?

BREAK

PUMP CURVE ACTIVITY

Pump Activity

EFFICIENCY WITH PUMPING



- You get to design a new pump station
- Booster Pump is at 820 feet
- Discharge point elevation is 860 feet
- What is the static head?

40 feet

Let's Draw!

Design flow is 350 GPM, and the pipe friction loss is estimated as follows:

100 GPM = **1 foot**

200 GPM = **5 feet**

300 GPM = **15 feet**

400 GPM = **30 feet**

500 GPM = **50 feet**

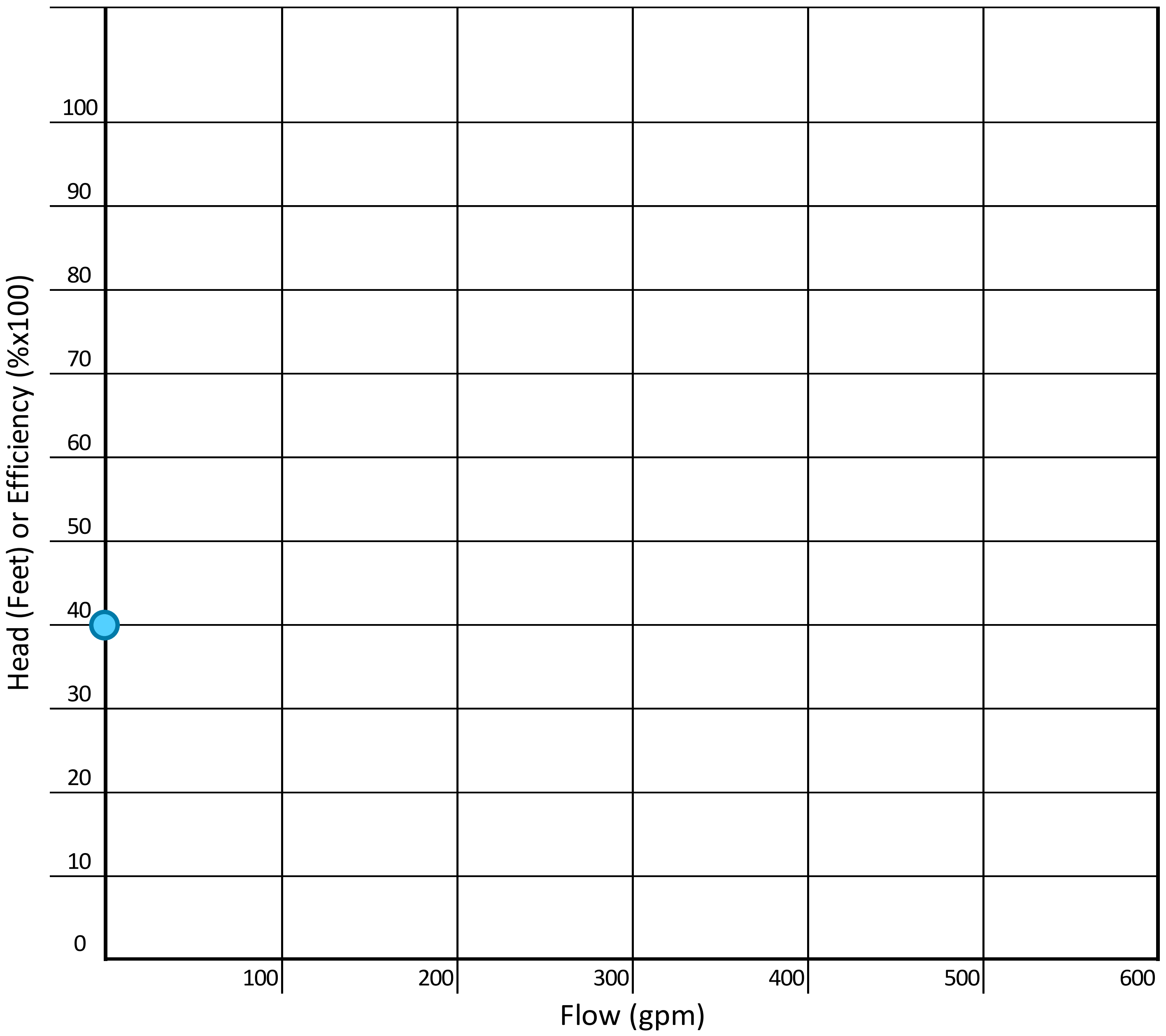
Static Head = 40 feet

Use circles to mark the system curve points

System curve head = static + friction at each flow point

Let's Draw!

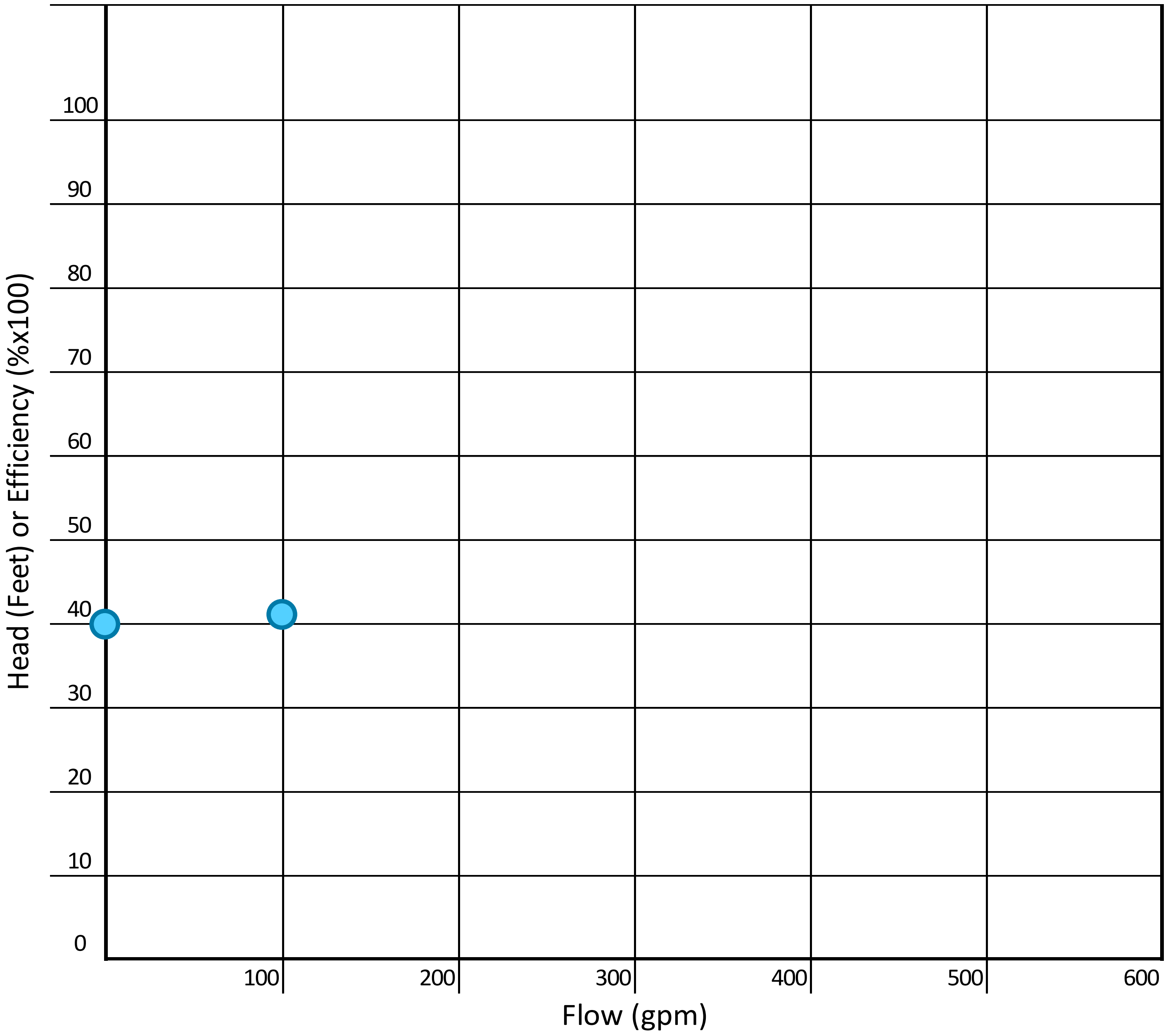
Flow (gpm)	Static Head (ft)	Friction Head (ft)	System Curve Head (ft)
0			
100		1	
200		5	
300		15	
400		30	
500		50	



Head (Feet) or Efficiency (%x100)
100
90
80
70
60
50
40
30
20
10
0
100
200
300
400
500
600
Flow (gpm)

Let's Draw!

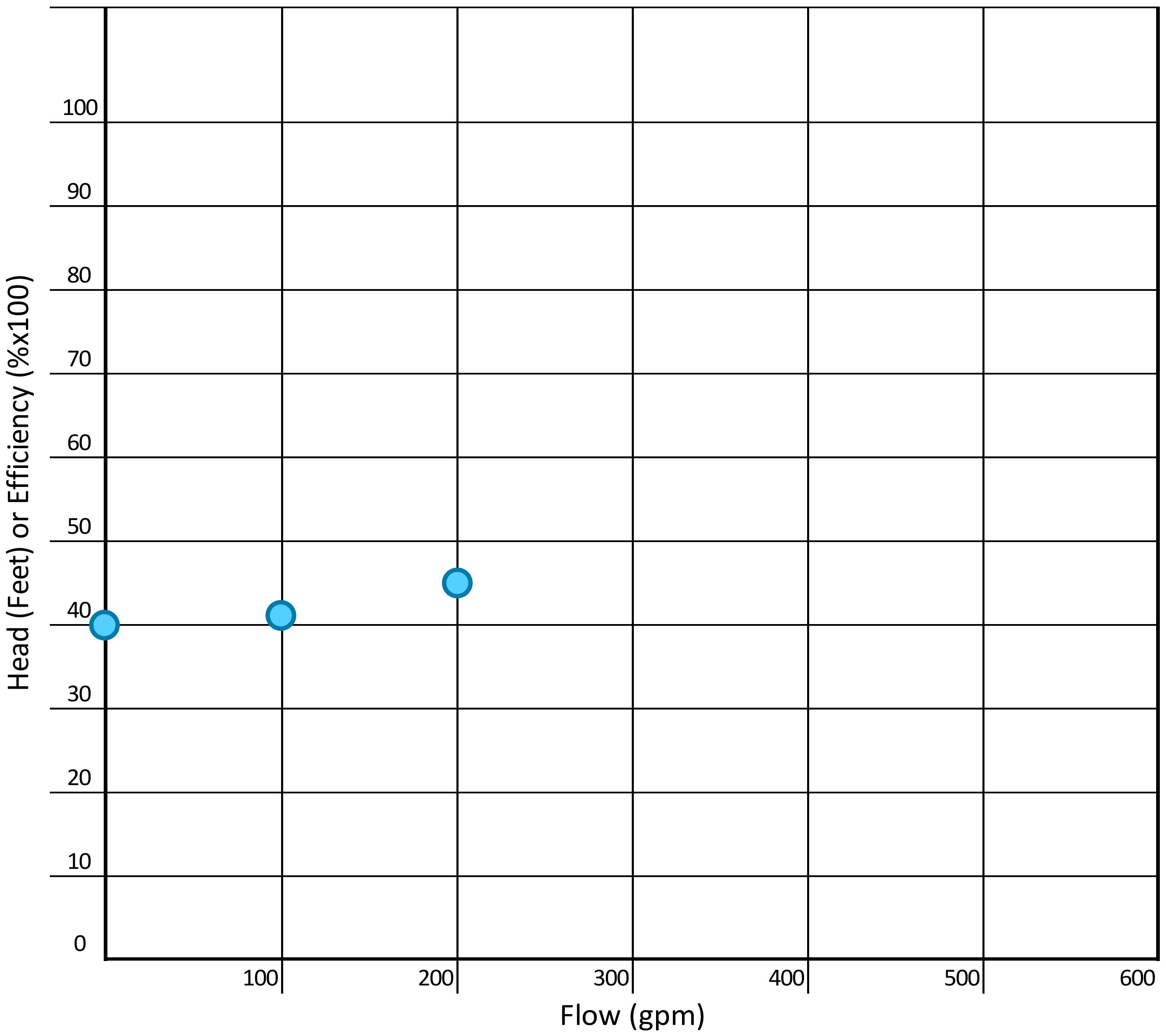
Flow (gpm)	Static Head (ft)	Friction Head (ft)	System Curve Head (ft)
0	40	0	40
100		1	
200		5	
300		15	
400		30	
500		50	



100
90
80
70
60
50
40
30
20
10
0
Head (Feet) or Efficiency (%x100)
100
200
300
400
500
600
Flow (gpm)

Let's Draw!

Flow (gpm)	Static Head (ft)	Friction Head (ft)	System Curve Head (ft)
0	40	0	40
100	40	1	41
200		5	
300		15	
400		30	
500		50	



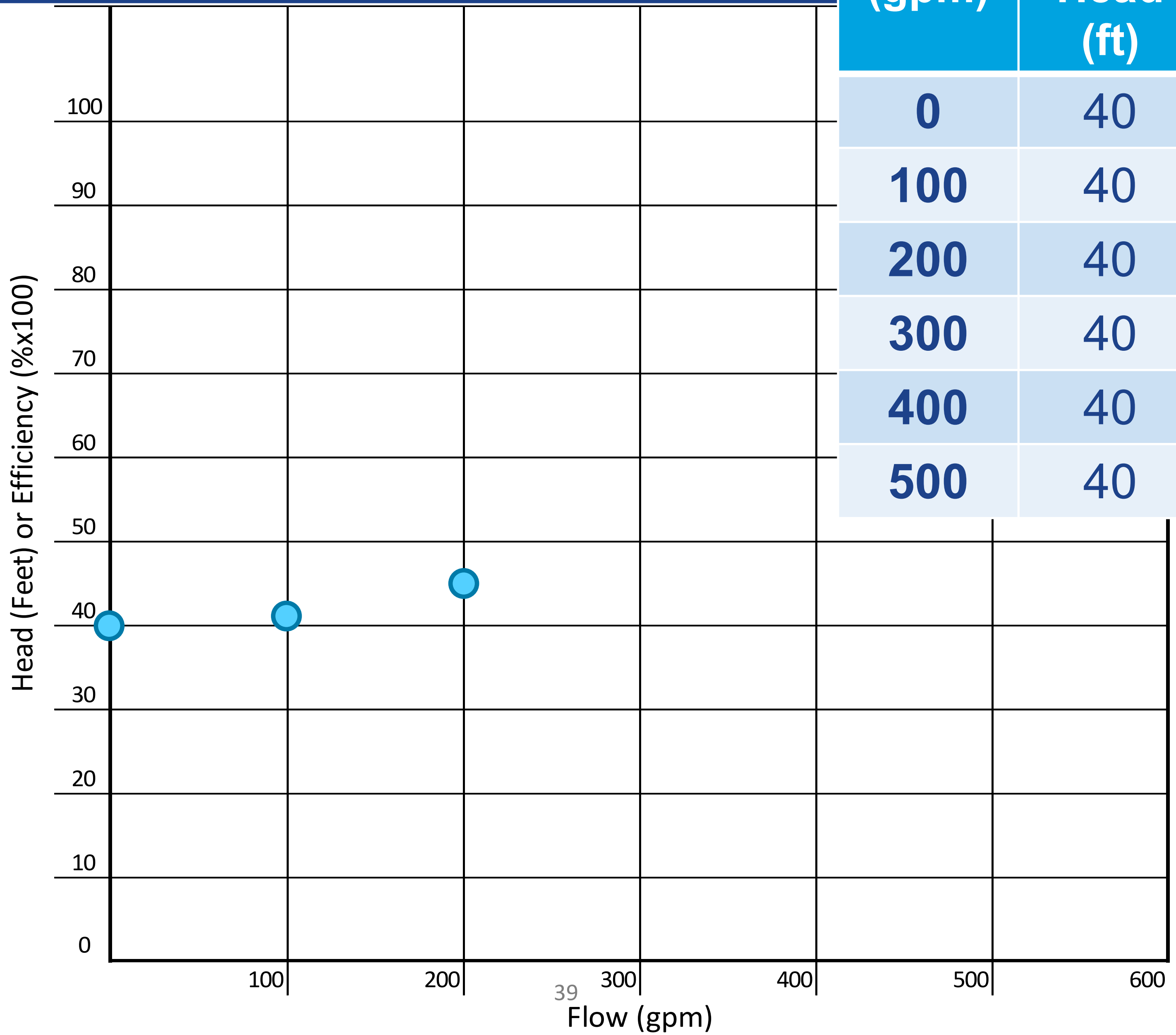
Head (Feet) or Efficiency (%x100)
100
90
80
70
60
50
40
30
20
10
0
100
200
300
400
500
600
Flow (gpm)

Let’s Draw!

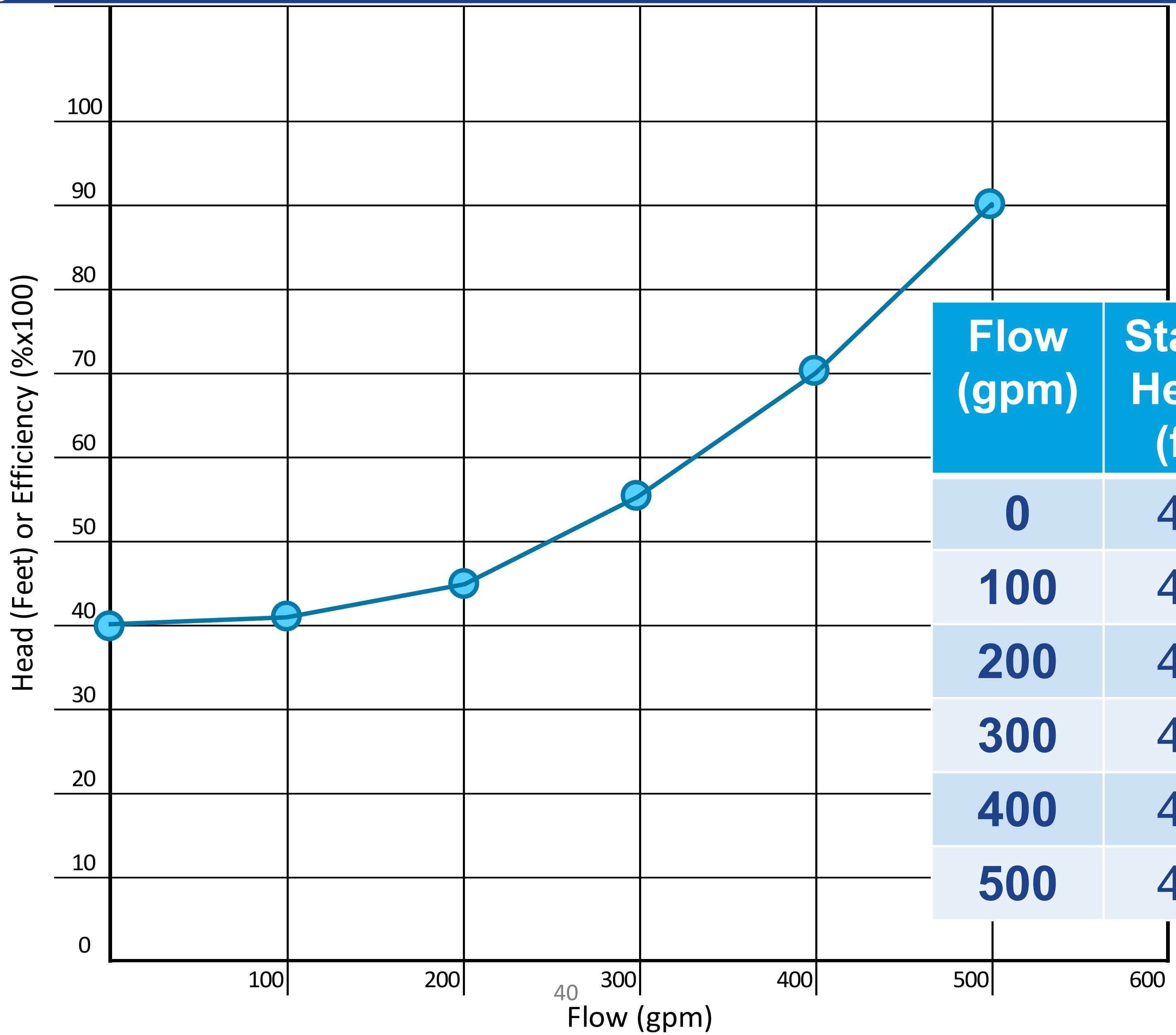
Flow (gpm)	Static Head (ft)	Friction Head (ft)	System Curve Head (ft)
0	40	0	40
100	40	1	41
200	40	5	45
300	40	15	
400	40	30	
500	40	50	

Let's Draw!

Flow (gpm)	Static Head (ft)	Friction Head (ft)	System Curve Head (ft)
0	40	0	**40**
100	40	1	**41**
200	40	5	**45**
300	40	15	**55**
400	40	30	**70**
500	40	50	**90**



System Curve



Flow (gpm)	Static Head (ft)	Friction Head (ft)	System Curve Head (ft)
0	40	0	**40**
100	40	1	**41**
200	40	5	**45**
300	40	15	**55**
400	40	30	**70**
500	40	50	**90**

Now We Pick a Pump

Draw the pump curve:

0 GPM = **92 feet**

100 GPM = **90 feet**

200 GPM = **85 feet**

300 GPM = **75 feet**

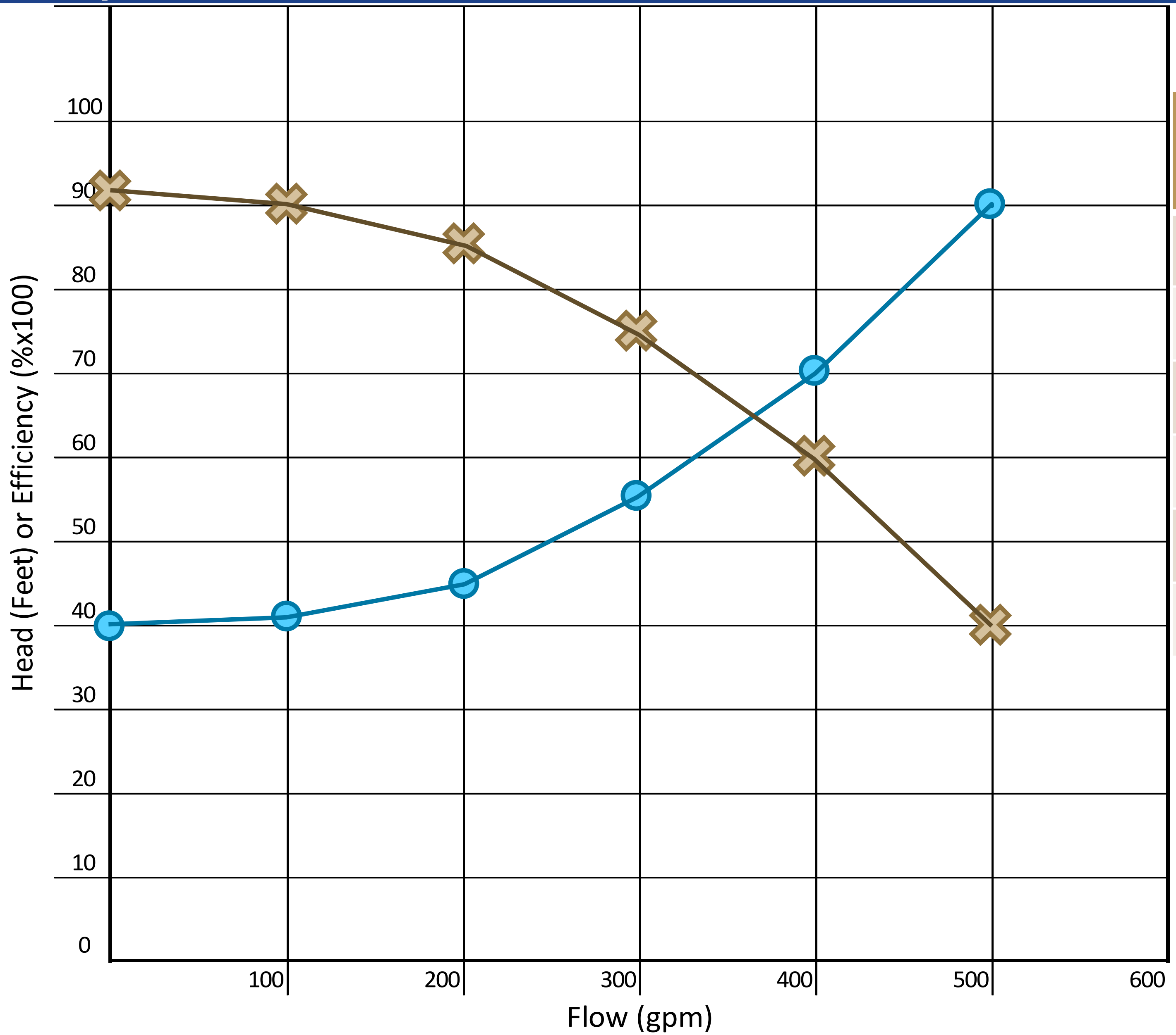
400 GPM = **60 feet**

500 GPM = **40 feet**

- Use Xs to mark the pump curve points

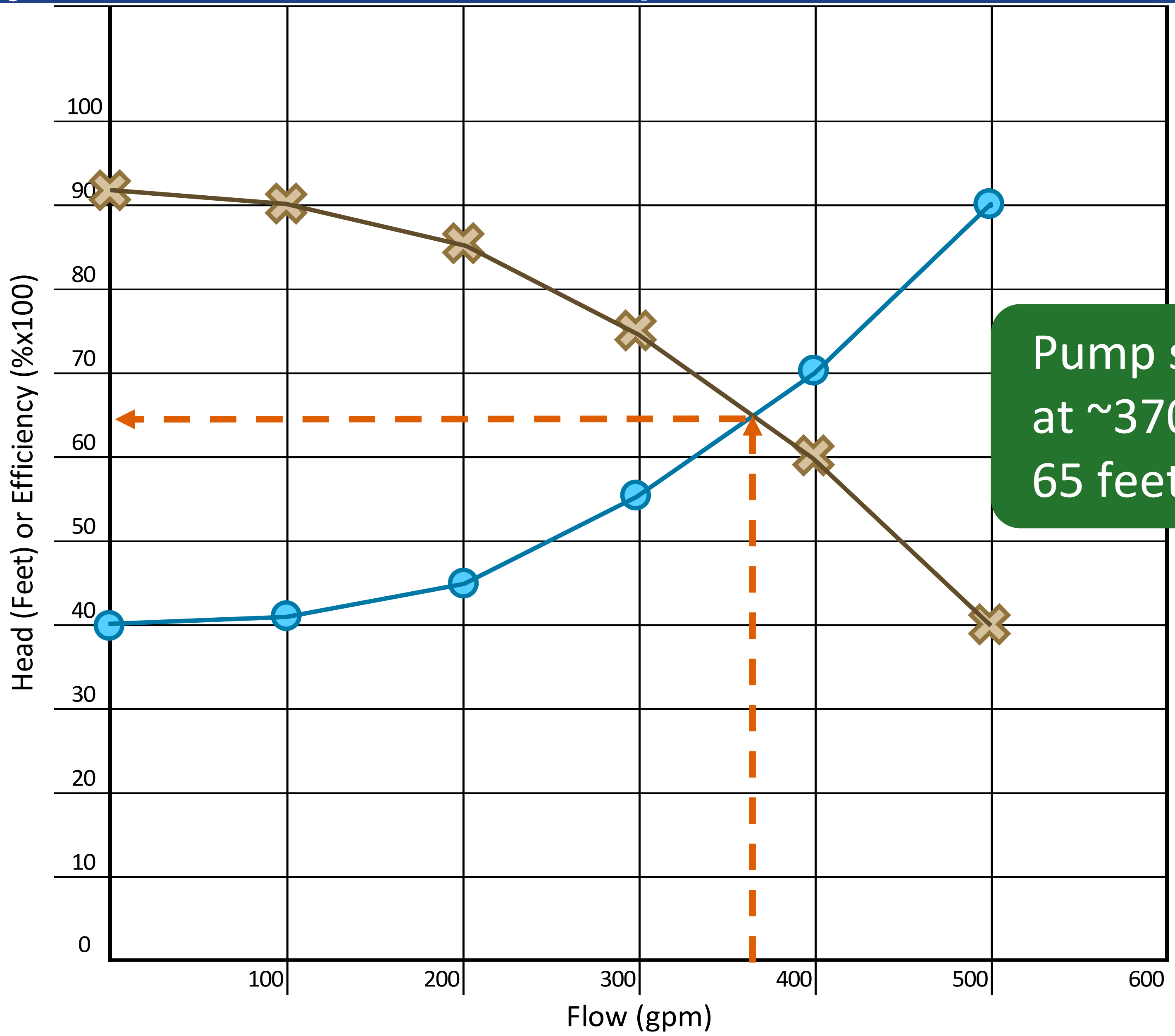
Where do the curves intersect?

Pump Curve



Flow (gpm)	Pump Head (ft)
0	92
100	90
200	85
300	75
400	60
500	40

System Curve and Pump Curve Intersection?



Pump should run at ~370 GPM and 65 feet.

How Efficient is our Pump?

The pump we've selected has the following efficiency points:

0 GPM = **0%**

100 GPM = **30%**

200 GPM = **50%**

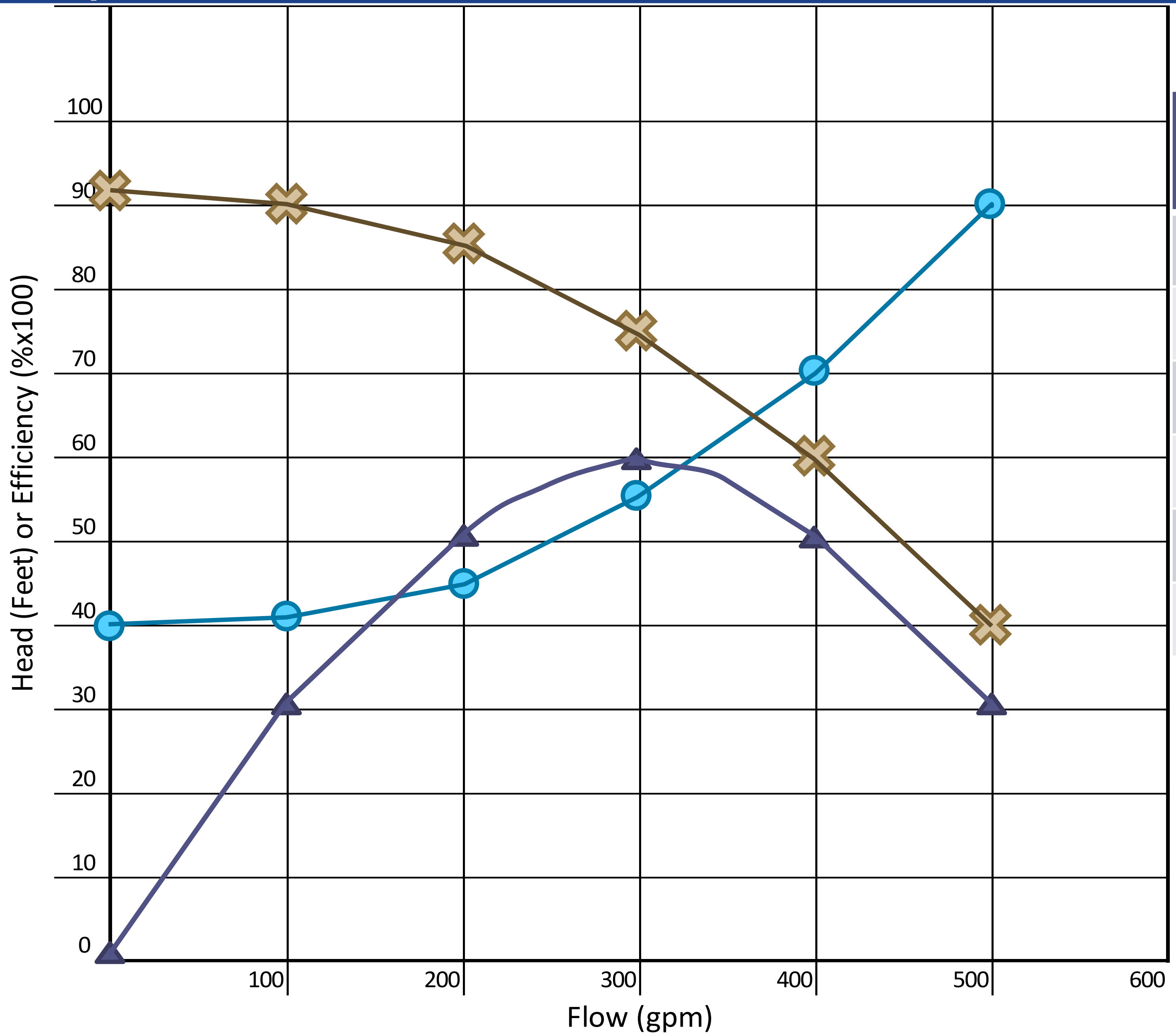
300 GPM = **60%**

400 GPM = **50%**

500 GPM = **30%**

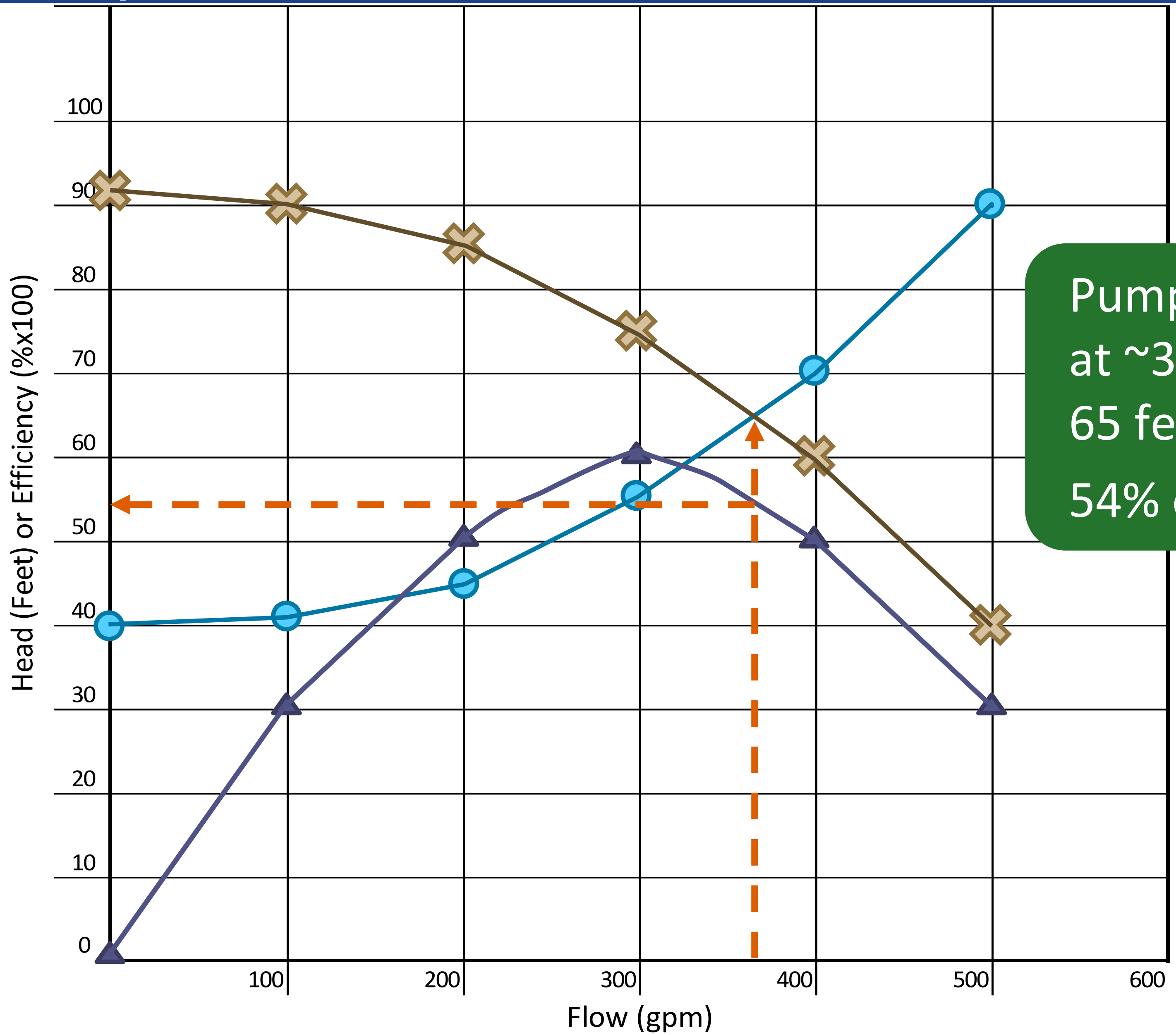
Use Δ's to mark the pump curve efficiency points

Pump Curve



Flow (gpm)	Efficiency (%)
0	0
100	30
200	50
300	60
400	50
500	30

Pump Curve



Pump should run at ~370 GPM and 65 feet and

54% efficiency.

What Power Will It Require?

Pumping Power Equation	
Q	370 GPM
H	65 feet
s.g.	1.0 (we're pumping water)
η	54% (0.54)
BHP	

$$BHP = \frac{s.g. \cdot Q \cdot H}{3960 \cdot \eta}$$

$$11.2 \text{ hp} \times \frac{0.75 \text{ kW}}{\text{hp}} = 8.4 \text{ kW}$$

How Much Will It Cost To Run?

Use 94% motor efficiency

$$\frac{8.4\ \text{kW}}{0.94} = 8.9\ \text{kW into motor}$$

$$8.9\ \text{kW} \times \frac{8{,}760^{**}\ \text{hrs}}{\text{year}} = \frac{78{,}000\ \text{kWh}}{\text{year}}$$

$$\frac{78{,}000\ \cancel{\text{kWh}}}{\text{year}} \times \frac{\$0.06}{\cancel{\text{kWh}}} = \frac{\$\ 4{,}680}{\text{year}}$$

**Assume continuous operation

Uh oh . . .

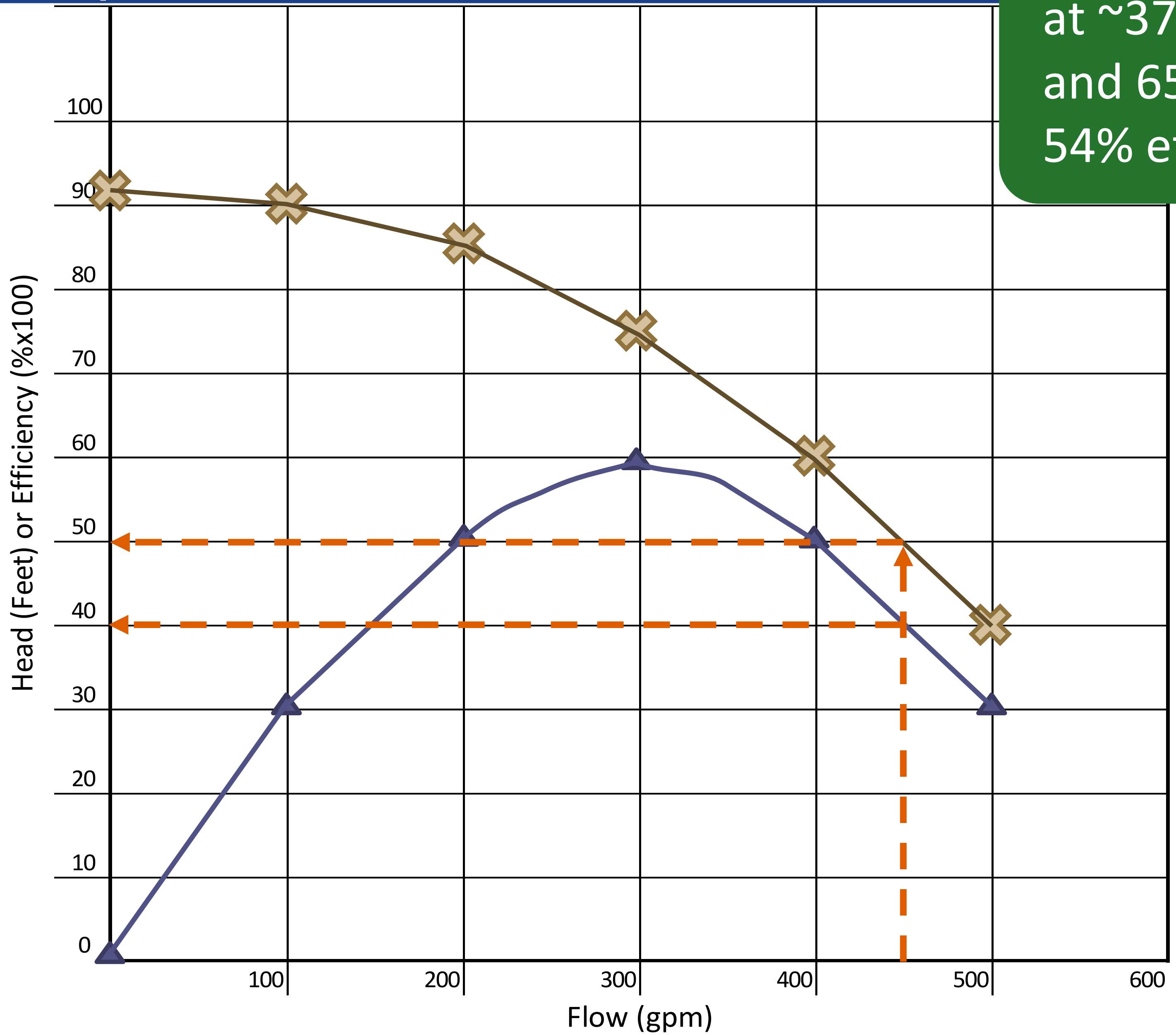
$$BHP = \frac{s.g.\cdot Q \cdot H}{3960 \cdot \eta}$$

You install the pump, and determine that it's actually running at 450 GPM

Pumping Power Equation

Q	450 GPM
H	_______ feet
s.g.	1.0 (we're pumping water)
η	_______%
BHP	______ x 0.75 = _____ kW

Pump Curve



Pump should run at ~370 GPM and 65 feet and 54% efficiency.

Pumping Power Equation

Q	450 GPM
H	50 feet
η	40 %

Quick Power Check

$$BHP = \frac{s.g.* Q * H}{3960 * \eta}$$

Pumping Power Equation	
Q	450 GPM
H	50 feet
s.g.	1 (we're pumping water)
Pump Efficiency η	40%
BHP	

$$BHP = \frac{450\ gpm * 50\ feet}{3960 * 0.40} = 14.2\ HP$$

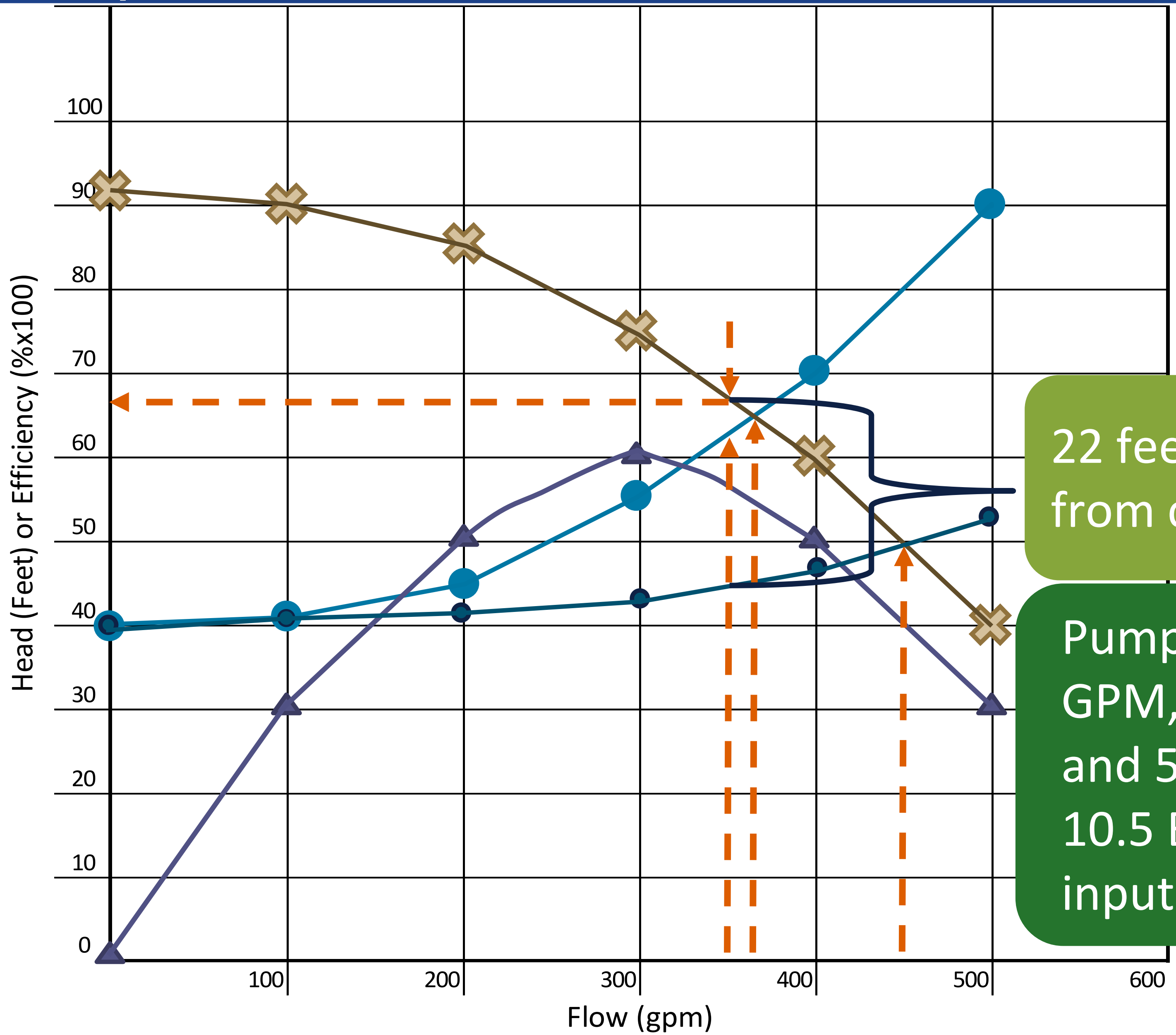
Quick Power Check

Pumping Power Equation	
Q	450 GPM
H	50 feet
η	40%
BHP	14.2 HP

$$\text{Motor Output} = \text{BHP} * \frac{0.75\ \text{kW}}{\text{hp}} = 14.2\ \cancel{\text{hp}} * \frac{0.75\ \text{kW}}{\cancel{\text{hp}}} = 10.6\ \text{kW}$$

$$\text{Motor Input} = \frac{\text{Motor Output kW}}{\text{Motor Efficiency}} = \frac{10.6\ \text{kW}}{0.94} = 11.3\ \text{kW}$$

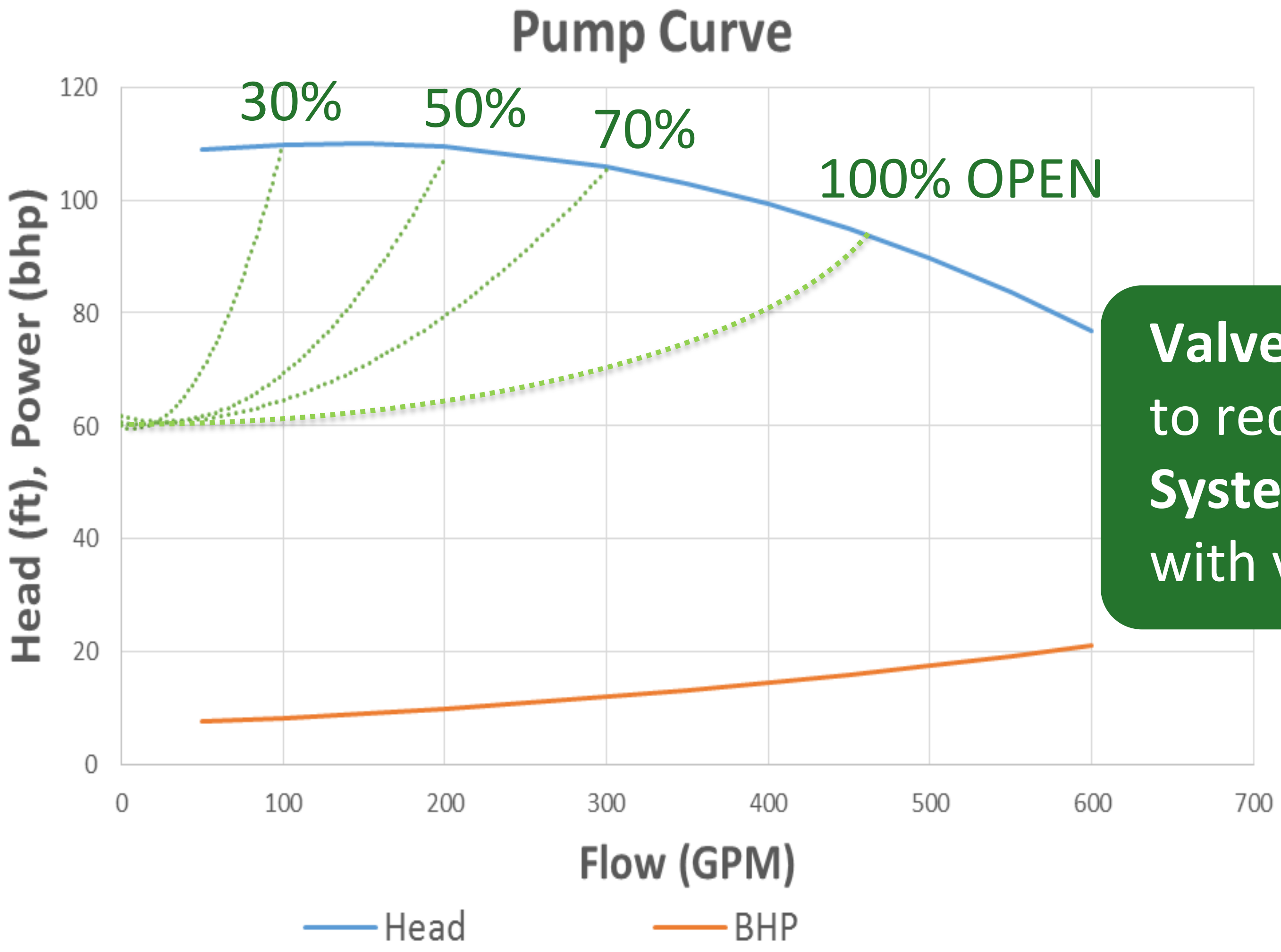
Pump Curve



22 feet of friction head from control valve

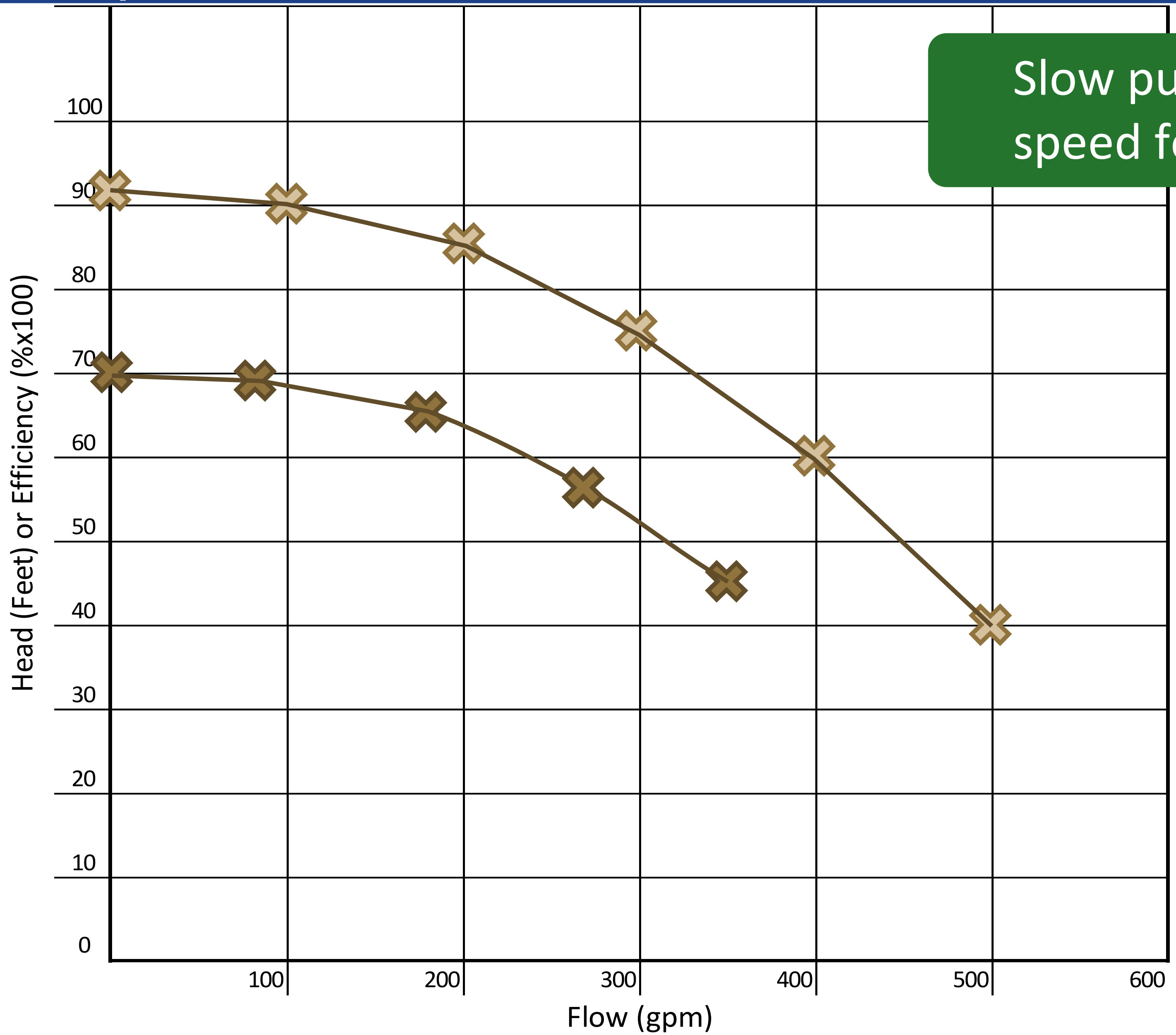
Pump runs at 350 GPM, 68 feet, and 57% efficiency. 10.5 BHP, 8.4 kW input to motor.

Throttled Valve



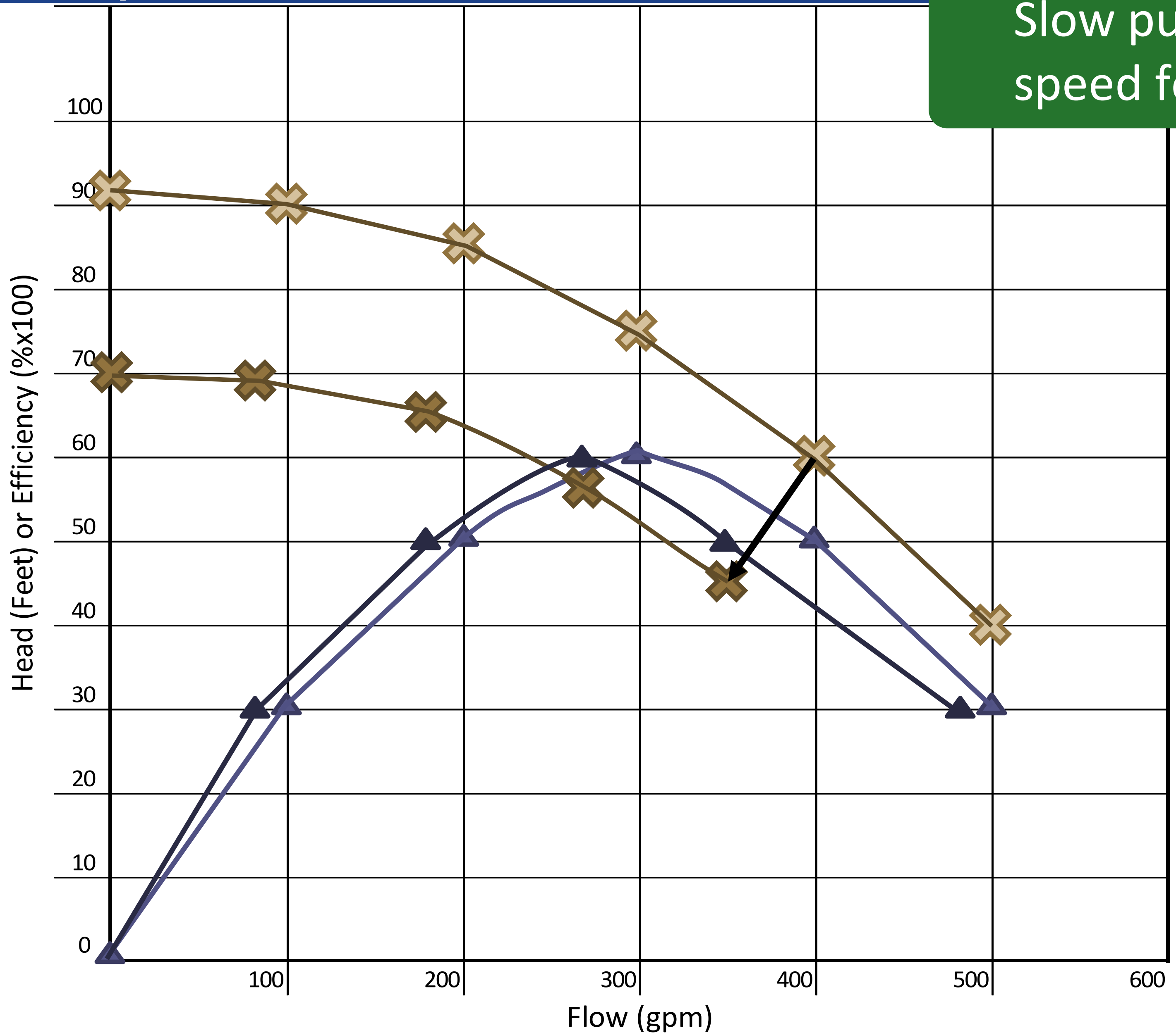
Valve is throttled back to reduce the flow. **System curve** changes with valve position.

Pump Curve



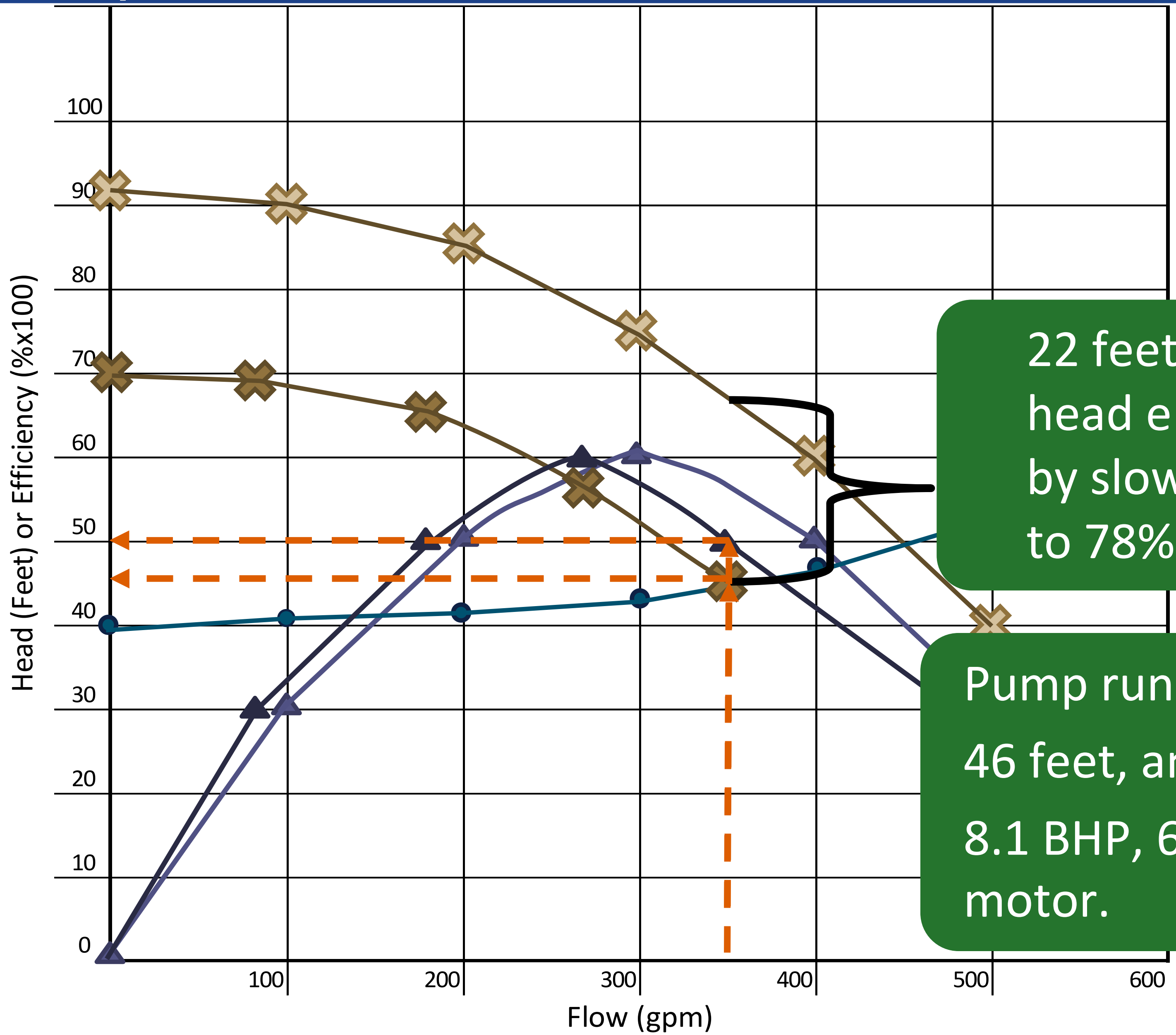
Slow pump to 78% speed for 350 gpm

Pump Curve



Slow pump to 78% speed for 350 gpm

Pump Curve



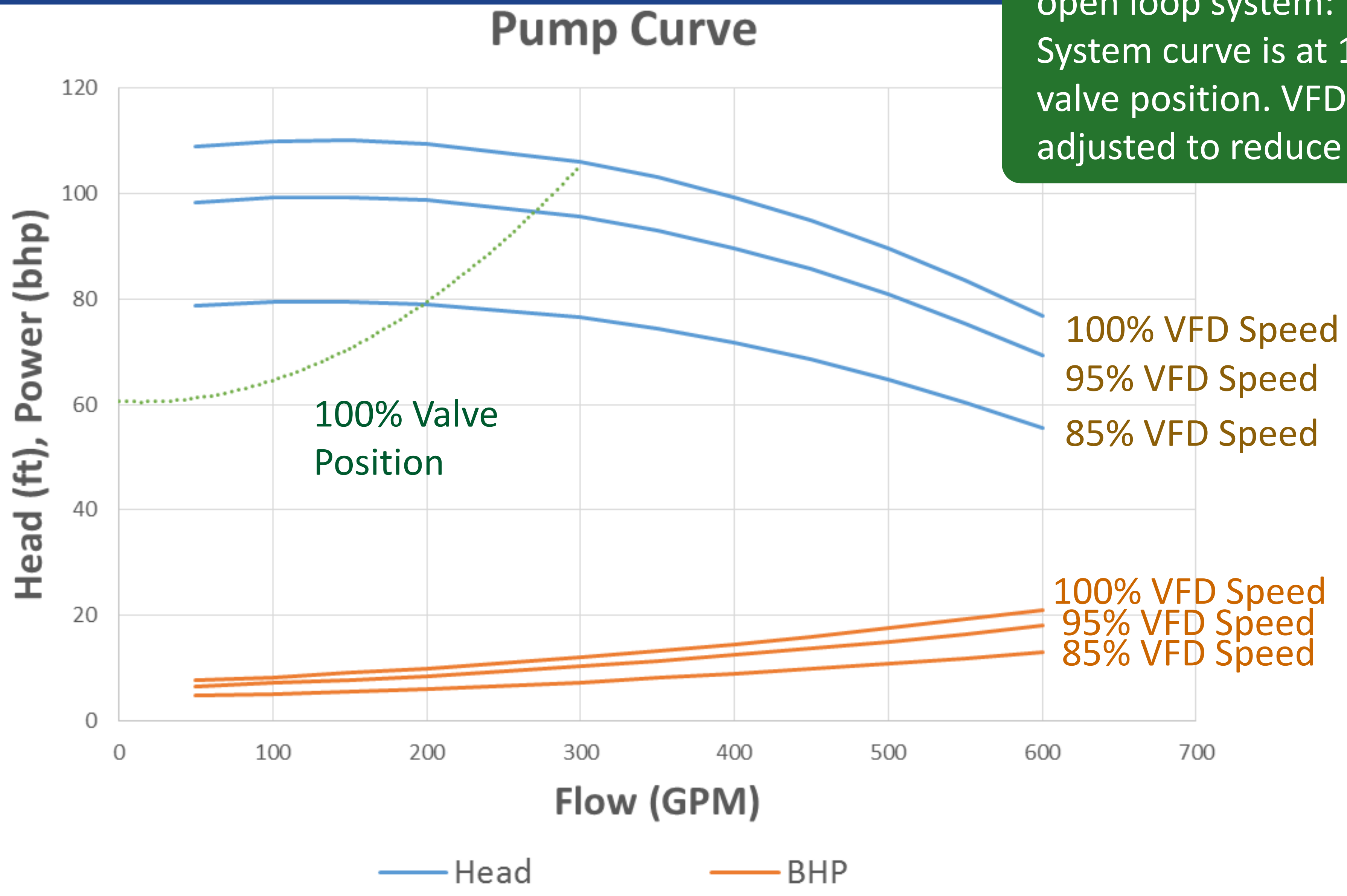
22 feet of friction head eliminated by slowing pump to 78% speed.

Pump runs at 350 GPM, 46 feet, and 50% efficiency.

8.1 BHP, 6.7 kW input to motor.

System Curves: with VFD Operation

Example of system curve for open loop system:
System curve is at 100% valve position. VFD speed is adjusted to reduce the flow.



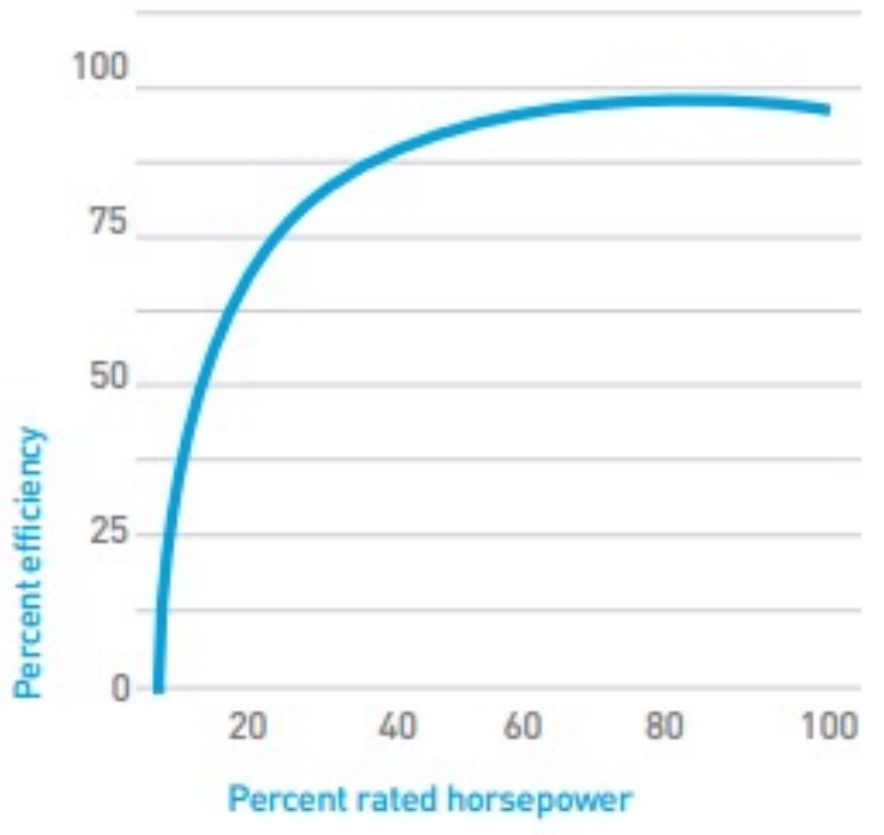
Summary

Condition	Flow (GPM)	Head (Feet)	Input Power (kW)	Annual Cost (@ $.06 /kWh)
Designed	370	65	8.9	$4,680
Installed	450	50	11.3	$5,940
Throttled	350	68	8.4	$4,420
Add VFD	350	46	6.7	$3,520

Summary

Condition	Flow (GPM)	Input Power (kW)	GPM / kW	kWh/MG Pumped
Designed	370	8.9	42	401
Installed	450	11.3	40	420
Throttled	350	8.4	42	400
Add VFD	350	6.7	52	319

Figure 4: Efficiency versus Load Curve for Induction Motors



Source: Courtesy EASA. *Understanding Energy Efficient Motors*. Out of print.

Oversize motors can cost you a LOT of money over the years!

Motor Efficiency, Selection and Management

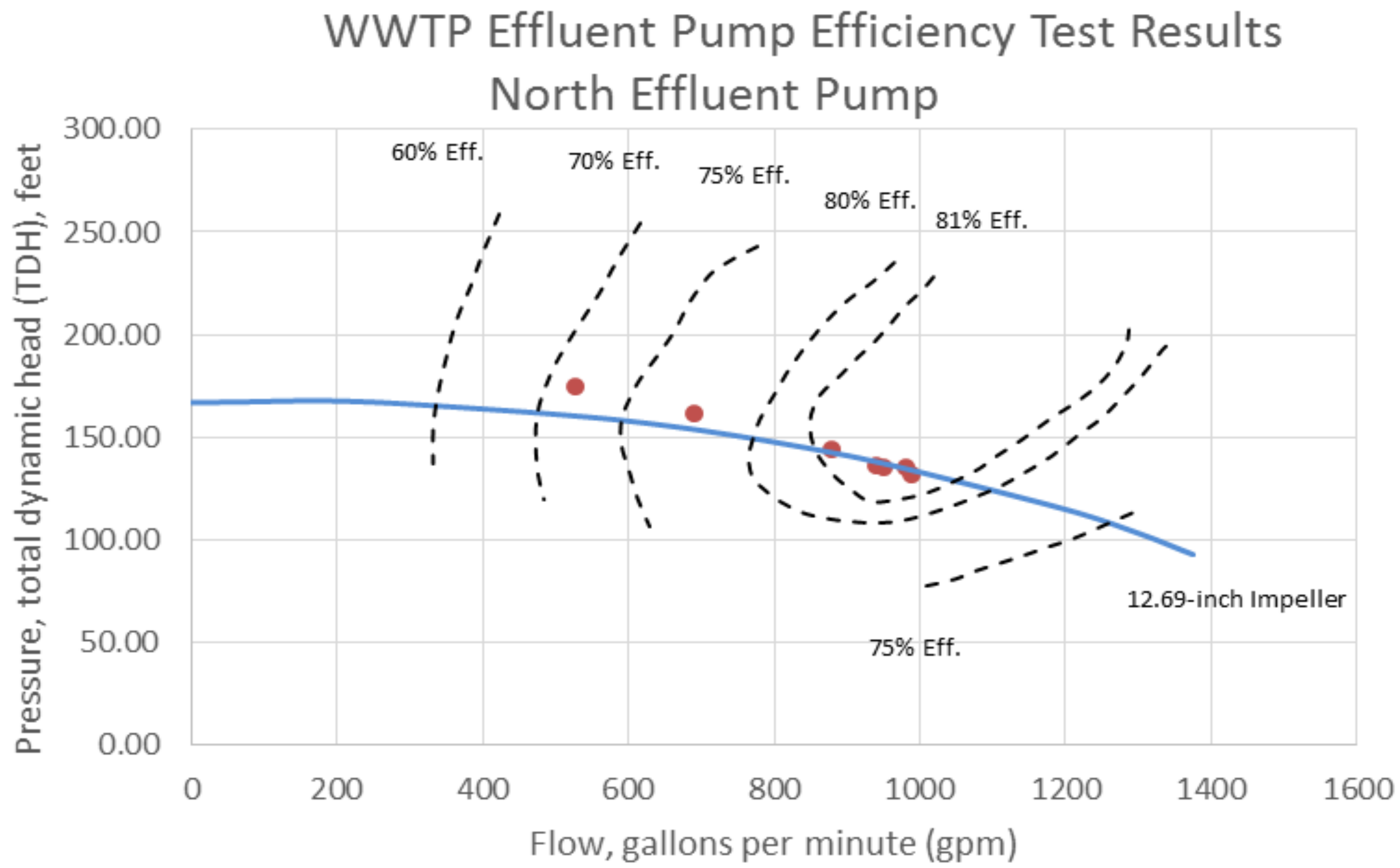
A Guidebook for Industrial Efficiency Programs

http://www.pge.com/includes/docs/pdfs/mybusiness/energysavingsrebates/incentivesbyindustry/agriculture/industrial_guidebook.pdf

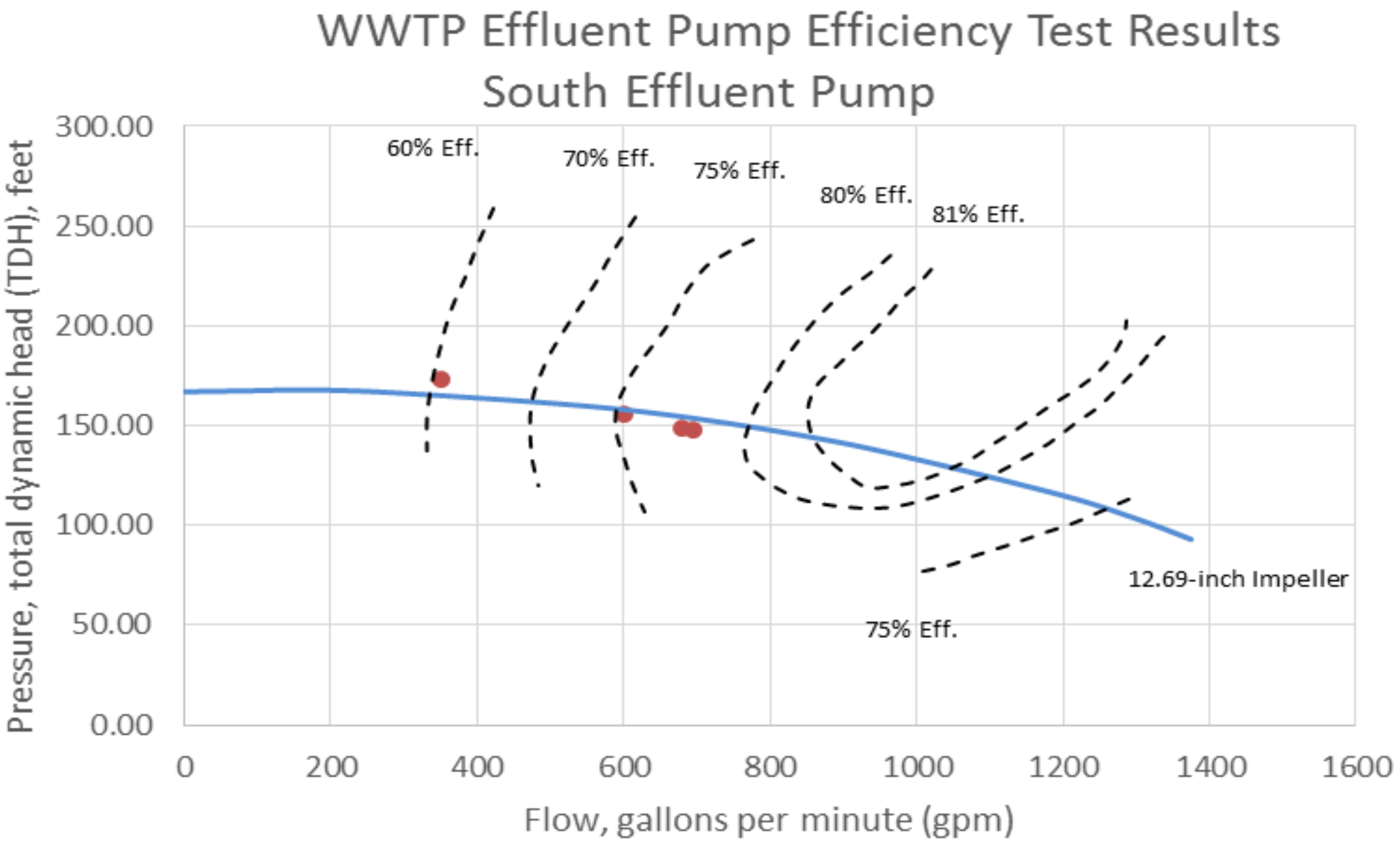
CEE Consortium for Energy Efficiency

Better Plants U.S. DEPARTMENT OF ENERGY

U.S. DEPARTMENT OF ENERGY



WWTP Effluent Pump Efficiency Test Results
North Effluent Pump
60% Eff.
70% Eff.
75% Eff.
80% Eff.
81% Eff.
12.69-inch Impeller
75% Eff.
Pressure, total dynamic head (TDH), feet
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0
200
400
600
800
1000
1200
1400
1600
Flow, gallons per minute (gpm)


WWTP Effluent Pump Efficiency Test Results
South Effluent Pump
Pressure, total dynamic head (TDH), feet
300.00
250.00
200.00
150.00
100.00
50.00
0.00
0
200
400
600
800
1000
1200
1400
1600
Flow, gallons per minute (gpm)
60% Eff.
70% Eff.
75% Eff.
80% Eff.
81% Eff.
75% Eff.
12.69-inch Impeller

PUMP ENERGY CALCULATIONS

A 100 hp pump is 80% loaded and runs 24/7. Motor efficiency is 95%. What is the operating power? Annual energy use and cost?

BHP = 100 hp x 0.80 load = **80 hp**

Annual energy use?

- $$\frac{80\ \text{hp} \times \frac{0.746\ \text{kW}}{\text{hp}} \times \frac{24\ \text{hr}}{\text{day}} \times \frac{365\ \text{days}}{\text{year}}}{0.95\ \text{motor efficiency}} = \mathbf{\frac{550{,}000\ kWh}{year}}$$
- $$\text{Energy \$} = \frac{550{,}000\ \text{kWh}}{\text{yr}} * \frac{\$0.05}{\text{kWh}} = \mathbf{\frac{\$27{,}500}{year}}$$

A 100 hp pump draws 70 amps at 460 volts operating at 100 psi year-round. Assume power factor is 0.8.

How much energy would be saved by reducing the discharge pressure to 90 psi (estimate)?

AMP TO kWH CALCULATION

For three phase power (be wary of using amps from a VFD panel readout):

$$Amps \times Volts \times 1.73 \times Power\ Factor \times \frac{1}{1{,}000} \times hours = kWh$$

70 x 460 x 1.73 x 0.8 / 1,000 x 8,760 = 390,000 kWh

- % savings = (100 psi – 90 psi) / 100 psi = 10%
- Energy reduction = 390,000 kWh x 0.10 = 39,000 kWh
- Energy Savings $ = 39,000 kWh/yr * $0.05/kWh = $1,950/year

$$\text{Energy Savings \$} = 39{,}000\ \frac{\text{kWh}}{\text{yr}} \times \frac{\$0.05}{\text{kWh}} = \frac{\$1{,}950}{\text{year}}$$

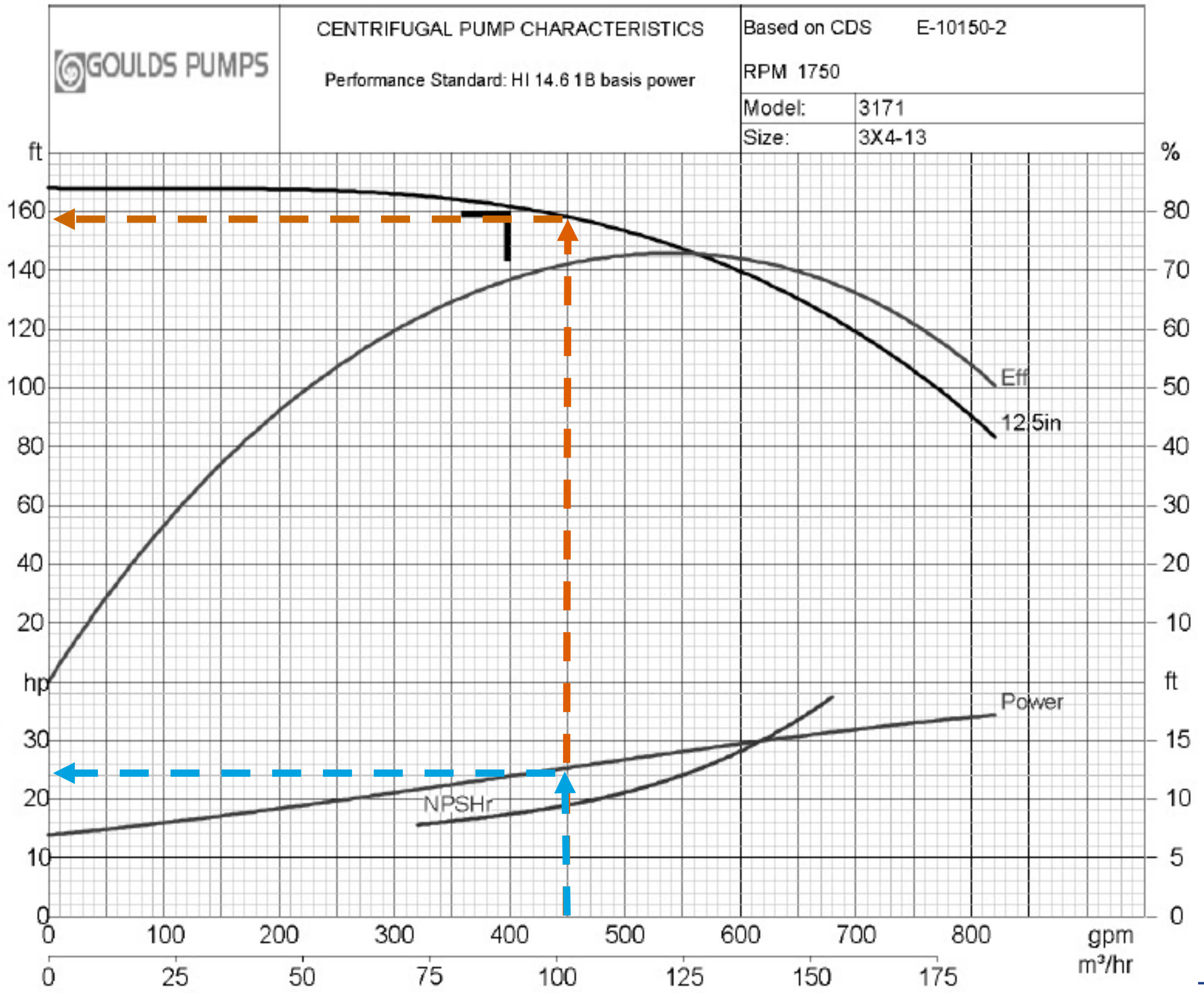
Activity

Calculate the energy savings for installing a VFD on a 50 hp pump

Currently throttled condition is 450 gpm

Actual pressure needed downstream of the valve is 40 psi

Baseline Pump Energy



- Flow: 450 gpm
- Head: 159 ft
- BHP: 25 BHP

Baseline Energy Calculations

Input Motor Power

$$\underline{\quad 25 \quad} BHP \times \frac{1}{\underline{\quad 94 \quad} \% \; motor \; eff} \times \frac{0.746 \; kW}{hp} = \underline{19.8} \; kW$$

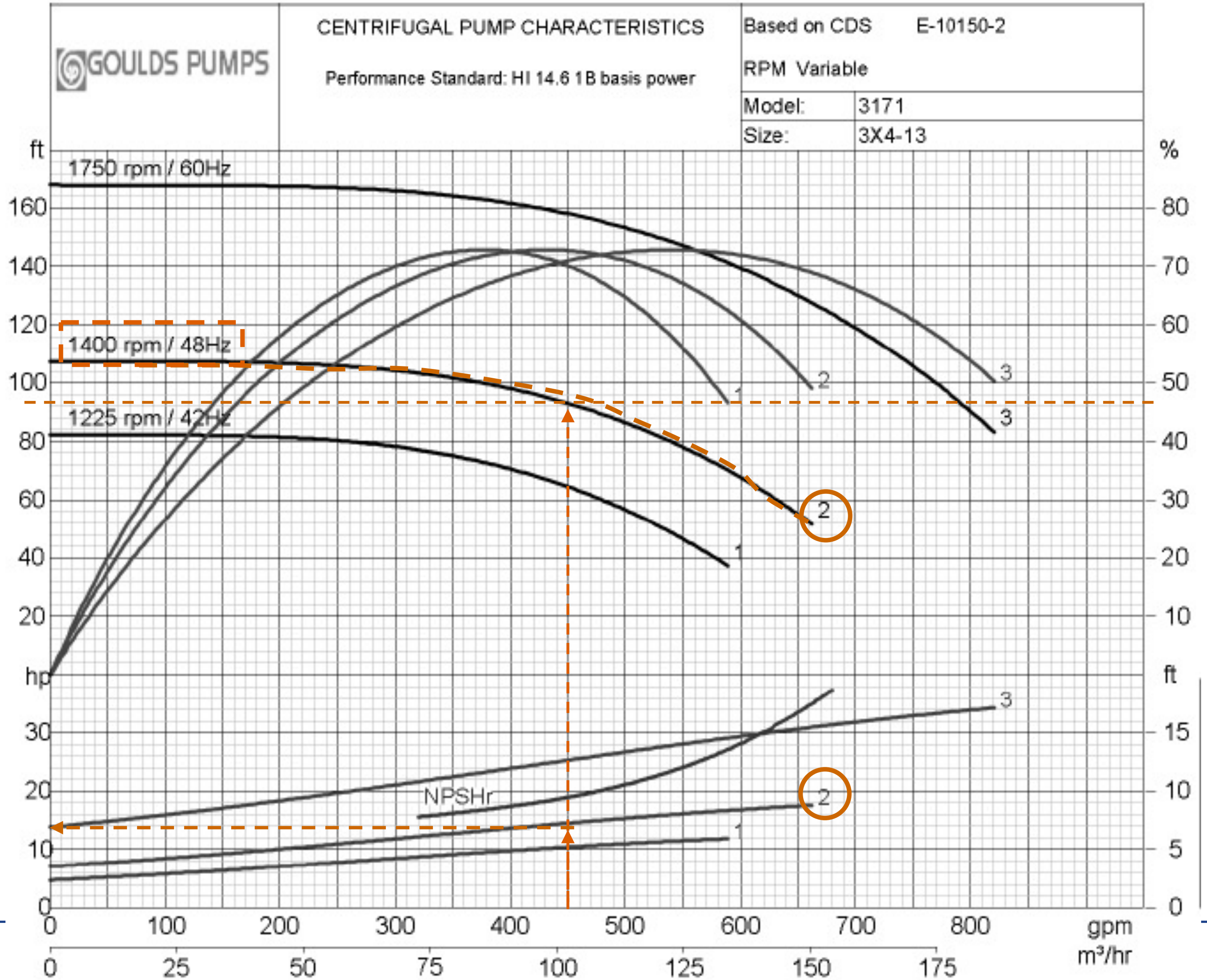
Baseline Pump Energy

___19.8___kW x ______8,760_ Hours /yr = ______174,000______ kWh/yr

Baseline Pump Energy Costs

174,000_________kWh x $__0.05_____ /kWh =____$8,700____ $/yr

VFD Energy Calculations



Pump Head:

40 psig x $\frac{2.31ft}{psi}$ = 92.4 FT

Pump Speed:
(Which of the pump curves provides 92.4 ft @450 gpm)

1400 RPM x $\frac{1}{1750\ RPM}$ = 80 % Speed

Pump Brake Horsepower:

15 BHP

VFD Energy Calculations

Input Motor Power

$$\underline{\quad 15 \quad} BHP \times \frac{1}{\underline{\quad 94 \quad}\%\ motor\ eff} \times \frac{0.746\ kW}{hp} \times \frac{1}{\underline{97}\ \%\ VFD\ eff} = \underline{\ 12.3\ }\ \text{kW}$$

(read from above)

VFD Pump Energy

____12.3 kW x ______8,760 Hours of Operation/yr = _____108,000_ kWh/yr

VFD Pump Energy Costs

108,000__________kWh x $__0.05_____ /kWh =____$5,400_____ $/yr

VFD Energy Savings

________$8,700_______________$/yr

(baseline operating costs read from above)

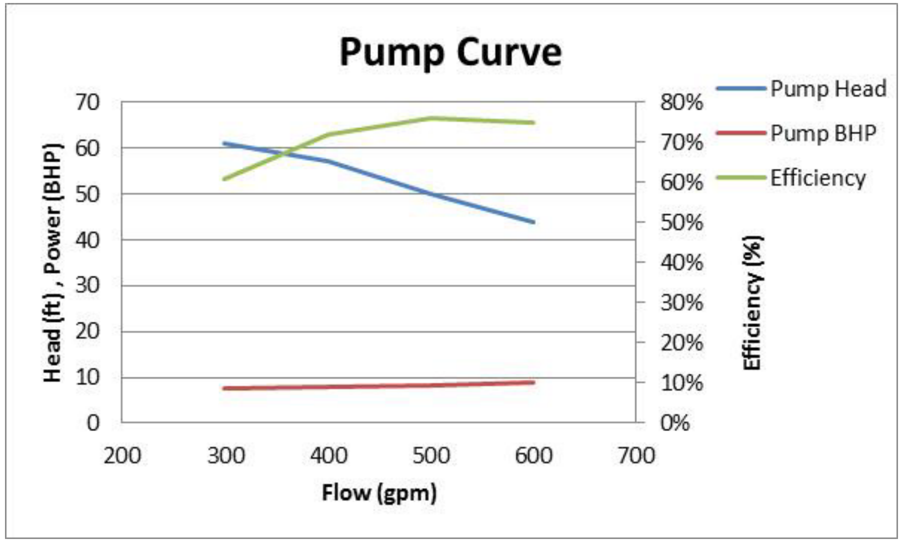
\- _____$5,400___________ $/yr

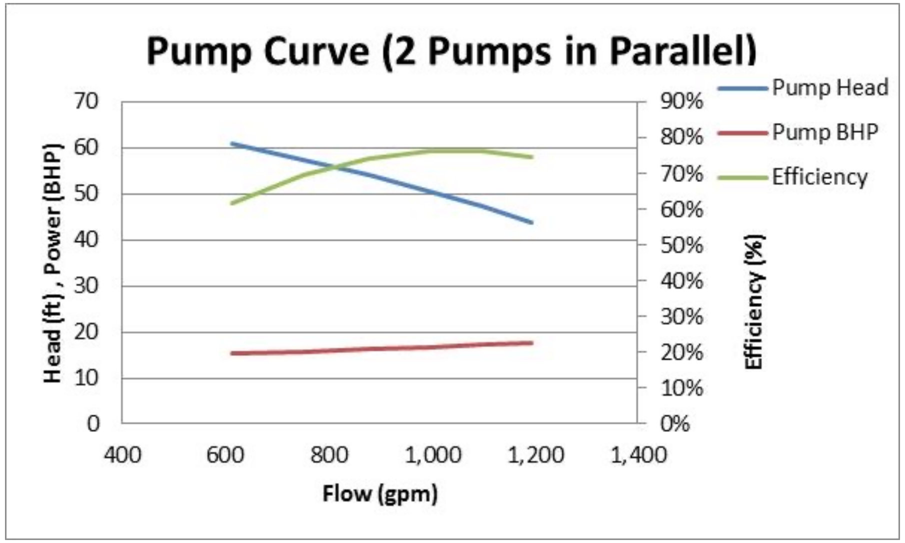
(VFD operating costs read from above)

=_____$3,300______________ $/yr

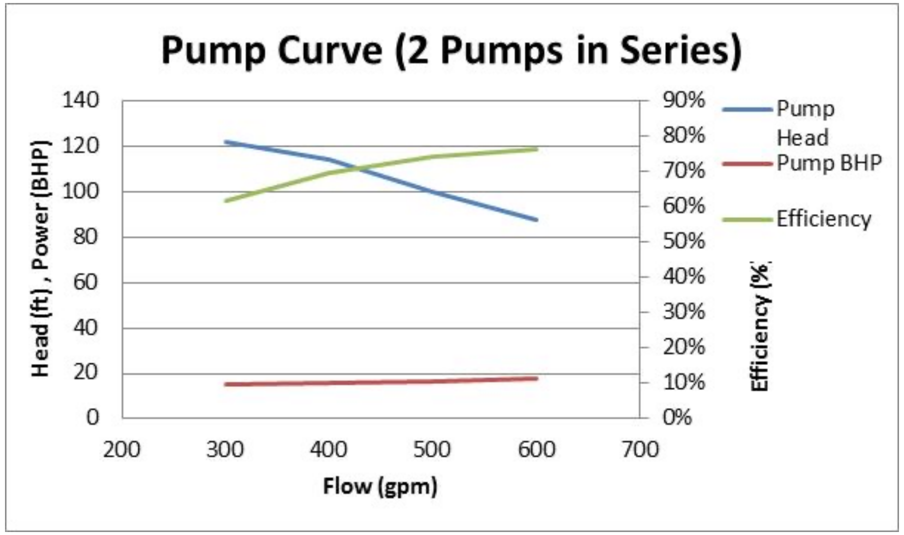
MULTIPLE PUMPS

Combining Pump Curves



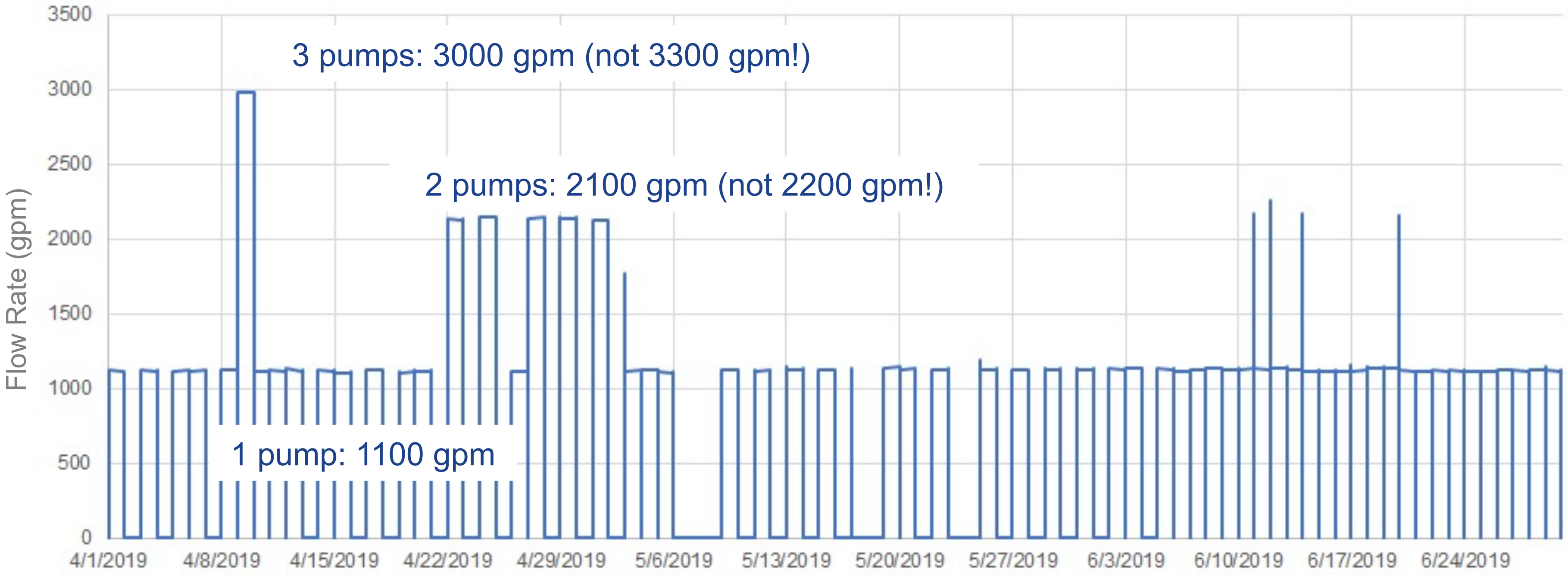


Pumps in Parallel
Add flows at same pump head...in theory.



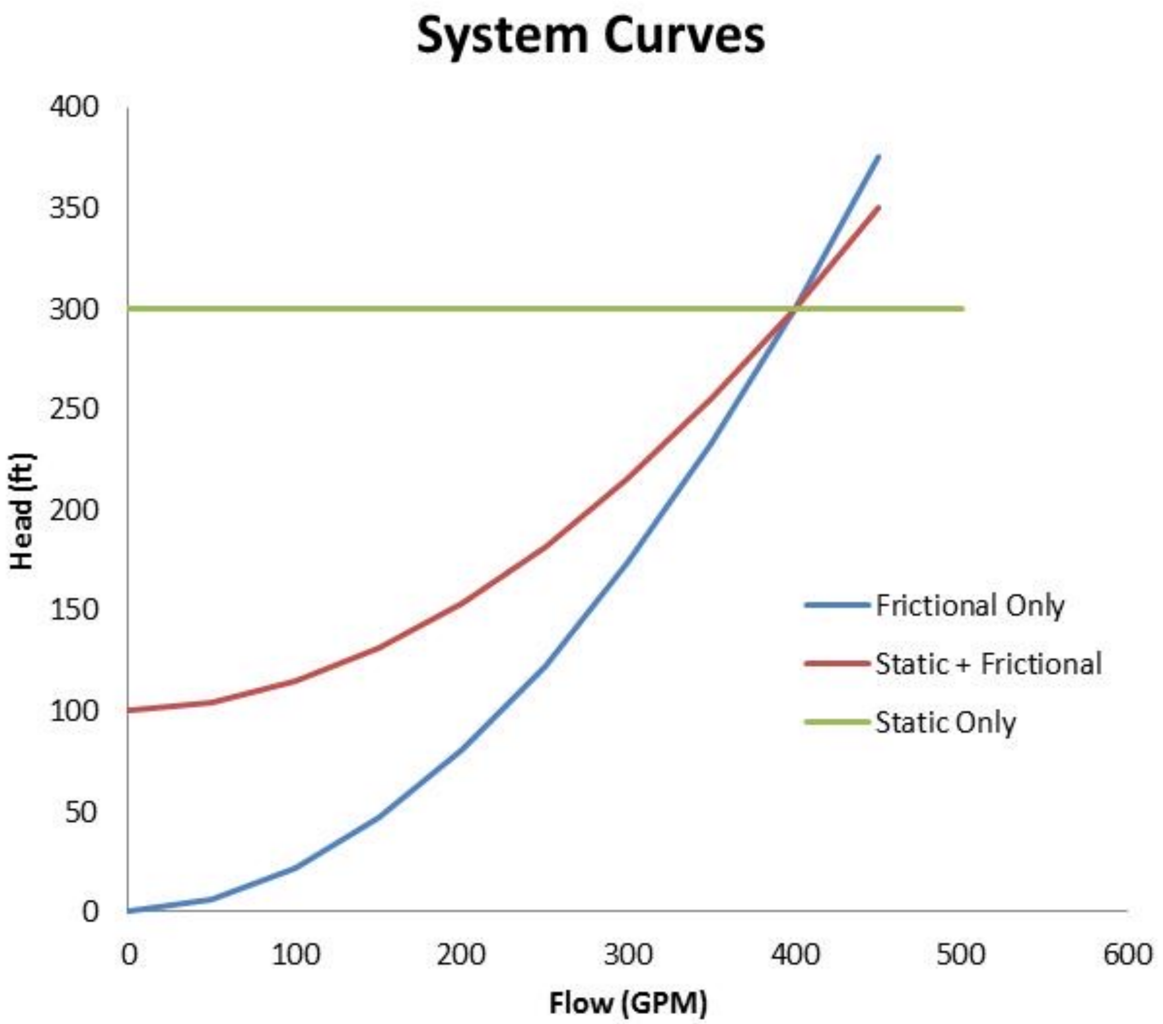
Pumps in Series
Add pump head at same flow...in theory.

Pump Station with 3 Pumps



Why? The faster you pump, the more friction you create!

Remember the System Curve!



What affects head loss the most?

Total Dynamic Head = Static Head + Head Loss

$$h_L = f\frac{L}{D}\frac{v^2}{2g}$$

Head loss is most sensitive to changes in **diameter**

On your smart phone

Go to: https://kahoot.it/

Game PIN: 7327687

KAHOOT!

Takeaways

- Use your pump curves to see where they can operate efficiently
- Review pump curves when picking new equipment
- Consider VFD’s where they make sense
- Reach out to your power provider about incentives when you are considering new equipment

Closing

Questions
Comments
Discussion

SEE YOU TUESDAY!

aquafficiency

Saving energy, one gallon at a time