

Introduction to PUMP CURVES

Introduction to *Pump Curves*

A performance curve is normally a curved line drawn on a grid or graph of vertical and horizontal lines. This curved line represents the performance of a specific pump. The vertical and horizontal lines represent units of measure that illustrate that performance.

In our application there is a tank or well full of water. We want to use the water for a specific process or in a home. Often the water is at a lower level and gravity will not allow it to flow uphill, so a pump is used. A pump is a machine used to transfer or move a volume of water (or fluid) a given distance. This volume is measured over a period of time expressed in gallons per minute (gpm) or gallons per hour (gph). This volume is also referred to as capacity or flow.

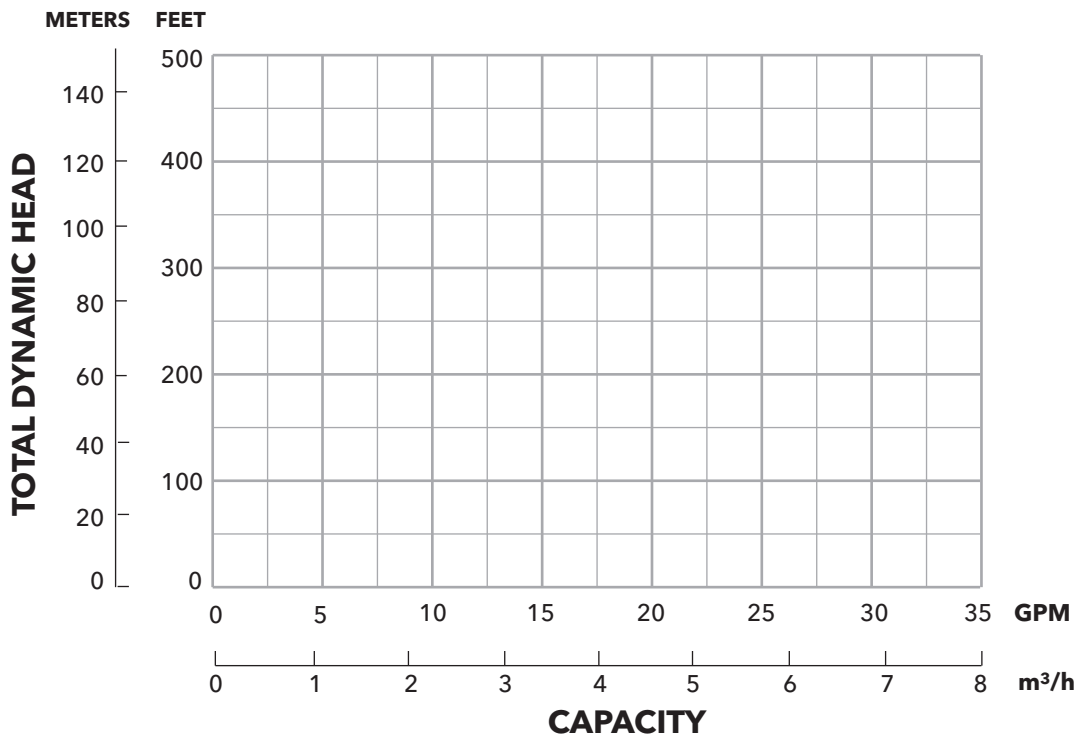
The pump develops energy called discharge pressure or total dynamic head (tdh). This pressure is expressed in units of measure called pounds per square inch (psi) or feet of head(ft.). NOTE: 1 psi will push a column of water up a pipe a distance of 2.31'. A performance curve is used to determine which pump best meets the system requirements.

Example 1

The graph below would be used to illustrate a pump's performance. It is important to determine the value of each grid line or square. On the left hand side of the graph Total Dynamic Head (TDH) is shown with the unit of measure in feet. The numbers start at the bottom, left hand corner with 0 and go up the vertical axis. This is the ability of the pump to produce pressure expressed in feet of head, which is a term used by many engineers. Sometimes the measure will say total dynamic head -- feet of water. This is another term which means a gauge was installed at the discharge of the pump and a reading was taken in psi. This reading is converted to feet (1 psi = 2.31 feet) and water was the liquid being pumped.

The other unit of measure is gallons per minute and is shown across the bottom (horizontal axis). Start at the bottom, left corner with 0 and go to the right. These numbers relate to the ability of the pump to produce flow of water expressed as capacity in gallons per minute (GPM).

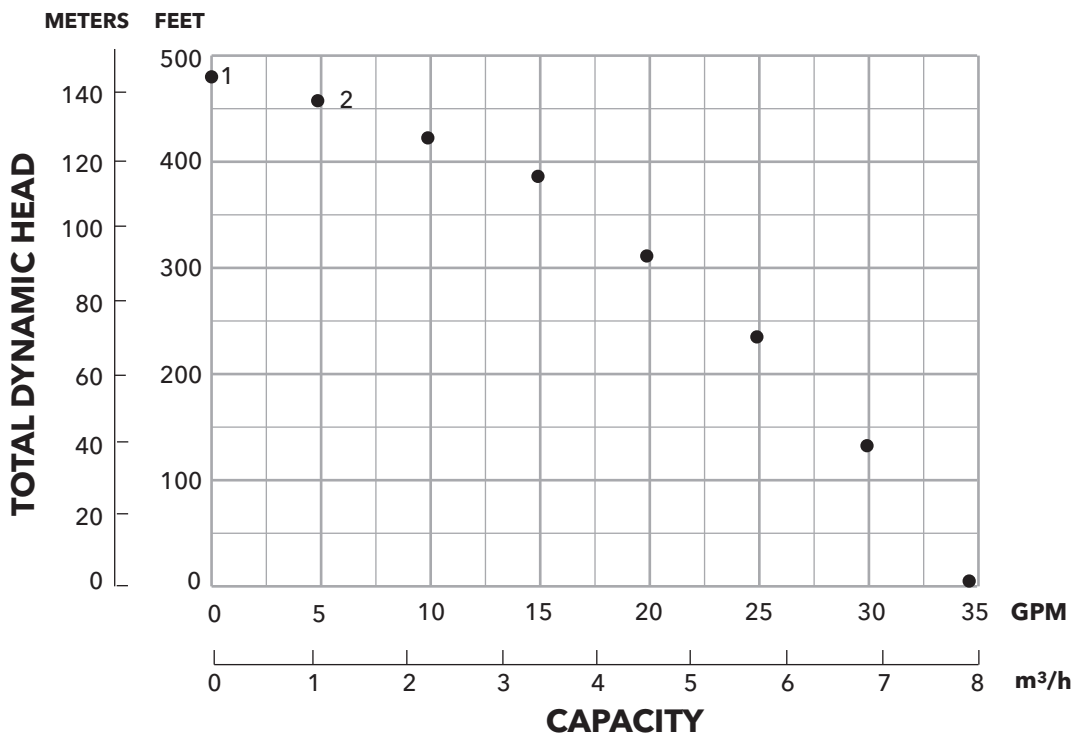
Also shown are the metric measures in meters for the TDH and cubic meters per hour for the capacity.



Example 2a

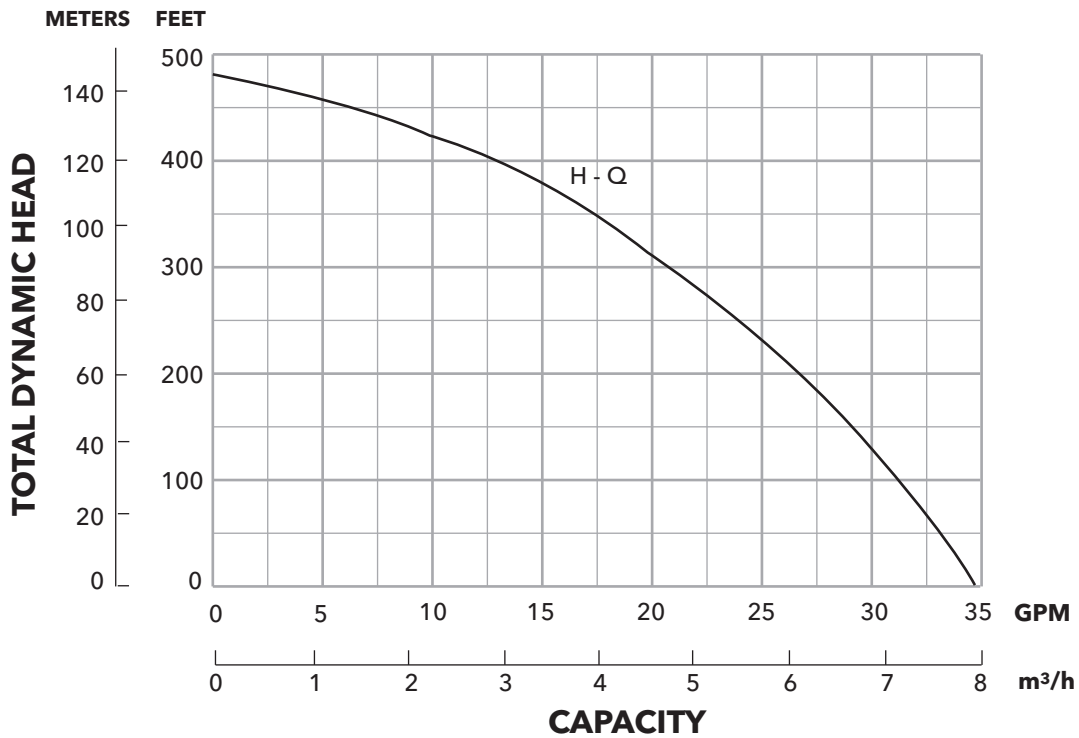
To produce a performance curve the pump is operated using a pressure gauge, throttling valve and flow meter installed in the discharge pipe. The pump is run with the throttling valve completely closed so there is no flow and a reading is taken from the pressure gauge. This is referred to as the maximum shutoff pressure. Convert this psi reading (1 psi = 2.31 ft.) to feet of head and this is the pump's maximum Total

Dynamic Head (TDH) at 0 capacity. A mark is placed on the graph to indicate this performance (Point 1). The valve is opened until the flow meter reads 5 gpm and another pressure reading is taken from the gauge. A second point (2) is marked on the graph to indicate this performance. This process is continued at 5 gpm increments across the graph.



Example 2b

We now connect all the points. This curved line is called a head/capacity curve. Head (H) is expressed in feet and capacity (Q) is expressed in gallons per minute (GPM). The pump will always run somewhere on the curve.



Example 3

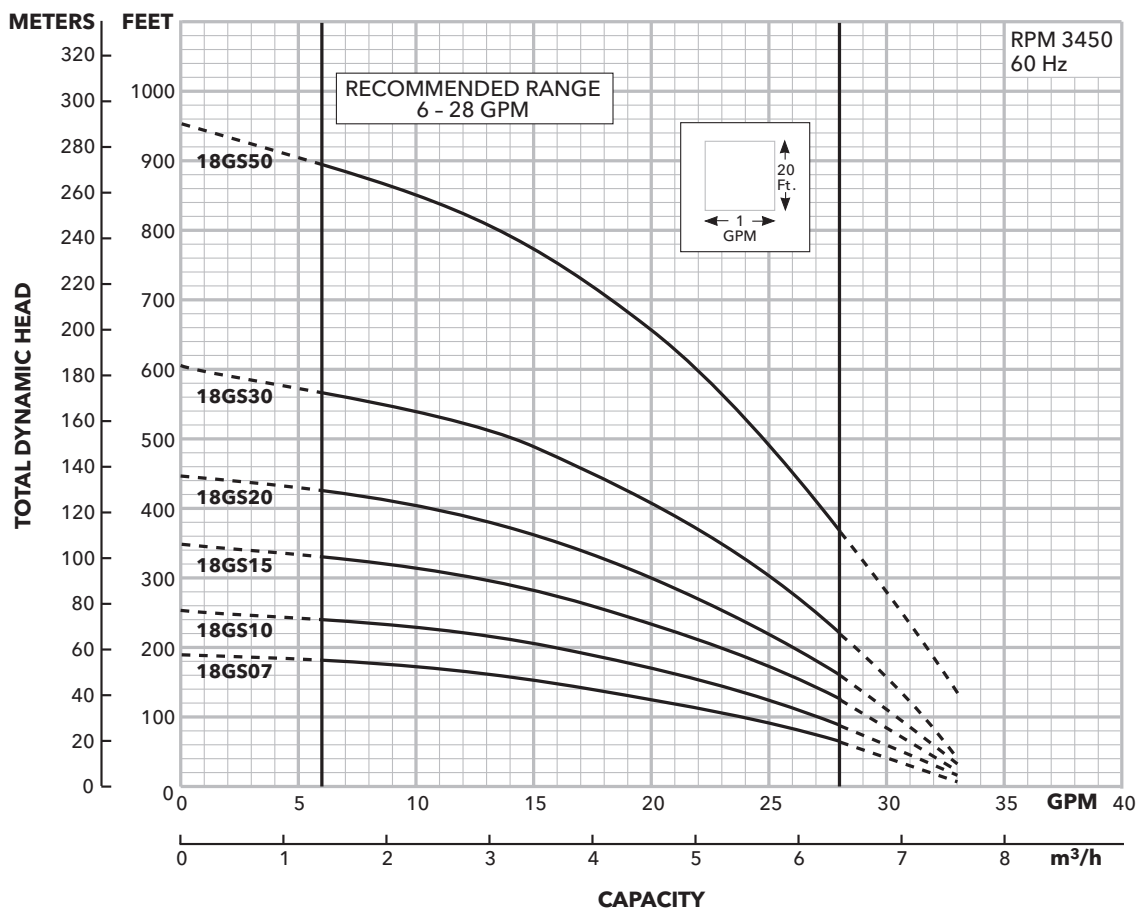
There are many different type curves shown in our catalog. Here is a composite performance curve (more than one pump) for the 18GS performance submersible. There is a separate curve for each horsepower size.

Let's compare two sizes:

1. First look at the 18GS07, 3/4 HP, 6 impellers. At 15 GPM capacity this model will make 158 feet.
2. Now look at the 18GS20, 2 HP, 14 impellers. At 15 GPM capacity this model will make 360 feet.

When you add impellers, the pump makes more pressure (expressed in feet). This allows the pump to go deeper in a well, but also takes more horsepower.

COMPOSITE PERFORMANCE CURVES



Example 4

Here is a different kind of curve you will find used on some grids called "efficiency curve". Efficiency as a percentage is shown on the scale at the right side of the grid.

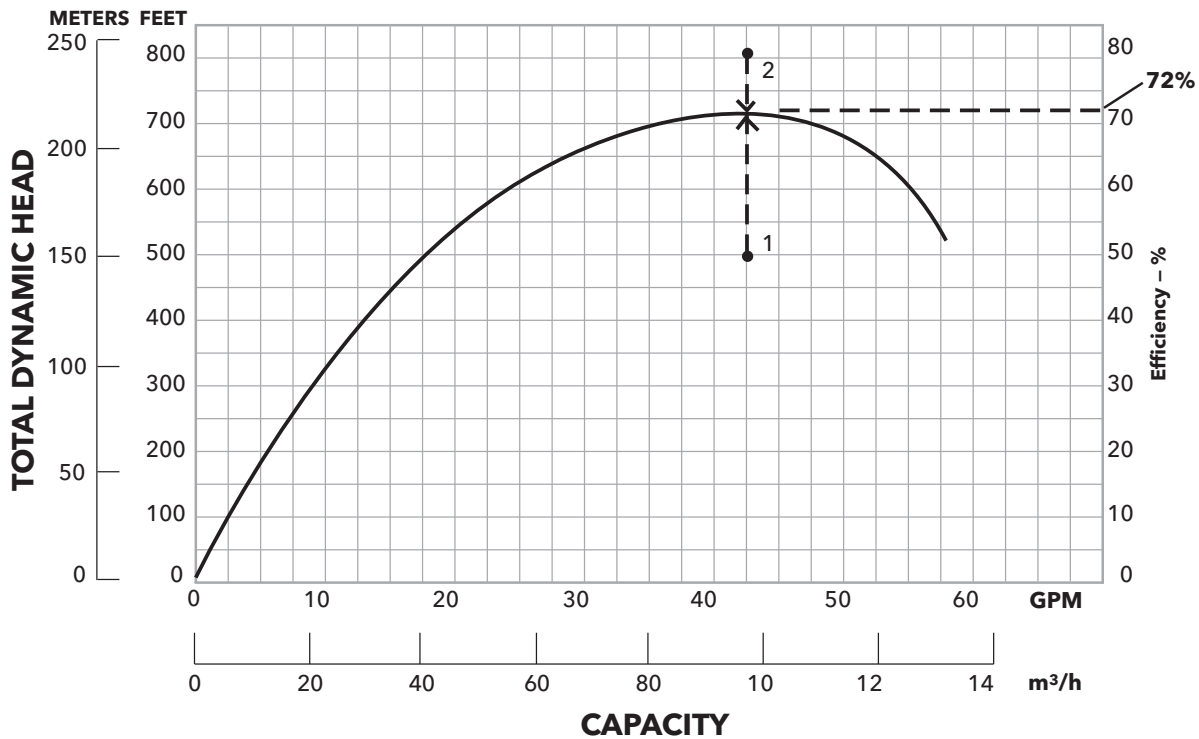
1. Find 425 GPM at 500'. From this point read vertically UP until you touch the efficiency curve line. Then go horizontally to the right to find the percent. In this example it would be 72%.
2. Find 425 GPM at 800'. From this point read vertically DOWN until you touch the efficiency curve line. Then go horizontally to the right to find the percent. In this example it would be 72%.

The highest point of the efficiency curve line is called the "B.E.P." or "Best Efficiency Point".

Pump manufacturers describe pumps in terms of the flow rate at the best efficiency point. In Example 4, the pump would be classified as a 425 gallon per minute pump.

We have included a sheet called (4A) "How to figure horsepower and operating cost". You may want to make copies and pass this out. This sheet shows why, with larger pumps, you want to select the one that has the best efficiency.

EFFICIENCY CURVE LINE SHOWN BY ITSELF



How to Figure Horsepower and Operating Cost

BHP = Brake Horsepower

Sp. Gravity = Specific Gravity of Water is (1)

1 HP = 746 Watts

3960 = Constant

WATTS = Volts x Amps

Note: No motor is 100% efficient, so we say 1 HP = 1000 Watts which is (1) kilowatt or KW

The formula for figuring brake horsepower (BHP) is as follows:

$$\frac{\text{GPM} \times \text{Total Dynamic Head (TDH)} \times \text{Sp. Gravity}}{3960 \times \text{Efficiency (Decimal)}}$$

Select a submersible pump for the following application:
100 GPM at 375 ft. TDH 460V

There are several which will meet this application:

Pump 1	65% eff. 15 HP motor (14.8 HP)
Pump 2	67% eff. 15 HP motor (16.4 HP)
Pump 3	67% eff. 15 HP motor (14.1 HP)
Pump 4	74% eff. 15 HP motor (12.8 HP)

Note: Impeller trim to 375' TDH

Pump 1 =	14.8 HP	Pump 4	Cost = \$4,600
Pump 4 =	<u>12.8 HP</u>	Pump 1	Cost = <u>4,280</u>
Difference =	2.0 HP	Cost difference =	\$ 320

We assume – 1 kilowatt hour (KWH) cost \$.10/KWH. We multiply the HP difference 2.0 HP x \$.10 and the Cost Savings per hour \$.20. If the pump runs 10 hours per day then the cost savings is \$2.00 per day. In 30 days, the savings is \$60. Take the cost difference and divide by the cost savings per day (\$320 / \$2.00) and the difference in price is paid back in 160 days.

Example 5

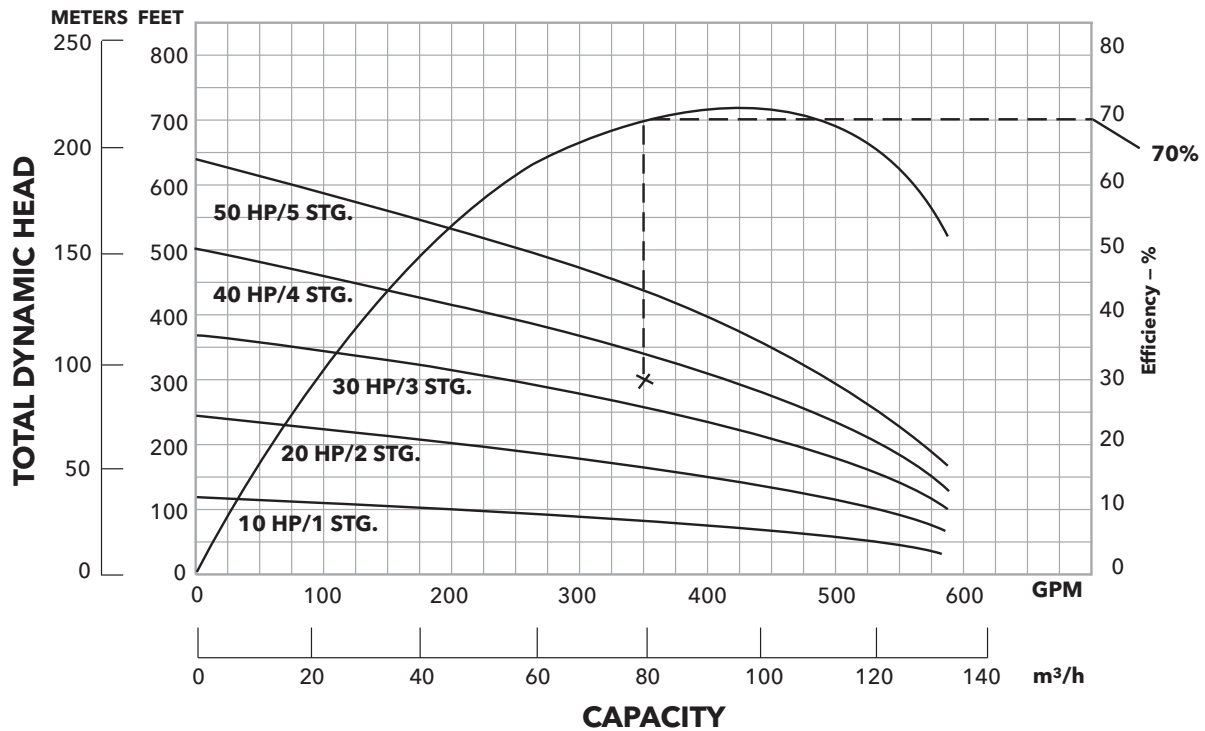
Find the point 350 GPM at 300 feet. What is the efficiency? 70% is correct. When your capacity/head that you plan to use falls between two horsepower sizes, the curve line you always use is the one above or the larger horsepower.

We have decided to use the 40 HP pump and our head requirements are 300 feet. We have to install a throttling valve, and throttle the pump capacity to 350 GPM. If we don't, the pump will run with a capacity of 420 GPM.

To determine this find 350 GPM at 300' again. From this point go horizontally to the right until you touch the 40 HP, H-Q curve line. A pump will always run somewhere on its curve. At 420 GPM what is the pump's efficiency? 72%.

There is one other consideration called upthrust, which may occur when running the pump at open discharge. Note that each curve line stops just past 575 GPM. Under normal conditions the thrust in a submersible pump is downwards, toward the motor. At abnormally high flows, which results when there is insufficient head on the pump, this thrust is upset and goes the opposite way because the impeller is not developing sufficient head. This is called upthrust. To prevent this, install a throttling valve and throttle the pump to 575 GPM when running the pump open discharge.

COMPOSITE PERFORMANCE CURVES



Example 6

Here is a curve that shows Head/Capacity and also shows suction lift.

The upper left part of the curve is divided into two parts. Find 4 GPM and read vertically up. If your suction lift is 20' or 25' the pump will make 114 feet of head. If your suction lift is 5', 10' or 15', the pump will make a little more – 119 feet.

We always show what the pump will do at all points on the curve. We would not recommend or select this pump to run below 16 gallons per minute.

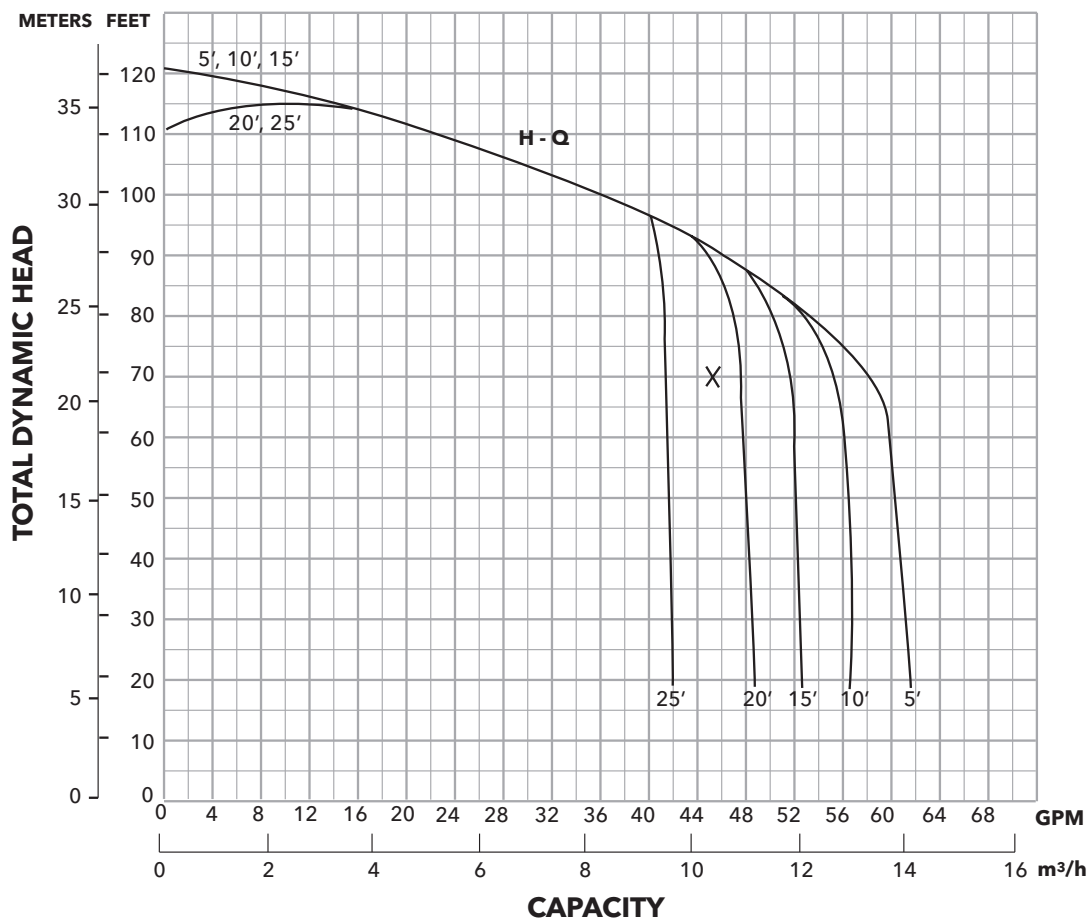
The vertical curve lines on the right also relate to suction lift in 5' increments. Find 45 GPM at 70'. This

pump will work if your suction lift is 22' or less. Remember as your capacity increases, your suction lift ability decreases.

When considering capacity, in gallons per minute, and the suction lift you are trying to overcome, you must stay to the left of the vertical suction curve line.

Find 45 GPM at 70'. If you had a 20' lift to overcome, this pump would work fine.

Find 50 GPM at 70'. If you had a 20' lift to overcome, this pump will not work. You are to the right of the 20' suction curve line. The next higher horsepower model may be the pump to meet this requirement.



Example 7

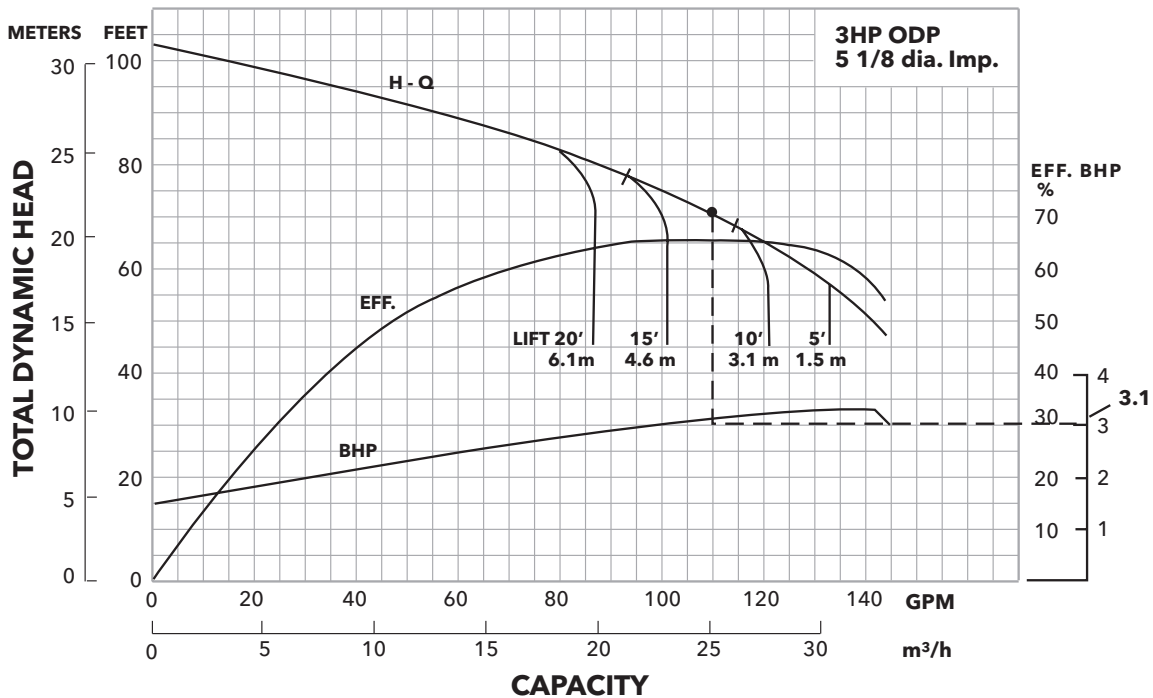
Here is a new curve line shown called BHP (Brake Horsepower). BHP is charted to the right just past efficiency scale.

Find 110 GPM at 71'. From this point read vertically down until you touch the BHP curve line. Then go horizontally to the right to find the horsepower required.

In this case, it is 3.1 BHP. The motor used is 3 HP with 1.15 service factor ($3 \times 1.15 = 3.45$). We really have 3.45 HP to use.

Find 110 GPM at 71' again. What is the efficiency? 66% is correct.

COMPOSITE PERFORMANCE CURVES 3500 RPM SELF-PRIMING CENTRIFUGAL



Example 8

Pictured is a single line curve for a centrifugal pump.

Find 70 GPM at 56 ft. Since the point we need is below the head/capacity curve line, the pump will exceed our requirements.

We can have the pump meet our exact requirements by proper trimming of the impeller. This will establish a new curve for the pump. The curve will run approximately parallel to the curve shown and through the point required; i.e., 70 GPM at 56 ft.

What happens if we don't trim the impeller to meet our exact requirements? The pump will run somewhere on its curve. Our head requirement is 56 ft. Follow 56 ft. horizontally to the right until you meet the curve line. Your capacity is 80 GPM. Can this installation handle the additional capacity? Notice also that efficiency (EFF), brake horsepower (BHP), and net positive suction head required (NPSH_R) also change, with the capacity of 80 GPM.

If we use a throttling valve on the discharge side of the pump we can regulate the capacity of the pump to 70 GPM using the standard impeller. Read vertically up from 70 GPM until you meet the curve line. The pump will make 58½ ft. Can this installation handle the extra head?

Remember, trimming the impeller will make the pump meet your exact requirements, 70 GPM at 56 ft. (The head/capacity requirements should always be furnished when the pump is ordered.)

What other information is shown? Efficiency, brake horsepower, and net positive suction head required. All of these values are measured on the left hand side of the grid.

Find 70 GPM at 56 ft. again

What is the efficiency? 70.5% is correct.

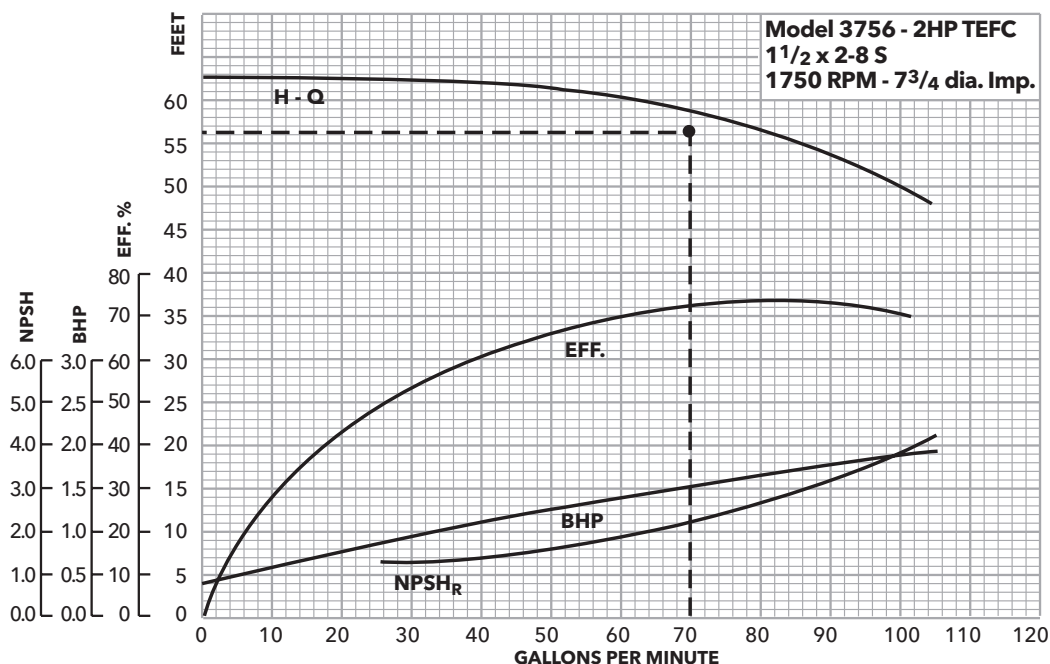
What is the brake horsepower required?
1.5 BHP is correct.

What is the net positive suction head required?

NPSH_R = 2.2 ft. You will have to determine the NPSH_A.

NPSH_A = Net Positive Suction Head available.

NPSH_A has to be greater than NPSH_R for the pump to work.



Example 8 continued

Centrifugal Pump Fundamentals

NET POSITIVE SUCTION HEAD (NPSH) AND CAVITATION

The Hydraulic Institute defines NPSH as the total suction head in feet absolute, determined at the suction nozzle and corrected to datum, less the vapor pressure of the liquid in feet absolute. Simply stated, it is an analysis of energy conditions on the suction side of a pump to determine if the liquid will vaporize at the lowest pressure point in the pump.

The pressure which a liquid exerts on its surroundings is dependent upon its temperature. This pressure, called vapor pressure, is a unique characteristic of every fluid and increases with increasing temperature. When the vapor pressure within the fluid reaches the pressure of the surrounding medium, the fluid begins to vaporize or boil. The temperature at which this vaporization occurs will decrease as the pressure of the surrounding medium decreases.

A liquid increases greatly in volume when it vaporizes. One cubic foot of water at room temperature becomes 1700 cu. ft. of vapor at the same temperature.

It is obvious from the above that if we are to pump a fluid effectively, we must keep it in liquid form. NPSH is simply a measure of the amount of suction head present to prevent this vaporization at the lowest pressure point in the pump.

NPSH Required is a function of the pump design. As the liquid passes from the pump suction to the eye of the impeller, the velocity increases and the pressure decreases. There are also pressure losses due to shock and turbulence as the liquid strikes the impeller. The centrifugal force of the impeller vanes further increases the velocity and decreases the pressure of the liquid. The NPSH Required is the positive head in feet absolute required at the pump suction to overcome these pressure drops in the pump and maintain the liquid above its vapor pressure. The NPSH Required varies with speed and capacity within any particular pump. Pump manufacturer's curves normally provide this information.

NPSH Available is a function of the system in which the pump operates. It is the excess pressure of the liquid in feet absolute over its vapor pressure as it arrives at the pump suction. Figure 4 shows four typi-

cal suction systems with the NPSH Available formulas applicable to each. It is important to correct for the specific gravity of the liquid and to convert all terms to units of "feet absolute" in using the formulas.

In an existing system, the NPSH Available can be determined by a gage reading on the pump suction.

The following formula applies:

$$NPSH_A = P_B - V_p \pm Gr + h_v$$

Where

Gr = Gage reading at the pump suction expressed in feet (plus if above atmospheric, minus if below atmospheric) corrected to the pump centerline.

h_v = Velocity head in the suction pipe at the gage connection, expressed in feet.

Cavitation is a term used to describe the phenomenon which occurs in a pump when there is insufficient NPSH Available. The pressure of the liquid is reduced to a value equal to or below its vapor pressure and small vapor bubbles or pockets begin to form. As these vapor bubbles move along the impeller vanes to a higher pressure area, they rapidly collapse.

The collapse, or "implosion" is so rapid that it may be heard as a rumbling noise, as if you were pumping gravel. The forces during the collapse are generally high enough to cause minute pockets of fatigue failure on the impeller vane surfaces. This action may be progressive, and under severe conditions can cause serious pitting damage to the impeller.

The accompanying noise is the easiest way to recognize cavitation. Besides impeller damage, cavitation normally results in reduced capacity due to the vapor present in the pump. Also, the head may be reduced and unstable and the power consumption may be erratic. Vibration and mechanical damage such as bearing failure can also occur as a result of operating in cavitation.

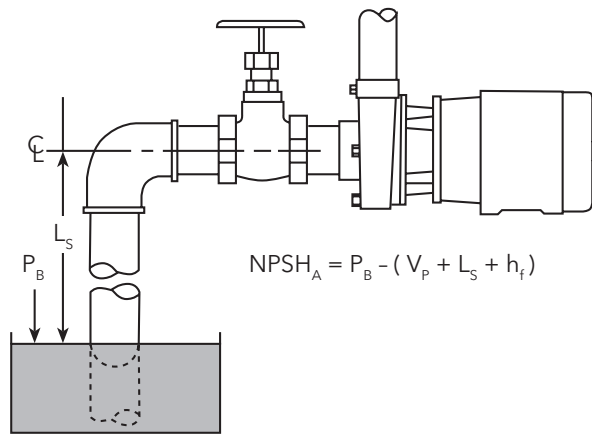
The only way to prevent the undesirable effects of cavitation is to insure that the NPSH Available in the system is greater than the NPSH Required by the pump.

Example 8 continued

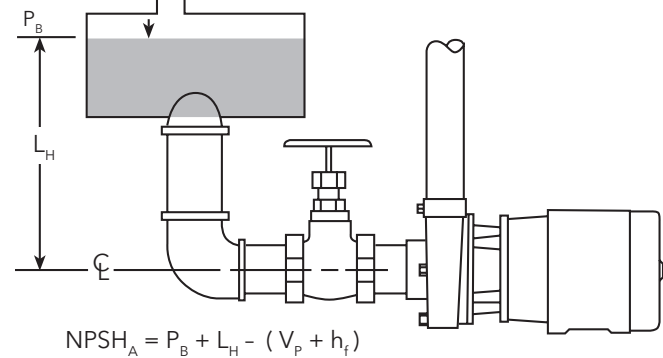
Centrifugal Pump Fundamentals

NET POSITIVE SUCTION HEAD (NPSH) AND CAVITATION

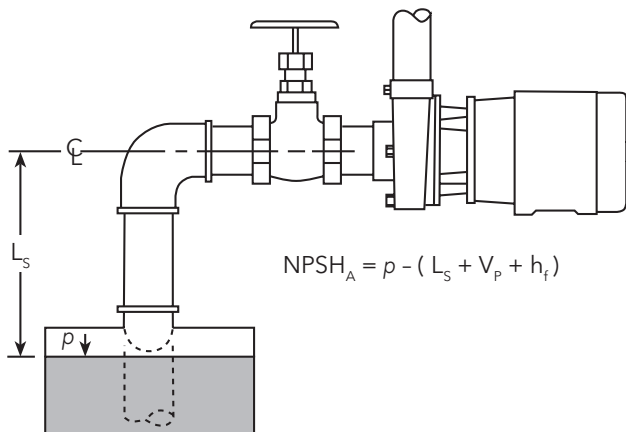
4a SUCTION SUPPLY OPEN TO ATMOSPHERE
- with Suction Lift



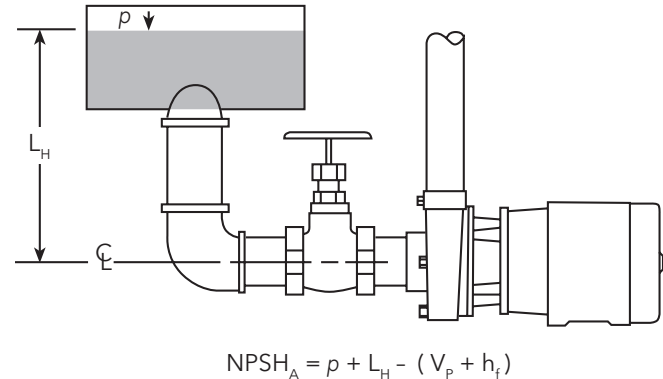
4b SUCTION SUPPLY OPEN TO ATMOSPHERE
- with Suction Head



4c CLOSED SUCTION SUPPLY
- with Suction Lift



4d CLOSED SUCTION SUPPLY
- with Suction Head



P_B = Barometric pressure, in feet absolute.

V_p = Vapor pressure of the liquid at maximum pumping temperature, in feet absolute (see page 16).

p = Pressure on surface of liquid in closed suction tank, in feet absolute.

L_s = Maximum static suction lift in feet.

L_H = Minimum static suction head in feet.

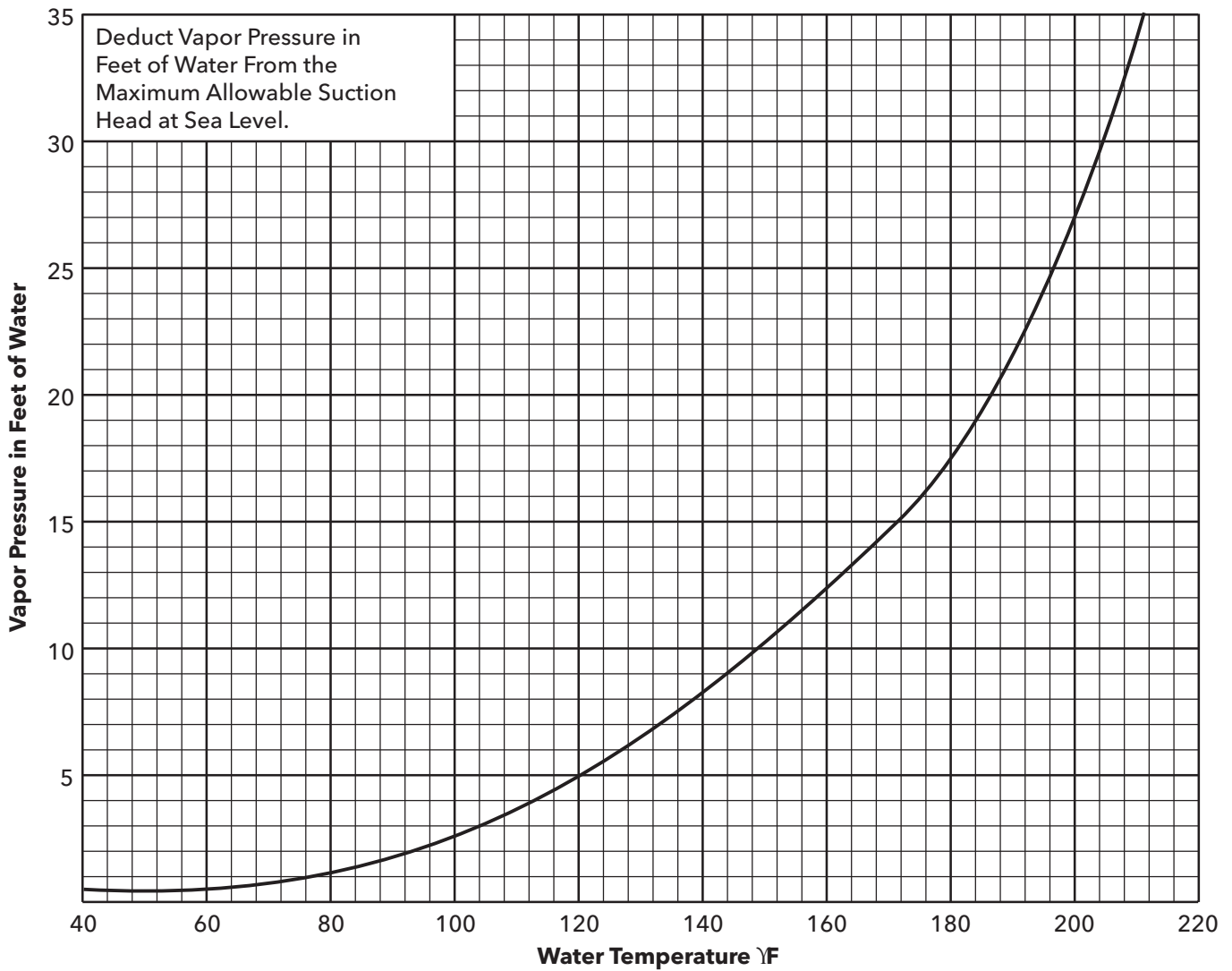
h_f = Friction loss in feet in suction pipe at required capacity.

Note: See Vapor Pressure Chart in Technical Manual.

Example 8 continued

Centrifugal Pump Fundamentals

VAPOR PRESSURE OF WATER



Example 9

Here is a centrifugal pump curve showing information that we have already covered, but in a different format.

This is a Model 3656, 1½ x 2-6 ODP.

1½ = Discharge size in inches

2 = Suction size in inches

6 = Basic diameter of the impeller in inches.

The top head/capacity curve line shows an actual impeller diameter of 5¹⁵/₁₆ inches.

Our requirement is 140 GPM at 95 ft. We can properly trim the impeller to meet our requirement, since the pump with the 5¹⁵/₁₆ inches diameter will more than meet our needs.

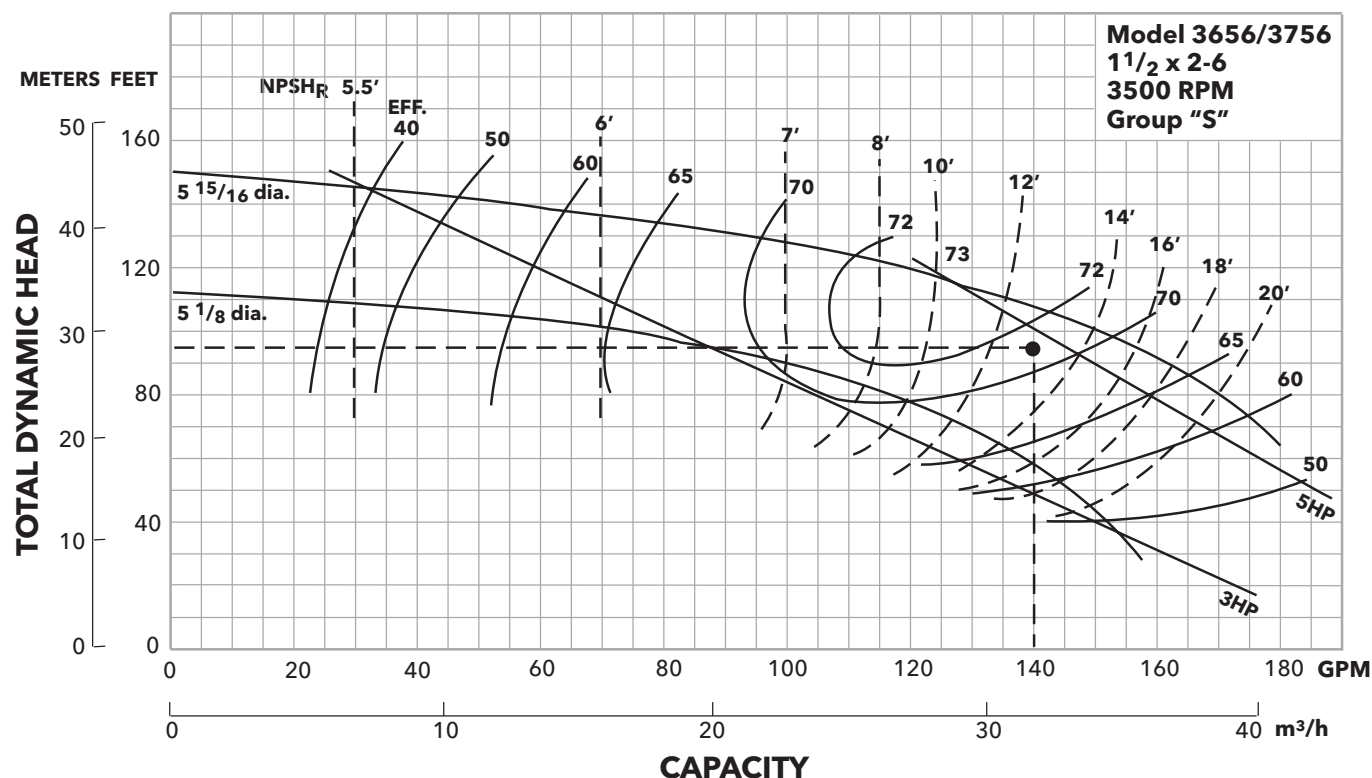
What happens if we install the pump and don't trim the impeller? Our head requirement is 95 ft. Follow 95 ft. horizontally to the right until you meet the curve line. Your capacity is 157 GPM.

If we use a throttling valve on the discharge side of the pump we can regulate the capacity of the pump to 140 GPM using the standard impeller. Read vertically up from 140 GPM until you meet the curve line. The pump will make 109 ft. Can the installation handle this extra head?

Remember, trimming the impeller to the proper diameter will make the pump meet your exact requirements, 140 GPM at 95 ft. (The head/capacity requirements should always be furnished when the pump is ordered.)

Consider our original requirement again: 140 GPM at 95 ft. What is the brake horsepower required? A little less than 5 HP. What is the efficiency? 71% is correct. What is the NPSH_R? 13 ft. is correct.

MODELS 3656/3756 S GROUP PERFORMANCE CURVES



Example 10

To better understand brake horsepower as shown in these two curves, consider the following: Brake horsepower (BHP) is the actual horsepower delivered to the pump shaft. The formula for figuring brake horsepower is:

$$\text{Brake Horsepower} = \frac{\text{GPM} \times \text{Feet Head} \times \text{SP.GR.}}{3960 \times \text{Pump Efficiency}}$$

Compare the two curves at 150 gallons per minute. Horsepower is given so we don't have to calculate what it is. The grid shows an ODP motor (Open Drip Proof) which has a 1.15 service factor.

$$5 \text{ HP} \times 1.15 \text{ SF} =$$

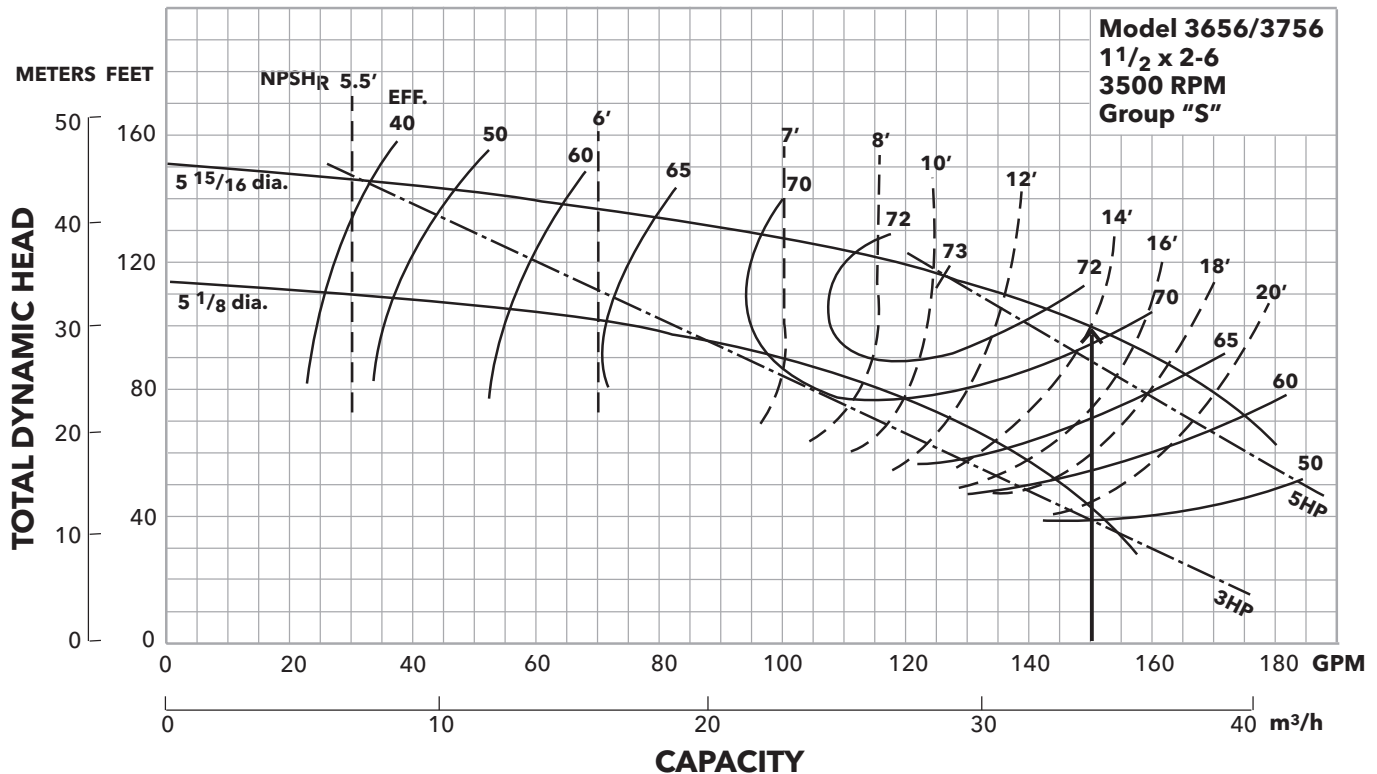
5.75 available horsepower

The 5 15/16" diameter impeller at 150 GPM uses more than 5 HP, but does not exceed 5.75 HP.

$$\text{BHP} =$$

$$\frac{150 \times 100 \times 1.0}{3960 \times 70.5\%} = 5.37 \text{ BHP}$$

MODELS 3656/3756 S GROUP PERFORMANCE CURVES



Example 11

Now look at the grid for TEFC motor (totally enclosed – fan cooled).

A TEFC motor has a 1.0 service factor.

$$5 \text{ HP} \times 1.0 \text{ SF} =$$

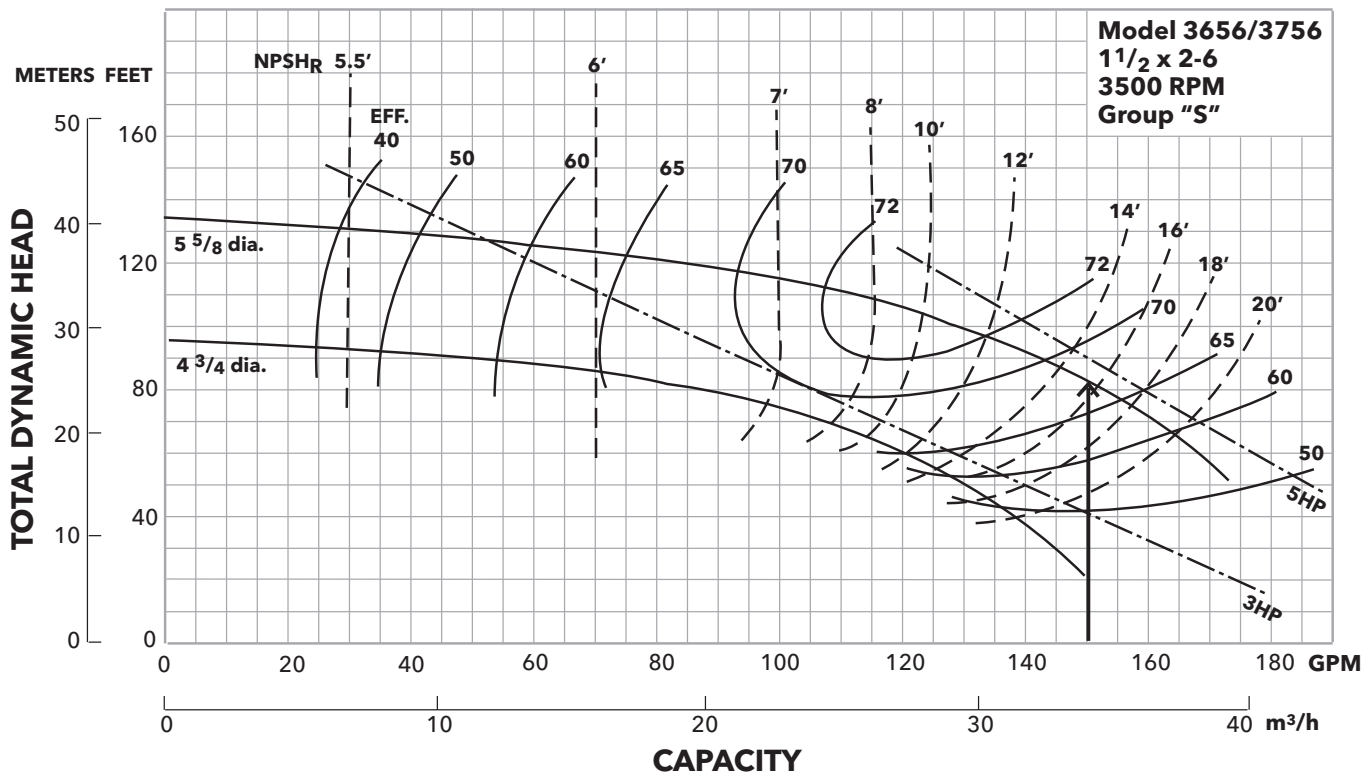
5 available horsepower

The 5 5/8" diameter impeller at 150 GPM does not exceed the 5 HP line.

BHP =

$$\frac{150 \times 82 \times 1.0}{3960 \times 67\%} = 4.64 \text{ BHP}$$

MODELS 3656/3756 S GROUP PERFORMANCE CURVES



Example 12

PUMP SYSTEM HEAD CURVE

A System Head Curve is the easiest and most accurate way to decide which pump is best suited for an application. The factors used to create a System Head Curve are gallons per minute, friction loss data and pipe size, total head (lift or depth to water) and pressure desired (expressed in feet).

To be able to pick the best pump for any given job we must be given some data.

Let's look at a 50 gpm irrigation system.

Pumping Level - 250' at 50 gpm

Pump Set - 280'

Well Depth - 300'

Need 50 psi (115') to operate the sprinkler heads.

Distance to 1st lateral is 1000'.

The only variable or controllable item is the pipe friction loss which varies with pipe size. We cannot change the flow, the pumping level, the pressure or the length of pipe. We will look at the difference between using 1½", 2" and 3" pipe.

We have 1000' of offset pipe and 280' of drop pipe for a total pipe length of 1280'. Divide the 1280 by 100, because F.L. tables show the loss per 100' of pipe, to get a multiplier of 12.8.

We add the Total Head to the F.L. to find the TDH. Plot the Flow/TDH on any curve to show the System Head Curve for that system.

Pumping Level	250'
PSI in feet	<u>115'</u>
Total Head	365'
Friction Loss +	_____
	= TDH

Pipe Size	GPM	Friction Loss/100' of 1½"	Times 12.8	Plus 365' Total Head
1½"	30	6.26	80	445
1½"	50	16.45	210	575 TDH
1½"	70	31.73	406	771

Pipe Size	GPM	Friction Loss/100' of 2"	Times 12.8	Plus 365' Total Head
2"	30	1.81	23	388
2"	50	4.67	60	425 TDH
2"	70	8.83	113	478

Pipe Size	GPM	Friction Loss/100' of 3"	Times 12.8	Plus 365' Total Head
3"	30	.26	4	369
3"	50	.66	9	374 TDH
3"	70	1.24	16	381

You can see that there is a big difference in TDH due to the pipe used. The 1½" pipe would require a 15 hp pump, the 2" and 3" can use a 7.5 hp. The 2" pipe will give us 46 gpm and the 3" will yield 53 gpm. The difference of 7 gpm is 420 gph or 10,080 gpd. If you do not need the extra water use 2" and save money

on the pipe. If you need all the water you can get the 3" pipe will be much cheaper over the life of the pipe than using a larger pump. There has never been a customer who wanted less water next year than this year. Large pipe leaves room to grow the system if necessary.

Example 12 continued

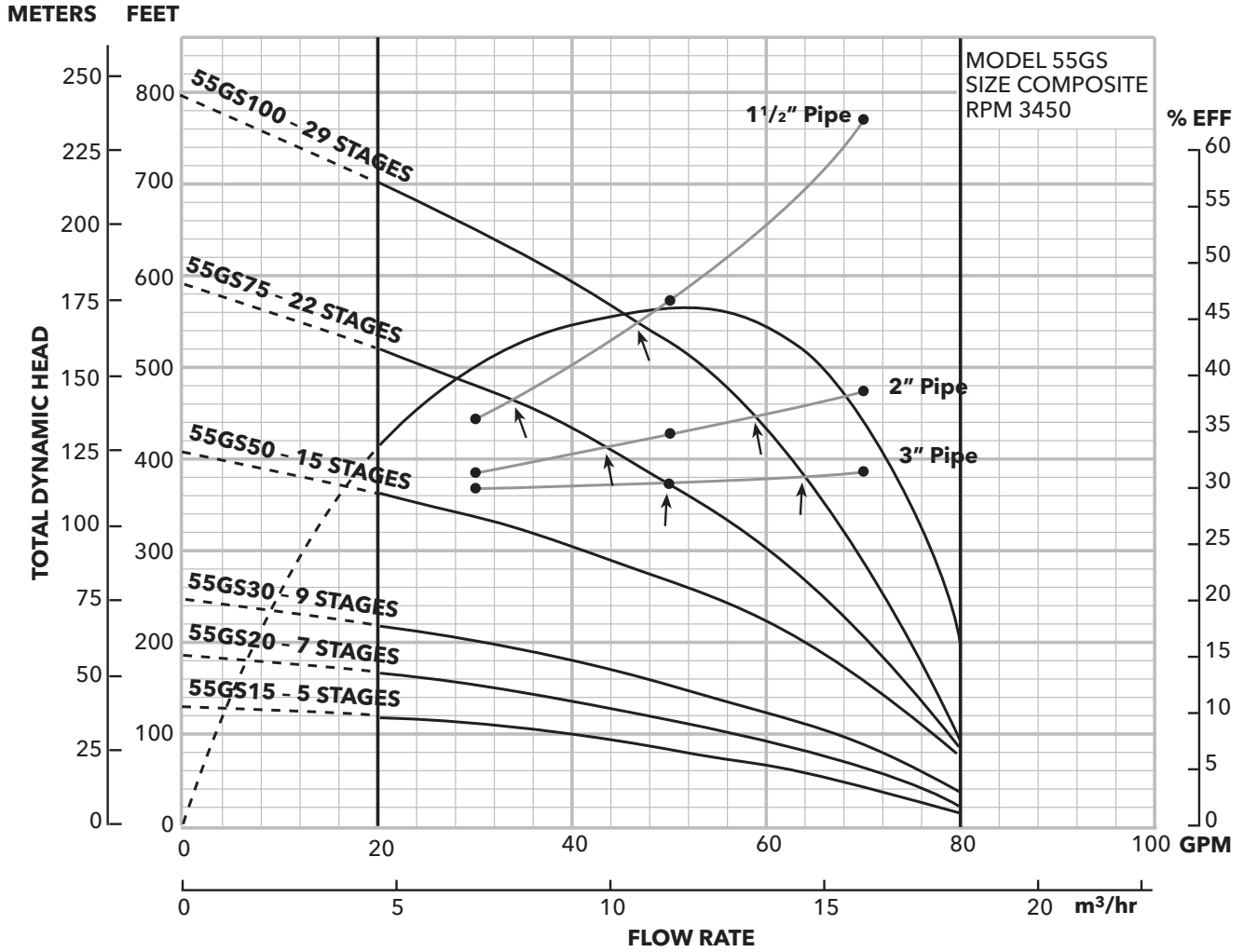
Plastic Pipe: Friction Loss (in feet of head) per 100 Ft.

GPM	GPH	3/8" ft.	1/2" ft.	3/4" ft.	1" ft.	1 1/4" ft.	1 1/2" ft.	2" ft.	2 1/2" ft.	3" ft.
25	1,500				38.41	9.71	4.44	1.29	.54	.19
30	1,800					13.62	6.26	1.81	.75	.26
35	2,100					18.17	8.37	2.42	1.00	.35
40	2,400					23.55	10.70	3.11	1.28	.44
45	2,700					29.44	13.46	3.84	1.54	.55
50	3,000						16.45	4.67	1.93	.66
60	3,600						23.48	6.60	2.71	.93
70	4,200						31.73	8.83	3.66	1.24
80	4,800							11.43	4.67	1.58

Equivalent Number of Feet Straight Pipe for Different Fittings

Size of fittings, Inches	1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	2 1/2"	3"	4"	5"	6"	8"	10"
90° Ell	1.5	2.0	2.7	3.5	4.3	5.5	6.5	8.0	10.0	14.0	15	20	25
45° Ell	0.8	1.0	1.3	1.7	2.0	2.5	3.0	3.8	5.0	6.3	7.1	9.4	12
Long Sweep Ell	1.0	1.4	1.7	2.3	2.7	3.5	4.2	5.2	7.0	9.0	11.0	14.0	
Close Return Bend	3.6	5.0	6.0	8.3	10.0	13.0	15.0	18.0	24.0	31.0	37.0	39.0	
Tee-Straight Run	1	2	2	3	3	4	5						
Tee-Side Inlet or Outlet or Pitless Adapter	3.3	4.5	5.7	7.6	9.0	12.0	14.0	17.0	22.0	27.0	31.0	40.0	
Ball or Globe Valve Open	17.0	22.0	27.0	36.0	43.0	55.0	67.0	82.0	110.0	140.0	160.0	220.0	
Angle Valve Open	8.4	12.0	15.0	18.0	22.0	28.0	33.0	42.0	58.0	70.0	83.0	110.0	
Gate Valve-Fully Open	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.7	2.3	2.9	3.5	4.5	
Check Valve (Swing)	4	5	7	9	11	13	16	20	26	33	39	52	65
In Line Check Valve (Spring) or Foot Valve	4	6	8	12	14	19	23	32	43	58			

Example 12 continued



Example 13

SEWAGE SYSTEM HEAD CURVE

The System Head Curve can be very steep when the friction loss makes up a larger part of the Total Dynamic Head. We see this clearly on a sewage job.

Total Lift 20'

200' of 2" Pipe

3 Baths

2" Solids Handling Pump

As you can see from the plotted system curve it crosses 5 pump curves. You can now accurately pick the best pump for the job or tell exactly how much a certain pump will pump in a given situation. It is a good way to show customers that there is always more than one pump for every application. It also shows the wisdom of properly sizing the pipe to the flow to save horsepower and electricity.

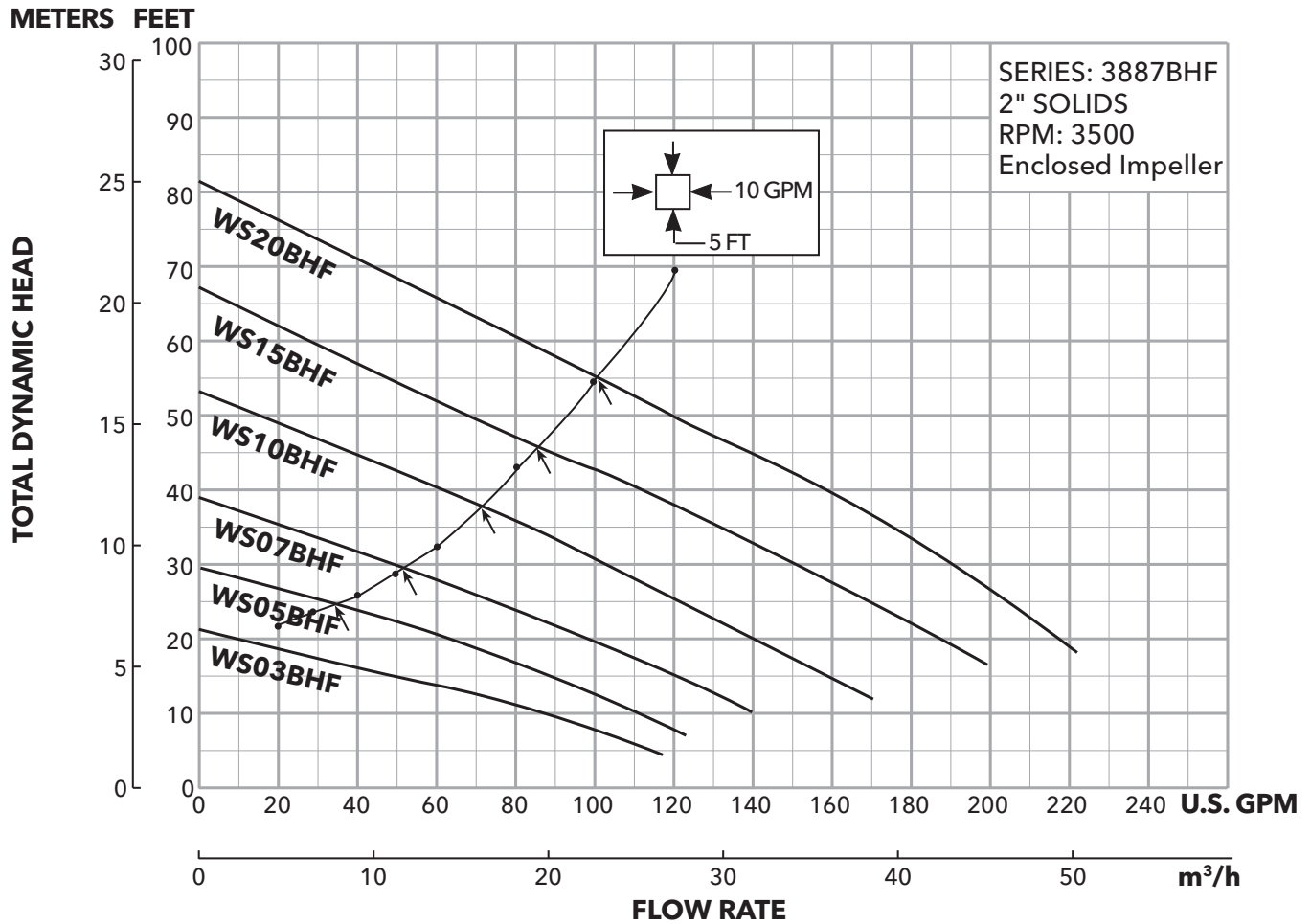
2" PVC Pipe x 200' long

20' Discharge Head (Vertical Lift)

We need to pump at least 30 gpm, 2" solids.

GPM	Friction Loss at GPM	$\times \frac{200}{100}$	=	+Dis. Head (Lift)	= TDH (Total Dynamic Head)
20	.86	2	1.72	20'	22'
30	1.81	2	3.62	20'	24'
40	3.11	2	6.22	20'	26'
50	4.67	2	9.34	20'	29'
60	6.6	2	13.2	20'	33'
80	11.43	2	22.86	20'	43'
100	17.0	2	34	20'	54'
120	24.6	2	49.2	20'	69'

Example 13 continued



This curve shows that we could use 5 different pumps on this job and pump between 33 gpm at 25' TDH and 100 gpm at 55' TDH.

The pumps will operate where the pump curve and system curve cross. The longer the discharge pipe the steeper the curve.

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