Water Measurement

Units

- Volume
  - Quantity of water; Water “at rest”
  - Gallon, cubic foot, etc.
  - $V = A\ d$ (units: acre-inch, acre-foot, hectare-meter etc.)
- Depth
  - Rainfall measured as depth; Useful for irrigation applications as well
  - Inch, foot, millimeter, centimeter, etc.
  - $D = V / A$ (units: usually inches or millimeters)
- Flow
  - Volume of water per unit time; Water “in motion”
  - Gallons per minute, cubic feet per second, acre-inches per day, liters per second, cubic meters per second etc.
  - $Q = V / t$ (units must be consistent)

Table 3.1. Conversion factors used in water measurement.

English System	Metric System
Volume Units	
1 gallon = 8.33 pounds	1 cubic foot = 0.02832 cubic meters
1 cubic foot = 7.48 gallons	1 liter = 0.264 gallons
1 acre-inch = 3,630 cubic feet	1 gallon = 3.79 liters
1 acre-inch = 27,154 gallons	1 cubic meter = 264.2 gallons
1 acre-foot = 43,560 cubic feet	1 cm^3 = 1mL
1 acre-foot = 325,851 gallons	
Flow Units	
1 cfs = 449 gpm (450 for practical purposes)	1 cfs = 0.02832 cms
1 cfs = 1 acre-inch/hr	1 cms = 35.31 cfs
452 gpm (450 for practical purposes) = 1 acre-inch/hr	1 gpm = 0.06309 L/s
1 gpm = 0.00223 cfs	1 L/s = 15.85 gpm
1 gpm = 0.00221 acre-inches/h	1 gal/h = 63.1 mL/s
Length Units	
1 mile = 5280 feet	1 foot = 0.3048 meters
1 rod = 16.5 feet	1 meter = 3.281 feet
Area Units	
1 acre = 43,560 square feet	1 acre = 0.4047 hectare
	1 hectare (ha) = 2.471 acres

cfs = cubic feet per second   gpm = gallons per minute
cms = cubic meters per second   L/s = liters per second

- Volume balance (Qt=Ad)
  - V = Q t and V = A d, so Q t = A d
  - (Flow rate) x (time) = (area) x (depth)
  - Knowing any of the three factors, you can solve for the fourth
  - Units must be consistent (conversion constant, k_v, to balance units: $Qt=k_vAd$)

English Units Conversion for Irrigation Flows

Values of conversion constant, k_v, based on combinations of units.

Q, Flow Rate Units	t, Time Units	A, Units for Area: Acres — d, Depth Units: inches	Acres — feet	Square Feet — d, Depth Units: inches	Square Feet — feet
gallons/minute (gpm)	minutes	27,150	325,830	0.62	7.48
	hours	453	5,430	0.0104	0.125
	days	18.9	226	0.000433	0.00519
cubic feet/second (ft^3/sec) (cfs)	minutes	60.5	726	0.00139	0.0167
	hours	1.01	12.1	0.0000231	0.000278
	days	0.042	0.50	0.000000965	0.0000116

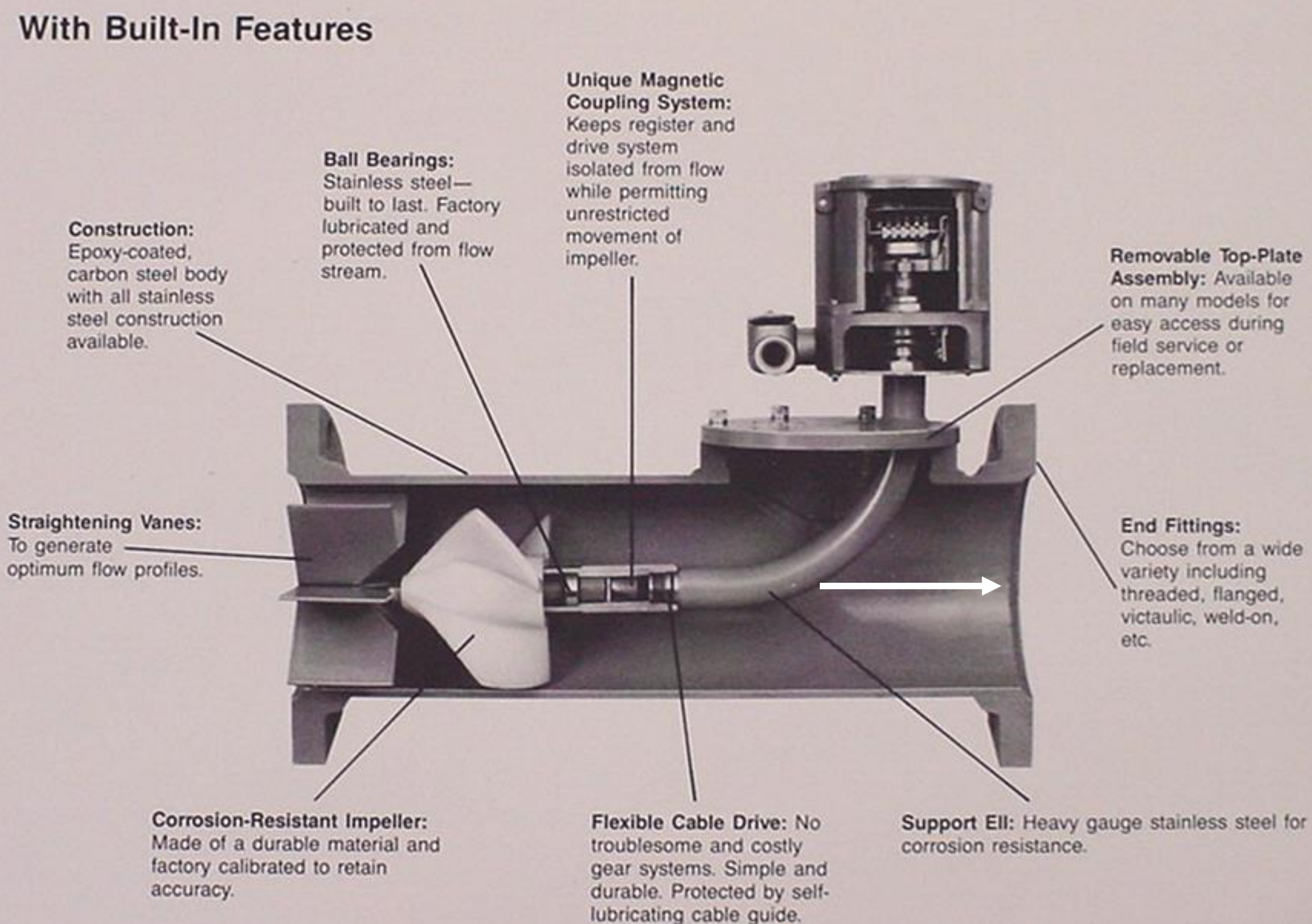
Flow Measurement

- "Good water management begins with water measurement"
- Basic principle
  - $Q = V_m A_f$
  - Q = flow rate in a pipeline or channel
  - V_m = mean or average velocity of flow in the pipeline or channel
  - A_f = cross-sectional area of flow
- Velocity is not constant throughout the cross-section

Flow Measurement in Pipelines

- Mechanical meters
- Propeller senses velocity; Converted to flow rate via gear ratios
  - Straight section of pipe is best (avoid turbulence); Pipe must be full
- Pressure differential methods
  - Difference in pressure is directly related to velocity (fundamental energy relationship in hydraulics)
  - Pitot tubes, Venturi meters, orifice methods
- Ultrasonic methods
  - Non-intrusive (transducers clamped on the outside of the pipe)

Typical Propeller Flow Meter



A “Bolt-On Saddle” Propeller Flow Meter

Options for Propeller Meter Read-Outs

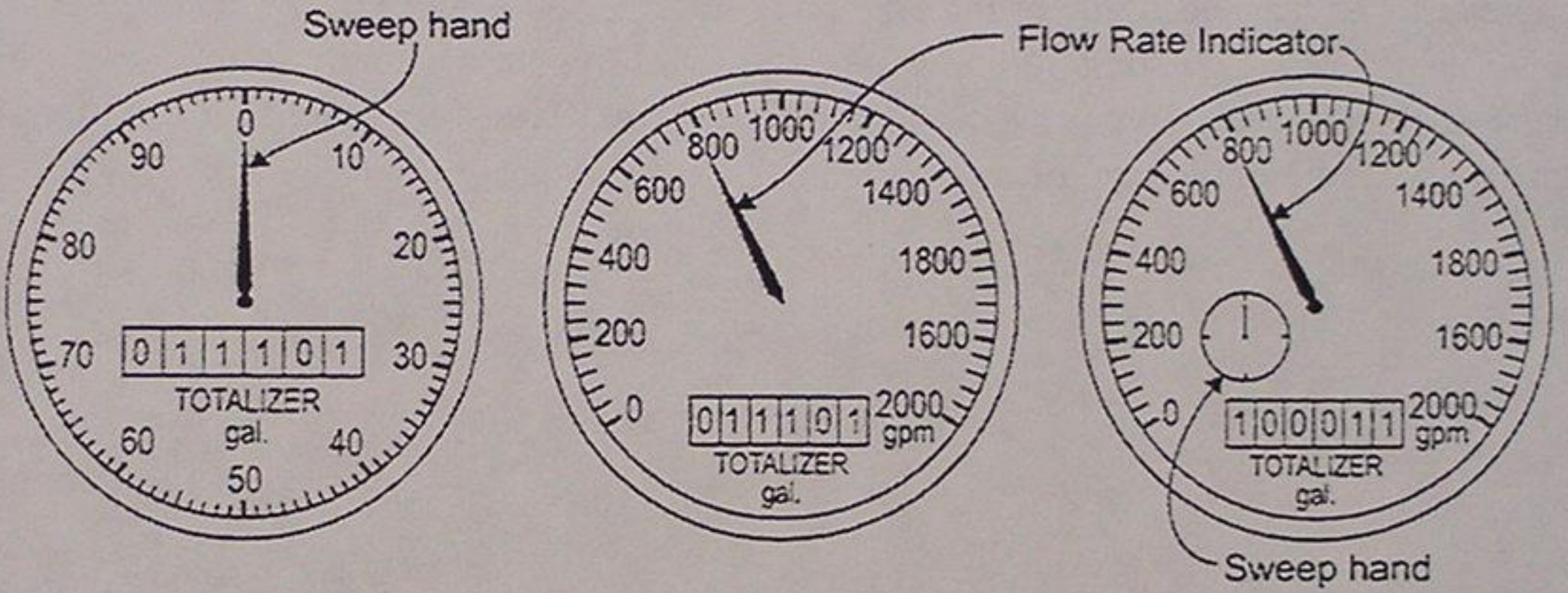


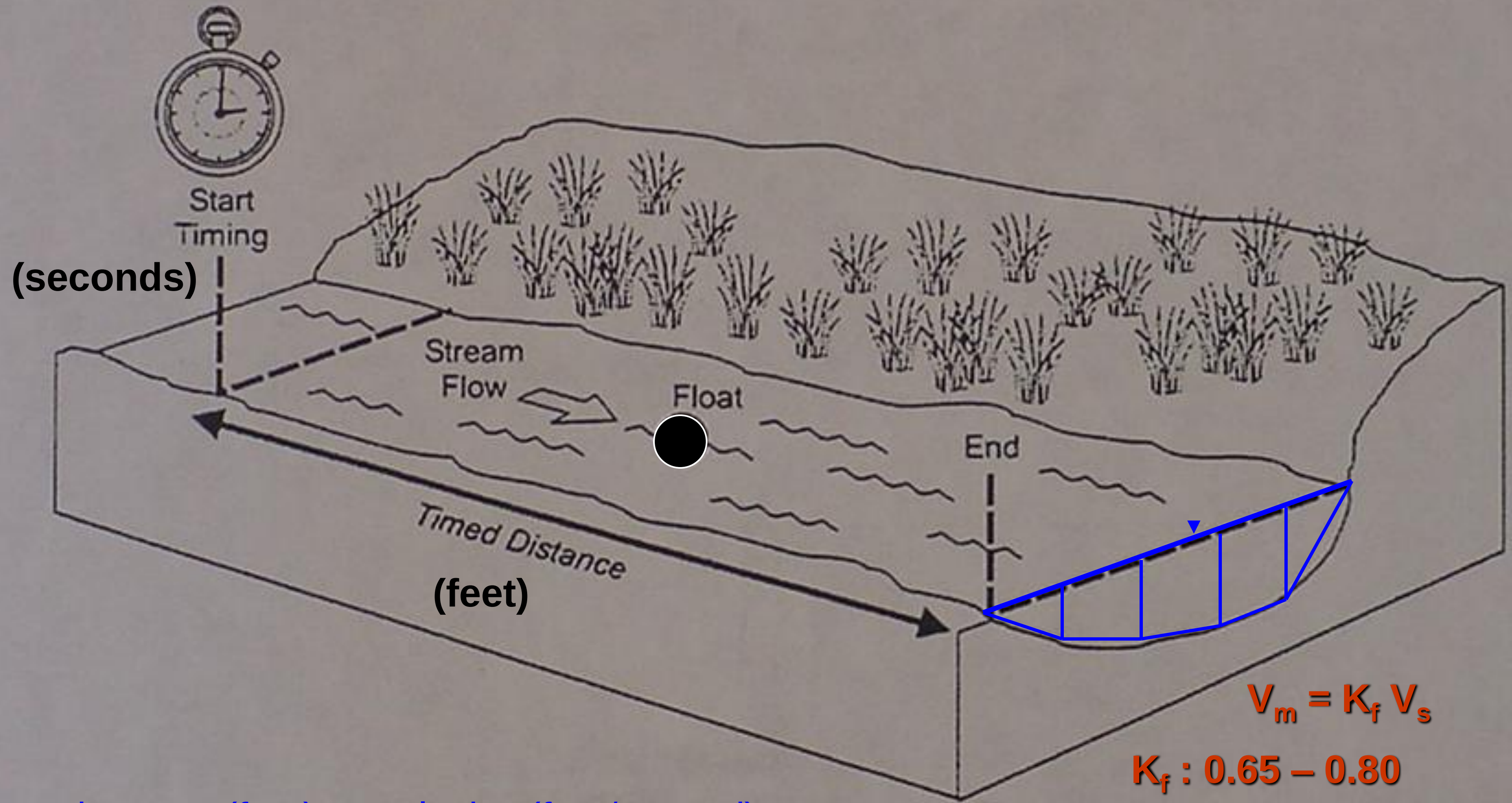
Figure 3.5. Options available for registers on a propeller meter.


072552
U.S.GALLONS
06-07

Open Channels

- Different from pipe flow because water surface is at atmospheric pressure
- Velocity methods ($Q = V_m A_f$)
  - Current meter (measure velocity at a number of points in the cross-section using a calibrated meter)
  - Float method ($V_m = K_f V_s$ where V_s is surface velocity measured with a float, and K_f is a velocity correction factor ranging from 0.65 to 0.8)

Estimating Surface Velocity, V_s, of a Straight Stream with a Float and Stopwatch



$$V_m = K_f V_s$$

K_f : 0.65 – 0.80

K_f = 0.65 (if d ≤ 1 ft)

K_f = 0.80 (if d > 20 ft)

$$\frac{\text{Distance, (feet)}}{\text{Time, (seconds)}} = \text{Velocity, (feet/second)}$$

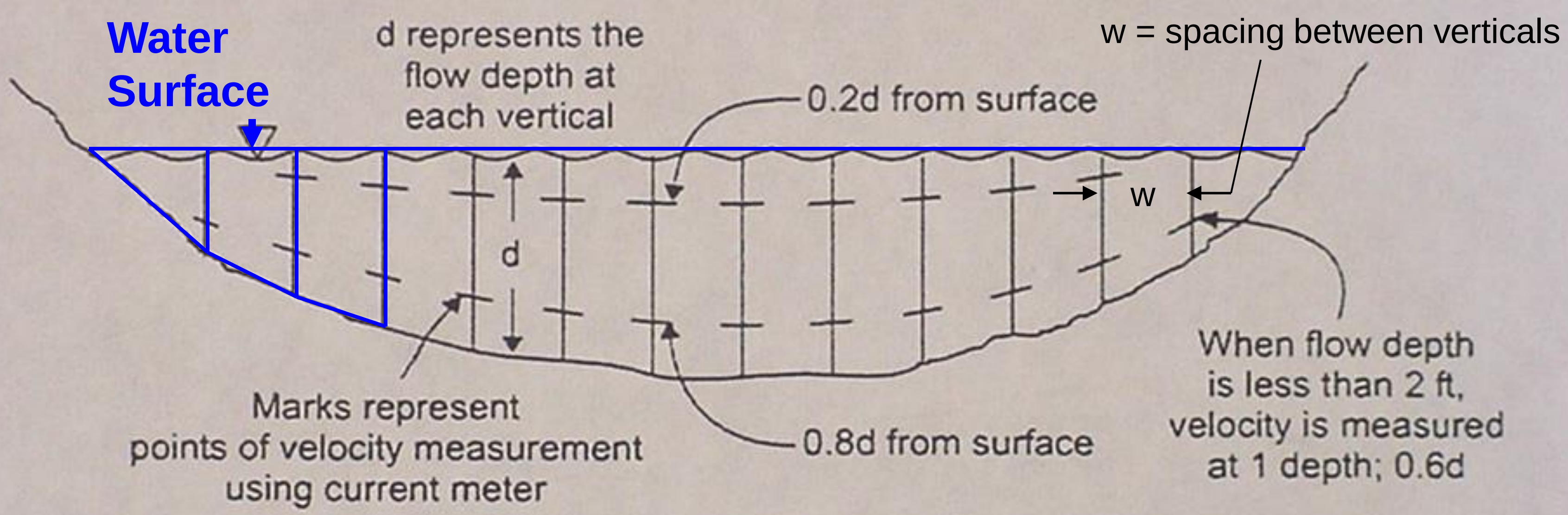
Estimating the Cross-Sectional Area of Flow, A_f

Dividing the Streambed into Triangles, Rectangles and Trapezoids

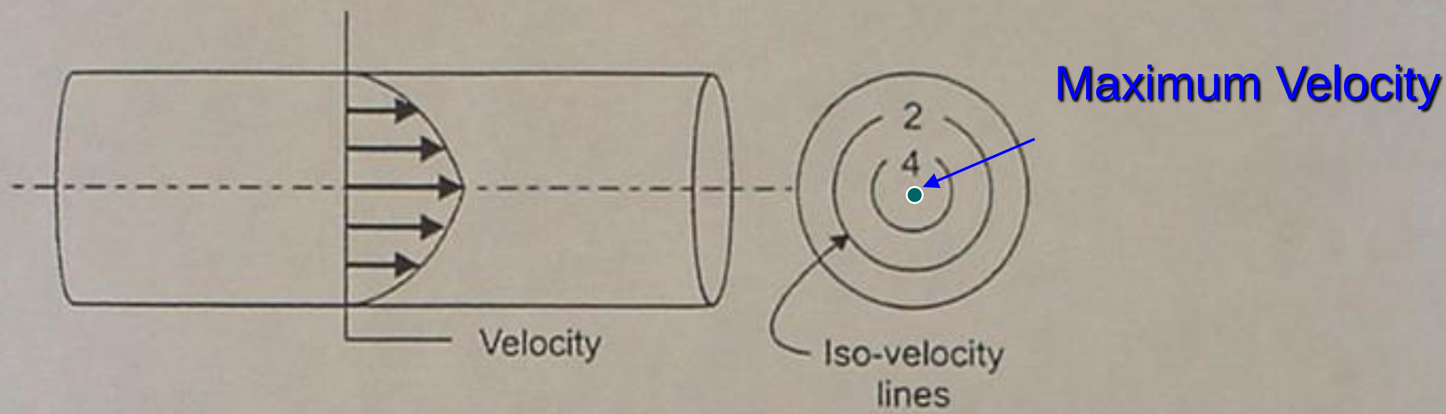
Rectangle Area $A_r = d\ w$

Trapezoid Area, $A_{tz} = ½\ (d_i + d_{i+1})\ w$

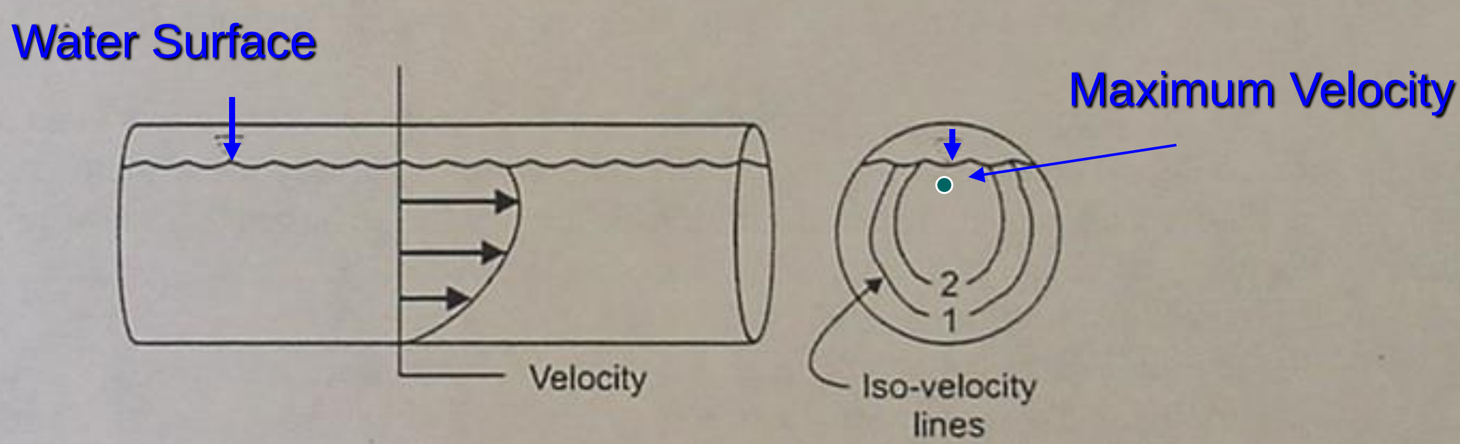
Triangle Area, $A_{tr} = ½\ d\ w$



Velocity Profiles



Closed Pipeline Flow

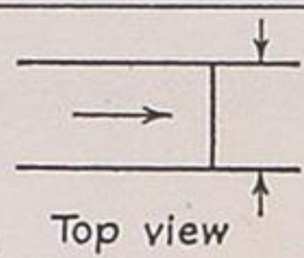
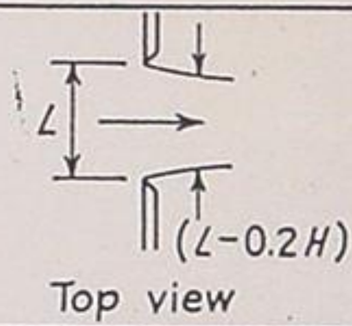
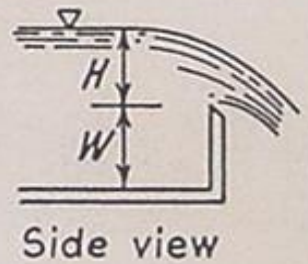
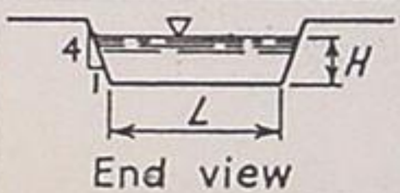
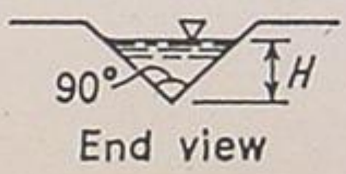


Open Channel Flow

Open Channels Contd…

- Pressure differential methods
  - Contract the flow through a metering section, and measure the depth of water upstream of the metering section
  - Use a calibrated depth-flow relationship
  - Weirs -- rectangular, trapezoidal, triangular
  - Flumes -- many types
  - Submerged orifices

Weir Shapes and Formulas

Measuring Device (all sharp crested)	Views (H and L are in ft; Q is in ft³/sec)		Formula
Rectangular Weir (without contraction)			$Q = 3.33 L H^{3/2}$
Rectangular Weir (with contraction)			$Q = 3.33 (L - 0.2H) H^{3/2}$
Trapezoidal Weir			$Q = 3.37 L H^{3/2}$
90° Triangular Weir			$Q = 2.49 H^{5/2}$