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RIVER FLOOD ROUTING

Lecture 11, 05/07/2013

Arturo Leon, Oregon State University (Spring 2013)

Adapted from notes of Transient Flows (Arturo leon), course textbook and notes of Philip B. Bedient

Hydraulic routing requires sol. of eqs. continuity and momentum

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CALIFORNIA FLASH FLOOD

A brief overview on levees

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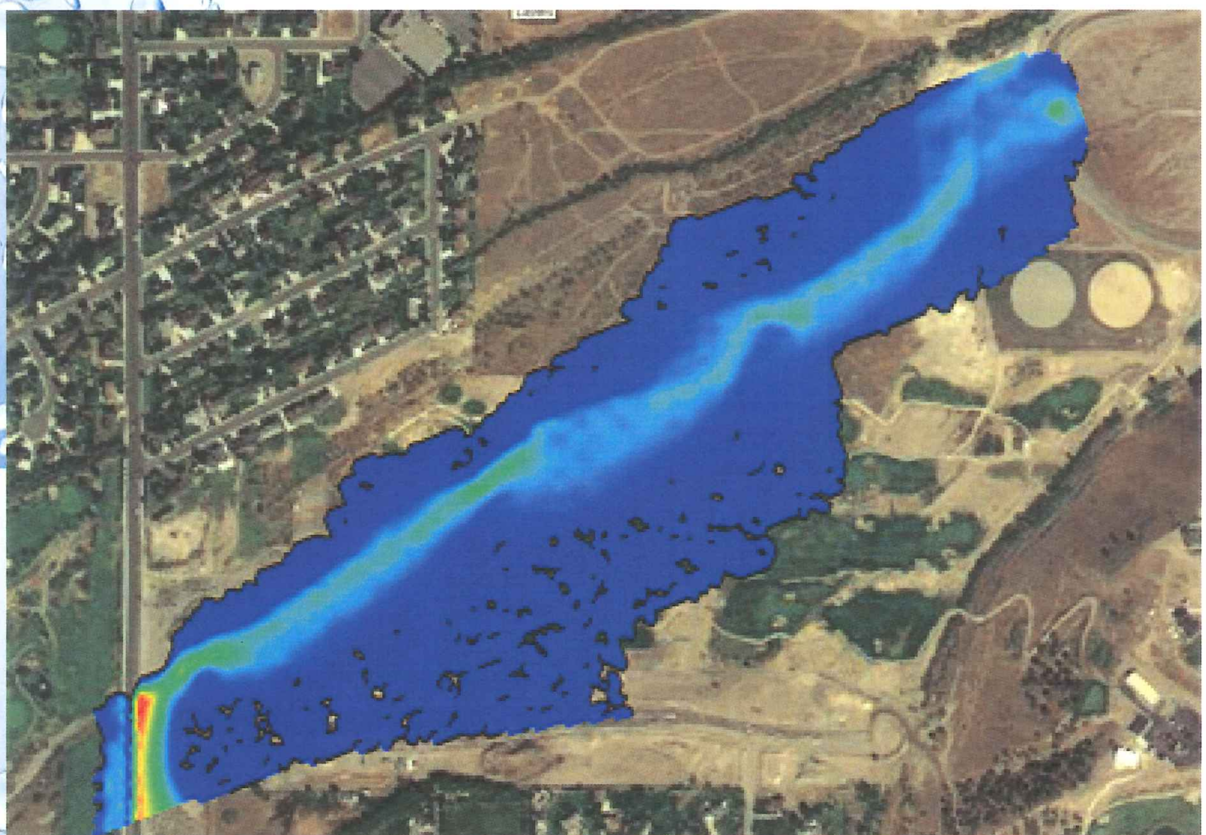

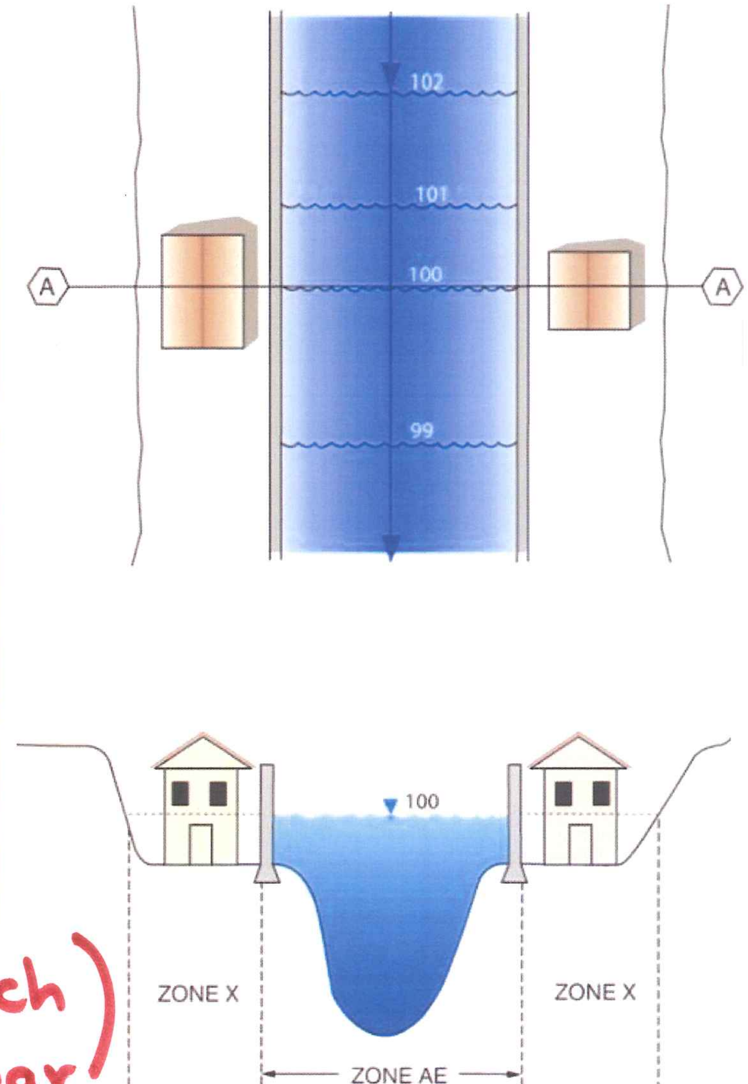

100 yr flood ($P = \frac{1}{100}$ each year)

Source: Analysis and Mapping Procedures for Non-Accredited Levees, FEMA

A brief overview on levees (Cont.)

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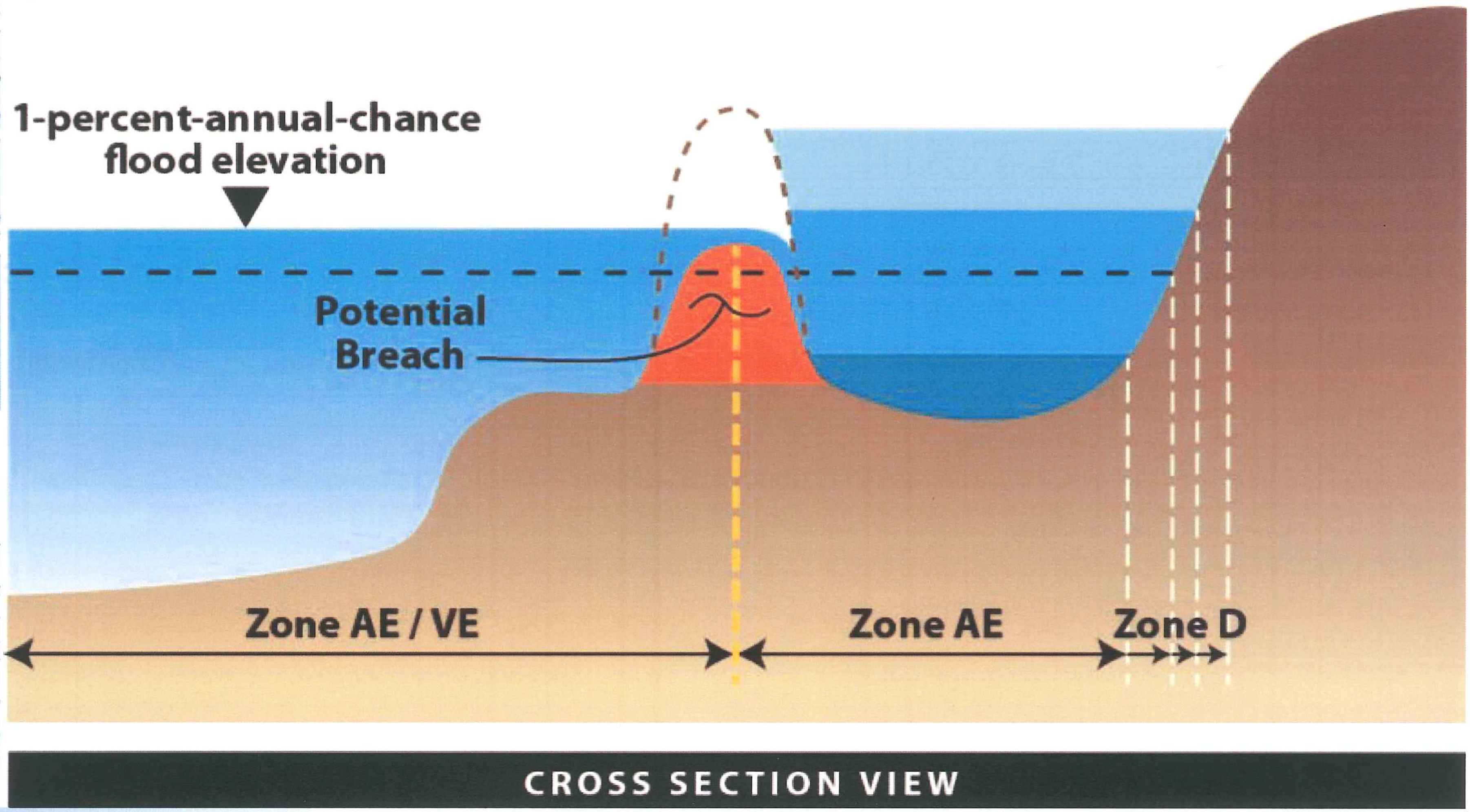

Source: Analysis and Mapping Procedures for Non-Accredited Levees, FEMA

Loss of Life Estimation in Flood Risk Assessment

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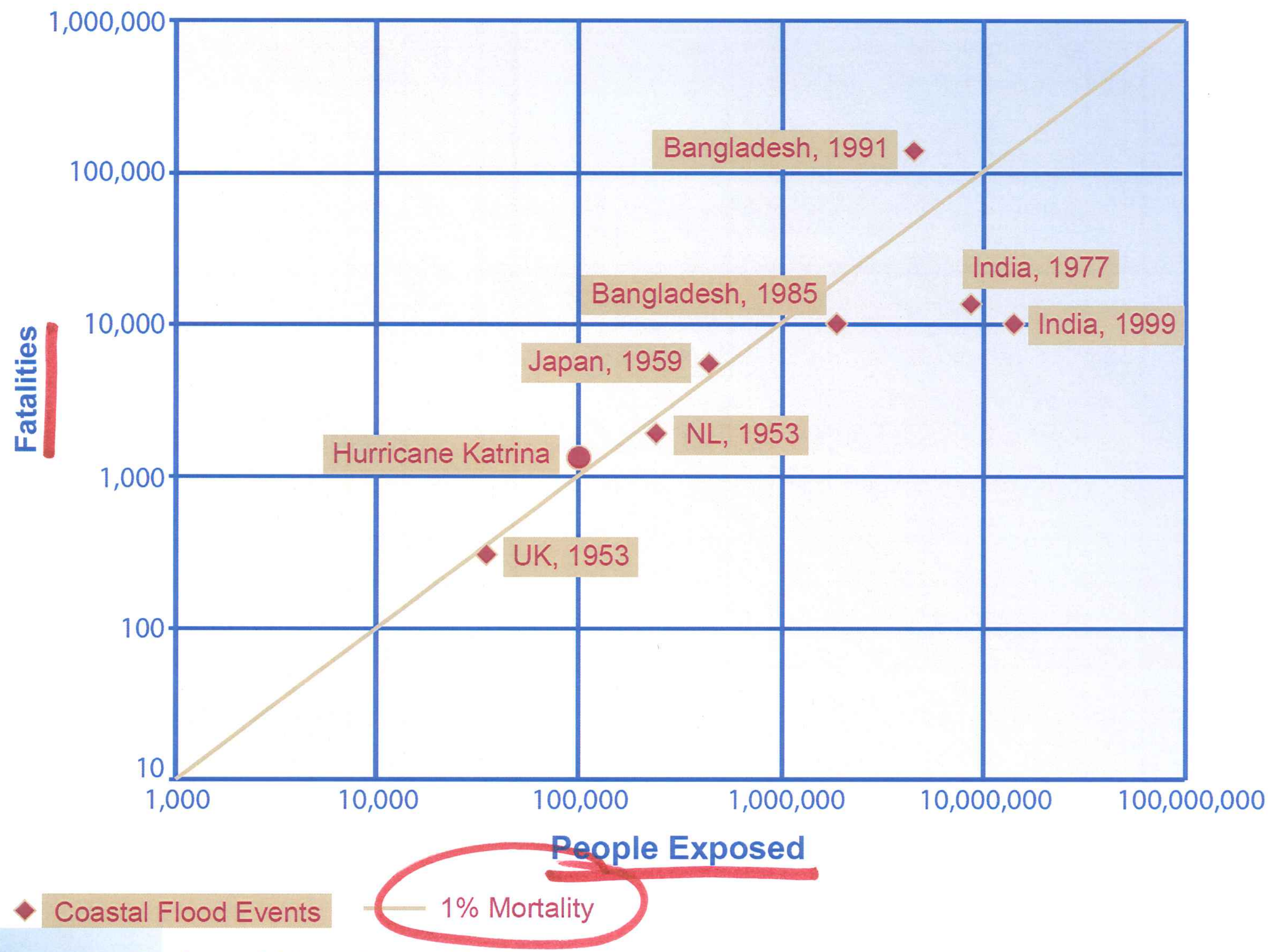
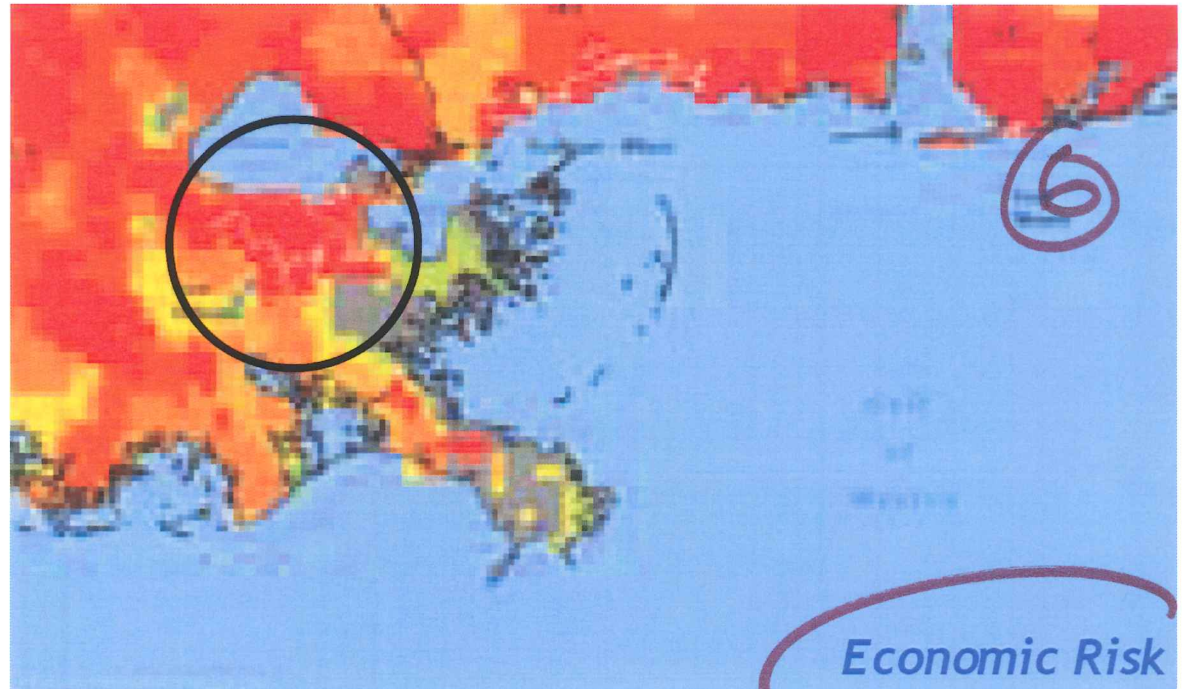
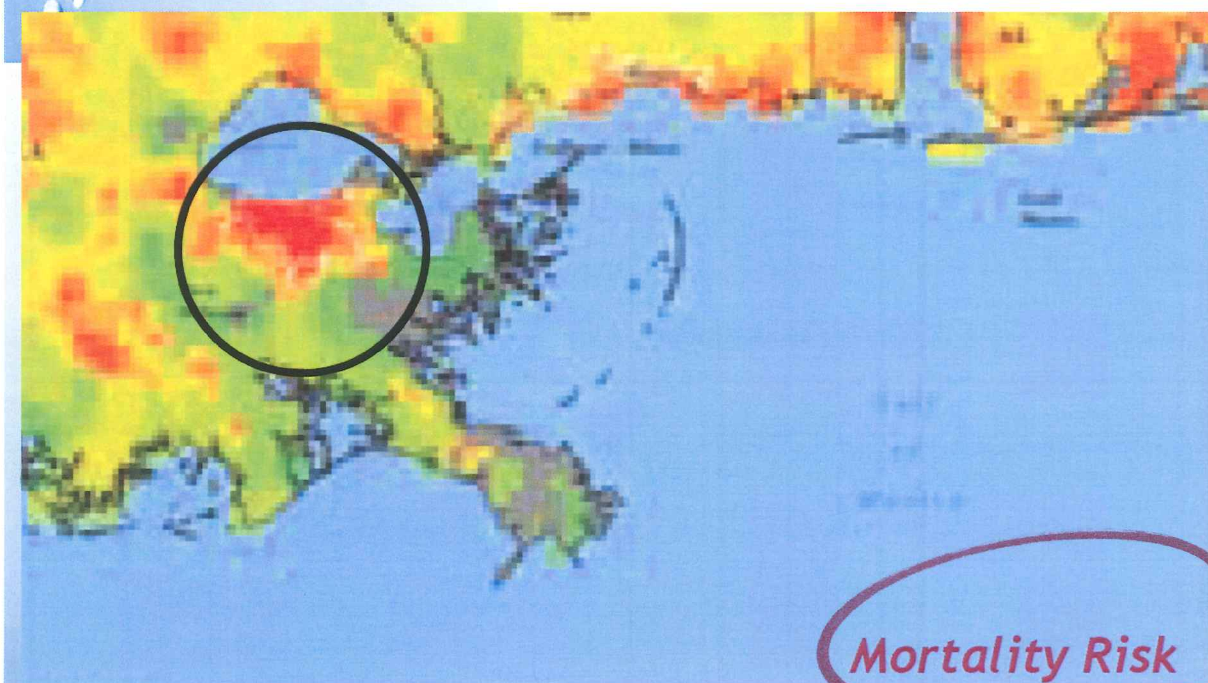


Source: Theory and Applications, S.N. Jonkman, 2007

Risk-based mapping





Source: RECOMMENDATIONS FOR A NATIONAL LEVEE SAFETY PROGRAM: *A Report to Congress from the National Committee on Levee Safety*

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Navier-Stokes (N-S) Equations

The three N-S momentum equations can be written in compact form as

$i = 1, 2, 3$

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = \frac{-1}{\rho}\frac{\partial p}{\partial x_i} + \nu \frac{\partial^2 u_i}{\partial x_j \partial x_j} + g_i$$

The equation of continuity for an incompressible fluid

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

$$\boxed{\frac{\partial u_i}{\partial x_i} = 0}$$

u : Velocity x-direction

V : Veloc y-direction

W : Vel. z-direction

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Reynolds Time-averaged Navier-Stokes Equations

These are obtained from the N-S equations and include the flow turbulence effect as well.

$$\frac{\partial \overline{u_i}}{\partial t} + \overline{u_j} \frac{\partial \overline{u_i}}{\partial x_j} = -\frac{1}{\rho} \frac{\partial \overline{p}}{\partial x_i} + \frac{\partial \tau_{vij}}{\partial x_j} + \frac{1}{\rho} \frac{\partial \tau_{Rij}}{\partial x_j} + g_i$$

$$\frac{\partial \overline{u_i}}{\partial x} = 0$$

$u = \overline{u} + u'$

$\overline{u}$ (averaged velocity)

where $\tau_{vij} = \nu \left(\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i} \right)$ **viscous stress tensor**

u' (fluctuation)

$\tau_{Rij} = -\rho \overline{u'_i u'_j}$ **Reynold stress tensor**

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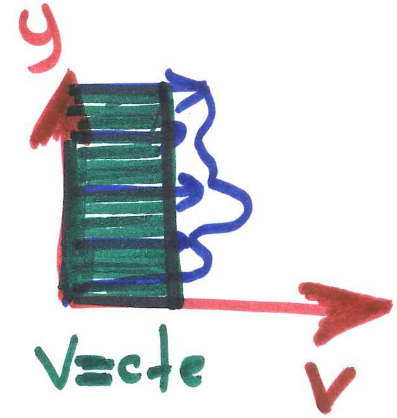
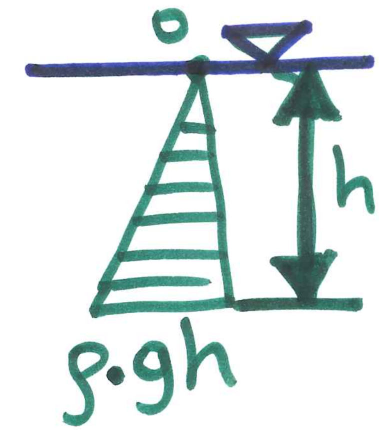
2D Saint Venant Equation



- Obtained from RNS equations by depth-averaging.
- Suitable for flow over a dyke, through the breach, over the floodplain.
- Assumptions:

hydrostatic pressure distribution, small channel slope



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2D Saint Venant Equations

$$\frac{\partial h}{\partial t}+\frac{\partial(hu)}{\partial x}+\frac{\partial(hv)}{\partial y}=0 \quad \textit{continuity eq.}$$

h: water depth
u: vel. x-dir.
v: vel. y-dir.

$$\frac{\partial(hu)}{\partial t}+\frac{\partial(hu^2)}{\partial x}+\frac{\partial(huv)}{\partial y}+gh\frac{\partial h}{\partial x}=-gh\frac{\partial z_b}{\partial x}$$

$$-gn^2u\frac{\sqrt{u^2+v^2}}{h^{1/3}} \quad \textit{x-momentum eq}$$

n: Manning's roughness

$$\frac{\partial(hv)}{\partial t}+\frac{\partial(huv)}{\partial x}+\frac{\partial(hv^2)}{\partial y}+gh\frac{\partial h}{\partial y}=-gh\frac{\partial z_b}{\partial y}$$

$$-gn^2v\frac{\sqrt{u^2+v^2}}{h^{1/3}} \quad \textit{y-momentum eq}$$

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1D Saint-Venant Equation

$$\boxed{\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=0}$$

Eq. continuity

$$\boxed{\frac{\partial U}{\partial t}+U\frac{\partial U}{\partial x}+g\frac{\partial h}{\partial x}=g(S_0-S_f)}$$

Momentum X-direction

The friction slope Sf is usually obtained from a uniform flow formula such as Manning or chezy.

$$Q=\frac{K}{n}AR^{2/3}S_f^{1/2}$$

Manning's equation

$$S_f=\frac{Q|Q|\,n^2}{K^2A^2R^{4/3}}$$

important for dam break or sudden opening of gates

important for expansions/contractions

(12)

Identifying terms in the Equations of Saint Venant

$$\underbrace{\frac{1}{g}\frac{\partial u}{\partial t}}_{\text{Local acceleration}} + \underbrace{\frac{u}{g}\frac{\partial u}{\partial x}}_{\text{convective acceleration}} + \underbrace{\frac{\partial h}{\partial x}}_{\text{Pressure gradient (tailwater)}} = \underbrace{S_o}_{\text{gravity}} - \underbrace{S_f}_{\text{friction}}$$

dynamic wave	*dyn. quasi steady wave*	*diffusive wave*	*kinematic wave*

minimum for rivers

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Relative Weight of Each Term in SV Equation

Order of magnitude of each term In SV equation for a flood in the Rhone river

$$\frac{1}{g}\frac{\partial u}{\partial t} \quad O(10^{-5})$$

$$\frac{u}{g}\frac{\partial u}{\partial x} \quad O(10^{-5})$$

$$\boxed{S_o \quad O(10^{-3})}$$ 1/1000

$$S_f \quad O(10^{-3})$$

Steep slope

Kinematic wave works very well (overland flows)

Flat slope

May need to add other terms

River Routing

$k = 1$ (SI)

$k = 1.49$ (English)

n = Manning's roughness coefficient

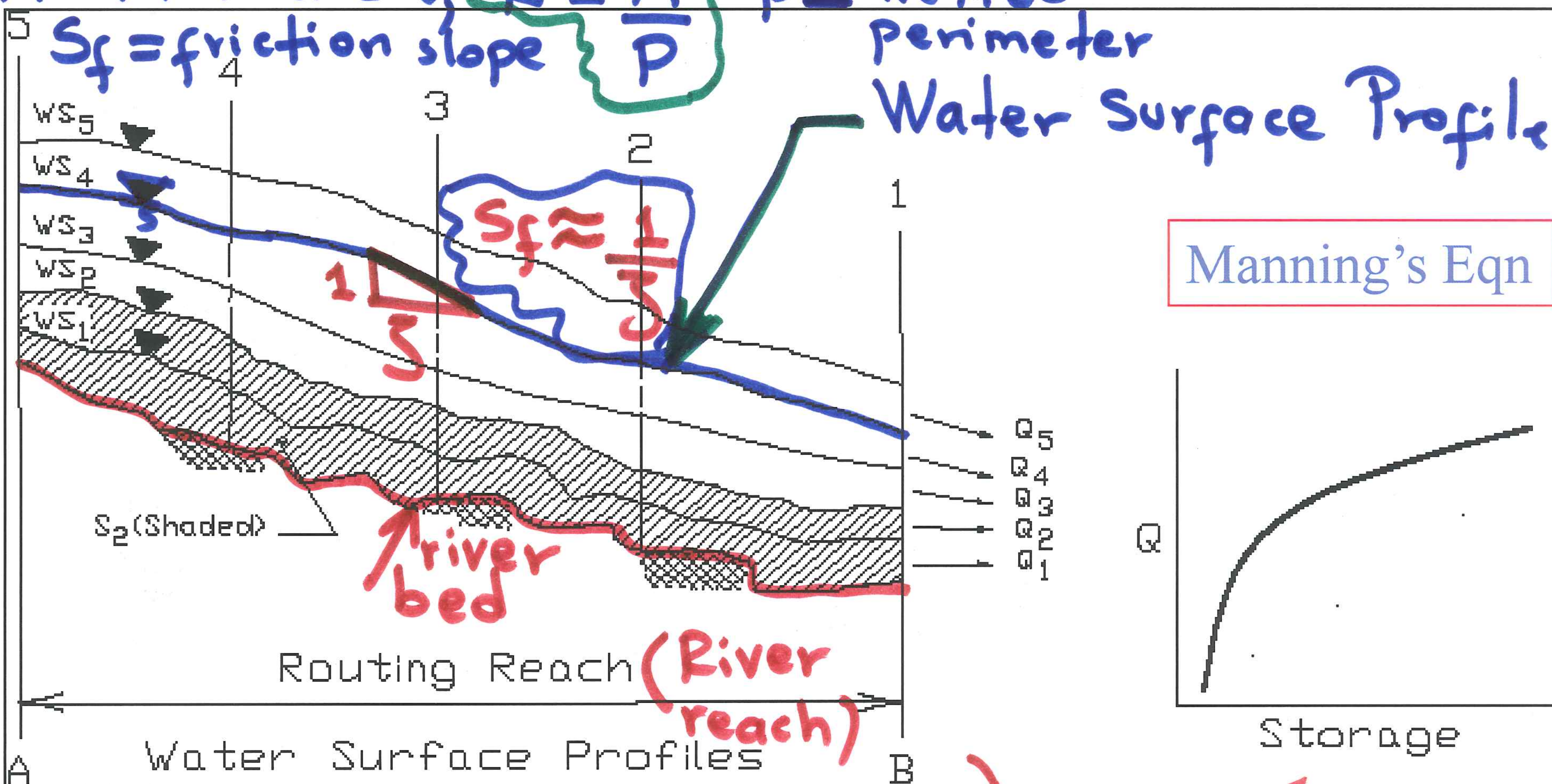
A = Flow area, $\boxed{R = \frac{A}{P}}$ P = Wetted perimeter

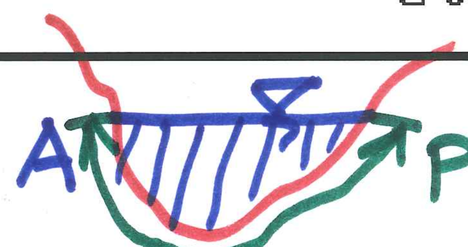
S_f = friction slope

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

Water Surface Profile

$\boxed{S_f \approx \frac{1}{5}}$

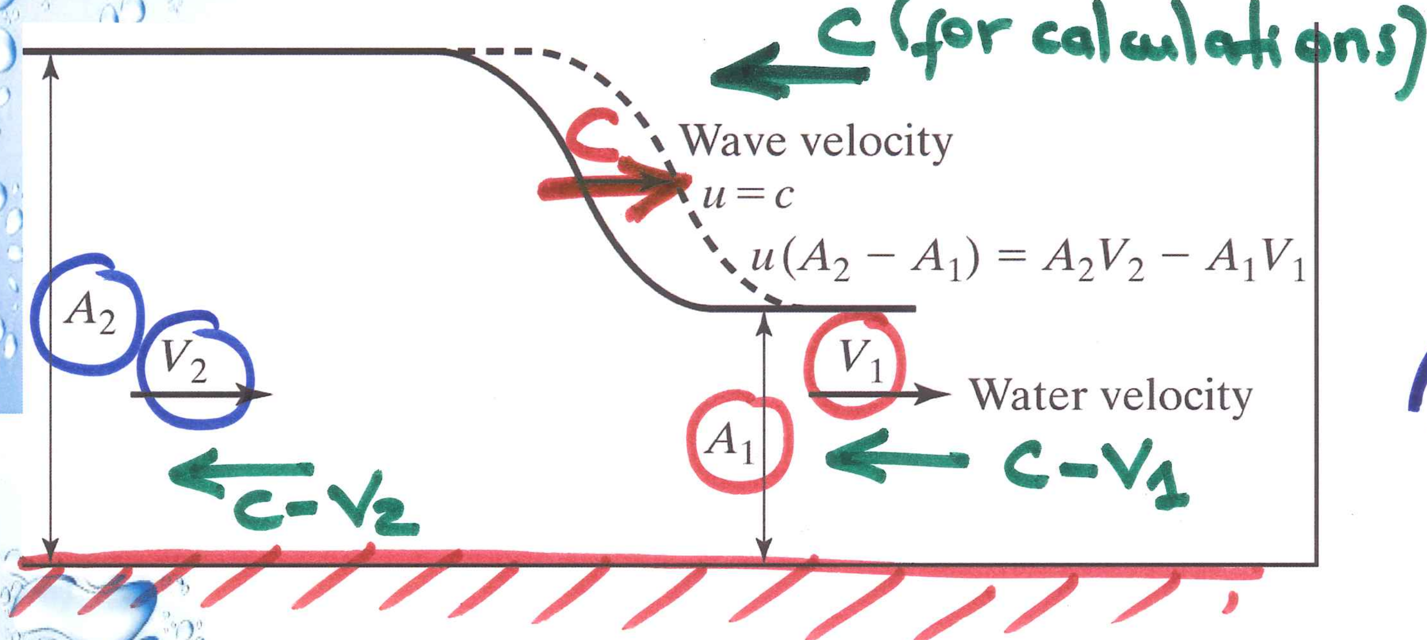


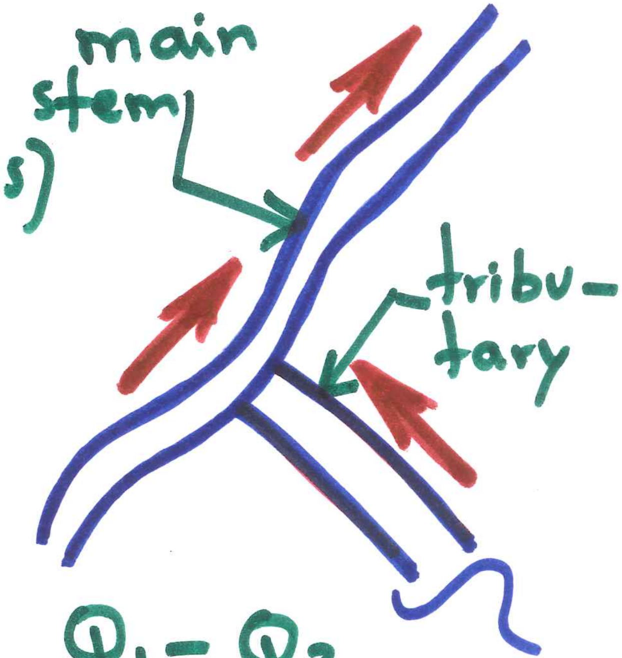


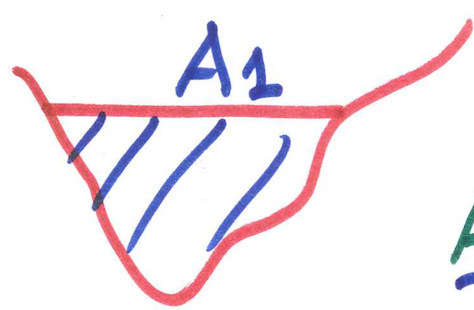
Movement of a flood wave

15 a

Monoclinal rising flood wave







$Q_1 = Q_2$

$Q = AV$

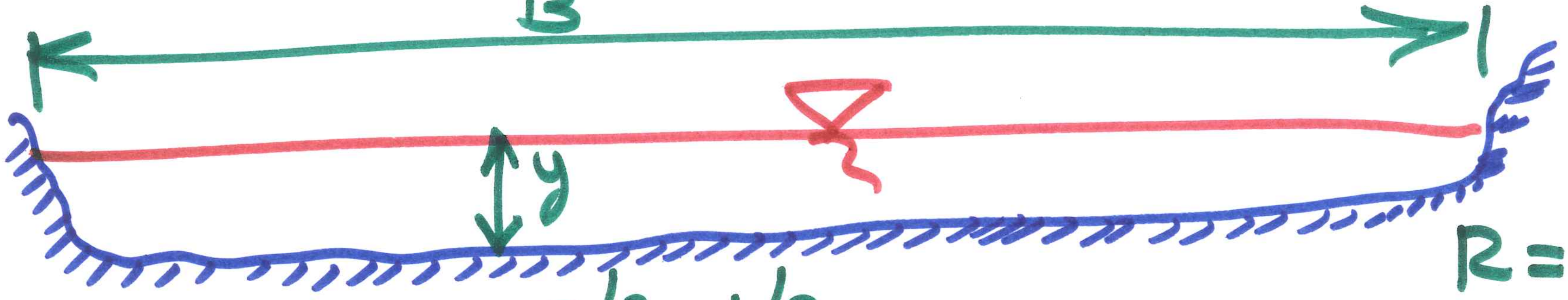
$(c - V_1)A_1 = (c - V_2)A_2$

$A_2V_2 - A_1V_1 = c(A_2 - A_1)$

$Q_2 - Q_1 = c(A_2 - A_1)$

(1) $\boxed{c = \Delta Q / \Delta A} = \frac{dQ}{dA} = \frac{dQ}{B\,dy}$

15 b



$R = y$

$R = \frac{A}{P} = \frac{By}{B + \cancel{2y}^{\,0}}$

when $\frac{2y}{B} \ll 0$

$R \approx \frac{\cancel{B}y}{\cancel{B}} = y$

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

$Q = \frac{k}{n} By \cdot y^{2/3} S_f^{1/2}$

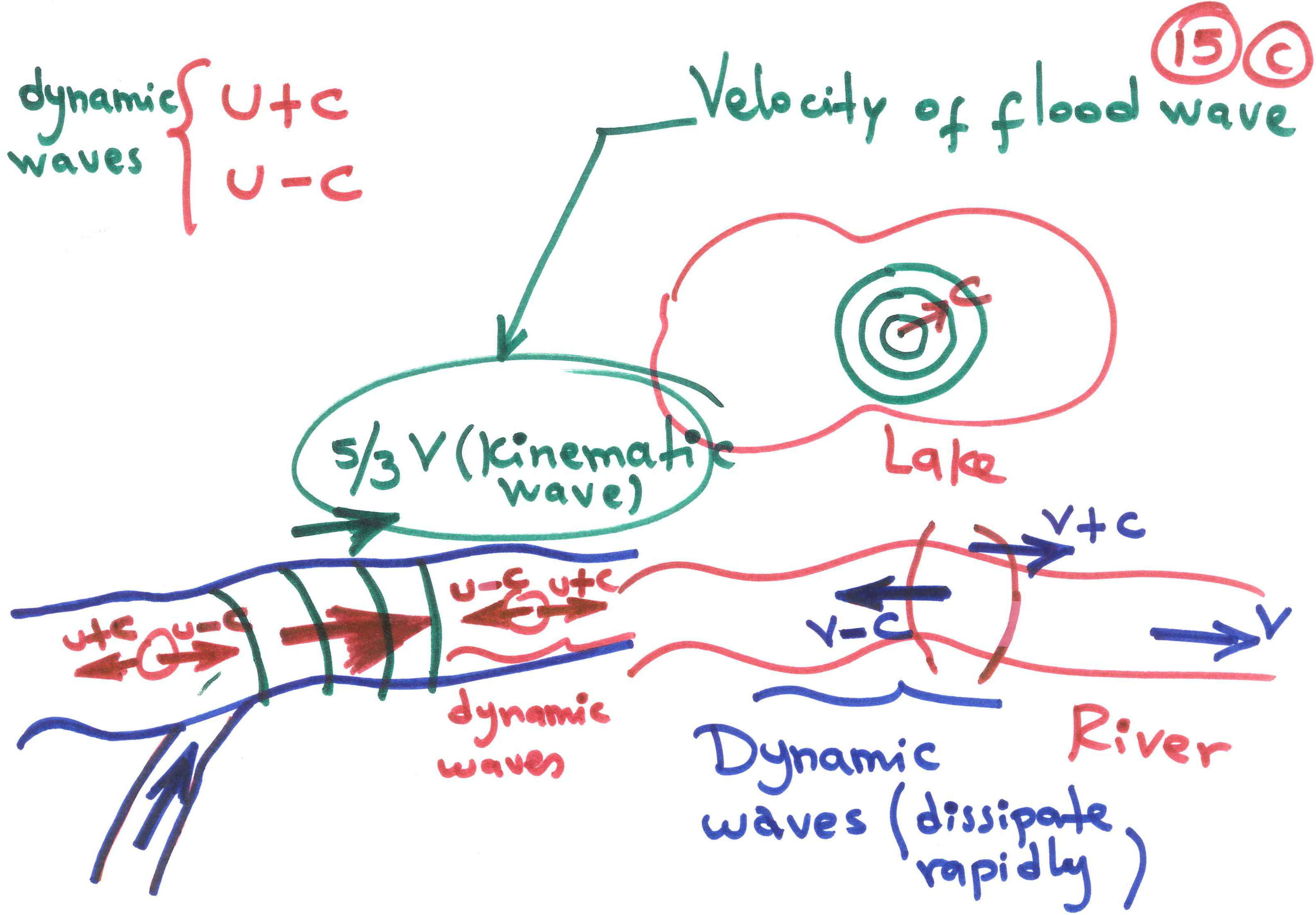
(2) $\boxed{Q = \frac{k}{n} B \cdot y^{5/3} S_f^{1/2}}$ $\rightarrow$ $V = \frac{Q}{A} = \underline{\underline{\frac{k}{n} y^{2/3} S_f^{1/2}}}$

(2) in (1)

$c = \frac{1}{\cancel{B}} \frac{k}{n} \cancel{B} S_f^{1/2} \left(\frac{5}{3}\right) y^{2/3} = \frac{5}{3} \underline{\underline{\frac{k}{n} y^{2/3} S_f^{1/2}}} = \frac{5}{3} V$

$C = \frac{5}{3} V$

if $V = 3\ m/s$,
$c = 5\ m/s$


15 c
Velocity of flood wave
dynamic waves
U+c
U−c
5/3 V (Kinematic wave)
Lake
c
u−c
u+c
dynamic waves
V+c
V−c
V
River
Dynamic waves (dissipate rapidly)

River Rating Curves

- Inflow and outflow are complex
- Peak flow Q_p greater on rise limb than on the falling limb
- Peak storage occurs later than Q_p

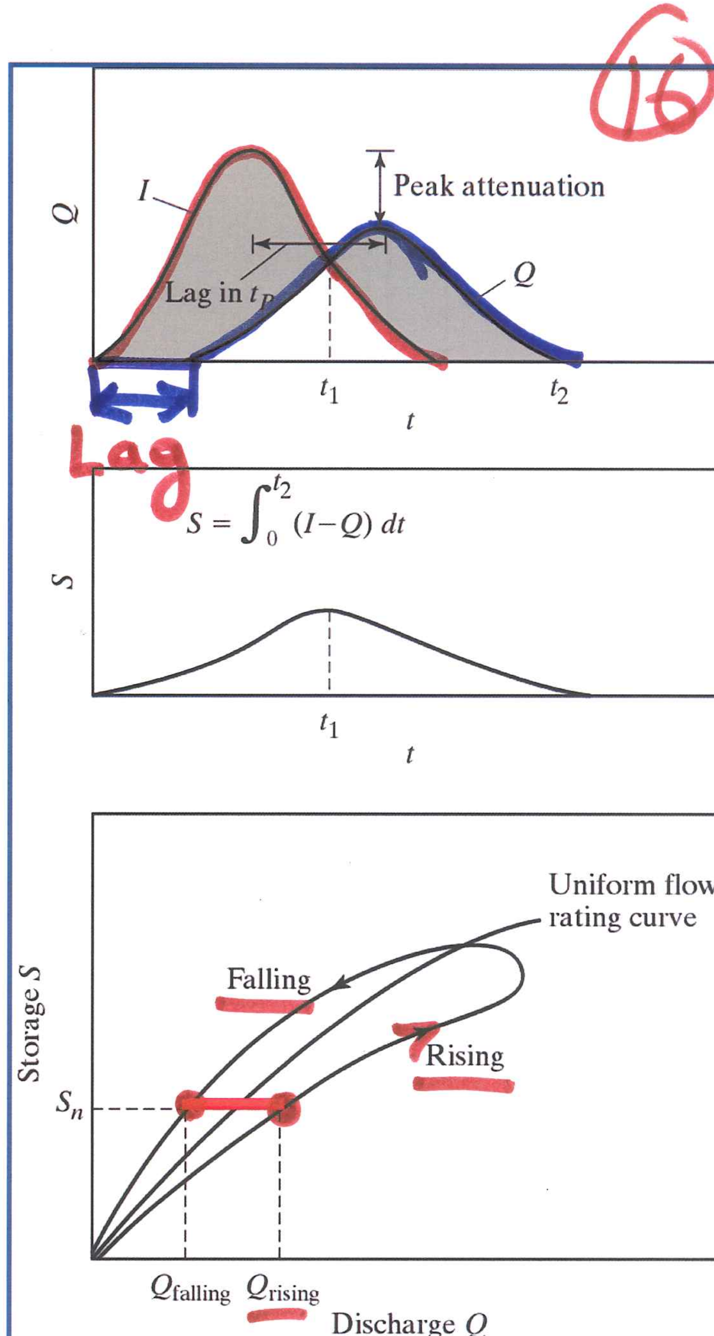


Figure 4.2

Storage in a river reach.

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Wedge and Prism Storage

- Positive wedge $I > Q$
- Maximum S when $I = Q$
- Negative wedge $I < Q$

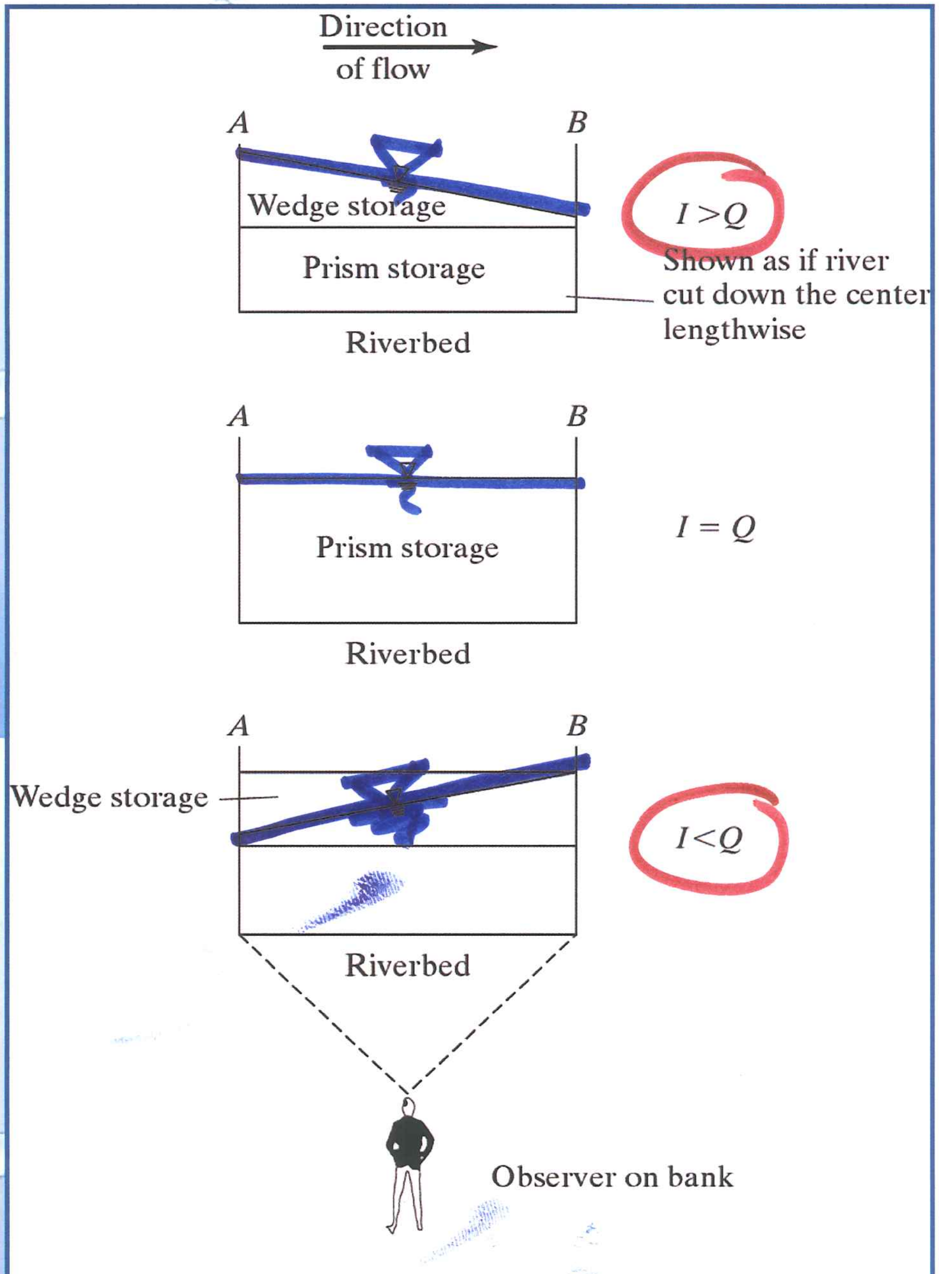
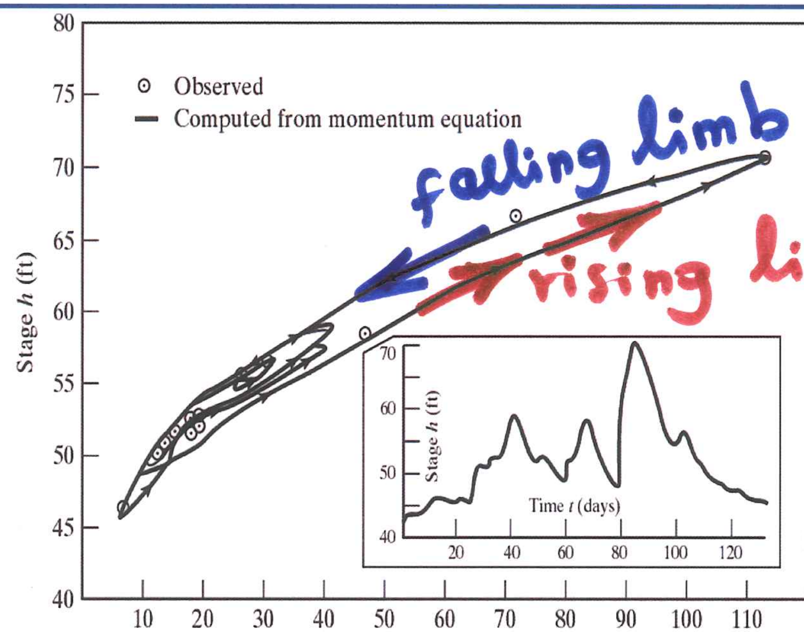


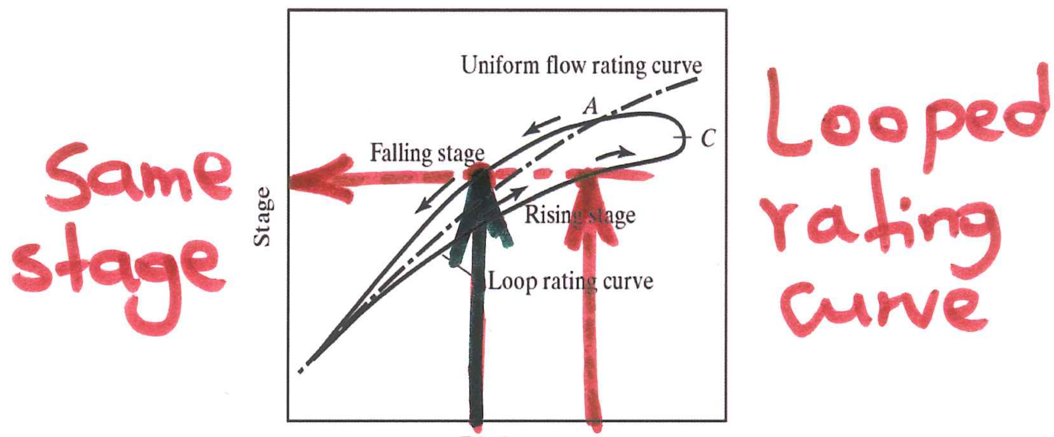
Figure 4.3

Prism and wedge storage concepts.

(18)



(a)



(b)

different flow discharge

Figure 4.20

Actual Looped Rating Curves

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Manning's Equation

Manning's Equation (**English units**)

$$Q_p = \frac{1.49}{n} A R^{2/3} S^{1/2}$$

Where Q_p = flow rate (cfs)

n = roughness

A = cross sectional Area (ft^2)

$R = A / P$ (ft)

S = Bed Slope

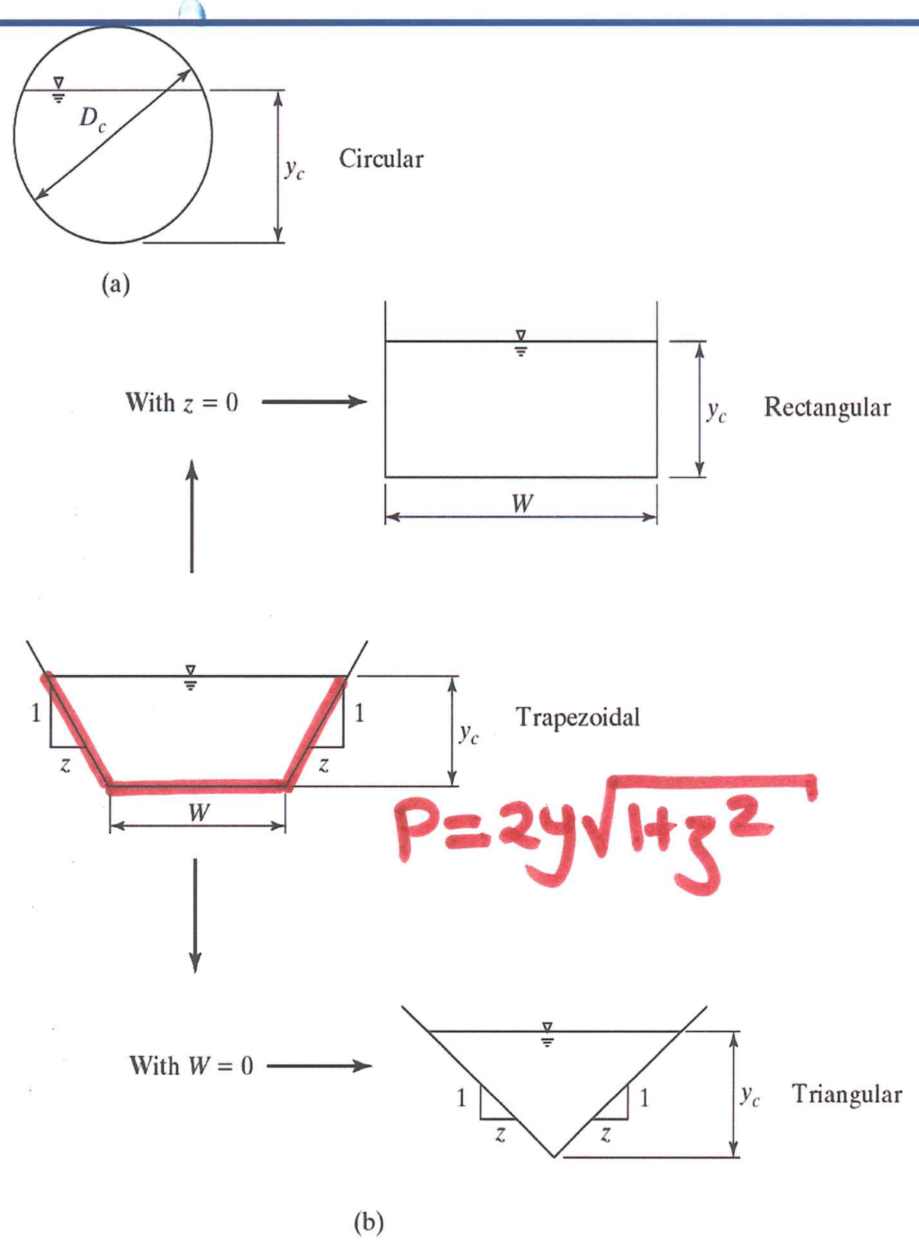

Figure 4.12

Basic channel shapes and their variations used by the HEC-1 flood hydrograph package for kinematic wave stream routing.