

# Open Channel Flow

An Introduction  
 Joseph Orlins  
 Rowan University

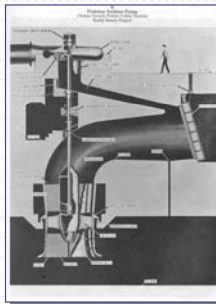
# Where are we?

- ◆ Closed Conduit Flow
  - Headlosses
  - Pumps & Turbines
- ◆ Hydrology
- ◆ Open Channel Flow
  - Steady Uniform Flow
  - Non-Steady & Non-Uniform Flows
  - Flood Routing



# Closed Conduit Flow

- ◆ Headlosses
  - Friction
  - Transitions
- ◆ Pumps
  - Pump curves
  - System Curves
- ◆ Turbines



# Hydrology

- ◆ Rainfall / runoff
  - Losses
  - Unit hydrographs
- ◆ Regressions, statistics
  - Recurrence intervals
- ◆ Simulation programs
  - TR-55
  - HEC-HMS, HEC-1

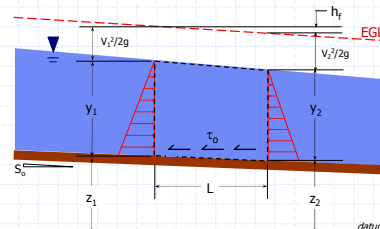


# Open Channel Flow

- ◆ Driven by gravity
- ◆ Depth usually unknown
  - Function of discharge, geometry
- ◆ Flow boundaries change with depth



# Force & Energy Balance



$$\frac{V_1^2}{2g} + z_1 + y_1 = \frac{V_2^2}{2g} + z_2 + y_2 + h_f \quad (1)$$

## Simplifying Assumptions

- ◆ If flow is *steady*:
  - Depth does not change with time
- ◆ If flow is *uniform*:
  - Depth does not change with distance
  - Therefore  $y_1 = y_2 = y$  and  $V_1 = V_2 = V$
- ◆ Energy Equation becomes:

$$h_f = (z_1 - z_2) = S_o \cdot L \quad (2)$$

## Headloss in a Channel

- ◆ Recall: Darcy-Weisbach Equation
  - For circular pipes:

$$h_f = \left( \frac{f \cdot L}{D} \right) \frac{V^2}{2g} \quad (3)$$

- For non-circular conduits:

$$h_f = \left( \frac{f \cdot L}{4R_h} \right) \frac{V^2}{2g}; \quad R_h = \frac{A}{P} \quad (4)$$

## Headloss in a Channel

- ◆ Substitute (4) into (2):

$$h_f = S_o \cdot L = \left( \frac{f \cdot L}{4R_h} \right) \frac{V^2}{2g} \quad (5)$$

- ◆ Solve for V:

$$V = \sqrt{\frac{4S_o R_h 2g}{f}} \quad (6)$$

$$V = \sqrt{\frac{8g}{f} \cdot R_h^{3/2} \cdot S_o^{1/2}} \quad (7)$$

## Chezy Equation

- ◆ For a given channel shape and roughness:

$$\sqrt{\frac{8g}{f}} = \text{Constant} = C \quad (8)$$

- ◆ This leads to the *Chezy Equation*

- Named after Antoine Chezy, who did experiments in the River Seine in 1760s

$$V = C \cdot (R_h S_o)^{1/2} \quad (9)$$

## Chezy Roughness Coefficient

- ◆ Varies with channel size & bed material

Channel Type	C (USC)	C (SI)
Small & rough	60 ft <sup>0.5</sup> /s	30 m <sup>0.5</sup> /s
Large & smooth	160 ft <sup>0.5</sup> /s	90 m <sup>0.5</sup> /s

## Manning's Analysis

- ◆ Robert Manning (Irish engineer, 1880s)

- Found C increases with channel size:

$$C \approx C_m \frac{R_h^{1/6}}{n} \quad (10)$$

- Where n = a roughness coefficient

- Kutter's n, Manning's n, Gauckler-Manning coefficient

- $C_m$  = a unit conversion factor

- 1.0 m<sup>1/3</sup>/s for SI
- 1.49 ft<sup>1/3</sup>/s for USC

## Manning's Equation

- ◆ Substituting (10) into (9) leads to the widely-used *Manning Equation*:

$$V = \frac{C_m}{n} \cdot R_h^{2/3} \cdot S_o^{1/2} \quad (11)$$

$$Q = \frac{C_m}{n} \cdot A \cdot R_h^{2/3} \cdot S_o^{1/2} \quad (12)$$

## Manning's Roughness, n

- ◆ "Manning's n" is a function of channel roughness, and varies widely!

Channel Type or Material	n (typical)
Clean, straight, minor stream	0.030
Windy, many weeds	0.100
Floodplains, dense trees	0.150
Concrete ( <i>e.g.</i> , culverts)	0.012

## How to get "n" ?

- ◆ Field studies – expensive!
- ◆ References
  - USGS, *Roughness Characteristics of Natural Channels*
  - Chow, *Open Channel Flow*
  - Online
- ◆ Estimate based on roughness height

## References with measured "n"



Columbia River at Vernita Bar – n = 0.024

## Estimating Manning's n

- ◆ Williamson (1950's)
  - Investigated relationship between D-W friction factor and channel properties:

$$f \cong 0.113 \left( \frac{k_s}{R_h} \right)^{1/4} \quad (13)$$

- Leads to expression between characteristic stone or gravel size, d and n:

$$n \cong 0.031 \cdot d^{1/6} \quad (14)$$

## Where We're Going

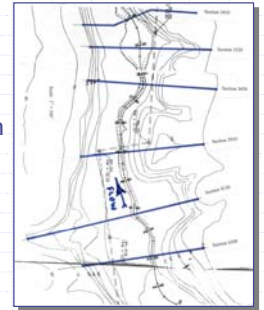
- ◆ Application of Manning's Equation
  - Steady, uniform flow
  - Gradually varied flow
- ◆ Water Surface Profiles
  - Step method
  - Numerical Models – e.g. HEC-RAS

## Where We're Going

- ◆ Application of Manning's Equation
  - Steady, uniform flow
  - Gradually varied flow
- ◆ Water Surface Profiles
  - Step method
  - Numerical Models – e.g. HEC-RAS

## Water Surface Profiles

- Determine WSEL, velocity for arbitrary channel shapes
- Floodplain delineation
- Effects of bridges & culverts



## Water Surface Profiles

