Welcome to the MFD **Short Course Engineering** Event.

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Our topic today is a set of some of the tools used by the hydraulic engineer in the planning, design, and analysis of water-resource projects. The hydraulic engineering that we will discuss is a part of civil engineering, and pertinent water-resource projects include: drinking water distributions systems, storm drainage systems, sanitary sewer systems, irrigation systems, canals, rivers and dams.

The **salmon colored sheet** shows symbols, formulas, conversion factors, constants, and definitions to be used today. Notice that you are to use the foot-pound-second system of units (USCS). This means that: lengths in other units (e.g. miles, inches, meters) must be converted to feet; volumes (e.g. gallons) must be converted to cubic feet; time (e.g. hours, minutes, days) must be converted to seconds. This also means that: volume flow in gpm (gallons per minute) must be converted to ft^3 per second; and pressure in psi (pounds per square inch) must be converted to psf (pounds per square foot). Conversion factors and some examples of conversions are shown on the salmon sheet.

We're confining our discussion today to the study flow of water in two types of conduits: (1) an open channel with a rectangular cross-section (with atmospheric pressure or zero gage pressure at the surface); and (2) a pipe of circular-cross section. For the pipe, however, we shall consider two types of flow: pipes flowing under pressure with the flow filling the cross-section of the pipe; and pipes flowing only partially full where the pressure at the surface is atmospheric or zero gage. Partial full flow in a pipe is then a type of open channel flow.

Types of questions to be answered include:

- How much water will a pipe or channel carry?
- What slope do we need to make a channel able to carry a given flow?
- What cross-sectional area is needed to carry a given flow (how wide or deep or what diameter)?
- What is the velocity of the flow?
- How much loss in energy do we need to expect for a given flow? (This can be used to determine pumping needs or ,in gravity flow, the grade needed in the conduit.)
- What happens to the velocity of the water if the cross-sectional area of the flow changes?
- What are the depth and energy consequences when a hydraulic jump occurs in an open channel.

The salmon colored sheet gives five main sets of equations to be used in the problems, along with some definitions and unit conversion examples.

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Equation #1 Equation of Continuity

$$Q = A_1 V_1 = A_2 V_2 = \text{ constant}$$

This equation results from the principle of conservation of mass. For study flow, the mass (and in our case the volume) of fluid passing all sections in a stream of fluid per unit of time is the same. A_1 and V_1 are respectively the cross-sectional area and average velocity at section 1, with similar terms for section 2.

Continuity

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Equation #2 Energy Equation (Bernoulli Theorem)

$$\frac{p_1}{w} + \frac{{v_1}^2}{2g} + z_1 - h_L = \frac{p_2}{w} + \frac{{v_2}^2}{2g} + z_2$$

The energy equation results from application of the principle of conservation of energy to fluid flow. The energy possessed by a flowing fluid consists of energies due to pressure, velocity, and position. In the direction of flow, the energy principle can be summarized by the general equation:

energy at section 1	-	energy lost	=	energy at section 2

The units used are feet of fluid (this can be interpreted as foot-pounds per pound).

The first term on each side of the equation, p_i/w , is known as the *pressure head* and represents internal energy due to pressure.

The second terms, $v_i^2/2g$, is known as the *velocity head* and is a measure of the kinetic energy due to the velocity.

The third terms, z_i , is known as the *elevation head* or *static head* and is the energy due to the elevation of the fluid.

The final term on the left side of the energy equation, h_L , represents the energy lost as the fluid flows from section 1 to section 2.

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Equation #3 Manning formula for open channel flow (for use only in foot-pound-second system!)

$$Q = AV = A(\frac{1.486}{n})R^{2/3}S^{1/2}$$

This is an empirical formula that gives the flow, Q, in $ft^3/_{sec}$. This form of the equation can only be used in the foot-pound-second system.
Notice that another form of this equation (dividing through by the area A) is:

$$Q/A = V = (\frac{1.486}{n})R^{2/3}S^{1/2}$$

S is the slope or grade of the channel (in feet per feet) and R is known as the **hydraulic radius** and is the cross-sectional area of flow divided by the wetted perimeter. (Intuitively, the larger the cross-sectional area of flow, the greater the flow expected, and the larger the wetted perimeter of flow the more the flow will be impeded. Hence the ratio of $Area/_{wetted\ perimeter}$.)

Manning Formula

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Equation #4 Darcy-Weisbach formula (head loss for flow in pipes under pressure)

$$h_L = f\left(\frac{L}{d}\right)\left(\frac{V^2}{2g}\right)$$

This is the basis for evaluating lost head (energy) for fluid flow in pipes and conduits. The equation is :

lost head = friction factor f x $\frac{length\ L}{diameter\ d}$ x velocity head $\frac{V^2}{2g}$

Darcy-Weisbach

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Equations #5 Hydraulic Jump

Hydraulic jump occurs, in an open channel with rectangular cross-section, when a supercritical flow (shallow depth, high velocity) changes to a subcritical flow (greater depth, lower velocity). In such cases, the elevation of the liquid surface increases suddenly in the direction of flow.

For a constant flow in a rectangular channel, the depth upstream, y_1, the depth downstream, y_2, and the flow per unit width of channel, q, ($q = \frac{Q}{b}$, where b is the channel width) are related as follows:

$$\frac{q^2}{g} = y_1 y_2 \left(\frac{y_1 + y_2}{2} \right)$$

Specific energy (E) is defined as the energy per unit weight (ft lb/lb) relative to the bottom of the channel or

$$E \ = \ \text{depth + velocity head} \ = \ y + \frac{V^2}{2g}$$

The energy lost in a hydraulic jump or loss of head is

$$\text{loss of head} \ = \ E_1 - E_2$$

Where E_1 is the specific energy upstream and E_2 is the specific energy downstream.