Flood Hydraulics

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Introduction

- During floods, part of the discharge of a river is carried by the simple main channel and the rest are carried by the floodplains located to its sides.
- For such compound channels, the flow structure becomes complicated due to the transfer of momentum between the deep main channel and the adjoining floodplains which magnificently affects the shear stress distribution in flood plain and main channel sub sections.

Objective

- Learn about basic concept of Flood Hydraulics
- Understand the Relationship between Hydraulics and the factors which causes flooding.
- Gain knowledge about shear stresses that causes failures on hydraulic structures.
- Able to calculate some parameters with available data For Natural Rivers

Hydraulic Flood Routing

- Once a storm water hydrograph has been generated for a site, people are commonly asked to predict what happens to the flood as it moves downstream.
- There are generally two issues:
  - *How big will the flood peak be?*
  - *When will the flood peak reach us?*
- Hydraulic routing: Based on the solution of partial differential equations of unsteady open-channel flow. The equations used are the St. Venant equations or the dynamic wave equations.

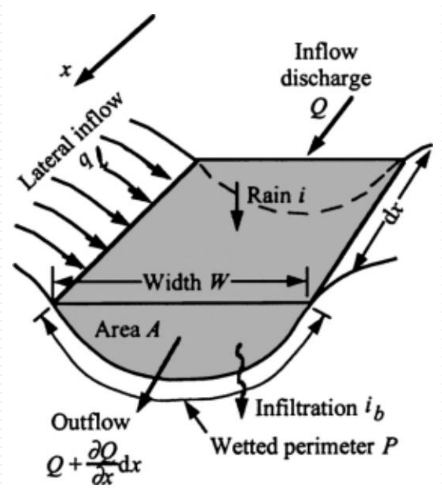
Governing Equations

- **Continuity equation**
  - 3D, 2D, and 1D
  - The simplified 1D form is widely used in analysis of flood hydraulics:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} + i_b P - i W - q_l = 0$$

Impervious channel (i_b = 0)
no rainfall (i = 0),
no lateral inflow (q_l =0):

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



Governing Equations

- **Momentum equations**
  - Saint Venant equation (1D):

$$S_f \cong S_0 - \frac{\partial h}{\partial x} - \frac{V \partial V}{g \partial x} - \frac{1}{g} \frac{\partial V}{\partial t}.$$

(1) (2) (3) (4) (5)

kinematic

diffusive

quasi-steady

dynamic

(1) friction slope

(2) bed slope

(3) pressure gradient

(4) velocity head gradi

(5) local acceleration

Wave Celerity

- Kleitz-Seddon law
  - From conservation of mass

$$c = \frac{\partial Q}{\partial A}$$

- For wide-rectangular channel:

$$\frac{\partial h}{\partial t} + c\frac{\partial h}{\partial x} = 0,$$

$$c = \frac{\partial q}{\partial h} = \beta\alpha h^{\beta-1} = \beta V$$

		Turbulent Flow		
Surface	Laminar flow k_0	Manning n	Chézy C ($\mathrm{ft}^{1/2}/\mathrm{s}$)	Darcy–Weisbach f
Concrete or asphalt	24–108	0.01–0.013	78–38	0.03–0.4
Bare sand	30–120	0.01–0.016	65–33	0.04–0.5
Graveled surface	90–400	0.012–0.03	38–18	—
Bare clay–loam soil (eroded)	100–500	0.012–0.033	36–16	—
Sparse vegetation	1,000–4,000	0.053–0.13	11–5	0.1–1000
Short grass prairie	3,000–10,000	0.10–0.20	6.5–3.6	0.5–13,000
Bluegrass sod	7,000–100,000	0.17–0.48	4.2–1.8	1–10,000

Wave Celerity

- The floodwave celerity c is always faster than the flow velocity when $\beta > 1$
- Floodwave celerity increases with flow depth
  - Larger floodwaves (larger flow depth) propagate faster than small floodwaves
  - Cause nonlinearity in the downstream propagation of floodwaves
  - Linear techniques based on superposition fail to adequately simulate floodwave propagation in channels
  - Method of isochrons used in hydrology is not applicable to both small and large floodwaves
- The value of β and flow velocity will affect the arrival of a flood peak.

Flood wave Attenuation and Dispersion

- Based on St. Venant equation, continuity and resistance relationships:

$$S_f = S_0 - \underbrace{[1 - (\beta - 1)^2 \, \mathrm{Fr}^2]}_{\text{floodwave diffusivity}} \frac{\partial h}{\partial x}$$

- The floodwave-diffusivity plays a dominant role in the alteration of floodwaves.

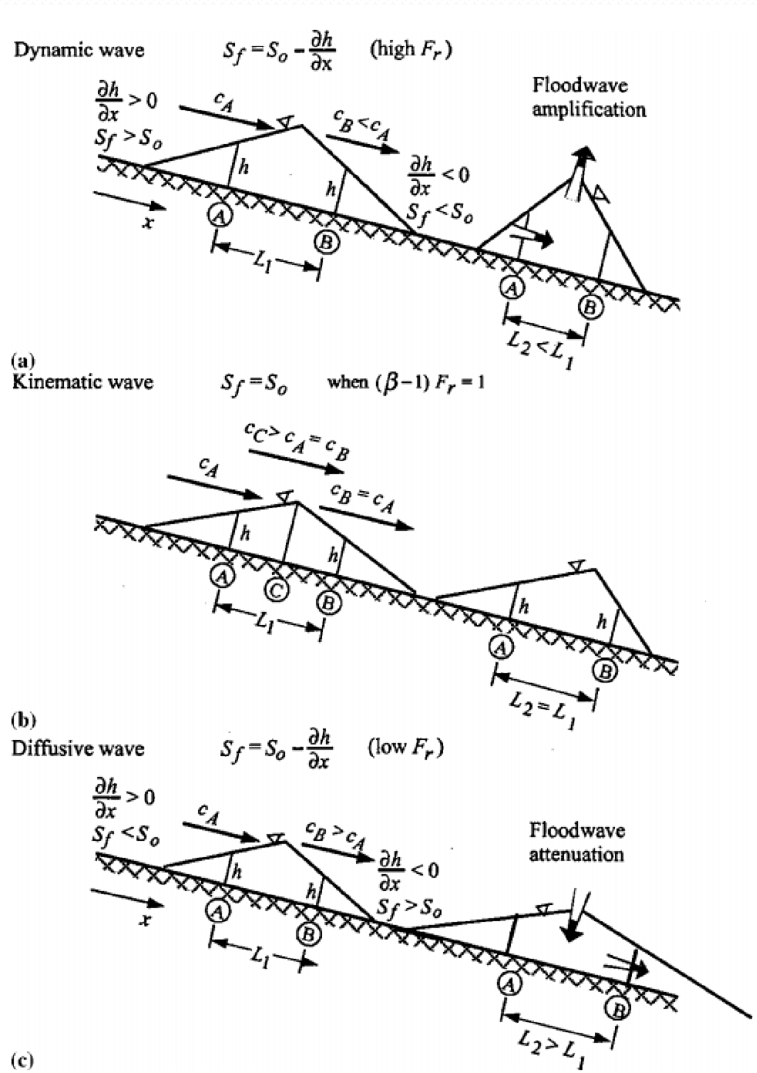
Flood wave Attenuation and Dispersion

- Assuming Manning equation is applicable, the following relationships are important in determining the flow velocity V and the flood wave celerity c:

$$V = \frac{1}{n} R_h^{2/3} \left\{ S_0 - [1 - (\beta - 1)^2 \, \mathrm{Fr}^2] \frac{\partial h}{\partial x} \right\}^{1/2},$$

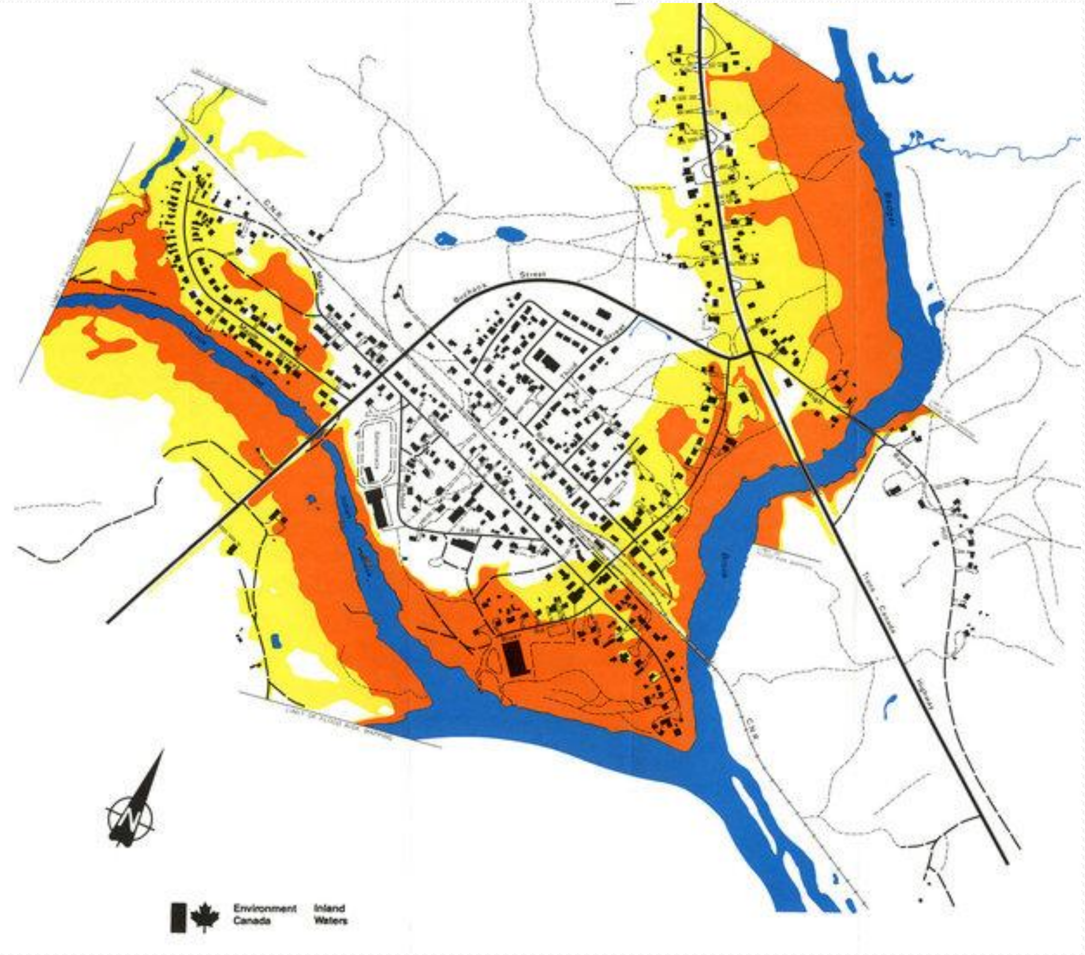
$$c = \frac{\beta}{n} R_h^{2/3} \left\{ S_0 - [1 - (\beta - 1)^2 \, \mathrm{Fr}^2] \frac{\partial h}{\partial x} \right\}^{1/2}.$$

Flood wave Attenuation and Dispersion



- Dynamic wave
  - Amplification
  - Tend to form pulsating flows or surges
- Kinematic wave
  - No amplification or attenuation
  - Well-defined wave front
- Diffusive wave
  - Attenuation
  - Most effective when *Fr* is low
  - In most rivers, the flow is subcritical and flood routing is adequately described by the diffusive-wave approximation

Flood Mapping



Risk map showing areas prone to flooding

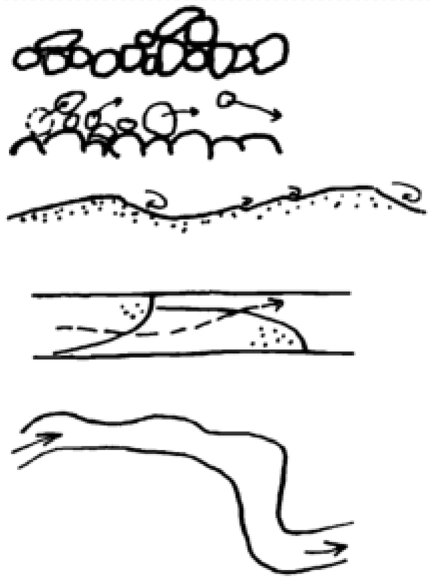
- Blue: Normal water surface
- Red: ‘designated floodway’, meaning flood waters often reach this area
- Yellow: ‘designated floodway fringe’ where flooding is less common

Shear Stress

- Provides an index of fluid force per unit area on the stream bed, which has been related to sediment mobilization and transport in many theoretical and empirical treatments of sediment transport

- Various methods based on
  - Reach-averaged relations
  - Theoretical assumptions about structure of turbulence
  - Direct measurements of turbulence

- Boundary shear stress components
  - Grain resistance
  - Bedload resistance
  - Bedform resistance
  - Bar resistance
  - Bank and planform resistance



Shear Stress Calculation

- Mean Bed Shear Stress
  - Force per unit area exerted by a block of water on the channel boundary as it moves downstream

$$\tau_b = \gamma RS$$

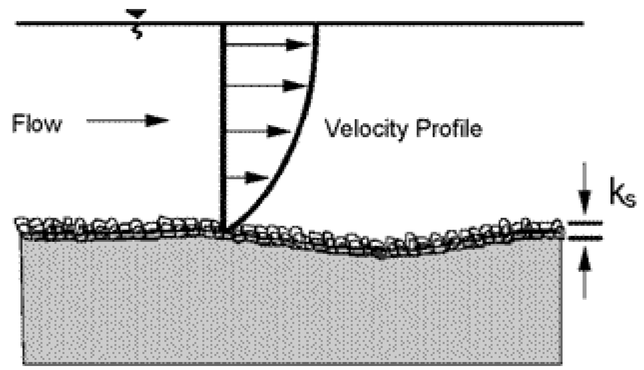
(downstream oriented component of the weight of the block)

- Advantages
  - Serves as an index of the total resistance by all frictional influences on the flow (particle-, bedform-, bar-, and planform-scale effects)
  - Relatively easy to measure
- Disadvantages
  - Does not provide information on spatial variation in resistance at sub-reach scale
  - Not necessarily a good index of the competence of the stream to move sediment

Shear Stress Calculation

- Law of the wall
  - Based on the assumption that the velocity profile in the lower portion (15-20%) of an open channel flow has a logarithmic structure

$$\frac{V}{u_*} = \frac{1}{\kappa} \ln\left(\frac{z}{z_0}\right)$$



- V = mean flow velocity
- u_* = shear velocity ($\sqrt{gRS} = \sqrt{\tau_b/\rho}$)
- κ = von Karman's constant
- z = distance above bed
- z_0 = roughness height (height above bed where velocity goes to zero)

Shear Stress Calculation

- Advantages
  - Provides local measure of shear stress
  - Can be used to map spatial patterns of shear stress and roughness height at subreach scale
  - Standard error of estimate of regression can provide an estimate of error in u_*
- Disadvantages
  - Flow must conform with logarithmic velocity profile
  - Errors in measurement of u and z can influence results (least precise of “law of wall” methods)

Case Study - Shear Stress Distribution

- An experimental study of shear stress distribution in a compound meandering channel (Amin et al., 2013)

Figure 1. Schematic diagram of the laboratory experimental setup.

Shear stress distribution curves

- Shear stress increases with the increase of depth and width ratio.
- Because shear stress depend on the hydraulic radius as well as velocity distribution of a channel section.
- Hydraulic radius increases with the increase of depth and width ratio.
- With increase of depth ratio, velocity increases and the correspondingly shear stress increases.

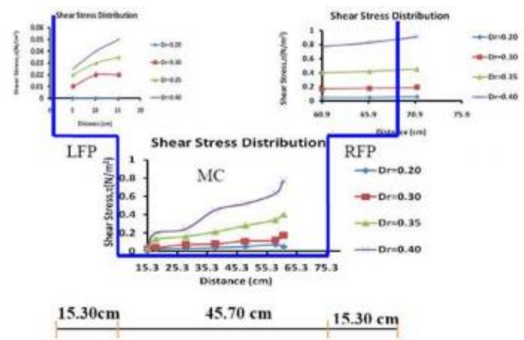


Figure 4. Shear Stress Distribution at u/s bend section for Wr=1.67.

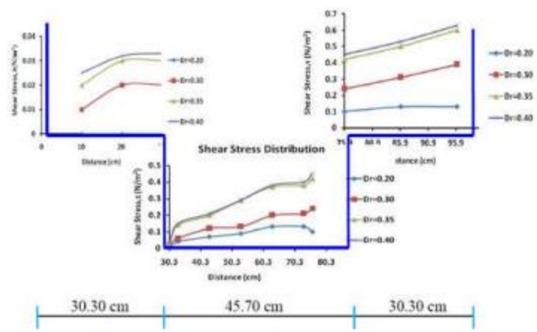


Figure 5. Shear Stress Distribution at u/s bend section for Wr=2.33.

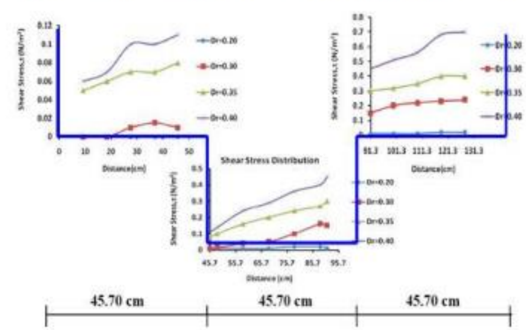


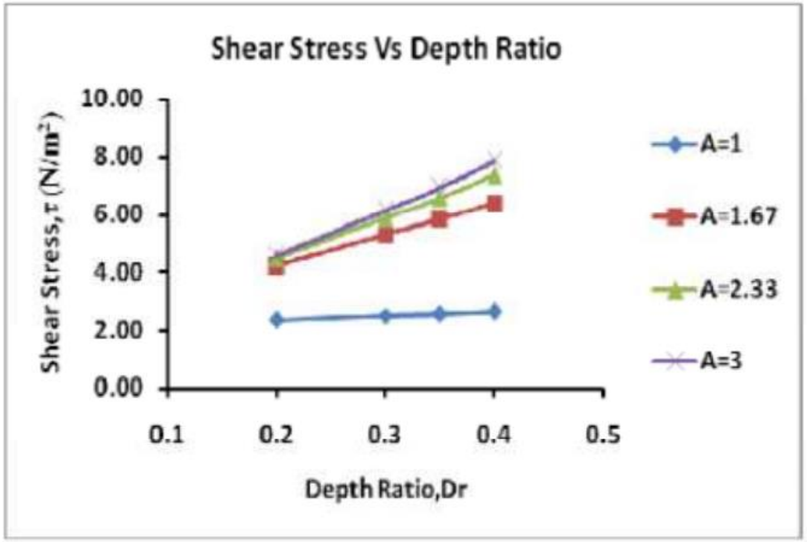
Figure 6. Shear Stress Distribution at u/s bend section for Wr=3.00.

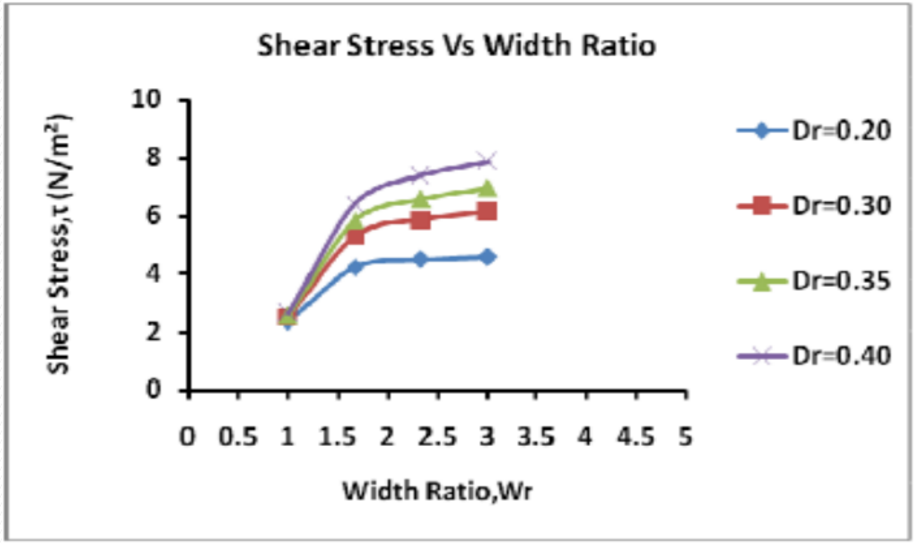
Shear Stress Distribution

- In a compound meandering channel
  - The shear stress is increasing and decreasing in the inner and outer bend respectively.
  - The maximum value of shear stress occurs along the inner bend of the main channel at low water depth ratio.
  - For higher depth ratio, the maximum shear stress occurs along the inner bend of the floodplain. Because at low over bank depths, the slow moving flow in the floodplain interact with the fast moving main channel intensely and considerable momentum exchange takes place giving rise to large non uniformity in the longitudinal velocity distribution.
  - As the depth ratio increases, the intensity of interaction diminishes considerably.

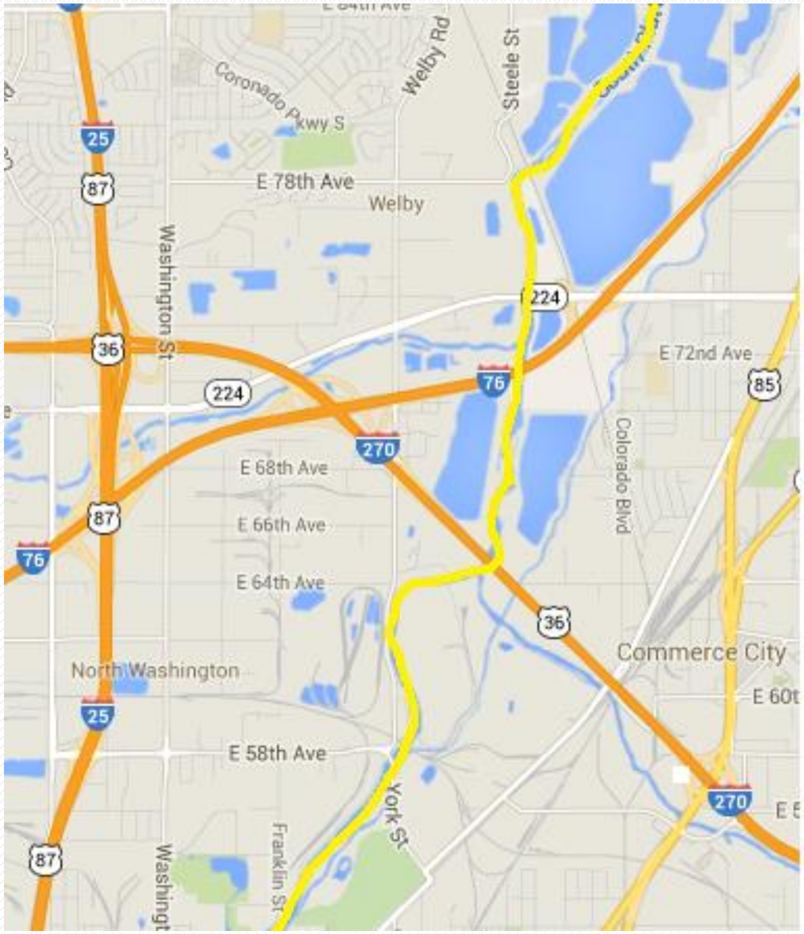
Shear Stress Distribution

- Variation of shear stress in terms of depth and width ratio





Case Studies



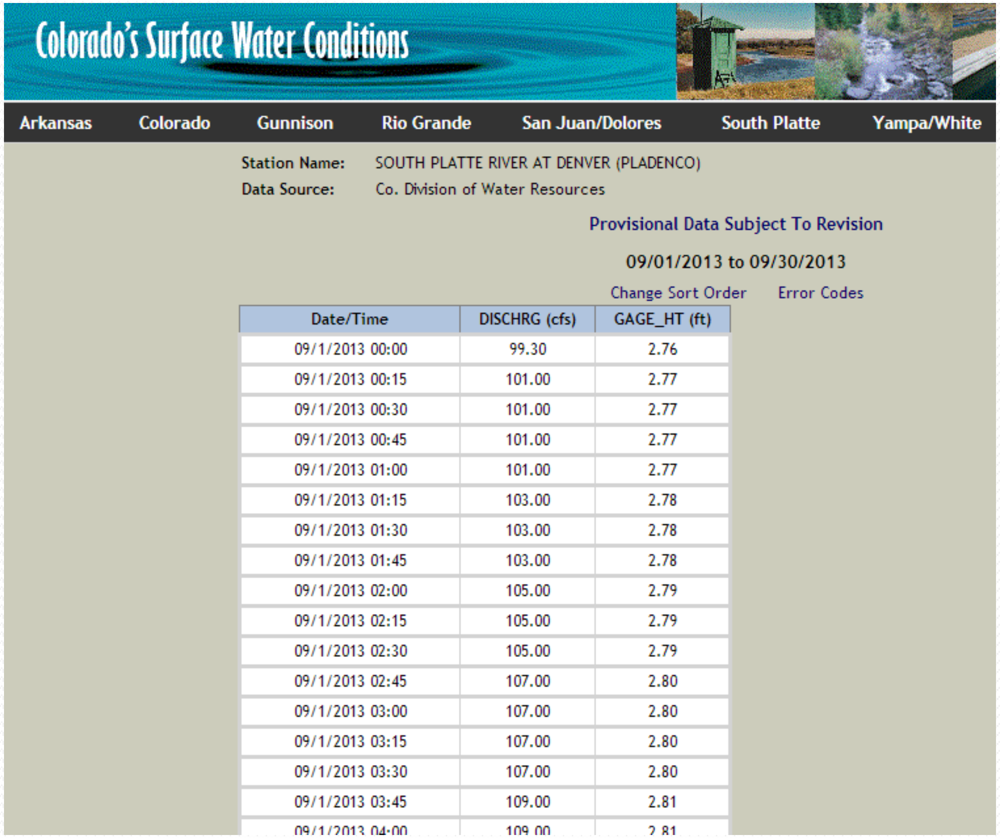
The flood occurred in Colorado in September 2013. We have taken the discharge data and flow depth over the entire month of September in at three stations along the Big Thompson, St-Vrain and South Platte Rivers.

- (http://www.dwr.state.co.us/SurfaceWater/Default.aspx)

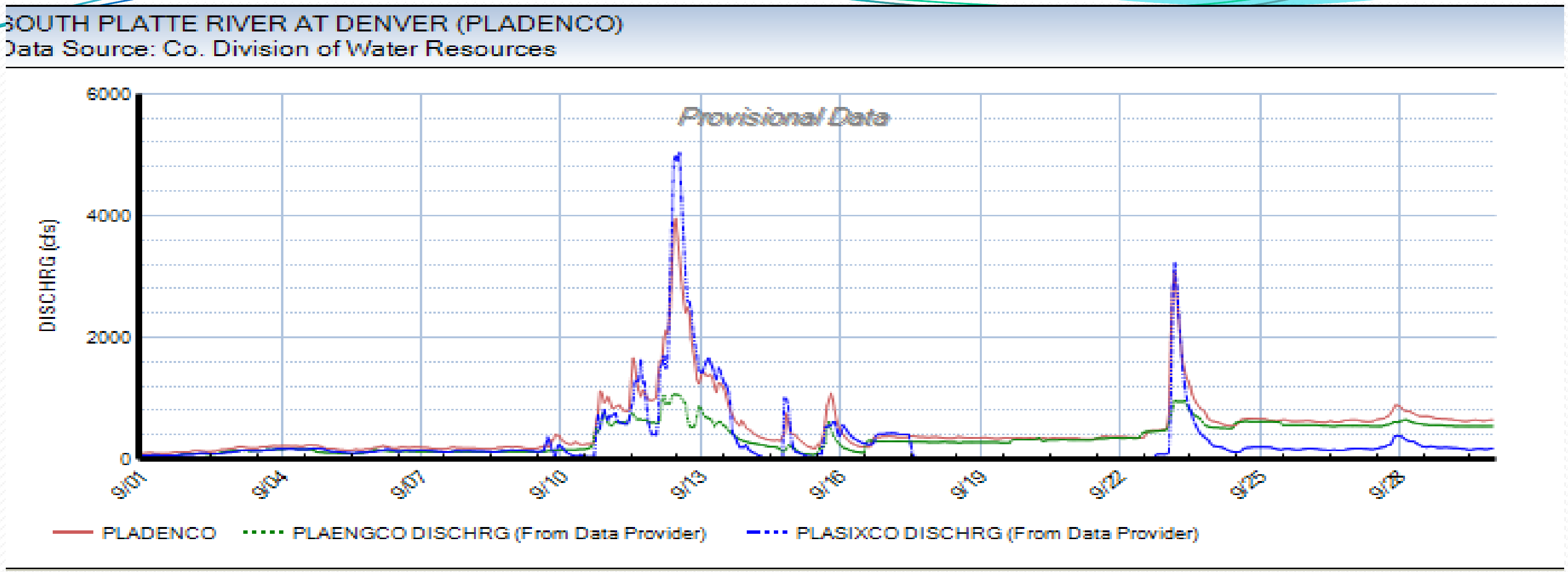
- Three stations were selected for each river and using the Colorado Surface water Condition's Web site, the Discharge and the Flow depth were obtained
- We couldn't get Flow depth for all stations and Rivers

- There fore it has been assumed that, average depth is same for all stations for a particular river.

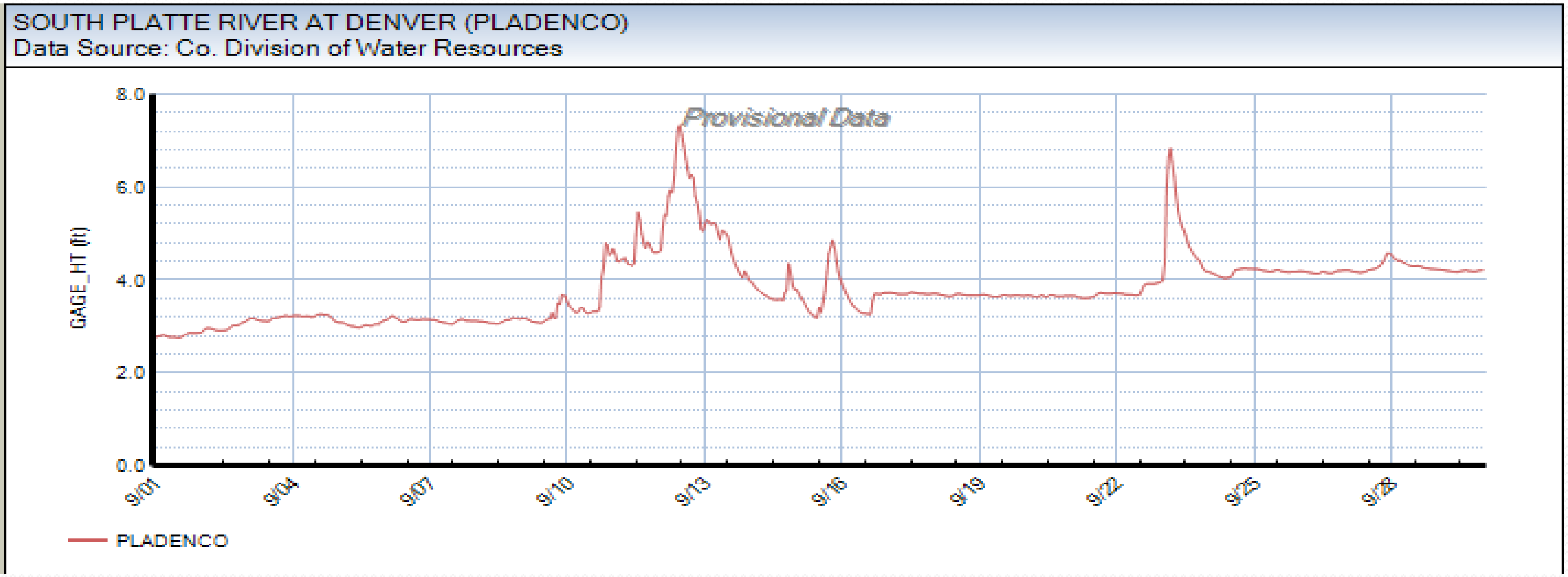
River	No	Station
Big Thompson	1	Mouth Near La Salle
	2	Hillsborough
	3	Loveland
South Plate	1	Denver
	2	Engle Wood
	3	Commerce City
Saint Vrain	1	Longmont
	2	Mouth Near La Salle
	3	Lyons



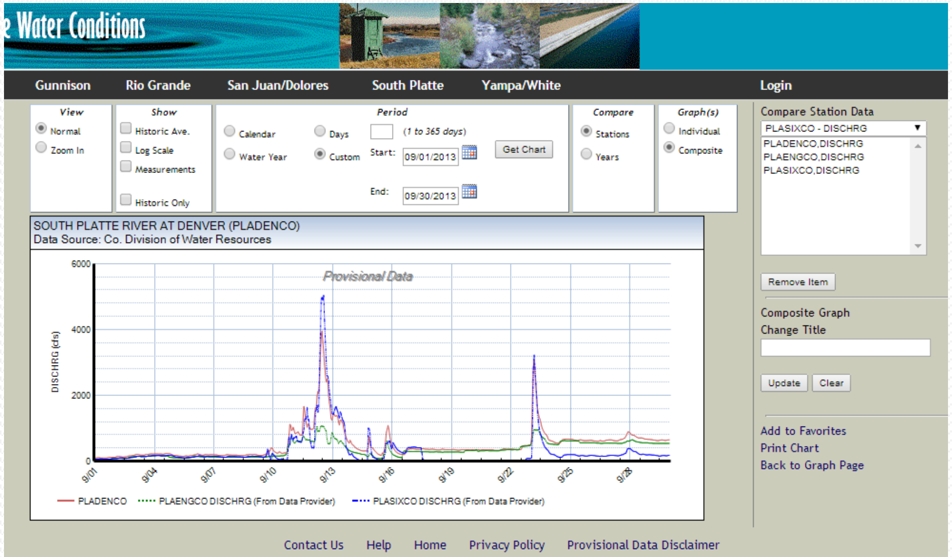
Date/Time	DISCHRG (cfs)	GAGE_HT (ft)
09/1/2013 00:00	99.30	2.76
09/1/2013 00:15	101.00	2.77
09/1/2013 00:30	101.00	2.77
09/1/2013 00:45	101.00	2.77
09/1/2013 01:00	101.00	2.77
09/1/2013 01:15	103.00	2.78
09/1/2013 01:30	103.00	2.78
09/1/2013 01:45	103.00	2.78
09/1/2013 02:00	105.00	2.79
09/1/2013 02:15	105.00	2.79
09/1/2013 02:30	105.00	2.79
09/1/2013 02:45	107.00	2.80
09/1/2013 03:00	107.00	2.80
09/1/2013 03:15	107.00	2.80
09/1/2013 03:30	107.00	2.80
09/1/2013 03:45	109.00	2.81
09/1/2013 04:00	109.00	2.81



SOUTH PLATTE RIVER AT DENVER (PLADENCO)
Data Source: Co. Division of Water Resources
Provisional Data
DISCHRG (cfs)
6000
4000
2000
0
9/01
9/04
9/07
9/10
9/13
9/16
9/19
9/22
9/25
9/28
PLADENCO
PLAENGCO DISCHRG (From Data Provider)
PLASIXCO DISCHRG (From Data Provider)



SOUTH PLATTE RIVER AT DENVER (PLADENCO)
Data Source: Co. Division of Water Resources
Provisional Data
GAGE_HT (ft)
8.0
6.0
4.0
2.0
0.0
9/01
9/04
9/07
9/10
9/13
9/16
9/19
9/22
9/25
9/28
PLADENCO



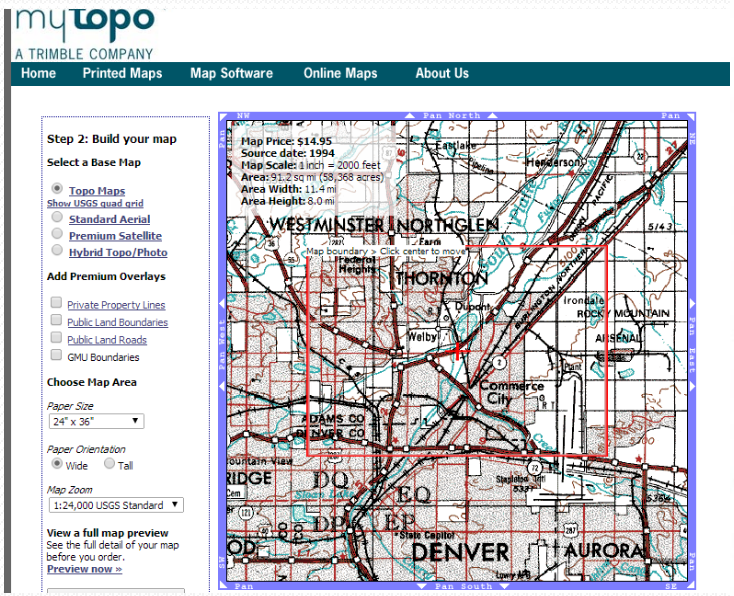
We could plot the composite graphs for discharge for all stations of a particular river

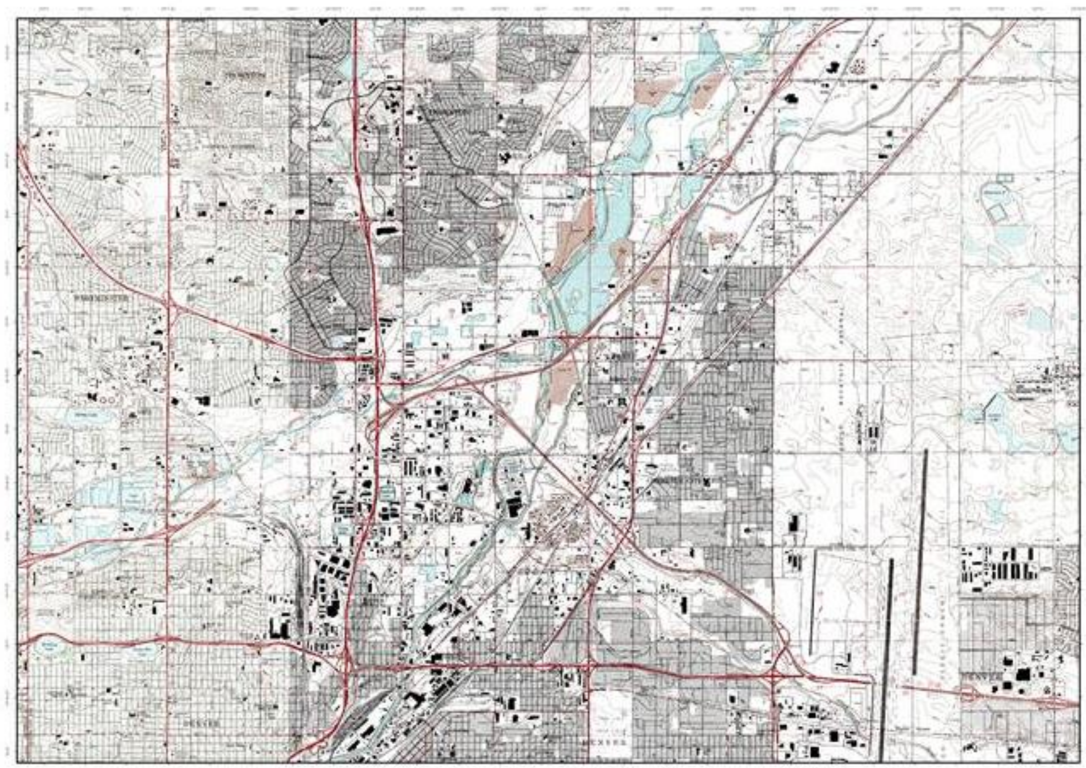
From the plotted data, we tabulated the Peak flow rate in the river during the flood 2013.

River	No	Station	Peak flow (cfs)	Period
Big Thompsan	1	Mouth Near La Salle	6010	9/16/2013
	2	Hillsborough	378	9/13/2013
	3	Loveland	3070	9/12/2013
South Plate	1	Denver	3450	9/12/2013
	2	Engle Wood	943	9/12/2013
	3	Commerce City	3210	9/12/2013
Saint Vrain	1	Longmont	1840	9/12/2013
	2	Mouth Near La Salle	2040	9/12/2013
	3	Lyons	882	9/11/2013

Calculating Slope of the river

- The slope was calculated using topographic map from the below website and Google earth to measure the distance and the elevation difference to calculate the slope.





Scale 1:24000

http://www.mytopo.com/search.cfm?

Calculating Parameters

- After figured out the average depth and average slope of the rivers, the manning coefficient n was determined for the natural major streams from web site as n=0.035
- Then average velocity of each river was calculated using manning's equation

$$\bar{u} = \frac{1}{n} h^{2/3} S^{1/2}$$

- Finally Celerity of the wave was calculated as C=β V when the β=1.67 as the manning value

River	Stattions	Average depth h(ft)	dx (mile)	dh (ft)	Average slope s(ft/ft)	manning coefficient n	Velocity (ft/s)	for β=1.67 Celerity C(ft/s)
Big Thompson	Hillsborough-loveland	4	1.21	20	0.0031	0.035	6.0	10.00
	La Salle-Hillsborough	4						
	La Salle-Loveland	4						
South Platte	Denver-Englewood	3.8	1.62	20	0.0023	0.035	5.0	8.35
	Denver-Commerce City	3.8						
	Englewood-Commerce city	3.8						
Saint Vrain	Longmont-La salle	1.8	1.9	50	0.0050	0.035	4.4	7.41
	Longmont-Lyons	1.8						
	La salle-lyon	1.8						

Conclusions

- Flow depth, Velocity, Shear stress and Wave celerity can be determined from Flood Hydraulics.
- Flood Hydraulics can answer the questions
  - *How big will the flood peak be?*
  - *When will the flood peak reach us?*
- Flood Hydraulics is important to learn about Flood mapping and Flood Prevention.

References

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