Better Plants®
U.S. DEPARTMENT OF ENERGY

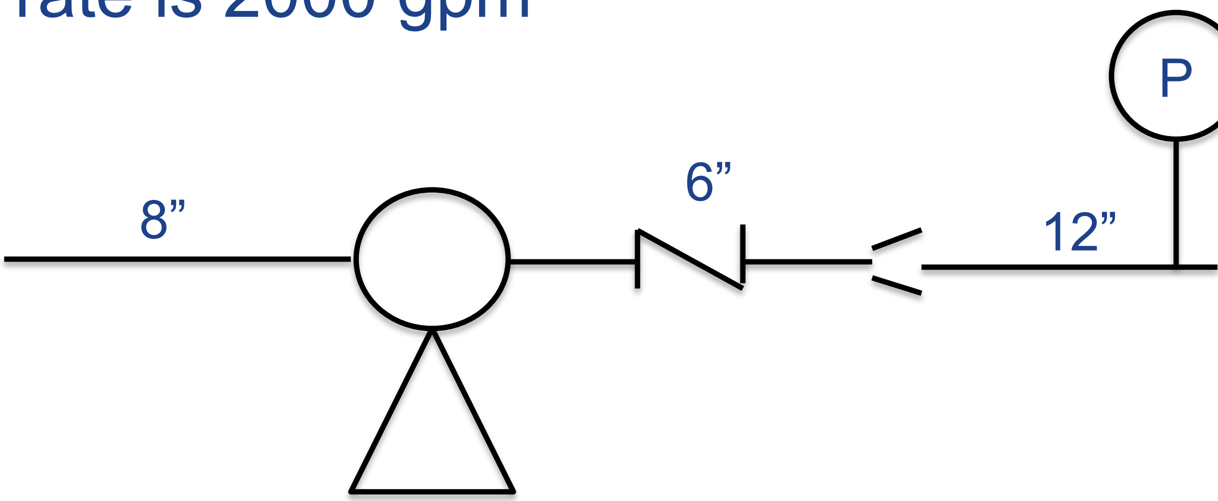
Pumping System Assessment

Week 5: Expanded Discussions

U.S. DEPARTMENT OF ENERGY

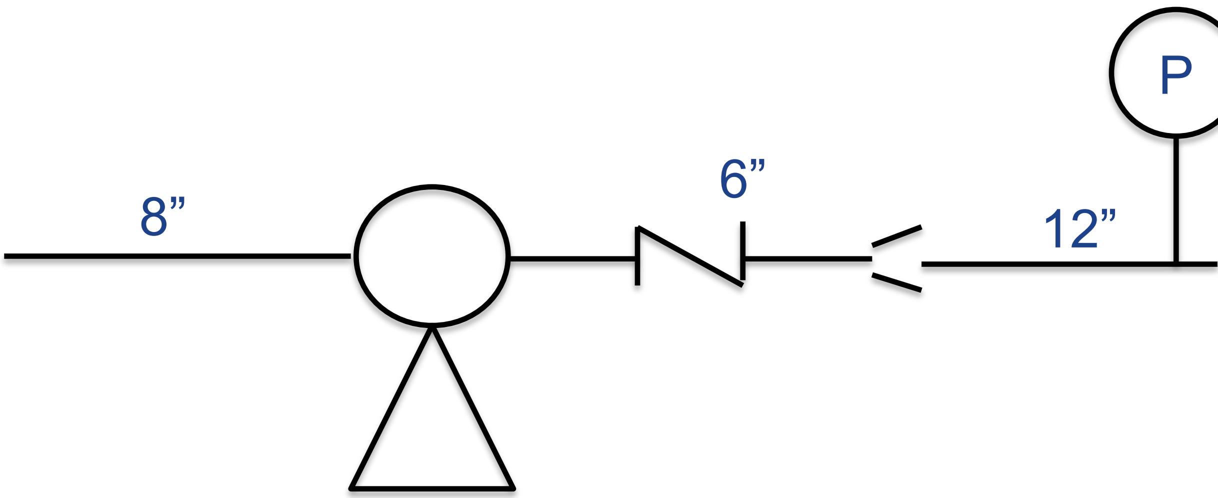
Scaling Loss Coefficients

- Centrifugal pump with 8” suction and 6” discharge pipe
- On discharge there is a 6” check valve (k = 2)
- Downstream of the check valve the pipe expands to 12” diameter
- Discharge pressure gauge is located in the 12” diameter piping
- Flow rate is 2000 gpm

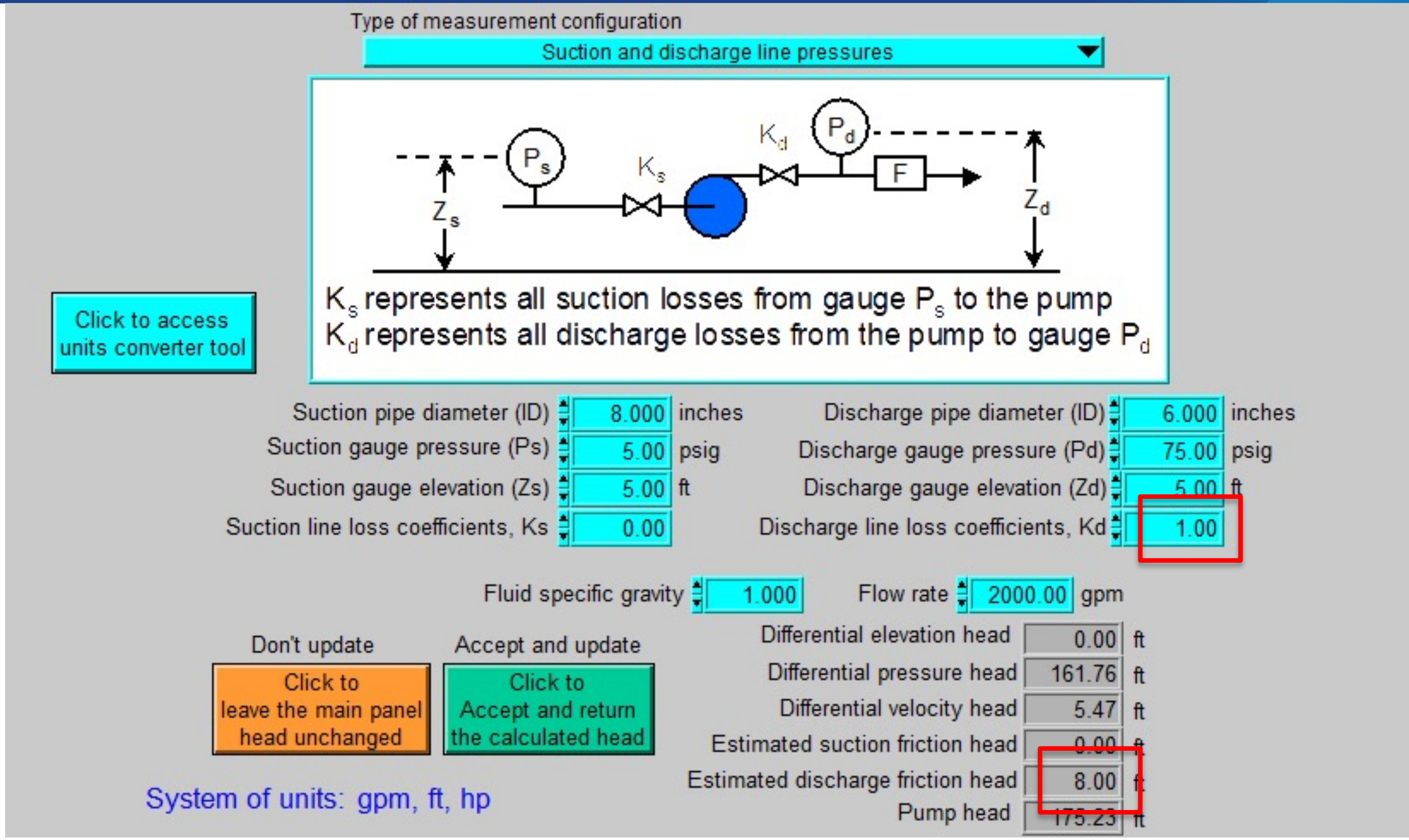


Scaling Loss Coefficients

- Friction loss for the check valve is = $k(V^2/2g)$ where $k = 2$ and V is the average velocity in the 6” diameter pipe
- Use the pump head calculator to calculate the velocity head



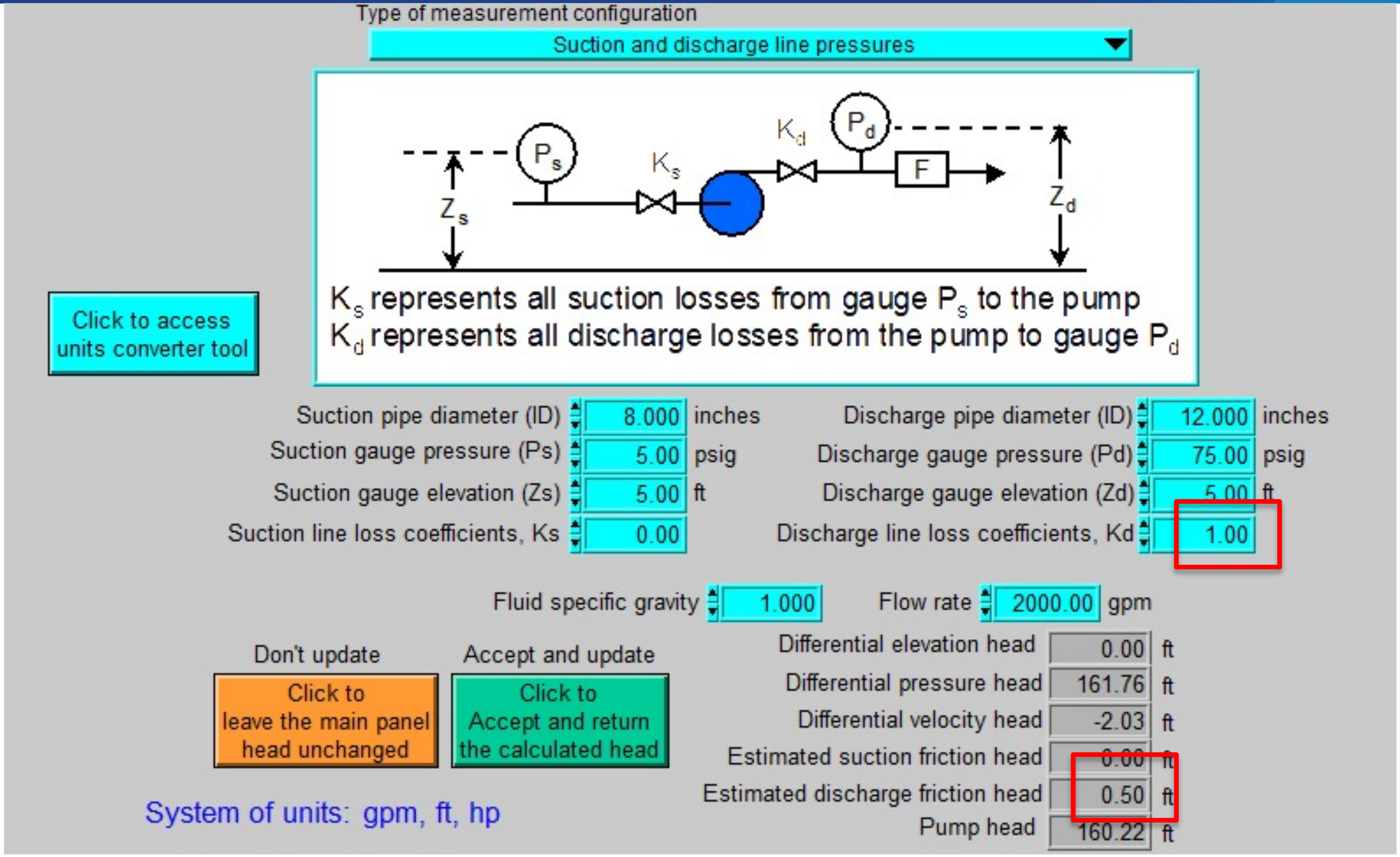
Scaling Loss Coefficients



2000 gpm in a 6" pipe: $V^2/2g$ = 8.00 ft

Check valve k = 2: valve friction loss = 2 x 8.00 = 16.00 ft

Scaling Loss Coefficients

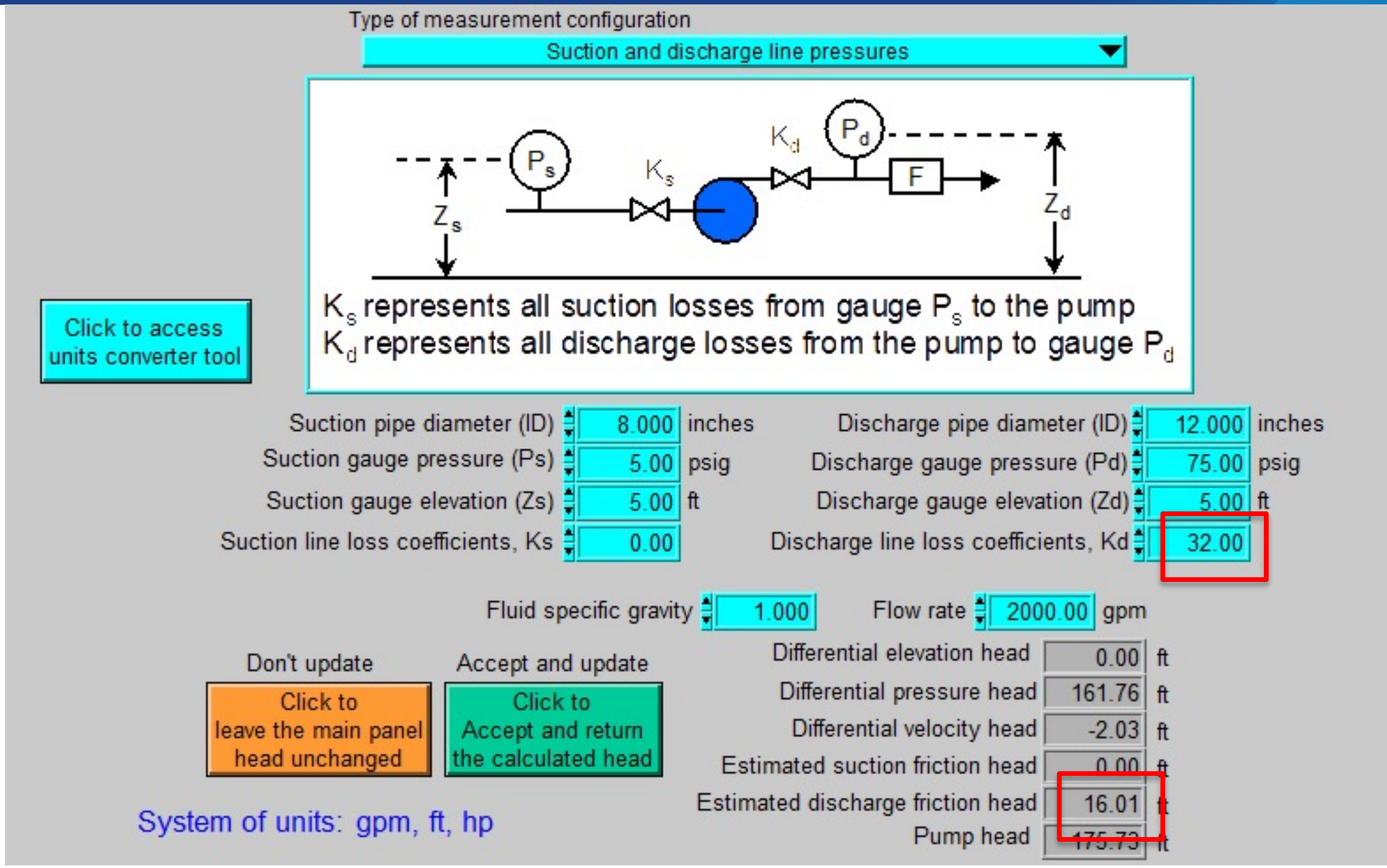


2000 gpm in a 12" pipe: $V^2/2g = 0.50$ ft

Check valve k = 2 (in 6" pipe)

valve friction loss = $2 \times (12/6)^4 \times 0.50 = 16.00$ ft

Scaling Loss Coefficients



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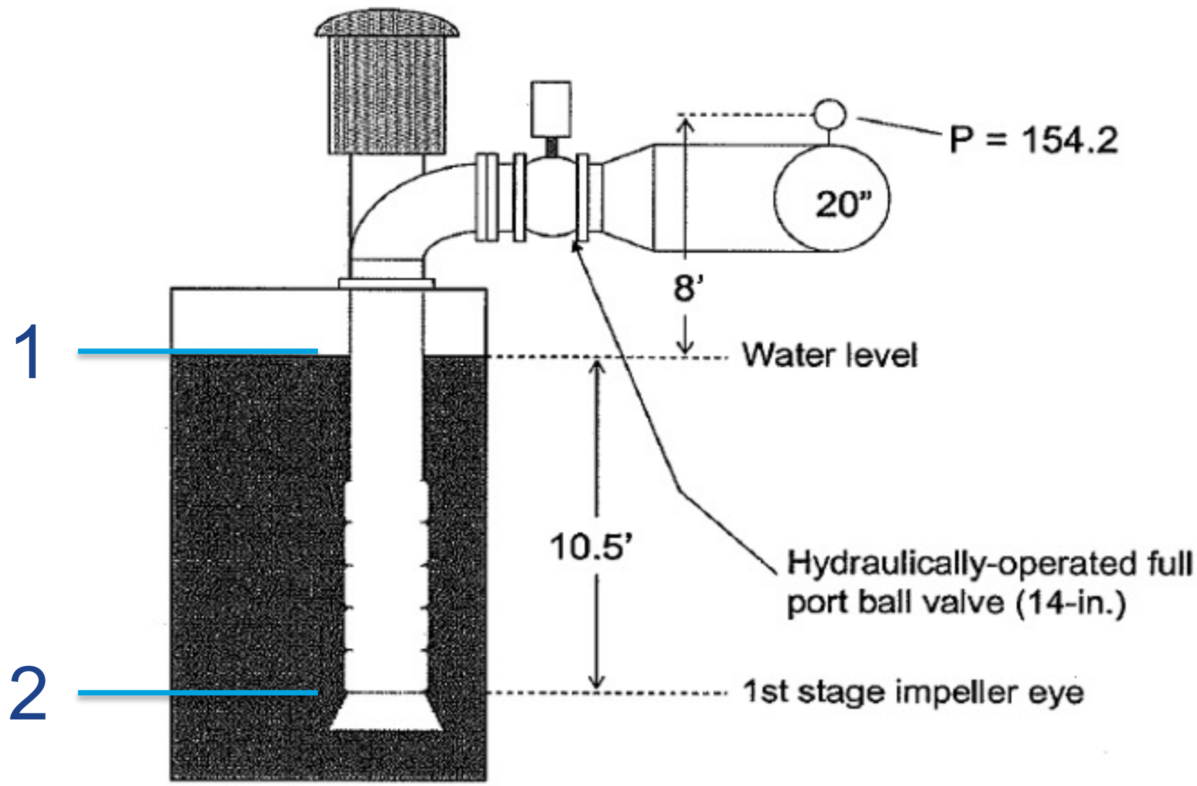
Finish water pump layout - NPSHA

- Want the total head at location 2
- Don't know P_2 and V_2, typically
- Easier to start at location 1, know P_1 = atmospheric pressure and $V_1 = 0$
- Then, $P_2 = P_1 + 10.5$ feet



Calculate NPSHA

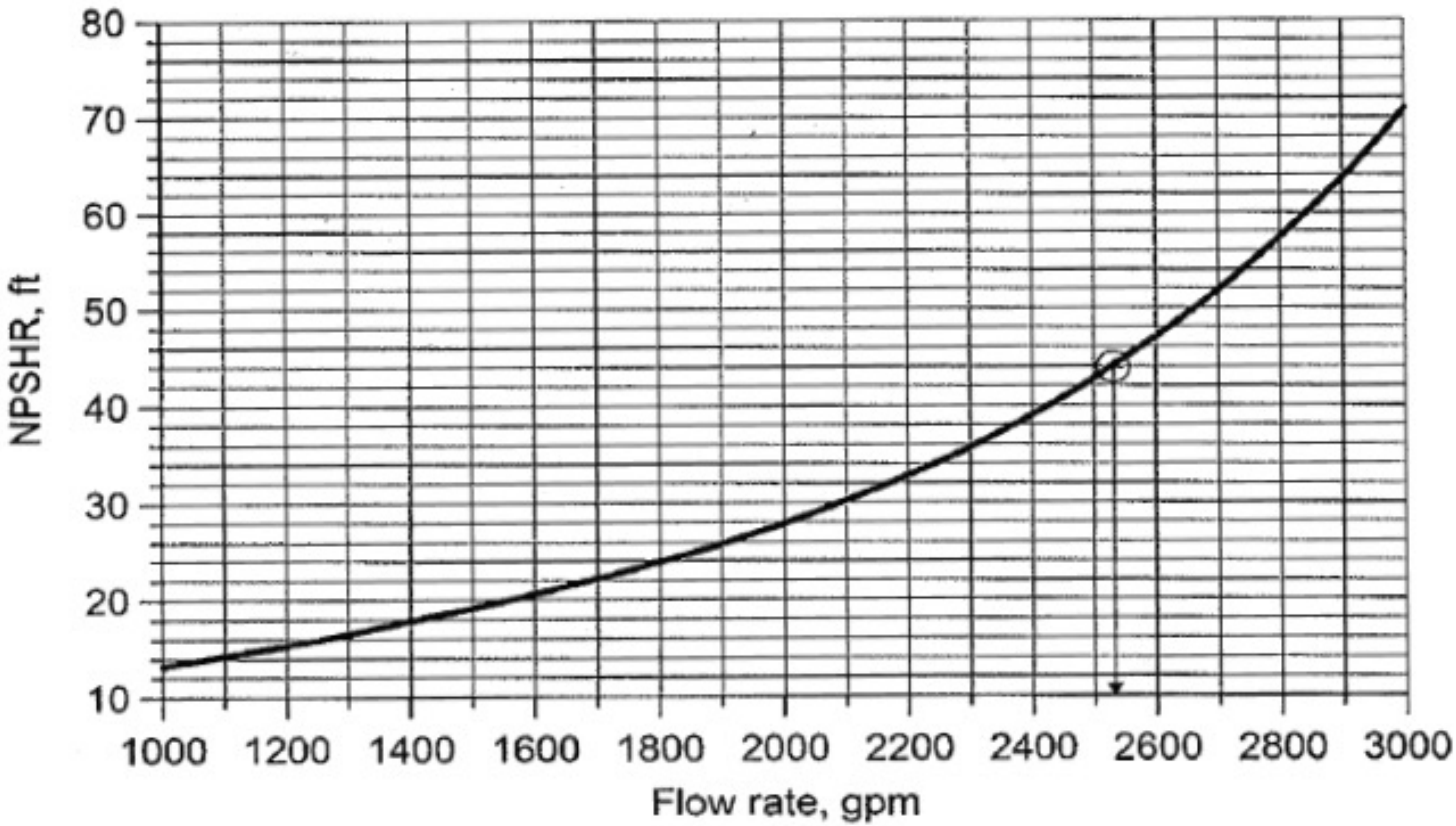
Water saturation vapor pressure at 60 F= 0.26 psia

Reference location for suction head determination is the water surface

$$\text{NPSHA} = \frac{V_s^2}{2g} + \frac{2.31\,(P_s + P_a - P_v)}{\text{s.g.}} + Z_s$$

$$\text{NPSHA} = \frac{0^2}{64.352} + \frac{2.31\,(0 + 14.7 - 0.26)}{1.00} + 10.5 = \boxed{43.9\text{ ft}}$$

Answer: NPSHR would exceed NPSHA at just over 2500 gpm

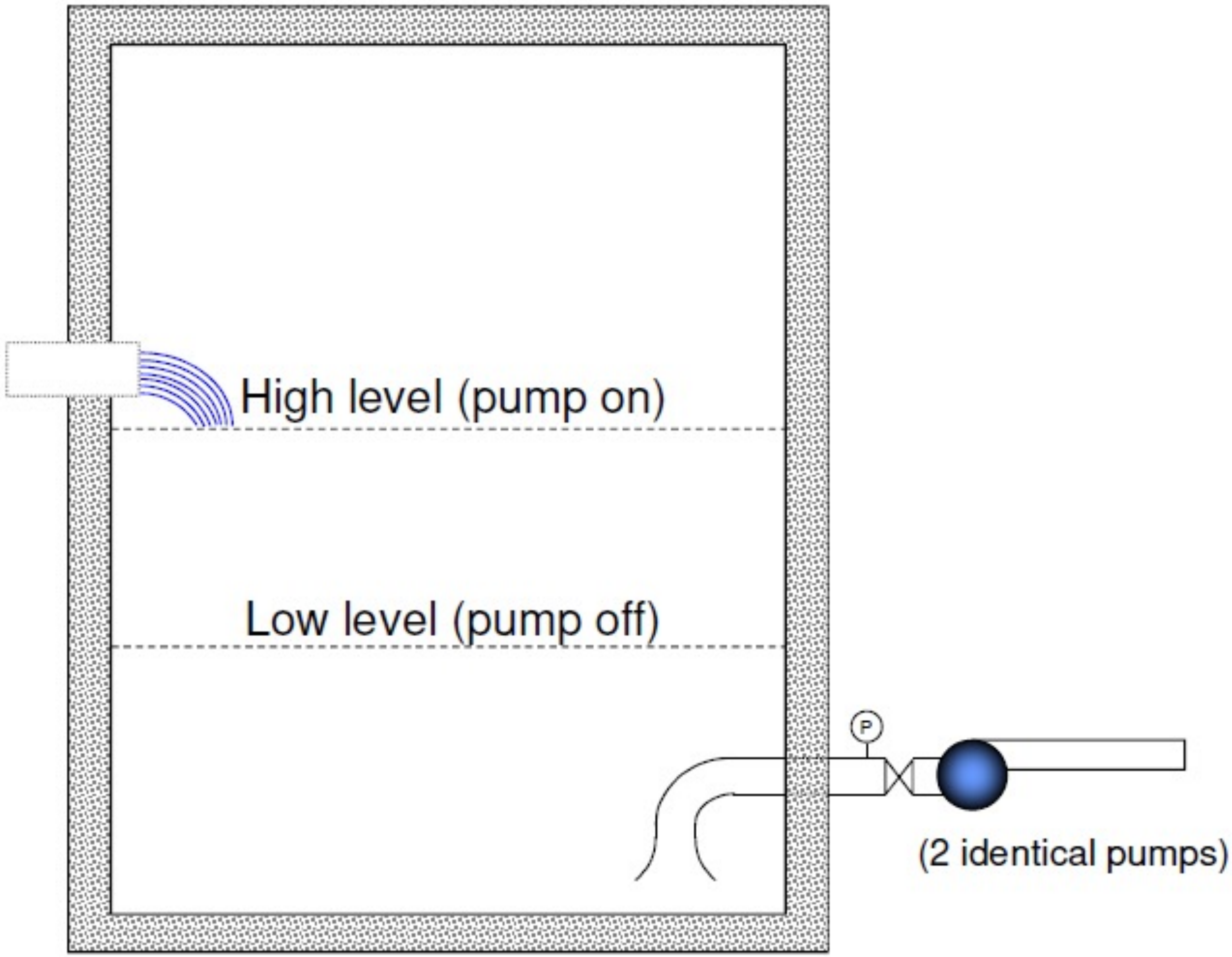


Flow estimation from suction pressure measurements

Using velocity and friction head components - two approaches

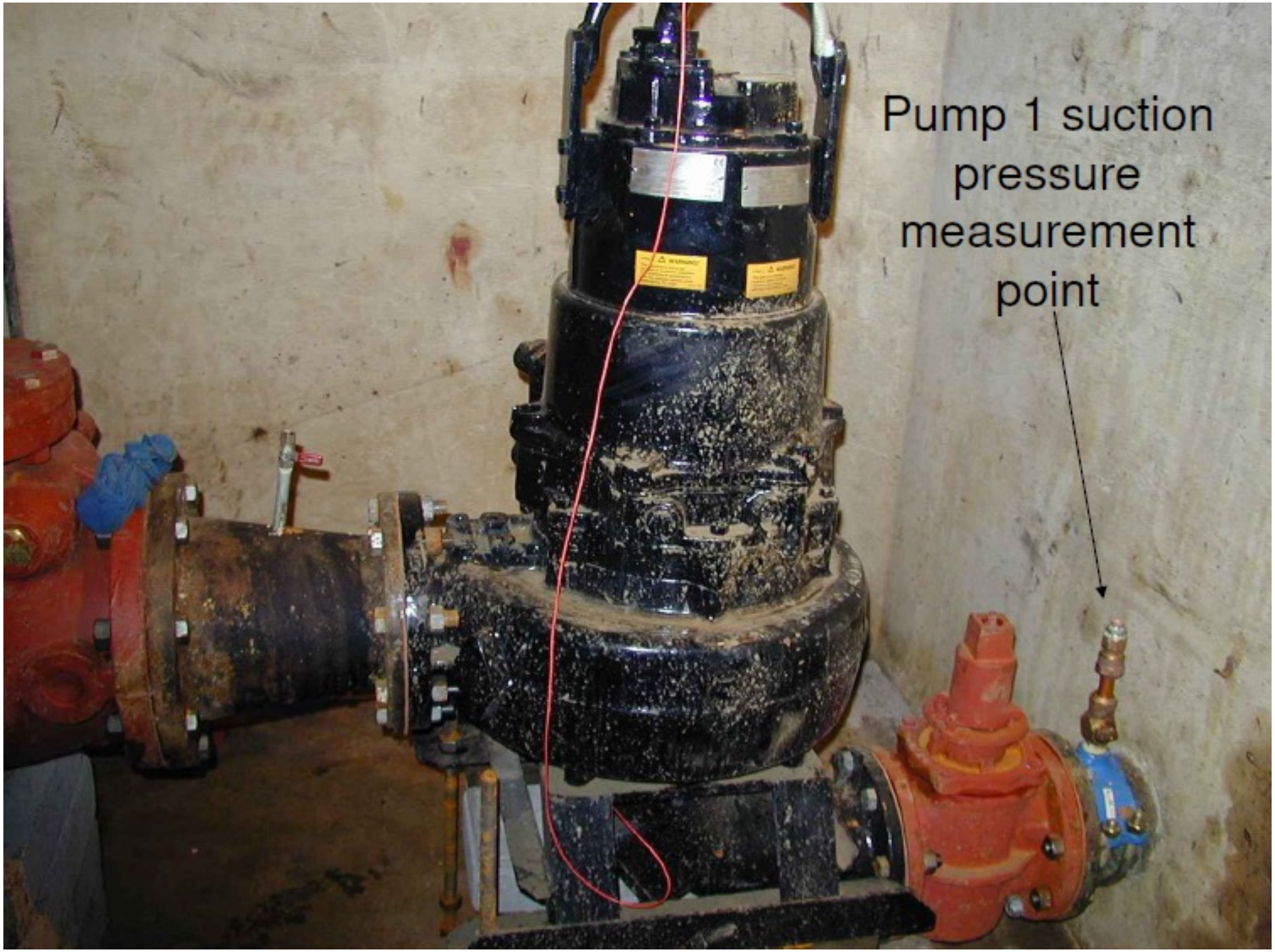
1. On-off transition
2. Comparison between running and non-running pump

A standard wastewater lift station



Incoming fluid spilling into the wet well

Pump 1 suction pressure measurement point

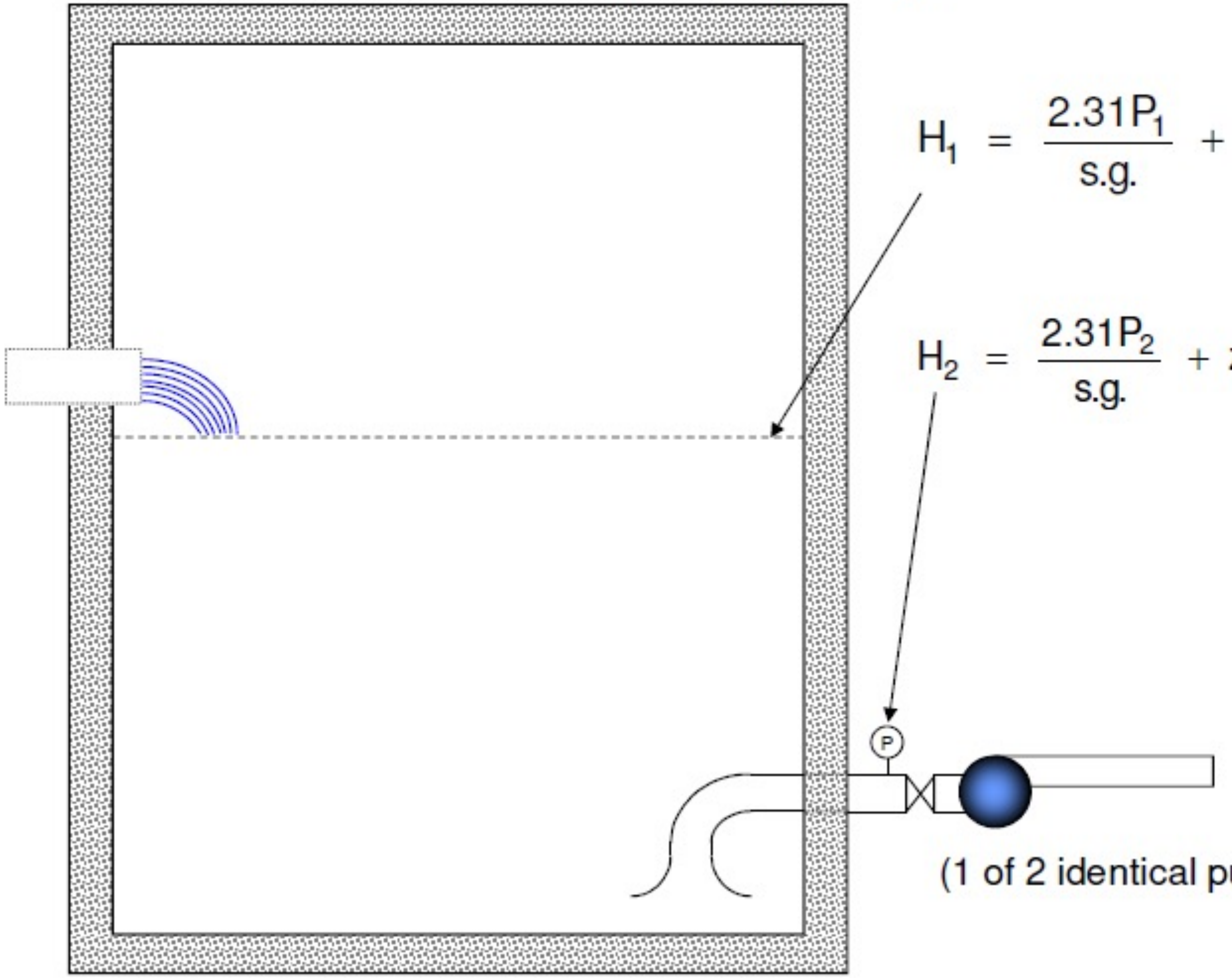


Total head (including friction) is the same at two points

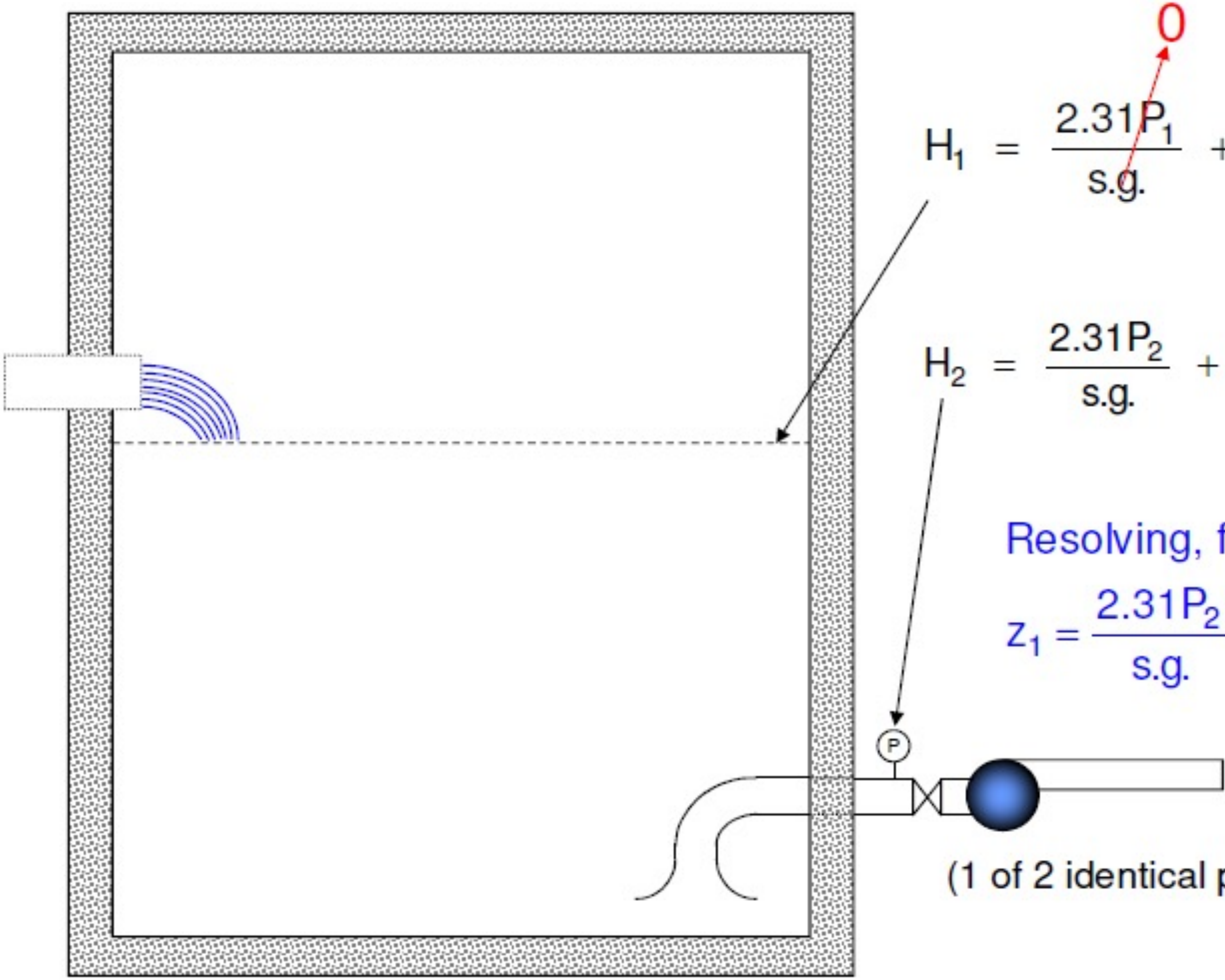
(i.e., $H_1 = H_2$)

$$H_1 = \frac{2.31P_1}{\text{s.g.}} + z_1 + \frac{V_1^2}{2g}$$

$$H_2 = \frac{2.31P_2}{\text{s.g.}} + z_2 + \frac{V_2^2}{2g} + K\left(\frac{V_2^2}{2g}\right)$$



We can relate terms and arrive at:
Two knowns, one guess, and one unknown



$$H_1 = \cancelto{0}{\frac{2.31P_1}{s.g.}} + z_1 + \cancelto{0}{\frac{V_1^2}{2g}}$$

$$H_2 = \frac{2.31P_2}{s.g.} + \cancelto{0}{z_2} + \frac{V_2^2}{2g} + K\left(\frac{V_2^2}{2g}\right)$$

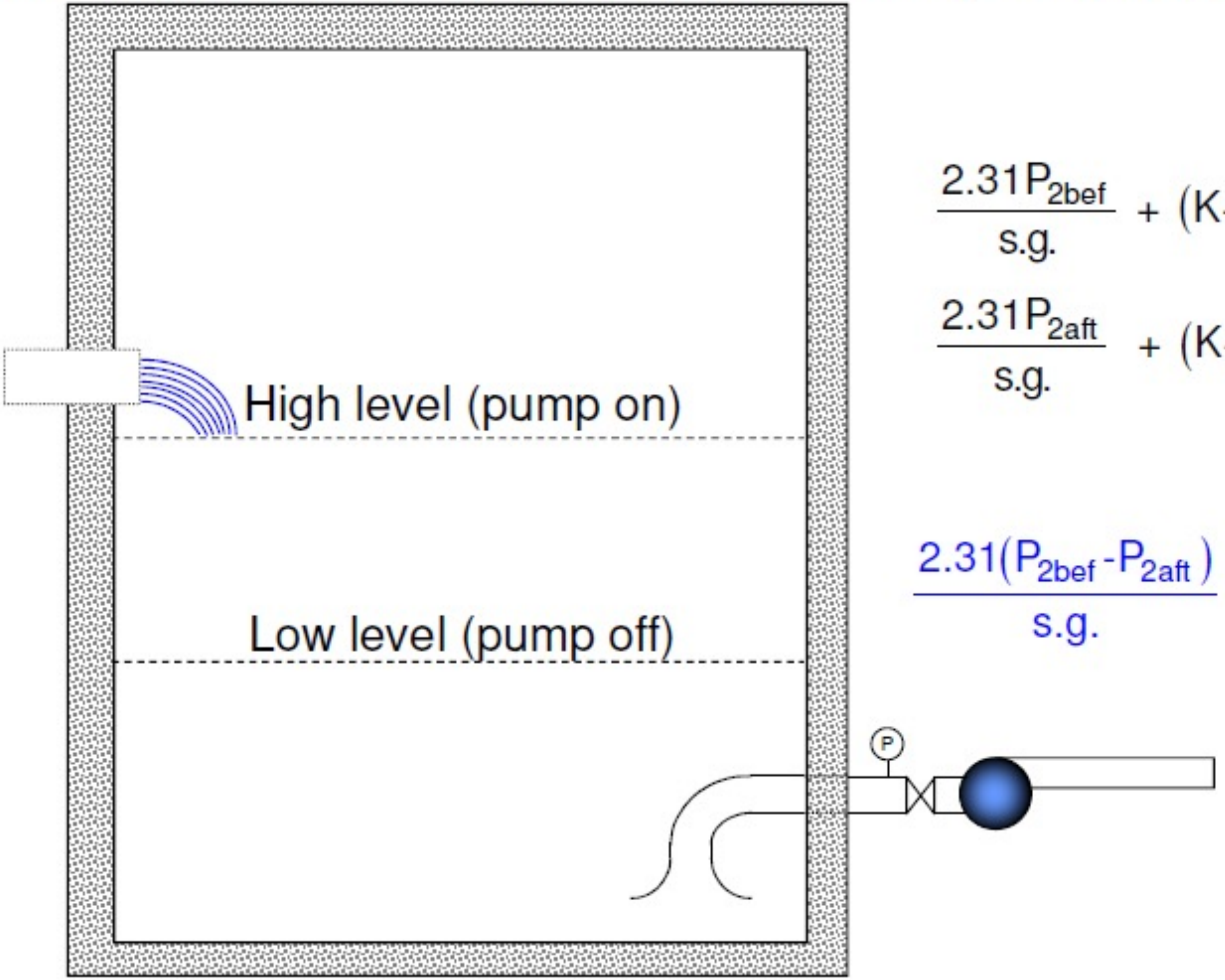
Resolving, for $H_1 = H_2$:

$$z_1 = \frac{2.31P_2}{s.g.} + (K+1)\left(\frac{V_2^2}{2g}\right)$$

(1 of 2 identical pumps)

$\therefore$ if we can measure elevation and pressure, we can estimate velocity

An alternative perspective:
If level doesn't change instantaneously on pump start/stop……



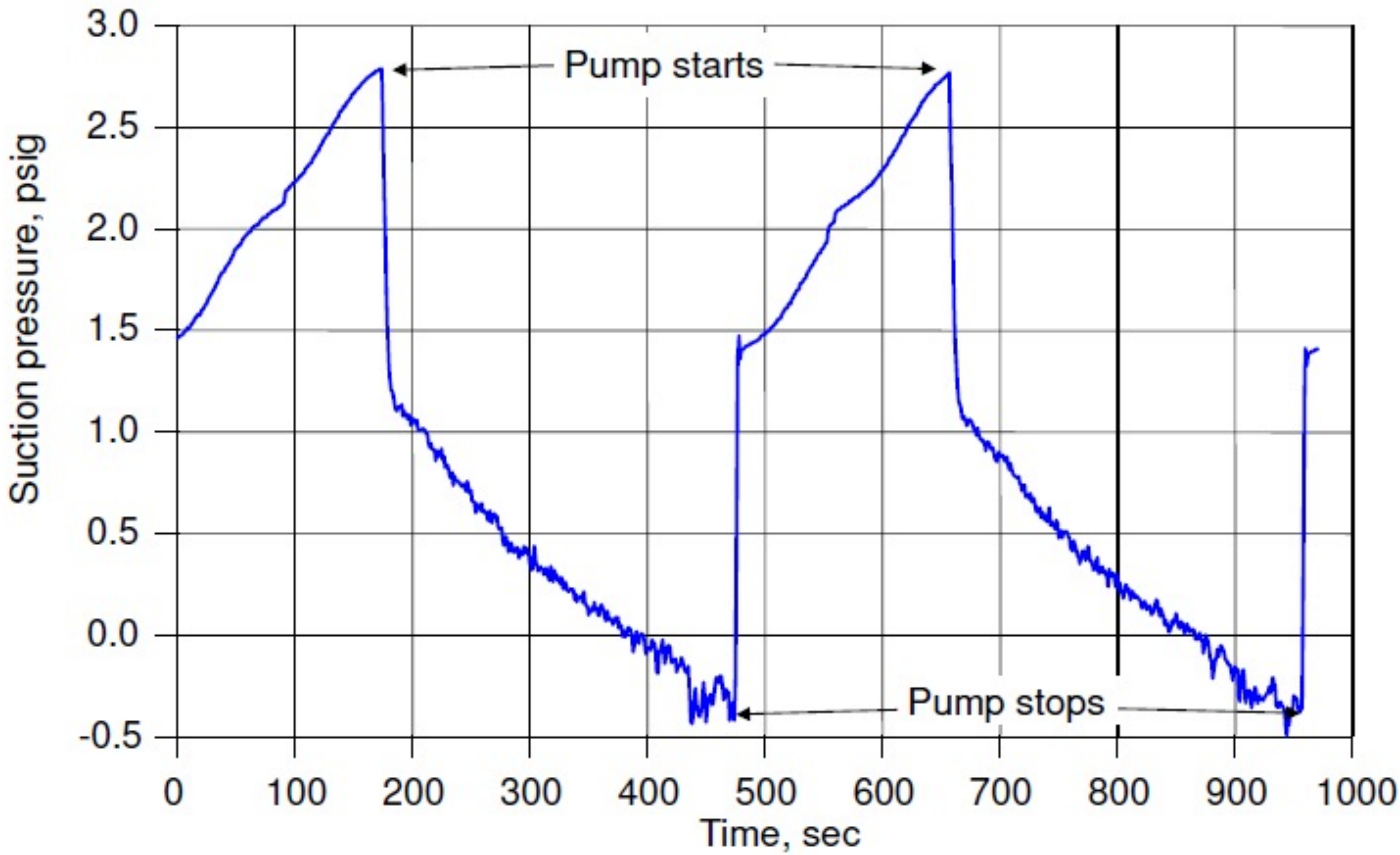
$$\frac{2.31P_{2bef}}{s.g.} + (K+1)\left(\xcancel{\frac{V_{2bef}^2}{2g}}^{\,0}\right) =$$

$$\frac{2.31P_{2aft}}{s.g.} + (K+1)\left(\frac{V_{2aft}^2}{2g}\right)$$

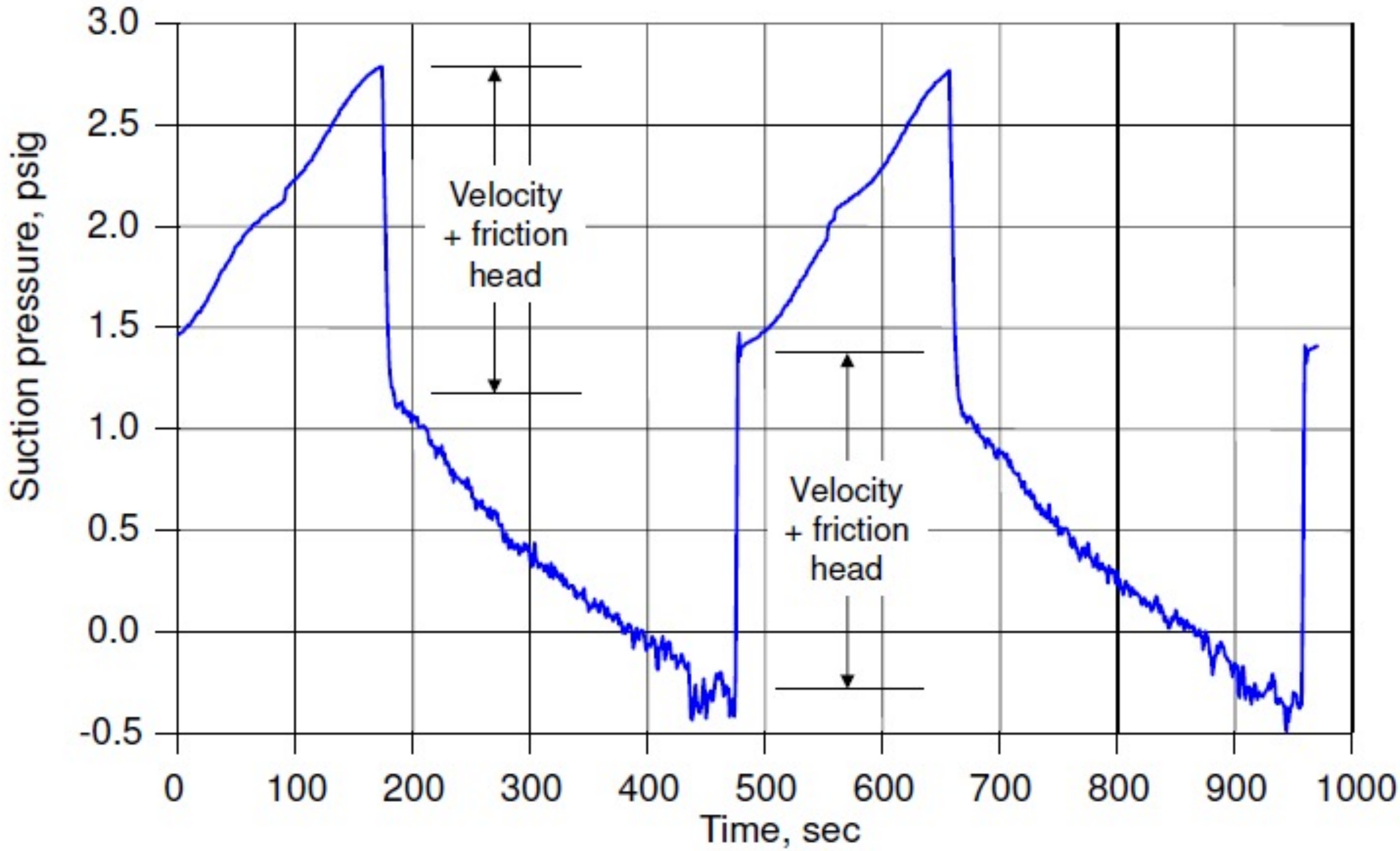
$$\frac{2.31(P_{2bef} - P_{2aft})}{s.g.} = (K+1)\left(\frac{V_{2aft}^2}{2g}\right)$$

$\therefore$ if we observe the step pressure change, we can estimate velocity

Pump suction pressure over two fill and drain cycles



Pump suction pressure over two fill and drain cycles



Average change in pressure (combining on-off and off-on transitions) was 1.67 psig

$$\frac{2.31(P_{2bef} - P_{2aft})}{s.g.} = \frac{2.31(1.67)}{1.00} = 3.86 \text{ ft}$$

Pressure depression is the combination of velocity head and frictional head losses between the wet well and pump suction

$$3.86 \text{ ft} = \frac{V_2^2}{2g} + K\left(\frac{V_2^2}{2g}\right) = \frac{V_2^2}{2g}(1 + K)$$

For bell-mouth reducer:	K = 0.05
For long radius 6-in. elbow:	K = 0.18
Overall loss coefficient:	K = 0.23

$$3.86 \text{ ft} = \frac{V_2^2}{2g}(1 + K)$$

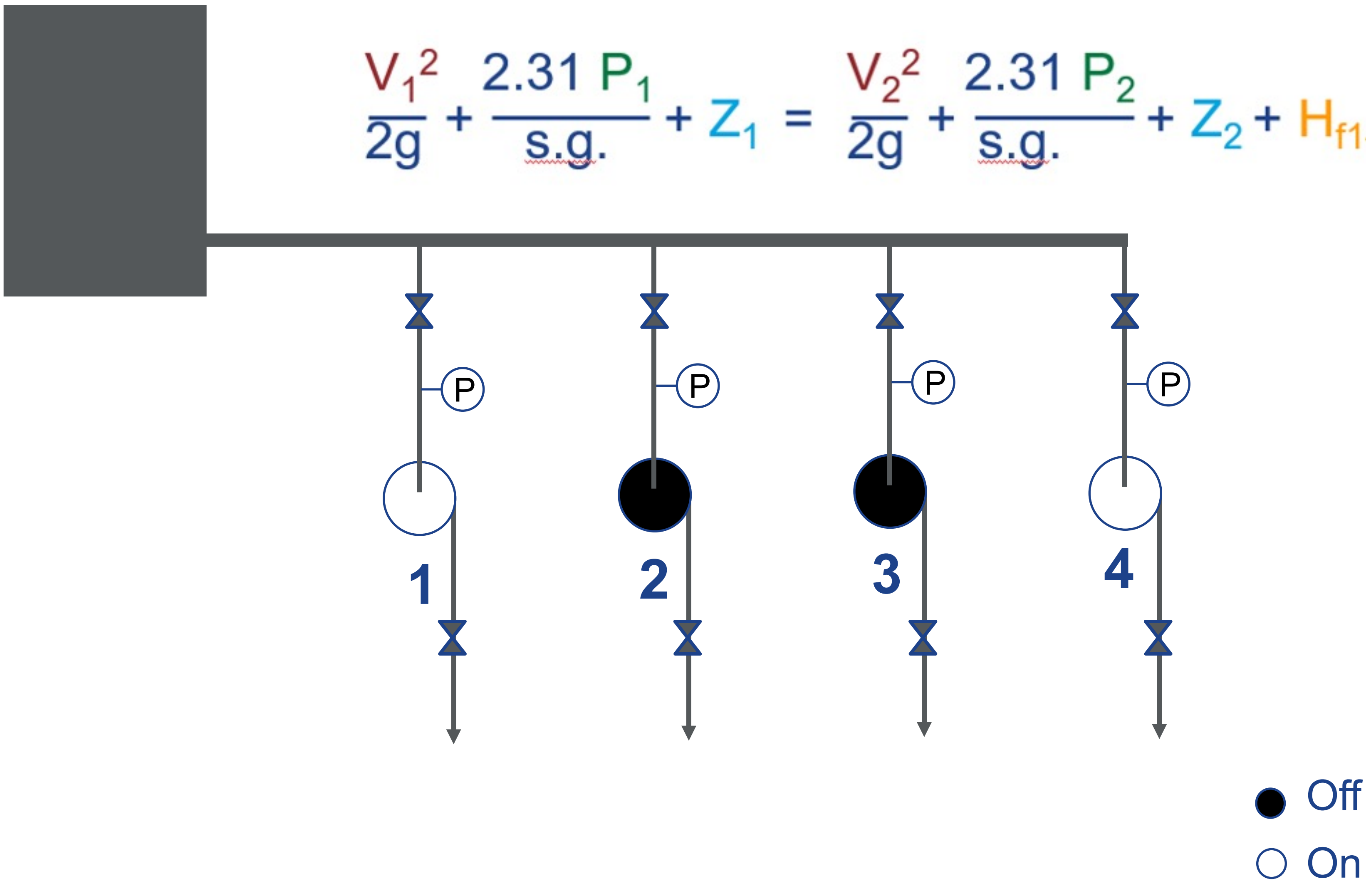
$$\Rightarrow \frac{V_2^2}{2g} = 3.14 \text{ ft}$$

$$\Rightarrow V = 14.2 \text{ ft/s}$$

⇒ calculated flow rate = 1209 gpm

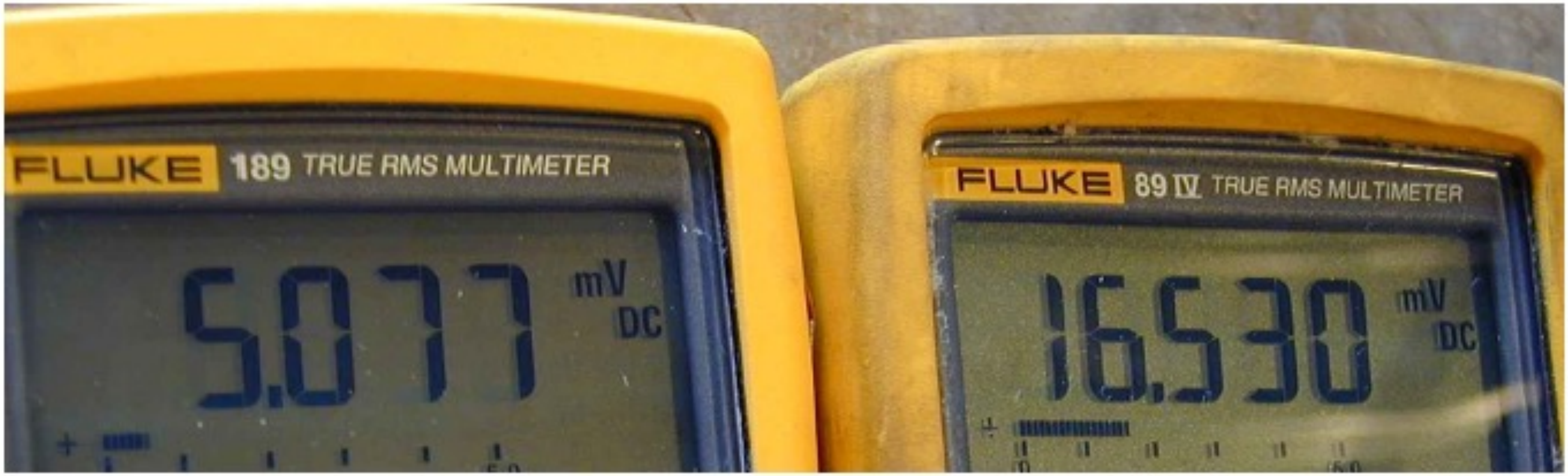
An effective way to measure flow rate in parallel pumping applications: use Bernoulli

$$\frac{V_1^2}{2g} + \frac{2.31\,P_1}{s.g.} + Z_1 = \frac{V_2^2}{2g} + \frac{2.31\,P_2}{s.g.} + Z_2 + H_{f1\text{-}2}$$



An alternative method: compare suction pressures for the pump that is on with a parallel one that is off

Suction pressures on both pumps were monitored during drawdown
(Instrument scaling: 1 mV = 1 kPa)



Pump 1 suction pressure (Pump on)

Pump 2 suction pressure (Pump off)

Differential = 11.453 kPa = 1.66 psig = 3.84 ft
(again, this is combined velocity head and friction loss)

Flow rate was calculated from differential pressure at several points during wet well drawdown

pipe diameter	5.895	(6.02" pipe with nominal 1/16" cement-mortar liner)						
Area, sq ft	0.190							
estimated K	0.23							
	Event	P1 (kPa)	P2 (kPa)	delta kPa	dH, ft	Vhead = dH/(1+K)	Vel, ft/s	gpm
	1	6.69	17.5	10.80	3.62	2.94	13.76	1170
	2	5.98	16.8	10.86	3.64	2.96	13.80	1174
	3	5.08	16.5	11.45	3.84	3.12	14.17	1205
	4	1.82	13.4	11.60	3.89	3.16	14.26	1213
	5	1.48	12.9	11.44	3.83	3.12	14.16	1205
	6	0.72	11.8	11.04	3.70	3.01	13.91	1183
	7	-0.1	11.2	11.32	3.79	3.08	14.09	1198
	8	-0.7	10.6	11.26	3.77	3.07	14.05	1195
				Average	3.76	3.06	14.02	1193

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				Average	**3.76**	**3.06**	**14.02**	**1193**

An independent method of estimating flow rate in level-controlled operations

- Measure time between on and off events
- Calculate the volume between level switches
- Incoming flow rate with pump off = volume/time
- Assume that the incoming flow rate when the pump is running is equal to that calculated from before and after pump off periods

$$\boxed{Q = \frac{t_{on}\left(\dfrac{V_w}{t_{off}}\right) + V_w}{t_{on}} = \left[\left(\frac{V_w}{t_{off}}\right) + \left(\frac{V_w}{t_{on}}\right)\right] = V_w\left(\frac{t_{off} + t_{on}}{t_{off} \times t_{on}}\right)}$$

Q = Pump flow rate, gpm
t_{on} = Pump run time, min
t_{off} = Pump off time, min
V_w = Well volume, gallons

Estimated flow rate at the lift station using this method was 1161 gpm

Manometers – even the home made kind – provide excellent accuracy

An exercise: estimate the flow rate for the previous slide

Suction header: 18" standard (17.25-inch ID)

Individual pump suction lines: 16" standard (15.25-inch ID)

Suggested loss assumptions:

Branch tee:	0.45
18-16 reducer:	0.11
16-inch gate valve:	0.04

$$z_1 - z_2 = \frac{V_2^2}{2g}(1+K)$$

$$\text{gpm} = 2.448\ V\ d^2$$

Where z is elevation in feet, g is 32.174 ft/s^2, V is velocity in ft/s, and d is the pipe inside diameter in inches

An exercise: estimate the flow rate for the previous slide

16" standard (15.25-inch ID)

Branch tee:	0.45
18-16 reducer:	0.11
16-inch gate valve:	0.04
	0.60

$$z_1 - z_2 = \frac{V_2^2}{2g}(1+K) \qquad \frac{17.5}{12} = \frac{V_2^2}{2 \times 32.174}(1.6) \Rightarrow V = 7.66 \text{ ft/s}$$

$$\text{gpm} = 2.448\ V\ d^2 \qquad 2.448 \times 7.66 \times 15.25^2 = 4360 \text{ gpm}$$

Where z is elevation in feet, g is 32.174 ft/s^2, V is velocity in ft/s, and d is the pipe inside diameter in inches


The End