FUNDAMENTALS OF HYDRAULIC ENGINEERING SYSTEMS - 5TH Edition

Houghtalen, Akan, and Hwang

Pearson/Prentice Hall

Chapter 6

Water Flow in Open Channels

Central Arizona Project (USA)

(336 miles of canals)

Rf.➔http://www.usbr.gov/lc/images/gallery/CAP/index.html

Water Flow in Open Channels

Chapter 6 - STUDENT OUTCOMES

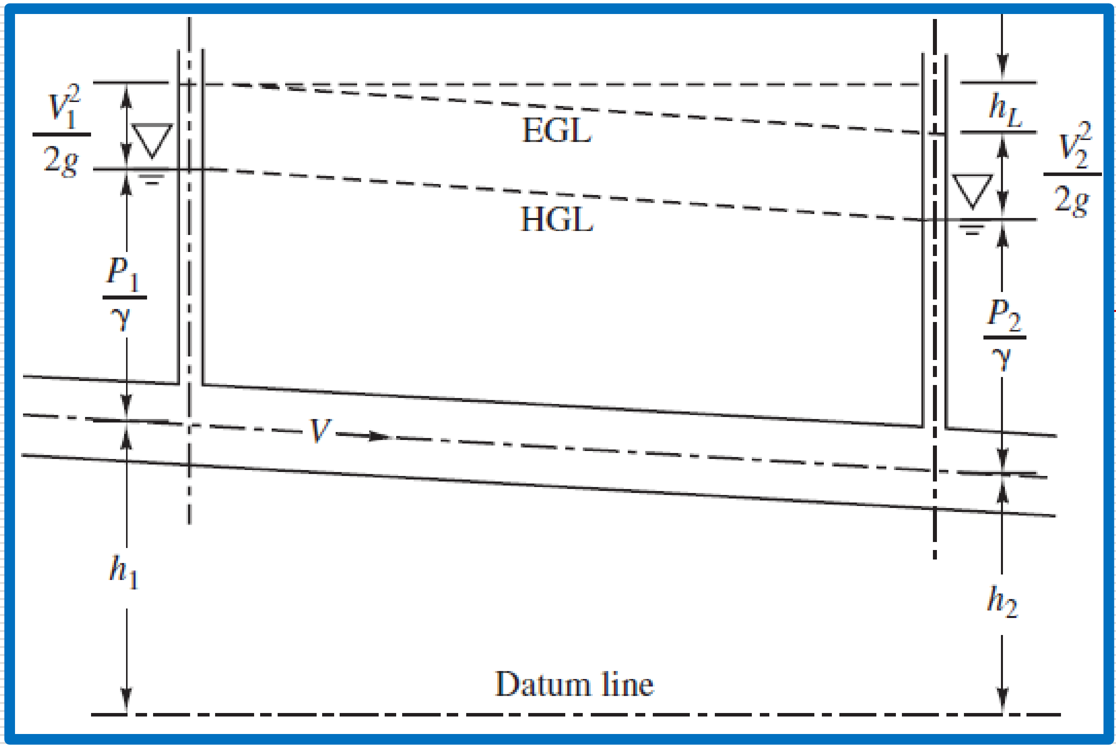
1. Describe the **characteristics** of open-channel flow and its various **classifications**.
2. Define **uniform flow, normal depth**, and **hydraulic efficiency** in open channels.
3. Explain open-channel flow **energy principles**, **hydraulic jumps**, and **gradually varied flow**.
4. Understand the **classification** and **computation procedures** for gradually varied flow.
5. **Calculate solutions to various problems that involve these open-channel flow concepts.**

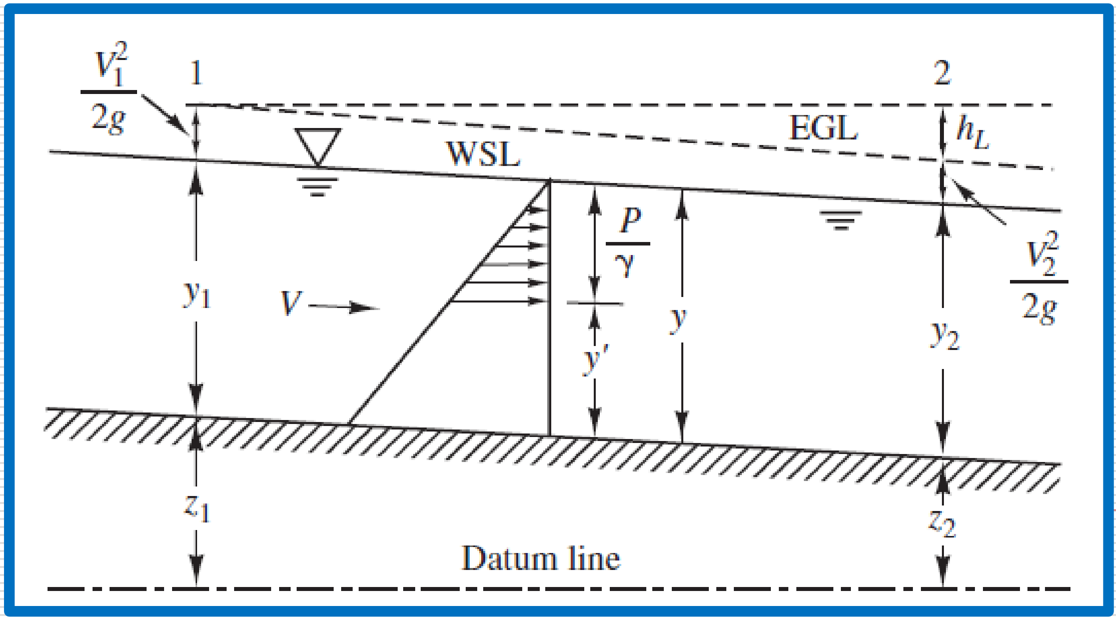
Water Flow in Open Channels

(Introduction and Basic Concepts)

When rainfall exceeds losses, runoff begins to move over the land surface and through a watershed (see Chap 11) as open channel flow. Engineers model these flow processes and design open channels and pipes to convey the storm water to streams, rivers, lakes, etc. An understanding of open channel flow phenomena is critical to proper design. Answer the following:

1. **"Energy"** differences are often the driving force behind pipe flow. Open channel flow is always driven by ____________
2. Is open channel flow possible in storm water pipes? Explain.
3. Define the three forms of energy (head) in pipe flow and the three forms of energy (head) in open channel flow.





Flow Comparisons

(Pipe Flow vs. Open Channel Flow)

Questions:

Identify similarities.

Identify differences.

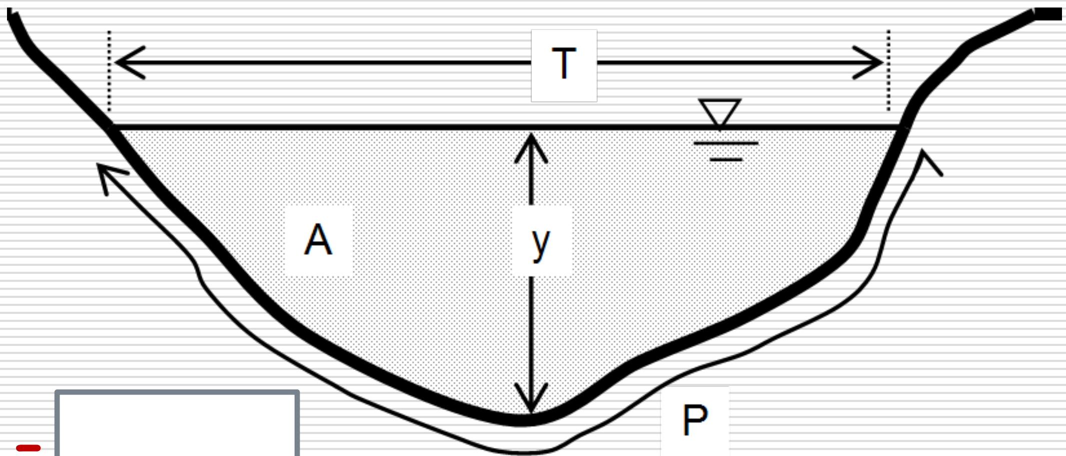
Define HGL & EGL.

Where is the HGL in open channel flow?

Open Channel Flow Characteristics

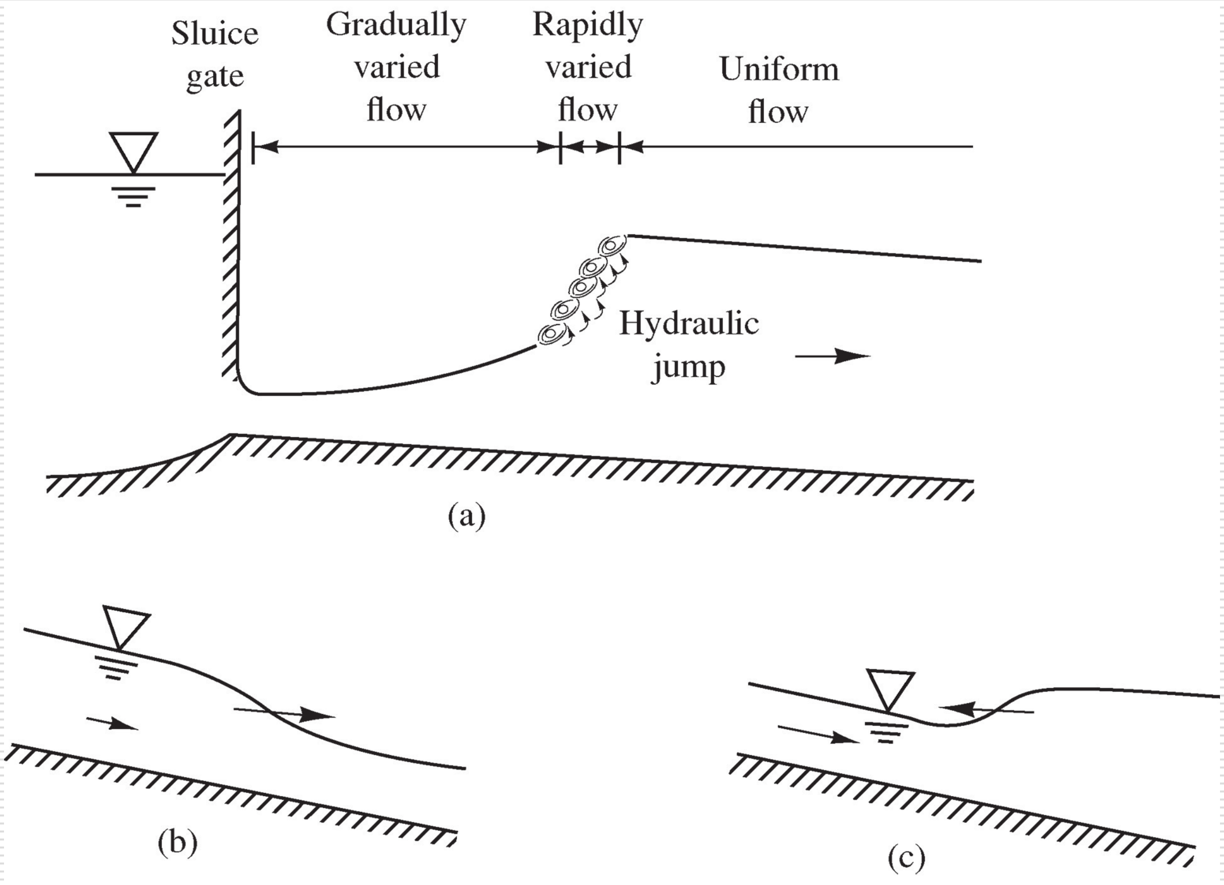
(Basic Geometric & Hydraulic Definitions)

Given a flow rate Q through an open channel with A, y, T, and P defining certain channel properties. Define these variables (including units) and provide equations for the following:



- Average velocity = **V** =
- Hydraulic (weighted) depth = **D** =
- Hydraulic radius = **R_h** =

Figure 6.2 Classifications of open-channel flow: (a) gradually varied flow (GVF), rapidly varied flow (RVF), and uniform flow (UF); (b) unsteady varied flow; (c) unsteady varied flow



Open Channel Flow Classifications

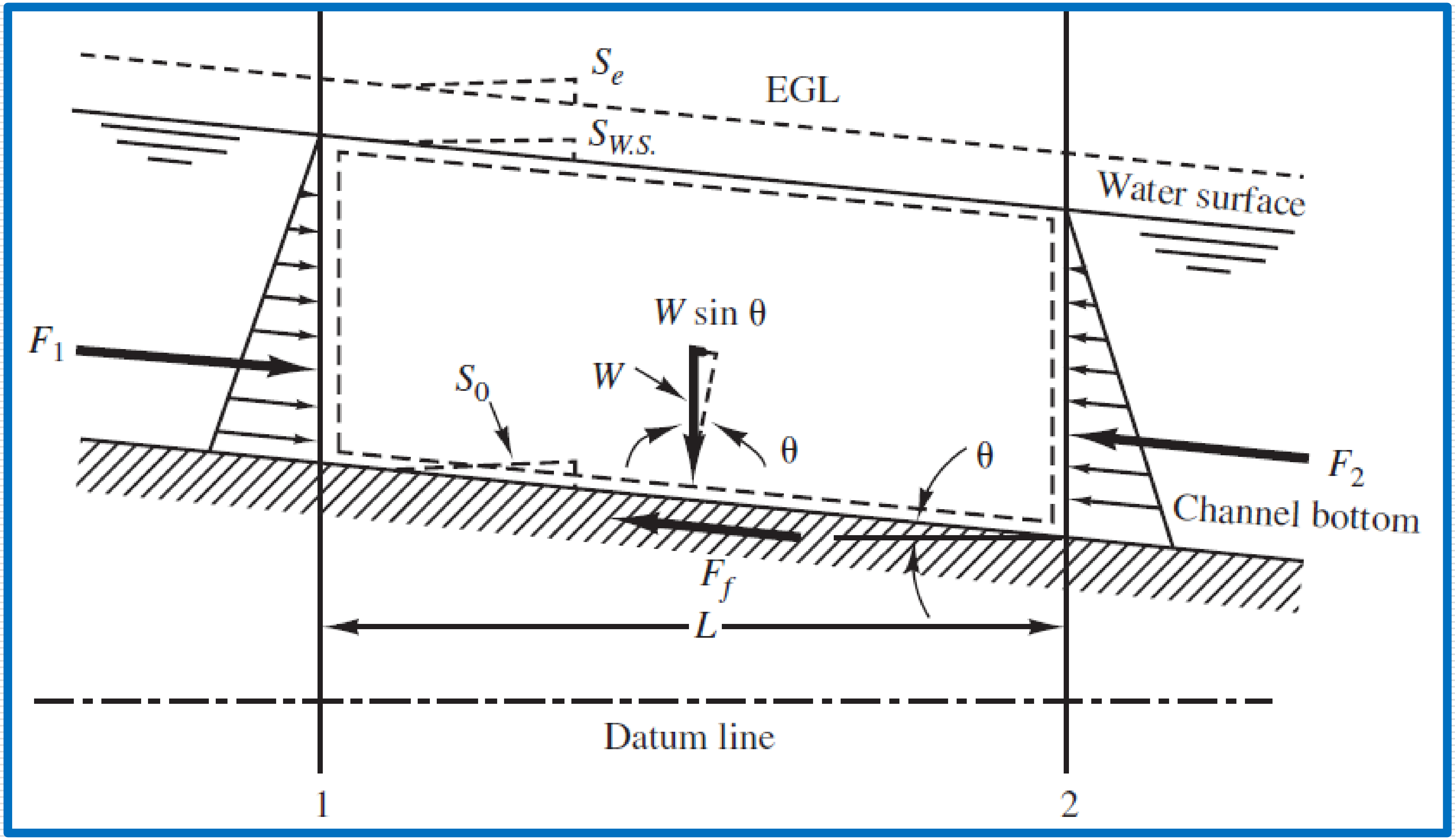
(Space and Time Criteria)

Open channel flow is classified as either **unsteady** or **steady** ("Q" and "D" at a given location remain constant with respect to time). Also the flow is either **uniform** ("D" remains constant up and down a channel at a given time), **gradually varied**, or **rapidly varied**. Classify the following:

- flow on a roof during a uniform intensity R/F:
- flow in a street gutter in a time varying R/F:
- constant flow in a prismatic channel (cross-sectional area and bottom slope are constant):
- flow in a river (during a storm):
- flow in a river (not during a storm):

Uniform Flow in Open Channels

(Manning's Eq'n – Free Body Diagram, FBD)



Uniform Flow in Open Channels

(Development of Manning's Equation)

Uniform flow is defined by:

- Constant Q, A, D, V distribution
- $S_o = S_{ws} = S_e$ (see previous slide)
- No acceleration or deceleration

Often occurs in prismatic channels →

Based on FBD on the previous slide:

- What forces produce flow?
- What forces resist flow?
- What forces are balanced? Why?
- What is the general eq'n for F_f?

Note: A_c = water-channel contact area, not x-sectional area

The Manning Equation
(Theory, Background, and Development)

A force balance in the direction of flow yields:

$$F_1 + W(\sin\theta) - F_2 - F_f = 0$$

Noting that $F_1 = F_2$ and substituting based on open channel & hydraulic properties (definition sketch – previous slide):

$W(\sin\theta)$ = $\quad$ $F_f = \tau A_c =$

Note: $\sin\theta = \tan\theta$ for small angles. From Chezy we have:

$F_f = \tau PL =$ $\quad$ Substituting: $\quad$ and thus:

$V = [(\Upsilon/k)(A/P)S_o]^{1/2} = C\,[R_h S_e]^{1/2}$ where $R_h = A/P$ & $S_o = S_e$

The Manning Equation

(Uniform Flow ➔ Widely Used & Accepted)

Chezy formula: $V = C\,[R_h S_e]^{1/2}$; C = Chezy resistance factor.

Irish engineer, Robert Manning did experiments on "C."

$C = (1/n)R_h^{1/6}$ where n = Manning's channel roughness coef.

Substituting yields, **$Q = AV =$** [blank box] where

$k_M = 1.00\ m^{1/3}/sec = 1.49\ ft^{1/3}/sec$. Units of other variables?

The flow depth using Manning's eq'n. is called [blank box]

Where is normal depth (y_n) in the eq'n? [blank box]

Find it using successive substitution, charts, or software.

Typical Values for Manning's "n"

TABLE 6.2 Typical Values of Manning's *n*

Channel Surface	*n*
Glass, PVC, HDPE	0.010
Smooth steel, metals	0.012
Concrete	0.013
Asphalt	0.015
Corrugated metal	0.024
Earth excavation, clean	0.022–0.026
Earth excavation, gravel and cobbles	0.025–0.035
Earth excavation, some weeds	0.025–0.035
Natural channels, clean and straight	0.025–0.035
Natural channels, stones or weeds	0.030–0.040
Riprap lined channel	0.035–0.045
Natural channels, clean and winding	0.035–0.045
Natural channels, winding, pools, shoals	0.045–0.055
Natural channels, weeds, debris, deep pools	0.050–0.080
Mountain streams, gravel and cobbles	0.030–0.050
Mountain streams, cobbles and boulders	0.050–0.070

Questions:

What causes differences in the "n" values?

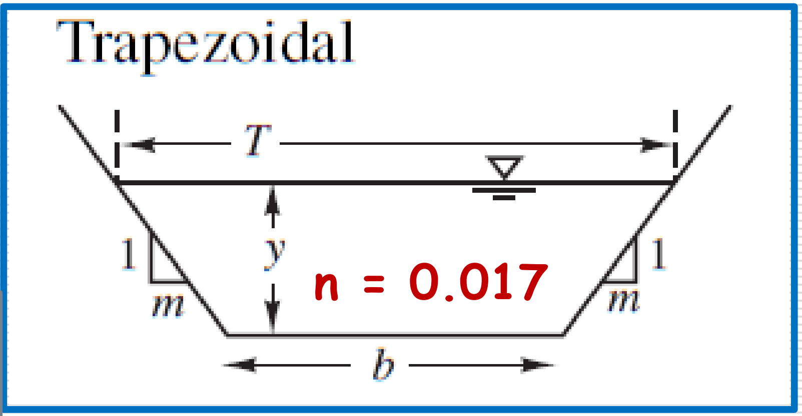
How do you think the values were obtained?

Normal Depth Calculations

(Example Problem → Trapezoidal Channel)

Given: Channel w/Q = 1510 cfs

$S_o = 0.00088$, $m = 1.5$, $b = 25$ ft



Solution: From Table 6.1:

A = [ ] P = [ ]

Now: $Q = (1.49/n)AR_h^{2/3}S_o^{1/2} = (1.49/n)(A^{5/3}/P^{2/3})S_o^{1/2}$

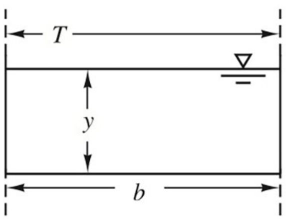
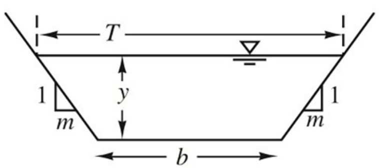
where A = [ ] & P = [ ] Thus

$$\frac{Q\,n}{1.49S_o^{1/2}} = \frac{(1510)(0.017)}{(1.49)(0.00088)^{1/2}} = \frac{[y_n(25 + 1.5y_n)]^{5/3}}{[25 + 2y_n(3.25)^{1/2}]^{2/3}}$$

Solving iteratively (or w/charts or software), $y_n = 6.22$ ft

TABLE 6.1 Cross-Sectional Relationships for Open-Channel Flow

TABLE 6.1 Cross-Sectional Relationships for Open-Channel Flow

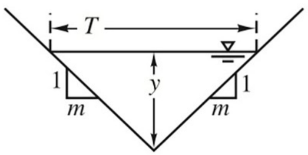
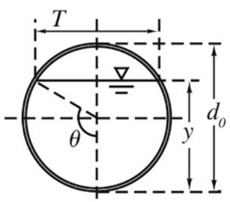
Section Type	Area (A)	Wetted perimeter (P)	Hydraulic Radius (R_h)	Top Width (T)	Hydraulic Depth (D)
Rectangular 	by	$b + 2y$	$\dfrac{by}{b + 2y}$	b	y
Trapezoidal 	$(b + my)y$	$b + 2y\sqrt{1 + m^2}$	$\dfrac{(b + my)y}{b + 2y\sqrt{1 + m^2}}$	$b + 2my$	$\dfrac{(b + my)y}{b + 2my}$

Source: Based on V. T. Chow, *Open Channel Hydraulics* (New York: McGraw-Hill, 1959).

continued on next slide

TABLE 6.1 (continued) Cross-Sectional Relationships for Open-Channel Flow

TABLE 6.1 Cross-Sectional Relationships for Open-Channel Flow

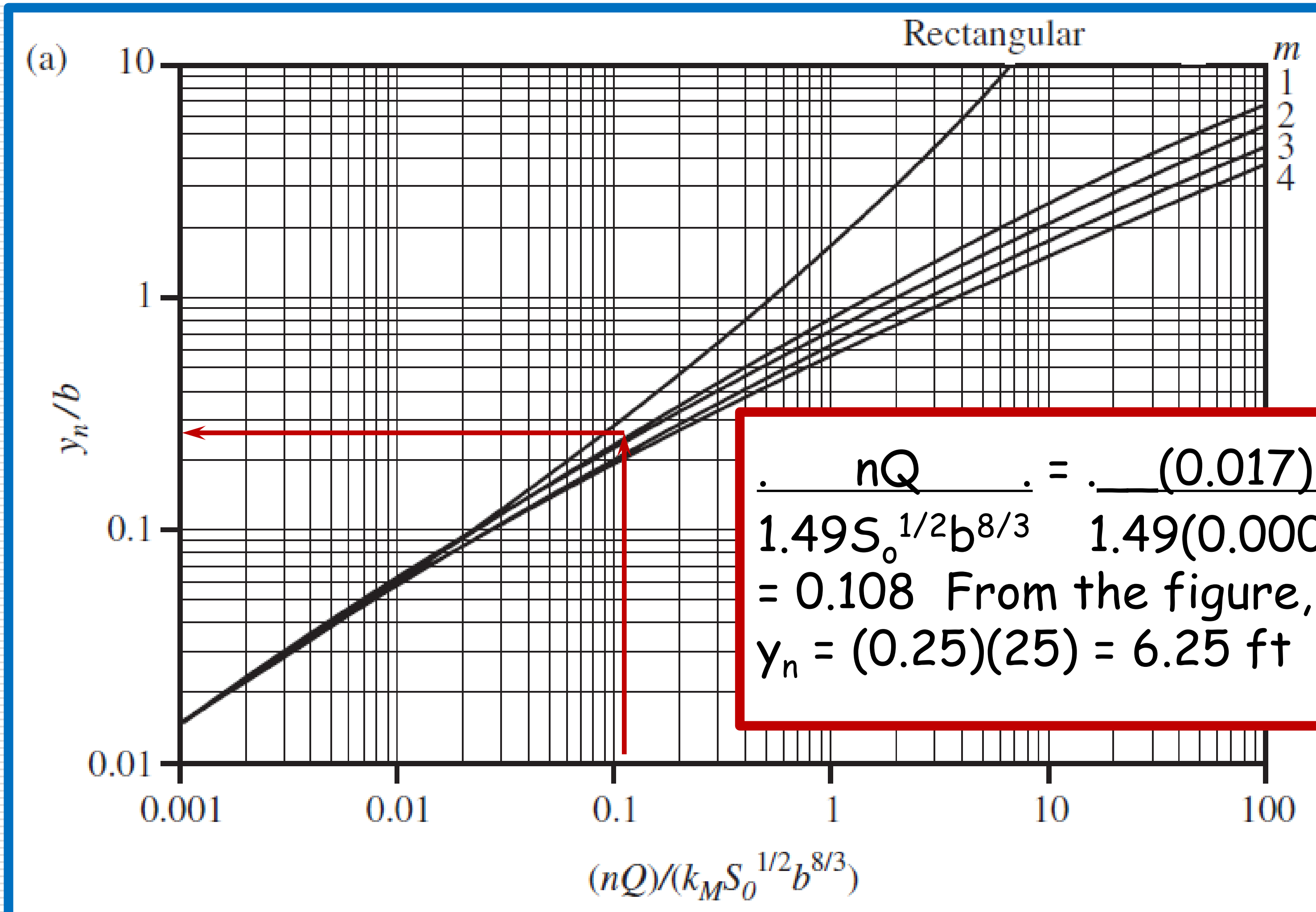
Section Type	Area (A)	Wetted perimeter (P)	Hydraulic Radius (R_h)	Top Width (T)	Hydraulic Depth (D)
Triangular 	my^2	$2y\sqrt{1+m^2}$	$\dfrac{my}{2\sqrt{1+m^2}}$	$2my$	$\dfrac{y}{2}$
Circular (θ is in radians) 	$\frac{1}{8}(2\theta - \sin 2\theta)d_0^2$	θd_0	$\frac{1}{4}\left(1 - \dfrac{\sin 2\theta}{2\theta}\right)d_0$	$(\sin\theta)d_0$ or $2\sqrt{y(d_0 - y)}$	$\frac{1}{8}\left(\dfrac{2\theta - \sin 2\theta}{\sin\theta}\right)d_0$

Source: Based on V. T. Chow, *Open Channel Hydraulics* (New York: McGraw-Hill, 1959).

Alternative Solution

(Trapezoidal Channel, Fig. 6.4a)

Homework Problems:

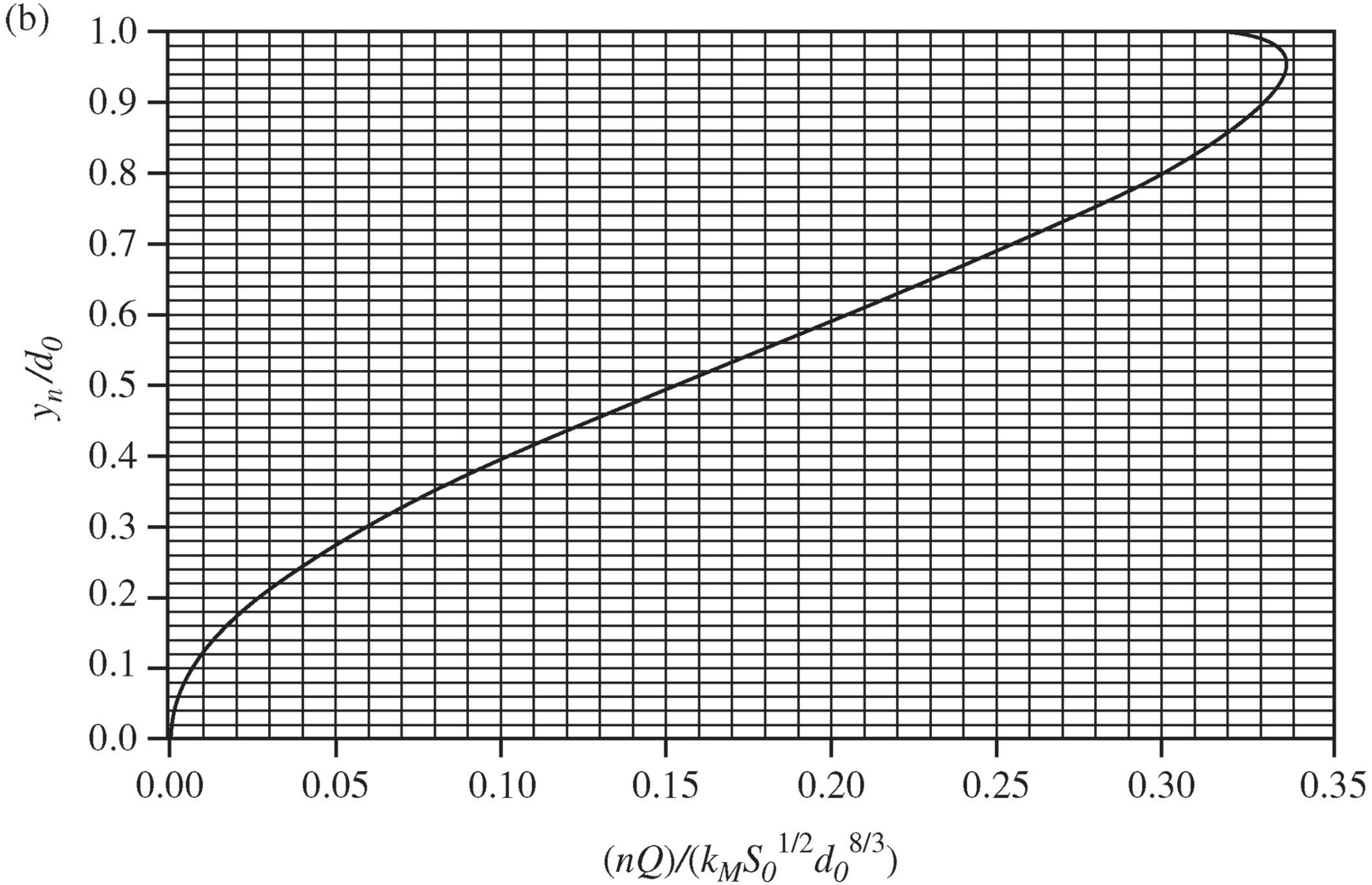


$$\frac{nQ}{1.49 S_o^{1/2} b^{8/3}} = \frac{(0.017)(1510)}{1.49(0.00088)^{1/2}(25)^{8/3}}$$

$= 0.108$ From the figure, $y_n/b = 0.25$

$y_n = (0.25)(25) = 6.25$ ft

Figure 6.4b Normal depth solution procedure: circular channels (d_0 = diameter)



Central Arizona Project (USA)

(336 miles of canals)

Rf.➔http://www.usbr.gov/lc/images/gallery/CAP/index.html