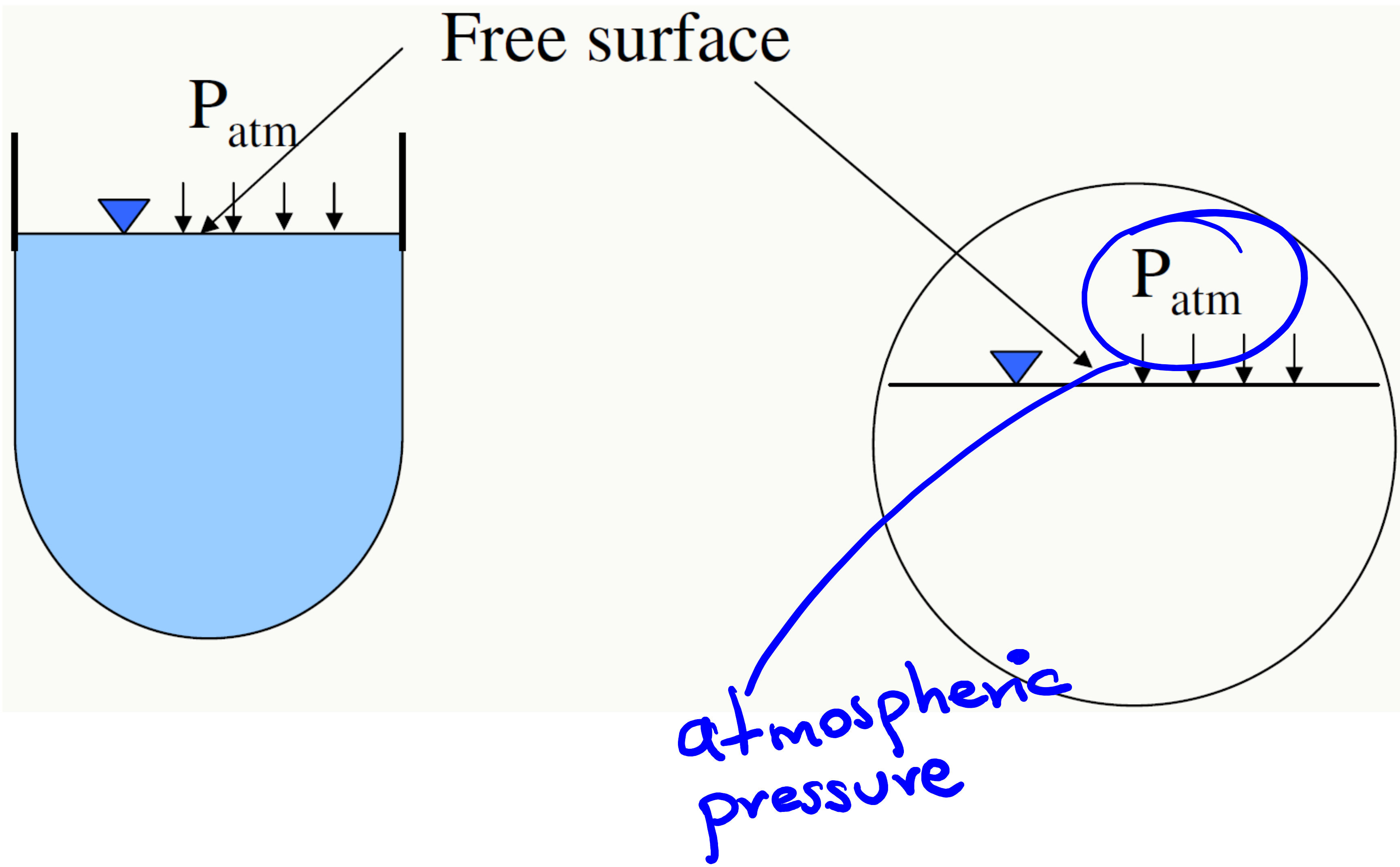
An Overview of Steady and Unsteady Flows

Arturo S. Leon, Ph.D., P.E., D.WRE
Florida International University

Open-channel Flow



Types of Open-channel

Canal: A canal is usually a long and mild-sloped channel built in the ground

Types of Open-channel (Cont.)

Chute: A chute is a channel with a steep slope

Types of Open-channel (Cont.)

Drop: A drop is a channel with a sudden change in elevation

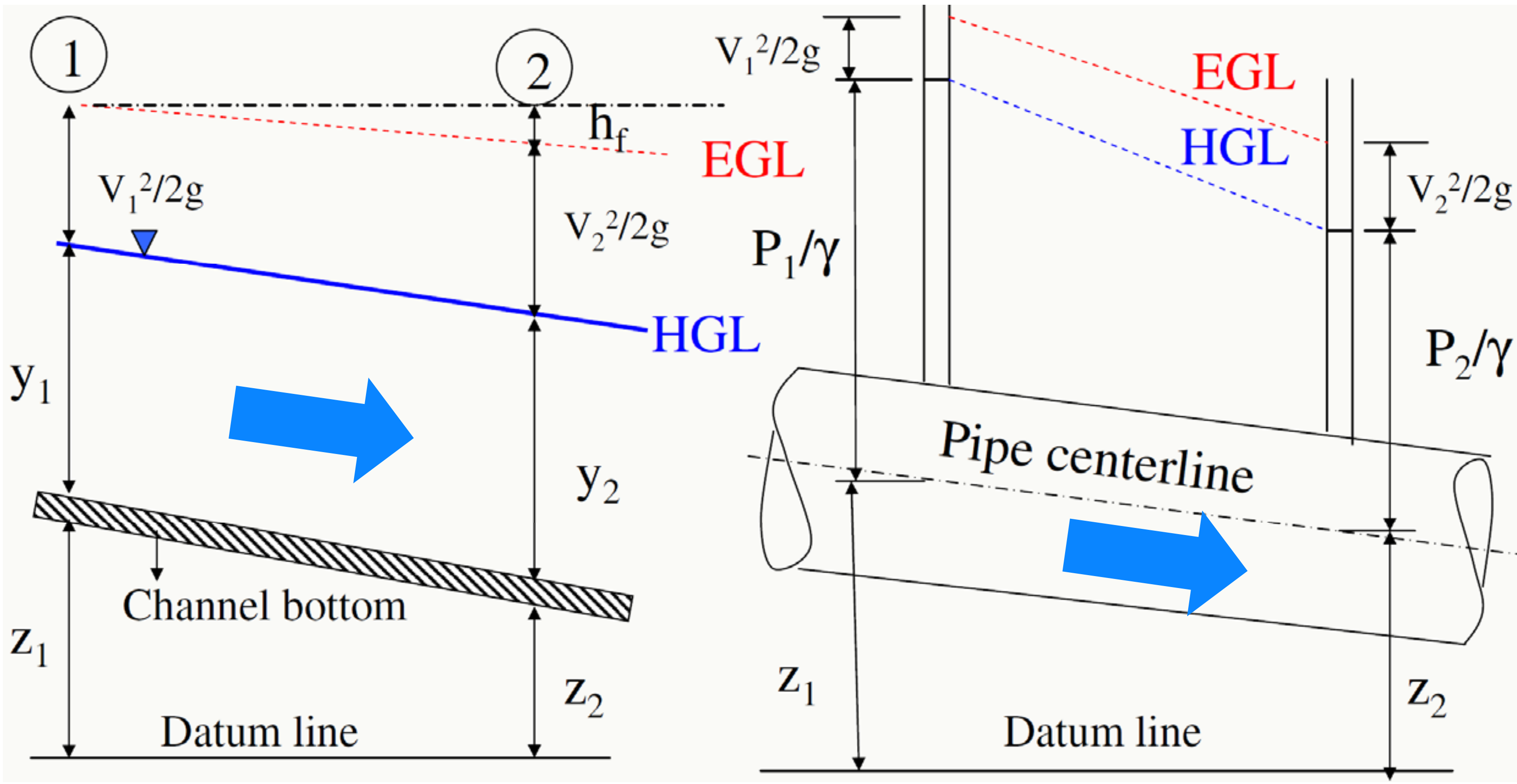
Types of Open-channel (Cont.)

<u>Culvert</u>: A culvert is a covered channel flowing usually partly full.

Types of Open-channel (Cont.)

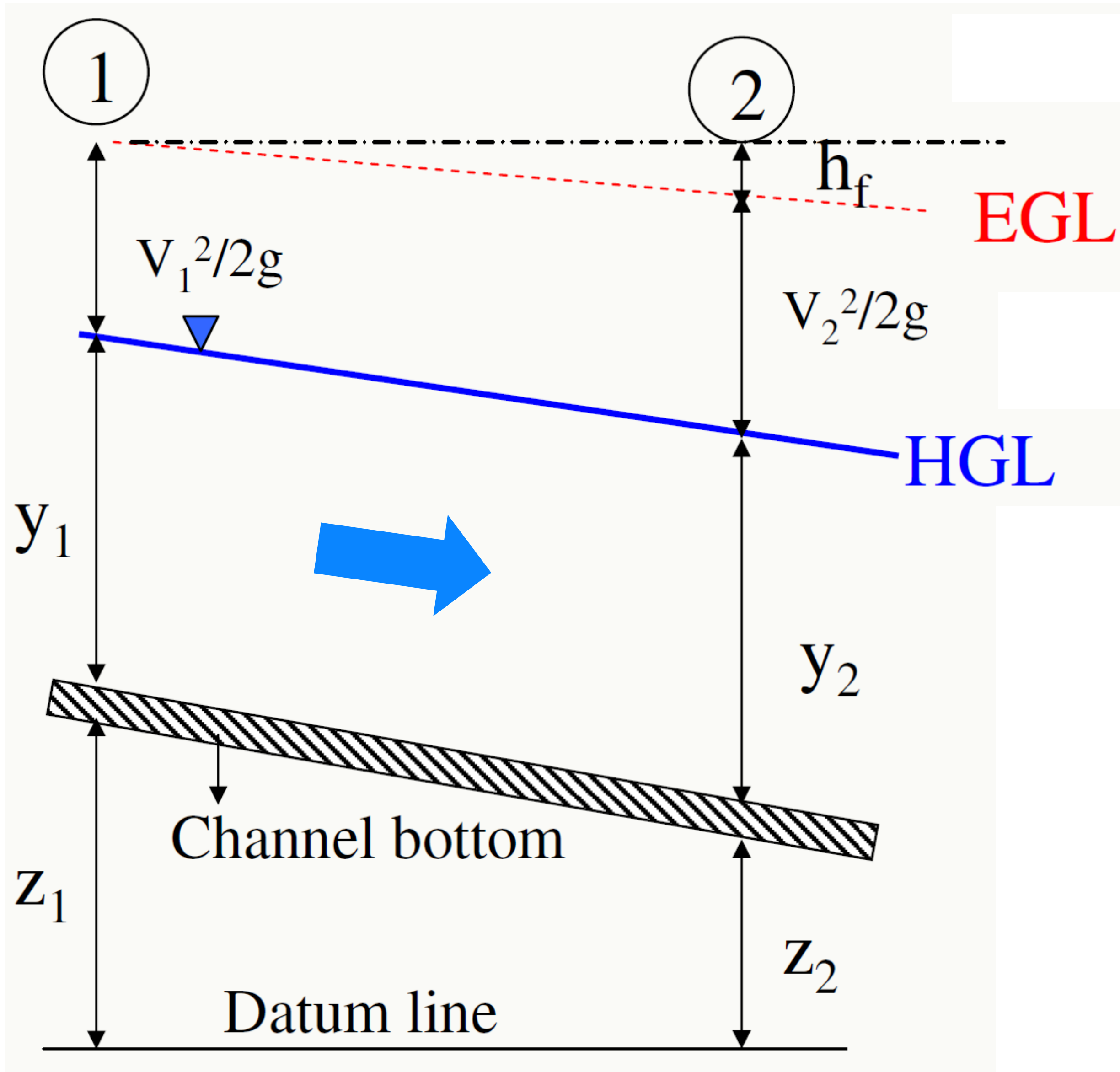
Natural channel: A natural channel has irregular geometry. Examples include, rivers and creeks.

Comparison of Open-Channel Flow and Pipe Flow

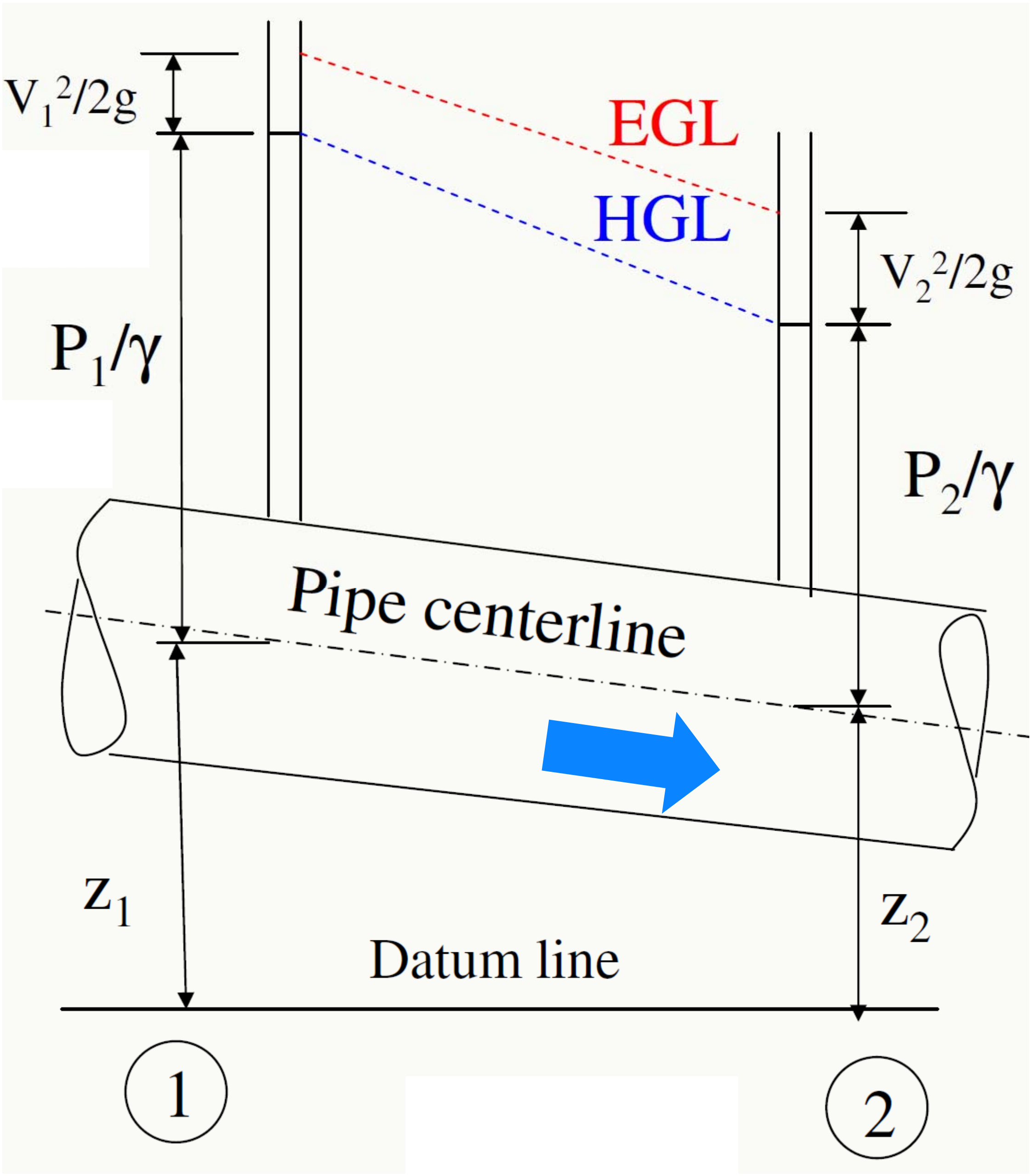


Open-Channel Flow **Pipe Flow**

Open-Channel Flow



Pipe Flow



$V_1^2/2g$
EGL
HGL
$V_2^2/2g$
P_1/γ
P_2/γ
Pipe centerline
z_1
z_2
Datum line
1
2

Comparison of Open-Channel Flow and Pipe Flow (Cont.)

1) Open-channel flow has a free surface

2) A free surface is subject to atmospheric pressure

1) No free surface in pipe flow

2) No direct atmospheric pressure, hydraulic pressure only

Comparison of Open-Channel Flow and Pipe Flow (Cont.)

3) Gravity is the main driving force

4) HGL is coincident with free surface

3) Pressure is the main driving force

4) HGL is (usually) above the conduit

HGL: Hydraulic Grade Line

Comparison of Open-Channel Flow and Pipe Flow (Cont.)

5) Flow area is a function of channel geometry and free surface elevation.

6) Relative roughness changes with water depth

5) Flow area is fixed by pipe dimensions. The cross section of a pipe is usually circular.

6) Relative roughness is constant

Steady and Unsteady Flow

Steady Flow

$$\frac{\partial Q}{\partial t} = 0$$

$$\frac{\partial y}{\partial t} = 0$$

Unsteady Flow

$$\frac{\partial Q}{\partial t} \neq 0$$

$$\frac{\partial y}{\partial t} \neq 0$$

Animations of unsteady Flows

- **Explosive Breach of Condit Dam:**

https://www.youtube.com/watch?v=ubXmfUTTA4s

- **Deep tunnel Geyser (Minnesota):**

http://www.youtube.com/watch?v=NDy3fBLfhYQ

- **Urban Flooding**

http://www.youtube.com/watch?v=kYUpkPTcqPY

- **Road Collapse- Maine 2008**

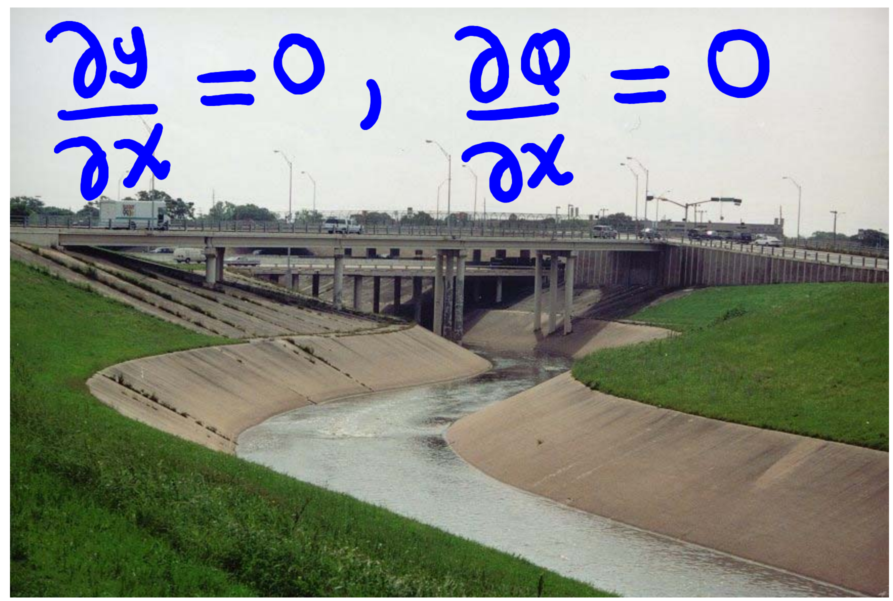
https://www.youtube.com/watch?v=NTbhyHNA1Vc

Steady Open Channel Flow

Arturo S. Leon,
Florida International University

Uniform Open-Channel Flow

Uniform flow



$$\frac{\partial y}{\partial x} = 0, \quad \frac{\partial Q}{\partial x} = 0$$

Rapidly varying flow

Unnumbered 10 p555b
Photo by Marty Melchior

$\frac{dy}{dx} \sim 1$

$$\frac{dy}{dx} \ll 1$$

much smaller

Gradually varied flow

Critical Flow $(F = 1)$

Classification of open-channel flows

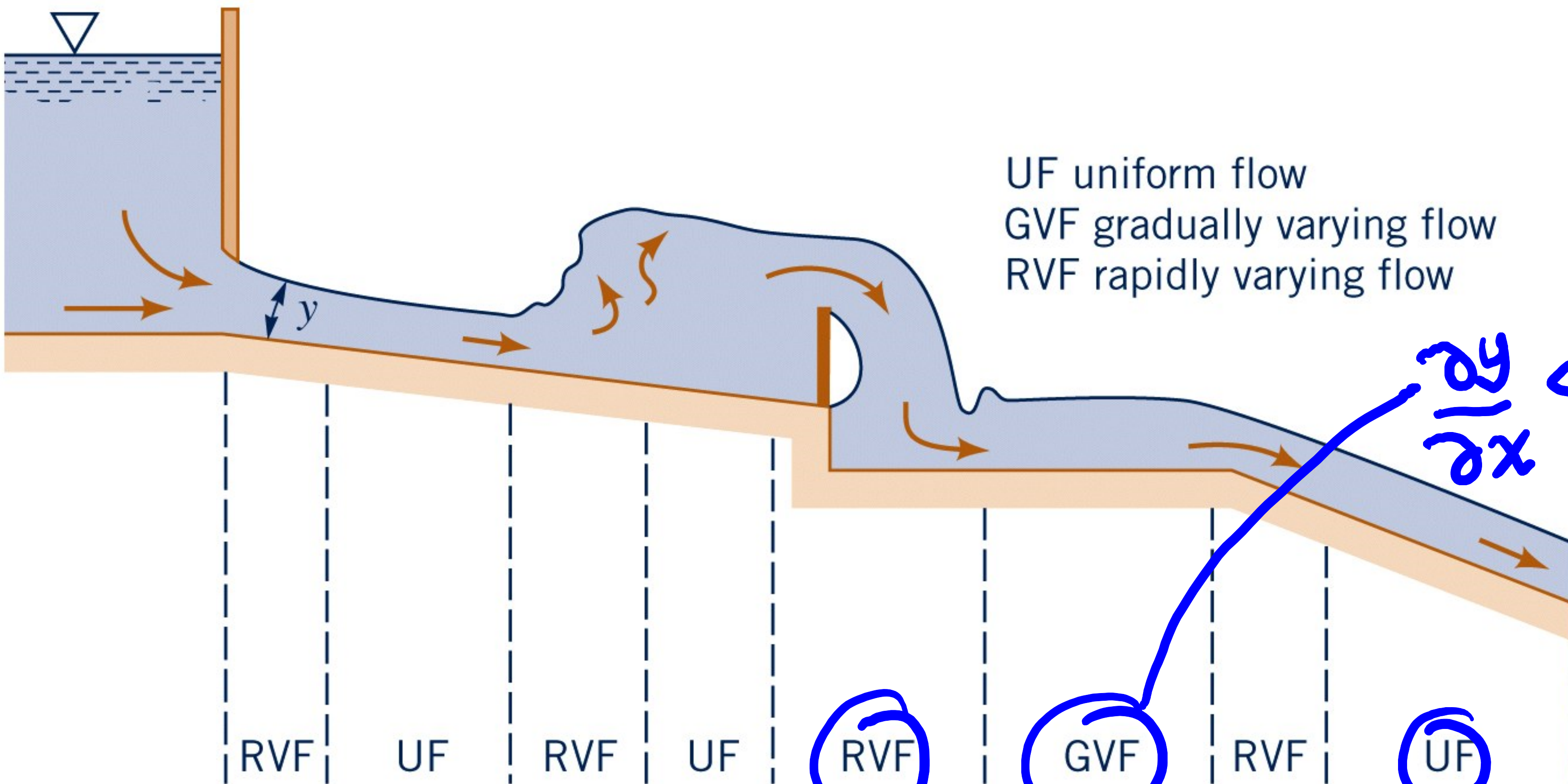


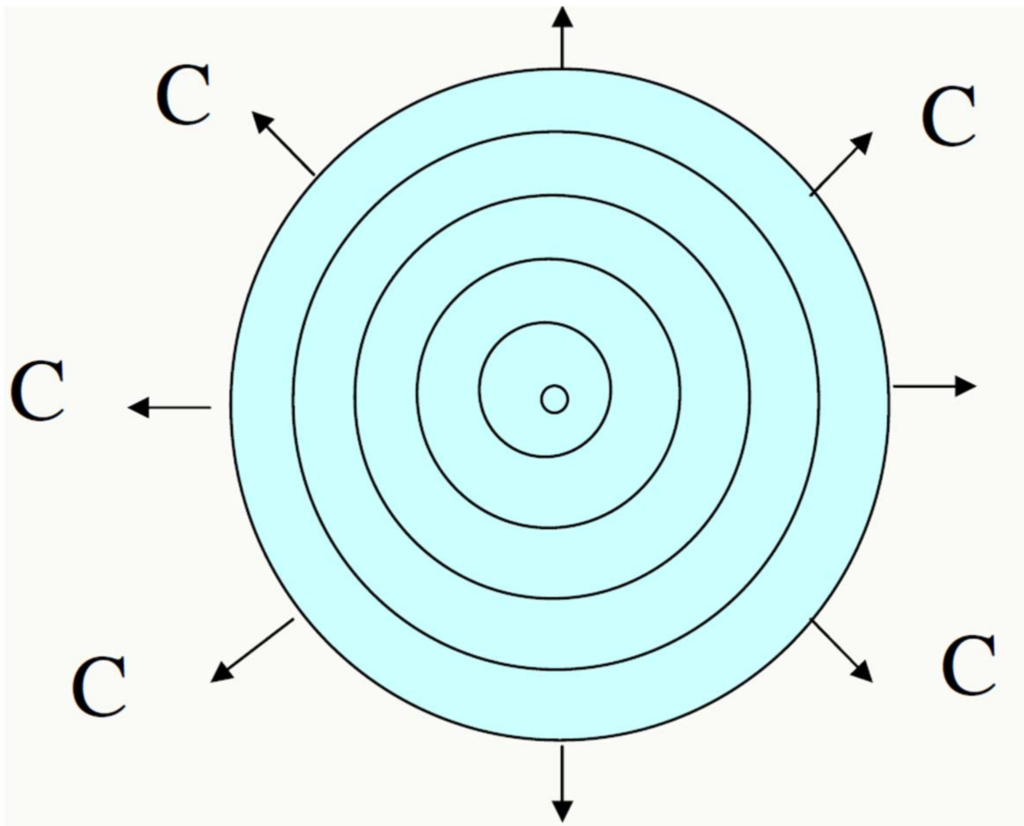
Figure 10.1

$\frac{\partial y}{\partial x} \ll 1$

$\frac{\partial y}{\partial x} \sim 1$

$\frac{\partial y}{\partial x} = 0$

Propagation of a disturbance in still water



C: gravity wave speed

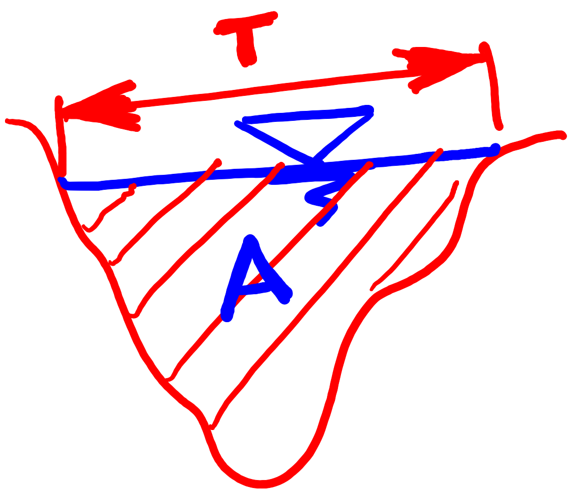
Wave speed in open channel flows

For wide channels and rectangular channels:

$$c = \sqrt{gy}$$

For any cross-section:

$$c = \sqrt{g\frac{A}{T}}$$



T: Top surface width, A: Hydraulic area

Froude Number:

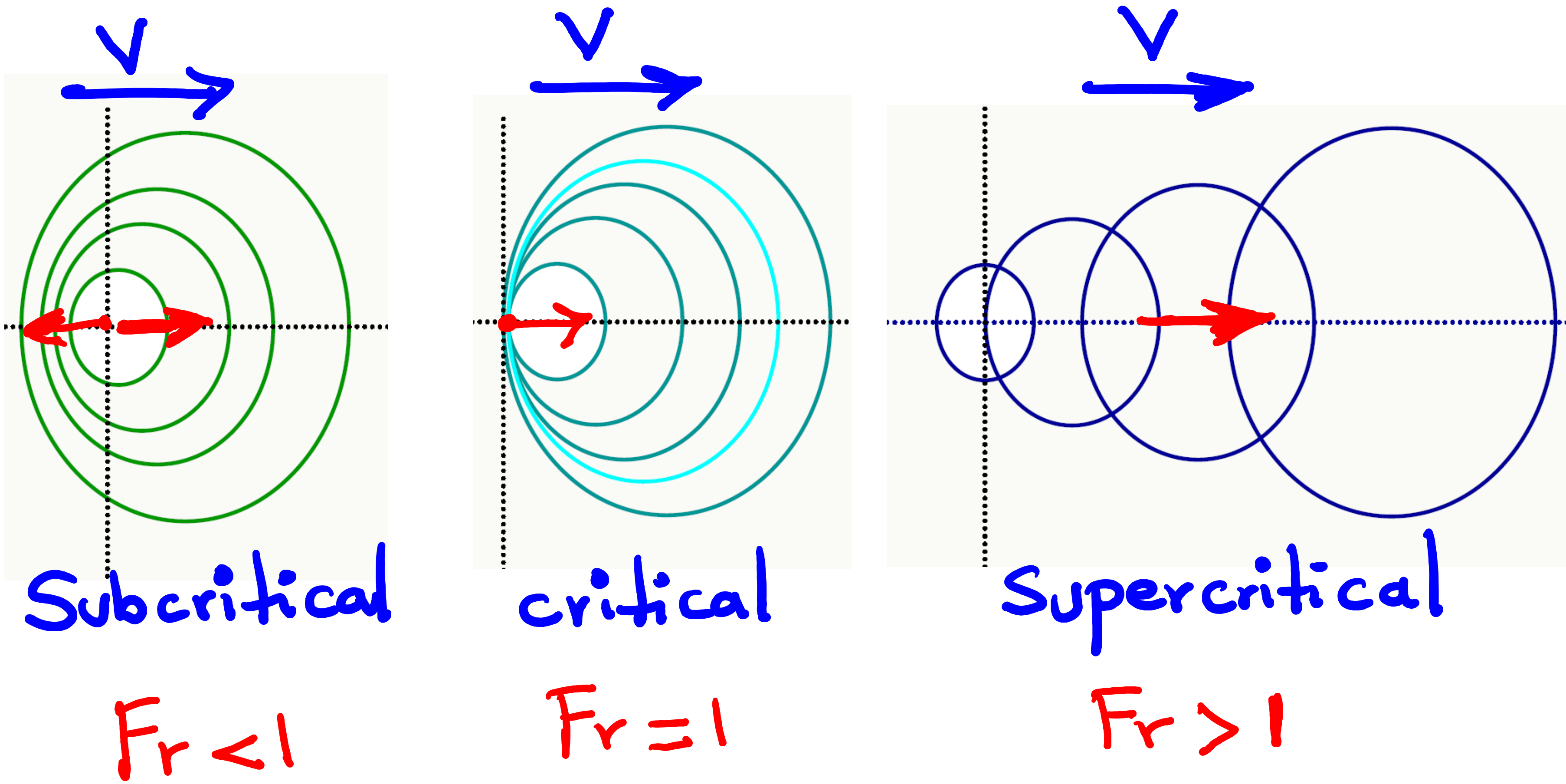
$$F_r = \frac{V}{\sqrt{g\frac{A}{T}}}$$

$F_r < 1$: Subcritical flow

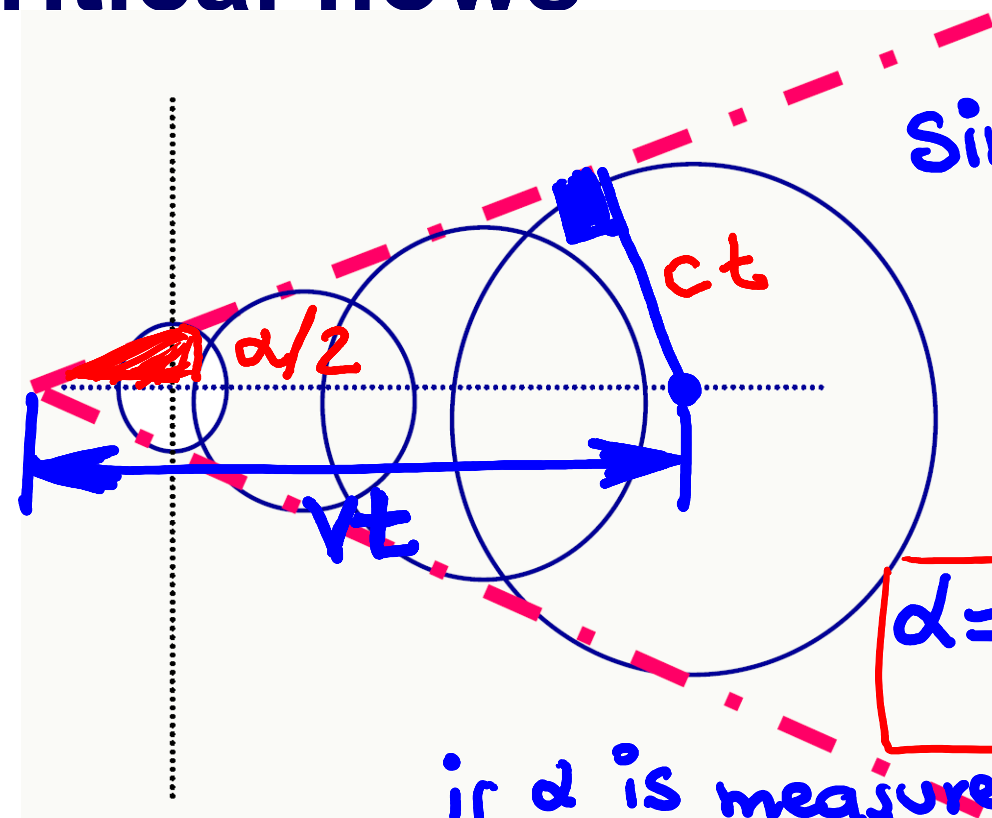
$F_r = 1$: Critical flow

$F_r > 1$: Supercritical flow

Propagation of a disturbance in subcritical, critical and supercritical flows



Propagation of a disturbance in supercritical flows



$$\sin\left(\frac{\alpha}{2}\right) = \frac{c\cancel{t}}{V\cancel{t}}$$

$$\frac{\alpha}{2} = \arcsin\frac{c}{V}$$

$$\boxed{\alpha = 2\arcsin\left(\frac{1}{F}\right)}$$

if α is measured, F can be known and hence discharge can be computed.

Show angle as a function of Froude number.

Classification of open channel according to Reynolds Number

$$Re = \frac{V \cdot R_h}{\nu}$$

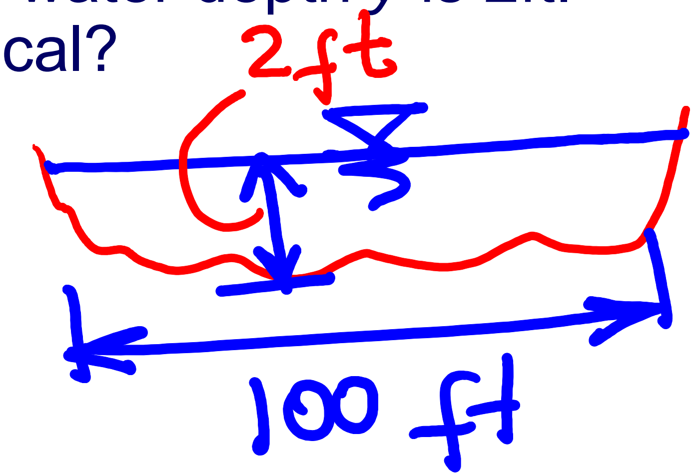
V is the average velocity of the fluid. R_h is the hydraulic radius of the channel.

- Laminar flow: Re < 500.
- Transitional flow: $500 \leq Re \leq 12{,}500$
- Turbulent flow: Re > 12,500.

Example of application:

In the picture below the river travels to the left and the surface wave travels upstream (to the right). The width of the river is 100 ft, the flow velocity V is 8ft/s, and the water depth y is 2ft. Is the flow subcritical, critical or supercritical?

Figure E10.1a



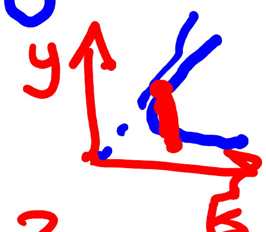
$$V = 8\ \text{ft/s}$$
$$y = 2\ \text{ft}$$

$$Fr = \frac{V}{\sqrt{g\frac{A}{T}}} \quad \Rightarrow \quad Fr = \frac{8}{\sqrt{32.2 \times \frac{200}{100}}}$$

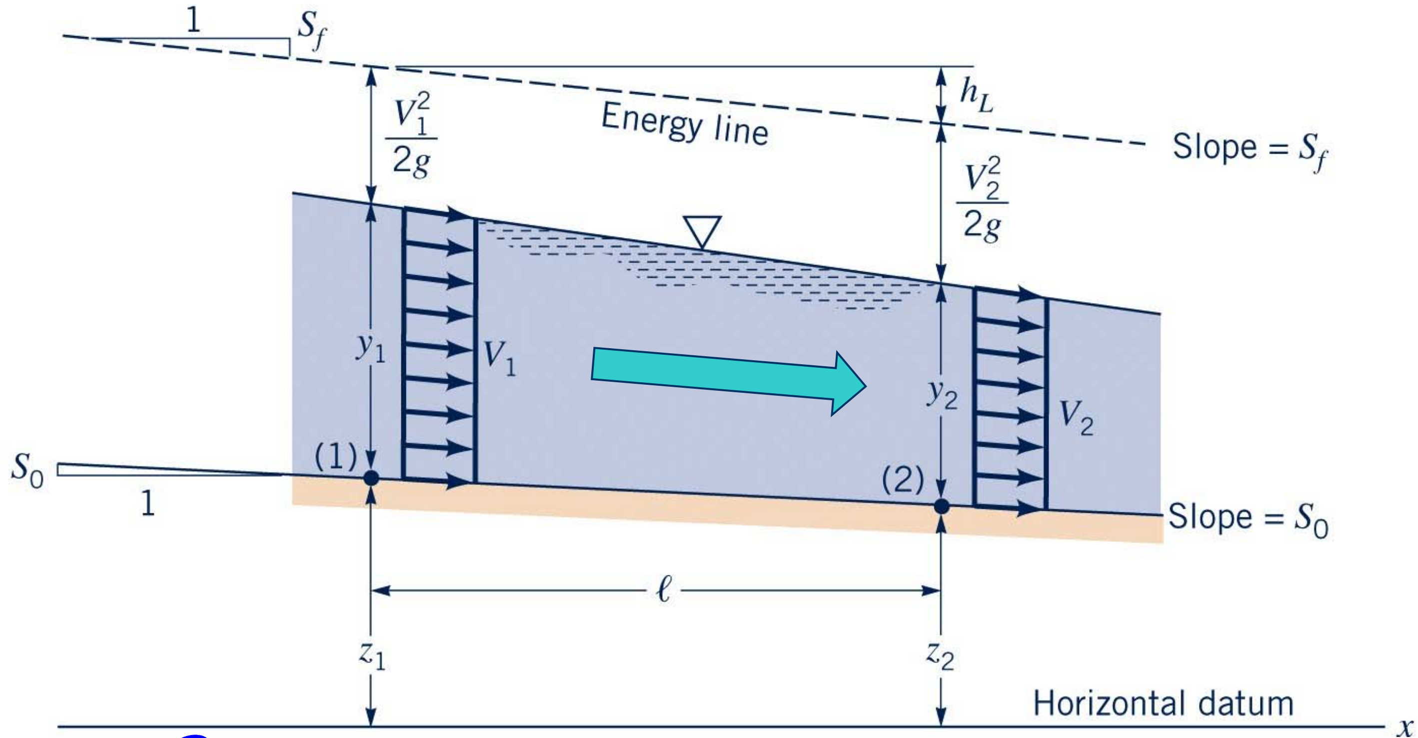
$$\boxed{Fr = 0.997}$$

Flow is highly unstable.

In practice, we should try to avoid the range $0.8 < Fr < 1.2$



Energy considerations

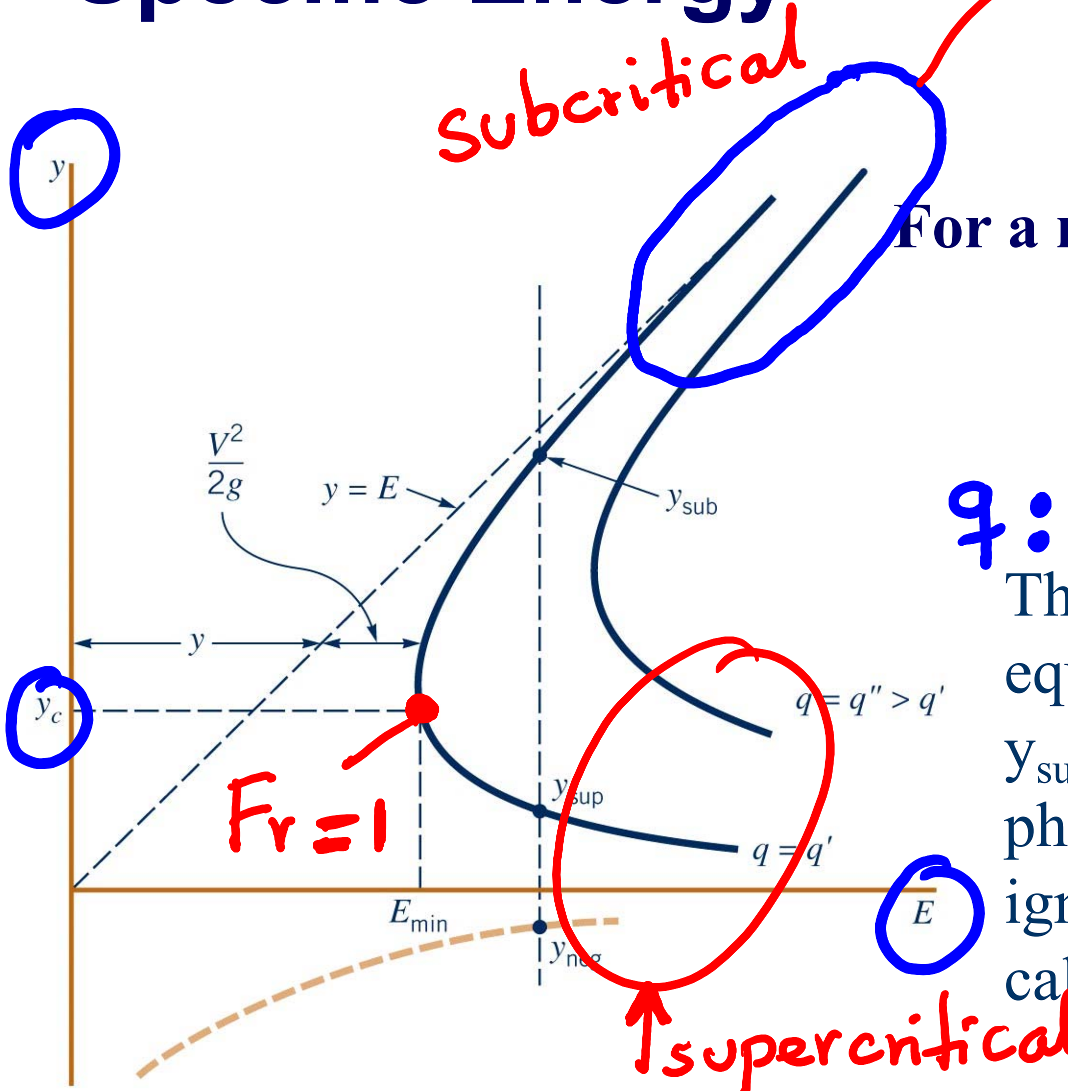


$$\frac{P_1}{\gamma} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + z_2 + h_L$$

$$y_1 + \frac{V_1^2}{2g} + S_0 L = y_2 + \frac{V_2^2}{2g} + h_L$$

Specific Energy

$E = y + \frac{V^2}{2g}$



Specific energy diagram

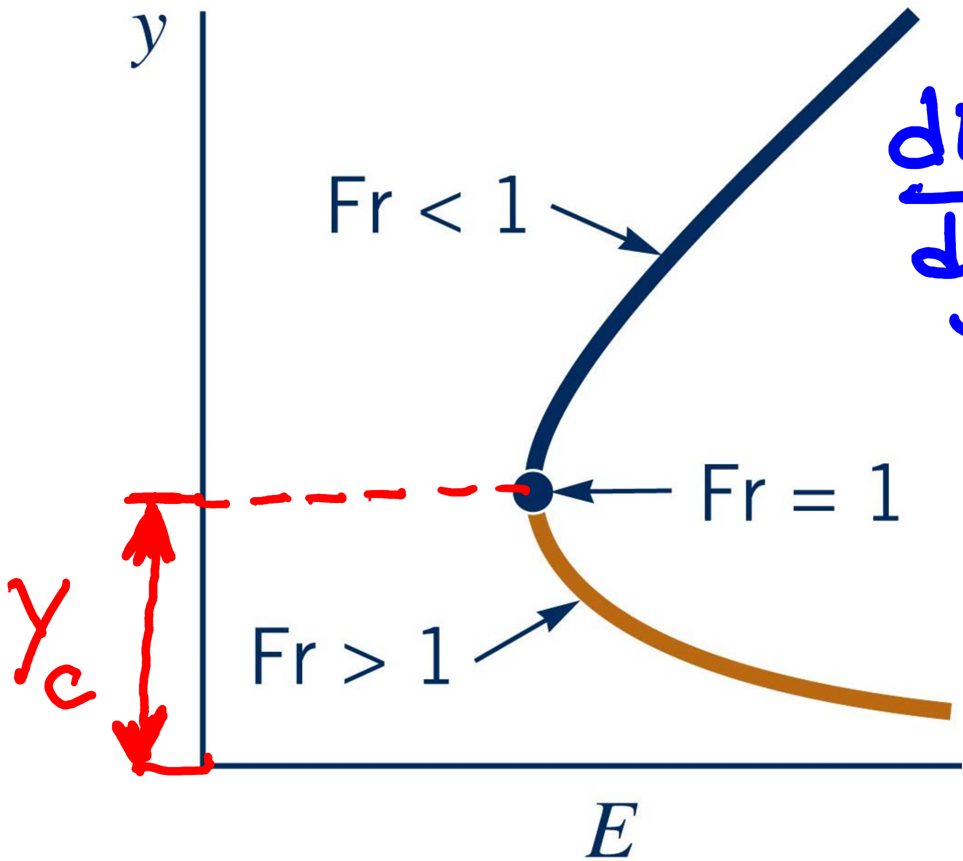
For a rectangular channel, *q* = *Q/b*

$$E = y + \frac{q^2}{2gy^2}$$

q: unit flow discharge

The above formula is a cubic equation with three solutions, y_{sup}, y_{sub}, and y_{neg}. y_{neg} has no physical meaning and can be ignored. Y_{sup} and y_{sub} are called alternative depths.

Critical depth



To determine $E_{min,}$ $dE/dy = 0$

$$E = y + \frac{Q^2}{2gA^2}$$

$$\frac{dE}{dy} = 1 + \frac{Q^2}{2g}(-2)A^{-3}\overbrace{\frac{dA}{dy}}^{T} = 0$$

$$\frac{Q^2 T}{gA^3} = 1$$

For a rectangular channel (*q* = *Q/b*)

$$y_c = \sqrt[3]{\frac{q^2}{g}}$$

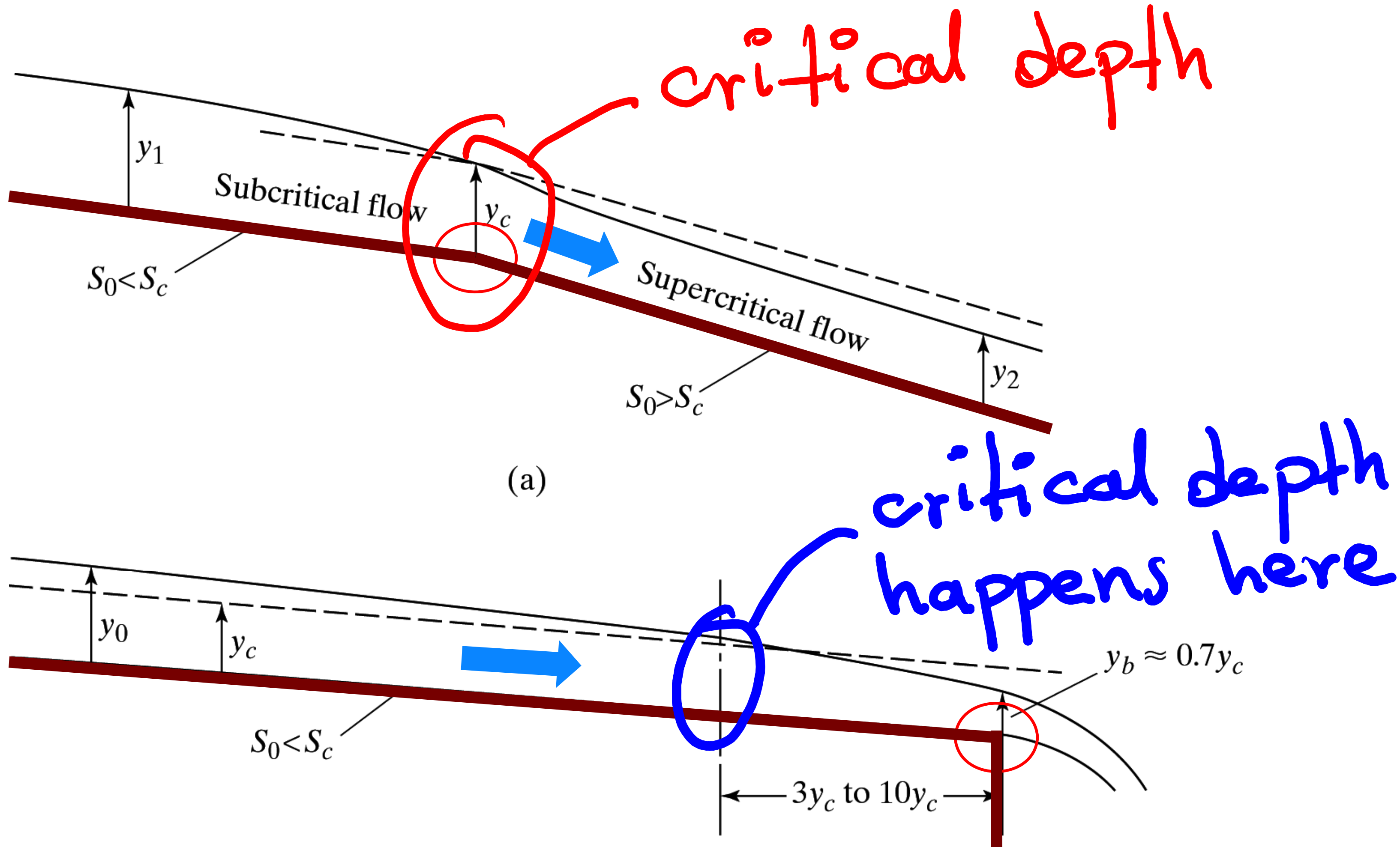


Figure 7.4

Occurrence of critical depth. (a) Change in flow from subcritical to supercritical at a break in slope. (b) Free outfall. Mild slope.

Source: Hydrology and Floodplain Analysis by Philip B. Bedient (2002)

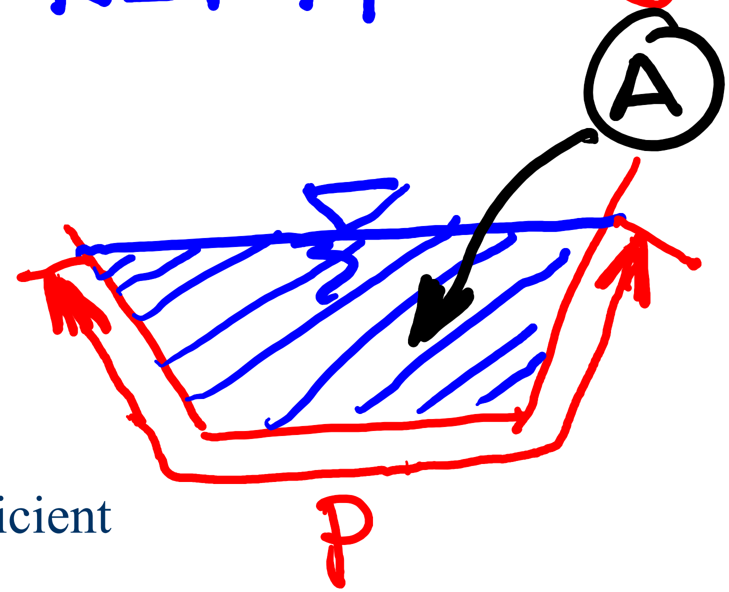
Uniform Open Channel Flow

Manning's Equation

$$Q = \frac{K}{n} A R^{2/3} S_o^{1/2}$$

$k = 1.0$ (SI)

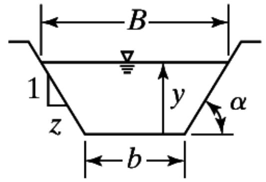
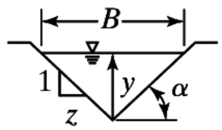
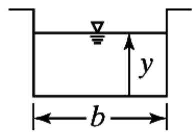
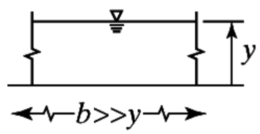
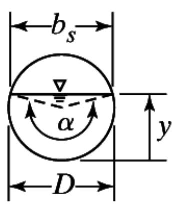
$k = 1.49$ (English)

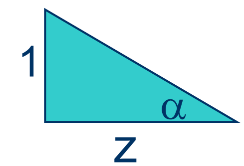


Where:

Q = flow discharge
v = flow velocity
n = Manning's roughness coefficient
R = hydraulic radius = *A/P*
S = channel slope
y = normal flow depth

$R = A/P$

SHAPE	SECTION	FLOW AREA A	WETTED PERIMETER P	HYDRAULIC RADIUS R
Trapezoidal		$y(b+ y\cot\alpha)$	$b + \frac{2y}{\sin\alpha}$	$\frac{y(b+ y\cot\alpha)}{b + \frac{2y}{\sin\alpha}}$
Triangular		$y^2\cot\alpha$	$\frac{2y}{\sin\alpha}$	$\frac{y\cos\alpha}{2}$
Rectangular		by	$b+2y$	$\frac{by}{b+2y}$
Wide flat		by	b	y
Circular		$(\alpha-\sin\alpha)\frac{D^2}{8}$	$\frac{\alpha D}{2}$	$\frac{D}{4}\left(1-\frac{\sin\alpha}{\alpha}\right)$



tan $\alpha = 1/z$

Geometric elements for different channel cross sections

Source: Hydrology and Floodplain Analysis by Philip B. Bedient (2002)

Value of the Manning Coefficient, *n*

Table 10.1

Values of the Manning Coefficient, *n* (Ref. 6)

Wetted Perimeter	*n*	Wetted Perimeter	*n*
A. Natural channels		***D. Artificially lined channels***	
Clean and straight	0.030	Glass	0.010
Sluggish with deep pools	0.040	Brass	0.011
Major rivers	0.035	Steel, smooth	0.012
B. Floodplains		Steel, painted	0.014
Pasture, farmland	0.035	Steel, riveted	0.015
Light brush	0.050	Cast iron	0.013
Heavy brush	0.075	Concrete, finished	0.012
Trees	0.15	Concrete, unfinished	0.014
C. Excavated earth channels		Planed wood	0.012
Clean	0.022	Clay tile	0.014
Gravelly	0.025	Brickwork	0.015
Weedy	0.030	Asphalt	0.016
Stony, cobbles	0.035	Corrugated metal	0.022
		Rubble masonry	0.025

The best hydraulic cross section

The best hydraulic cross section is defined as the section of maximum flow rate (Q) for a constant hydraulic area (A), slope (S_o), and roughness coefficient (n).

constant

$$Q = \frac{k}{n} A R_h^{2/3} S_o^{1/2}$$

$$Q = \frac{k}{n} \frac{A^{5/3}}{P^{2/3}} S_o^{1/2}$$

For constant $A \rightarrow Q_{max}$

Q is maximum when P is minimum.

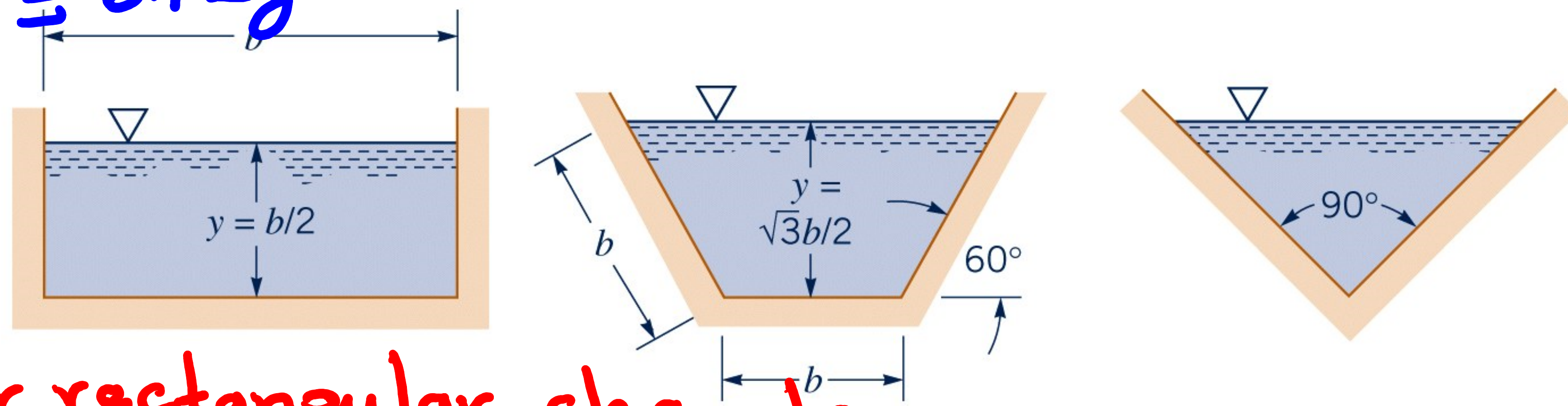
$$\therefore \frac{dA}{dy} = 0, \quad \frac{dP}{dy} = 0$$

maximum Q corresponds to minimum P

The best hydraulic cross-section for common channel shapes

$A = by$

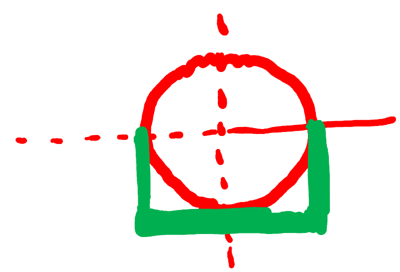
$P = b + 2y$



For rectangular channel:

$\frac{dA}{dy} = 0 \quad b + y\frac{db}{dy} = 0 \cdots (1) \qquad \frac{dP}{dy} = 0 \rightarrow \frac{db}{dy} + 2 = 0 \cdots (2)$

$\therefore b + y(-2) = 0 \qquad \boxed{y = b/2}$



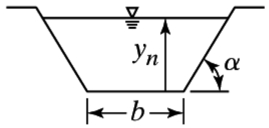
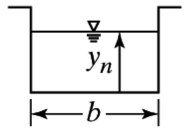
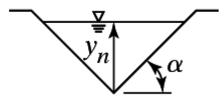
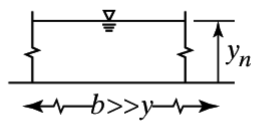
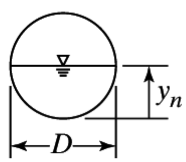
SHAPE	SECTION	OPTIMUM GEOMETRY	NORMAL DEPTH y_n	CROSS-SECTIONAL AREA A
Trapezoidal		$\alpha = 60^\circ$ $b = \frac{2}{\sqrt{3}} y_n$	$0.968\left[\frac{Qn}{S_b{}^{1/2}}\right]^{3/8}$	$1.622\left[\frac{Qn}{S_b{}^{1/2}}\right]^{3/4}$
Rectangular		$b = 2y_n$	$0.917\left[\frac{Qn}{S_b{}^{1/2}}\right]^{3/8}$	$1.682\left[\frac{Qn}{S_b{}^{1/2}}\right]^{3/4}$
Triangular		$\alpha = 45^\circ$	$1.297\left[\frac{Qn}{S_b{}^{1/2}}\right]^{3/8}$	$1.682\left[\frac{Qn}{S_b{}^{1/2}}\right]^{3/4}$
Wide flat		None	$1.00\left[\frac{(Q/b)n}{S_b{}^{1/2}}\right]^{3/8}$	—
Circular		$D = 2y_n$	$1.00\left[\frac{Qn}{S_b{}^{1/2}}\right]^{3/8}$	$1.583\left[\frac{Qn}{S_b{}^{1/2}}\right]^{3/4}$

Figure 7.2

Properties of optimum open channel sections.

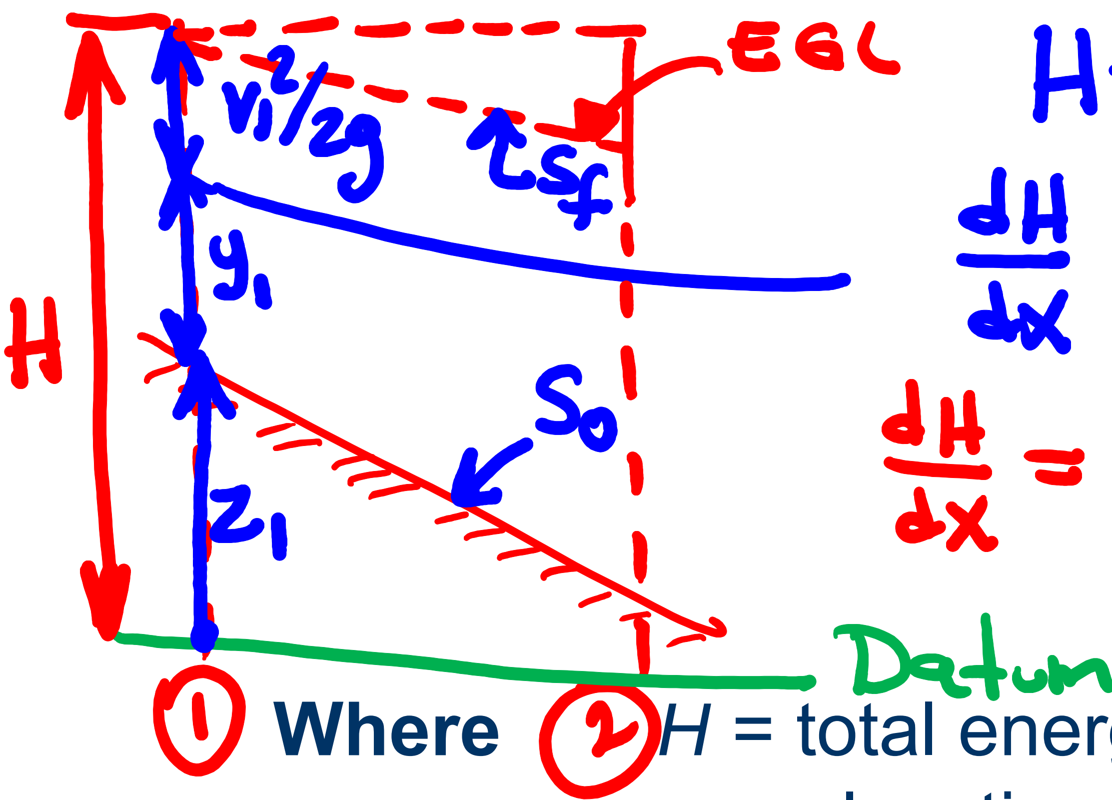
Optimal Cross-sections - Min P for a constant A

Source: Hydrology and Floodplain Analysis by Philip B. Bedient (2002)

Gradually varied Flows

$\frac{dy}{dx} << 1$

Let's evaluate H, total energy, as a function of x.



$$H = z + y + V^2/2g$$

$$\frac{dH}{dx} = \frac{dz}{dx} + \frac{dy}{dx} + \frac{d}{dx}\left(V^2/2g\right) \quad \ldots\ldots (1)$$

$$\frac{dH}{dx} = -S_f, \quad \frac{dz}{dx} = -S_o$$

$$Q = V \cdot A$$

Q is constant

Where *H* = total energy head

z = elevation head,

$v^2/2g$ = velocity head

Replace terms for various values of S and S_o and show that $\dfrac{dy}{dx} = \dfrac{S_o - S_f}{1 - Fr^2}$

where S_f = total energy slope

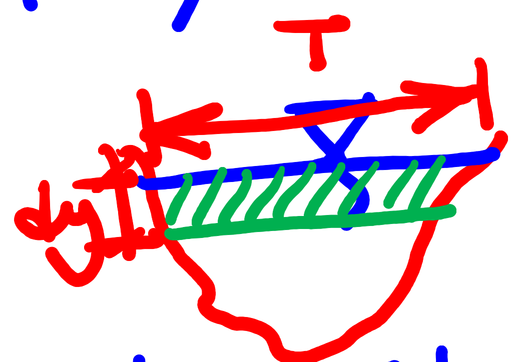
S_o = bed slope,

dy/dx = water surface slope

In (1)

$$-S_f = -S_o + \frac{dy}{dx} + \frac{1}{2g} Q^2 \frac{d}{dx}\left(\frac{1}{A^2}\right)$$

$$S_o - S_f = \frac{dy}{dx} + \frac{Q^2}{\cancel{2}g}(\cancel{-2})A^{-3}\frac{dA}{dx}$$



$$S_o - S_f = \frac{dy}{dx} - \frac{Q^2}{gA^3}\underbrace{\frac{dA}{dy}}_{T}\frac{dy}{dx}$$

$dA = T\,dy$

$dA/dy = T$

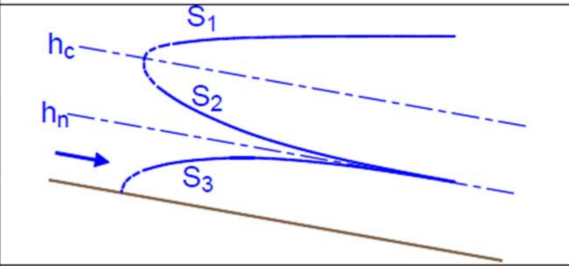
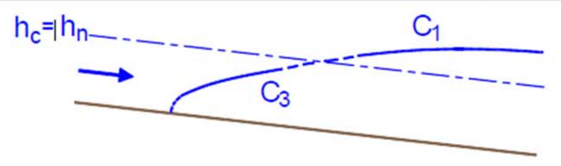
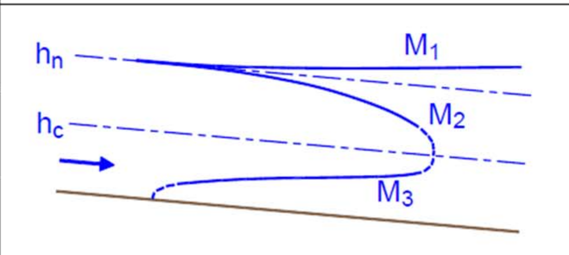
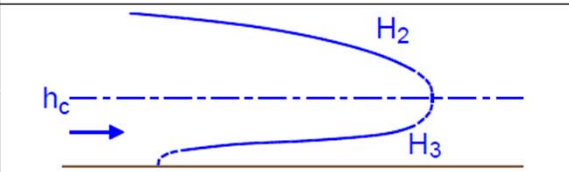
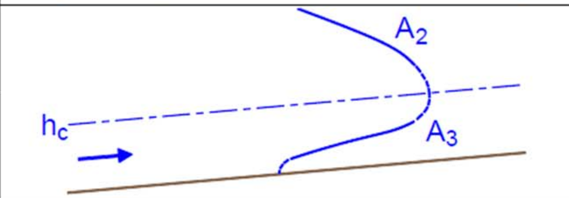
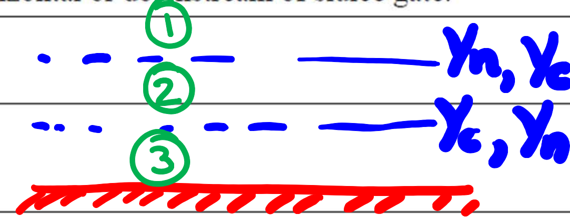
$$S_o - S_f = \frac{dy}{dx}\left(1 - \frac{Q^2 T}{gA^3}\right) \quad \cdots \text{②}$$

$$\frac{Q^2 T}{gA^3} = \frac{V^2 T}{gA} = \frac{V^2}{\frac{gA}{T}} = \left[\frac{V}{\sqrt{\frac{gA}{T}}}\right]^2 = Fr^2$$

In ②

$$S_o - S_f = \frac{dy}{dx}\left(1 - Fr^2\right)$$

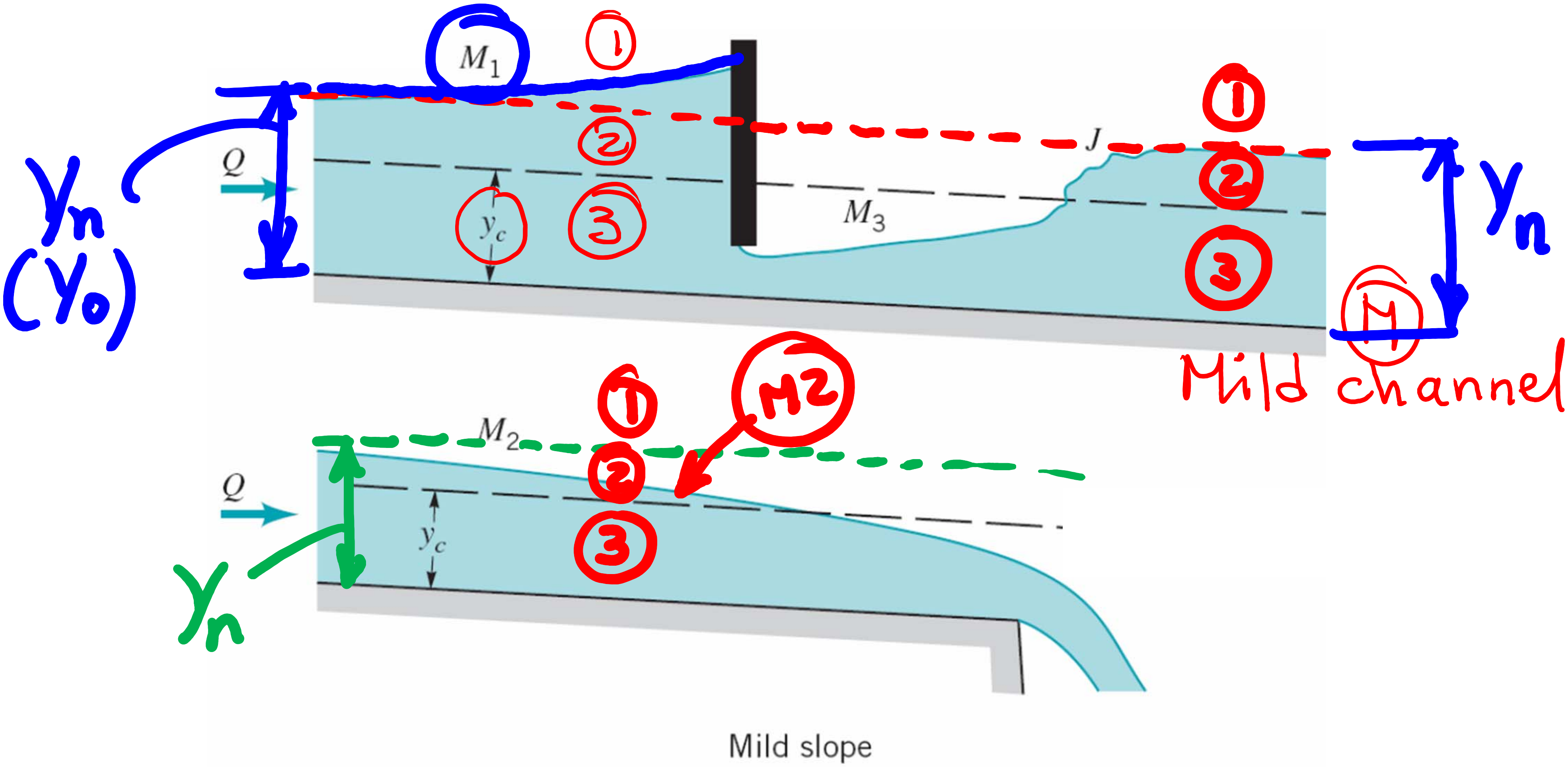
$$\frac{dy}{dx} = \frac{S_o - S_f}{1 - Fr^2}$$

Type	Symbol	Definition	Sketches	Examples
STEEP (S) (normal flow is supercritical)	S1	$h > h_c > h_n$		Hydraulic jump upstream with obstruction or reservoir controlling water level downstream.
	S2	$h_c > h > h_n$		Change to steeper slope.
	S3	$h_c > h_n > h$		Change to less steep slope.
CRITICAL (C) (undesirable; undular unsteady flow)	C1	$h > h_c = h_n$		
	C3	$h_c = h_n > h$		
MILD (M) (normal flow is subcritical)	M1	$h > h_n > h_c$		Obstruction or reservoir controlling water level downstream.
	M2	$h_n > h > h_c$		Approach to free overfall.
	M3	$h_n > h_c > h$		Hydraulic jump downstream; change from steep to mild slope or downstream of sluice gate.
HORIZONTAL (H) (limiting mild slope; $h_n \to \infty$)	H2	$h > h_c$		Approach to free overfall.
	H3	$h_c > h$		Hydraulic jump downstream; change from steep to horizontal or downstream of sluice gate.
ADVERSE (A) (upslope)	A2	$h > h_c$		
	A3	$h_c > h$		

Classification of Surface Shapes

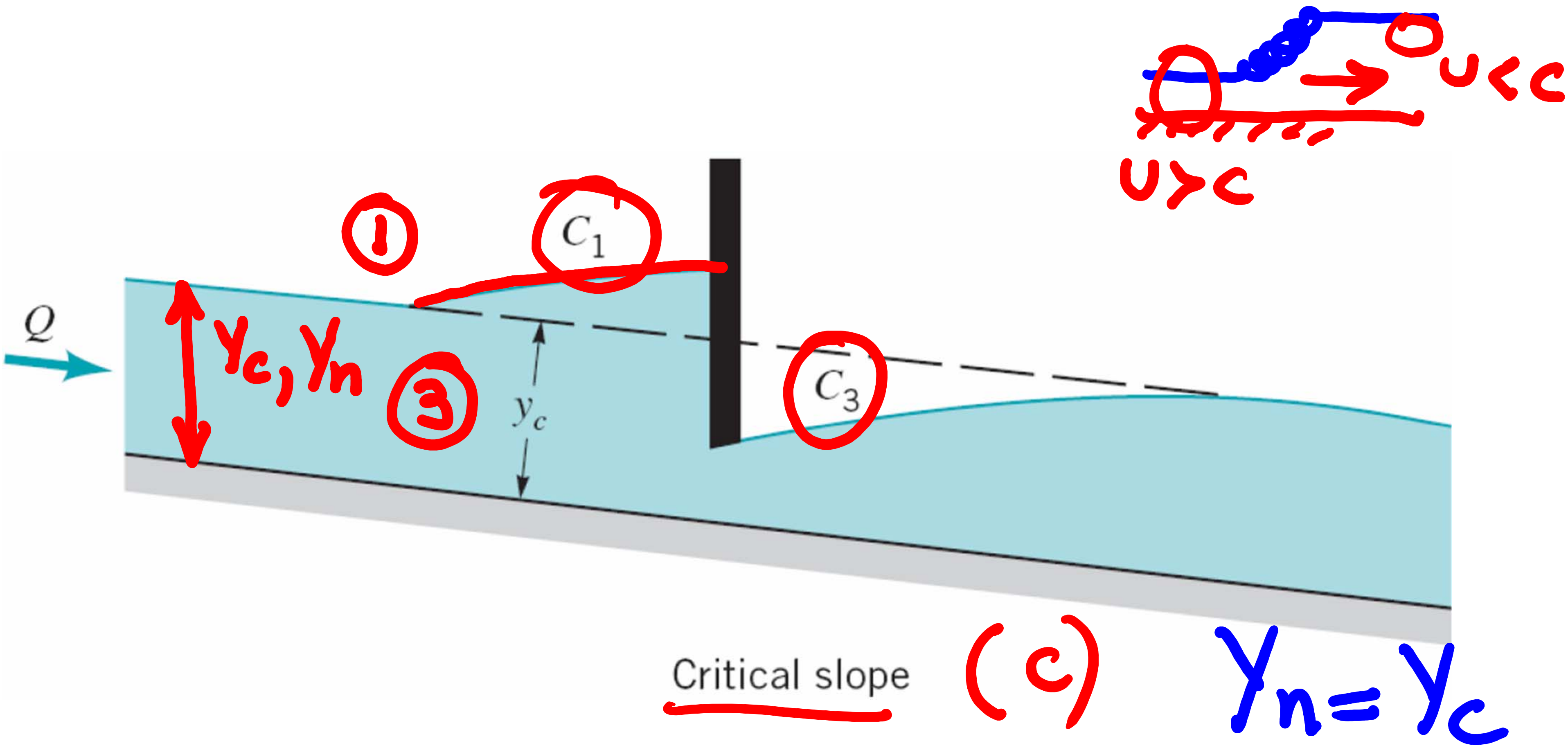
Source: Hydraulic notes, David Apsley

Examples of Gradually Varied Flows



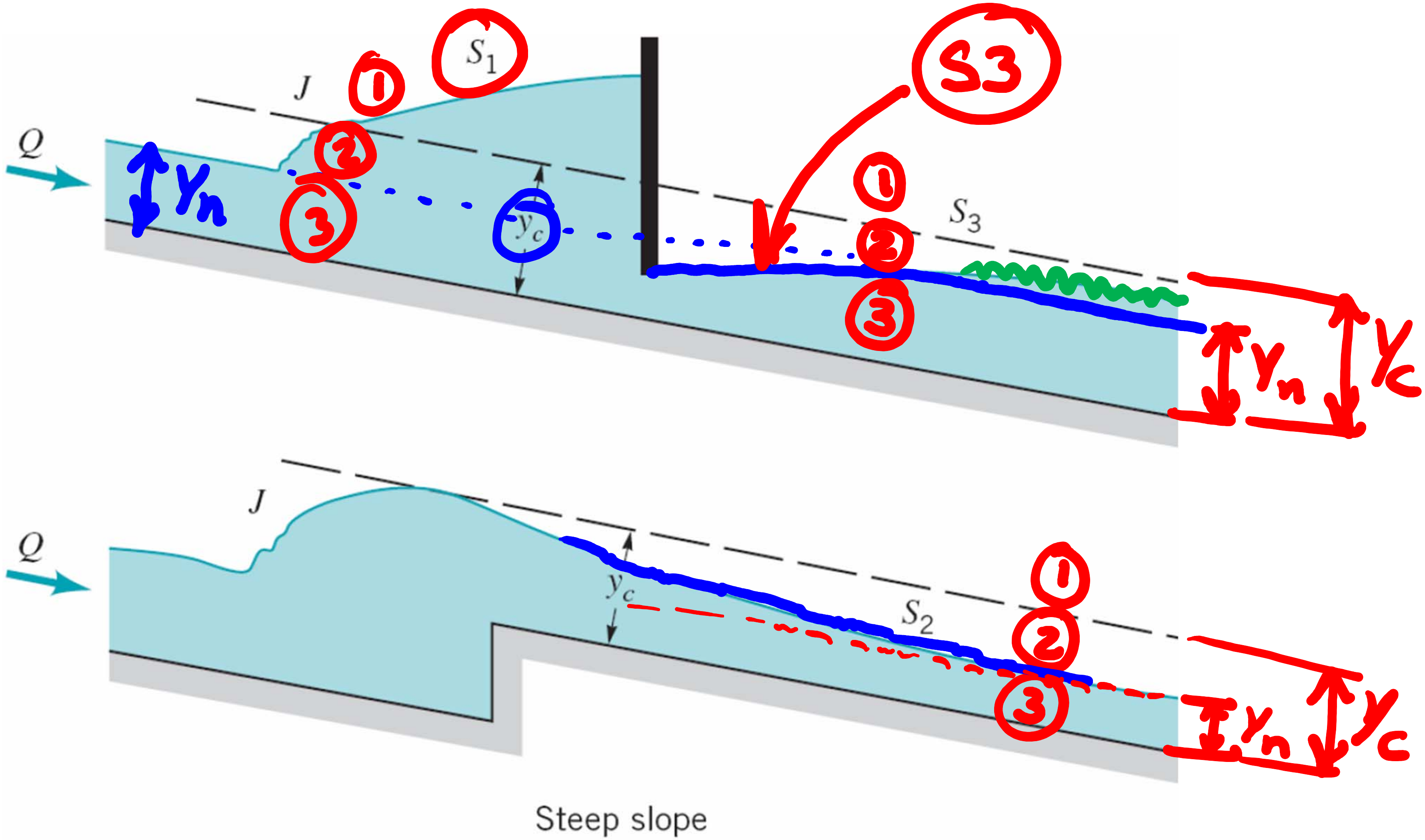
Typical surface configurations for nonuniform depth flow with a mild slope

Examples of Gradually Varied Flows (Cont.)



Typical surface configurations for nonuniform depth flow with a <u>critical slope</u>

Examples of Gradually Varied Flows (Cont.)



Typical surface configurations for nonuniform depth flow with a steep slope (S)

Examples of Gradually Varied Flows (Cont.) 1

$Q = \frac{k}{n} A R^{2/3} S_o^{1/2}$

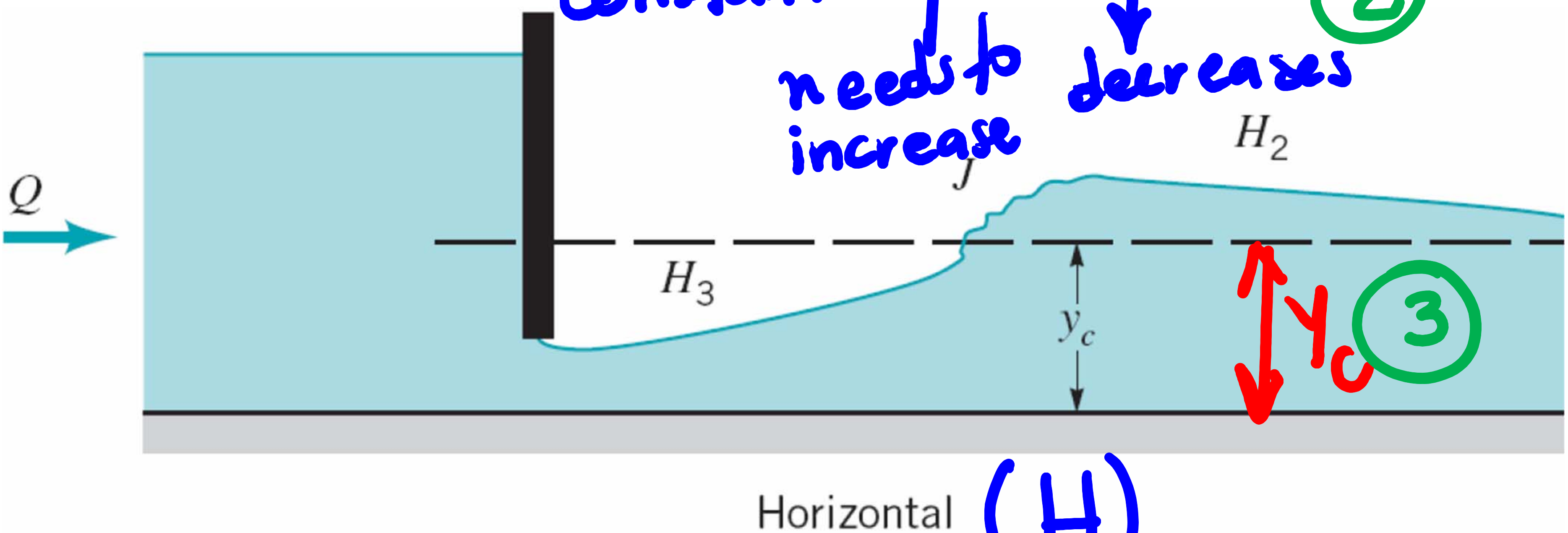
$\underline{\underline{C}} = f(y) \, S_o^{1/2} \ldots y_n \uparrow \infty$

constant

needs to increase

decreases

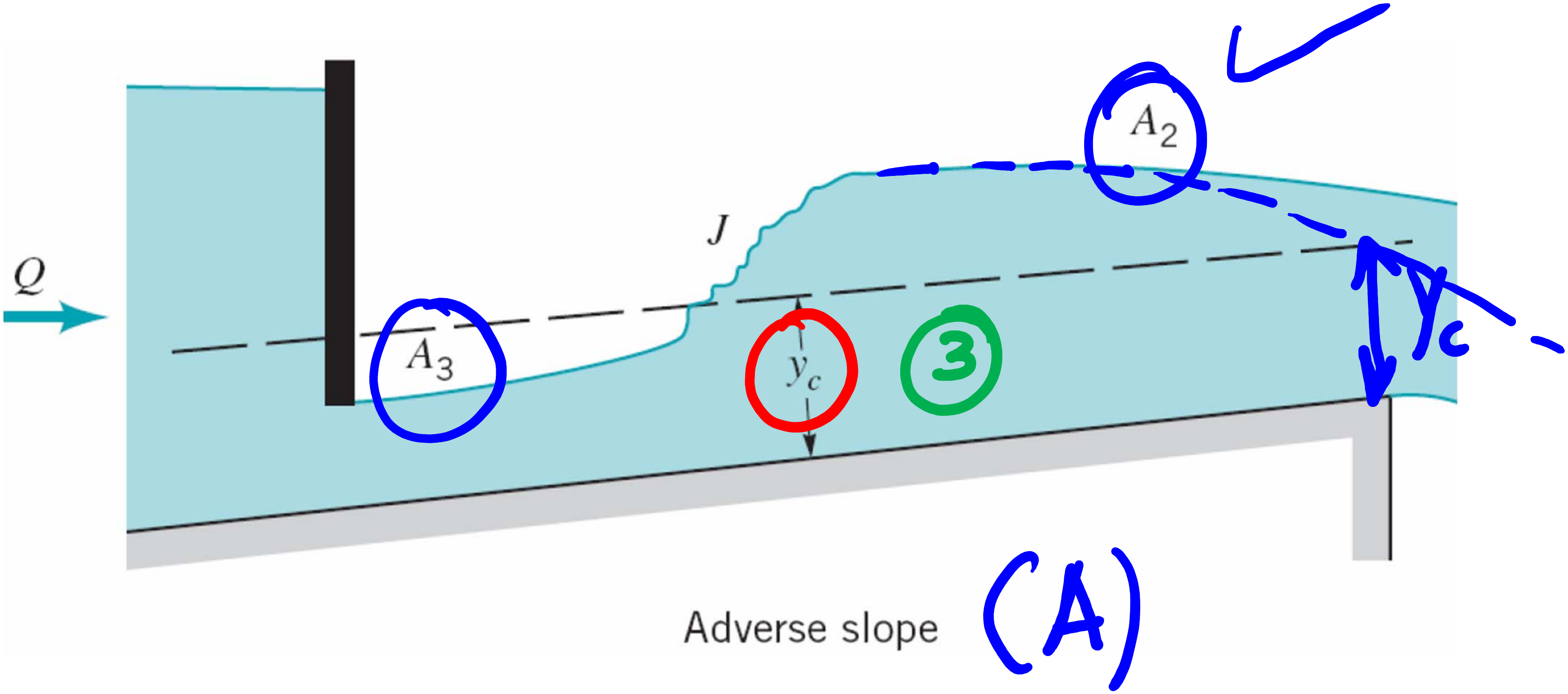
2



Typical surface configurations for nonuniform depth flow with a <u>horizontal slope</u>

Examples of Gradually Varied Flows (Cont.)

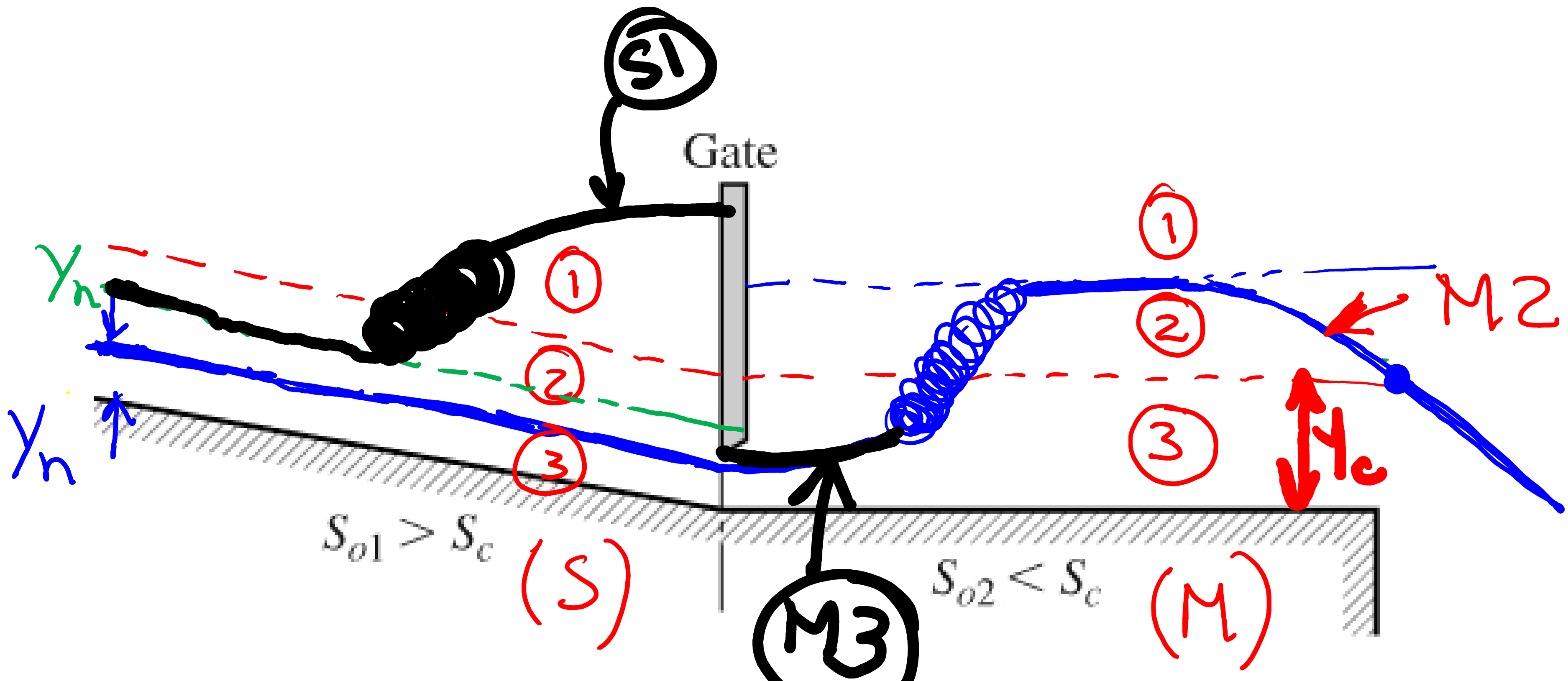
$y_n(\infty)$



Typical surface configurations for nonuniform depth flow with a <u>adverse slope</u>

Example

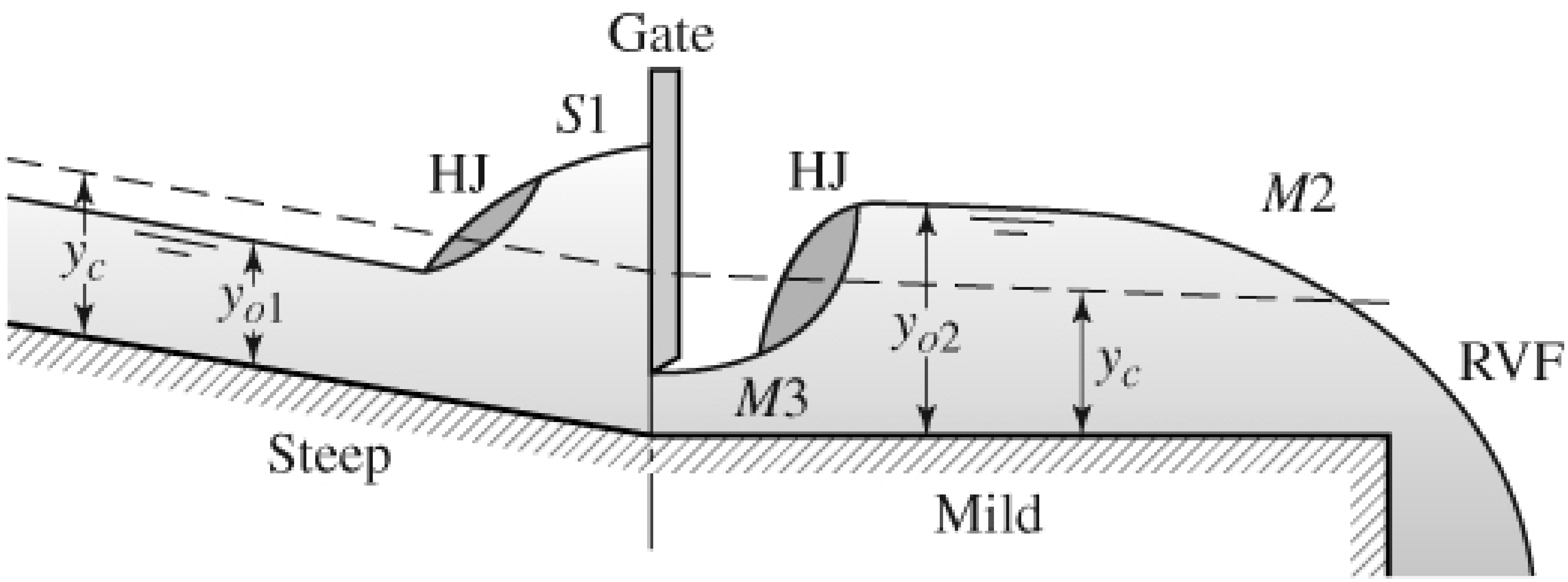
Sketch the water surface profile for the two-reach open-channel system below. A gate is located between the two reaches and the second reach ends with a sudden fall.



(a)

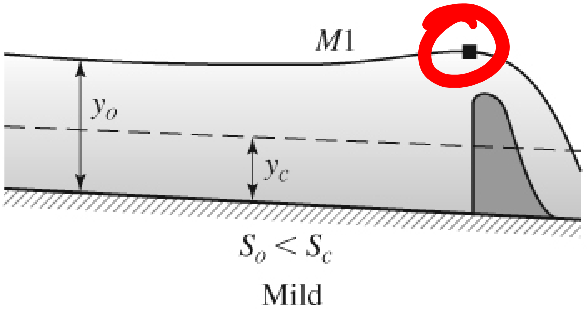
Example (Cont.)

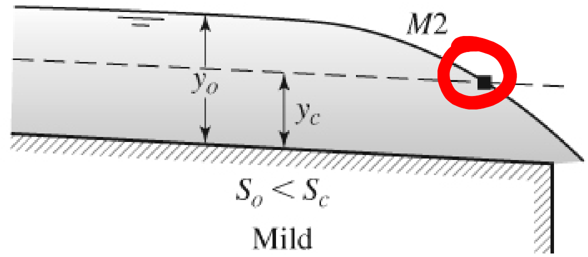
Sketch the water surface profile for the two-reach open-channel system below. A gate is located between the two reaches and the second reach ends with a sudden fall.



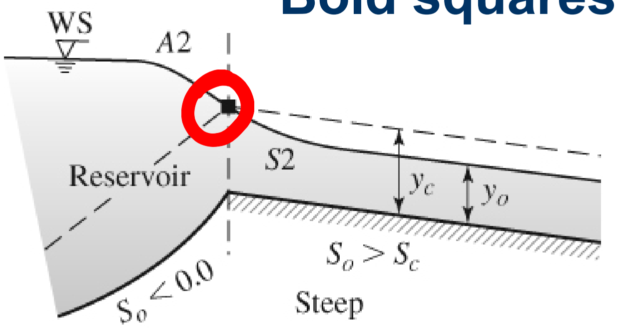
(b)

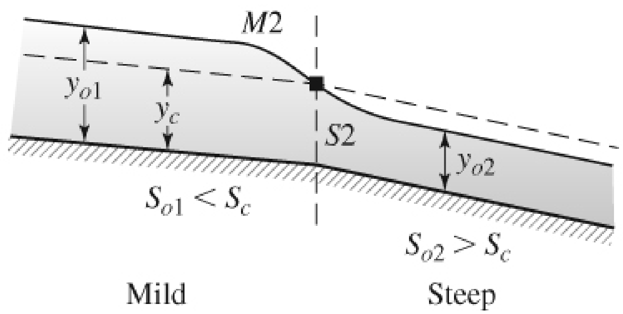
CONTROL SECTIONS

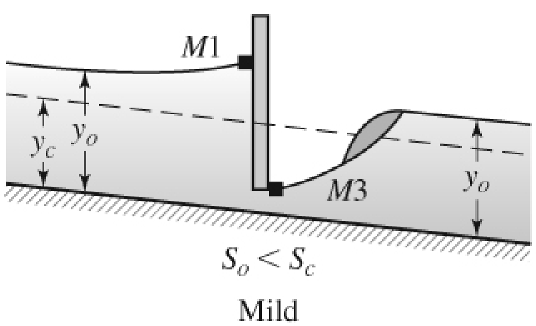


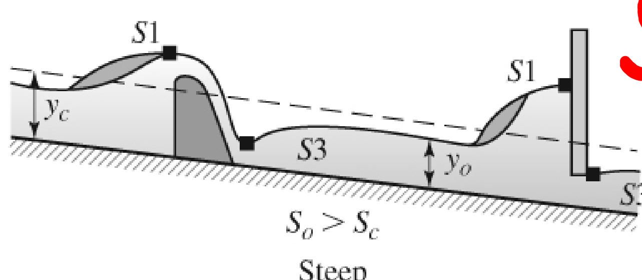


Bold squares show the control sections

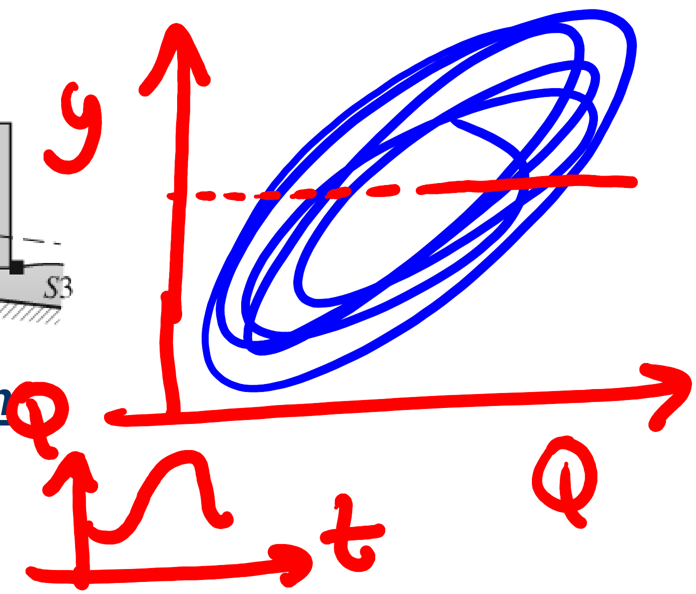








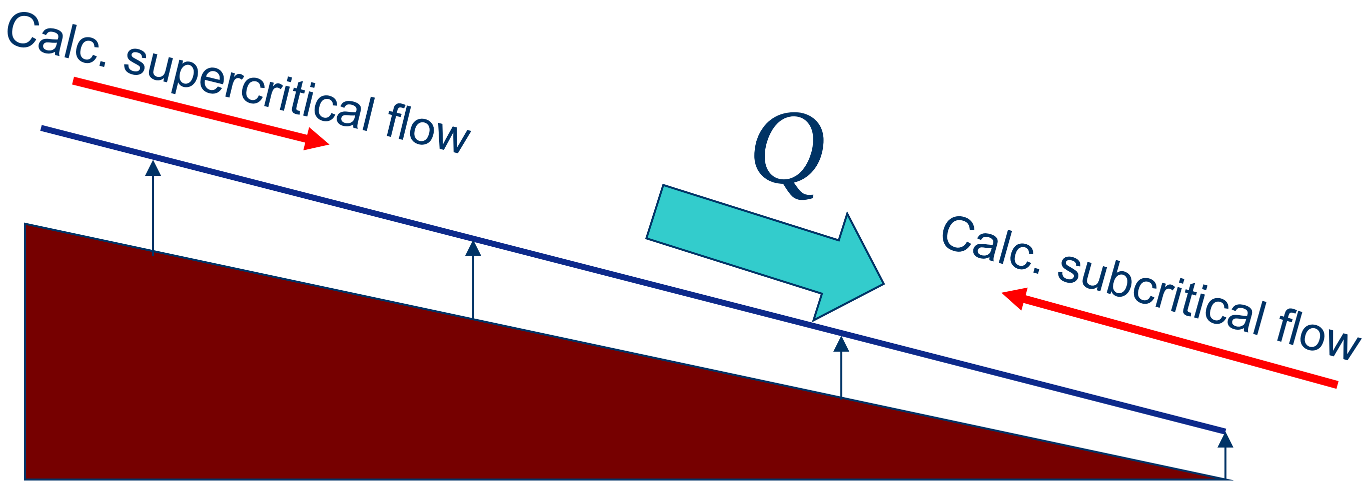
- Control section is a section where there is a unique relationship between discharge and flow depth.
- Gates, weirs, and sudden falls are some examples of control sections.



Subcritical flows have their CS at <u>downstream</u>
Supercritical flows have their CS at <u>upstream</u>

Computation of Water Surface Profiles for Gradually Varied Flows

1. Start at control section (upstream or downstream end) with known water level - $y_{o.}$
2. Proceed upstream or downstream with calculations using new water levels as they are computed.
3. The limits of calculation range between normal and critical depths.
4. In the case of subcritical flows, calculations start downstream.
5. In the case of supercritical flows, calculations start upstream.



The "Standard-Step" Method

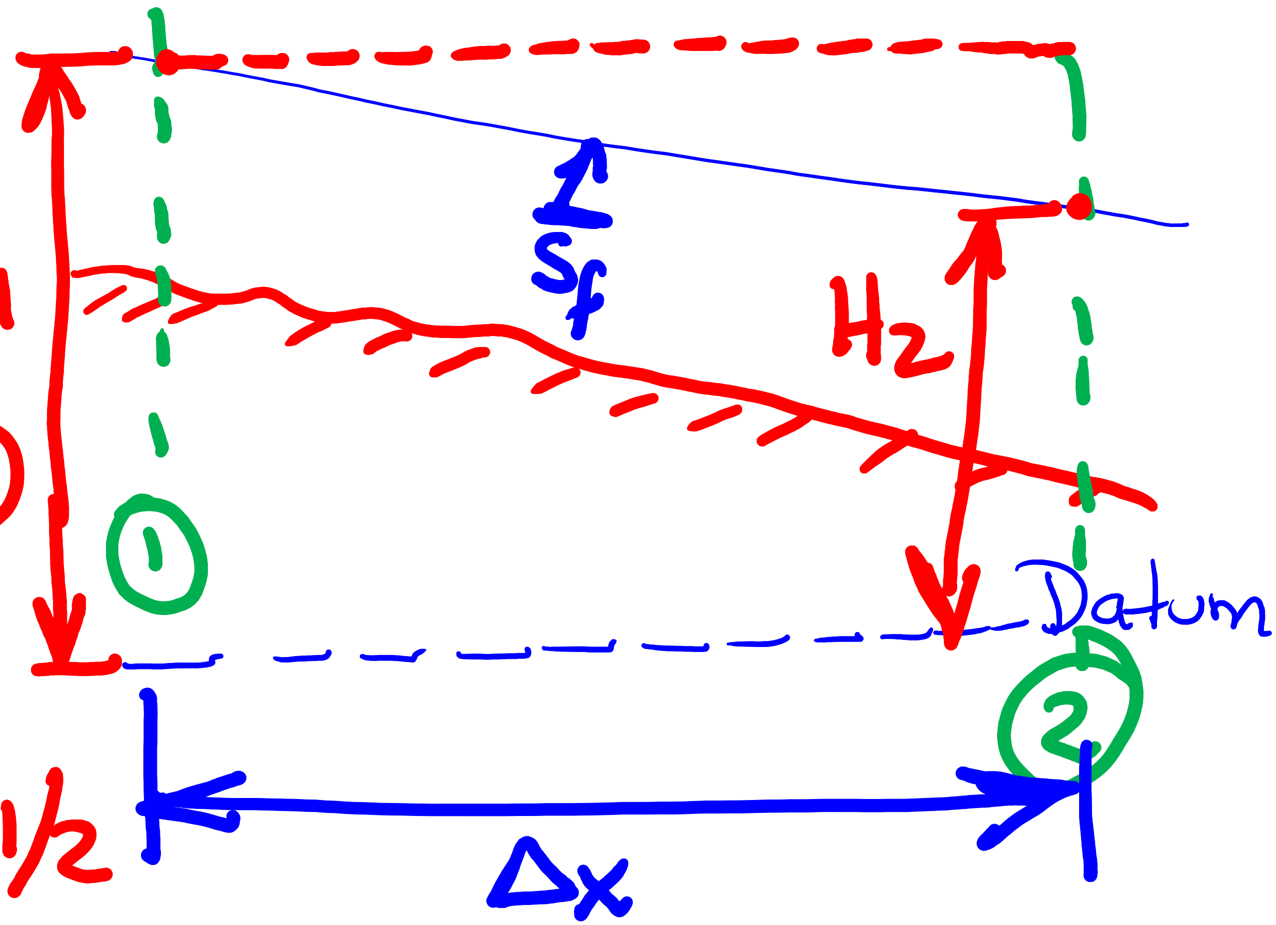
This method solves for depth h at specified distances x, separated by distance intervals Δx. This method solves sequentially for h_1, h_2, h_3, … starting at the control point with depth h_0. The method operates by adjusting h_{i+1} (iteratively) at each step so that the residual of the function is near zero within the specified tolerance. This method requires an iterative solution at each step. In this case we use the Newton Raphson Method as follows

The "Standard-Step" Method

$$H = z + y + \frac{v^2}{2g}$$

$$H_1 = H_2 + \bar{S}_f \Delta x \quad \ldots (1)$$

$$\bar{S}_f = \frac{S_{f1} + S_{f2}}{2}$$



$$Q = \frac{k}{n} A R^{2/3} S_f^{1/2}$$

$$S_f = \left[\frac{Q n}{k A R^{2/3}}\right]^2$$

Newton-Raphson:

$$y = y^* - \frac{f(y^*)}{f'(y^*)}$$

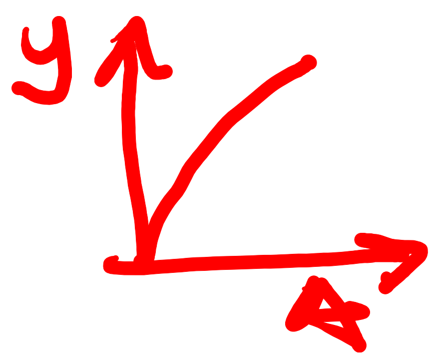
The “Standard-Step” Method Cont.)

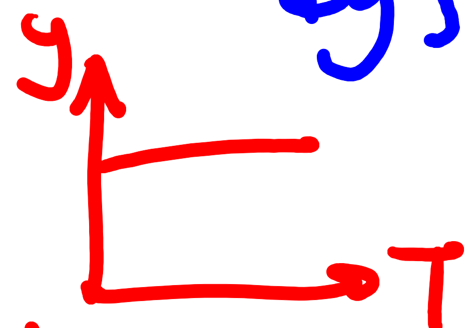
$$f(y) = H_2 - H_1 + \left(\frac{S_{f1} + S_{f2}}{2}\right)\Delta x$$

$$f'(y) = \frac{df}{dy} = 1 + \frac{d}{dy}\left(\frac{V^2}{2g}\right)^2 + \frac{\Delta x}{2}\,\frac{d\overline{S_f}}{dy}$$

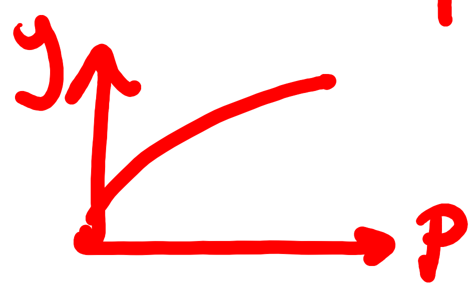
$$\frac{dS_f}{dy} = Q^2 n^2 \left[-\frac{10}{3} P^{4/3} A^{-13/3} T + \frac{4}{3} P^{1/3} A^{-10/3} \frac{dP}{dy}\right]$$

$$\frac{d}{dy}\left(\frac{V^2}{2g}\right) = -\frac{Q^2 T}{gA^3}$$





HEC-RAS

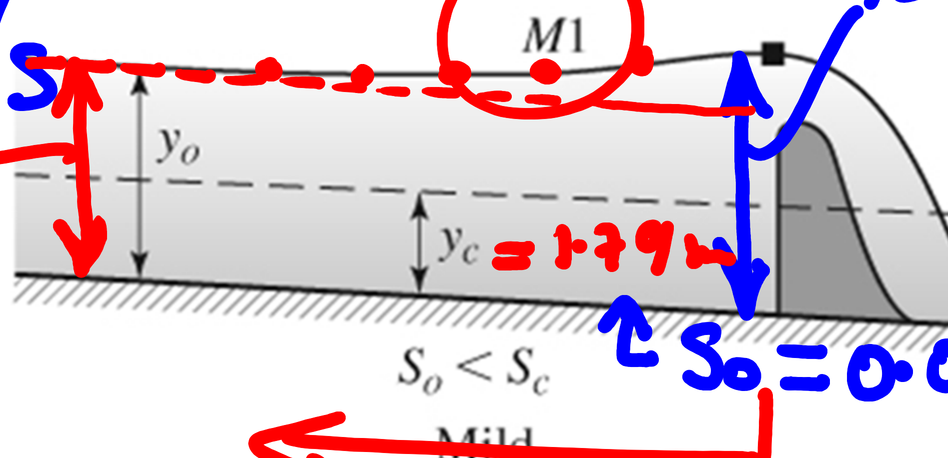


Example

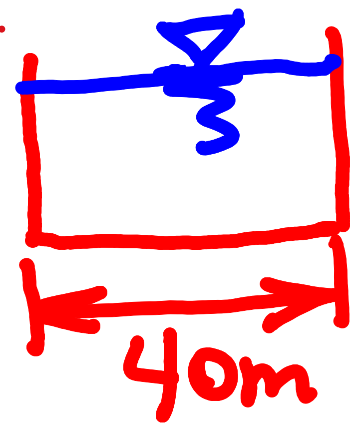
A rectangular concrete-lined channel (n = 0.015) has a constant bed slope of 0.0001 and a bottom width of 40 m. A control gate at the dam increased the depth at the dam to **12 m** when the discharge is 300 m^3/s. Compute the water surface profile from the dam up to 200 km upstream of the dam. (See Excel spreadsheet for rectangular channels).

$n = 0.015$

$Q = 300\ m^3/s$



12m



$y_c = 1.79\ m$

$y_n = y_o$
$= 4.64\ m$

$S_o = 0.0001$

200 Km

Solution

The first step is to calculate the critical and normal depths.

$A = 40y$

$R = A/P \quad P = 40 + 2y$

Y_n is computed using the Manning's formula

$$Q = \frac{K}{n} A R^{2/3} S_o^{1/2}$$

$Q = 300, \; K = 1.0 \; (SI)$

$n = 0.015$

$S_o = 0.0001$

$y_n = 4.64 \text{ m}$

y_c is computed using the critical flow condition:

$Fr = 1 \qquad \frac{Q^2 T}{g A^3} = 1$

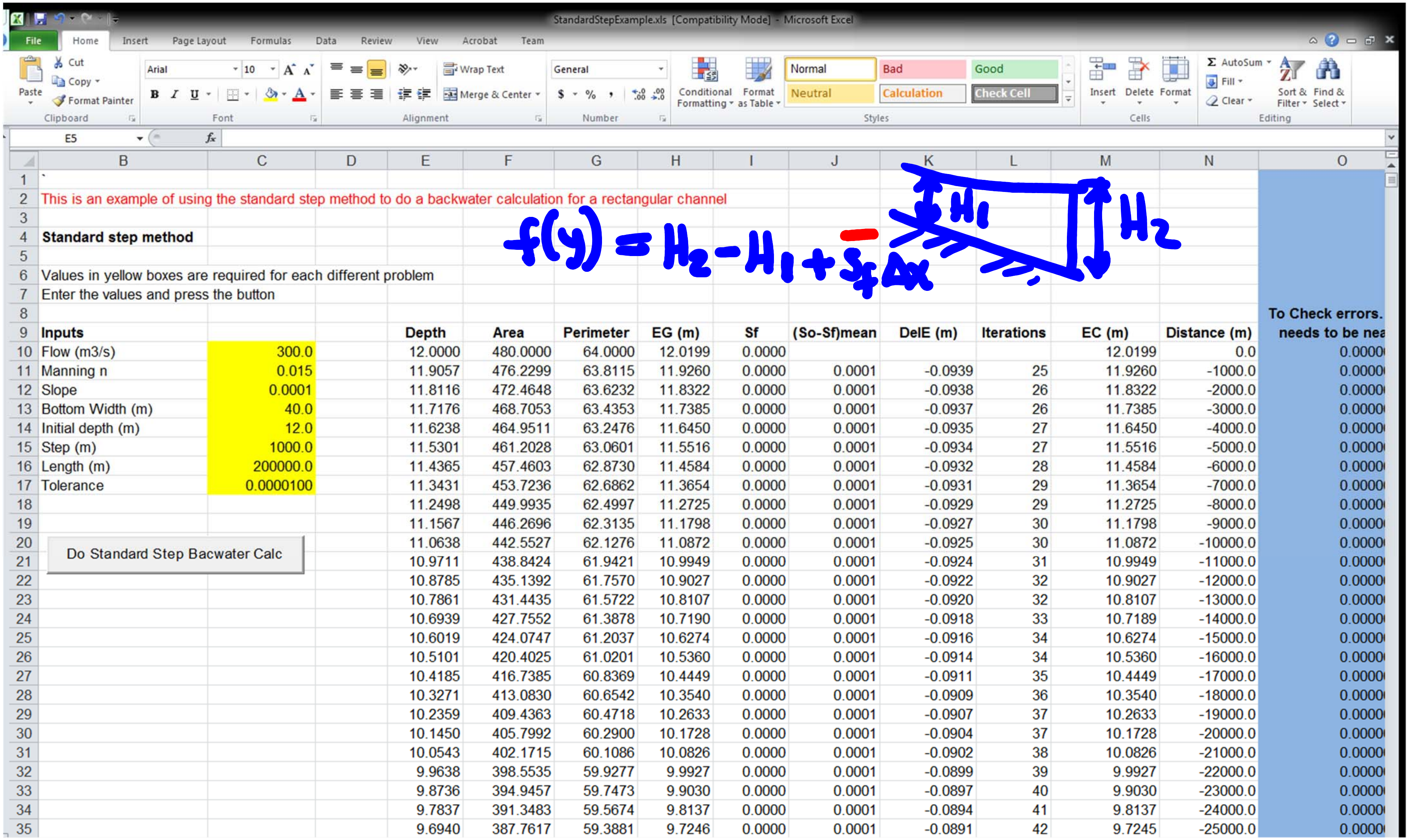
$T = b = 40$

$g = 9.8$

$A = 40y$

$$\boxed{y_c = 1.7899 \text{ m}}$$

Show exercises using Excel for rectangular channels



StandardStepExample.xls [Compatibility Mode] - Microsoft Excel

This is an example of using the standard step method to do a backwater calculation for a rectangular channel

$$f(y) = H_2 - H_1 + \bar{S}_f \Delta x$$

Standard step method

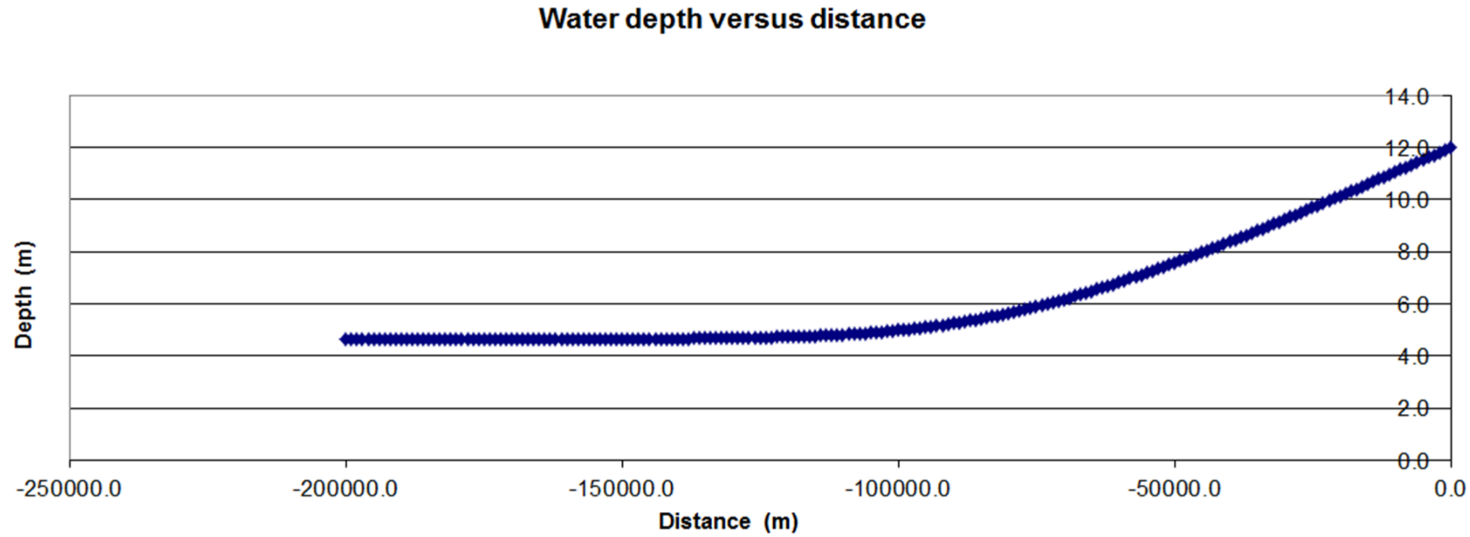
Values in yellow boxes are required for each different problem

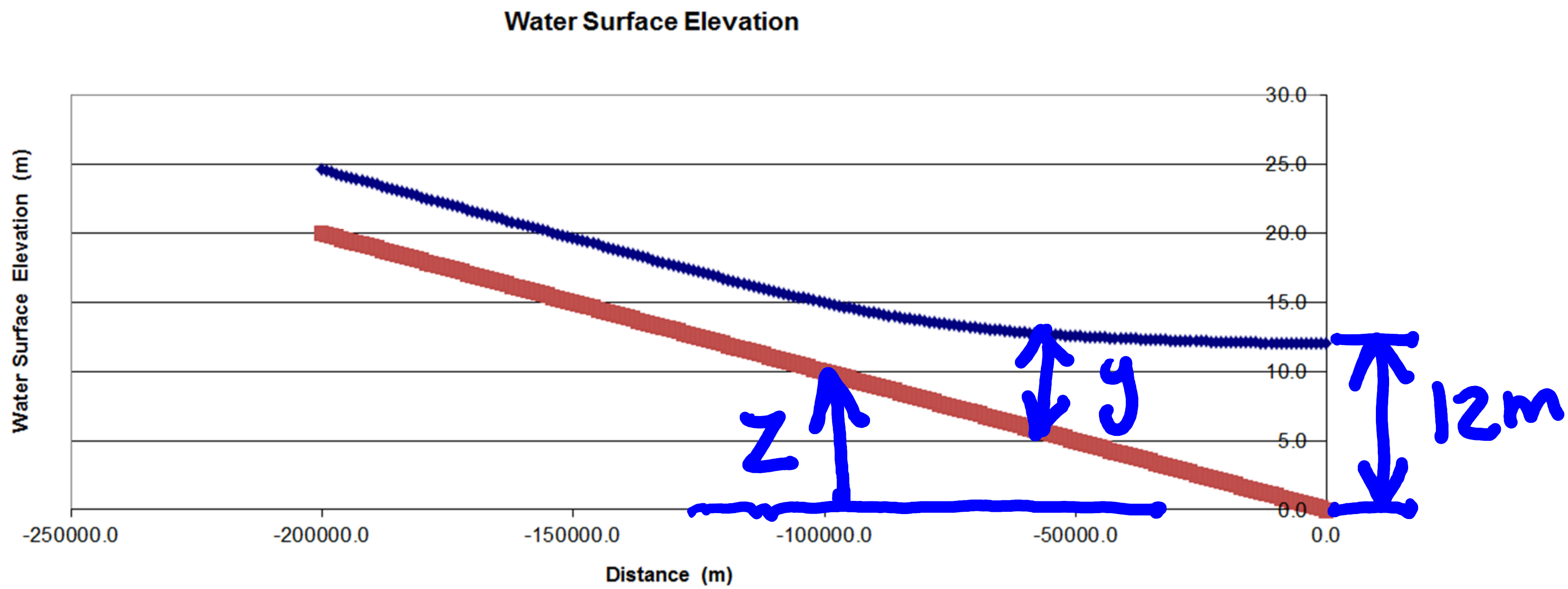
Enter the values and press the button

Do Standard Step Bacwater Calc

Inputs		Depth	Area	Perimeter	EG (m)	Sf	(So-Sf)mean	DelE (m)	Iterations	EC (m)	Distance (m)	To Check errors. needs to be nea
Flow (m3/s)	300.0	12.0000	480.0000	64.0000	12.0199	0.0000				12.0199	0.0	0.0000
Manning n	0.015	11.9057	476.2299	63.8115	11.9260	0.0000	0.0001	-0.0939	25	11.9260	-1000.0	0.0000
Slope	0.0001	11.8116	472.4648	63.6232	11.8322	0.0000	0.0001	-0.0938	26	11.8322	-2000.0	0.0000
Bottom Width (m)	40.0	11.7176	468.7053	63.4353	11.7385	0.0000	0.0001	-0.0937	26	11.7385	-3000.0	0.0000
Initial depth (m)	12.0	11.6238	464.9511	63.2476	11.6450	0.0000	0.0001	-0.0935	27	11.6450	-4000.0	0.0000
Step (m)	1000.0	11.5301	461.2028	63.0601	11.5516	0.0000	0.0001	-0.0934	27	11.5516	-5000.0	0.0000
Length (m)	200000.0	11.4365	457.4603	62.8730	11.4584	0.0000	0.0001	-0.0932	28	11.4584	-6000.0	0.0000
Tolerance	0.0000100	11.3431	453.7236	62.6862	11.3654	0.0000	0.0001	-0.0931	29	11.3654	-7000.0	0.0000
		11.2498	449.9935	62.4997	11.2725	0.0000	0.0001	-0.0929	29	11.2725	-8000.0	0.0000
		11.1567	446.2696	62.3135	11.1798	0.0000	0.0001	-0.0927	30	11.1798	-9000.0	0.0000
		11.0638	442.5527	62.1276	11.0872	0.0000	0.0001	-0.0925	30	11.0872	-10000.0	0.0000
		10.9711	438.8424	61.9421	10.9949	0.0000	0.0001	-0.0924	31	10.9949	-11000.0	0.0000
		10.8785	435.1392	61.7570	10.9027	0.0000	0.0001	-0.0922	32	10.9027	-12000.0	0.0000
		10.7861	431.4435	61.5722	10.8107	0.0000	0.0001	-0.0920	32	10.8107	-13000.0	0.0000
		10.6939	427.7552	61.3878	10.7190	0.0000	0.0001	-0.0918	33	10.7189	-14000.0	0.0000
		10.6019	424.0747	61.2037	10.6274	0.0000	0.0001	-0.0916	34	10.6274	-15000.0	0.0000
		10.5101	420.4025	61.0201	10.5360	0.0000	0.0001	-0.0914	34	10.5360	-16000.0	0.0000
		10.4185	416.7385	60.8369	10.4449	0.0000	0.0001	-0.0911	35	10.4449	-17000.0	0.0000
		10.3271	413.0830	60.6542	10.3540	0.0000	0.0001	-0.0909	36	10.3540	-18000.0	0.0000
		10.2359	409.4363	60.4718	10.2633	0.0000	0.0001	-0.0907	37	10.2633	-19000.0	0.0000
		10.1450	405.7992	60.2900	10.1728	0.0000	0.0001	-0.0904	37	10.1728	-20000.0	0.0000
		10.0543	402.1715	60.1086	10.0826	0.0000	0.0001	-0.0902	38	10.0826	-21000.0	0.0000
		9.9638	398.5535	59.9277	9.9927	0.0000	0.0001	-0.0899	39	9.9927	-22000.0	0.0000
		9.8736	394.9457	59.7473	9.9030	0.0000	0.0001	-0.0897	40	9.9030	-23000.0	0.0000
		9.7837	391.3483	59.5674	9.8137	0.0000	0.0001	-0.0894	41	9.8137	-24000.0	0.0000
		9.6940	387.7617	59.3881	9.7246	0.0000	0.0001	-0.0891	42	9.7245	-25000.0	0.0000

In-class exercises





Show Computer exercises using Annel2

Link of Annel 2 in course website was shown.