Basic Hydraulics for Water Operators

Tuesday November 10, 2026; 1–2 pm EST

Instructor: Daryl J. Gotham, PE, Senior Research Engineer

Great Lakes Environmental Infrastructure Center, MTU



This program is made possible under a cooperative agreement with US EPA.

Learning Objectives

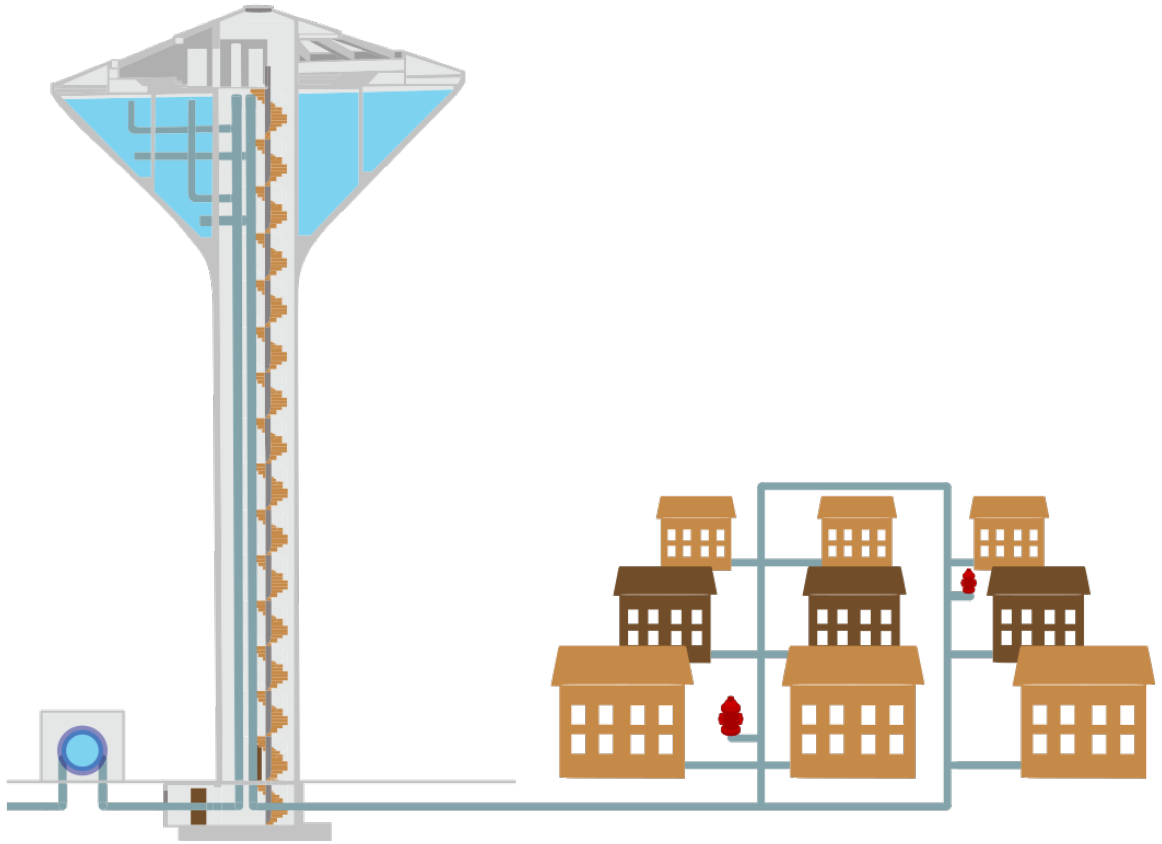
- Understand key hydraulic principles in water systems
- Reacquaint with how to calculate areas and volumes
- Apply the Continuity Equation and the Hazen-Williams Equation
- Relate concepts to real-world operator duties



What is Hydraulics?

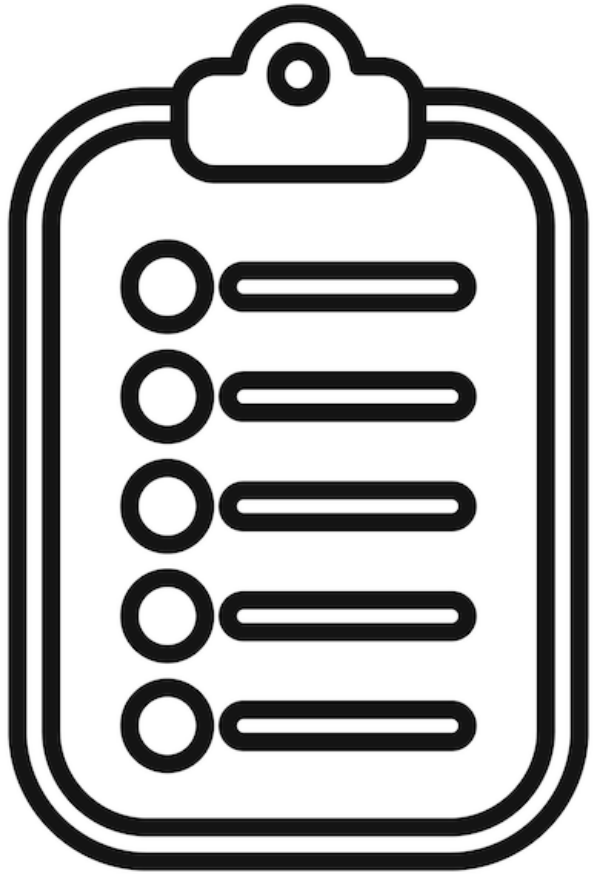
Study of liquids, both at rest and in motion

- Application of fluid mechanic principles to manage distribution of water
- For practicality, assume water is a perfect liquid
- Water takes shape of its container and has weight, density, and exerts pressure

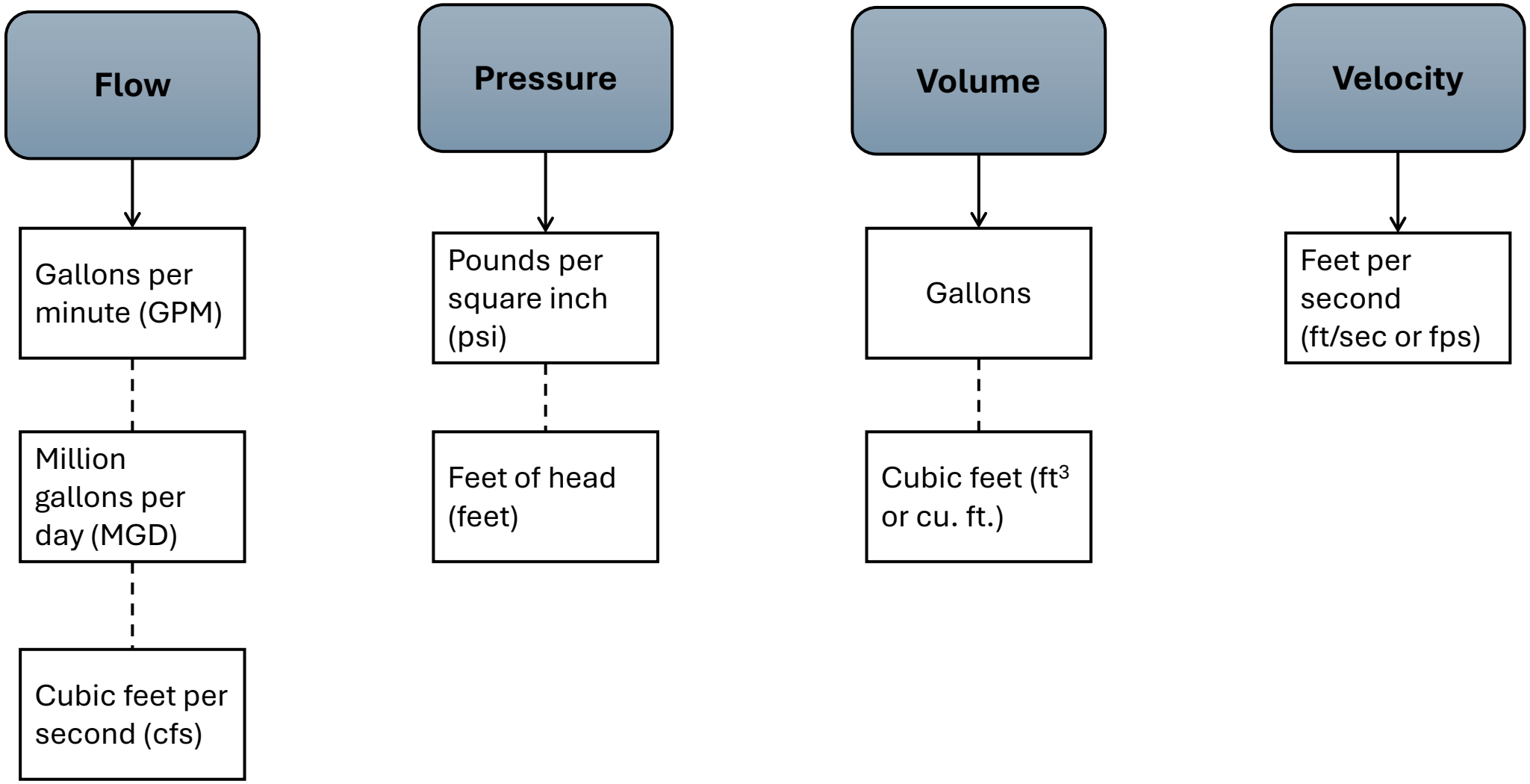


Why Hydraulics Matters

1. Ensure Consistent Water Pressure
2. Maintain Water Quality
3. Optimize System Performance
4. Respond to Emergencies
5. Support System Design and Upgrades
6. Regulatory Compliance



Units of Measure



Hydraulics Conversion Table

Multiply	By	**To Obtain**
Cubic Feet (ft^3 or cu. ft.)	7.48	Gallons of Water (gal)
Cubic Feet (ft^3 or cu. ft.)	62.4	Pounds (lbs) of Water
Feet of Water (ft)	0.433	Pounds/Square Inch (psi)
Gallons of Water (gal)	8.34	Pounds (lbs) of Water
Pounds/Square Inch (psi)	2.31	Feet of Water (ft)

Conversion Example



A storage tank holds 2000 cubic feet of water. Use the Conversion Table to first find it's equivalent in gallons and then in pounds.

- a) Multiply 2000 cubic feet by 7.48 to obtain the number of gallons. 2000 ft^3 x 7.48gal/ ft^3 = 14,960 or 15,000 gallons

b) How much does this amount of water weigh (in lbs)?

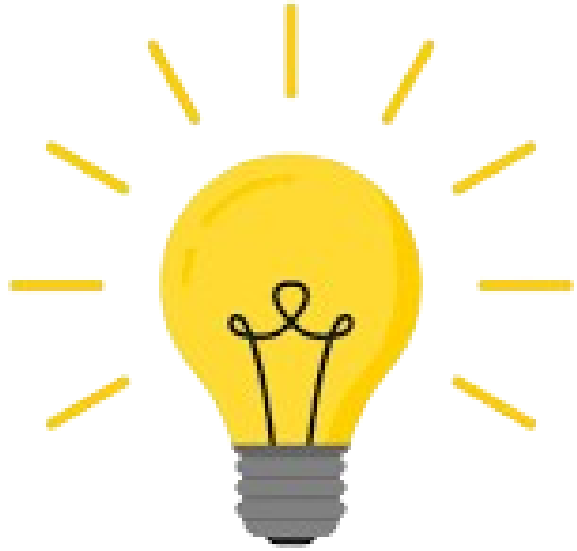
Convert from gallons to pounds. 15,000 gal x 8.34 lbs/gal = 125,100 lbs or 125,000 lbs.



Conversions to Memorize

7.48 gal/ft^3 and

8.34 lbs/gal



From these two conversion factors we can develop another important factor:

7.48 gal/ft^3 x 8.34 lbs/gal = 62.4 lbs/ ft^3

Canceling Units

Many of the hydraulics calculations require use of several different conversion factors.

Knowing what units you have and which ones you need determines which conversion factors to use.

Example: Convert from days to seconds.

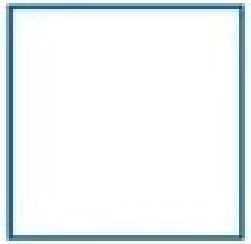
days x hrs/day x min/hr x **sec**/min = **seconds**

1 days x 24 hrs/day x 60 min/hr x 60 **sec**/min = 86,400 **sec**

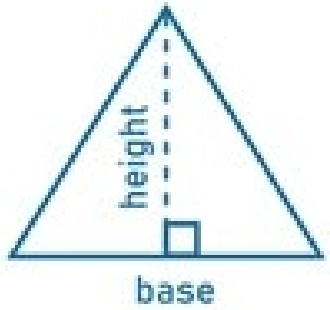
Areas used in pipe and tank calculations

- **Rectangle:** $A = L \times W$
- **Square:** $A = L^2$
- **Circle:** $A = \pi \times r^2 = 0.785 \times d^2$
- **Triangle:** $A = \frac{1}{2} \times b \times h$

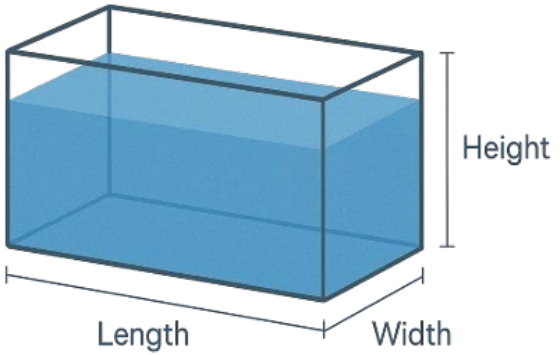








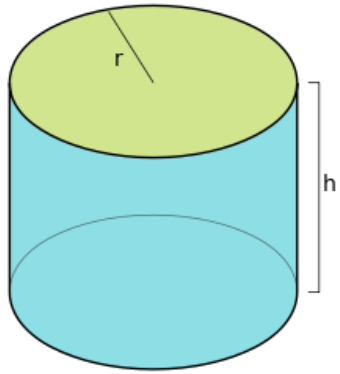
Volumes used in tank/pipe calculations



Rectangular Tank: $V = L \times W \times H$

Cylindrical Tank: $V = \pi \times r^2 \times h$ or $V = 0.785 \times d^2 \times h$

Cylindrical Pipe: $V = \pi \times r^2 \times l$ or $V = 0.785 \times d^2 \times l$



Lesser used volumes:

Cone: $V = 1/3\ (\pi r^2 h)$

Pyramid: $V = L \times W \times (1/3)H$

Sphere: $V = 4/3\ (\pi r^3)$



Sample Tank Volume Problem

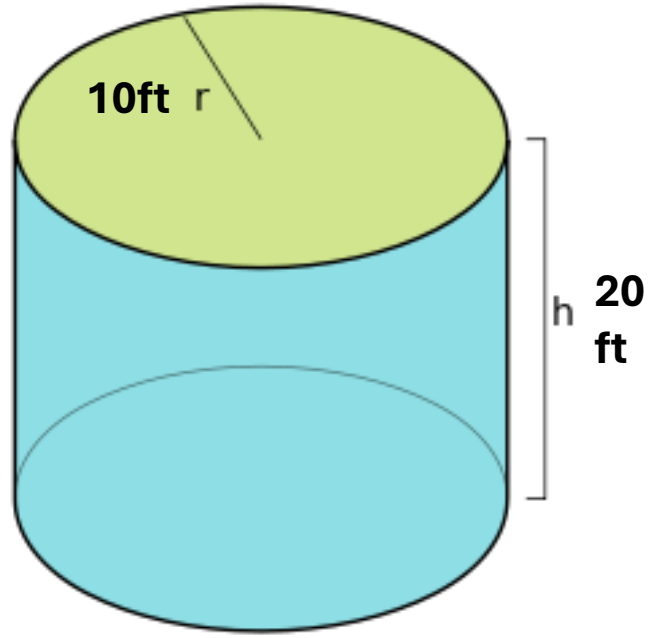
A cylindrical tank has a radius of 10 ft and a height of 20 ft. How many gallons can it hold?

We first determine the volume of the tank in cubic feet:

$V = \pi \times (10 \text{ feet})^2 \times 20 \text{ feet} = 6{,}283 \text{ ft}^3$

Next, we convert from cubic feet to gallons:

$6{,}283 \text{ ft}^3 \times 7.48 \text{ gallon/ft}^3 = 47{,}000 \text{ gallons}$



Poll Question #1

How many gallons does a 26 feet long, by 15 feet wide, by 9 feet deep tank hold?

a) 3,510 gallons
b) 29,273 gallons
c) 469 gallons
d) 26,255 gallons

d) 26ft x 15ft x 9 ft = 3,510 cu ft x 7.48gal/ cu ft = 26,255 gallons

Rate of Flow

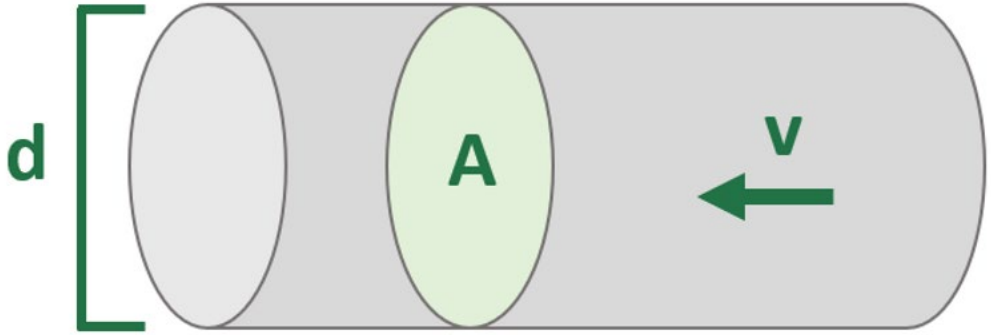
An indication of how much water (a volume) is moving past a spot in a unit of time.

Flow rates are typically referred to as discharge (Q) and expressed in volumes per units of time.

Gallons per minute (gpm)

Millions of Gallons per day (mgd)

Cubic feet per second (cfs)



$$Q = A \times v$$

Sample Flow Conversions

Convert 700 gpm to cfs.

700 gal/1 min x 1 ft^3/7.48 gal x 1 min/60 sec = 1.56 ft^3/sec

therefore, 700 gpm = **1.56 cfs**

Convert 2.25 cfs to gal/hr.

2.25 ft^3/sec x 7.48 gal/ft^3 x 60 sec/min x 60 min/hr = **60,588 gal/hr**

Convert 0.1 million lbs/day to gpm

100,000 lbs/day x 1 gal/8.34 lbs x 1 day/1440 mins ≈ **8.33 gpm**

Volume and Density

Volume = quantity of space occupied

Density = the weight of a substance per unit volume

1 cubic ft (ft^3) of water = 62.4 lbs.

Example

If a body that weighed 160 lbs. is all water within a thin weightless membrane, then the volume would be:

$$\frac{160 \text{ lbs.}}{62.4 \text{ lbs./ft}^3} = \mathbf{2.56 \text{ cubic } (ft^3)}$$

Pressure

Force water exerts over a unit area

- Expressed in terms of pounds per square inch (psi) or per square foot



Example psi Calculation

1 sq ft = 12 in. x 12 in. = 144 sq in

$$\frac{62.4\ \text{lbs}}{\text{ft}^2} \text{ x } \frac{1\text{ft}^2}{144\ \text{in}^2} = \mathbf{0.433\ psi\ for\ 1\ ft\ of\ water}$$

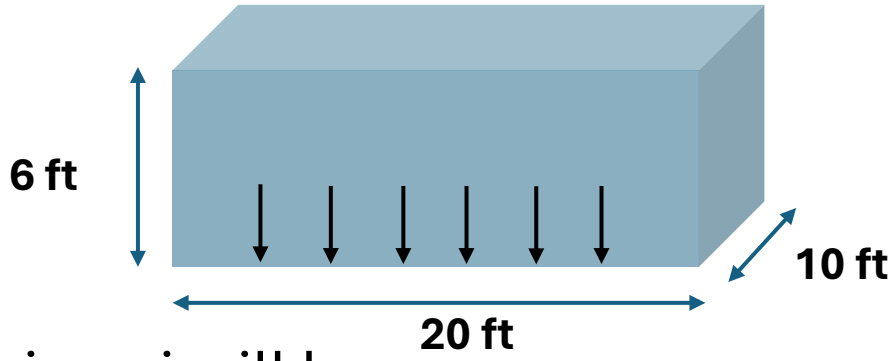
Pressure Example

Example

A 10 ft wide by 20 ft long by 6 ft deep tank will hold 8967 gallons of water when full. The water weighs 74,850 lbs (8976 gal x 8.34 lb/gal) and acts on the 10 ft by 20 ft bottom of the tank. What is the pressure in psi on the bottom of the tank?

1.) Calculate pressure in lbs/ft^2

$6\text{ft} \times 62.4\ \text{lbs/ft}^3 = 375\ \text{lbs/ft}^2$



2.)Convert to psi

Since $1\ \text{ft}^2 = 12\ \text{in.} \times 12\ \text{in.} = 144\ \text{in}^2$, the pressure in psi will be:

$$\frac{375\ \text{lbs}}{\text{ft}^2} \times \frac{1\text{ft}^2}{144\ \text{in}^2} = 2.6\frac{\text{lbs}}{\text{in}^2} = \mathbf{2.6\ psi}$$

Pressure as Cubes of Water

Pressure calculations can be thought of a “cubes” of water stacked one on top of the other.

Each cube weighs 62.4 lbs and exerts pressure on a one square foot area.

With a water height of 6 feet, the pressure is:

6 ft x 62.4 lbs/ft^3 =375 lbs/ft^2



Since 1ft^2 = 12 in x 12 in or 144 in^2 the pressure in lbs/in^2 is:

375 lbs /ft^2 x 1 ft^2/144 in^2 = 2.6 psi for 6 feet of water

Water Head relationships

Converting the pressure of our 62.4 pound cube of water from the pressure on one square foot to the pressure per square inch:

62.4 lbs/ft^2 x 1 ft^2/144 in^2 = 0.433 lb/ in^2 = 0.433 psi for one foot H_2O

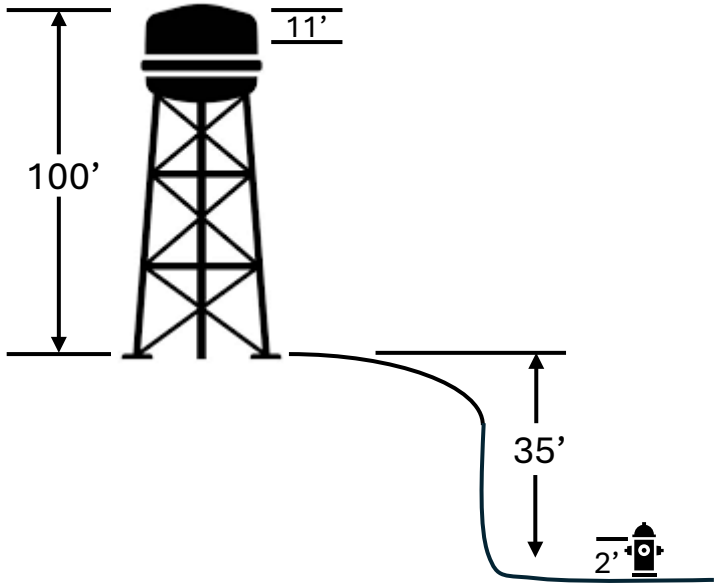
0.433 psi = 1 ft of water head

1/0.433 = 2.31 ft of water head, 1psi = 2.31 ft of water head

Hydraulics Example – Elevated Storage Tank

Problem Statement

A 100ft high elevated tank sits atop a 35ft high hill. The water level in the tank is 11ft below the tank's top. There is a hydrant at the base of the hill. What is the water pressure at the hydrant nozzle if the nozzle is 2ft above ground level? (Assume static conditions—no flow or head loss)



1.) Calculate feet of head

100ft-11ft+35ft-2ft = **122 ft**

2.) Calculate pressure in psi

$$122\text{ft} \times \frac{0.433\text{ psi}}{1\text{ ft}} = \mathbf{52.8\ psi}$$

OR

$$122\text{ft} \times \frac{1\text{ psi}}{2.31\text{ ft}} = \mathbf{52.8\ psi}$$

Elevated Storage Pressure Example 2

Calculate the water pressure
at the base of the elevated storage
tank and the standpipe.

Elevated storage Tank:

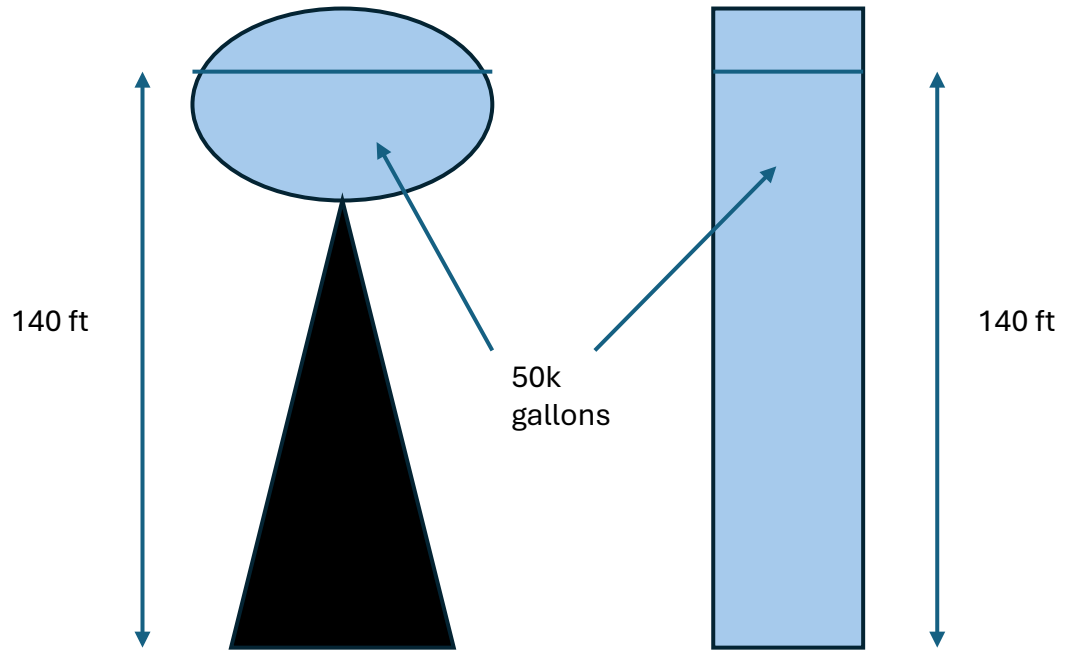
140 ft x 0.433 psi/ft = 60.6 psi

or 140 ft x 1 psi/2.31 ft = 60.6 psi

Standpipe:

140 ft x 0.433 psi/ft = 60.6 psi

or 140 ft x 1 psi/2.31 ft = 60.6 psi



Elevated Storage Pressure Example 3

Calculate the water pressure
at the base of the elevated storage
tank and the standpipe.

Elevated storage Tank:

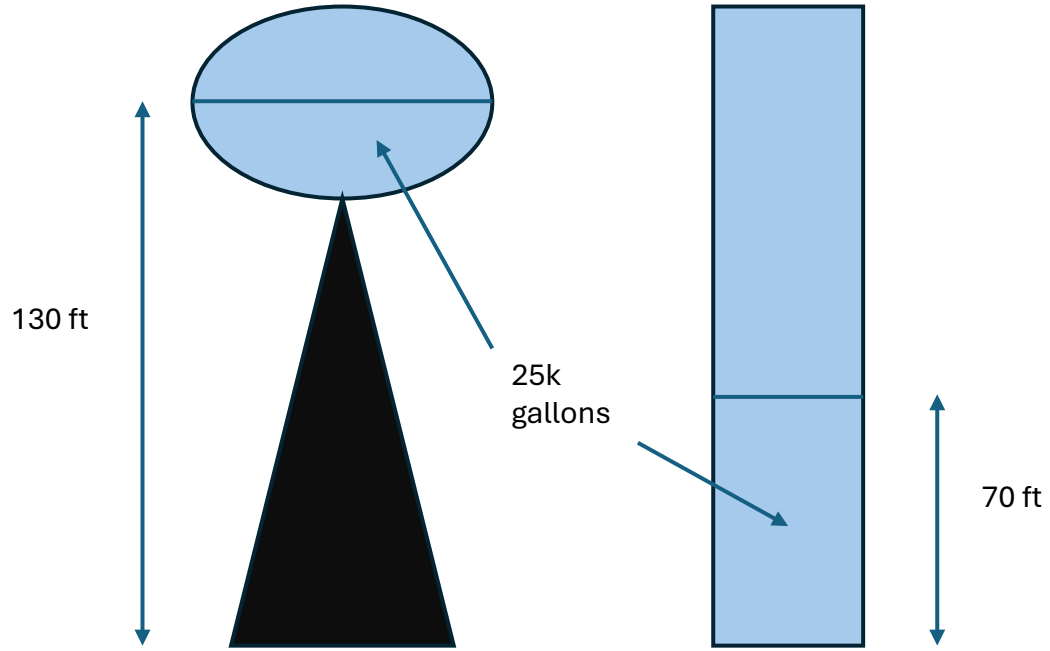
130 ft x 0.433 psi/ft = 56.3 psi

or 130 ft x 1 psi/2.31 ft = 56.3 psi

Standpipe:

70 ft x 0.433 psi/ft = 30.3 psi

or 70 ft x 1 psi/2.31 ft = 56.3 psi



Poll Question #2

What factor has the largest instantaneous effect on storage tank water pressure?

a) Water elevation
b) Tank shape
c) Tank height
d) Tank volume

a) The elevation of the water has the biggest effect on water pressure.

Friction and Head Loss



Friction = Resistance to flow of water in pipes

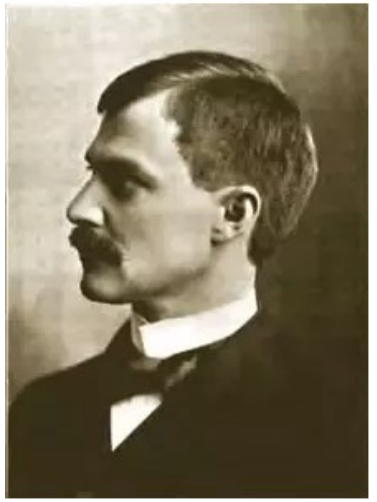
- Influenced by the roughness of the pipeline wall
- Higher roughness = higher friction

Head Loss = The decrease in the sum of velocity, pipe length, diameter, and roughness

- Depends on velocity, diameter and length of pipe, and roughness

Hazen-Williams Equation





$$V = 1.318CR^{0.63}S^{0.54}$$

V = Velocity of Flow in ft/s

C = Roughness Coefficient

R = Hydraulics radius (Pipe Area/Wetted Perimeter)

S = Feet of Head Loss per ft of Conduit

- Lower roughness = higher C factor
  - -C factors typically listed in informational tables
- Charts and tables used to determine head loss

Common C-values

- **Plastic (PVC, Polyethylene):** 140-150
- **Copper, Brass:** 140-150
- **Steel (new):** 140-150
- **Galvanized Iron:** 120
- **Cast Iron (unlined):** 100-120
- **Cast Iron (lined):** 130
- **Concrete:** 100-140
- **Vitrified Clay:** 110-140
- **Wood Stave:** 110-120
- **Corrugated Metal:** 60
- **Riveted Steel:** 90-110



Important Considerations



- **Age and Condition:**

  The C factor decreases as pipes age and accumulate deposits or corrosion, leading to increased friction.

- **Fluid Type:**

  The Hazen-Williams formula and its C factors are primarily designed for water. Using them with other fluids can lead to inaccuracies.

- **Flow Regime:**

  The Hazen-Williams equation is typically used for turbulent flow, not laminar flow.

Sample Hazen-Williams Problem



A 24-inch, old, unlined cast iron pipe carries a total flow of 6,000 gallons per minute.

a) What is the velocity of the flow in the pipe?

b) What is the head loss due to friction per 1,000 feet of pipe?

c) What is the value of “s” (head loss per foot)?

d) If the pipe is 10,000 feet long, what is the total head loss?

- L = 10,000 ft, D = 24 in, Q = 6,000 GPM, C = 100
- Use the Hazen-Williams Alignment Chart
- Use the Hazen-Williams Head Loss Calculator spreadsheet

Hazen-Williams Head Loss Calculator

Hazen-Williams Friction (Head Loss) Calculator				
	Input			
Actual pipe diameter (in):	24			
Friction coefficient:	100			
Flow rate (gpm):	6000			
Length of pipe (ft):	10000			
	Output			
Head loss (ft):	38.9			
Head Loss (psi):	16.7			
Head loss/ft:	0.0039			
Head loss/1000ft:	3.89			
Velocity (ft/s):	4.26			
References				
Adapted from: CIDWT. 2008. Installation of Wastewater Treatment Systems. Consortium of institutes for Decentralized Wastewater Treatment.				

Poll Question #3

The C factor of a water pipe is the

a.) Measurement of area to pipe diameter

b.) Measurement of pipe diameter to area

c.) Cost to diameter ratio

d.) Measurement of interior roughness

Head Loss Due to Pipe Fittings

Head loss in pipes due to fittings (also known as minor losses) can be a significant factor in fluid system design and can be calculated using loss coefficients(K-values).

These losses occur due to flow disturbances caused by fittings like elbows, valves, and changes in pipe diameter.

Understanding and accounting for these losses is crucial for ensuring efficient fluid flow and preventing pressure drops.

$h_L = K \times (V^2/2g)$

h_L is the head loss, K is the loss coefficient, V is the average velocity, g is acceleration due to gravity.

Equivalent Lengths Method for Head Loss

Head loss from fittings can also be calculated using the equivalent lengths method.

- This method involves replacing the fitting with an equivalent length of straight pipe that would cause the same head loss.
- Tables exist that provide equivalent lengths for different fittings and pipe sizes.
- The total head loss is then calculated using the equivalent lengths and the friction factor for the pipe material,

This is helpful in large projects for determining the total head loss

Examples of Head Loss of Pipe Fittings

TABLE 2.10-1. *Friction Loss for Turbulent Flow Through Valves and Fittings*

Type of Fitting or Valve	*Frictional Loss, Number of Velocity Heads, K_f*	*Frictional Loss, Equivalent Length of Straight Pipe in Pipe Diameters, L_e/D*
Elbow, 45°	0.35	17
Elbow, 90°	0.75	35
Tee	1	50
Return bend	1.5	75
Coupling	0.04	2
Union	0.04	2
Gate valve		
Wide open	0.17	9
Half open	4.5	225
Globe valve		
Wide open	6.0	300
Half open	9.5	475
Angle valve, wide open	2.0	100
Check valve		
Ball	70.0	3500
Swing	2.0	100
Water meter, disk	7.0	350

Source: R. H. Perry and C. H. Chilton, *Chemical Engineers' Handbook*, 5th ed. New York: McGraw-Hill Book Company, 1973. With permission.

Pipe Fittings Head Loss Example

If a 2-inch 90^0 elbow has a K value of 0.75, and the water velocity is 5 ft/s, the head loss due to the elbow would be:

$h_L = K \times (V^2/2g) = 0.75 \times (5ft/s \times 5ft/s)/(2 \times 32.2\ ft/s)$

$= 0.29$ ft of head loss

Impacts of Head Loss

Reduces available pressure and flow

- Potentially impacting customers and fire protection

Affects pumps

- Pump selection
- Pump efficiency and energy costs,
- Pump lifespan due to premature wear and cavitation

Leads to inefficiencies if not addressed

- Water loss
- Wasted resources







Hydraulic Gradient or Slope

Vertical rise or fall of something with respect to horizontal distance
“Steepness”

- Vertical rise and fall measured in ft, Rise over Run, Rise/Run
- Can be calculated if elevation of each end is known
- Can be expressed as a percent

Example

Length of 20 ft, rise of 1ft in a horizontal distance of 20 ft

Rise of 1 divided by a run of 20 = 1/20 = 0.05

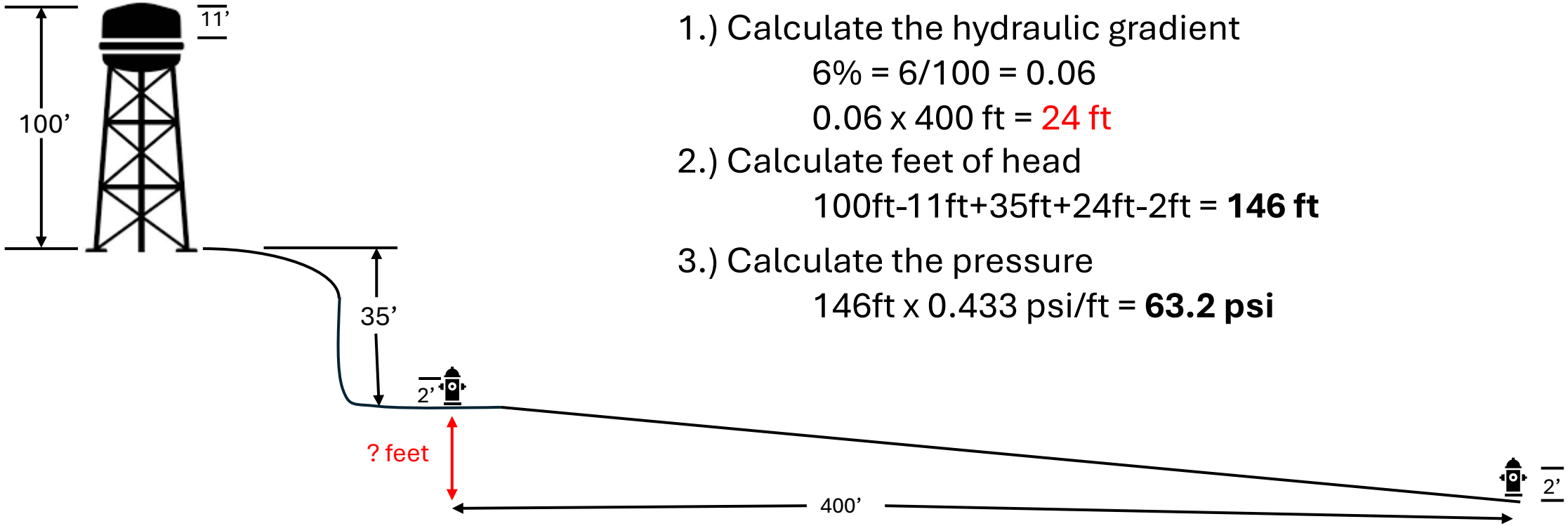
0.05 x 100 = **5%**



Hydraulics Example – Hydraulic Gradient

Problem Statement

Use the previous example of an elevated storage tank sits atop a hill. There is a water main leading from the first hydrant to a second hydrant that slopes downhill at a 6% grade 400 feet away. What is the water pressure at the hydrant nozzle if the nozzle is 2ft above ground level? (Assume static conditions—no flow or head loss)



1.) Calculate the hydraulic gradient

6% = 6/100 = 0.06

0.06 x 400 ft = 24 ft

2.) Calculate feet of head

100ft-11ft+35ft+24ft-2ft = **146 ft**

3.) Calculate the pressure

146ft x 0.433 psi/ft = **63.2 psi**

Flow Rate



- Water flows with a certain speed and velocity
- Velocity of flow changes with pipe diameter
- For a fixed rate of flow through pipes of different diameters, the velocity will be the greatest at the smallest diameter

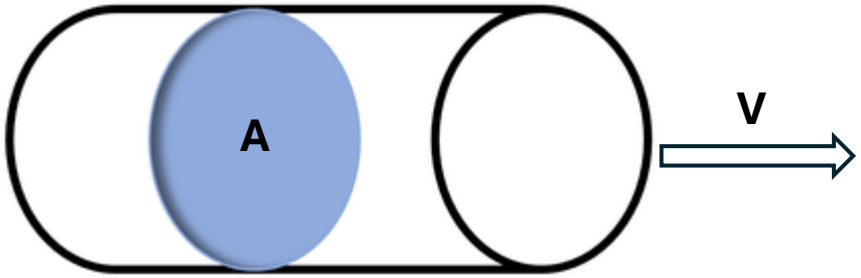
The Continuity Equation is

$Q = V \times A$

Q = Rate of flow (ft^3/s)

V = Velocity of flow (ft/s)

A = Cross-sectional area of pipe (ft^2)



Flow Rate [Q = V x A]

Example

Calculate velocity of water through 12-inch main when Q=3.0 million gal/day

1.) Convert Q to cubic ft/s

$$\rightarrow Q = \frac{3.0\ \text{M gal}}{1\text{day}} \text{x} \frac{1\ \text{day}}{86{,}400\text{s}} \text{x} \frac{1{,}000{,}000}{\text{M}} \text{x} \frac{1\text{ft}^3}{7.48\ \text{gal}} = 4.63\ \frac{\text{ft}^3}{\text{s}}$$

2.) Calculate A

$$\rightarrow A = \frac{\pi d^2}{4} = \frac{\pi(1\text{ft})^2}{4} = 0.785\ \text{ft}^2$$

3.)Rearrange equation and solve for V

$$\rightarrow \text{If } Q = V \text{ x } A, V = \frac{Q}{A}$$

$$\rightarrow V = \frac{4.63\frac{\text{ft}^3}{\text{s}}}{0.785\text{ft}^2} = \mathbf{5.9}\ \frac{\text{ft}}{\text{s}}$$



Poll Question #4

A well is pumping into a reservoir at 300 gpm while pumps are pumping out at 400 gpm. Which direction is the reservoir level going?

a) Up
b) Down
c) Stationary
d) Cannot determine from the information given

b) The level of the water is going down at a rate of 100 gpm.

Operator Applications

- **Monitoring and evaluating the system:** Regularly checking pressure gauges and flow meters to identify areas of significant head loss.
- **Maintaining infrastructure:** Conducting routine maintenance like cleaning pipes, repairing leaks, and replacing old pipes to reduce friction and improve flow.
- **Optimizing system operations:** Adjusting pumping schedules, flow rates, and valve positions to minimize turbulence and friction.
- **Identifying and addressing bottlenecks:** Identifying and addressing areas where fittings, bends, or changes in pipe diameter contribute to higher head loss.
- **Implementing pressure management strategies:** Using pressure regulators or managing pressure zones to ensure optimal pressure across the network.

Review of Key Formulas/Conversions

- **Area (circle):** $A = \pi \times r^2$
- **Volume (cylinder):** $V = \pi \times r^2 \times h$
- 8.34 lbs/gallon
- 7.48 gallons/ft^3
- 62.4 lbs/ ft^3
- **Continuity:** $Q = V \times A$
- **Head conversion:** 1psi = 2.31 ft, 0.433 psi = 1 foot
- **Hazen-Williams** chart and/or spreadsheet for head loss



Thank you for participating

Please share one thing you enjoyed learning about today in the chat.



Thank you for attending!

Great Lakes Environmental Infrastructure Center

https://gleic.org/

National EFC Network

www.efcnetwork.org

Daryl Gotham, P.E. | djgotham@mtu.edu |

