33.11 $80gpm$ **of** $60°F$ **water is pumped from 100 ft below the surface of a lake to a storage tank 100 ft above ground through 400 ft of 3 inch nominal schedule 40 welded steel pipe. The piping run contains four 90 degree elbows and a globe valve. The storage tank is at atmospheric pressure. What is the required hydraulic horsepower for this application?**

A. $3hp$

B. $6hp$

C. $7hp$

D. $10hp$

Write the form of the Bernoulli Equation suited for pumping applications.

$$h_A = \frac{P_2 - P_1}{\gamma} + \frac{v_2^2 - v_1^2}{2g} + z_2 - z_1 + h_f$$

For the static pressure term, observe that the lake and the open storage tank are both exposed to atmospheric pressure, so the only difference in static pressure is the hydrostatic pressure associated with the height of the water column comprising the lake. Since the lake is $100ft$ deep and the medium is liquid water, it is permissible to skip the calculation using specific weight and go immediately to length units, as below:

$$\frac{P_2}{\gamma} = 1atm$$

$$\frac{P_2}{\gamma} = 100ft\,H_2O + 1atm$$

$$\frac{P_2 - P_1}{\gamma} = (1atm) - (100ft\,H_2O + 1atm) = -100ft\,H_2O$$

The velocity of water in the lake and the storage tank is negligible.

$$v_1 = v_2 = 0$$

Find the difference in height between the bottom of the lake and the tank.

$$\Delta z = z_2 - z_1 = (100ft) - (-100ft) = 200ft$$

Friction losses include both major losses as handled by the Darcy-Weisbach Equation and minor losses to address the fittings.

$$h_f = h_{f,major} + h_{f,minor} = \frac{fLv^2}{2gD} + K\frac{v^2}{2g} = \left(\frac{fL}{D} + K\right)\left(\frac{v^2}{2g}\right)$$

Find the Reynolds Number and relative roughness in order to determine the friction factor using the Moody Diagram. Look up the Kinematic Viscosity using the Properties of Water table. Get the diameter from the Steel Pipe Friction Tables.

$$Q = 80gpm$$

$$D = 3.068in\left(\frac{1ft}{12in}\right) = 0.2557ft$$

$$v = 3.47\frac{ft}{s}$$

$$Re = \frac{vD}{\nu} = \frac{\left(3.47\frac{ft}{s}\right)(.2557ft)}{1.217\times10^{-5}\frac{ft^2}{s}} \approx 73,000$$

$$\frac{\epsilon}{D} = \frac{.0002ft}{.2557ft} \approx 0.0008$$

$$f = f(Re, \frac{\epsilon}{D}) \approx 0.0225$$

The length of pipe to be used for the major losses is $400ft$. This excludes Fittings Losses, which can be looked up using the phrase Welded Pipe Fittings. K factors summarized below.

Welded Pipe Fittings	K-Factor	Total
(4) 90° elbow	0.34	1.36
(1) globe valves	7	7

The total K factor is $K = 8.36$. Calculate the total friction losses.

$$h_f = \left(\frac{fL}{D} + K\right)\left(\frac{v^2}{2g}\right)$$

$$h_f = \left(\frac{(.0225)(400ft)}{.2557ft} + 8.36\right)\left(\frac{\left(3.47\frac{ft}{s}\right)^2}{2\left(32.2\frac{ft}{s^2}\right)}\right) = 8.1ft$$

Solve for total head added by the pump, h_A.

$$h_A = \frac{P_2 - P_1}{\gamma} + \frac{v_2^2 - v_1^2}{2g} + z_2 - z_1 + h_f$$

$$h_A = -100ft + 200ft + 8.1ft = 108.1ft$$

It is now possible to calculate the required hydraulic horsepower, *whp*, which depends on the volume flow rate and the total head added by the pump.

$$whp = \frac{Q_{[gpm]}\Delta h_{[ft]}}{3960} = \frac{(80)(108.1)}{3960} = 2.2hp$$

Answer A