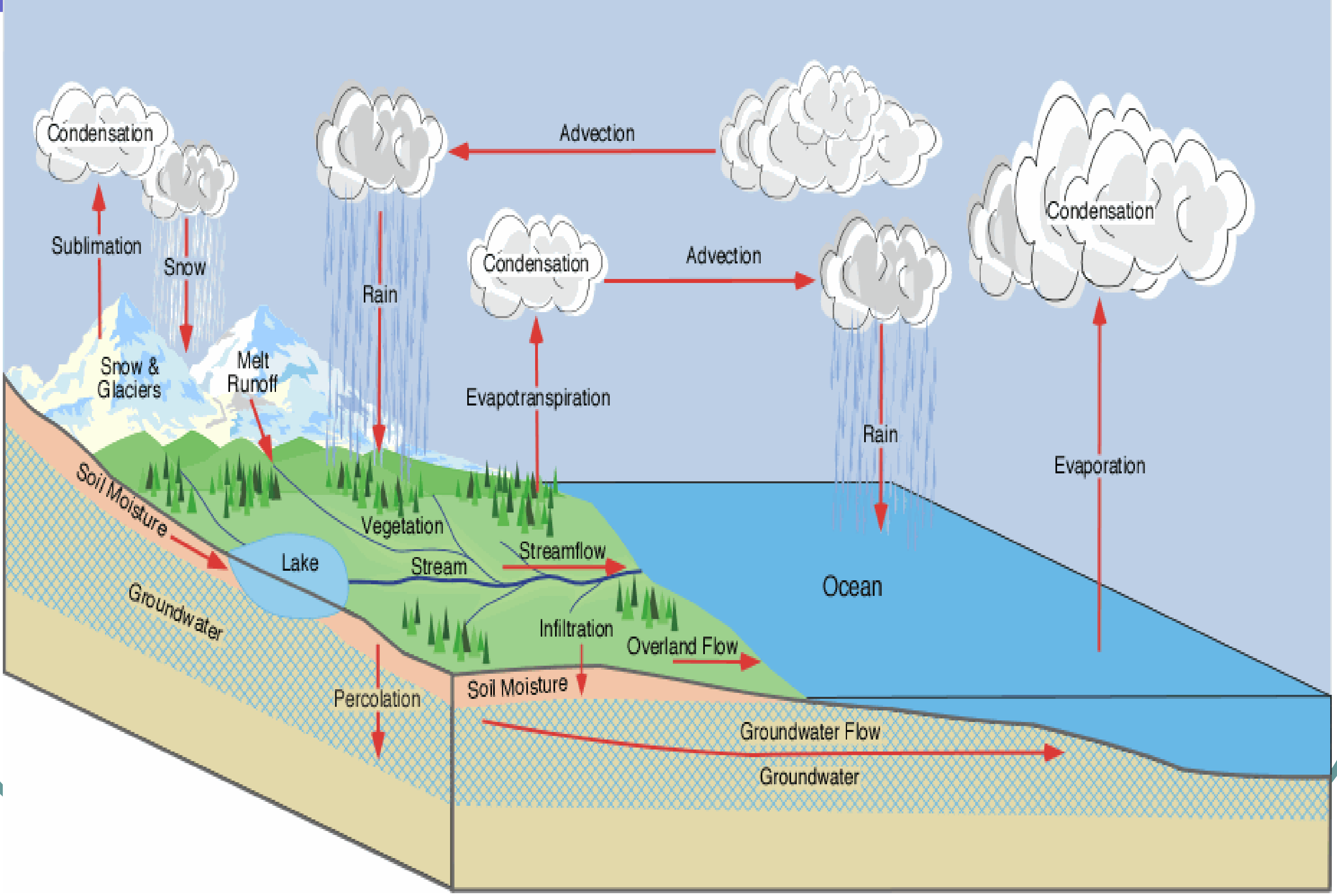
The next hour of your life…

- What are computer models and why should we care (basics)
- Types of models
- Overseeing/reviewing a model study
- Quick look at modeling science basics used for stream restoration and hot topics
- Q&A

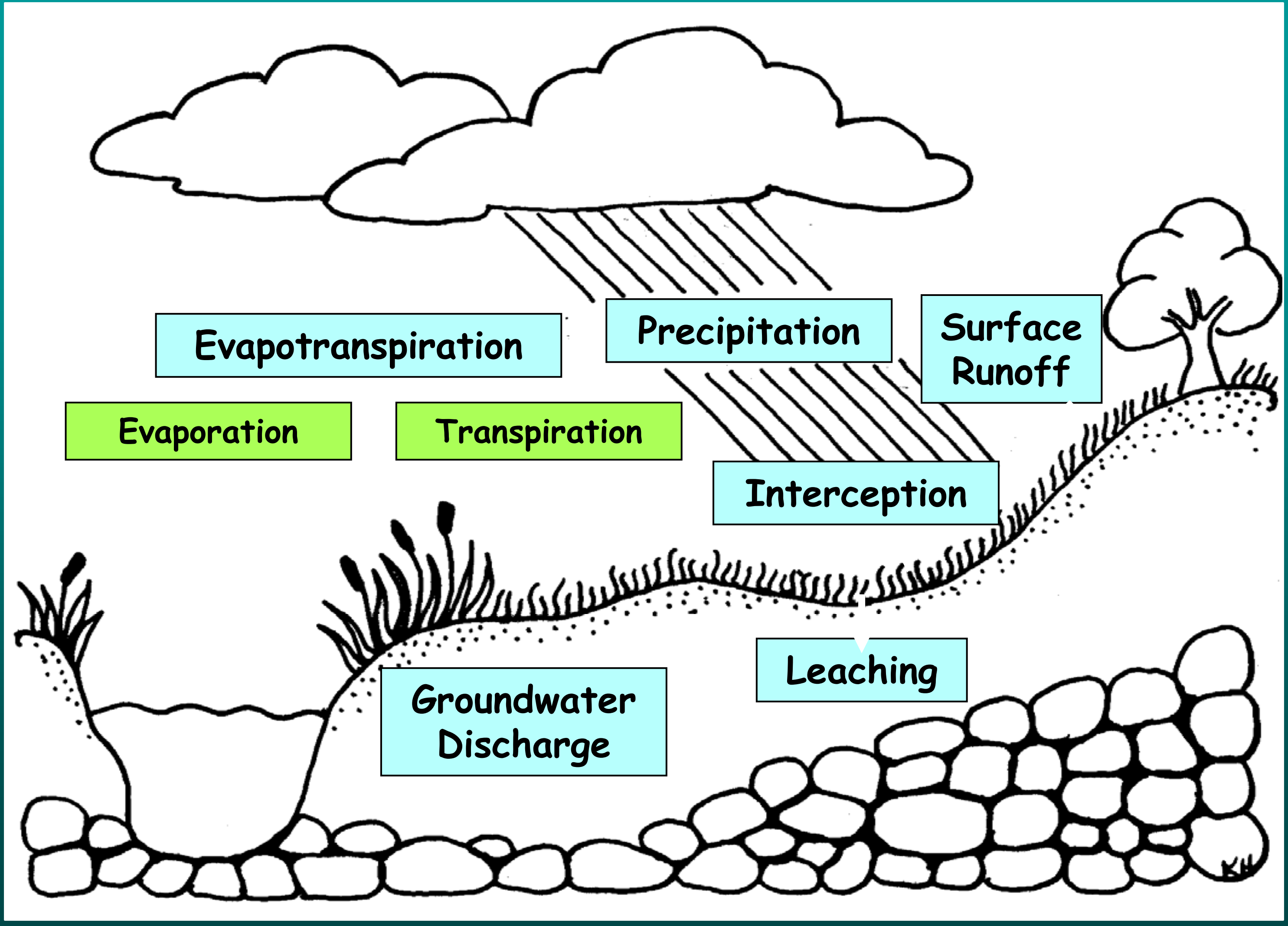
What is a computer model

- Model is a simulation of processes
- No model does everything and you don’t need everything (thousands of models)
- Think in terms of processes (examples)
  - Fluvial flow and sediment transport
  - Wind wave (estuaries)
  - Evaporation (ponds and lakes)
  - Overland flow
  - Many, many others
- Physical models (turbulence) and complexity

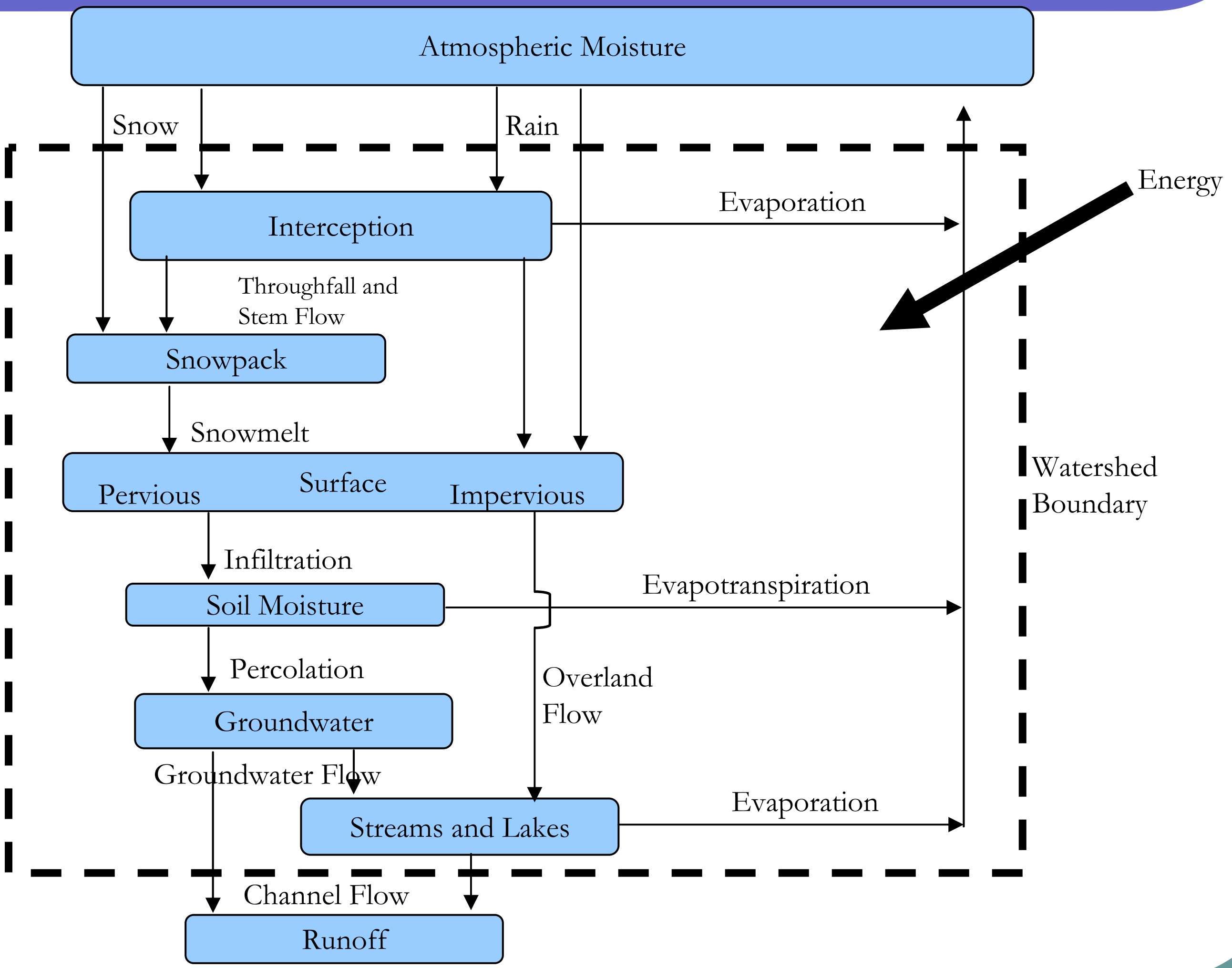
Hydrologic cycle



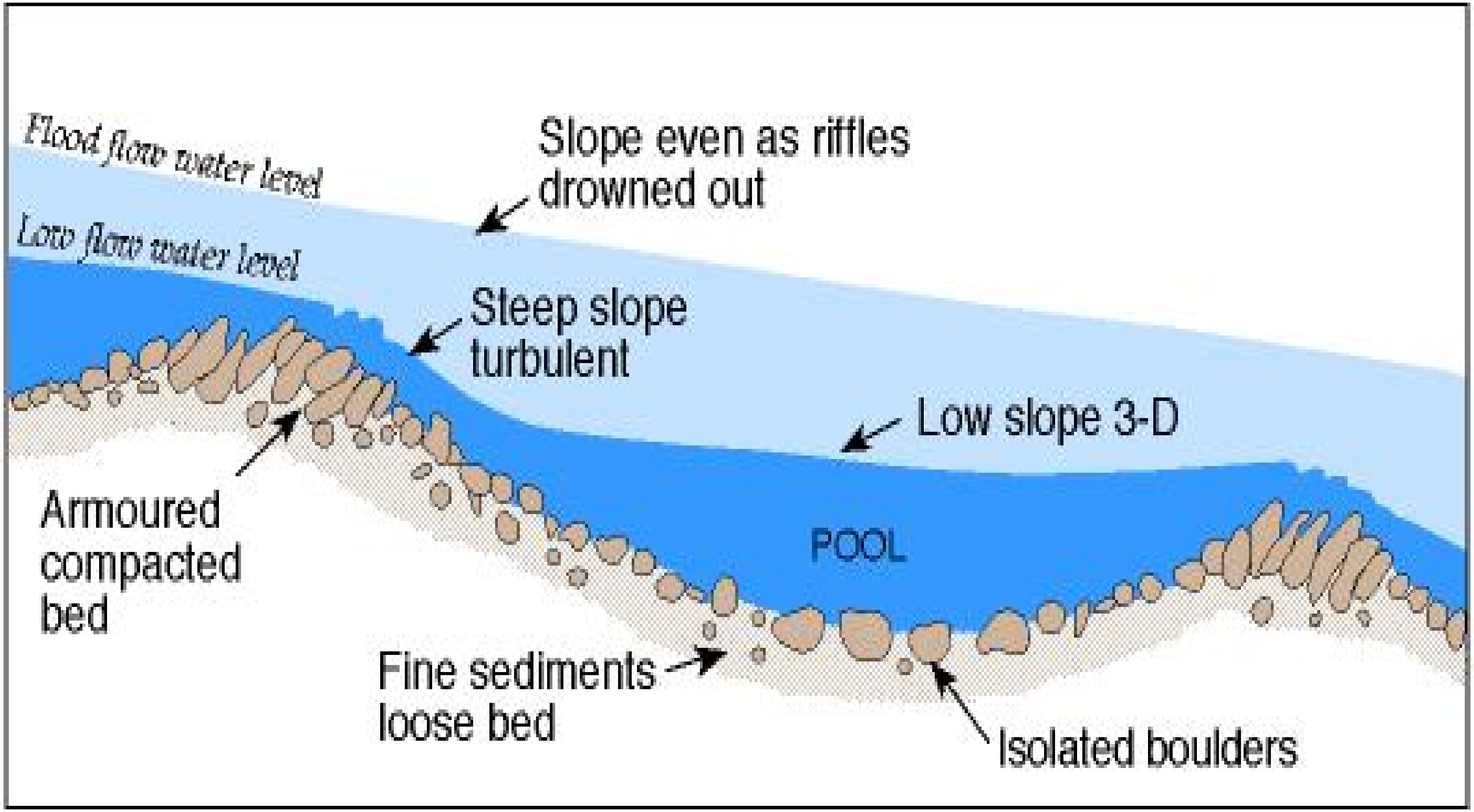
The hydrologic cycle: Overview



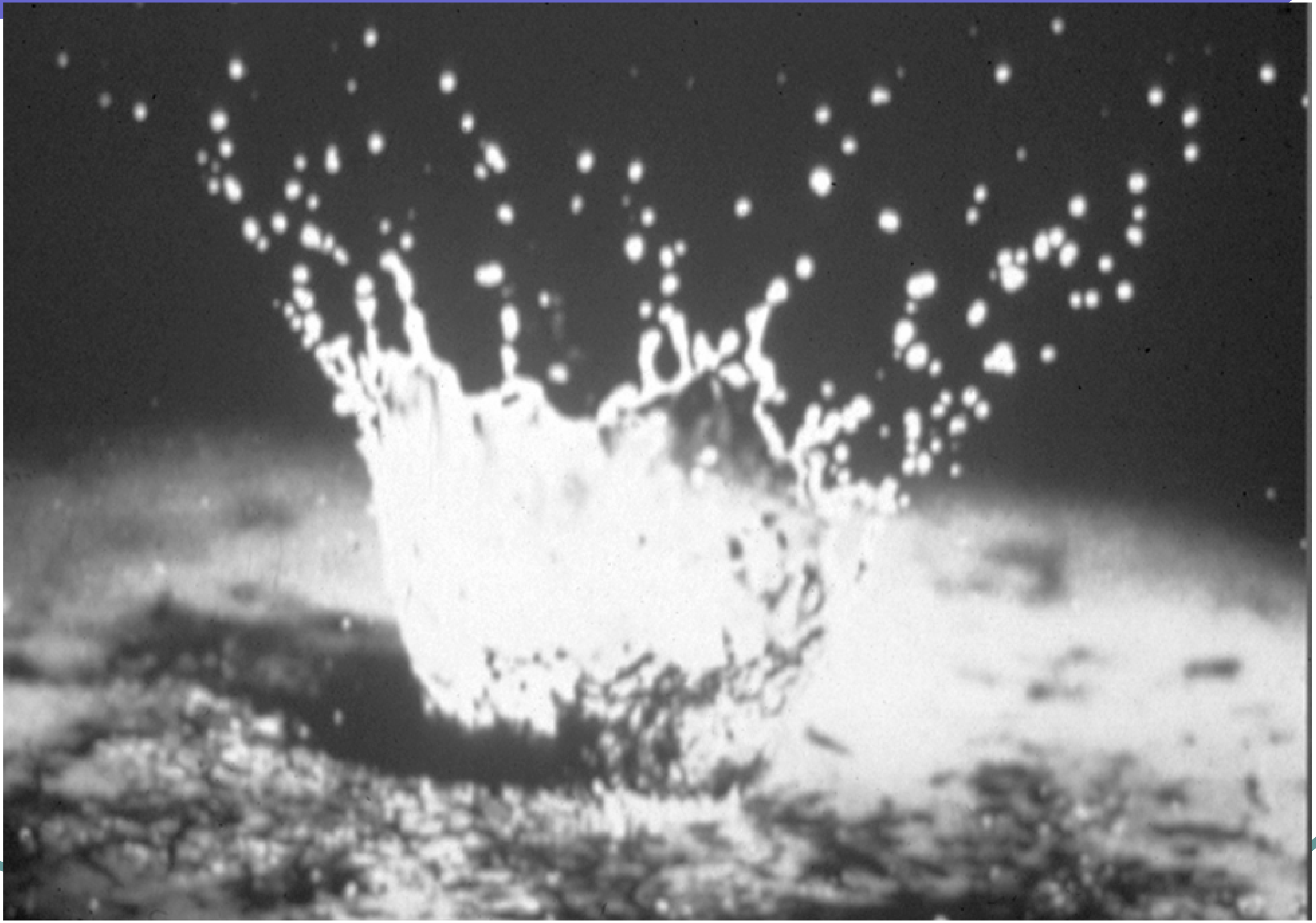
Runoff Processes Modeled



process changes by depth



Soil Erosion



and why should you care?

- Time and money to start
- Need to understand uncertainty and risk for decision making
- What-if scenarios

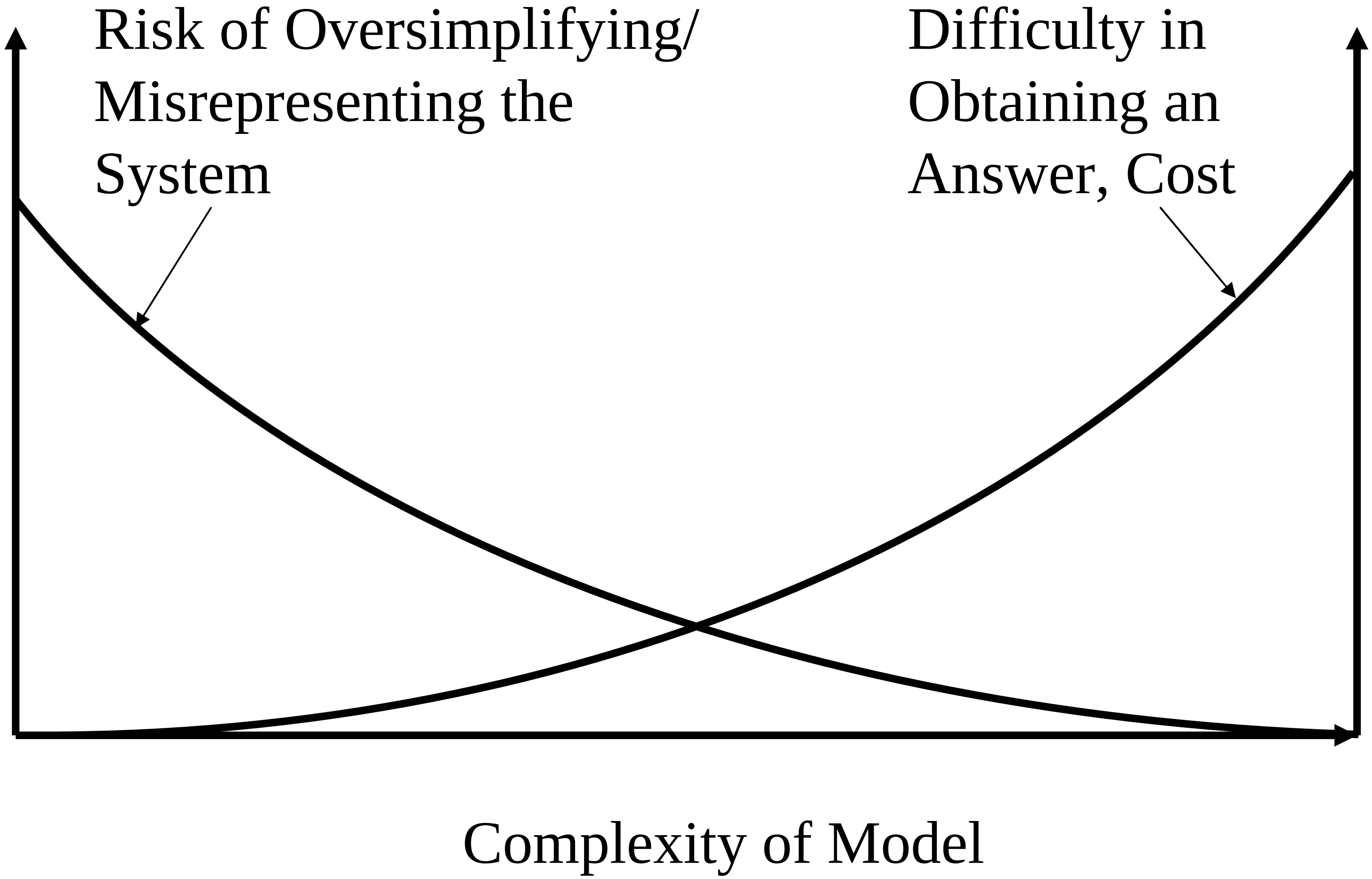
AND REMEMBER…

- Models are a tool, understanding comes form the field (geomorphology first)

Geomorphology and model selection

- Develop range of geomorphic responses
  - Problem lack of sediment and scour
  - Flatten slopes
  - Lower W:D ratio
  - Increases channel length (sinuosity)
  - Increase roughness
- Does the proposed model evaluate all practical responses?

Modeling Tradeoff Diagram



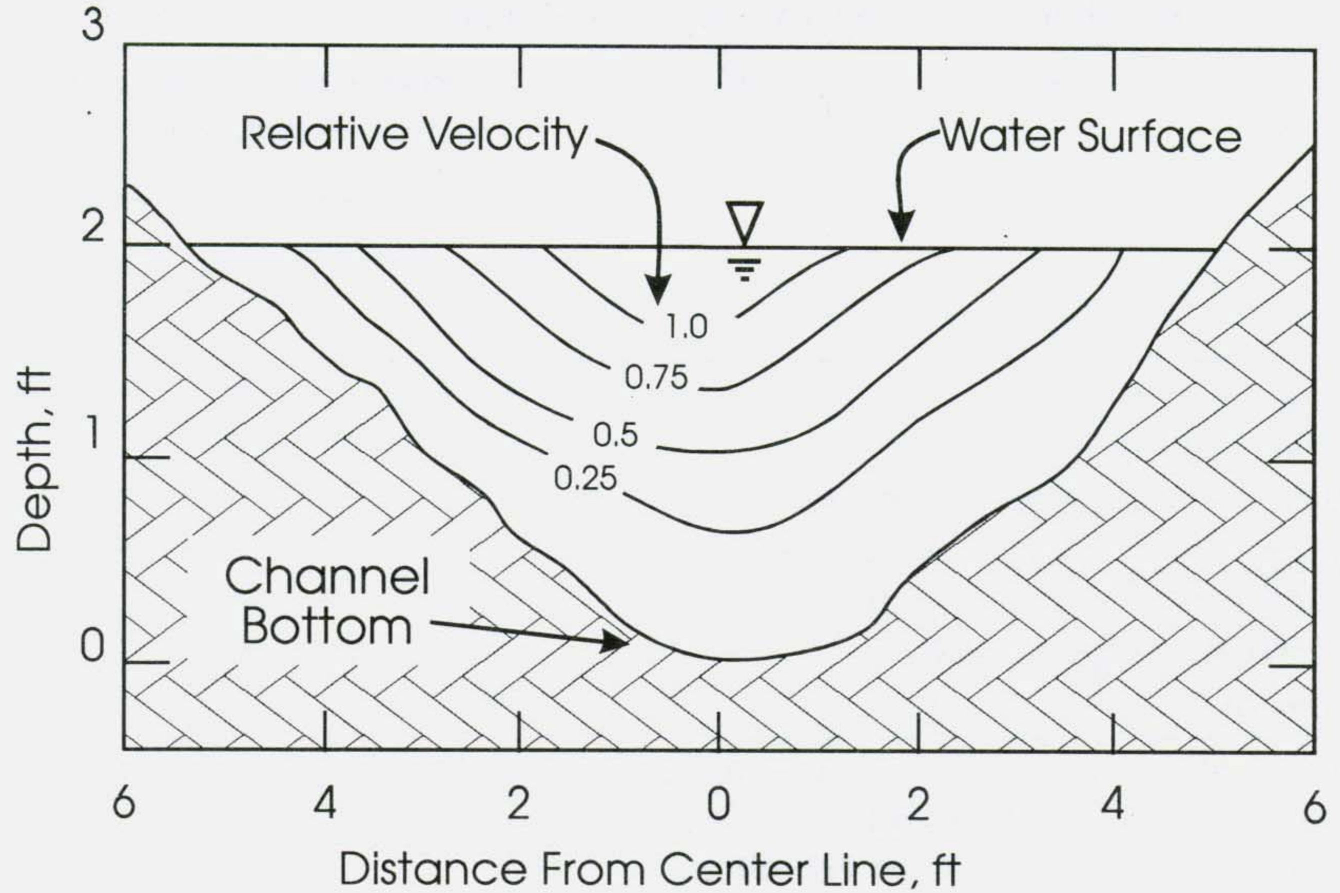
Modeling water in the natural world

- Most all hydrology/hydraulics models are a mixture of analytical and empirical routines
- Model building - discretize and disaggregate
  - Spatial
  - Temporal
  - Process

about computer models in general

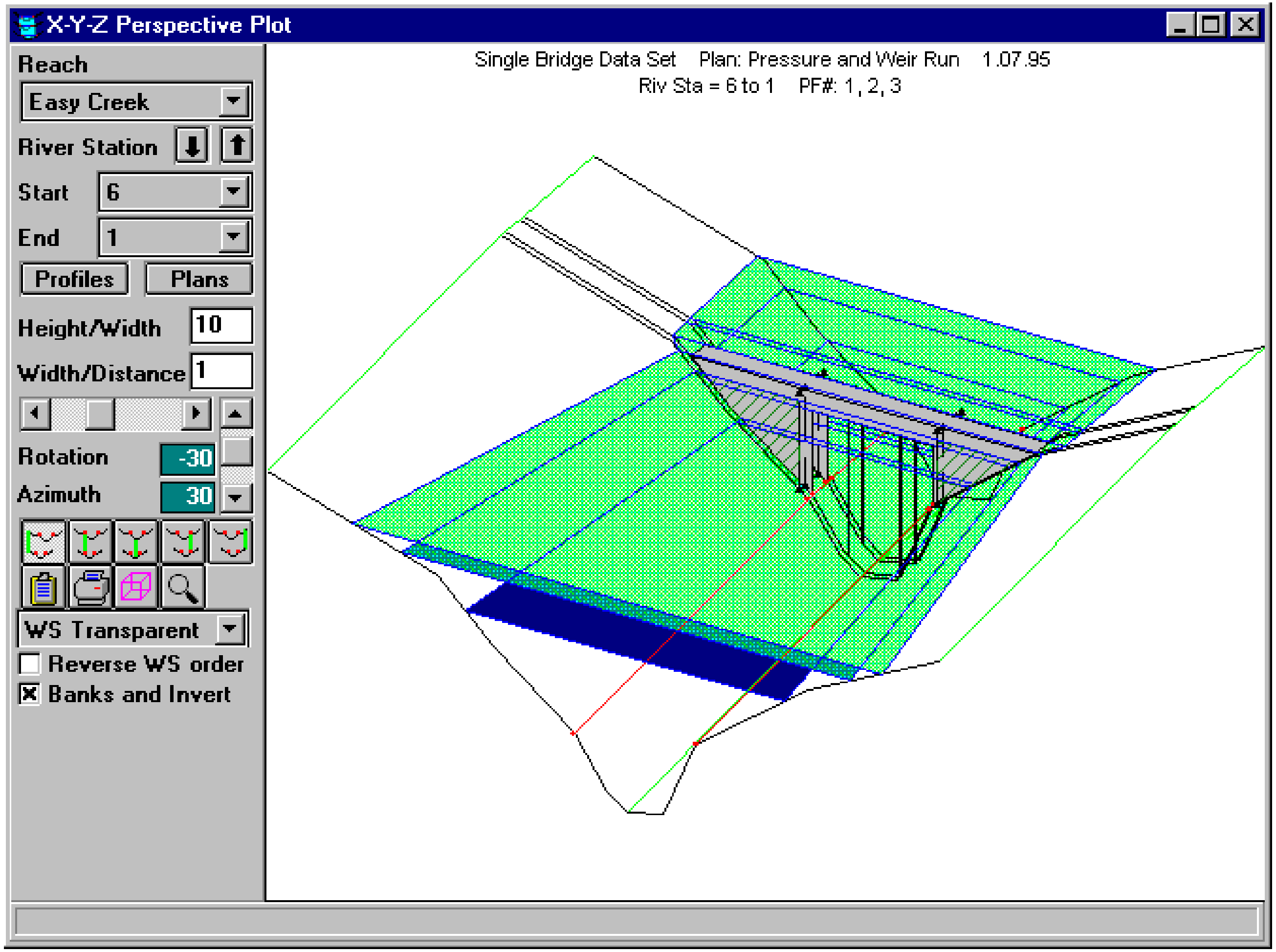
- Numerical Models
  - 1, 2, 3-D space numerical models
  - Steady versus unsteady state (time)
- Proprietary versus open source
- Analytical versus empirical
  - Many "analytical" models are semi-empirical
- Modeling as an "art"
- Developed over time as budget allows (LA funded bridge piers)

Velocity Distribution In A Channel

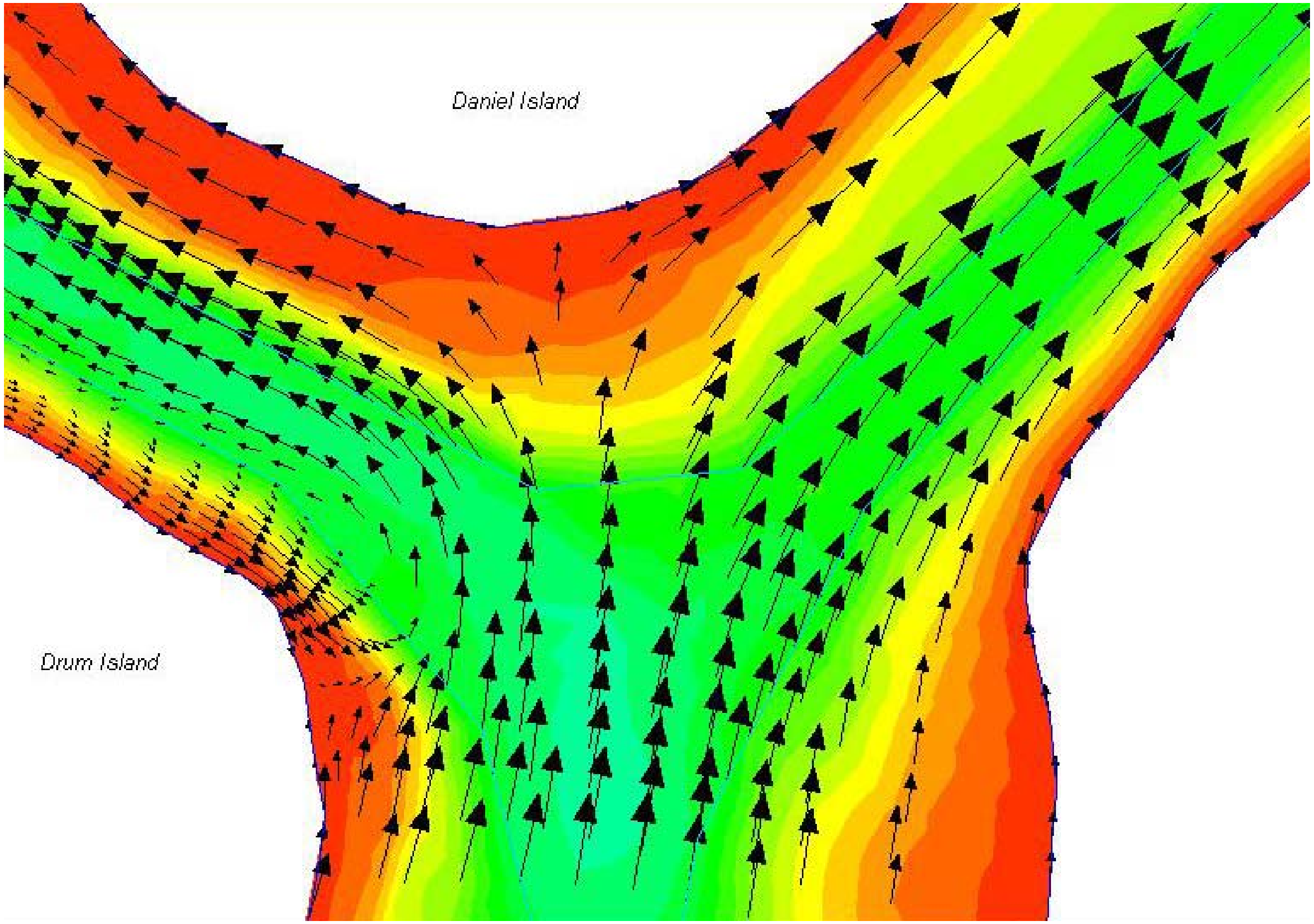


Depth-averaged velocity is above the bed at about 0.4 times the depth

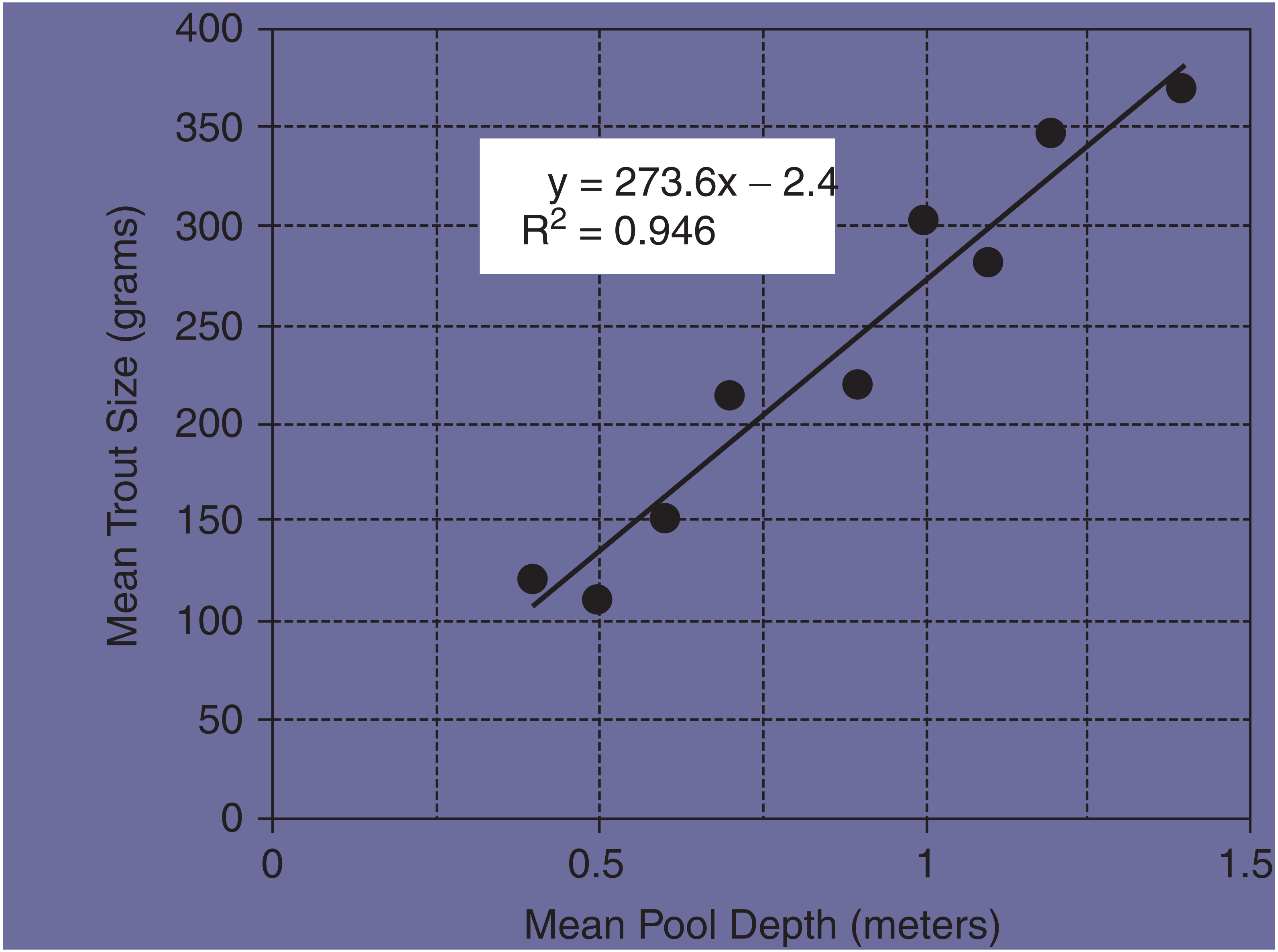
1D- Flow modeling - Output



2D- Flow modeling - Output



Empirical Relationships

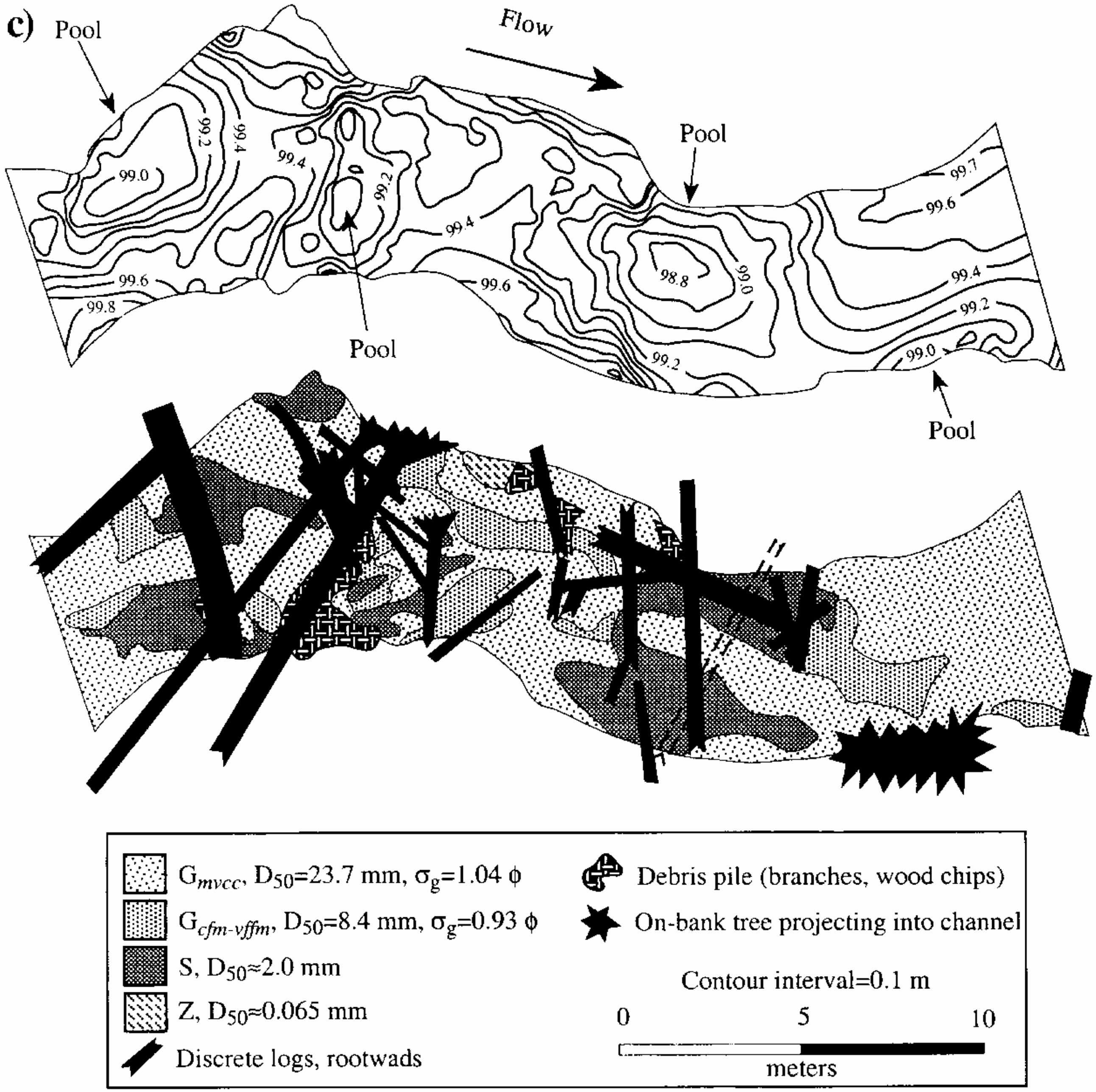


Equation Number	Equation	Applicable Range
Interrelations between meander features		
2	$L_m = 1.25_b$	18.0 L_b 43,600 ft
3	$L_m = 1.63B$	12.1 B 44,900 ft
4	$L_m = 4.53R_c$	8.5 R_c 11,800 ft
5	$L_b = 0.8L_m$	26 L_m 54,100 ft
6	$L_b = 1.29B$	12.1 B 32,800 ft
7	$L_b = 3.77R_c$	8.5 R_c 11,800 ft
8	$B = 0.61L_m$	26 L_m 76,100 ft
9	$B = 0.78L_b$	18.0 L_b 43,600 ft
10	$B = 2.88R_c$	8.5 R_c 11,800 ft
11	$R_c = 0.22L_m$	33 L_m 54,100 ft
12	$R_c = 0.26L_c$	22.3 L_b 43,600 ft
13	$R_c = 0.35B$	16 B 32,800 ft
Relations of channel size to meander features		
14	$A = 0.0094{L_m}^{1.53}$	33 L_m 76,100 ft
15	$A = 0.0149{L_b}^{1.53}$	20 L_b 43,600 ft
16	$A = 0.021B^{1.53}$	16 B 38,100 ft
17	$A = 0.117{R_c}^{1.53}$	7 R_c 11,800 ft
18	$W = 0.019{L_m}^{0.89}$	26 L_m 76,100 ft
19	$W = 0.026{L_b}^{0.89}$	16 L_b 43,600 ft
20	$W = 0.031B^{0.89}$	10 B 44,900 ft
21	$W = 0.81{R_c}^{0.89}$	8.5 R_c 11,800 ft
22	$D = 0.040{L_m}^{0.66}$	33 L_m 76,100 ft
23	$D = 0.054{L_b}^{0.66}$	23 L_b 43,600 ft
24	$D = 0.055B^{0.66}$	16 B 38,100 ft
25	$D = 0.127{R_c}^{0.66}$	8.5 R_c 11,800 ft

Equation Number	Equation	Applicable Range
Relations of meander features to channel size		
26	$L_m = 21A^{0.65}$	0.43 A 225,000 ft
27	$L_b = 15A^{0.65}$	0.43 A 225,000 ft
28	$B = 13A^{0.65}$	0.43 A 225,000 ft
29	$R_c = 4.1A^{0.65}$	0.43 A 225,000 ft
30	$L_m = 6.5W^{1.12}$	4.9 W 13,000 ft
31	$L_b = 4.4W^{1.12}$	4.9 W 7,000 ft
32	$B = 3.7W^{1.12}$	4.9 W 13,000 ft
33	$R_c = 1.3W^{1.12}$	4.9 W 7,000 ft
34	$L_m = 129D^{1.52}$	0.10 D 59 ft
35	$L_b = 86D^{1.52}$	0.10 D 57.7 ft
36	$B = 80D^{1.52}$	0.10 D 59 ft
37	$R_c = 23D^{1.52}$	0.10 D 57.7 ft
Relations between channel width, channel depth, and channel sinuosity		
38	$W = 12.5D^{1.45}$	0.10 D 59 ft
39	$D = 0.17W^{0.89}$	4.92 W 13,000 ft
40	$W = 73D^{1.23}K^{-2.35}$	0.10 D 59 ft and 1.20 K 2.60
41	$D = 0.15w^{0.50}K^{1.48}$	4.9 W 13,000 ft and 1.20 K 2.60

Derived empirical equations for river-meander and channel-size features.

A = bankfull cross-sectional area.
W = bankfull width.
D = bankfull mean depth.
L_m = meander wavelength.
L_b = along-channel bend length.
B = meander belt width.
R_c = loop radius of curvature.
K = channel sinuosity.


c)
Pool
Flow
Pool
Pool
Pool
99.0
99.2
99.4
99.4
99.2
99.4
99.6
99.8
99.6
98.8
99.0
99.2
99.7
99.6
99.4
99.2
99.0
G_mvcc, D50=23.7 mm, σg=1.04 ϕ
G_cfm-vffm, D50=8.4 mm, σg=0.93 ϕ
S, D50≈2.0 mm
Z, D50≈0.065 mm
Discrete logs, rootwads
Debris pile (branches, wood chips)
On-bank tree projecting into channel
Contour interval=0.1 m
0
5
10
meters

Setting up a model study

- Write down the specific questions you want answered
- Modeling should be commensurate with scale and importance of project
- Demand clarity in results – you are now <u>officially</u> empowered to understand your modeling study
- Calibration and sensitivity analysis

Does modeling depends on choice of firm hired?

- Old school field based geomorphologist
  - Model with slide ruler, beer and endless stories
- Groovy geomorph firms
  - Rosgen plus beer
- More polyester based corporate consulting firms
  - Latest 3-D Dutch turbo model with dual quad inputs
- Academics
  - 5D models with grad students swimming to collect data

Parameter uncertainty

- Binary (on or off)
- Parameters can be measured with almost total certainty (i.e. survey info)-5-10%
- Estimated with high degree of certainty (e.g. %imp, n for pipes, flow)-10-25%
- Not easily measured (e.g. infil rates, pollutant build-up) – 25-50%
- Not measurable w/ any certainty (infil cap.) - 50-100%?

Quality control checks

1. Uncertainty analysis (16 sources of error) – to quantify error
2. Sensitivity analysis – run model varying each parameter to identify most sensitive (=add'l field work)
3. Calibration against known results
    1. Is calibration unique? No
    2. Find "best" values for most sensitive parameters
4. Model validation

Embrace uncertainty in results

- Fuzzy logic
- USACE new levee analysis recognizes uncertainty in design
- Next generation…neural network modeling

Modeling report should have at minimum

- Clear description of dominant processes and how identified
- Data collected and utilized for study; accuracy and data error bars
- Description of model selection and basis
- List of model parameters and rationale for selection
- Boundary and Initial Conditions and why

Modeling report should have at a minimum

- Model calibration results (i.e. high water marks)
- Sensitivity analysis to identify key parameters; focus further field work
- Results clearly presented and labeled at areas of interest (not just data dumps)
- Next steps

Stream Restoration Modeling

- Look at two main questions
  - Will it flood?
  - Is it stable?
- Obviously, many other questions could be asked (fish, WQ)

Stream restoration models

- Hydrology – what happens when it rains
- Hydraulics – how does it flow
- Sediment – aggrade/degrade, scour, stability

Hydrologic modeling to develop design flows

- What happens when it rains?
- Physical versus black box models (lumped versus distributed parameters)
- Single event versus continuous simulation
- Uncertainty in hydrology
  - Ungauged watersheds have higher uncertainty (LAC 50yr=USACE 500yr)
  - Need tipping bucket gage data, please

Hydrology continued

- Physical versus black box models (lumped versus distributed parameters)
  - Precomputer approaches
    - Rational method, SCS (TR-55), unit hydrograph (user/predet), triangular
    - Physically based models using rainfall and actual physically based processes to determine runoff
  - HMS can do both! SWMM is physically based

Single event versus continuous simulation

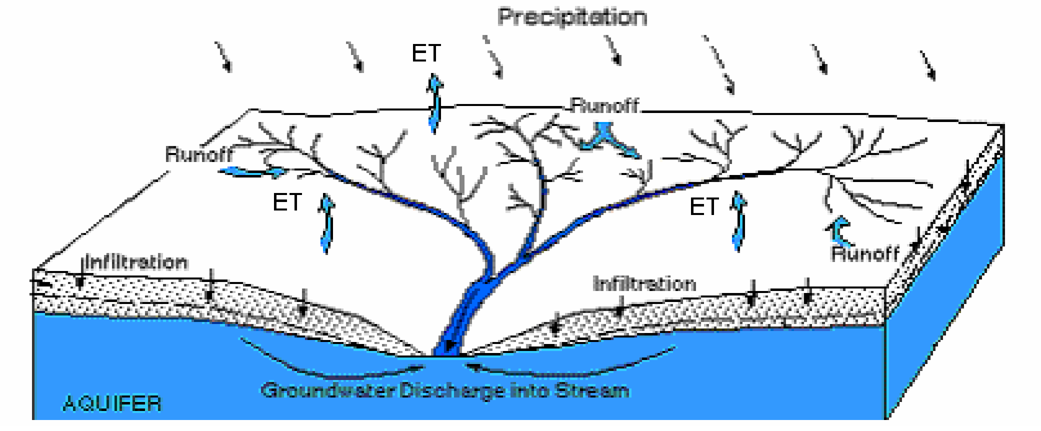
- Event based models using a single design storm period and duration (i.e. 24 hour 50 year storm event) for design
  - SCS has four 24 hours design storms and 4 antecedent water conditions
- With computers, now can easily run 50 or 100 years of rainfall through model. Need for WQ analysis
  - Uses local rainfall, better results = state of the art in hydrologic modeling
  - Calibrate against rainfall record; build design storm with local raingage info (stochastic methods)

note about California storms

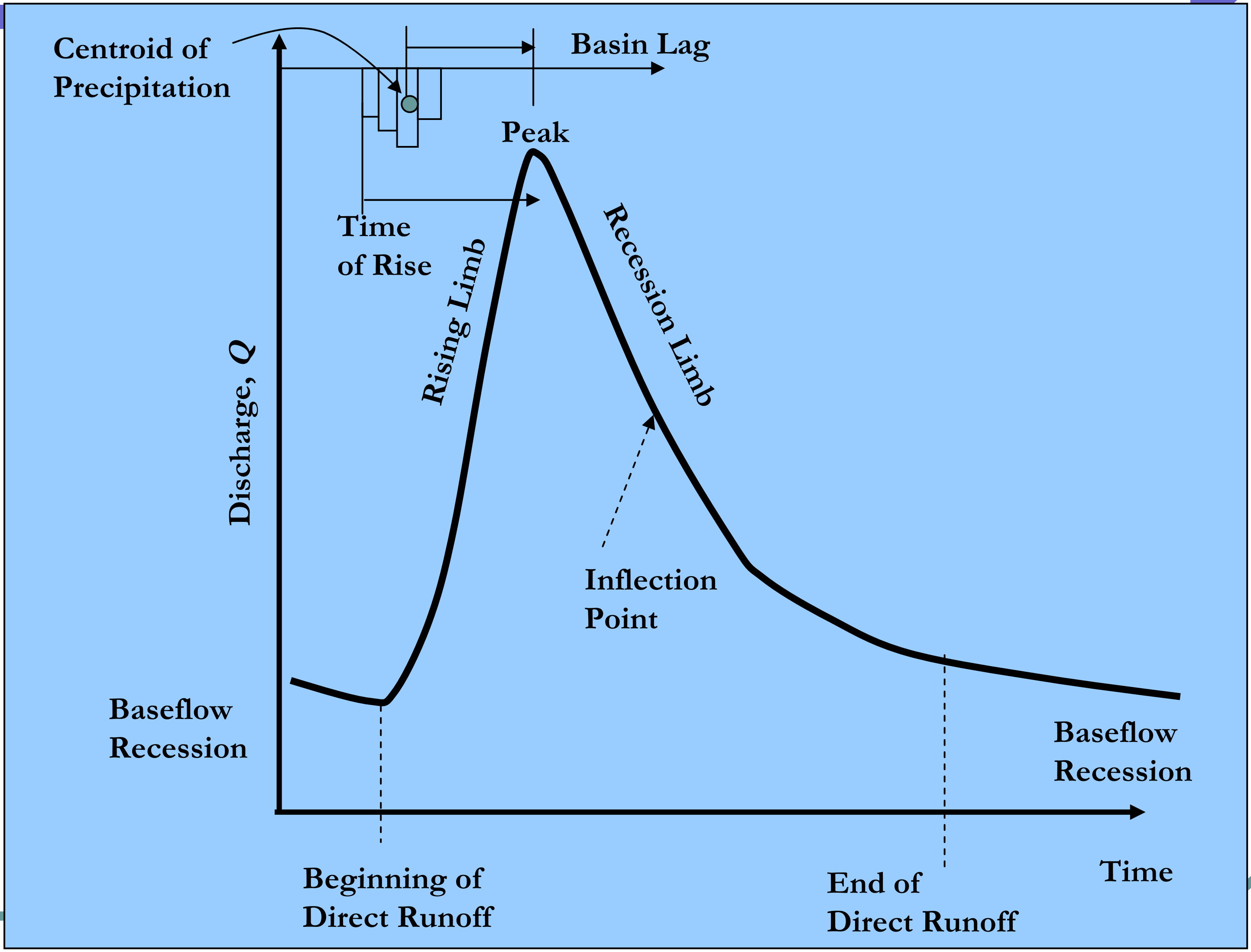
- In California, Oregon and W. Washington frontal storm system dominate cases of heavy precipitation
  - Last for days up to a month
  - Flow intensity long duration (10 to 20 days). Basin saturation over several days, small rains can cause big Q
  - Most analysis for thunderstorms patterns (high I, low D) (Denver east)
  - LA has both types, need to check in design

Hydrology Models

- What happens when it rains?
  - How does rainfall on a catchment translate into flow in a river?
  - Develop design Q for hydraulics
  - How does movement along these pathways impact the magnitude, timing, duration, and frequency of river flows, as well as water quality?

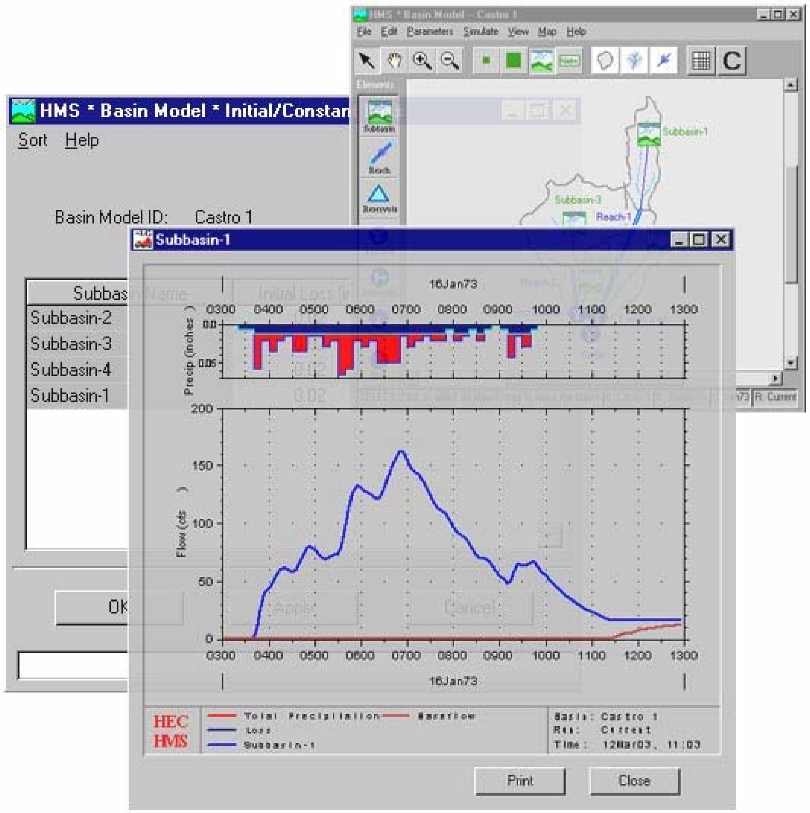


Hydrographs



Corps Hydrology Model

- HEC-HMS watershed scale, hydrologic simulation, of rainfall-runoff processes



Hydrologic models needs

- Rainfall precipitation
  - Gaged storms
  - Design storms (SCS 12-hour storms, 15 minute data – alt blocks)
  - Lumped (over subbasin)
  - linearly distributed (precip and losses for grid cells for radar R/F data)

Hydrology models needs

- Rainfall Losses
  - Physically based (Green Ampt)
  - SCS curve number
  - SMA (5 layer)
  - Exponential
  - initial/constant

Hydrology model needs

- Run-Off Transformation
  - Unit hydrograph (user specified, Clark, Synder, SCS)
  - Modified Clark
  - Kinematic wave (physically based)

Hydrology model again

- Routing (Channel)
  - Simple lag (keeps hydrograph shape)
  - Muskingham (3 types)
  - Mod Puls
  - Kinematic wave

HMS add'l capabilities

- Diversions and sinks
- Base flow and pumps
- Evapotranpiration
- Snowfall/melt
- Reservoir routing
- Dam break (use RAS)
- Erosion and sed transport (future versions)

Now to Hydraulic Modeling

- Steady versus unsteady-state flow
- Understanding how a model is set-up (boundary conditions, initial conditions)
- Assigning roughness (willows bend)
- Structures (culverts, bridges etc)
- Main model parameters are surveyed and lower uncertainty

HEC-RAS

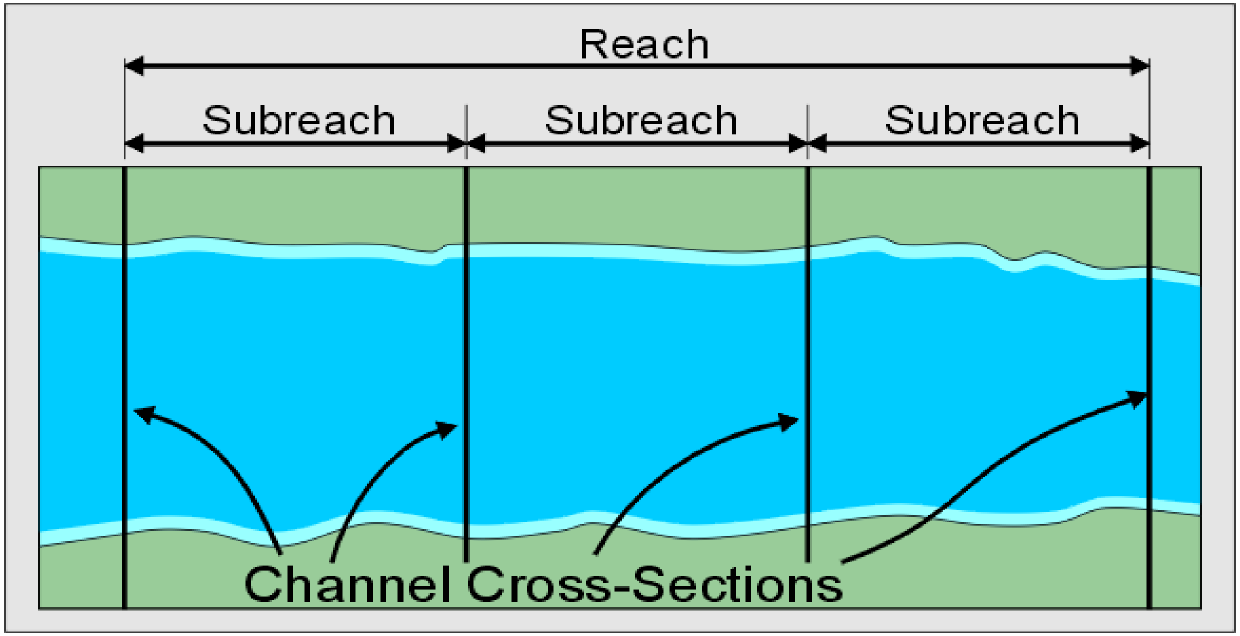
- Designed by US Army Corps of Engineers
- Easy to use, fast results, used for flood forecasts, free software
- Three 1D hydraulic analysis components
  - Steady flow simulation
  - Unsteady flow simulation
  - Sediment transport computations (beta!)

Flooding

Defining flow data in HEC-RAS

Required input for steady flow analysis:

- Discharge at cross sections with a change in flow.
- Boundary conditions
  - • Downstream Channel Slope (Used to calculate Normal Depth of US if supercritical flow)
- –Friction values (Mannings n)



Main empirical parameter Mannings n values

- Summation of all channel friction (veg+ surface irreg+xsec var + obstructions + meandering)
- Typical to use single value from Chow or picture books
- Current research in vegetated n values at Davis and USACE
  - Latest version of RAS allows for vertical variation in n value

Manning's *n* Examples

TABLE 6.1 Manning roughness coefficients (*n*) for different boundary types.

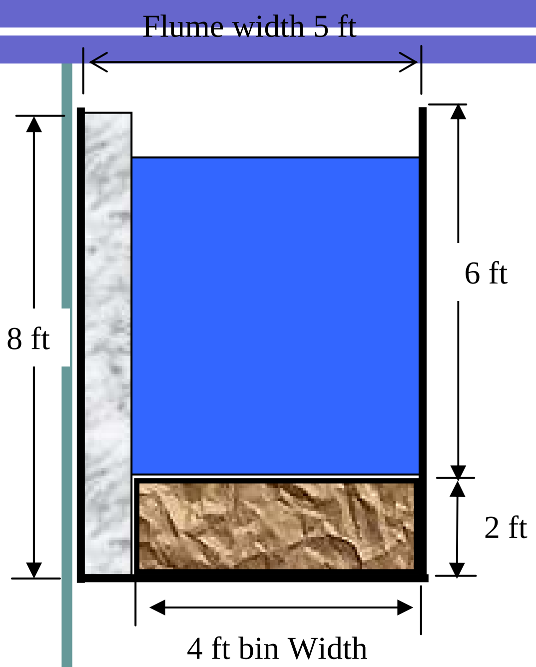
Boundary	Manning *n* ($ft^{1/6}$)
Very smooth surfaces such as glass, plastic, or brass	0.010
Very smooth concrete and planed timber	0.011
Smooth concrete	0.012
Ordinary concrete lining	0.013
Good wood	0.014
Vitrified clay	0.015
Shot concrete, untroweled, and earth channels in best condition	0.017
Straight unlined earth canals in good condition	0.020
Rivers and earth canals in fair condition; some growth	0.025
Winding natural streams and canals in poor condition; considerable moss growth	0.035
Mountain streams with rocky beds and rivers with variable sections and some vegetation along banks	0.041–0.050

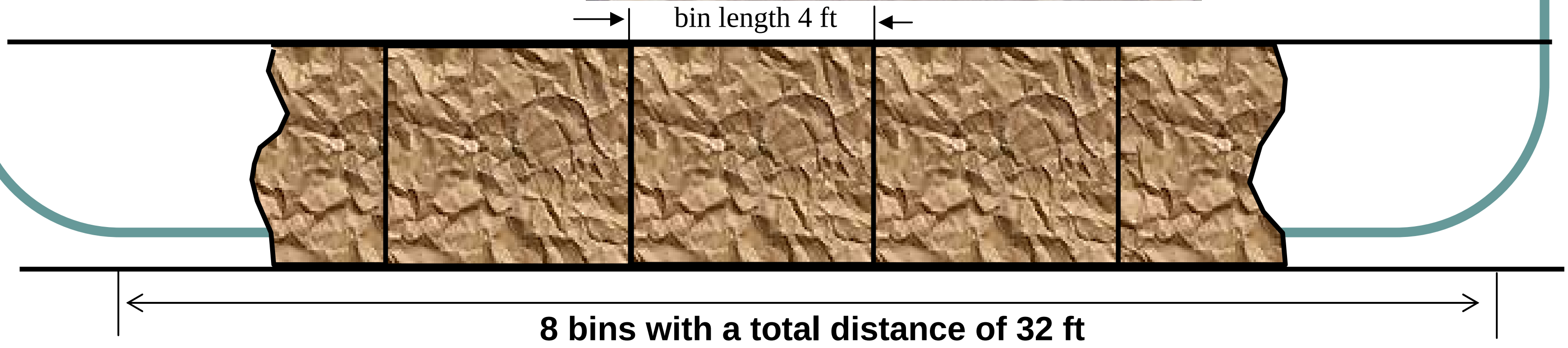
Source: *Handbook of Applied Hydrology,* ed. by Ven T. Chow, copyright 1964 McGraw-Hill Publishing Co., Inc.

Table 7.1 Manning's n Roughness Coefficient

Type of Channel and Description	Minimum	Normal	Maximum
Streams			
Streams on plain			
Clean, straight, full stage, no rifts or deep pools	0.025	0.03	0.033
Clean, winding, some pools, shoals, weeds & stones	0.033	0.045	0.05
Same as above, lower stages and more stones	0.045	0.05	0.06
Sluggish reaches, weedy, deep pools	0.05	0.07	0.07
Very weedy reaches, deep pools, or floodways	0.075	0.1	0.15
with heavy stand of timber and underbrush			
Mountain streams, no vegetation in channel, banks steep, trees & brush along banks submerged at high stages			
Bottom: gravels, cobbles, and few boulders	0.03	0.04	0.05
Bottom: cobbles with large boulders	0.04	0.05	0.07

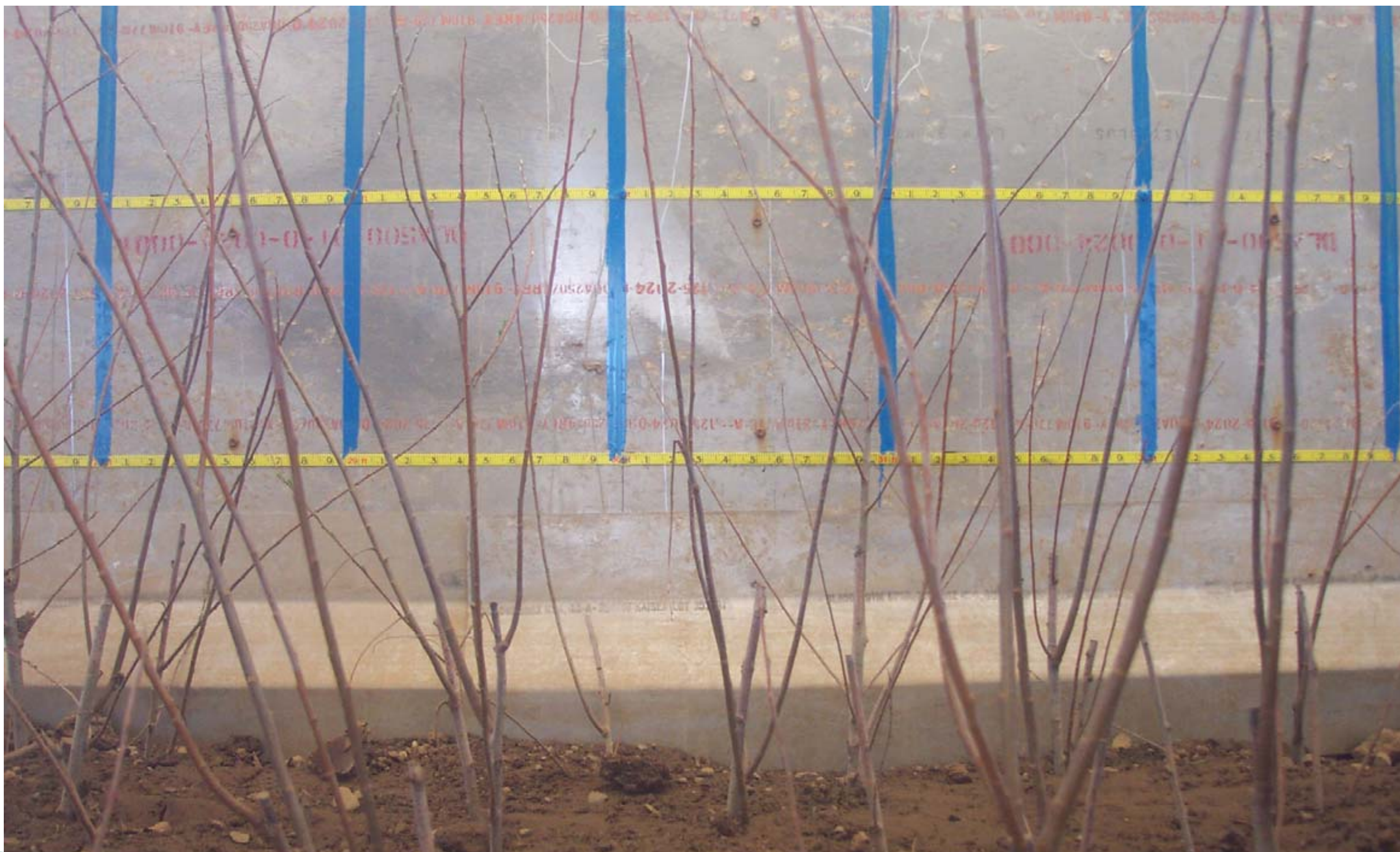
Sandbar Willow Test Configuration





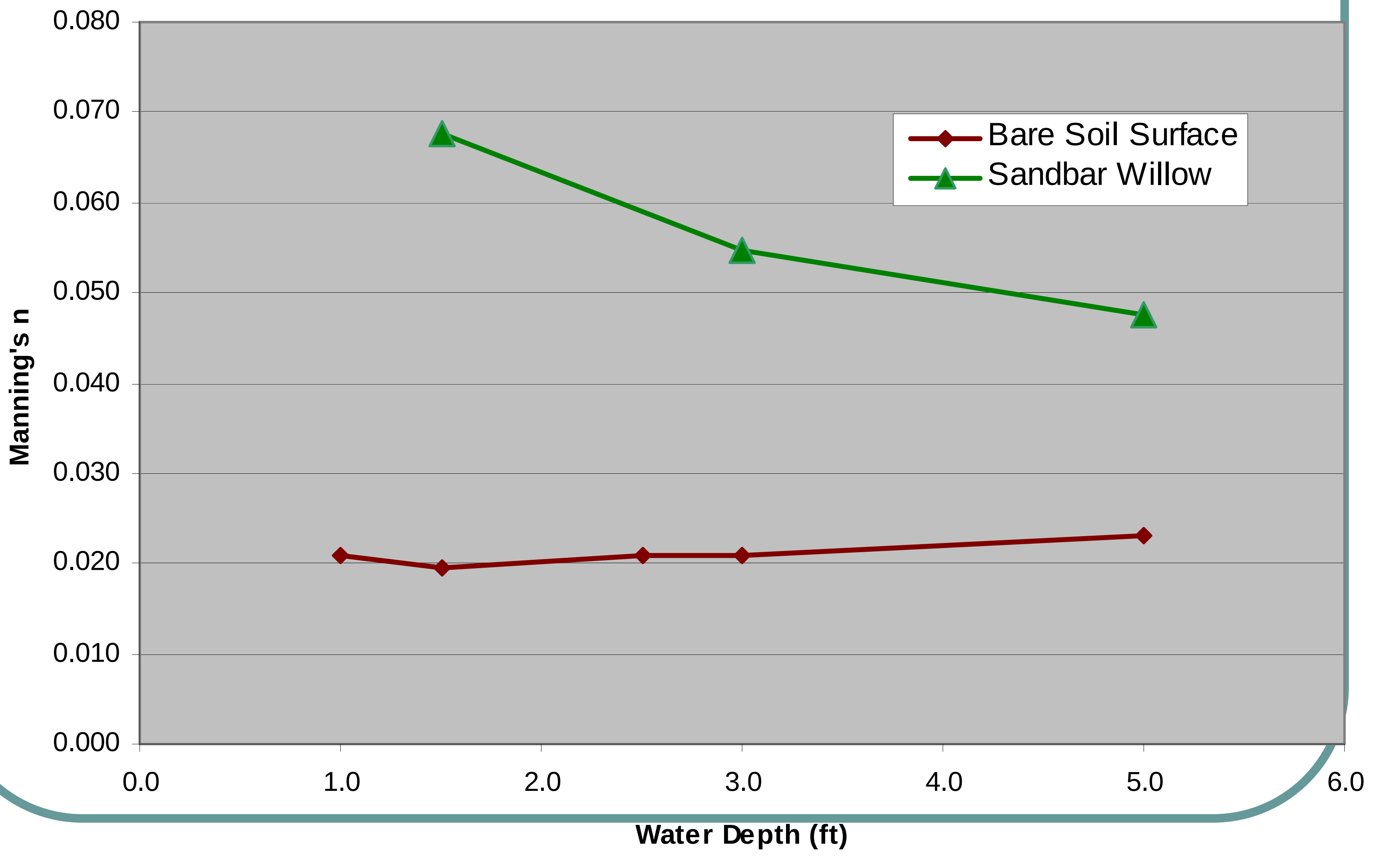
Plant Canopy Response Recording

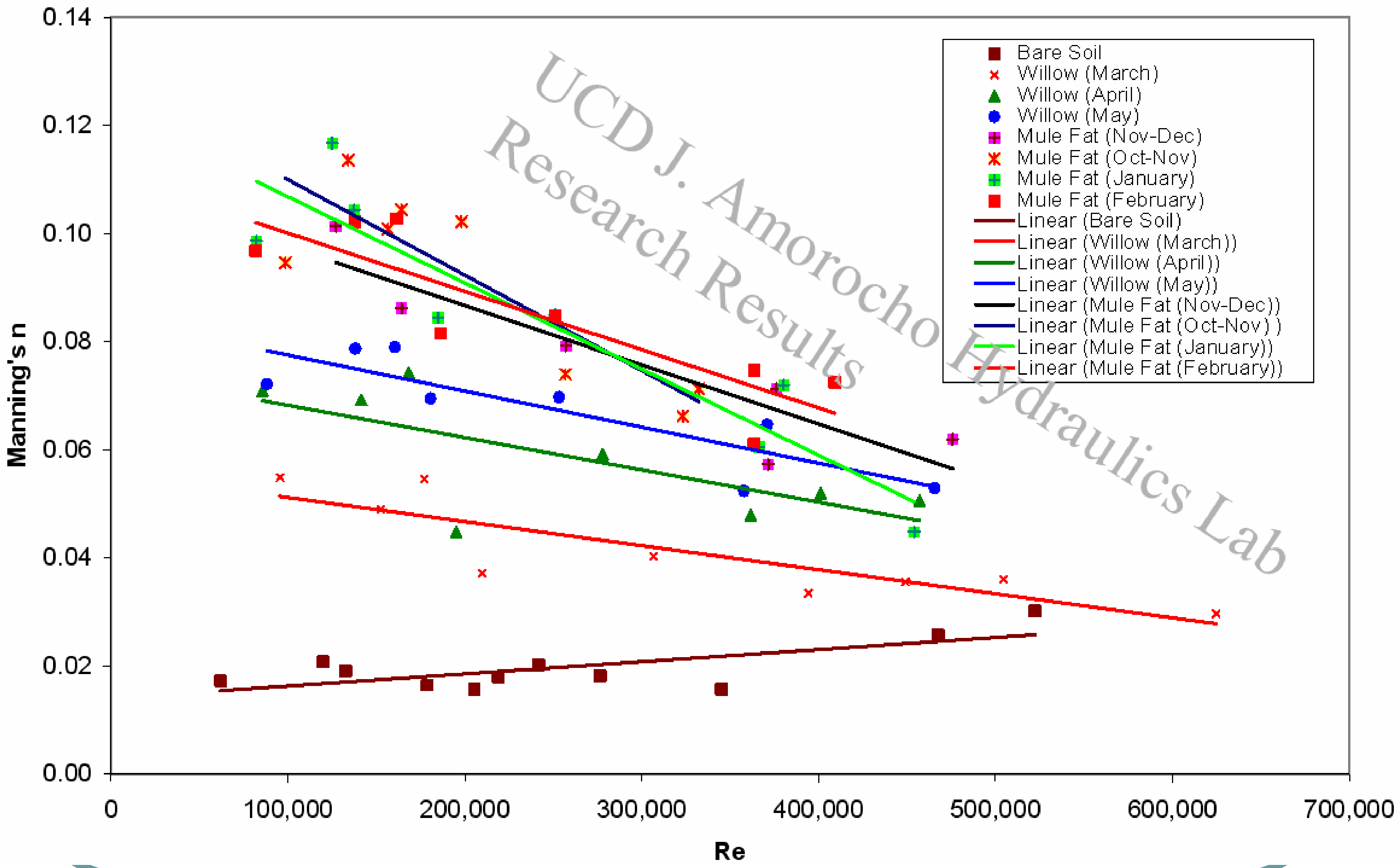
In order to measure the bending displacement of the plant stems/branches, several measuring tapes have been pasted to both flume walls in the horizontal direction at the plant patch section of the Flume at several depths along the range of stem heights, corresponding to a plant species canopy.



Sandbar Willow As Observed Through View Window

Roughness Coefficient





UCD J. Amorocho Hydraulics Lab
Research Results
Manning's n
Re
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
100,000
200,000
300,000
400,000
500,000
600,000
700,000
Bare Soil
Willow (March)
Willow (April)
Willow (May)
Mule Fat (Nov-Dec)
Mule Fat (Oct-Nov)
Mule Fat (January)
Mule Fat (February)
Linear (Bare Soil)
Linear (Willow (March))
Linear (Willow (April))
Linear (Willow (May))
Linear (Mule Fat (Nov-Dec))
Linear (Mule Fat (Oct-Nov))
Linear (Mule Fat (January))
Linear (Mule Fat (February))

Reviewing results for hydraulics model

- Do values change at boundary condition? (i.e. placed too close)
- Look for excessive jumps in egl and wse
- Ask for errors and warnings output file in report
- Tolerance of results
- Review calibration and qc checks
- Get peer review

Is it stable?

- Long term aggradation/degradation
- Local and short-term effects (i.e. pier scour, bank erosion)

Stable Channel Design

- Goal is no excessive erosion or deposition
- Methods available
  - Hydraulic geometry (regime theory) – esp width
  - Chanel competence methods based on incipient motion
  - Process-based models of erosion and deposition
- Do we always want no net storage?

Sediment and Stability Modeling

- Very empirically based
  - Even the “analytical” approaches have empirical transport func at core
- Very approximate
- Beta RAS 4.0 is more about long term aggradation/degradation
- Pier scour/incipient motion is empirical based analysis

Sediment Transport

Types

- **Wash Load**
- **Suspended Load**
- **Bed Load**

Methods

- **Shear Stress**
- **Power**
- **Parametric**

background

- Determine if supply or transport limited (what controls morphology)
- Sediment transport analysis
  - pebble counts/bulk analysis
  - Sediment gradations change at different flows
  - Collect at riffle sections/bank materials

Incipient motion of sediment

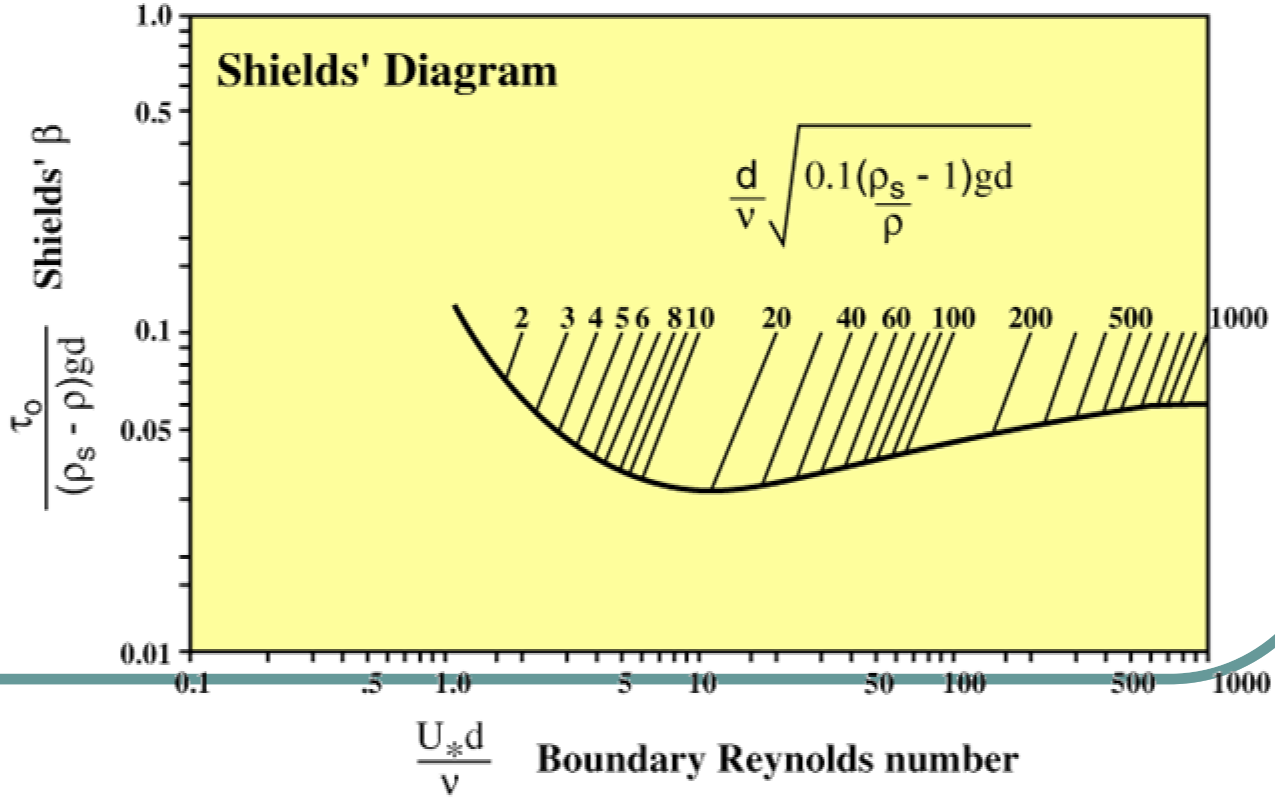
- Addresses mobility in terms of size and not sediment volume
- Average shear stress commonly determined by depth-slope product

$$\tau_0 = \gamma R_h S$$

Shields curve

Critical shear stress for motion.

$$\beta = \frac{\tau_o}{(\rho_s - \rho)gd}$$



Channel competence based methods

- Tractive force analysis (permissible shear or velocity)
- Mobile bed under fixed slope conditions (extremal hypothesis) –Fluvial 12 model
  - Minimize certain parameters
- Mobile bed under known sediment concentration (SAM model)
  - Adjust channel dimensions to transport sediment
  - Non-unique family of solutions (RAS toolbox)

Permissible Velocity for Grass

- p. 117 in

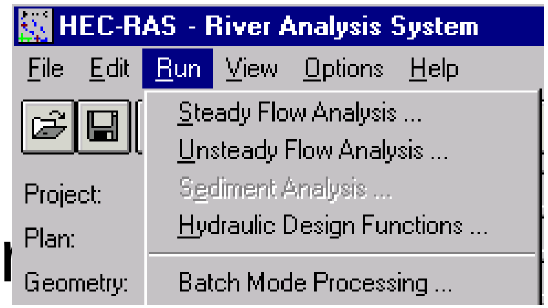
Table 4.5 Permissible velocities for Vegetated Channels (Ree, 1949)

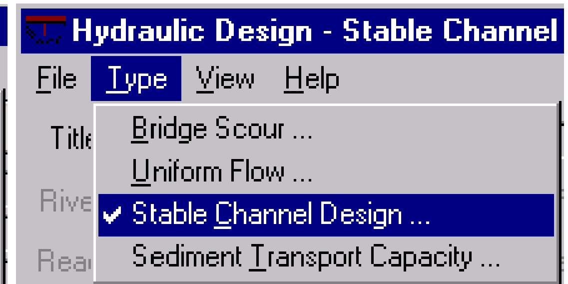
	Permissible velocity (fps)					
	Erosion-resistant soils (% slope)			Easily eroded soils (% slope)		
Cover	0–5	5–10	Over 10	0–5	5–10	Over 10
Bermuda grass	8	7	6	6	5	4
Buffalo grass Kentucky bluegrass Smooth brome Blue grama Tall fescue	7	6	5	5	4	3
Lespedeza sericea Weeping lovegrass Kudzu Alfalfa Crabgrass	3.5	NR[a]	NR	2.5	NR	NR
Grass mixture	5	4	NR	4	3	NR
Annuals for temporary protection	3.5	NR	NR	2.5	NR	NR

[a]Not recommended.

HEC-RAS Hydraulic Design: Stable Channel Design

- Copeland*
- Regime*
- Tractive For





  - Doesn’t account for input sediment
  - Utilizes critical shear stress to determine when bed motion begins
    - Particle size (d)
    - Depth (D)
    - Bottom Width (B)
    - Slope (S)
  - Uses shear stress and Manning equations

Given any two can solve for the other two

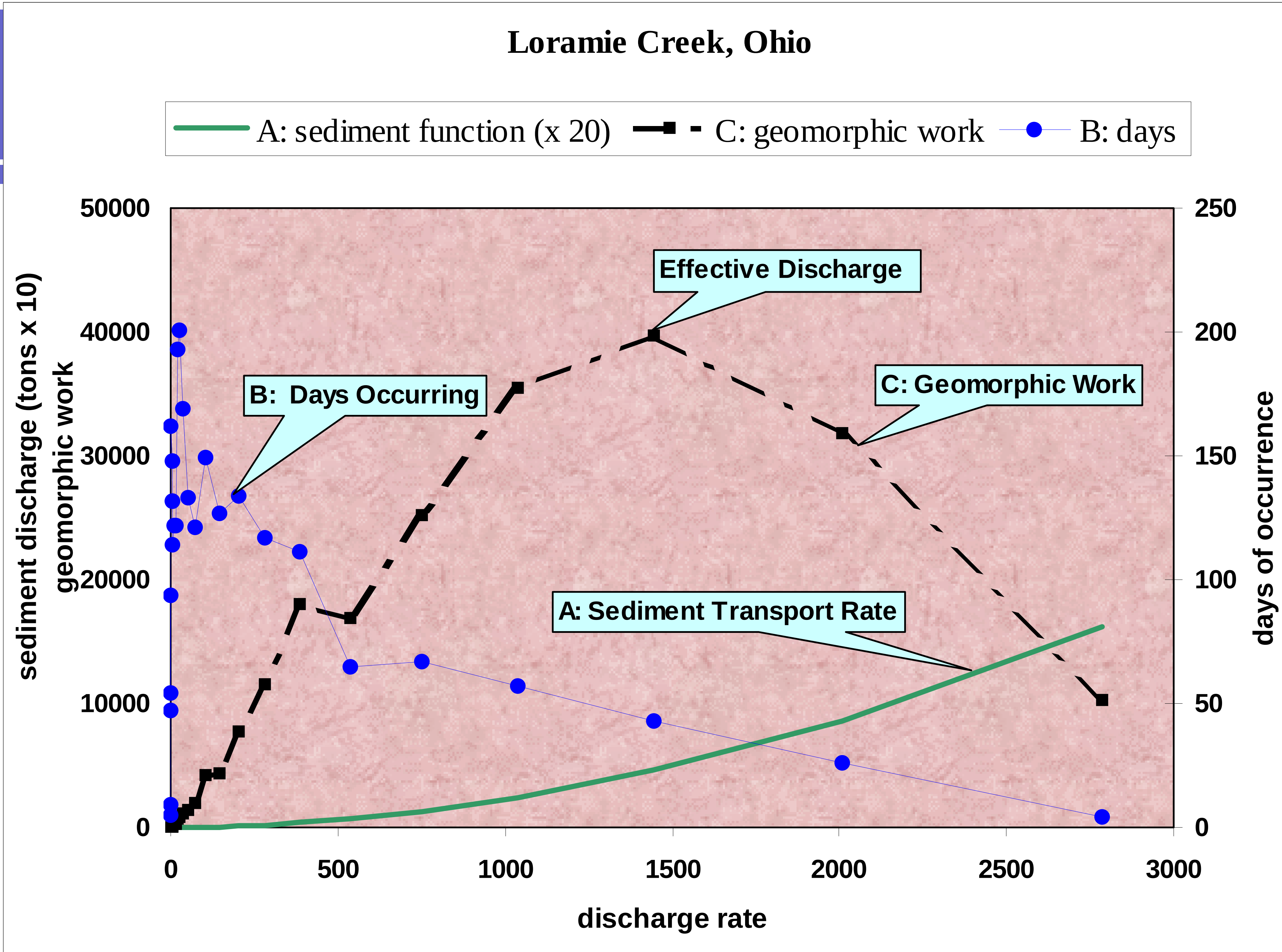
*Require input sediment discharge

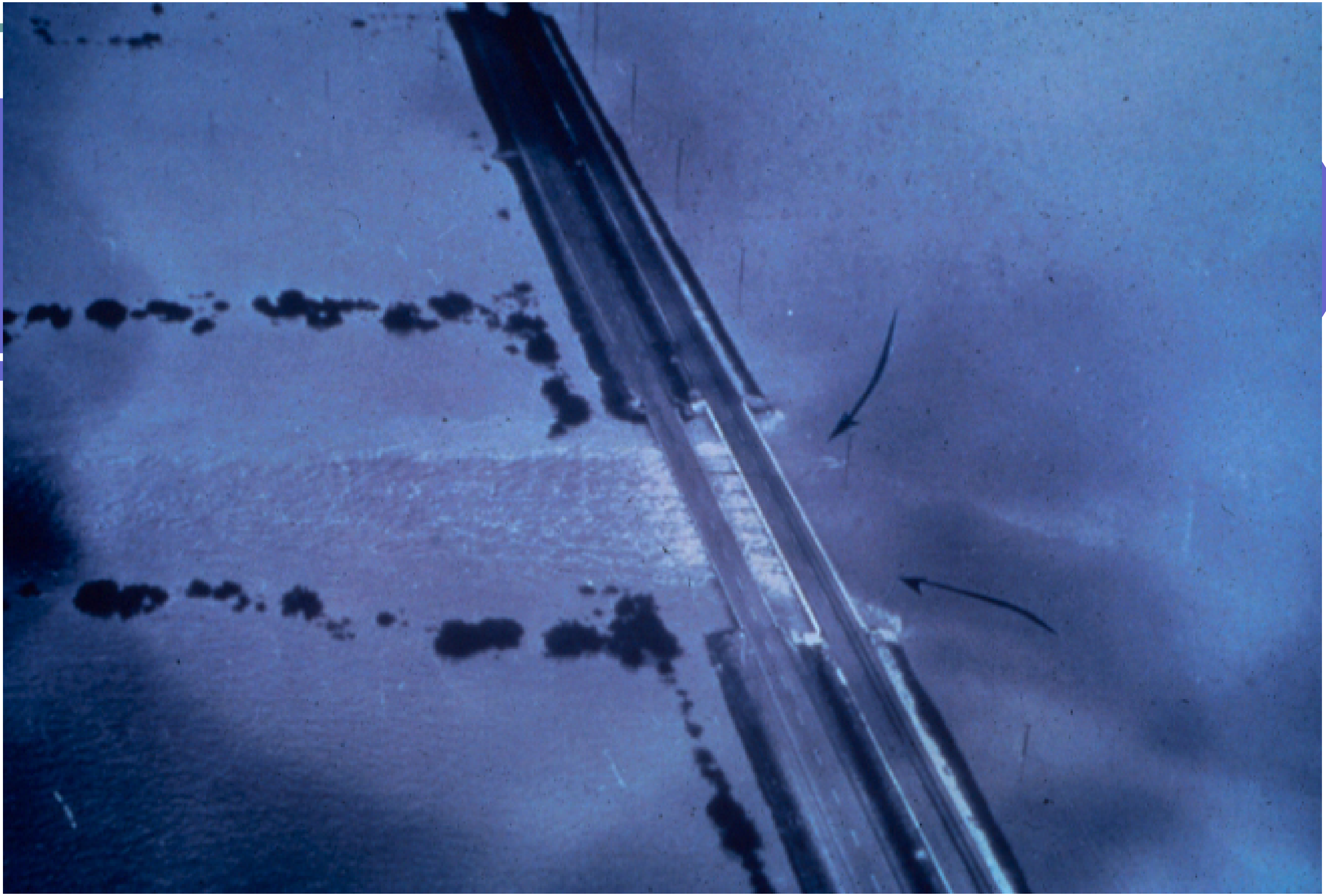
Sediment transport models

- RAS ver 4 beta
  - Compares transport capacity with supply to determine aggredation/degradtion
  - Quasi-unsteady
- Requires choice of sediment transport equation (empirical and varied)
- Site specific calibrated sediment transport model

Local effects

- Bridge Scour
  - Empirical methods in RAS toolbox
  - Contraction, abutment, pier scour computed separately and added together
- Bank Erosion
  - Not in RAS, USDA models use geotech properties


Loramie Creek, Ohio
A: sediment function (x 20)
C: geomorphic work
B: days
Effective Discharge
B: Days Occurring
C: Geomorphic Work
A: Sediment Transport Rate
sediment discharge (tons x 10)
geomorphic work
days of occurrence
discharge rate
50000
40000
30000
20000
10000
0
250
200
150
100
50
0
0
500
1000
1500
2000
2500
3000



Local Scour at Piers

Local Scour at Piers

Rock Channel Protection at Bridges

Water quality modeling

- Fish and benthic impacts
- Fish passage
- BMPs
- Temperature
- Chemicals of concern

Thanks for listening.