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HEC-RAS Sediment Transport Modeling

By WEST Consultants, Inc.

SEDIMENT TRANSPORT IN NATURAL STREAMS

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Outline

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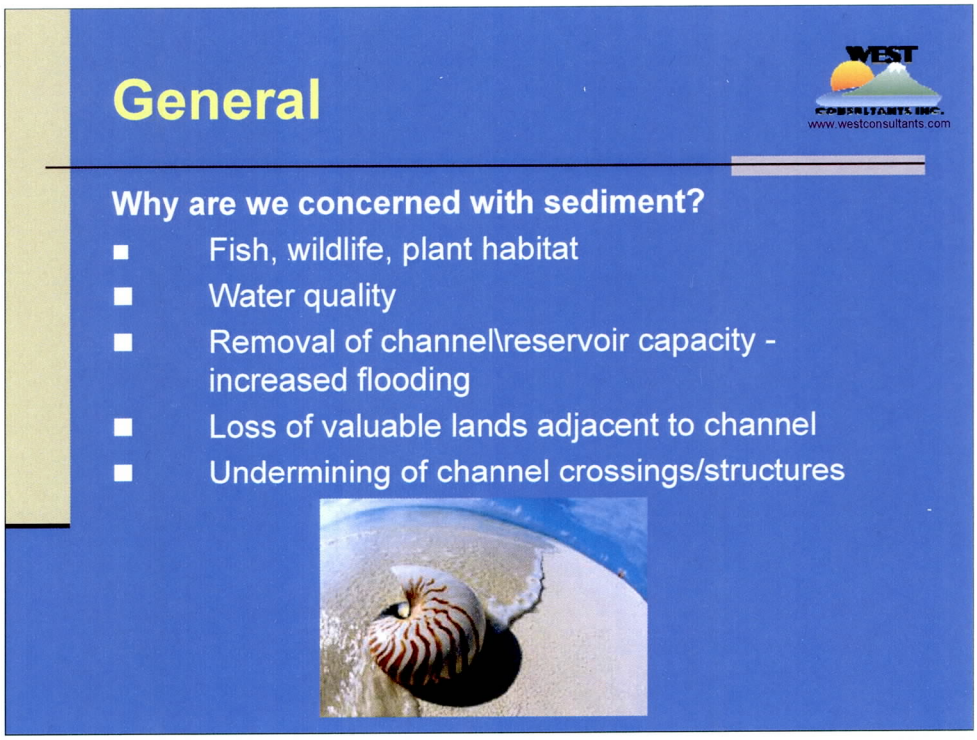
- General – Why are we concerned with sediment?
- Sediment Transport Processes
  - Agents
  - Processes
  - Time Scales
  - Erosion, Transport, Deposition
- Flow in Alluvial Channels
  - Lane's Balance
  - Regimes
  - General Effects (using Lane's Balance)
- Channel Stability



Sedimentation is a natural process that provides both problems and opportunities. Erosion, transport and depositional processes are often of concern in watershed, flood management, restoration, and environmental studies.

Sediment Transport Processes

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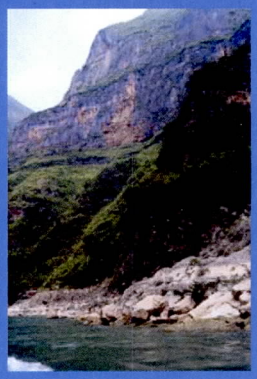
The principle external dynamic agents of sedimentation are:

1. water,
2. wind,
3. gravity,
4. ice, and
5. man.



Each of these sources of energy may be important locally or globally (on a larger scale).

Natural processes have been active throughout geological time and have shaped the present landscape of our world.

Sediment Transport Processes

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Definitions

Erosion may be defined as the detachment and removal of rocks or soil particles by the action of wind or water.

Fluvial sediment is a collective term meaning an accumulation of rock and mineral particles transported or deposited by flowing water.

Aeolian sediment is that moved or deposited by the wind.

Sediment Transport Processes

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Definitions

- Fluvial – Fluvius = River
- Geo – of or relating to earth, ground or soil
- Morphology – Study of form and structure
- Geomorphology - the study of landforms, the processes that created them, and the history of their development.
- Fluvial geomorphology - the examination of the processes that operate in river systems and the landforms which they create or have created.

Sediment Transport Processes

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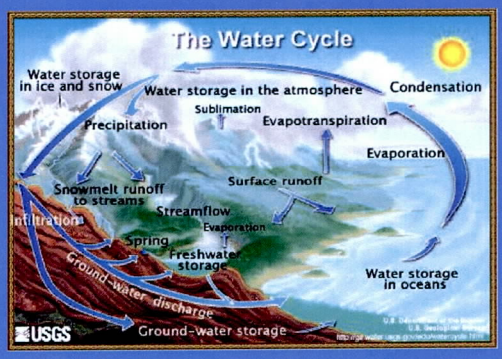
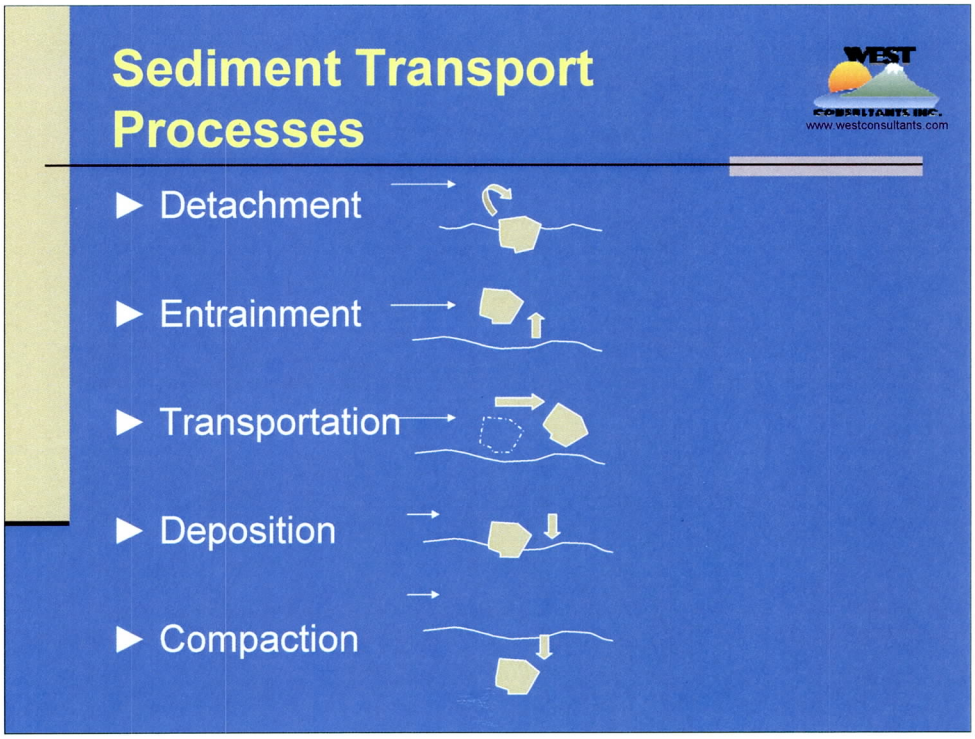
Important hydrospheric forces include:

1. Rainfall
2. Surface Runoff
3. Streamflow
4. Wind Forces





The processes of erosion, entrainment, transportation, and deposition of fluvial sediment are complex.

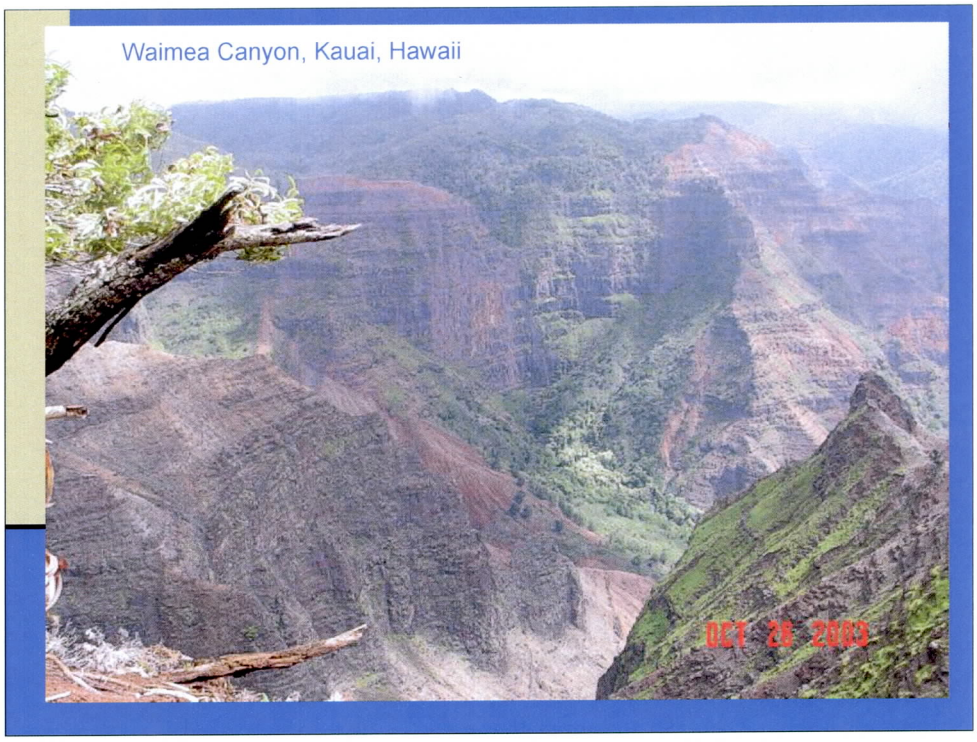
The detachment of particles in the erosion process occurs through the kinetic energy of raindrop impact, or by the forces generated by flowing water.

Once a particle has been detached, it must be entrained before it can be transported away.

Both entrainment and transport depend on the shape, size and weight of the particle and on the forces exerted on the particle by the flow.

When these forces are diminished to the extent that the transport rate is reduced or transport is no longer possible, deposition occurs.

Under the weight of depositional layers, compaction can occur over time depending on the size and shape of the particles.



Water erosion may be quite spectacular as seen in the Grand Canyon, Bryce Canyon, the Badlands of South Dakota, or Waimea Canyon on the Island of Kauai.

Time Scales for Sediment Processes

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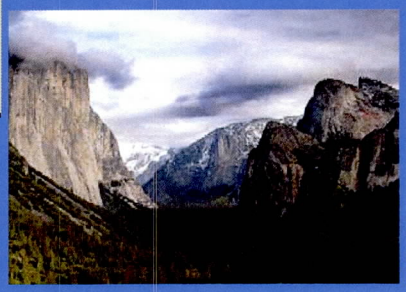
- Geologic Time (10^4-10^7 years)
  - Basins filling, plains degrading, swamps forming, etc.
  - Causes: Weather, mountain building, sea level changes, etc.



Time Scales for Sediment Processes

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- Project Time (100 years or less)
  - River meanders, channel erodes, shoaling, etc.
  - Causes: Transport capacity, sediment supply, human works
  - Reservoir Sedimentation

Time Scales for Sediment Processes

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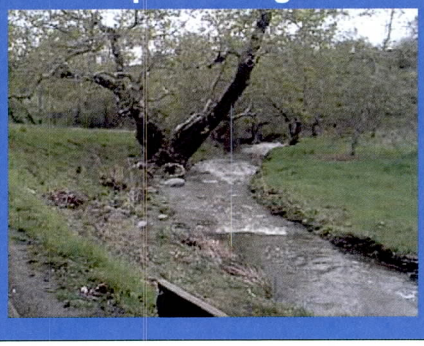
- Major Flood
  - Changes floodplain geometry, scours structures, debris/sediment deposits
  - Causes: Flood magnitude, specific location, specific regulation works



Time Scales for Sediment Processes

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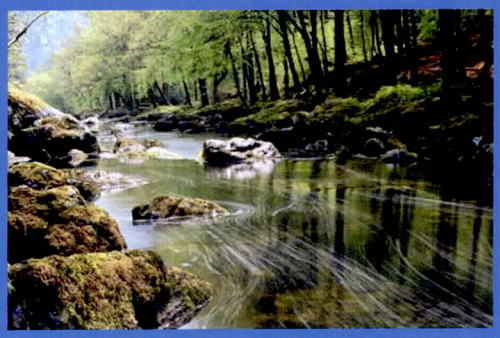
- Instantaneous
  - Sediment load, erosive power
  - Causes: Stream geometry, flow velocity, sediment gradation, armoring



Erosion

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Localized erosion can create serious problems and damage to banks, farm lands, reduction of agricultural lands. Some types of erosion:

- Geologic -- natural
- Accelerated -- Man's Activities
  - Agriculture
  - Animal Grazing
  - Urbanization
  - Road and Highway Construction
  - Mining Operations
  - Altering Runoff Conditions
  - River Control
  - Water Quality

Transport

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- Sediment transport affects water quality:

(1) Reduction of light penetration

Beer-Lambert Law (absorption of light)

Therefore reduction of algae

(2) Nutrient source

(3) Affects Benthos

(4) Adsorption of metal, sand, pesticides

Source or sink for these constituents

(5) May affect water temperature by absorbing radiation

(6) Appropriate particle sizes for fish spawning

Deposition

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- Deposited sediment may produce new lands or enhance existing lands, e.g., Nile or delta regions (the Sacramento Valley is several hundred feet deep in rich alluvial deposits); it may also cause serious and expensive problems.

Examples:

(1) Deposits after flood events
(2) Shoaling
(3) Dredging - commercial transport
(4) Behind dams
(5) Reduces river depth

Deposition is the counterpart to erosion. Deposited sediment may cause damages depending on the amount, timing, character and placement.

Flow in Alluvial Channels

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Stream Regime:

- **Upper:** Hilly, Steep, Boulders and Gravel in Bed
- **Lower:** Alluvial Plain, Sand-Silt-Clay in Bed

Alluvial streams evolve towards equilibrium (Lane)

$$Q_s \bullet D_{50} \propto Q \bullet S$$

where

Q_s = Bed material load D_{50} = Average sediment size

Q = Discharge S = Energy slope

On an annual basis, D_{50} and Q are approximately constant, so

Q_s □ □, S □ □

This varies along a stream -- have to account for sources and sinks

Flow in Alluvial Channels

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Lane's Balance

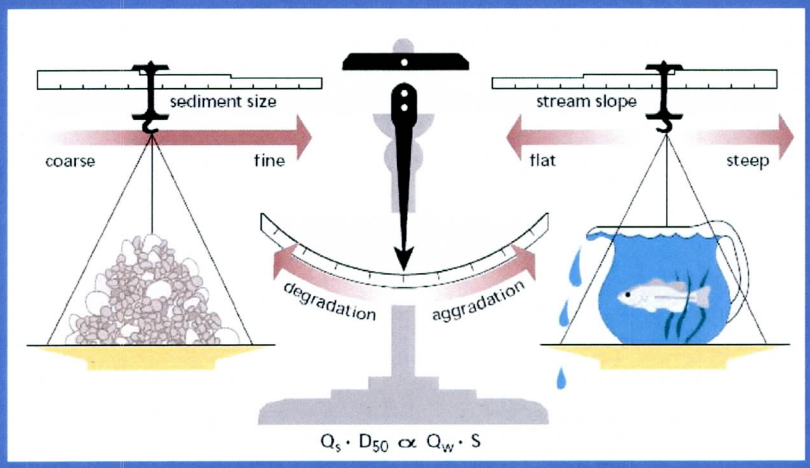
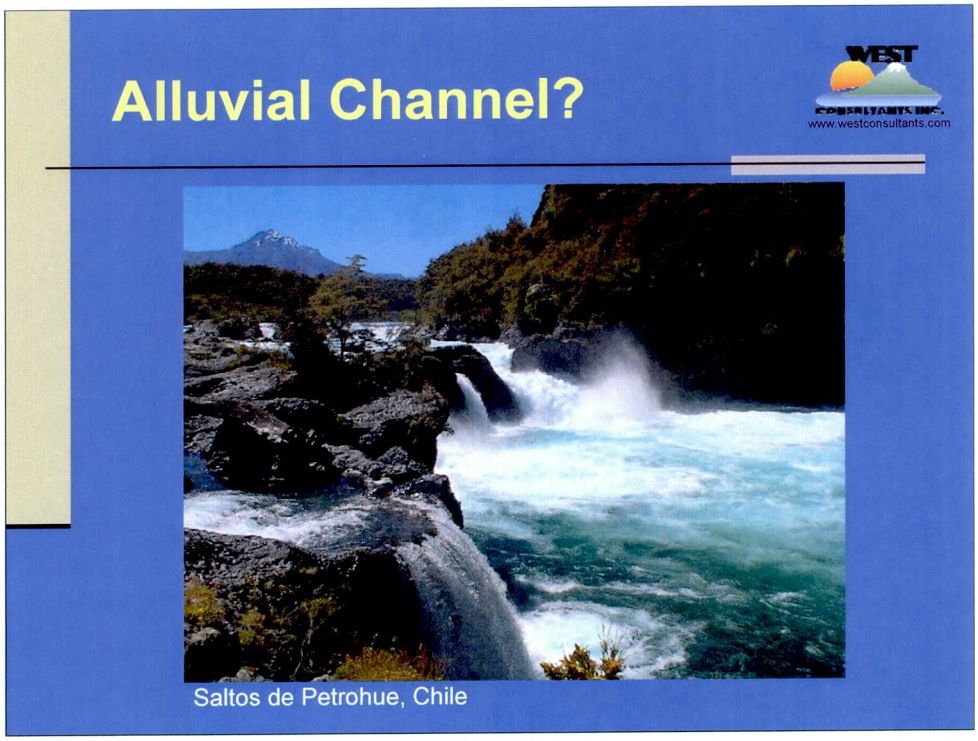


Figure from Rosgen (1996) - ASCE



Alluvial – Pertains to alluvium deposited by a stream or flowing water

Alluvium – Sand, clay, etc gradually deposited by moving water, as along a river bed.

Alluvial Stream – A stream whose channel boundary is composed of appreciable quantities of the sediments transported by the flow

Alluvial River Regimes

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- Degrading: Seeking Dynamic Equilibrium

  Sediment load in is less than transport capacity out causing deep rivers (Mountain Rivers, Urbanizing Streams).

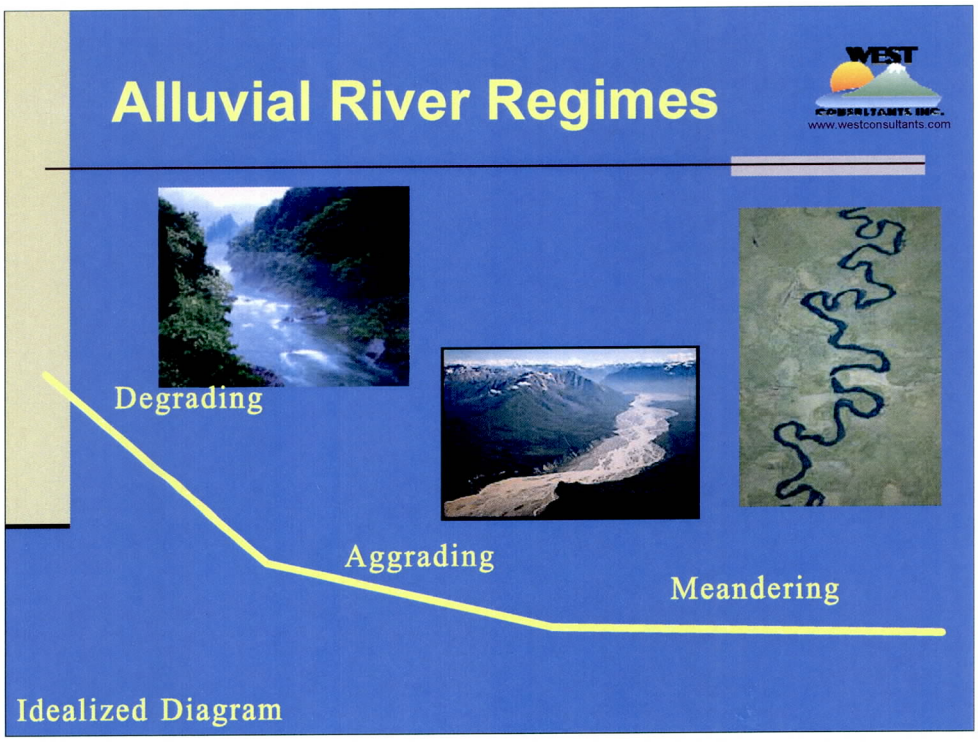
- Aggrading: Seeking Dynamic Equilibrium

  Sediment load in is greater than transport capacity out, causing wide, shallow (braided) streams (High Plains Rivers).

- Meandering: Fairly Stable Stream (Dynamic Equilibrium)

  Sediment load in is approximately equal to transport capacity out, causing bank erosion and deposition (Mississippi River).

$$Q_s \bullet D_{50} \propto Q \bullet S$$


Alluvial River Regimes
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Degrading
Aggrading
Meandering
Idealized Diagram

Degradation

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The Colorado River has cut downward more than 1,000 feet since the Plateau began to rise more than 1 million years ago

Meandering

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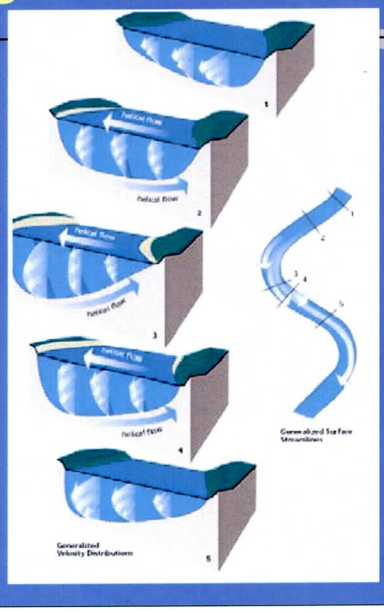
Helical flow causes erosion at outside of bend, deposition on inside



Aggradation

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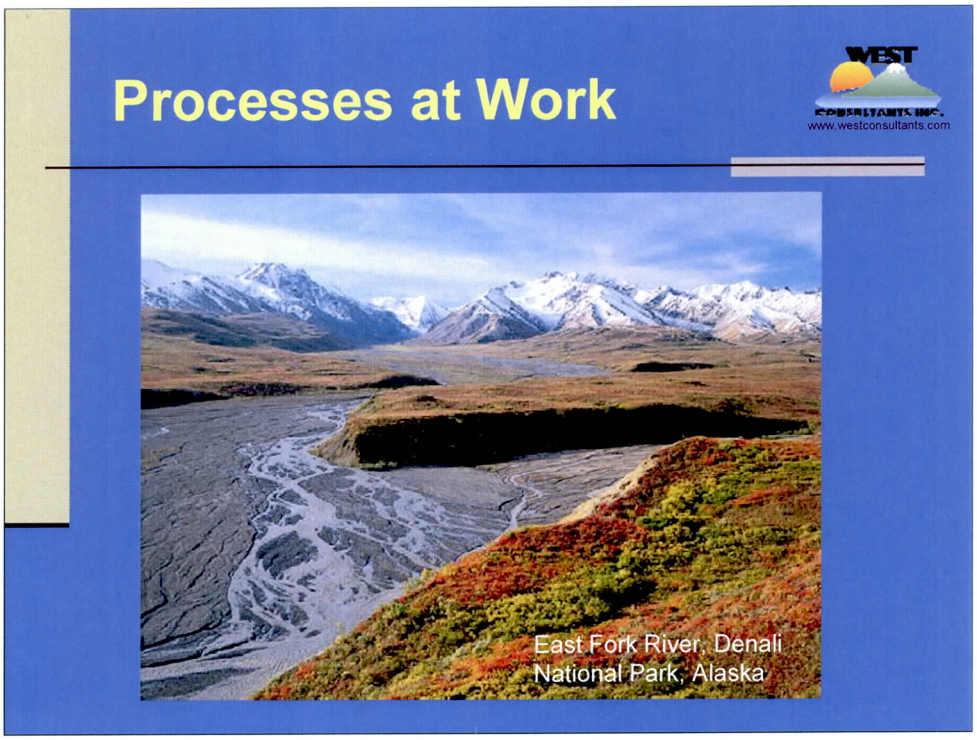
Braided streams have a much greater load of sediment than they can carry. Alluvial fans and deltas exhibit similar behavior.



Obvious braided stream, aggradation. Terraces may indicate previous downcutting. Changes in base level (e.g, mean sea level rise, lift due to plate tectonics) over time can trigger changes in processes.

General Effects

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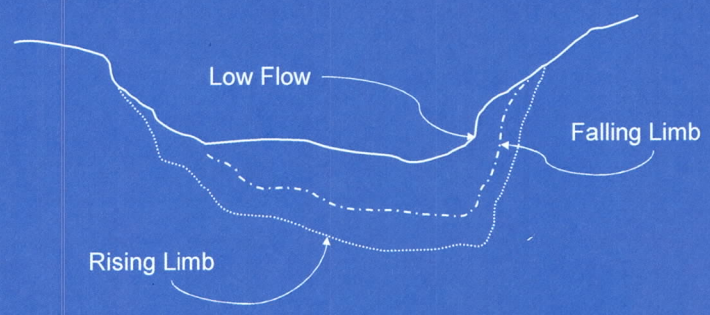
- Developing Water Surface Profiles
  - Usual Rigid Boundary Assumption
  - Often Bed Changes During the Year or During an Event



General Effects

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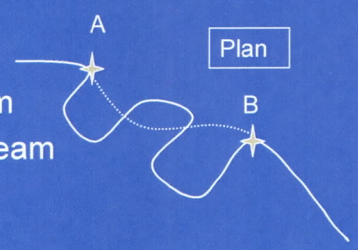
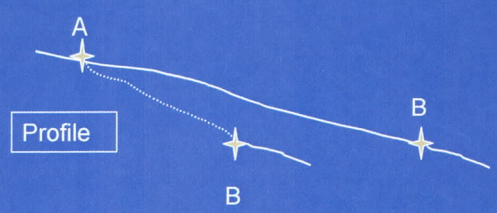
- Channelization
  - Shorten, Deepen, Widen Channel
  - Stream will Seek Equilibrium
  - Tributary Effects
  - Can Cause:

$$Q_s \bullet D_{50} \propto Q \bullet S$$

_____Upstream

_____Downstream





General Effects

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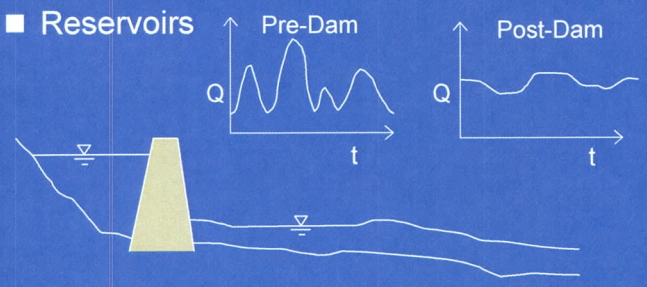
- Reservoirs



- Can cause
  - _____In Pool
  - _____Downstream (How Far?)
  - _____Transport (Increased, Decreased, Both)
- Tributary Effects

$$Q_s \bullet D_{50} \propto Q \bullet S$$

General Effects

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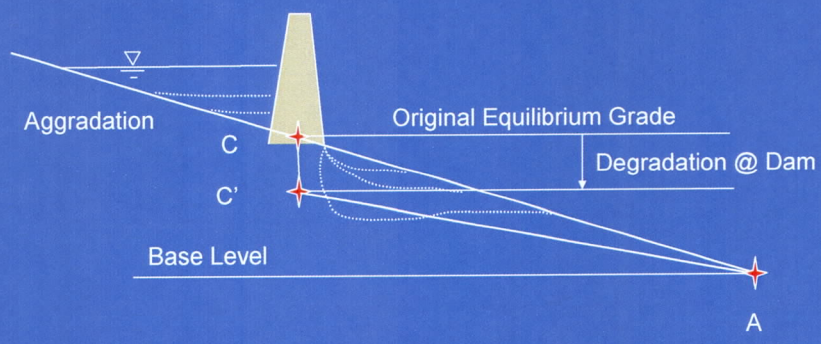
- Reservoir - Channel Adjustments



General Effects

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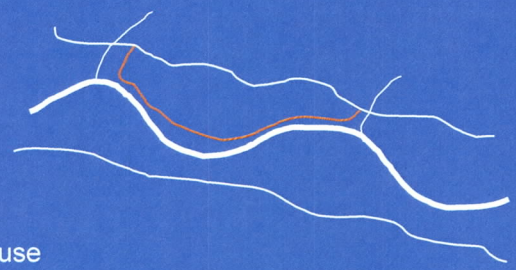
- Levees



  - Can Cause
    - _____Upstream
    - _____In Leveed Reach
    - _____Downstream

$$Q_s \bullet D_{50} \propto Q \bullet S$$

- Bypass – controlled cutoff
  - Diverting flow that would have gone into overbank storage
  - Difficult to predict scour-deposition

General Effects

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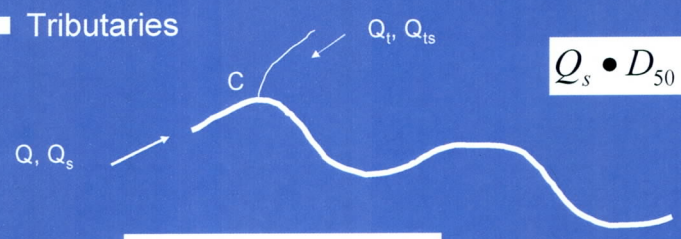
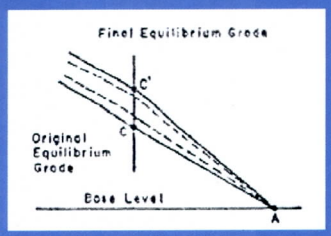
- Tributaries



$$Q_s \bullet D_{50} \propto Q \bullet S$$



Change in channel slope in response to an increase in sediment at point C

General Effects

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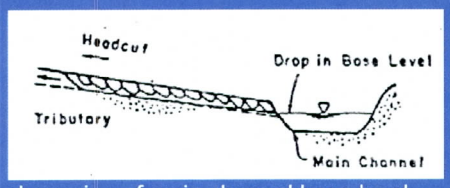
- Tributaries

$$Q_s \bullet D_{50} \propto Q \bullet S$$



Lowering of main channel base level

Local Effects	Upstream Effects	Downstream Effects
Headcutting	Increased velocity	Increased transport
General Scour	Increased transport	Aggradation
Local Scour	Unstable Channel	Increased Flood Stage
Bank Instability	Planform Change?	Planform Change?

Things to Remember

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- A River is part of a System
  - System is:
    - Dynamic
    - Complex
    - Thresholds Exist
    - Geomorphology Provides Historical Perspective
    - Size / Power of Stream is Important

A River is Part of System

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- The entire watershed forms a system
  - Rainfall => Runoff (Land Use)
  - Runoff Transports Sediment (Land Use/Cover)
  - Slope / Meanders Impact Transport
  - Sediment Size Impacts Transport and Erosion/Deposition
  - Manmade Features Impact Everything
  - Nature has its own plans and goals!!!
    - It's not always what we expect!

Sediment Transport

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IT'S NOT THAT SIMPLE

Every river/stream reach has erosion, transport and deposition occurring at the same time!

Channel Stability

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- Absolute Stability – Doesn't Change in Engineering Time Scale
  - Think Concrete / Bed Rock / Etc.
- Dynamic Stability – Changes but Relationships are Constant in Engineering Time Scale
- Unstable – Major Changes in Width, Depth, Flow, Sediment Transport, Sinuosity, Planform or all of These are Occurring over a Period of Days, Months or Years

Absolutely Stable

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Absolutely Stable

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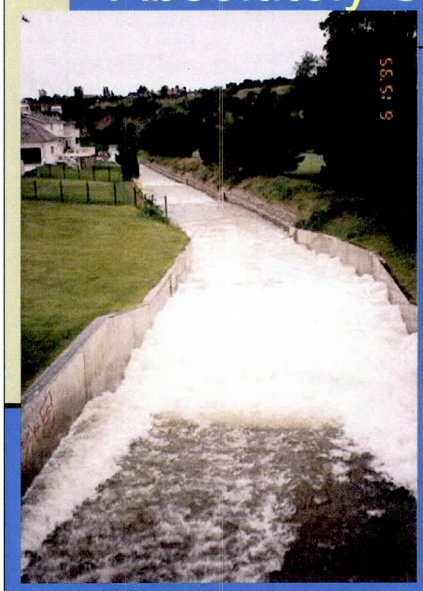

Little Cottonwood Creek, Salt Lake City, UT

Absolutely Stable

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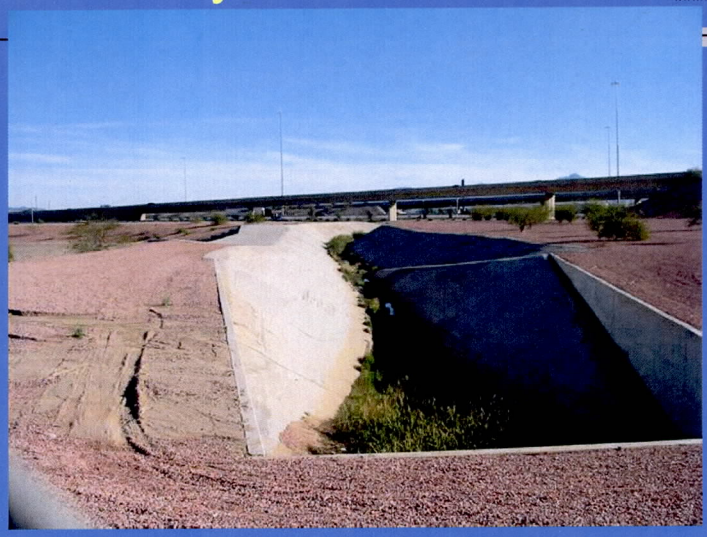

Who says concrete channels aren't green?

Dynamically Stable

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Dynamically Stable

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Unstable

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Unstable

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Las Vegas Wash, Nevada

Unstable

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Unstable?

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Stability

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- Rivers want to be Dynamically Stable
  - Not Necessarily Constant / The Same
    - Bank Location
    - Meander Locations
    - Sand / Gravel Bars
    - Anything having to do with location of features
  - Remember Locations Move under Dynamic Stability!

Stability

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- Some Streams are more Stable
  - Clay Bed & Banks
  - Rock Outcrops or Banks
    - Mountain Streams / Torrents
    - Steep Sediment Starved Systems
  - Concrete / Designed Channels

Stability

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- Less Stable Systems
  - Silt Bed & Banks
  - Sand or Gravel Banks
  - Any Non-cohesive / Uncemented Banks
  - Braided Systems
    - High Sediment Loads Fill Flow Areas
    - Channels Constantly Moving
  - Channels without Bedrock Controls

Stability Depends on Perspective

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- How fast does an unstable river move?
- How long does change take to be classed stable?
- If a river moves at 10' per year it's probably stable until it gets to 50' of your house!

Stream Stabilization in Mobile Rivers

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- Hard Points
  - Protect Permanently (Engineering Time)
  - Concrete
  - Riprap
- Soft Points
  - Protect for a While then Fail (Melt Away)
  - Bio-Engineering

Stream Stabilization in Mobile Rivers

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- What is your Purpose
  - Restoring River (allows adjustment)
  - Fixing One Bank in Place
  - Fixing River Reach in Place
    - Does it Matter if Concrete or Bio-engineering?
      - Fixed in Place = Fixed in Place!
  - Be Careful Who You Criticize!
    - Biologists & Single Purpose Refuges
    - Engineers & Single Purpose Projects
    - Stream Restoration & Fixed Designs

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HEC-RAS Sediment Transport Modeling

By WEST Consultants, Inc.

INTRODUCTION TO SEDIMENT TRANSPORT COMPUTATIONS WITH HEC-RAS & HEC-6T

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Topics

- Sediment in HEC-RAS background/status
- Sediment in HEC-RAS approach
  - Continuity
  - Transport Potential
  - Transport Capacity
- Limitations of Approach

Topics (cont'd)

- Constraints on Erosion & Deposition
  - Fall Velocity vs. Effective Depth
  - Sorting and Armoring
- Bed Movement
  - Special Problems
- Comparisons with HEC-6
- Model Capabilities and Limitations

Sediment Background

- HEC-6 was the COE sediment transport model
  - DOS based like HEC-2
  - HEC-6T is proprietary "improved" version, still DOS
- HEC goal is to be able to replicate and then improve HEC-6 capabilities in HEC-RAS
- Sediment planned from early on in RAS, "grayed out"
- Still one-dimensional with associated limitations, discussed later in this lecture

Sediment Status Jan 2010*

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- HEC-6 type sediment routing
- Only cross section and bridge nodes are movable
- Inline structures and culverts are "pass-through"
  - Can make other sections pass-through
  - Not movable
- No mixed flow yet
  - In future plans
- Only dendritic systems
  - No loops or reverse flow

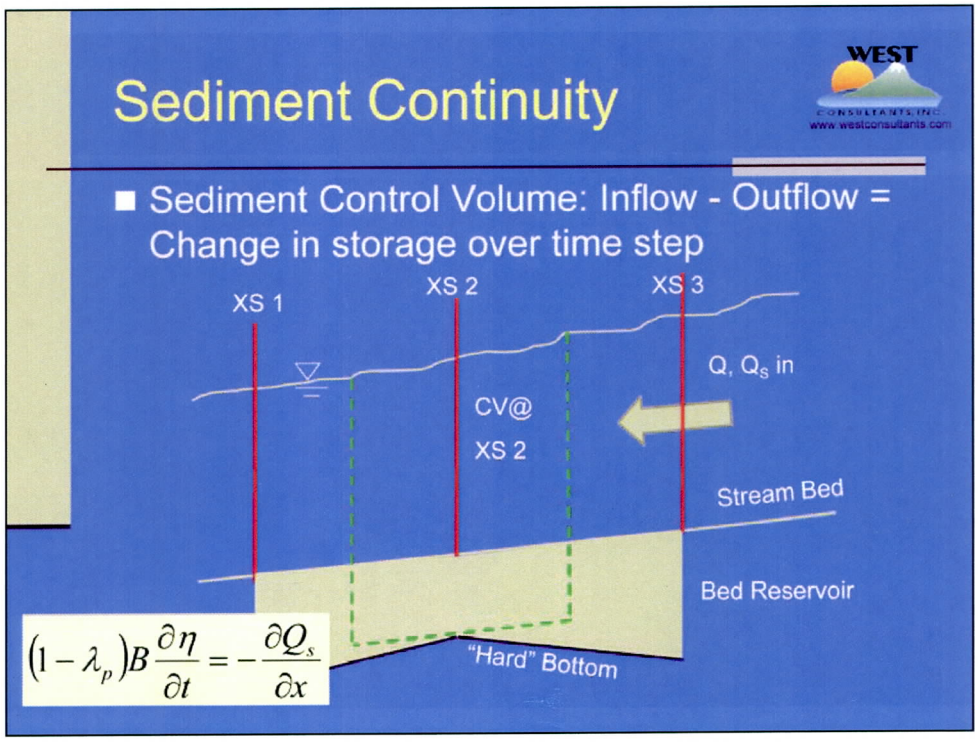
* Release of Version 4.1.0

Sediment Modeling Approach

- HEC-RAS is a fully coupled explicit model
- At each time step, hydraulics is computed first, then sediment transport
  - Hydraulics are computed in the normal HEC-RAS manner from downstream to upstream using standard step backwater computations
  - Using hydraulic results, sediment is routed from upstream to downstream using continuity approach
- Differs from uncoupled models (e.g., SED2D-WES)
  - Hydraulics computed for all time steps
  - Sediment routed in each time step using hydraulics, no bed adjustments
    - If bed adjustments exceed some threshold, need to adjust geometry, go back and re-run hydraulics

Summary of Solution Technique

1. Calculate water surface profile using standard step backwater procedure
2. Calculate sediment transport potential at each cross section
3. Calculate volume of material scoured or deposited between cross sections by solving sediment continuity equation
4. Calculate associated change in bed surface and modify cross section geometry
5. Read inflowing water discharge, sediment load by particle size, temperature, boundary conditions for next event
6. Repeat 1-5



The Exner Equation shown describes sediment continuity. An imbalance between sediment supplied and sediment transport will result in bed change (erosion or deposition), adjusted for porosity. *n* is the bed elevation in the equation. The control volume extends half way up and downstream to adjacent cross sections. The Exner equation is solved separately for each grain size in HEC-RAS.

Sediment Transport Potential

- Pick one of seven transport functions (Jan 2010), discussed in next lecture
  - Ackers - White (1973)
  - Engelund - Hansen (1977)
  - Laursen (Copeland) (1968, 1989)
  - Meyer-Peter – Muller (1948)
  - Toffaleti (1968)
  - Yang (1973, 1984)
  - Wilcock (2001)
- **<u>Potential</u> transport NOT actual amount**

HEC-6T Functions (3/10)

- **Toffaleti Method (1969)**
- **User Specified Transport Function**
- **Madden's (1963) modification of Laursen's (1958)**
- **Yang's stream power: Sand (1973); Gravel (1984)**
- **Duboy's (Brown, 1950)**
- Einstein (1950)
- **Ackers-White (1973)**
- **Colby (1964)**
- **Toffaleti and Schoklitsch combination**
- **Meyer-Peter and Muller Gravel Transport (1948)**
- Schoklitsch Gravel Transport
- **Toffaleti (1969) - Meyer-Peter and Muller (1948)**

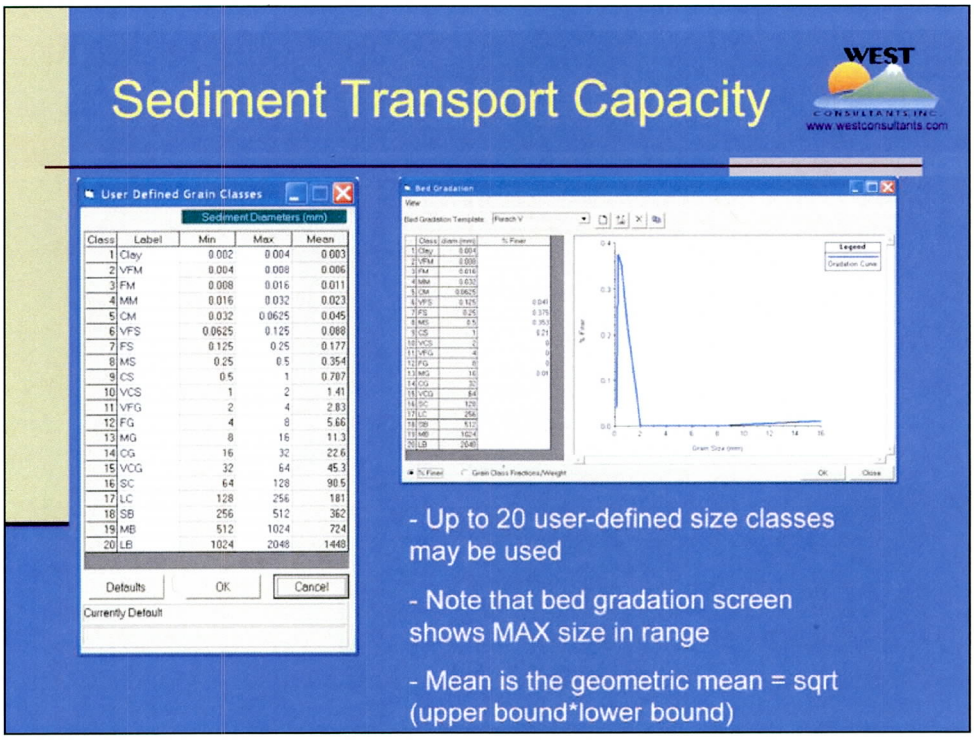
Bold indicates functions that were in HEC-6.

HEC-6T Functions (cont'd)

- **Madden's (1985) modification of Laursen's (1958)**
- Laursen-Copeland
- Engelund-Hansen
- Parker Gravel Transport (1990)
- Proffitt and Sutherland
- Brownlie (With Transport Normalized at D50 Value)
- Brownlie (With Transport Calculated for each Grain Size)
- Yang-High Concentration Formula, 1996
- Wilcox Gravel Function
- Danube River Function, BAW

Sediment Transport Capacity

- Potential = mass transported through control volume for a single grain class
- Capacity = (Potential for each grain class) X (fraction of that class in active bed layer)
- Bed material and inflowing load divided into separate grain classes (up to 20)
- Example:
  - Computed transport potential for medium sand is 100 tons/day and active bed layer contains 15% medium sand. Therefore, transport capacity for medium sand is 100 t/day X 15% = 15 t/day



To compute transport potential, most formulas require a D50 (median grain size). Using a simple arithmetic mean would tend to skew the sediment distribution which tends to be logarithmic in nature. Therefore the geometric mean is used.

Sediment Transport Capacity

$$T_c = \sum_{i=1}^{n} \beta_i T_i$$

T_c =Total Transport Capacity

n = number of grain size classes

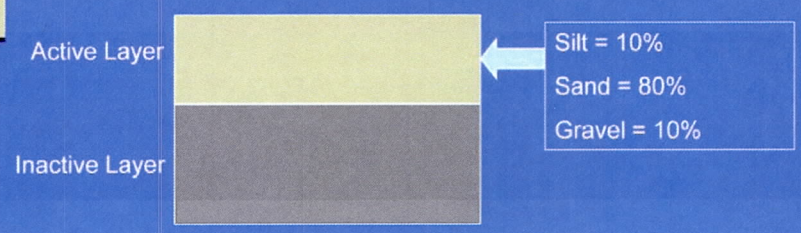
β_i = percent of grain size class "i" in the active layer

T_i = Transport potential for grain size class "i"

- Transport potential is computed for each size class (as if had uniform sediment)
- The potential for that size class is then multiplied by the percentage of that class in the active layer
- The sum of potentials for each class makes the total transport capacity

Potential/Capacity Example

Transport Potential	Transport Capacity
Silt = 1,000 T/d	Silt = 100 T/d
Sand = 100 T/d	Sand = 80 T/d
Gravel = 10 T/d	Gravel = 1 T/d
	Total = 181 T/d



Continuity Example (CV)

Inflowing Load	Transport Capacity
Silt = 300 T/d	Silt = 100 T/d
Sand = 50 T/d	Sand = 80 T/d
Gravel = 1 T/d	Gravel = 1 T/d

Surplus or Deficit

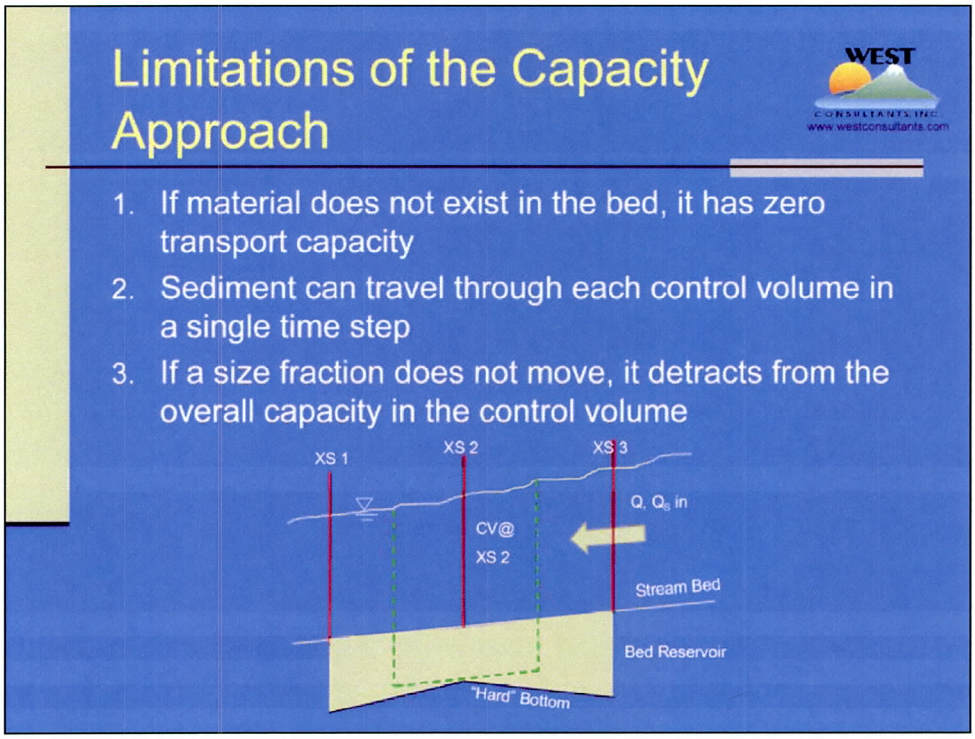
Silt = 300-100 = 200 T/d ▶ Deposition

Sand = 50-80 = -30 T/d ▶ Erosion

Gravel = 1-1 = 0 T/d ▶ No change

- Total surplus is 200-30+0 = 170 T/d

Note that can erode and deposit different size classes in the same time step.



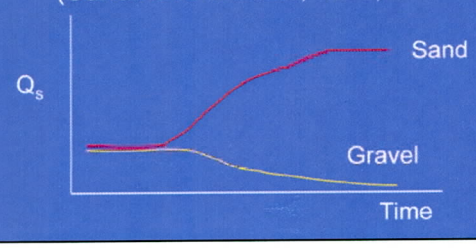
1. If a size class is missing from the active layer in the bed, for the first time step all inflowing sediment in that class will deposit as there is zero transport capacity of that class. It may take multiple time steps until there is a great enough percentage of material in that size class in the active layer to offset the inflowing load. This is more of a problem with larger material as smaller material has higher transport potential. This can effect results for hard bottomed channels.
2. Only the continuity equation is being used to route sediment, so particles can travel through the entire control volume during a time step. You need to consider time step and cross section spacing to limit particle motion to a physically reasonable range (particles should not travel faster than water!). Consider higher flows for selecting time step as this is when most of the sediment will be moving. Not as much as an issue for long term simulations, but have caution with single event analysis.
3. If the transport potential of sand is 100 T/d over a 100% sand bed, the capacity will also be 100 T/day. If the same transport potential of 100 T/d of sand is applied to an active bed layer composed of 50% sand and 50% gravel, the sand capacity will only be 50 T/day, even though the gravel may not be moving. If the inflowing sediment load is 100 T/d of sand, in the first case there will be no bed change, while in the second case 50 T/d of sand will deposit.

Limitations of the Capacity Approach

4. Increases in the percentage of one size fraction will reduce the capacity of other size fractions.

   Example:

   A pulse of sand from upstream arrives at a control volume with a sand-gravel bed. As the sand deposits, it captures a larger percentage of the capacity at the expense of the gravel capacity. As a result, gravel capacity drops in the presence of sand. This is directly opposed to observations (Curran and Wilcock, 2005, *JHE* Vol. 131, No. 11).



Limitations of the Capacity Approach

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5. Erosion and Deposition of a size class cannot occur at the same time in a control volume
   - One-dimensional modeling limitations (spatial)
   - "Representative" control volume (spatial)
   - Time step selection (temporal)
   - "Dumping" of entire inflowing load at a cross section (spatial/temporal)

Constraints (Limiters)

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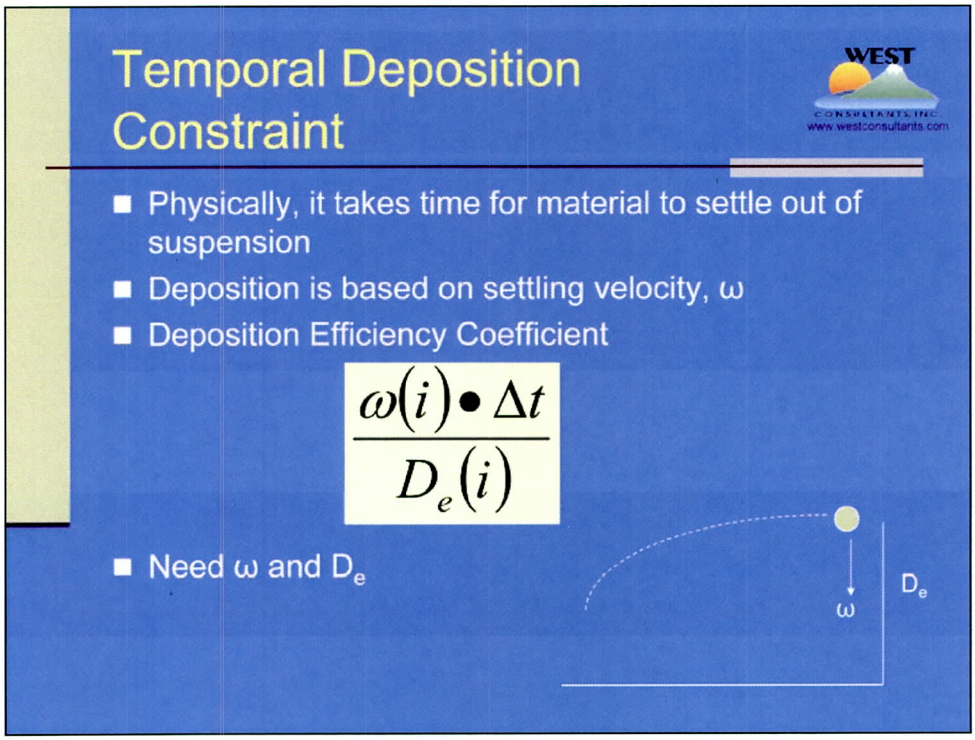
- Three limiters are used to ***modify*** the amount of material eroded or deposited during a time step:
  - Temporal Deposition (Physically takes time to deposit)
  - Temporal Erosion (Physically takes time to entrain)
  - Bed Armoring (Supply Reduction)
- HEC-RAS follows the HEC-6 routines in applying limiters



For each time step dt, a particle will fall a distance equal to the settling velocity (units of distance per time) multiplied by the time step. Similar to a settling tank analysis, will the particle reach the bottom (represented by De) while it is still in the control volume?

Sediment Fall Velocity

- Four Methods available in HEC-RAS (you choose):
  - Rubey
  - van Rijn
  - Toffaleti
  - Report 12 (Default)
- If transport method uses fall velocity, same method used both places
- Determination of suspended sediment relies heavily on fall velocity

Fall Velocity (Rubey, 1933)

- Works well for silts through gravel
- Based on Stoke's Law
- Best for crushed quartz grains, S=2.65
- Can under predict for cubic or more uniform particles

$$\omega = F_1 \sqrt{\frac{\gamma_s - \gamma}{\gamma} g d_s}$$

$$F_1 = \sqrt{\frac{2}{3} + \frac{36\nu^2}{g d_s^3 \left(\frac{\gamma_s}{\gamma} - 1\right)}} - \sqrt{\frac{36\nu^2}{g d_s^3 \left(\frac{\gamma_s}{\gamma} - 1\right)}}$$

Fall Velocity (Toffaleti, 1968)

- Table of fall velocities by grain size and temperature developed with shape factor of 0.9 and S=2.65
- RAS interpolates values from the chart
- Natural sands have shape factor of about 0.7, SF more important for medium sands and larger

Fall Velocity (van Rijn, 1993)

- Approximates US Inter-Agency Committee on Water Resources (IACWR) curves for fall velocity
- Sets the shape factor and temperature and computes a single fall velocity from the curve based on an initial Rubey fall velocity.
- Separates zones by grain size
  - $0.001 < d < 0.1$ mm ► Stoke's Law $\omega = (S-1)gd/(18v)$
  - $0.1 < d < 1$ mm ► curve fit
  - $d \geq 1$ mm ► Reynolds independent $\omega = 1.1[(S-1)gd]^{0.5}$
- Removal of RE allows non-iterative solution

Fall Velocity (Report 12, 1957)

- Allows variation in shape factor and iterates on Reynolds Number until converges on a solution
- Steps
  - Compute ω using Rubey Equation
  - Solve for RE
  - Compute drag coefficient (Cd)
  - Back calculate ω
  - Compare with last iteration, stop if acceptable
- Polynomial fitted to each of three zones
- Only allowed to switch zones once based on recomputed ω

Computing Effective Depth

- Uses Toffaleti's model of sediment concentration
- y/r is the ratio of effective depth (D_e) to water depth *r*
- Silts and very fine sands use entire water depth *r* as effective depth
- Fine sand uses *r* /2.5 as D_e
- Larger sizes use *r* /11.24 as D_e

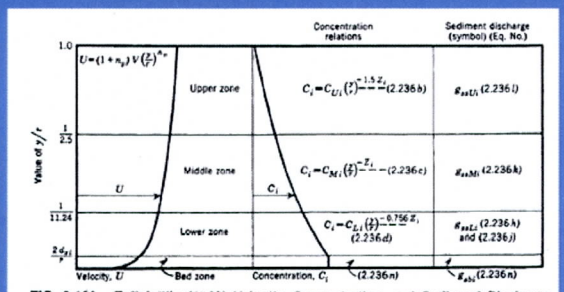


FIG. 2.108.—Toffaletti's (1969) Velocity, Concentration, and Sediment Discharge Relations

Temporal Constraints

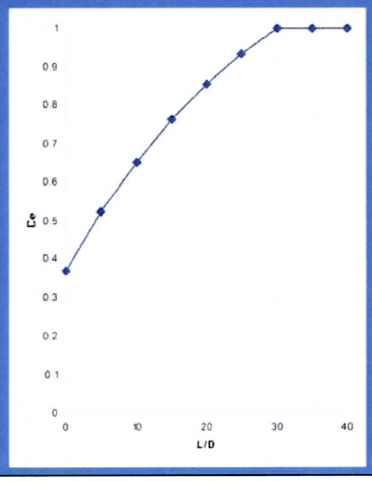
- Erosion does not occur instantaneously
- However, physical theory for limiting erosion process is not well established
- In HEC-RAS erosion is based on a "characteristic flow length"
- Erosion = (Gs – Qs) x Ce
  - Gs = transport capacity
  - Qs = current load in flow field
  - Ce = entrainment coefficient

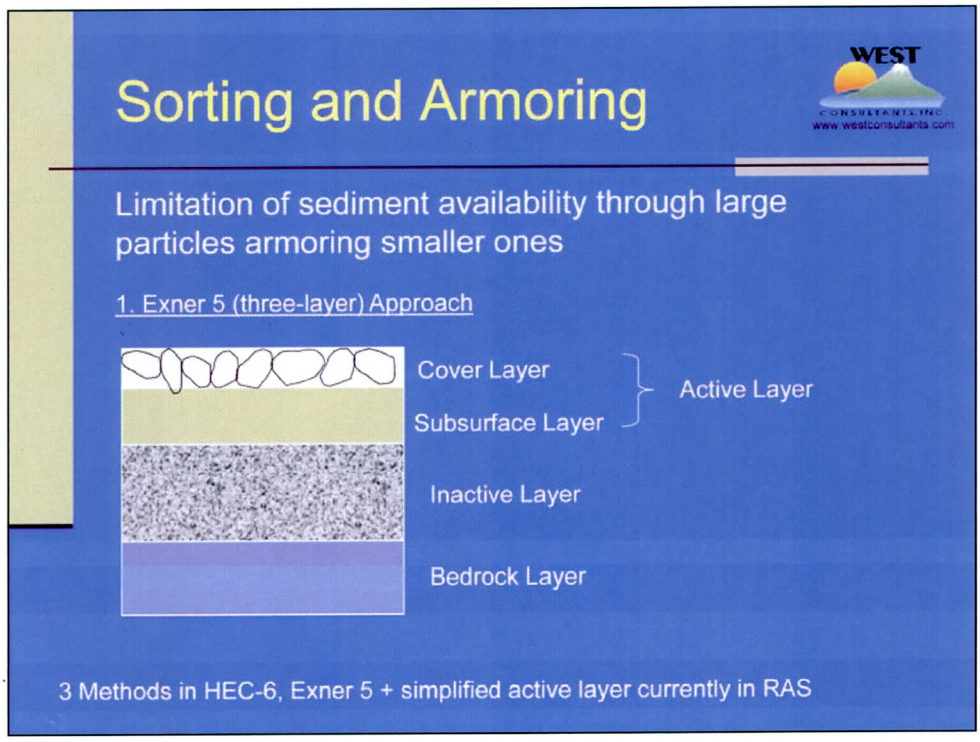
$$Ce = 1.368 - e^{-\left(\frac{L}{30D}\right)}$$

Temporal Constraints

- Exp (-1) =0.368; as L approaches 30D the coefficient approaches 1 and there is no limiter
- 0.368 ≤ Ce ≤ 1
- For very short reaches (small L) only about one-third of the deficit will be allowed

$$Ce = 1.368 - e^{-\left(\frac{L}{30D}\right)}$$





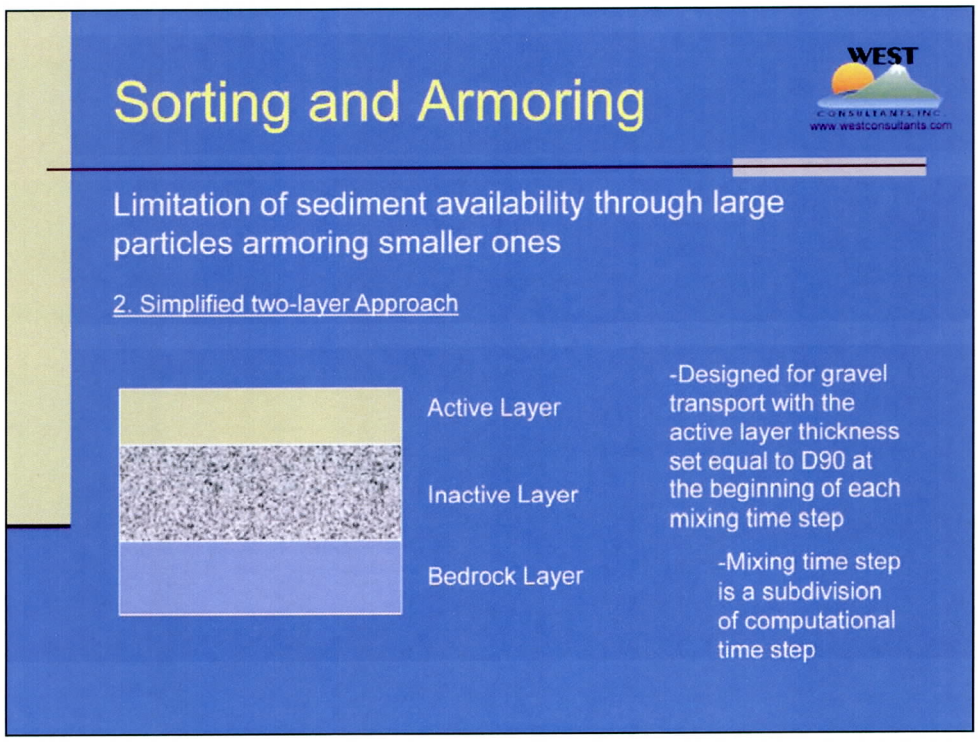
Exner 5 simulates surface coarsening by removing fines initially from a thin cover layer. During each time step, the composition of the cover layer is evaluated. If, according to an empirical relationship, the bed is fully or partially armored, the amount of material available to satisfy excess capacity is limited.

Armoring

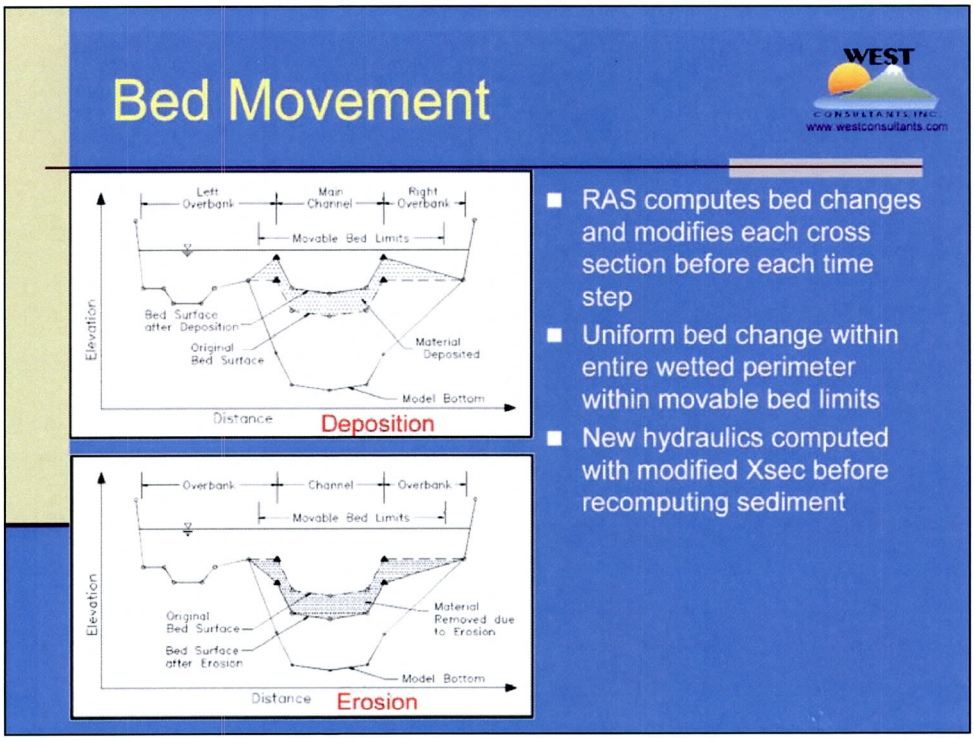
$$AR = -0.02611C^3 + 0.2847C^2 + 1.070C + 1.397$$

AR = Armoring Ratio
C = Cover, computed for each size class before solving continuity equation during each exchange increment

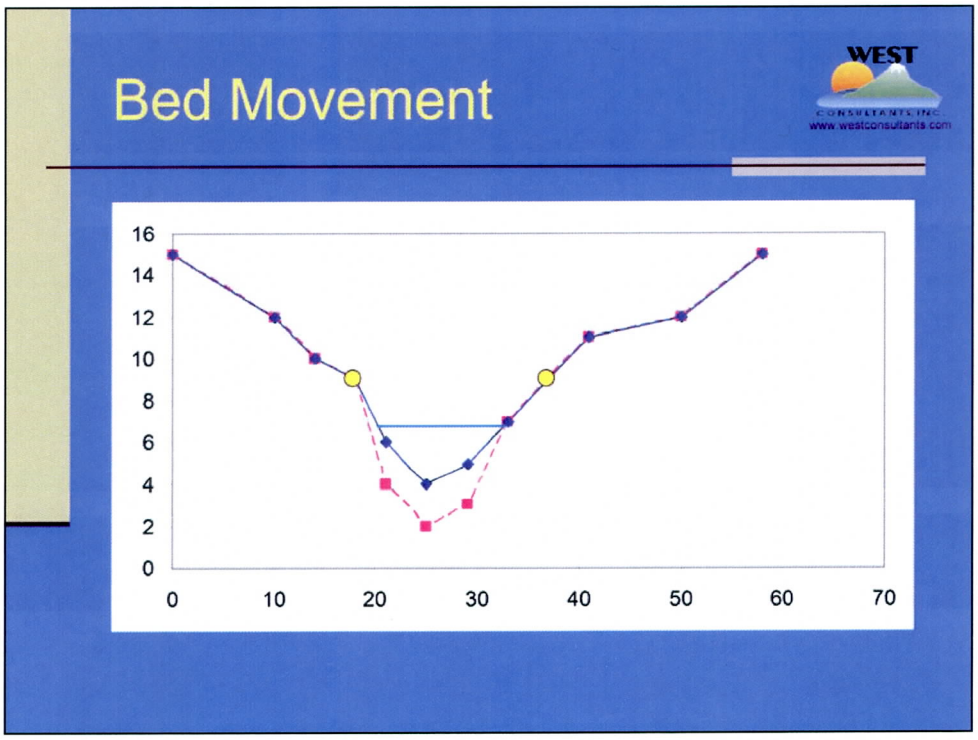
- Empirical, based on Missouri River experiments of Harrison and other sources (Thomas). Limits supply due to armor layer development
- Armor layer is destroyed once the cover layer thickness drops below 1D90 (at which point bed is then fully mixed)
- Copeland suggested that the EXNER5 method can be too resistant to armor layer destruction, which led to the EXNER7 method in HEC-6T (not yet in RAS)



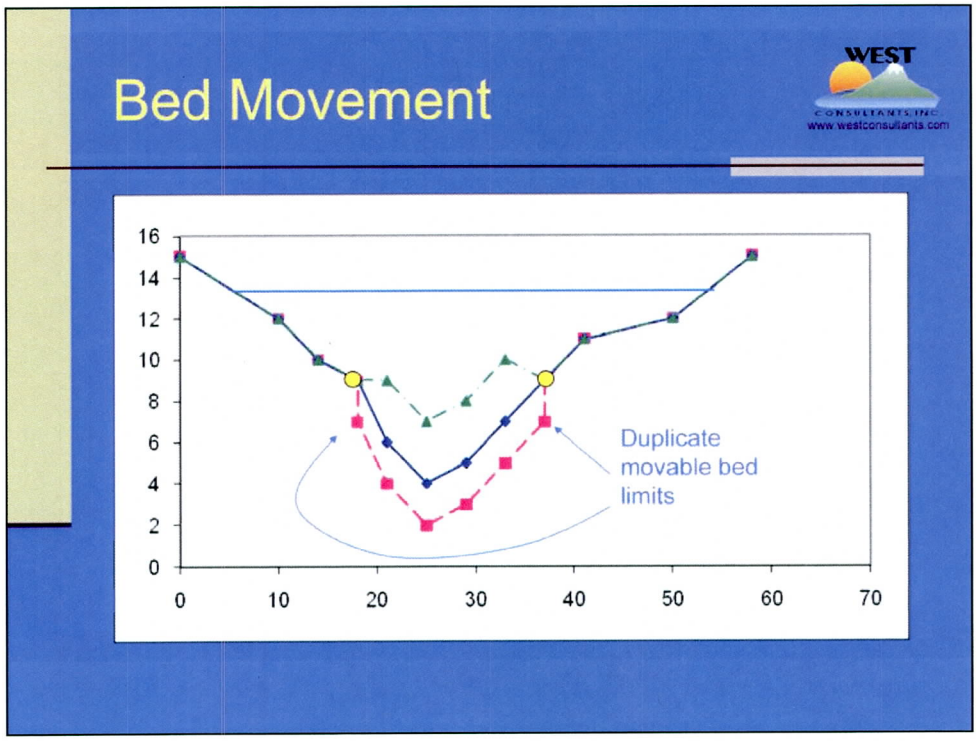
During the mixing time step the bed material is rearranged in response to erosion or deposition but the bed elevation is not recomputed. This is designed to work principally with the Wilcock transport method.



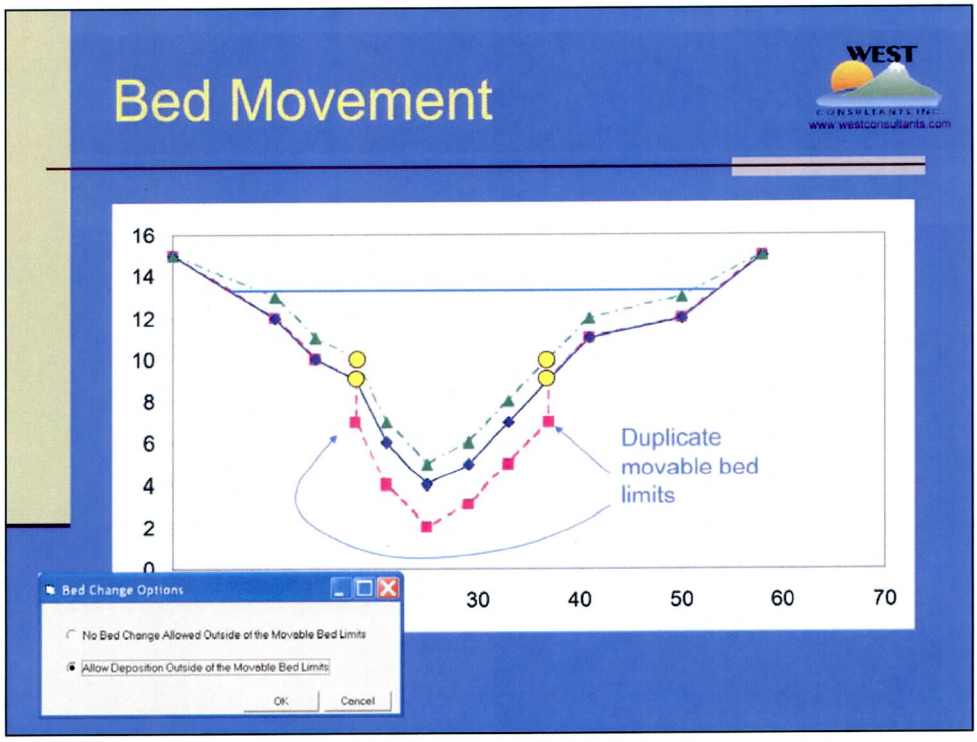
If movable bed limits are set at an existing ground point, that point will remain fixed. This is different from HEC-6 where that ground point was allowed to move. To avoid confusion, set the movable bed limits between ground points.



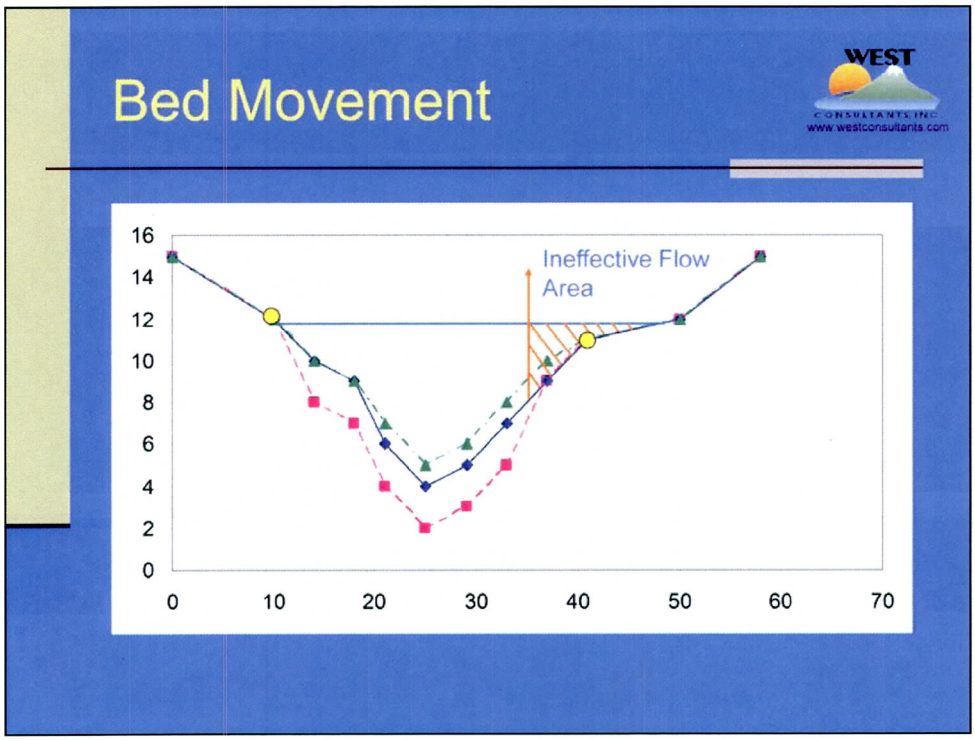
Case I: Water surface is below movable bed limits – only wetted nodes can move



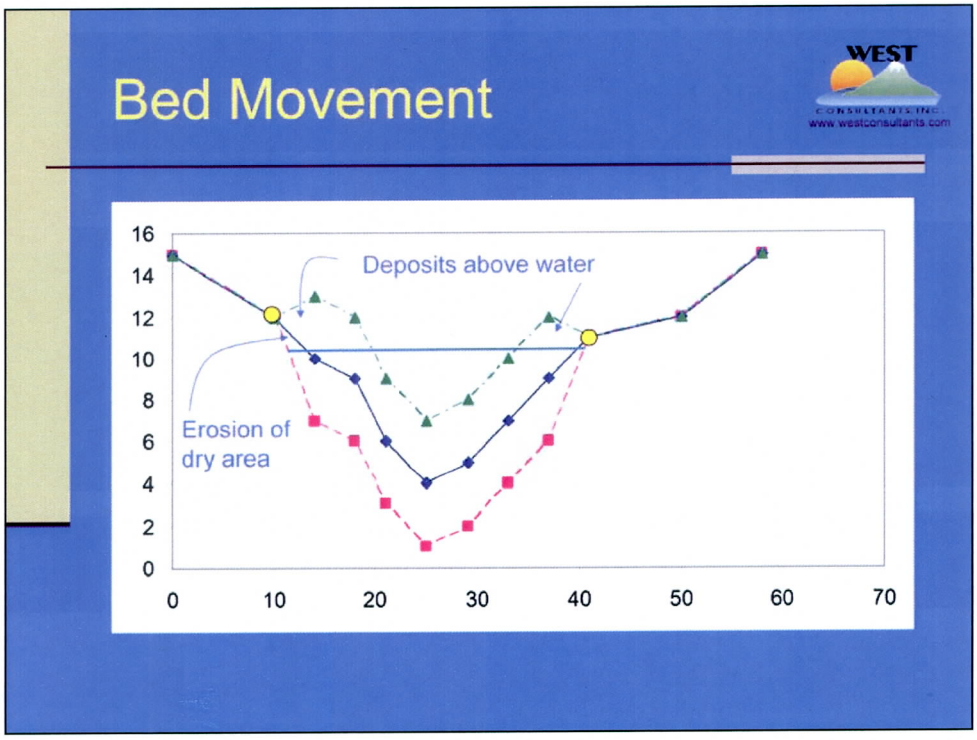
Case II: Water surface is above movable bed limits – only wetted nodes within the movable boundaries can move. If there is erosion, a duplicate node is created at the movable bed station which will drop with the others. This node can later aggrade back to the original position of the movable bed limit but can not rise above it.



Case III: Water surface is above movable bed limits AND deposition is allowed outside of limits using Bed Change Options – only wetted nodes within the movable boundaries can degrade, with duplicate nodes created if applicable. For deposition, ALL wetted nodes can aggrade. This can be useful to model deposition in the floodplain where velocities are not expected to be erosive.



Case IV: Ineffective Flow Limits – RAS will deposit at nodes within the movable bed limits even if they are also within an ineffective flow area. However, erosion will never occur in an ineffective flow area as the velocity is theoretically equal to zero.



Case V: Erosion or Deposition in Dry Areas – Can usually avoid this by having more nodes to define cross section. However, be careful as more nodes can also increase computational time.

Comparison with HEC-6

- MPM Flume test reproduced with very good agreement
- Depostional trapezoidal channel using Yang with single grain size
  - Difference in transport potential due to hydraulics ~0.5%
  - This difference resulted in ~6% difference in material deposited
  - Other settings could have affected results (fall velocity, friction slope method)
- HEC considers RAS hydraulics improved over 6, therefore sediment responses also improved

Model Capabilities

- 1-D hydraulics
- Movable Boundary
- Steady State Gradually Varied Open Channel Flow
- Continuous sequence of flows segmented into a series of steady state flow events
- Standard Step Backwater using RAS routines
- Volumetric accounting of sediment sizes in each reach between cross sections
- Scour/deposition computed for each reach and cross section geometry adjusted after each flow event
- Sediment calculations done by grain size fraction
- Allows for hydraulic sorting and armoring

Model Limitations

- 1-D hydraulics, 1-D sediment (e.g., no bend scour)
- Only vertical bed changes
- No channel widening or lateral migration
- Single gradation for entire cross section (no variation)
- Transport equation limitations
  - Based on average hydraulics for simple channel shapes
  - Only subcritical flows, steady state, equilibrium conditions
- Uncertainties in assumptions on transport rates, including armoring, hydraulic sorting, entrainment

➔ NEED CAREFUL APPLICATION BY PROFESSIONAL FAMILIAR WITH BOTH HYDRAULICS AND SEDIMENTATION

Sample Animation

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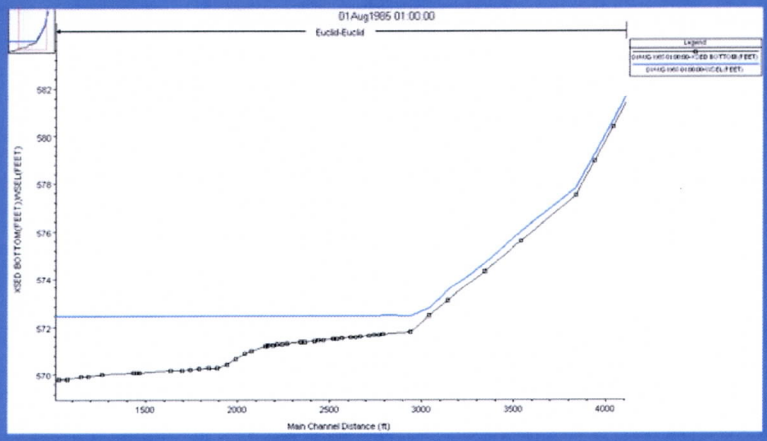

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HEC-RAS Sediment Transport Modeling

By WEST Consultants, Inc.

DEMONSTRATION OF BASIC SEDIMENT DATA ENTRY

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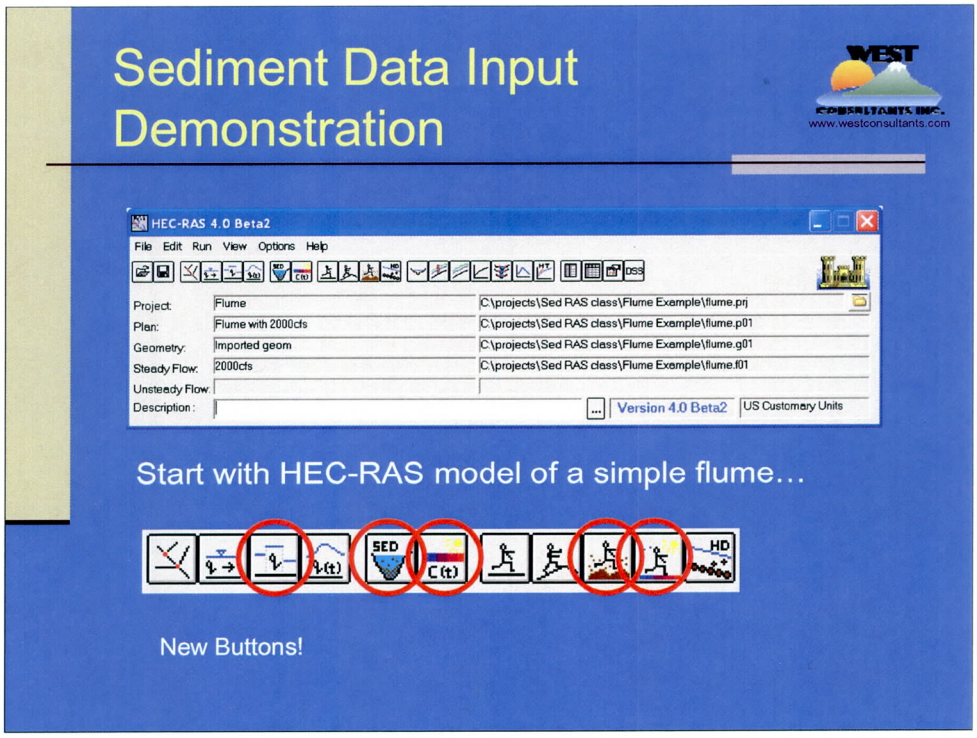

We've put together a very simple example to demonstrate how to input basic sediment data in HEC-RAS. The HEC-RAS model of a simple flume has already been assembled (not including sediment data).

Sediment Data Input Demonstration

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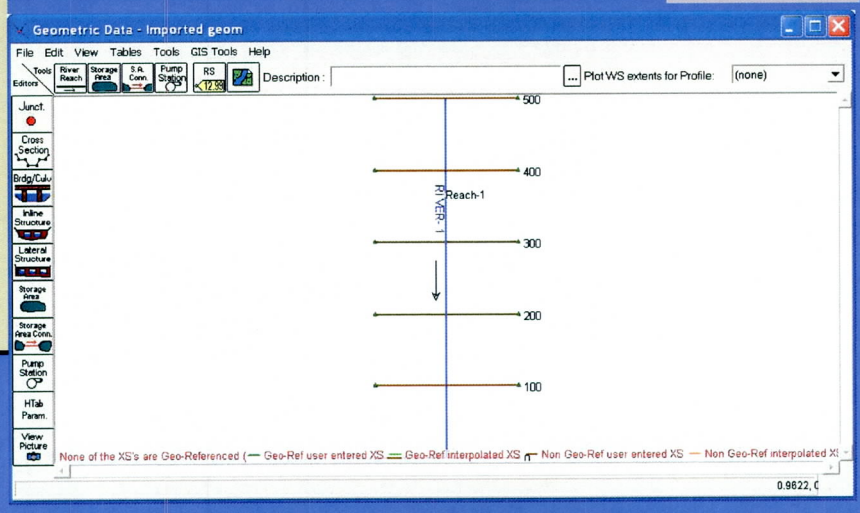
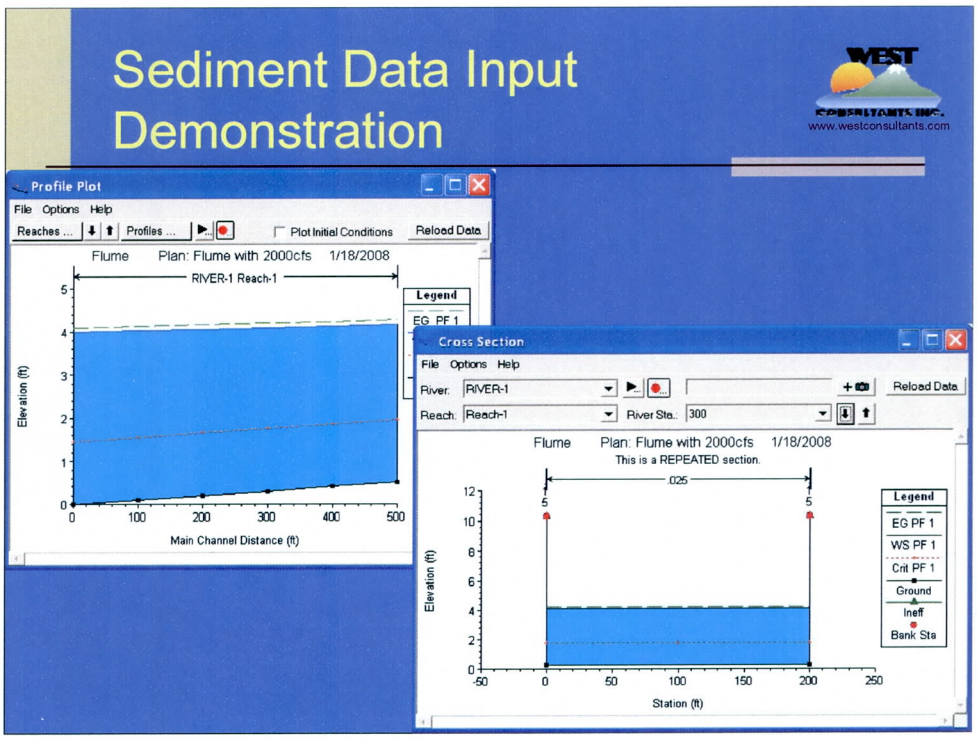
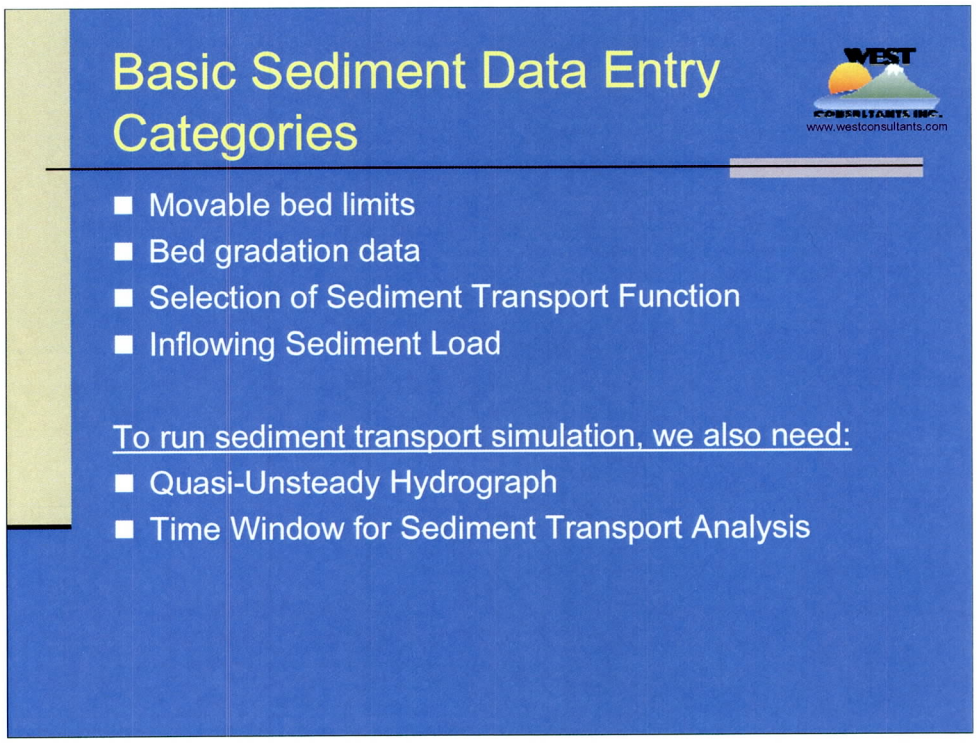


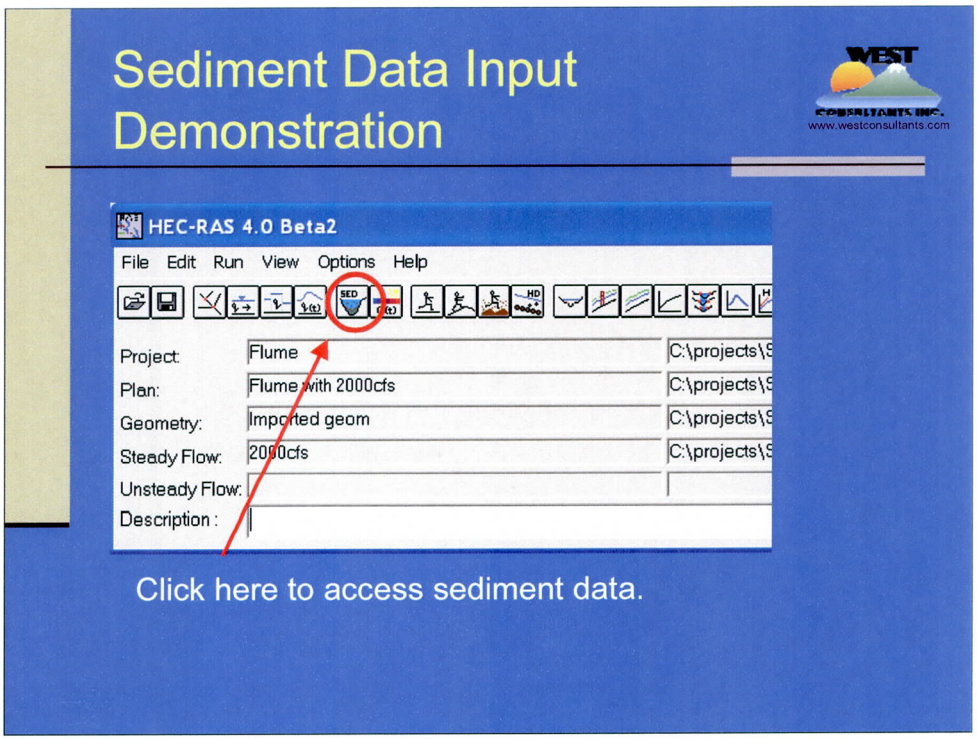
The demo reach has six equally spaced cross sections.



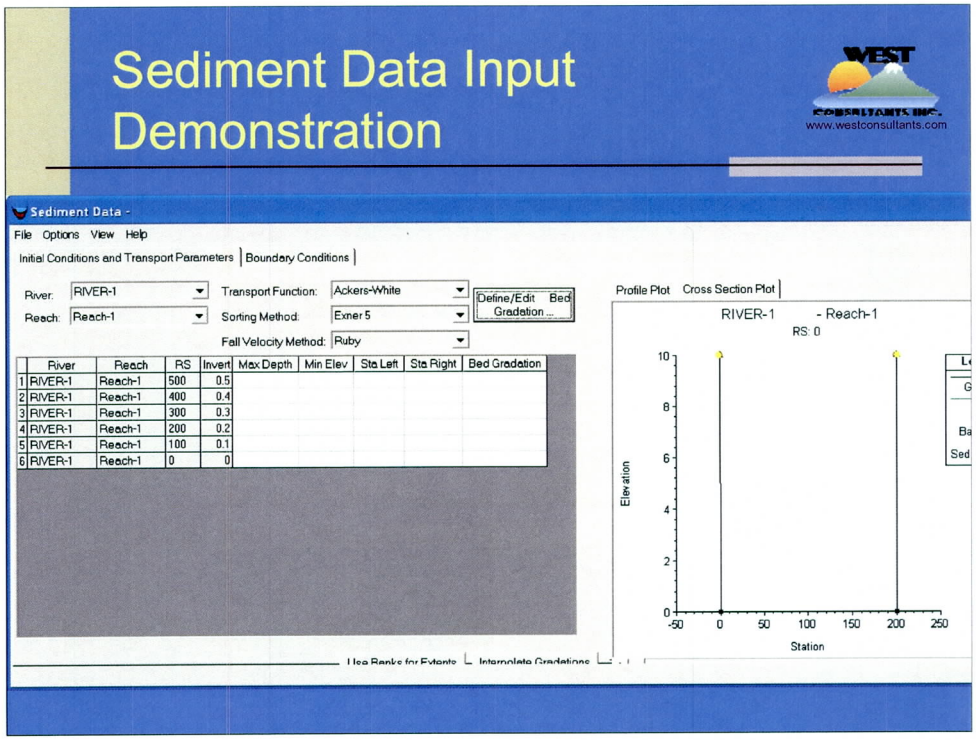
The cross sections are placed on a constant slope of 0.1 percent.



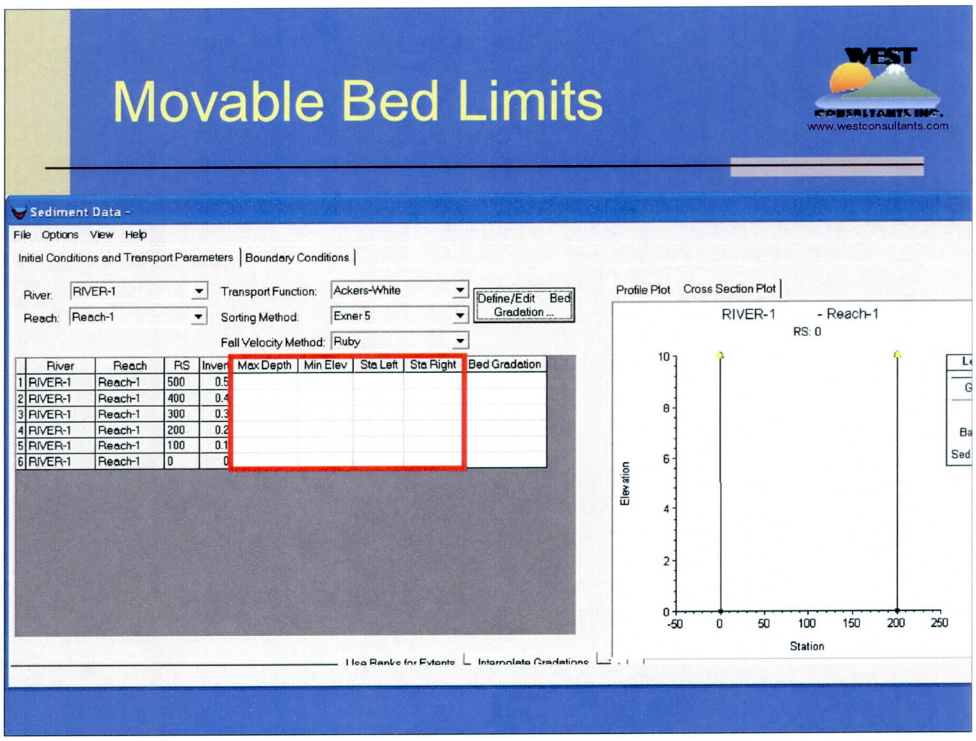
Here are the four categories of basic sediment data entry we will be covering. We will also enter a simple hydrograph to run the sediment transport analysis.



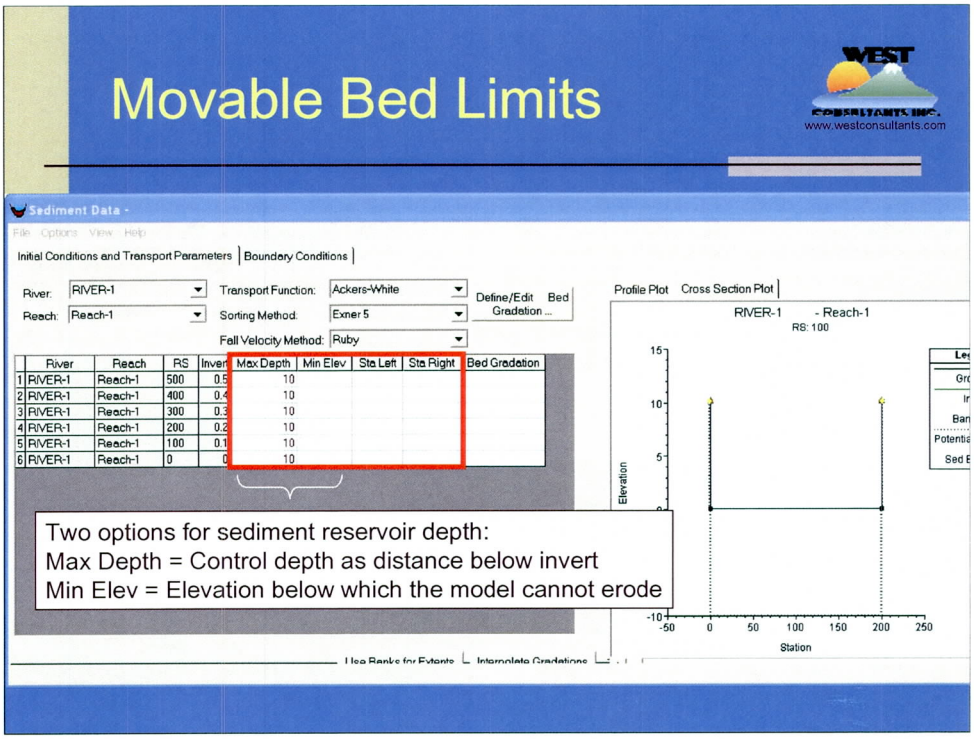
Click here to access sediment data.



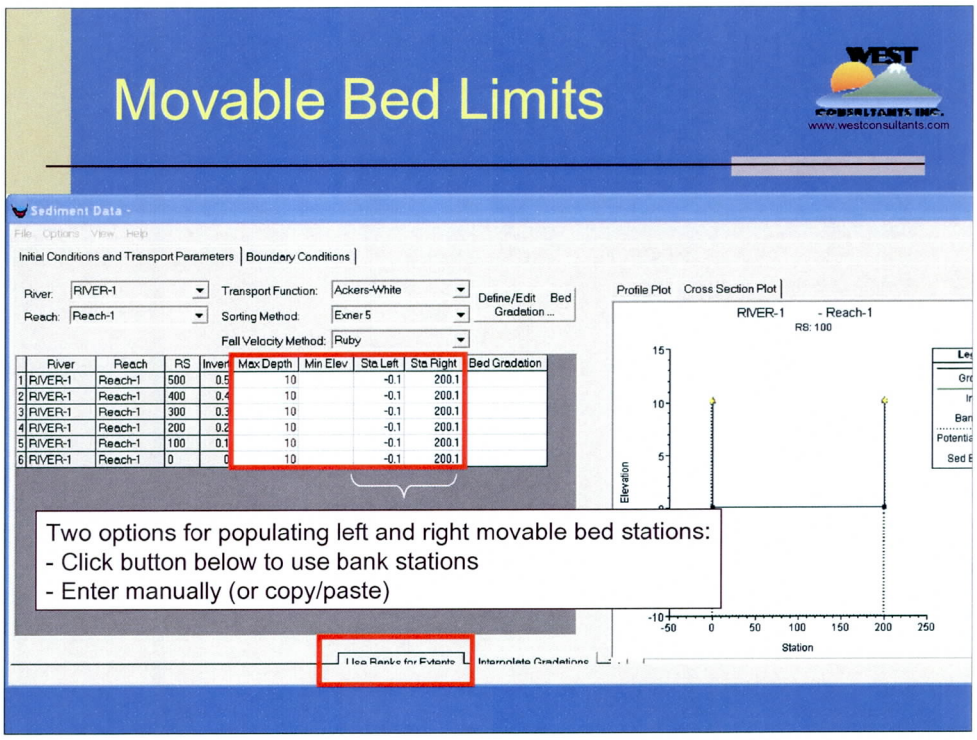
This window is the primary focus of this demonstration (although we will be looking at others as well).



Let's start with movable bed limits and sediment reservoir depth.



In our demonstration we will assume a sediment reservoir depth of 10 feet.



We will use the button to populate movable bed limits based on bank stations. Note that the program enters left and right stations just outside of the actual bank stations so the bank stations themselves can also move (this may not be desirable).

Movable Bed Options

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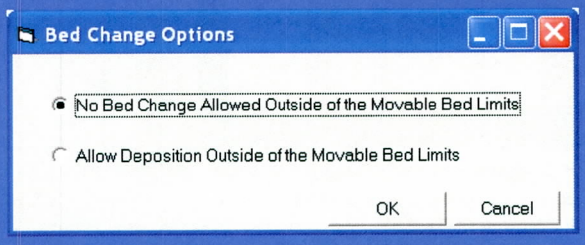
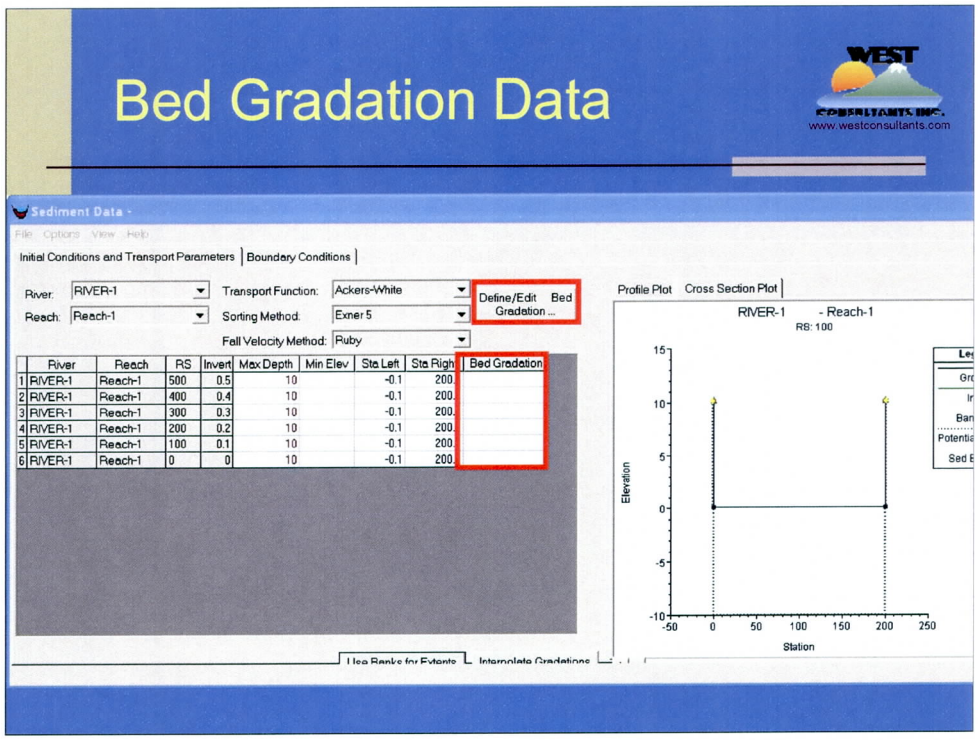
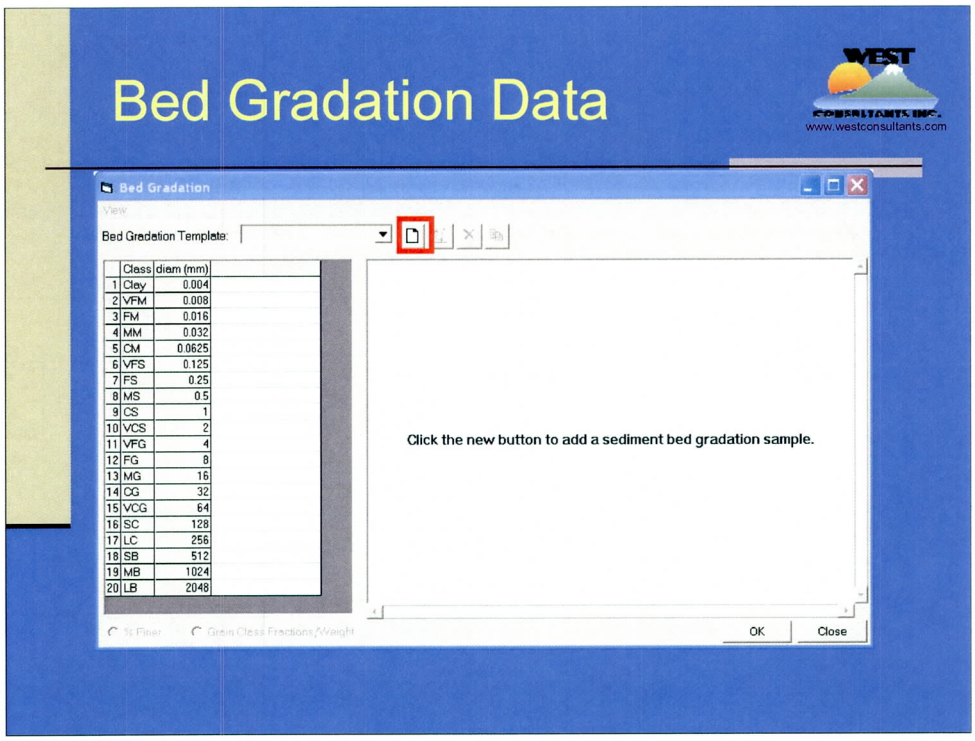
- Additional Movable Bed options from "Options" pull-down menu
- The default selection is "No Bed Change Allowed Outside of the Movable Bed Limits"
- Unlike HEC-6T, deposition station limits are not available

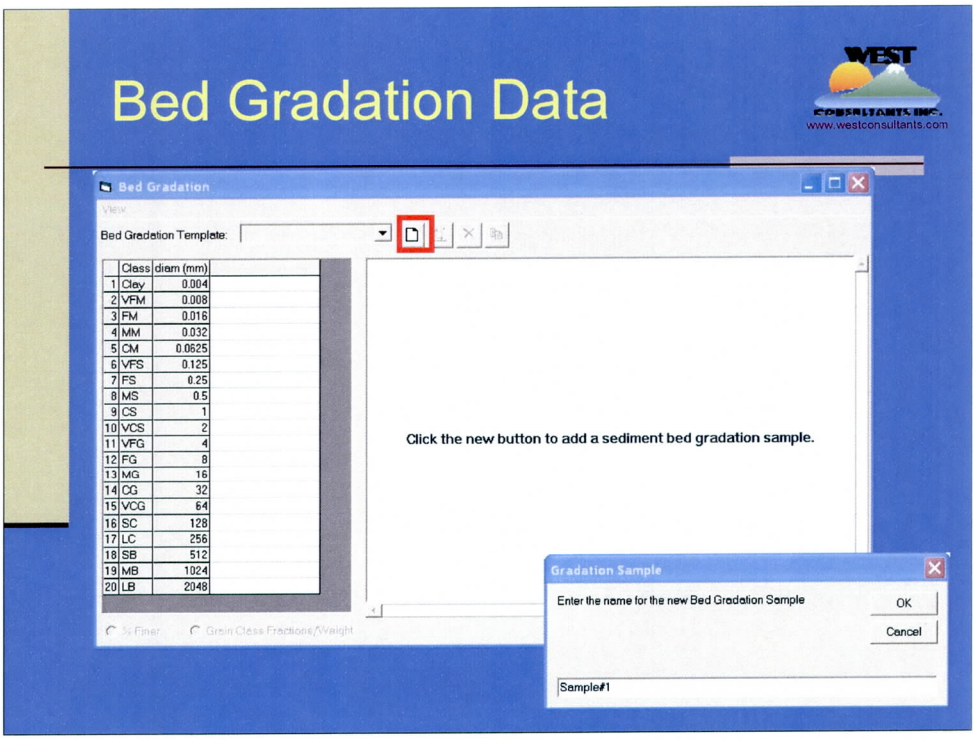




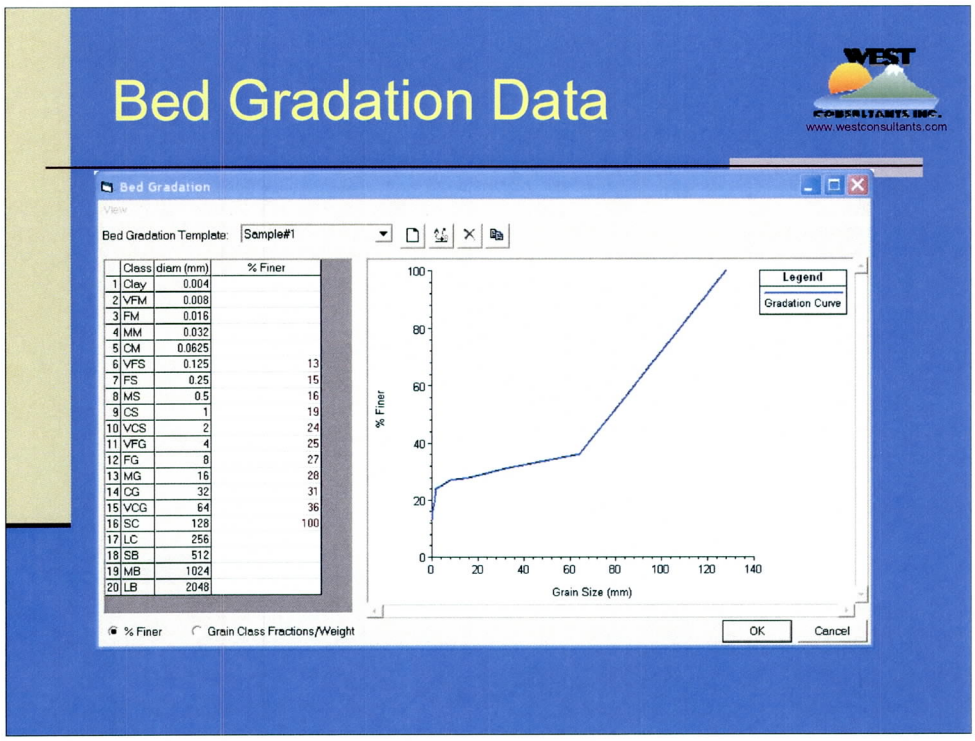
Next is bed gradation data. We start by clicking the "Define/Edit Bed Gradation…" button.



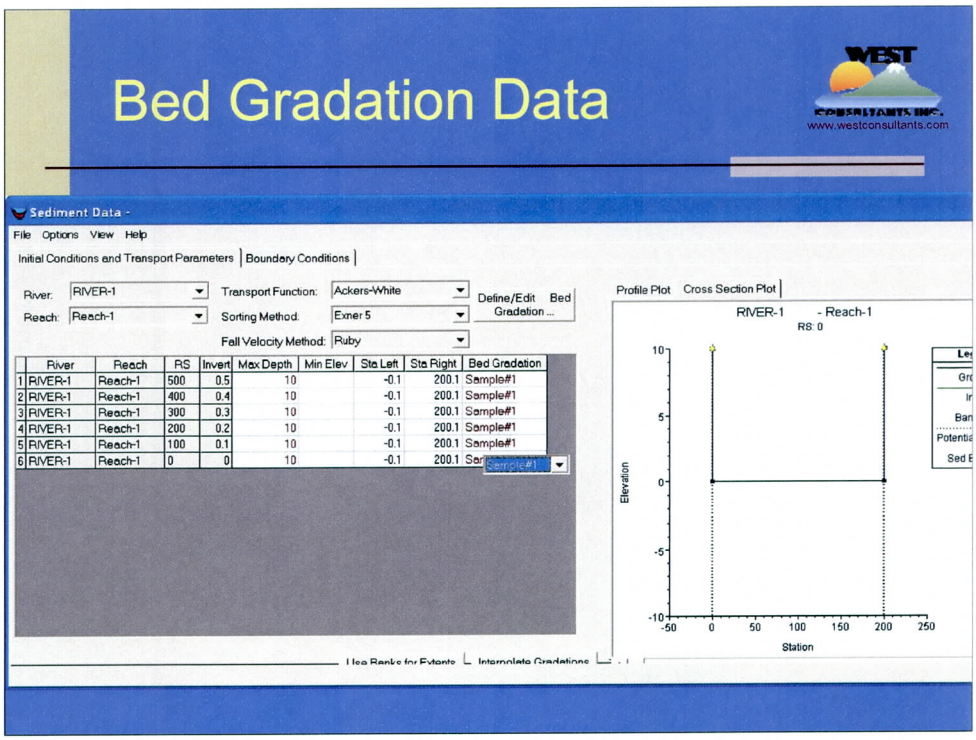
As directed in the big window, we click the new button to add a sediment bed gradation sample.



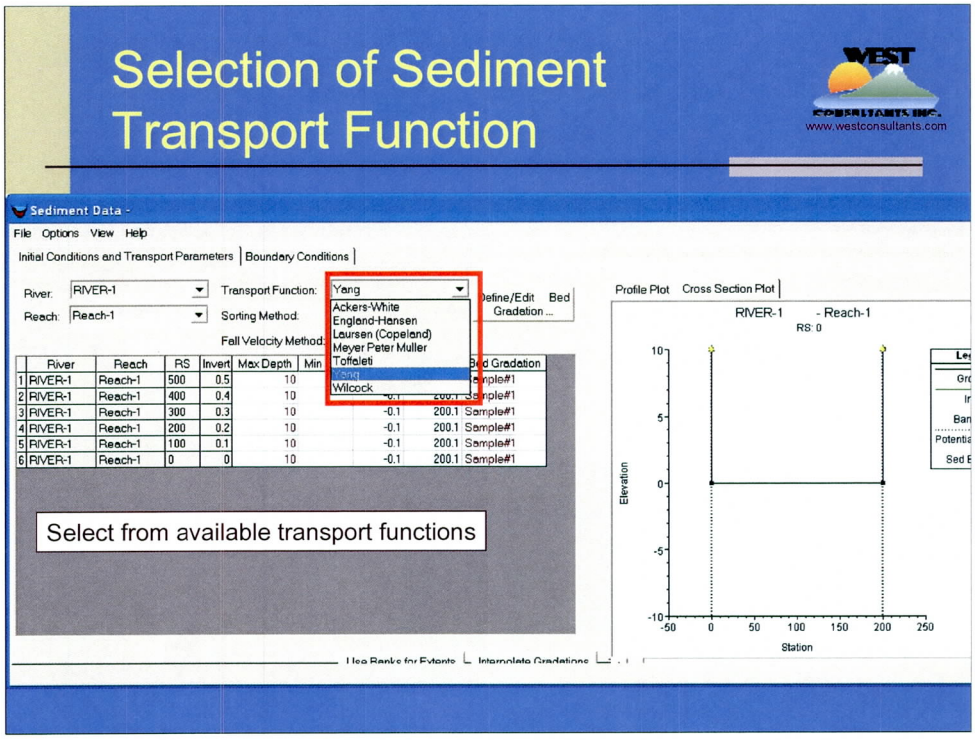
As directed in the big window, we click the new button to add a sediment bed gradation sample and name it “Sample#1”.



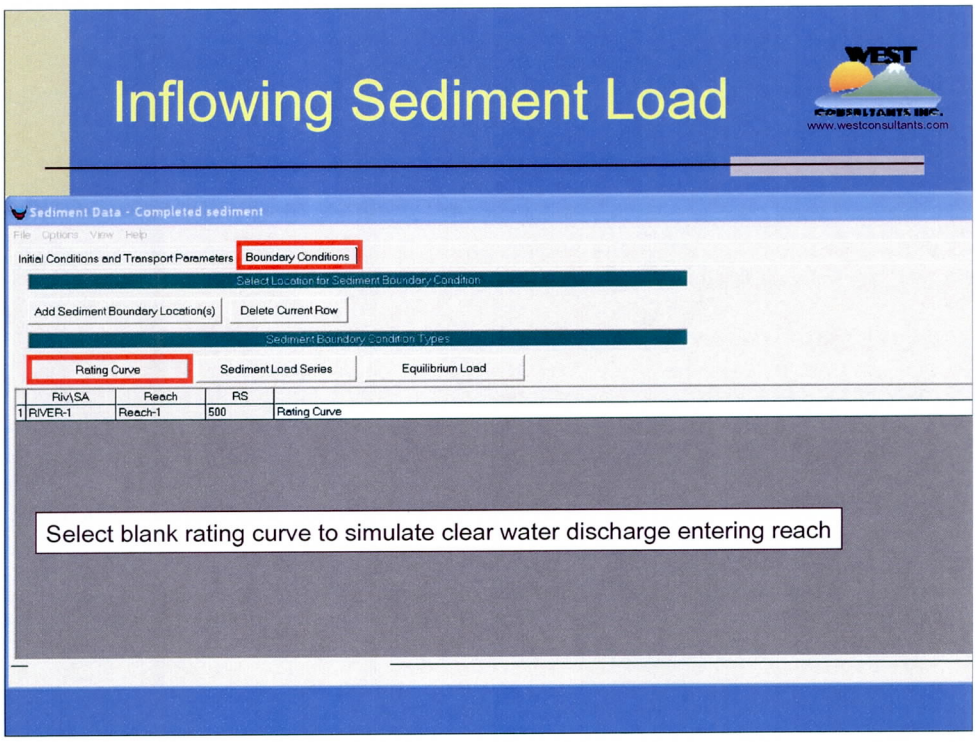
After entering the values for "% Finer" a graph appears. If you have other similar gradations you may want to use the "copy" button (last one on the right).



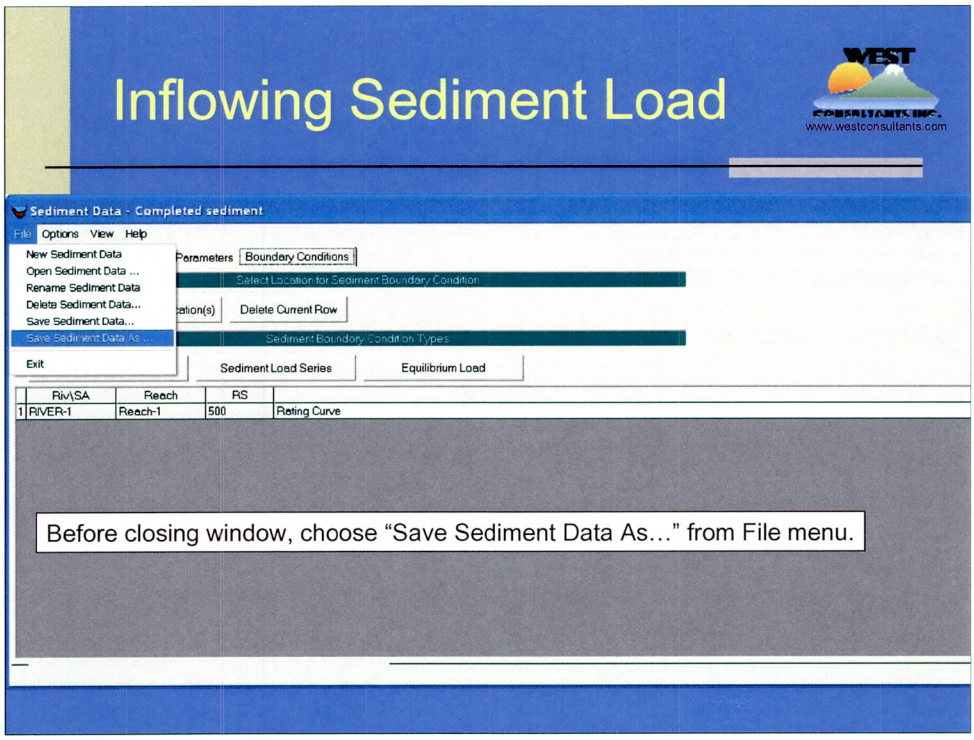
The last step is to use the pull down boxes to specify the gradation for each cross section. You can also copy and paste.



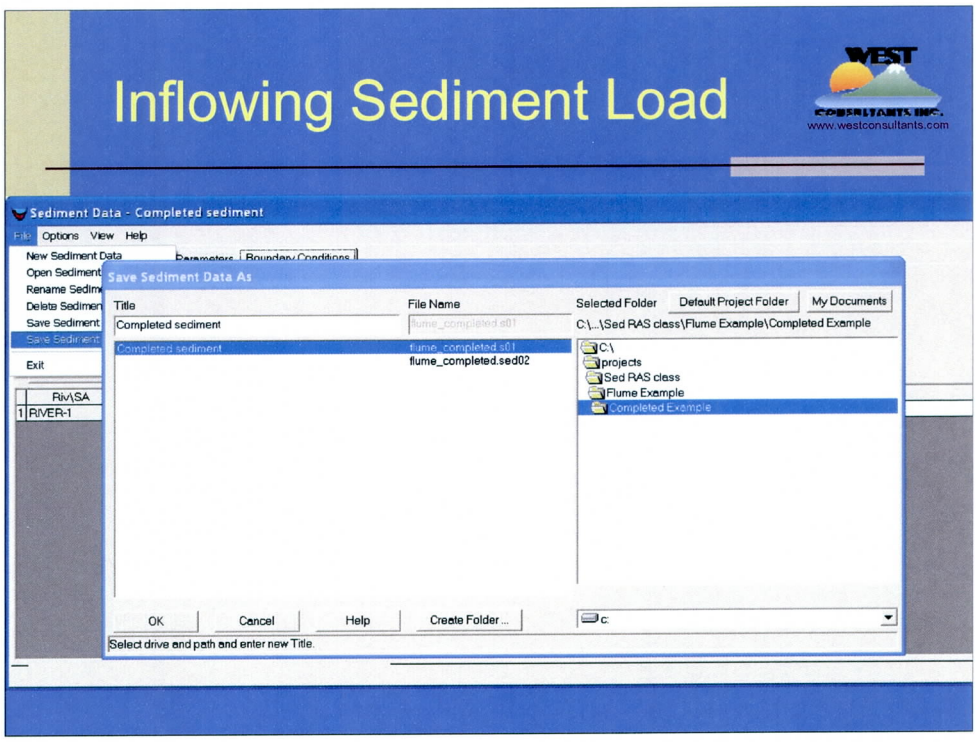
Select the Yang transport function.



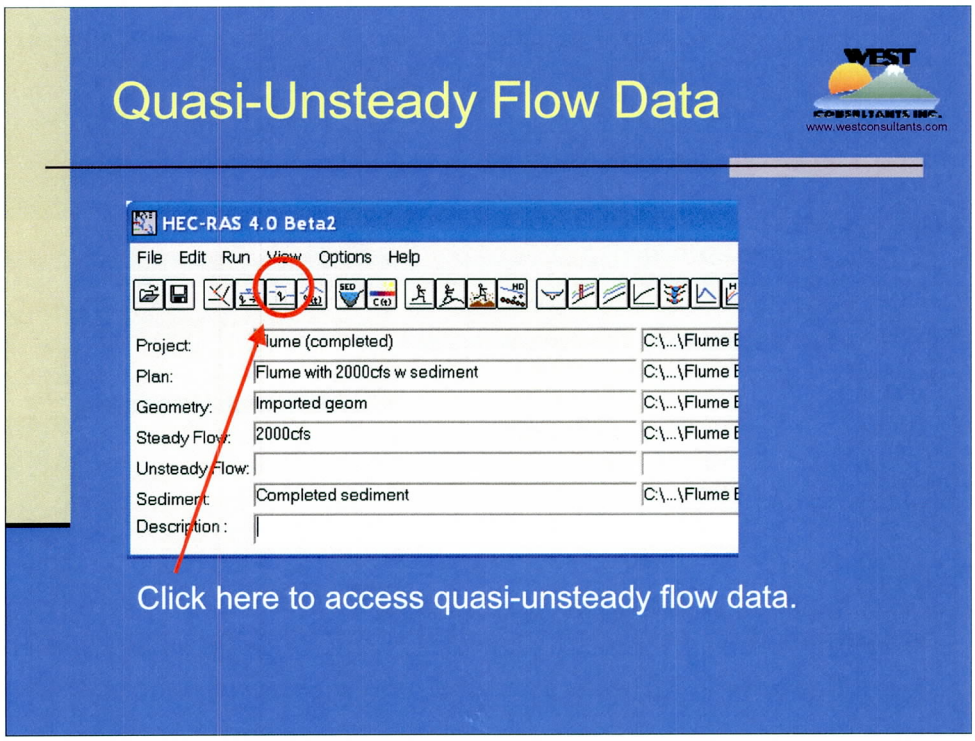
To enter a blank inflowing load, we click the “Boundary Conditions” tab and then select “Rating Curve” at cross section 500. This will describe the condition where clear water enters the upstream boundary.



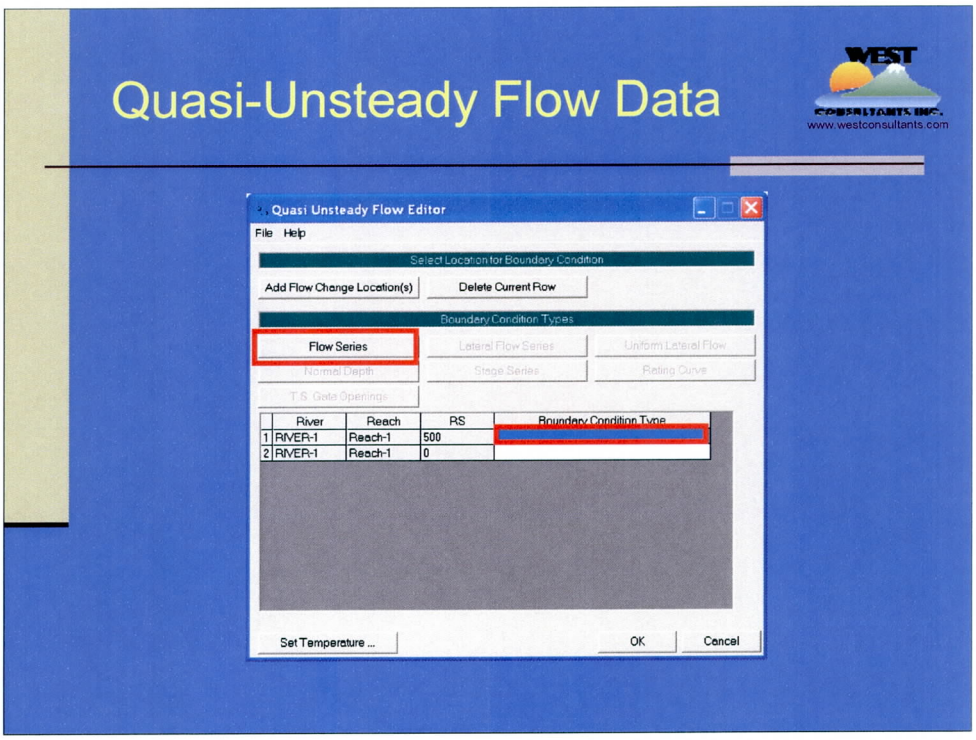
We are done entering the basic sediment data and need to save, so before closing the window choose "Save Sediment Data As…" from the file menu.



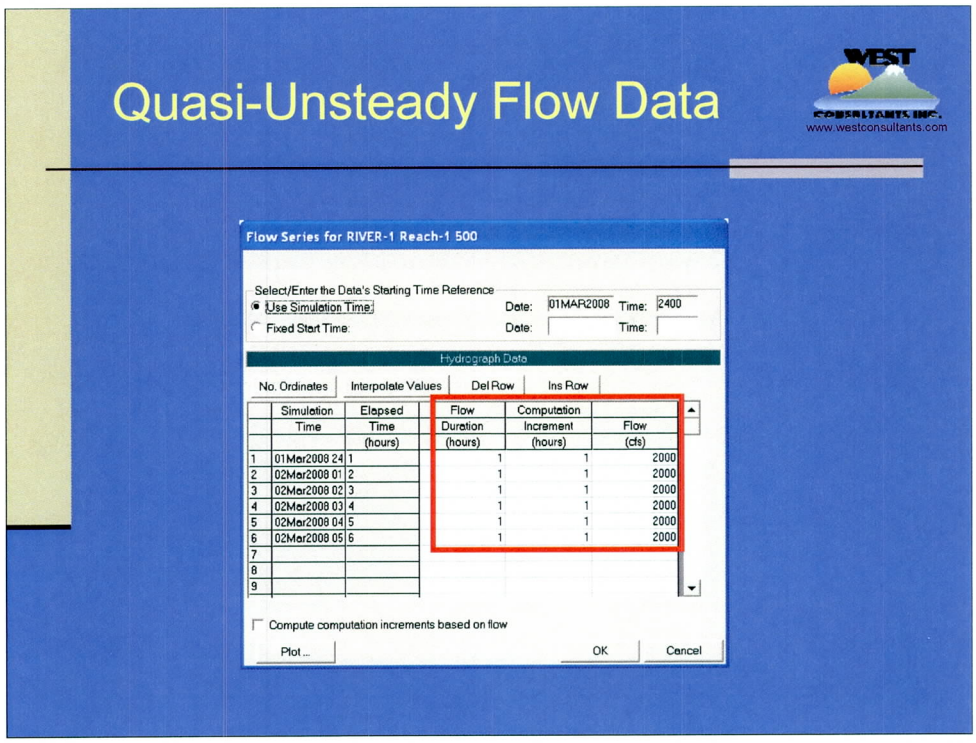
In this example, the sediment data was saved as “Completed Sediment”. HEC-RAS automatically assigns the next *.s number, as it does with flow, geometry, and other data files.



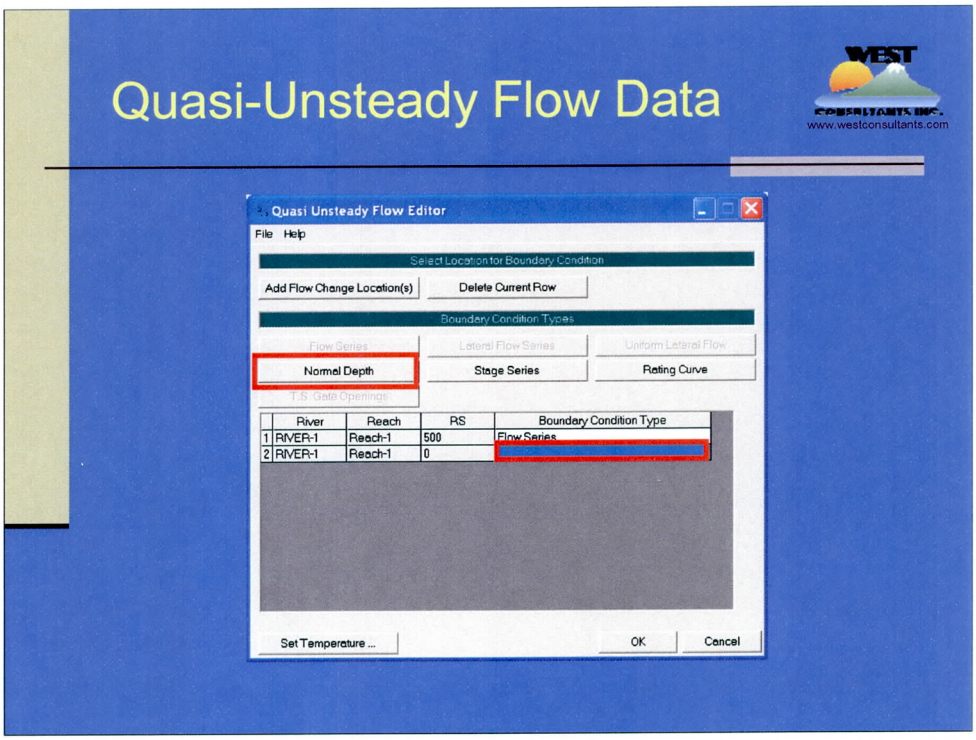
In order to run a simulation, we need to also enter quasi-unsteady flow data.



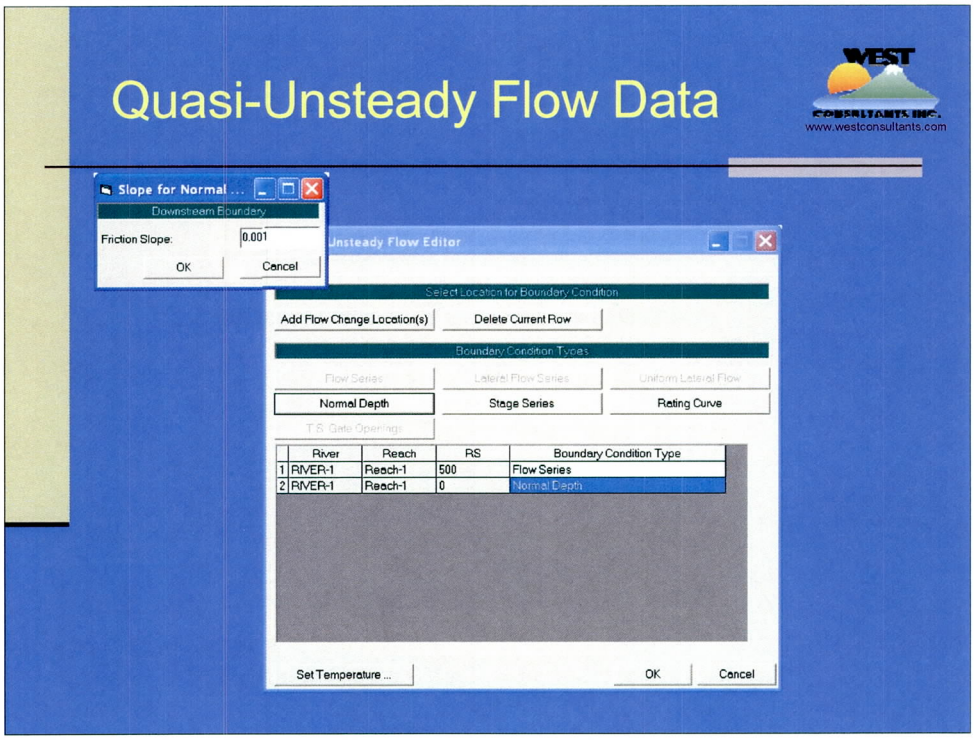
Clicking the box next to River Station 500 highlights it in blue, then you can select Flow Series to enter the flow entering that cross section.



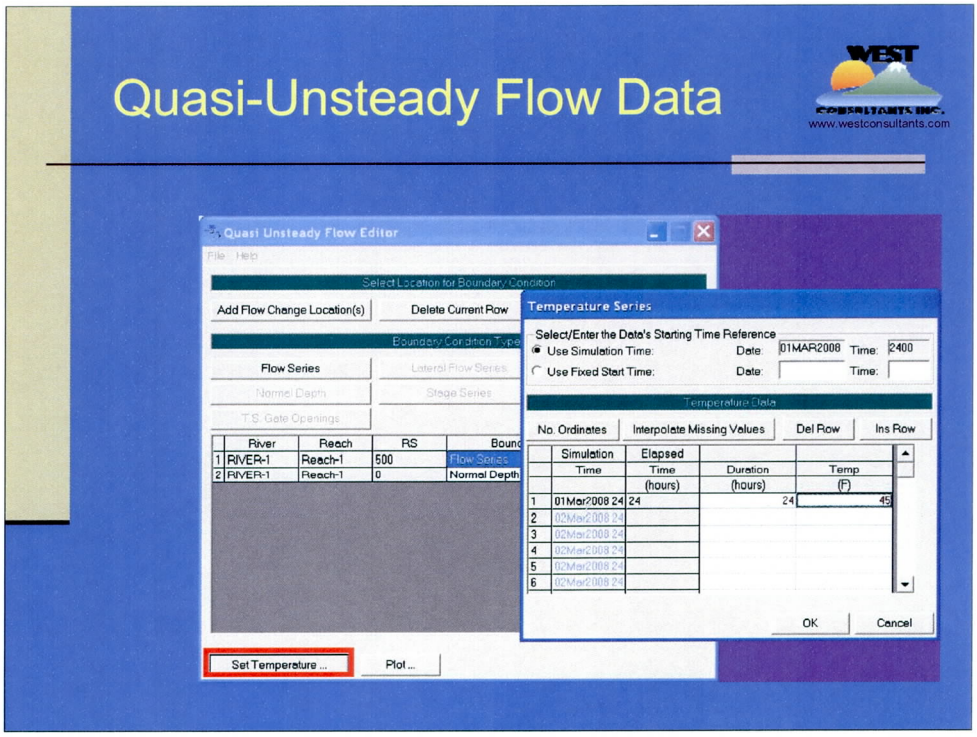
For this example, we will enter a constant flow of 2000 cfs at one hour increments, with a computation increment of 1 hour. Note that when preparing this example we skipped ahead a few steps and had already entered the time window data—March 1-2, 2008. The default time window is in the year 1899.



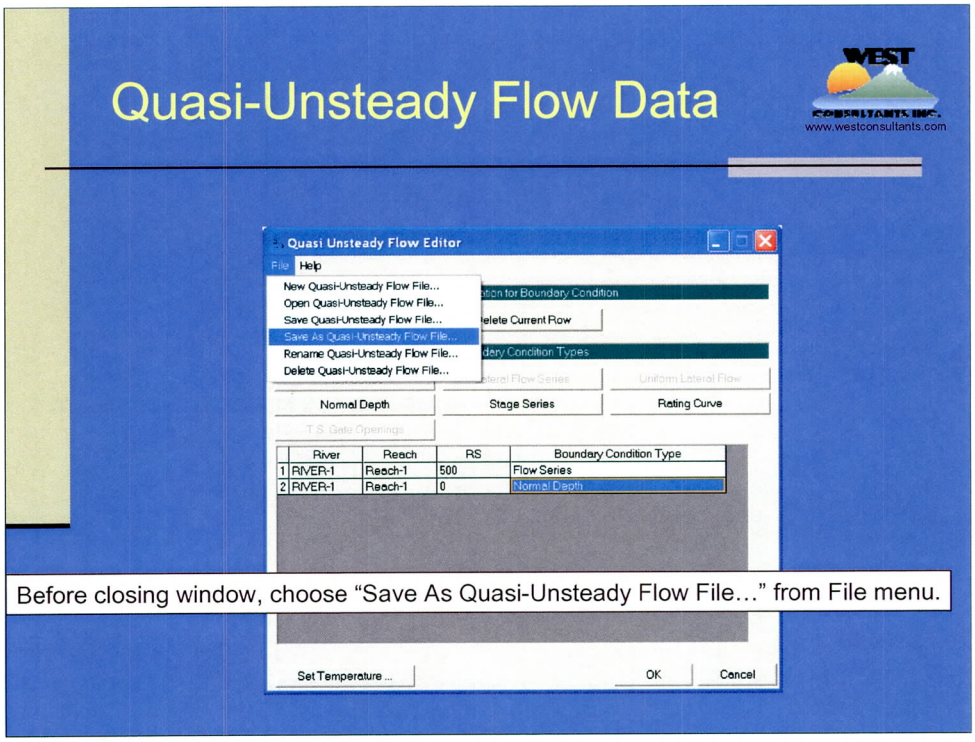
Clicking the box next to River Station 0 highlights it in blue, then you can select "Normal Depth" to enter a Normal Depth downstream boundary condition.



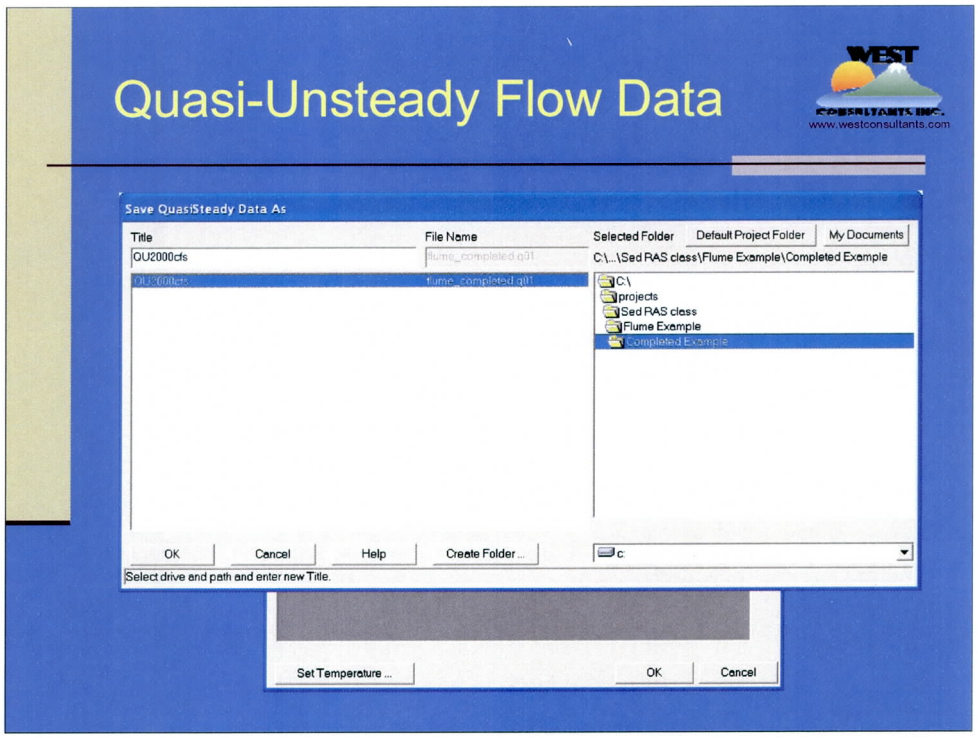
We will enter a slope of 0.001. Note that this value is fixed over the entire simulation.



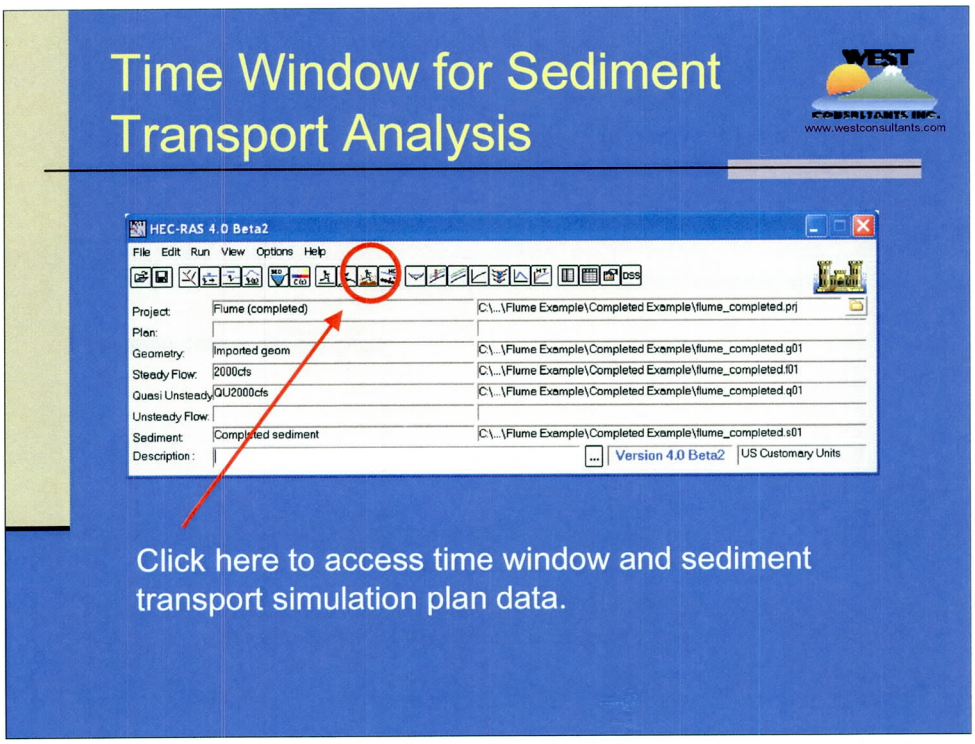
The model will not run if a temperature is not entered. The duration can be longer than the simulation, but not shorter. In this example, we are entering 24 hours even though the simulation is 6 hours.



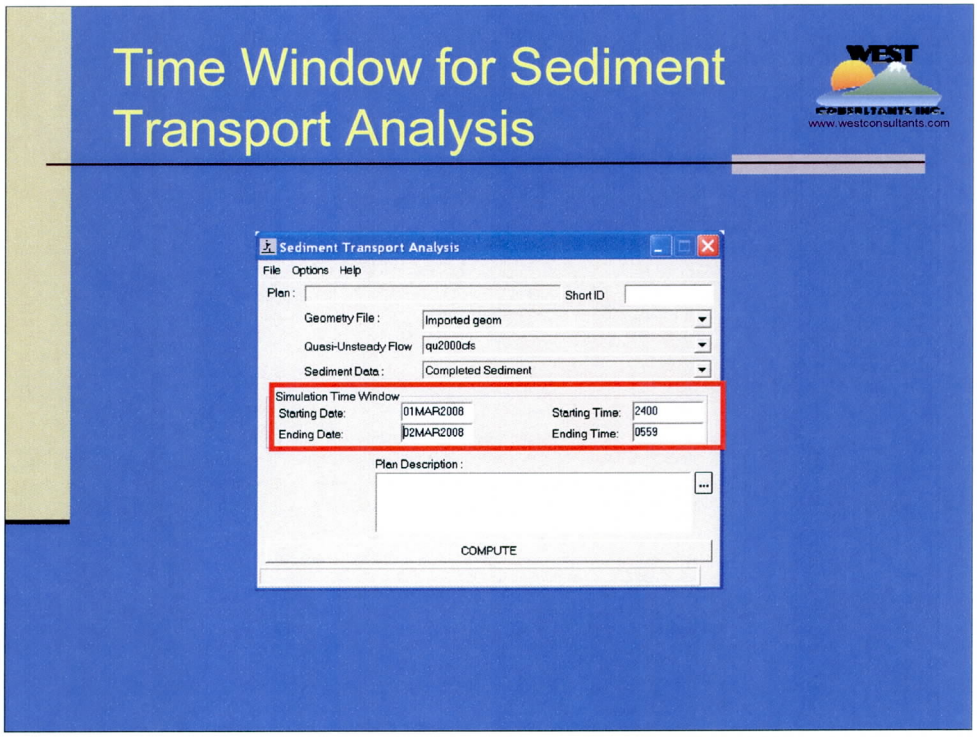
We are done entering the quasi-unsteady flow data and need to save, so before closing the window choose "Save As Quasi-Unsteady Flow File…" from the file menu.



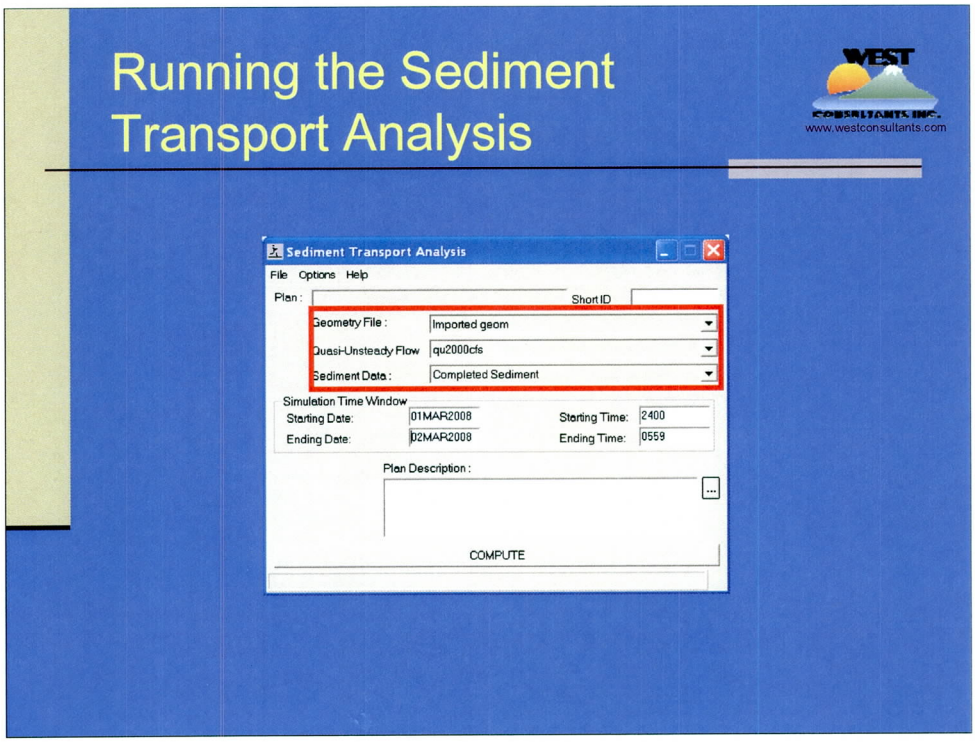
The quasi-unsteady data file is saved as “QU2000cfs.”



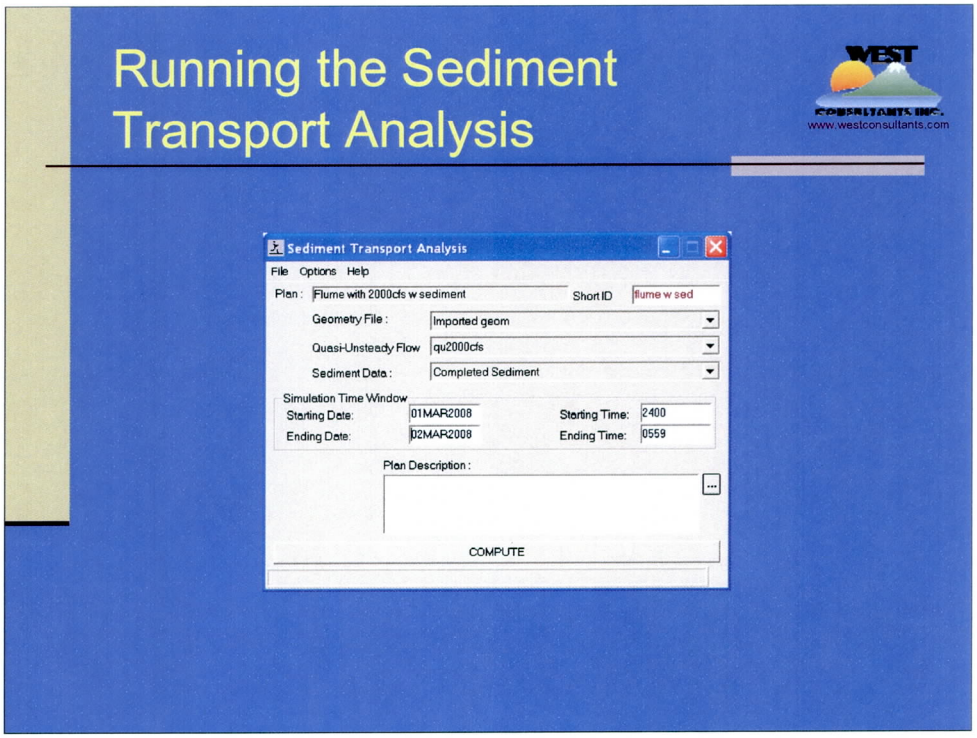
To enter time window data and to run the sediment transport analysis you click the man running on the dirt.



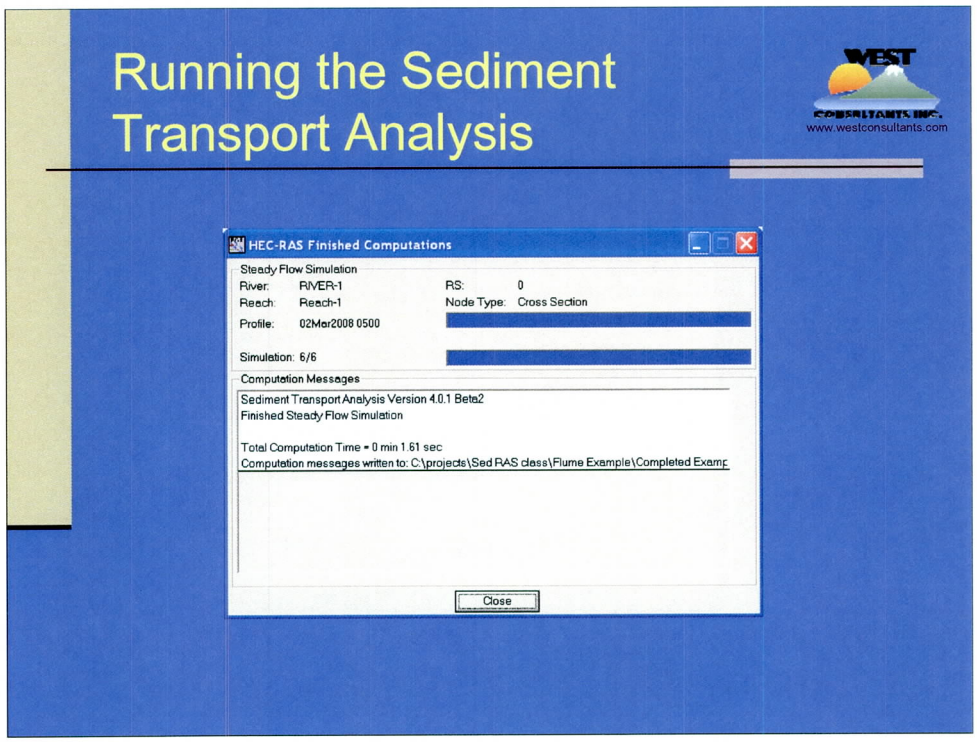
The simulation time window is entered here. In this example we started the simulation at midnight, March 1, 2008 and ended the simulation at 0559 on March 2, 2008. One note about the "ending time"—there is a bug in this version of HEC-RAS that will not run when we enter 0600 even though we have six hours of flow data (501 will also work to include the last hour increment in the simulation). The simulation described above actually begins on March 1 at 2400 hours and will end on March 2 at 0600 hours.



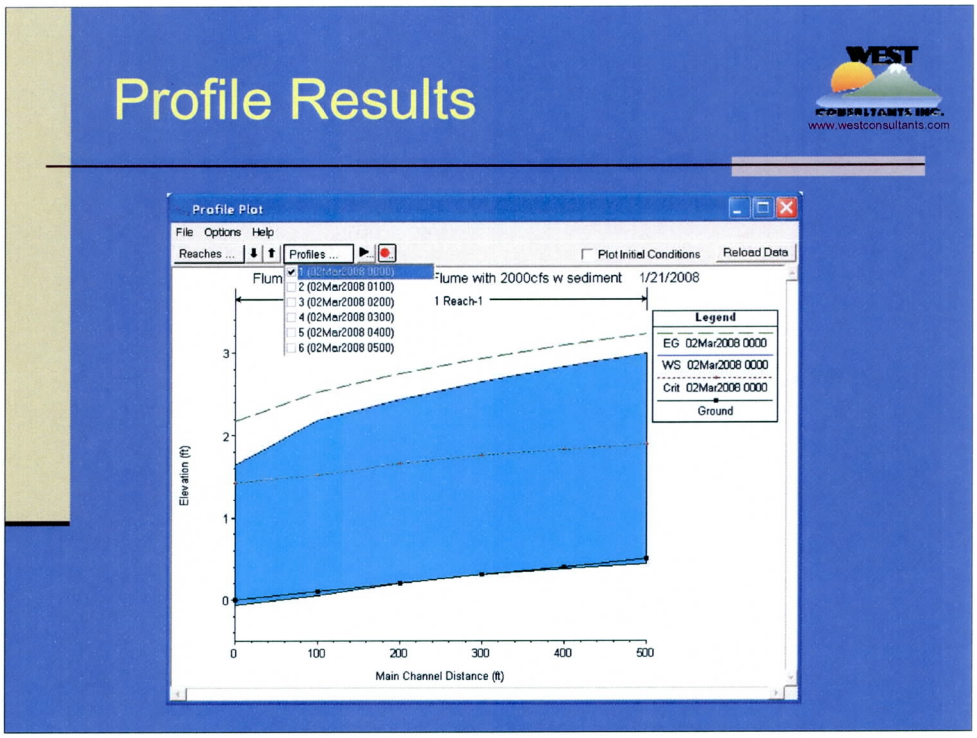
Now we are ready to assign a plan file and run the simulation. First we need to make sure the correct geometry file, quasi-unsteady flow file, and sediment data file are selected.



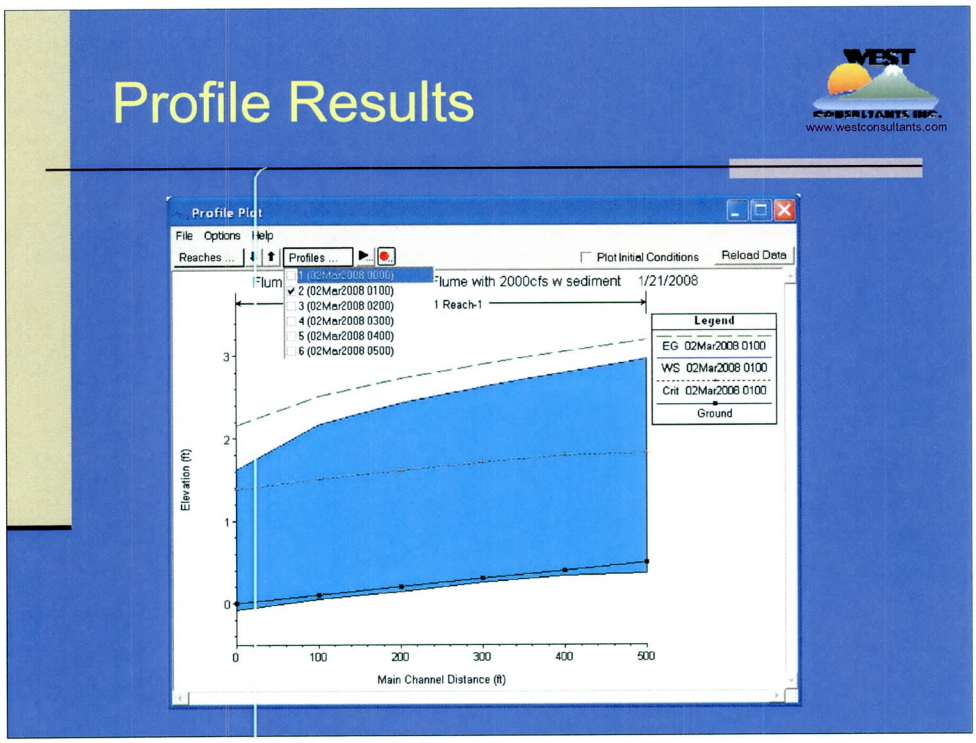
The plan is saved as “flume with 2000cfs w sediment” and is assigned the short ID “flume w sed”.



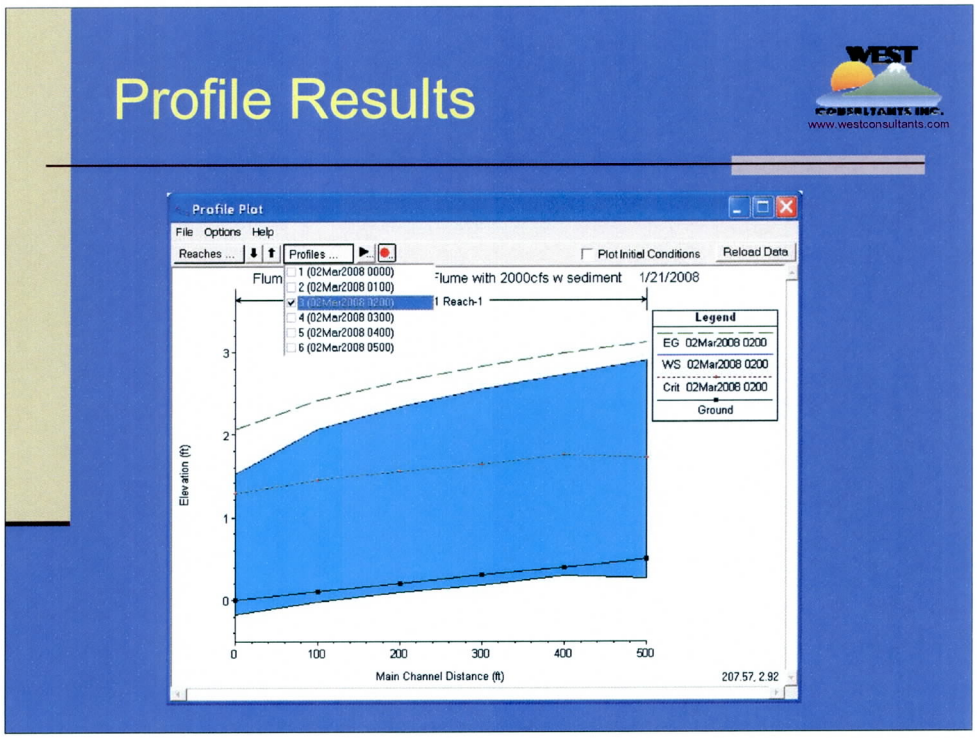
After clicking “compute” the model simulations proceed, ending with this screen.



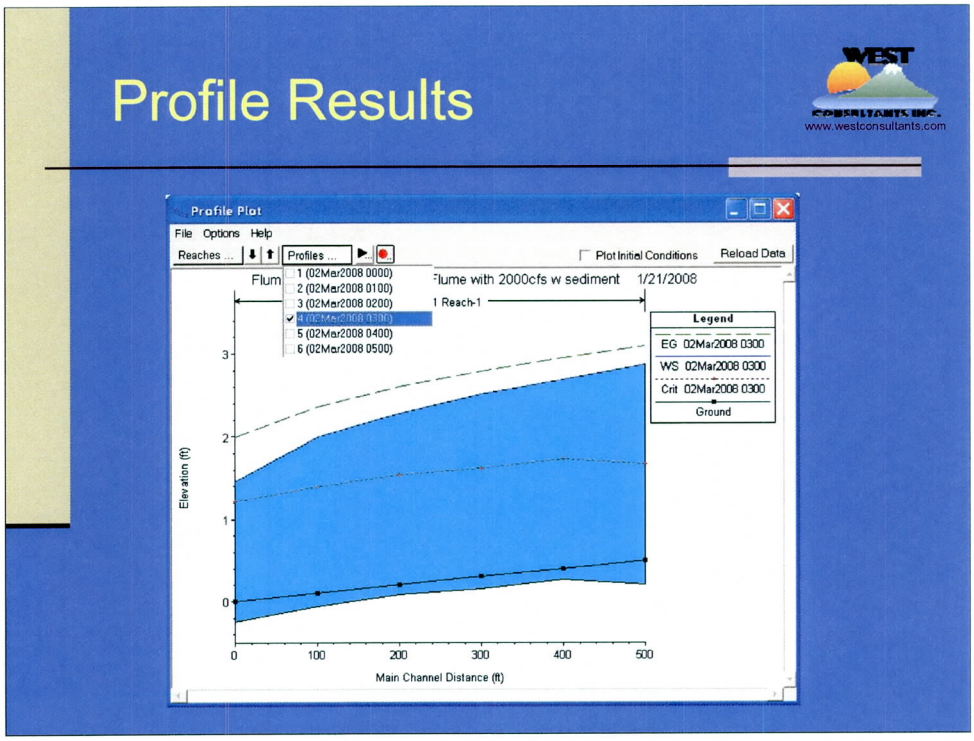
Going to the profile plot, we can see the results at each simulation time step. The first hour's results show a small amount of scour at several cross sections (scour indicated by the shaded region below the original ground points). Note that the time for these results indicates time 0000. This is not correct. The results for the first hour are for time 0000 to 0100. This appears to be a bug with the profile selection boxes.



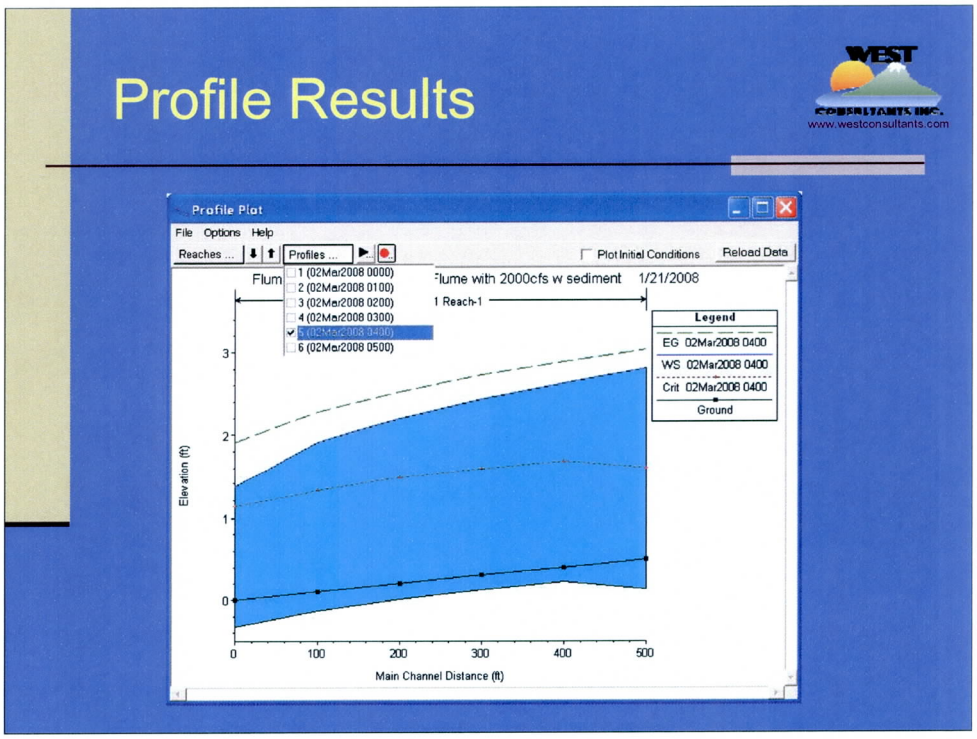
The second hour shows slightly more scour…



And the third…

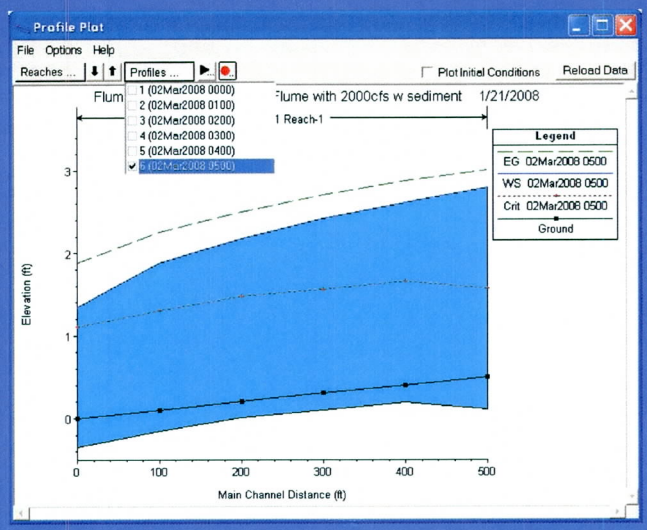


And the fourth…

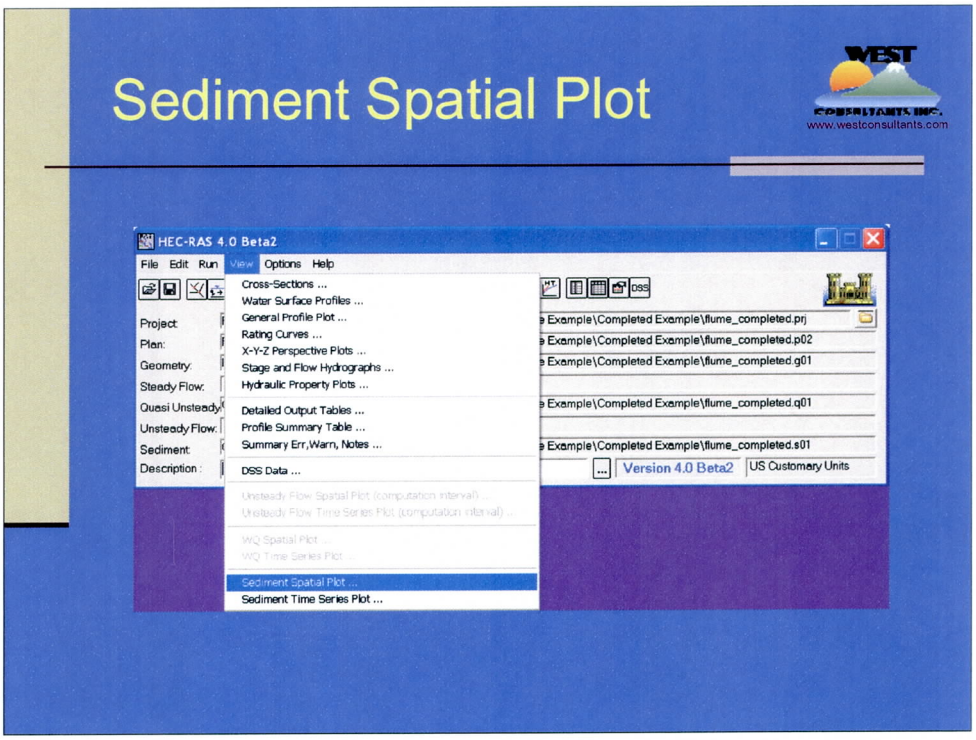


And the fifth…

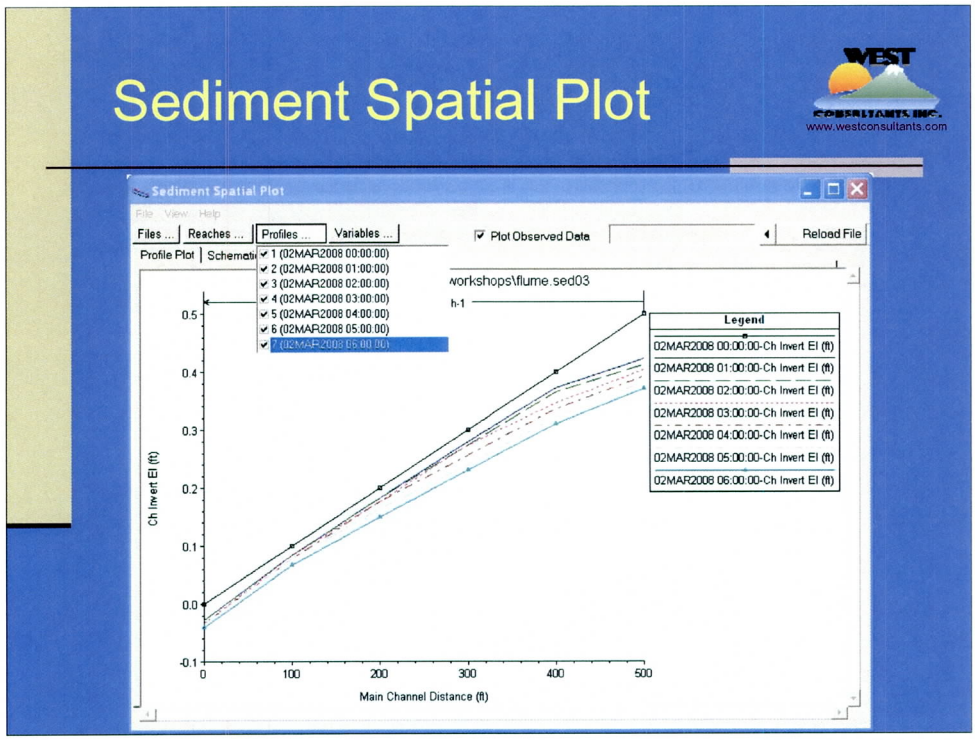
Profile Results



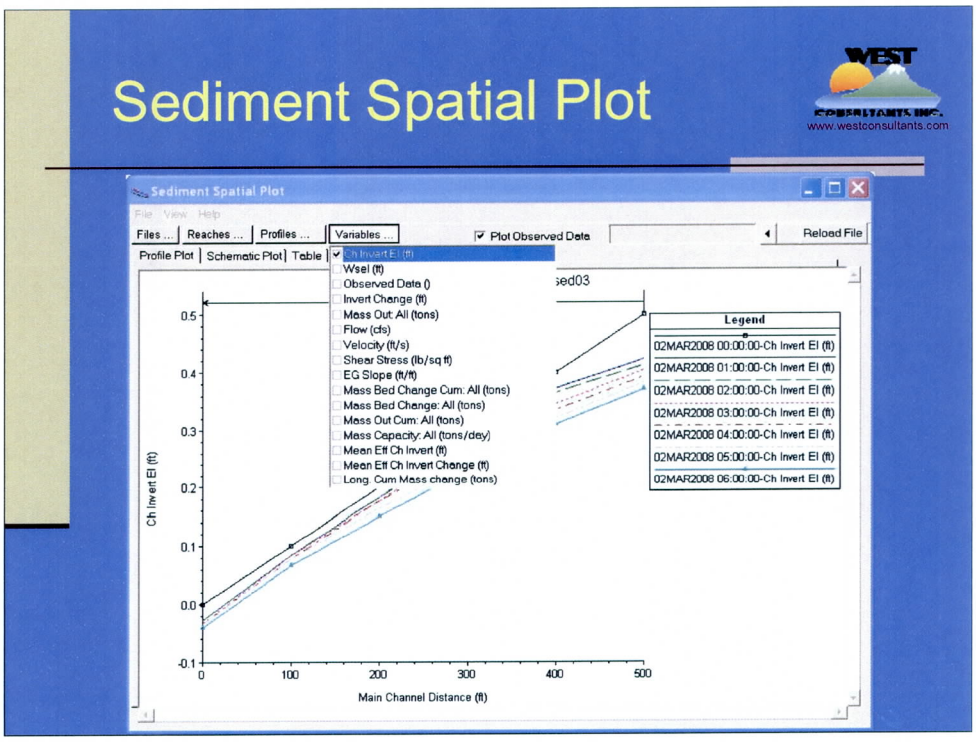
And the sixth…



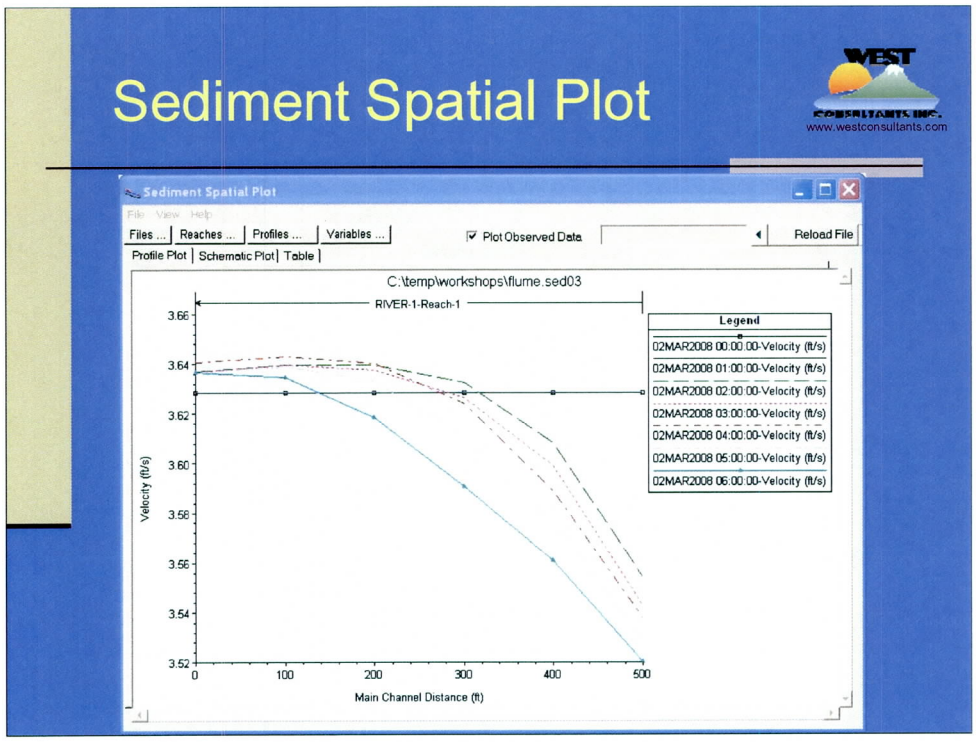
When sediment computations are performed, detailed sediment and hydraulic output are written to a separate binary file. The detailed output from the sediment computations can be displayed as spatial plots and tables, as well as time series plots and tables. First we will look at spatial plots.



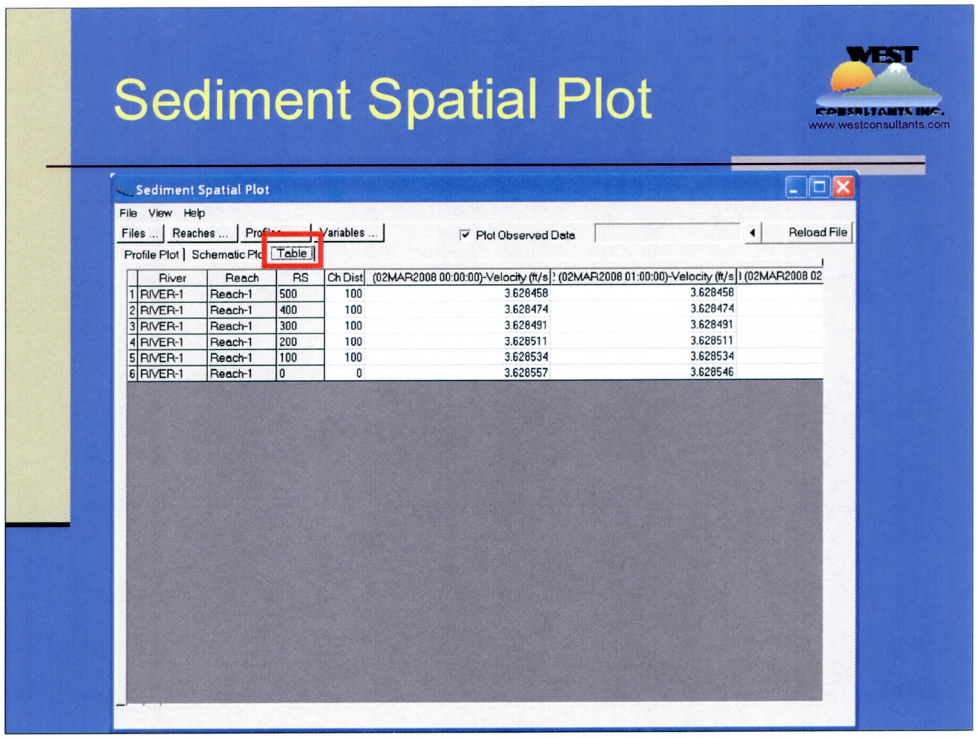
The default variable for the sediment spatial plot is xsed, which is thalweg elevation. When multiple profiles are selected, different line types and colors are generated automatically for each profile.



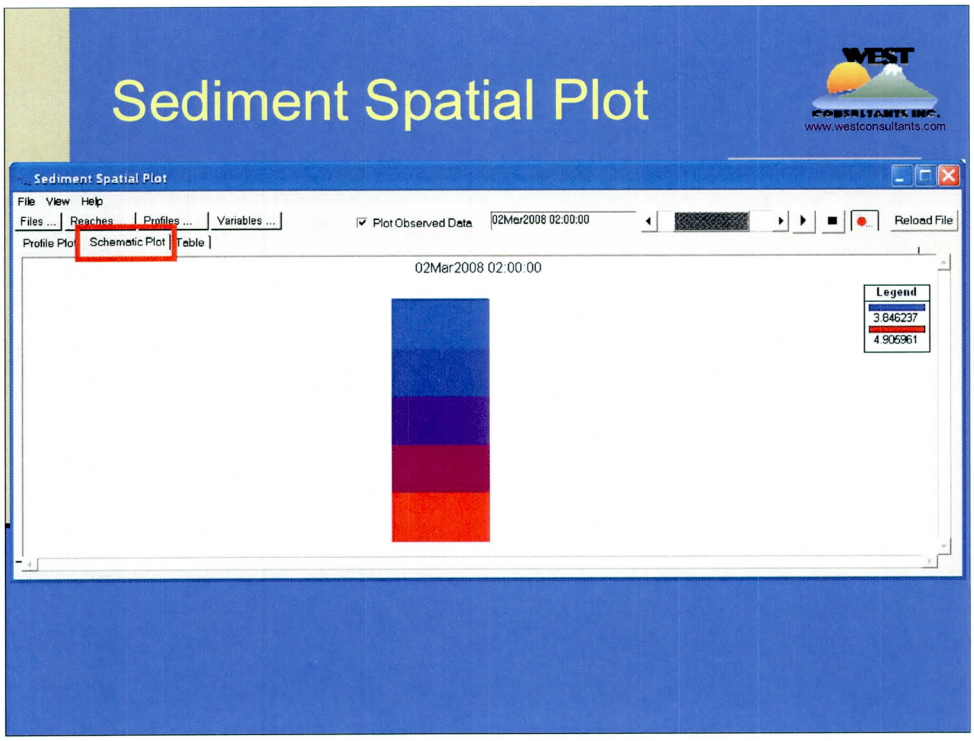
The plotted variable can be selected from a long list including channel invert elevation, invert change, shear stress, velocity, an array of weights and volumes tracked by layer and grain size, and others. Some variables are only available if the output level is changed from the default value of four to six.



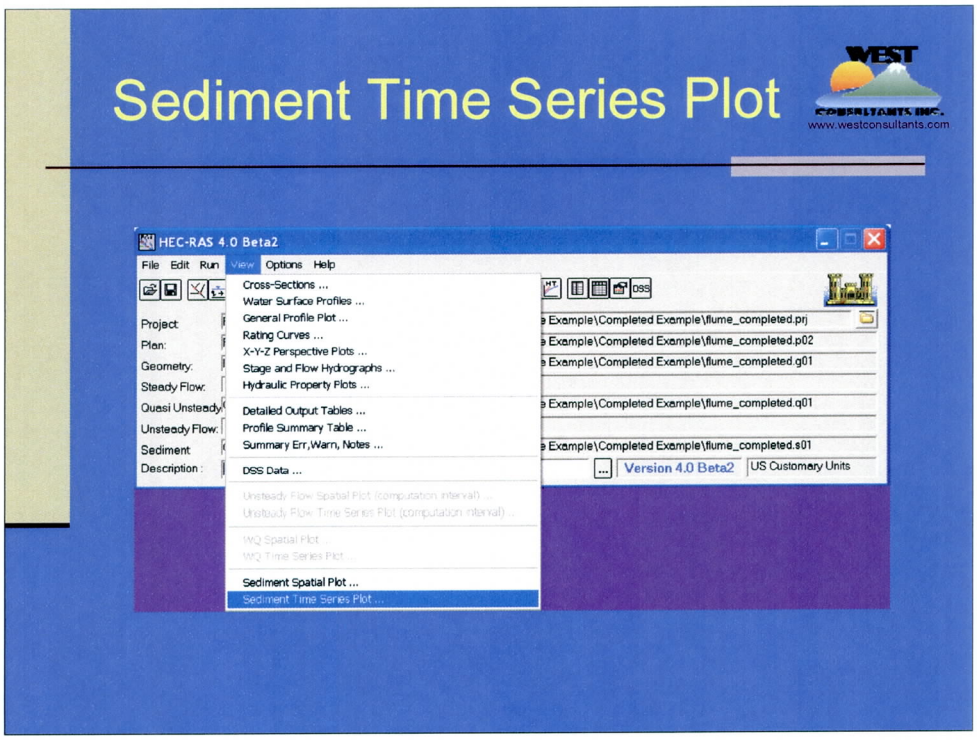
In this spatial plot, the velocity variable was selected.



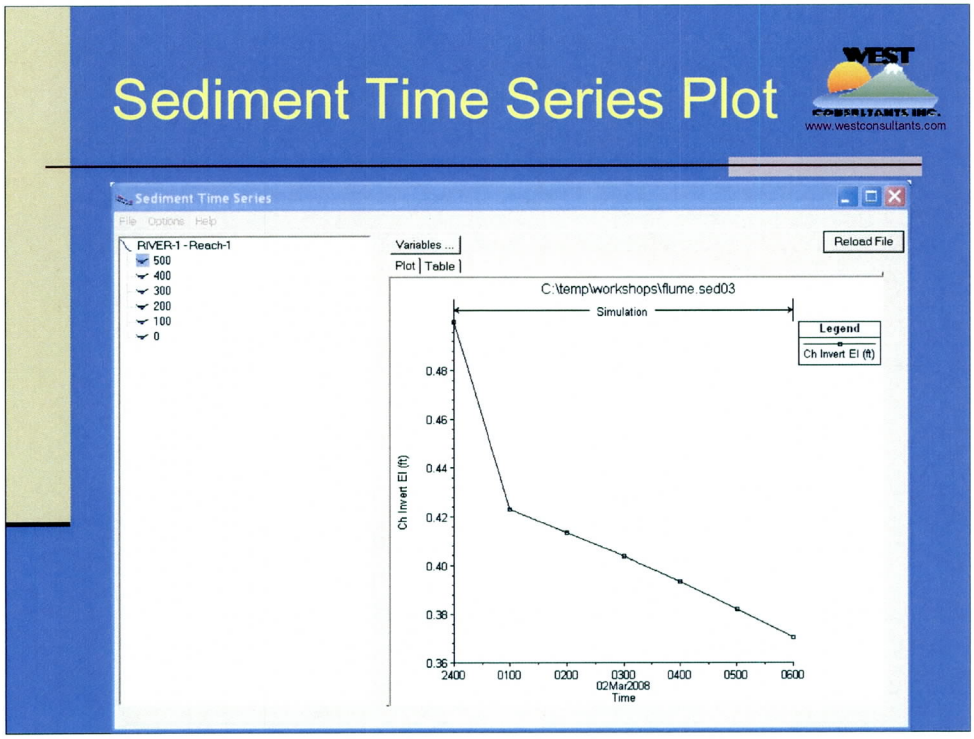
Selecting the “table” tab for a particular plot shows a tabular view of the data, which can be copied and pasted to a spreadsheet.



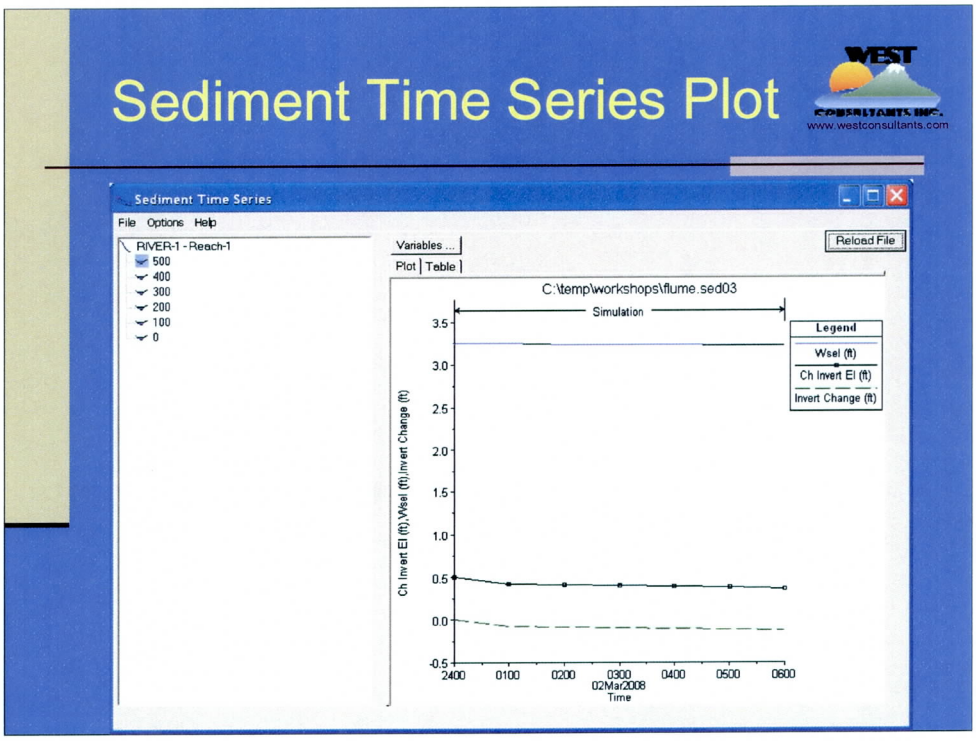
Selecting the "schematic plot" tab shows a plan view of the reach for the selected variable with a graded color scheme. Results are shown for the time step indicated. In this example, the plot is for t=2 hours.



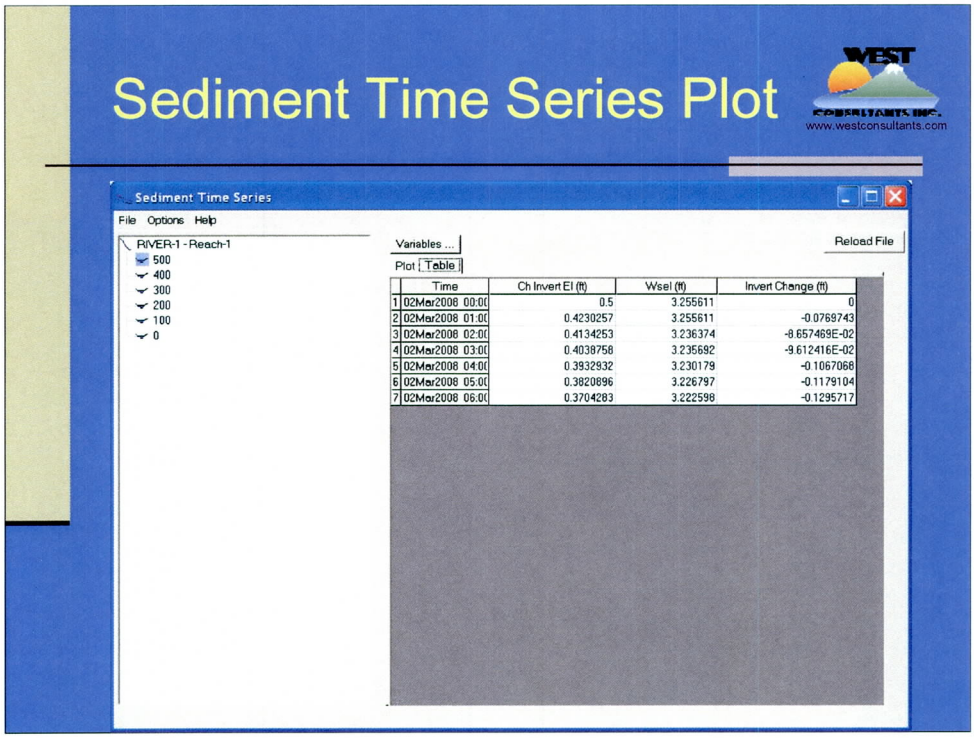
The next output feature we will look at is the sediment time series plot which shows results over time at a single location.



Each time step in the simulation is shown as an increment on the x-axis of the plot, and a list of cross sections is provided in the left pane of the plot. The default variable is channel invert elevation, but this can be changed by clicking the "variables…" button.



In this example, the channel invert elevation, invert change, and water surface elevation variables have been selected.



Clicking the “Table” button provides all three selected variables in tabular form for each time step.

HEC-RAS Sediment Workshop No. 1-4
The Flume Workshop Problem

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Objective: To prepare and execute a basic sediment transport model and view the results.

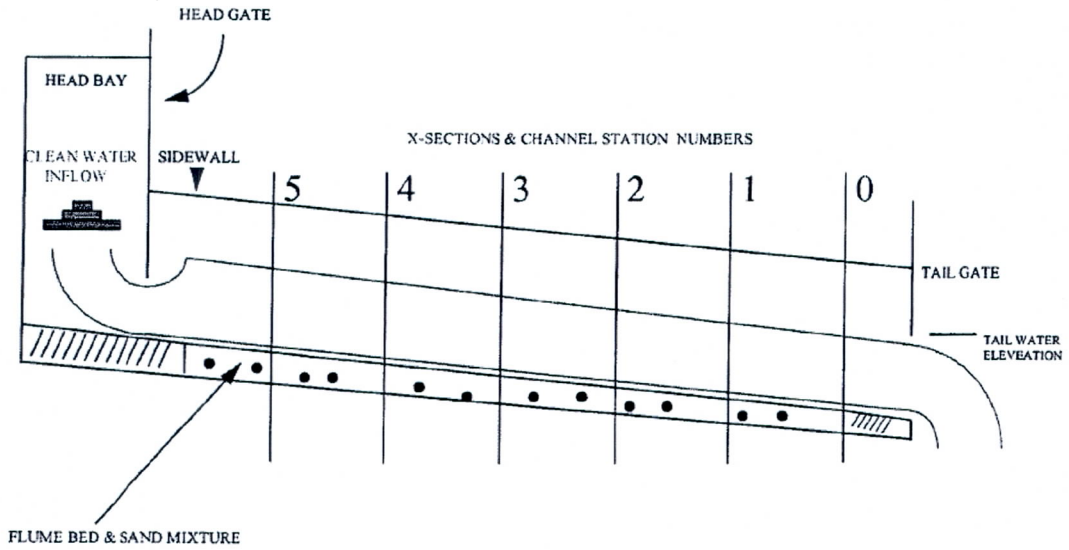
Time to Complete: 1 hour

The data files used for this workshop were developed for pedagogic purposes. The model and results of this workshop do not represent current or future conditions for any particular river.

Intro

Introduction

The HEC-RAS file, flume.prj, is a data set that models a simple flume. Below is a sketch of what the physical model of this flume would look like from a side view. Notice the six vertical lines numbered 0 through 5. These are cross sections and channel station numbers of the flume. The flume has a single inflow at the upstream end (cross section 5) and a single outflow at the downstream end (cross section 0). In this example, a sand mixture has been placed in the bed of this flume. The sketch shows clean water coming from the head bay. This flume will have a single gate across its entire width to insure that the inflowing water is distributed uniformly from one wall to the other. The tailwater elevation will be at normal depth. Since there is no bed material in the inflowing water, one



FLUME

expects erosion to take place as water flows down this flume.

Steps to Enter Sediment Data and Run Sediment Transport Simulation

Step 1 **Entering Sediment Data**

1. Open the HEC-RAS file: flume.prj

2. Click the Sediment Boundary Condition Data button.

3. On the Initial Conditions and Transport Parameters Tab, enter the following in the table:

   a. Max Depth = 10 (all cross sections)

   b. Min Elev field left blank

   c. Click the "Use Banks for Extents" button at bottom of page to populate left and right movable bed limits (Note: if the button is not visable, try changing the window size).

4. Now click the Define/Edit Bed Gradation ... button to define the gradation.

   a. Create a new gradation by clicking the button, and name the gradation "Sample#1."

   b. Enter the following gradation, then click OK:

5. Select the "Sample#1" gradation at each cross section.

Class	diam (mm)	% Finer
Clay	0.004	
VFM	0.008	
FM	0.016	
MM	0.032	
CM	0.0625	
VFS	0.125	13
FS	0.25	15
MS	0.5	16
CS	1	19
VCS	2	24
VFG	4	25
FG	8	27
MG	16	28
CG	32	31
VCG	64	36
SC	128	100
LC	256	
SB	512	
MB	1024	
LB	2048	

6. Define the sediment transport function as Yang

7. Click the Boundary Conditions tab, click in the white box next to cross section 500, then click the Rating Curve button, and without entering any data click OK.

8. To save the Sediment Data entered in the steps above, select "Save Sediment Data As…" from the File menu and name the Sediment Data Completed Sediment

Step 2 Entering Quasi-unsteady Flow Data

1. From the Main HEC-RAS window, click the Quasi-unsteady flow data button.

2. Click in the white box next to cross section 0, then click the Normal Depth button and enter a friction slope of 0.001.

3. Now click in the white box next to cross section 500, then click the Flow Series box and enter the following data:

Flow Duration (hours)	Computation Increment (hours)	Flow (cfs)
6	1	2000

4. At the bottom of the dialog box, click the Set Temperature ... box and enter the following data then "OK.":

Duration (hours)	Temp (F)
24	45

5. To save the Quasi-unsteady Data, select "Save Quasi-Unsteady Flow File…" from the File menu and name the file QU2000cfs

Step 3 Perform the Simulation

1. To run the simulation, click the Perform Sediment Transport Simulation button from the main HEC-RAS window.

2. Enter the following in the simulation time window:

Simulation Time Window			
Starting Date:	01MAR2008	Starting Time:	2400
Ending Date:	02MAR2008	Ending Time:	0559

3. To save the Sediment Transport Analysis plan data, select "Save Plan As…" from the File menu and name the file Flume with 2000cfs w sediment and name the short ID as flume w sed

4. Click COMPUTE to run the simulation

Step 4 Evaluate the Output

1. From the main HEC-RAS window, select "Sediment Spatial Plot…" from the View menu and select the Profile Plot tab.

2. The default variable plotted is "Ch Invert El" (channel invert elevation). Click the Profiles … button to select profile number 7. By clicking on the line, enter the final thalweg elevation at cross section 200 for profile 7:

   _____

3. Now click on the Table tab and provide the final thalweg elevation at cross section 200, profile 7, to four significant digits (just because we can):

   _____

4. How much degradation occurs at cross section 200 for profile 7? (hint: change Variables … from "Ch Invert El" to "Invert Change")

   _____

5. Which cross section degraded the most and to what depth?

   _____

6. How much scour occurs at cross section 400 after the third hour? (hint: turn on profile 4 and the "Invert Change" variable)

   _____

7. From the main HEC-RAS window, select "Sediment Time Series Plot…" from the View menu.

8. Based on the results of this simulation, what shear stress (rounded up to the nearest 0.01 lbs/ft^2) would you select for designing erosion countermeasures? (hint: change Variables ... to shear stress and view the chart and/or table for each cross section; watch out for boundary condition effects)

_____

9. Which cross section has its minimum velocity occur at hour 1, and what is that velocity? (hint: change Variables ... to velocity and view the chart and/or table for each cross section)

_____

_____

End of Workshop

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HEC-RAS Sediment Transport Modeling

By WEST Consultants, Inc.

SEDIMENT PROPERTIES

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Outline

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- Physical Characteristics of Sediment
  - Size
  - Shape
  - Unit Weight
  - Fall Velocity
- Initiation of Motion
- Sediment in Motion

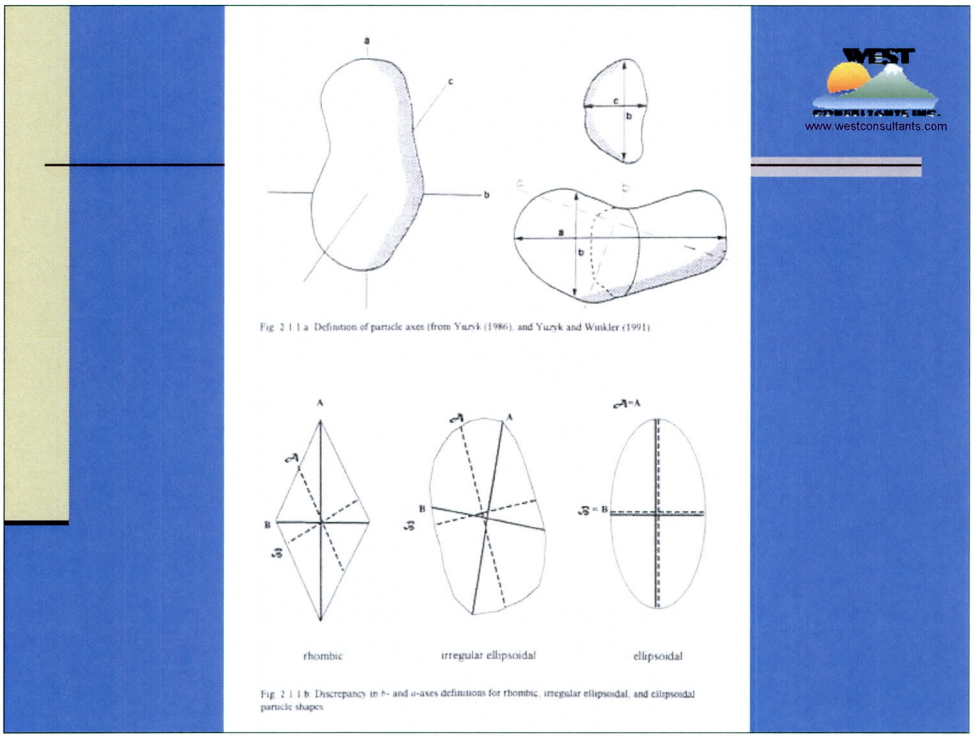

Figure Courtesy USGS

Size Classifications (AGU)

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Class Name	Millimeters
Boulders	>256
Cobbles	256 - 64
Very Coarse Gravel	64 – 32
Coarse Gravel	32 – 16
Medium Gravel	16 -8
Fine Gravel	8 – 4
Very Fine Gravel	4 -2

Class Name	Millimeters
Very Coarse Sand	2 -1
Coarse Sand	1 – 0.5
Medium Sand	0.5 – 0.25
Fine Sand	0.25 – 0.125
Very Fine Sand	0.125 – 0.0625
Silts	0.0625 – 0.004
Clays	0.004 – 0.00024

Sediment Size

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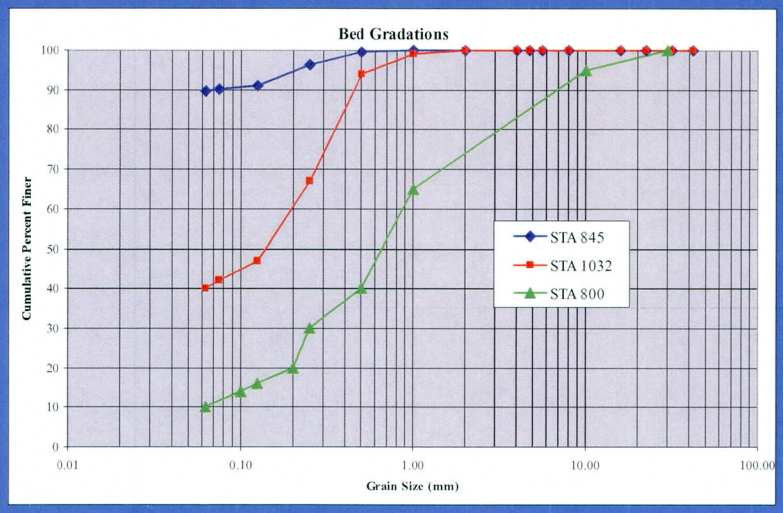

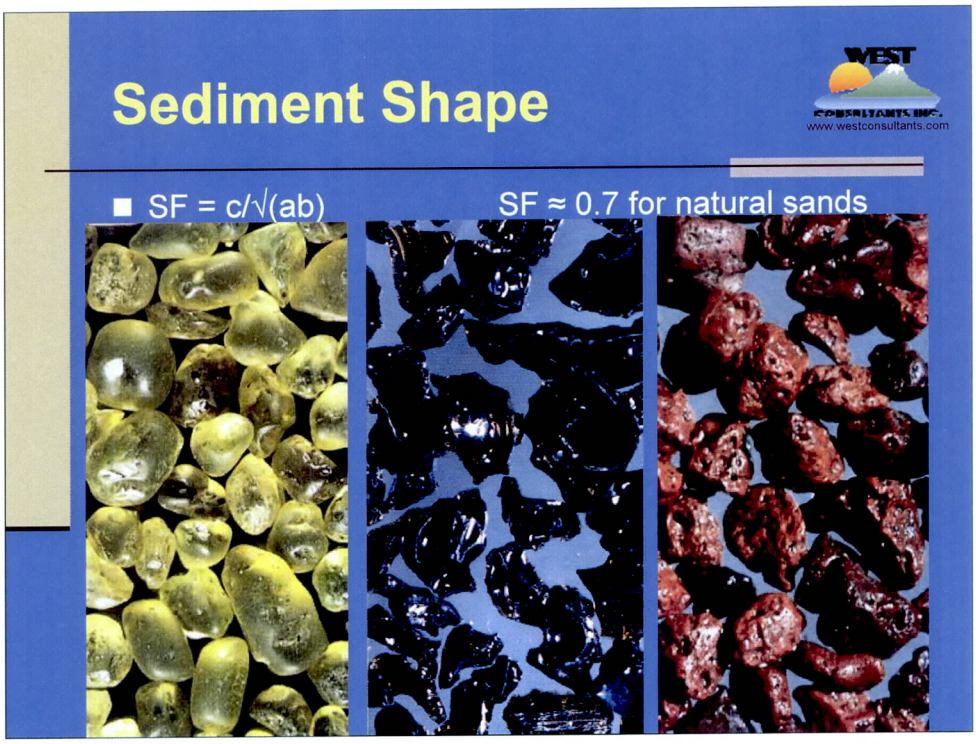

Photographs courtesy USGS

Sediment Unit Weight

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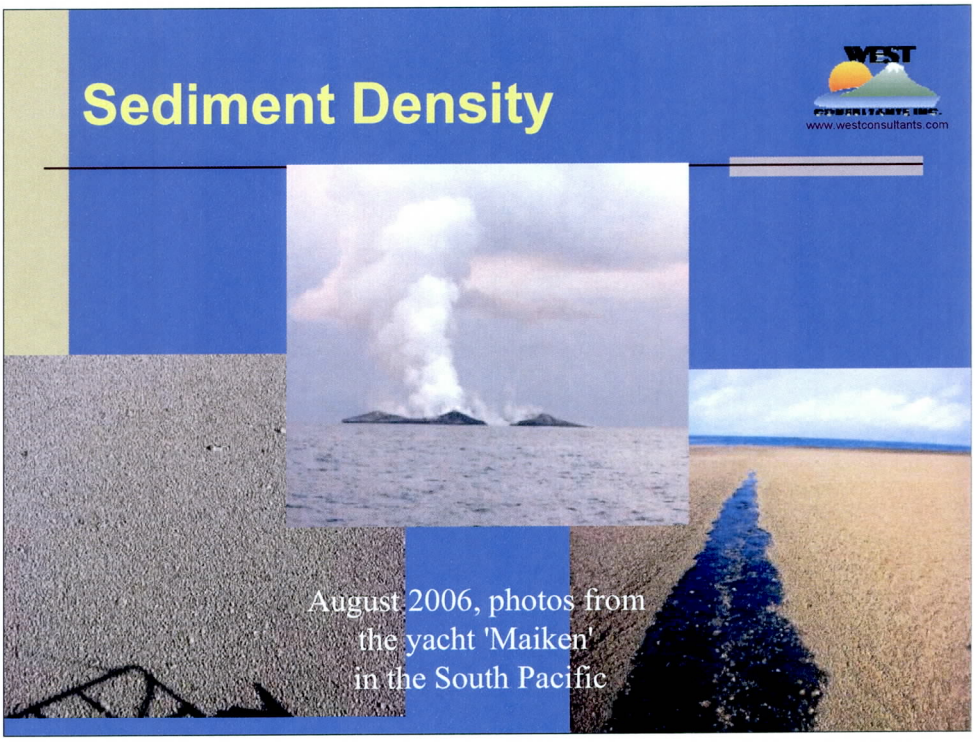
- Density (mass per unit volume).
  - wood <1
  - water 1.0 (pure, 4° C)
  - coal 0.9-1.4
  - quartz & feldspar ~**2.65** (prevalent minerals in nature)
  - magnetite 5.0+
  - iron 7.9
  - silver 10.5
  - lead 11.4
  - mercury 13.5
  - gold 19.3



Courtesy USGS

Sediment Fall Velocity

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- Necessary to determine how quickly sediment will settle
- Fall Velocity (ω) depends on
  - Size
  - Unit weight
  - Shape Factor (Drag)
  - Water Temperature (Viscosity)
  - Concentration (Interference)
  - Turbulence
  - Cohesiveness (Flocculation)

Sediment Fall Velocity

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- Standard Fall Velocity
  - Average rate of fall that the particle would obtain if falling alone in quiescent distilled water of infinite extent at 24° C.
- Standard Fall Diameter
  - Diameter of a sphere that has the same specific weight and the same standard fall velocity as the given particle

Sediment Fall Velocity

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- Stokes Law (1851, Re < 0.1)

$$\omega = \frac{gd^2}{18\upsilon}\left(\frac{\gamma_s - \gamma}{\gamma}\right)$$

- Rubey (1933)

$$\omega = F_1\sqrt{gd_s\left(\frac{\gamma_s - \gamma}{\gamma}\right)}$$

Here are two popular ones, there are many more

Initiation of Motion

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- Particles on the bed assumed to move when critical shear stress (τ_c) has been reached.

$$\tau = \gamma R S \geq \tau_c$$

- Most data from laboratory flumes; in reality
  - motion of sediment grains is highly unsteady
  - nonuniformly distributed over the bed area.
    - This suggests that process is statistical in nature (Einstein was the first to develop a transport relation based on statistical concepts).

Initiation of Motion

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- Disagreement by researchers as to when critical conditions exist, but reasonable agreement among published results.
- The inclusion of a critical shear stress below which no transport will occur is found in many sediment transport formulas.
- One of the most common figures referenced for critical conditions is that of Shields (usually with the data by White included, as shown below).

Initiation of Motion

- For a large boundary Reynold's number, the critical shear stress is nearly constant at 0.06.

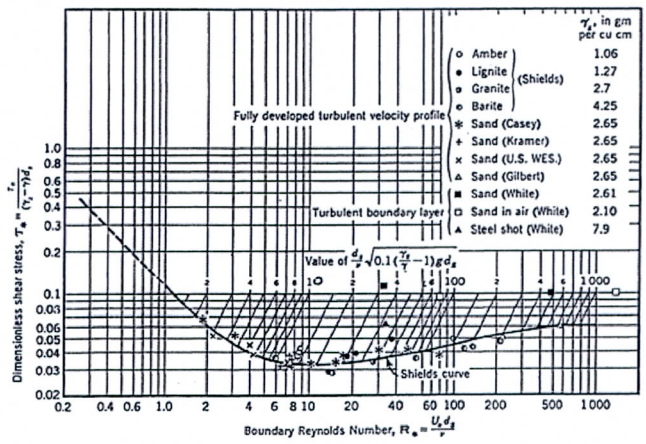

FIG. 2.43.—Shields Diagram with White Data Added

Sediment Load

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Transport Mechanism	Sediment Source	Measurement Method
Suspended Load	Wash Load	Measured Load
	Bed Material Load	
Bed Load		Unmeasured Load

When discussing the Sediment Load it is vital to be clear about which component of the load is being dealt with.

Sediment Load

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A. Distinction on basis of mode of transport:

1. Bed load: particles that roll and slide along bed, or move by short jumps (saltation).
2. Suspended load: particles supported above bed by turbulence, and transported at about the local flow velocity.

B. Distinction based on particle size:

1. Bed material load: particles found in appreciable quantities in bed material that is actively moving.
2. Wash load: finer material found in small quantities on bed. Transport rate depends on rate of supply of material to stream (usually finer than 0.062 mm).

Sediment Load

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C. Distinction based on measuring technique:

1. Measured sediment discharge = (meas. conc. of sediment) x (water discharge)˜ suspended-load discharge. Can't measure all load due to physical size of samplers.

2. Unmeasured-load discharge = total-load discharge - measured load dischargẽbed-load discharge.

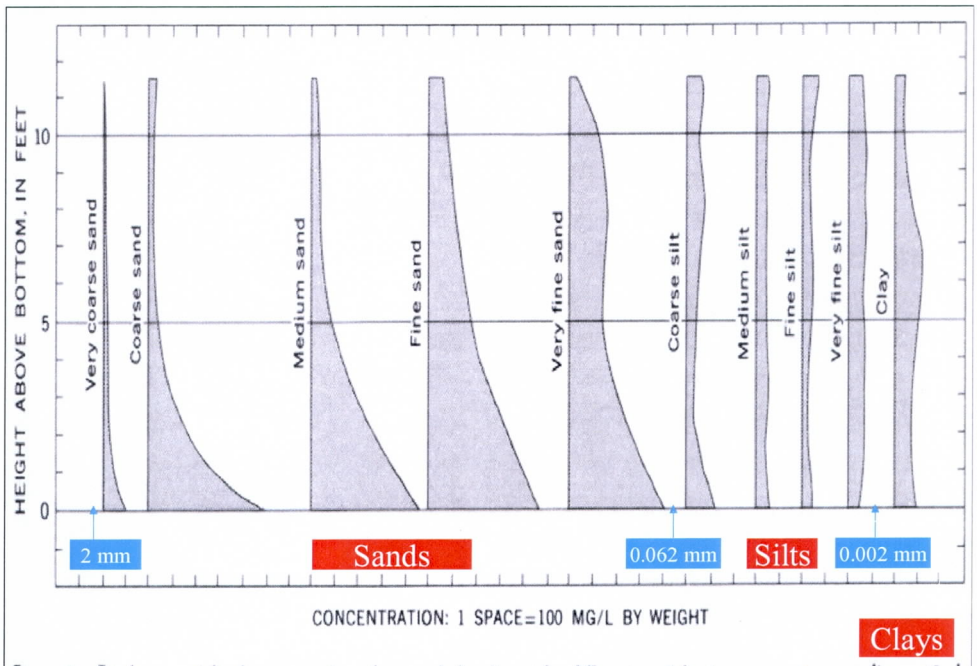
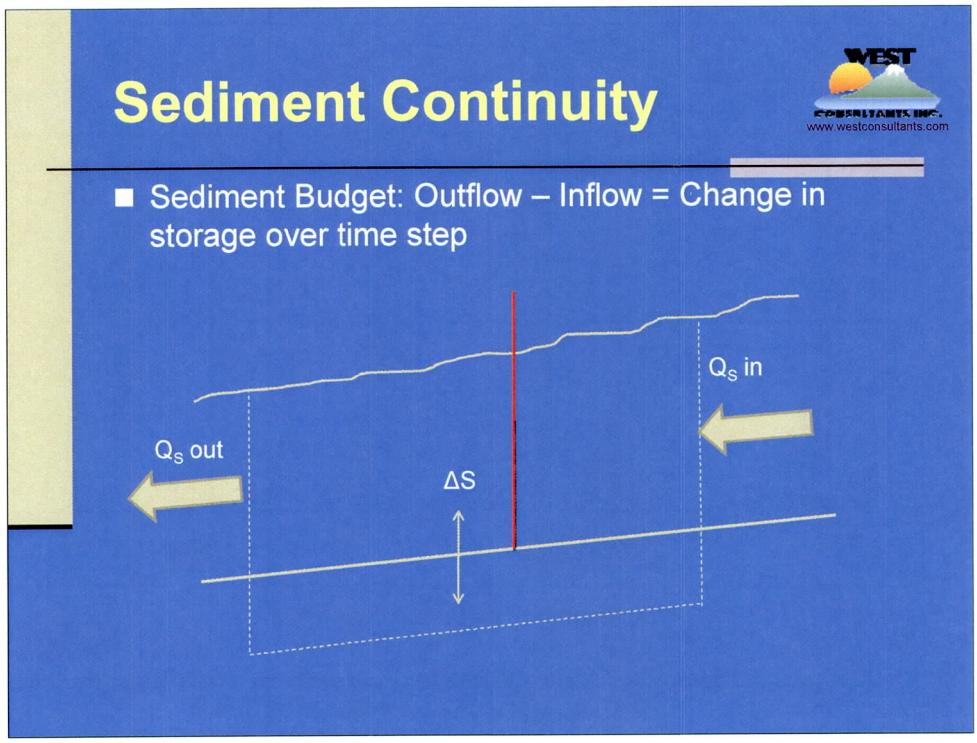
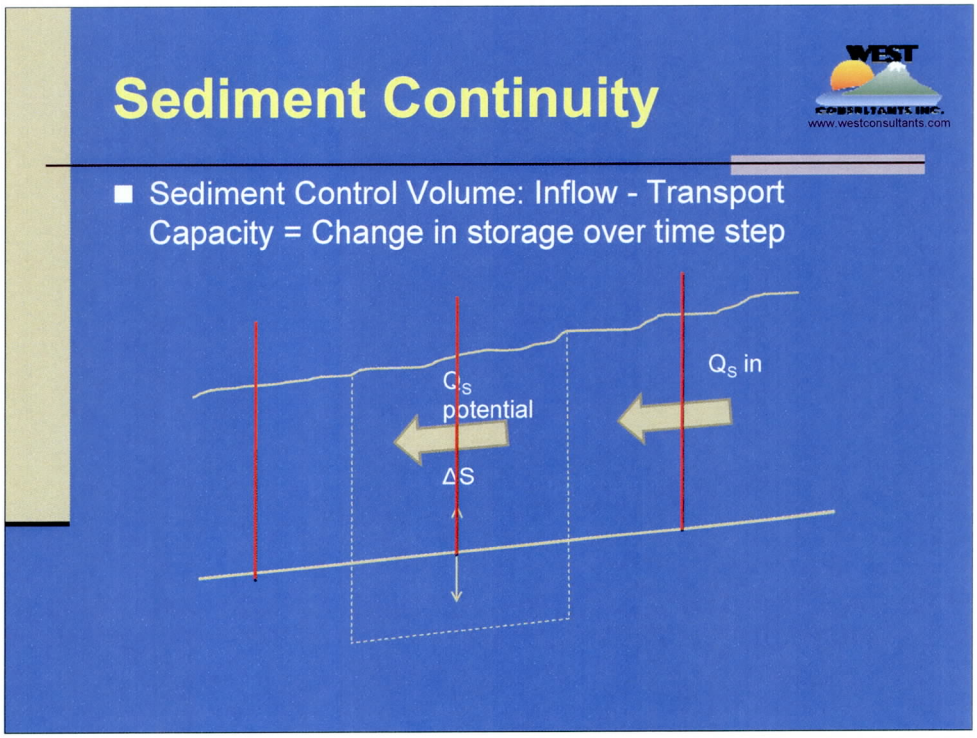


Figure 7.—Discharge-weighted concentration of suspended sediment for different particle-size groups at a sampling vertical in the Missouri River at Kansas City, Mo.

Figure Courtesy USGS



Qs out based on hydraulics from a single cross section or ensemble average to represent the whole reach for quick calculations, generally no adjusting geometry and recomputing hydraulics with time. NOT what HEC-RAS does for detailed sediment transport.



If Qsin > Qs potential, then aggradation

If Qsin = Qs potential, then no change

If Qsin < Qs potential, then erosion AS LONG AS - no armoring

- no hard bottom

Model attempts to transport up to capacity if possible

HEC-RAS, Sediment Transport Modeling

By WEST Consultants, Inc.

SELECTION OF SEDIMENT TRANSPORT RELATIONS

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Problem Statement

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Need to relate sediment transport capacity to sediment and hydraulic characteristics –

Which Sediment Transport Relation/Formula(s) should we use?

- HEC-6 has 11 formulas + user defined
- HEC-6T has all these plus a few others
- HEC-RAS has 7 (so far)
- Which one(s) are best????

SEDIMENT TRANSPORT

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$$Q_T = F(u, \rho, \rho_s, g, D_{50}, \sigma, \mu, \pi, d, b)$$

Q = Discharge

Q_T = Sediment Transport Rate

π = Manning Coefficient

d = Mean Flow Depth

b = Mean Flow Width

D_{50} = Particle Diameter

u = Mean Flow Velocity

σ_s = Geometrical Standard Deviation of Bed Material

μ = Dynamic Viscosity Coefficient

ρ = Density of Fluid

ρ_s = Density of Sediment

g = Acceleration of Gravity

General

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- Different functions can give widely varying results
  - Developed under different sets of field and laboratory data
- Best to have measured data to compare/calibrate
  - Often this is not available

General

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- Most relations predict rate of sediment transport using steady-state hydraulic and bed material information as input
  - Hydraulic variables often laterally averaged to some extent

General (cont'd)

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- Some general differences between formulae:
  - Bed load versus bed material load (coming up!)
    - Critical for sand bed streams – big suspended load
  - Single grain size versus multiple grain sizes
    - Single (usually median) better for equilibrium conditions
    - Multi-size better for non-equilibrium conditions, but sensitive to overall gradation, especially fines
      - Einstein recommended ignoring finest 10% of bed material sample
    - Careful when using single grain size relation for each size class
      - Assumes each class acts independently

Size Classifications (AGU)

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Class Name	Millimeters
Boulders	>256
Cobbles	256 - 64
Very Coarse Gravel	64 – 32
Coarse Gravel	32 – 16
Medium Gravel	16 -8
Fine Gravel	8 – 4
Very Fine Gravel	4 -2

Class Name	Millimeters
Very Coarse Sand	2 -1
Coarse Sand	1 – 0.5
Medium Sand	0.5 – 0.25
Fine Sand	0.25 – 0.125
Very Fine Sand	0.125 – 0.0625
Silts	0.0625 – 0.004
Clays	0.004 – 0.00024

Selection of a Function

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Traditional Approach:

- Collect field data
  - Different flow events
  - Suspended and bed material transport
  - Bed material gradations
- Test different functions, pick one that best matches field measurements

Selection of a Function

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Problems with Traditional Approach:

- Field data are limited in time and/or space or are non-existent
- We may be required to simulate future conditions where sediment regime (transport, propoerties, etc.) may change, for example
  - Impoundment
  - Channel Straightening

Selection of a Function

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Commonly Assumed that a function that performs well against measured data will also be a good predictor for ungaged streams with similar characteristics:

- Velocity
- Slope
- Depth
- Width
- D50
- Washload
- Bedforms
- Turbulent Intensity
- Armoring

Options Available to Select a Function

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1. List important variables for your project and compare directly with ranges from literature for each function

2. Use a computer program such as HEC-RAS or SAM to help in the comparison
   a. SAM.aid compares parameters with Brownlie's database, recommends three best functions

Options Available to Select a Function

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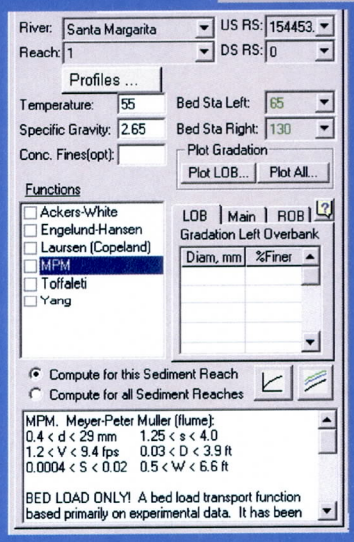
b. Sediment Transport Capacity Hydraulic Design Function in HEC-RAS

3. Use guidelines from Shen, Yang, and others (coming up!)
4. Used procedure by Williams and Julien (Sand Bed Streams Only!)
5. Use equations shown to be accurate on a regional basis.

One equation may not work best for all flows!



Total Load

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Table 7-2
Explanation of Total Load

Mode of Transport	Availability in Streambed	Method of Measurement
Suspended	Wash	Measured
	Bed Material	
Bed		Unmeasured

Sediment Transport Formulas

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- Bed Load + Suspended Load = Total Load
- Only Cohesionless Sediment Examined Here (separate algorithms for cohesive sediment available in HEC-6/6T)
- Can divide by derivation into 4 groups

1) Critical Shear (τ - τ_c) (MPM)
2) Probabilistic Arguments (Einstein)
3) Work/Stream Power (Yang)
4) Optimization of observed data (Ackers-White)

Sediment Transport Formulas

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Most formulas can be reduced to φ = f(θ) where

$$\phi = \frac{q_S}{[(S_s - 1)gd^3]^{1/2}}$$

$$\theta = \frac{\tau_o}{\rho g(S_s - 1)d} = Shields\ Parameter$$

q_s = material transport by volume per unit width
S_s = Specific Gravity of the sediment
d = representative grain size

Functions in RAS (4.0β)

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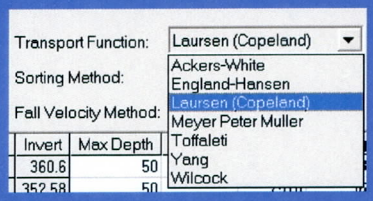
- Ackers - White (1973)
- Engelund - Hansen (1977)
- Laursen (Copeland) (1968, 1989)
- Meyer-Peter – Muller (1948)
- Toffaleti (1968)
- Yang (1973, 1984)
- Wilcock (2001)
- Parker is coming (FY09?)



- Krone – Partheniades for fine sediments under development (Feb 08)

Which One?

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Table 12-8 Range of input values for sediment transport functions (Sam User's Manual, 1998) HEC-RAS Hydraulic Reference Manual

Function	d	d_m	s	V	D	S	W	T
Ackers-White (*flume*)	0.04 - 7.0	NA	1.0 - 2.7	0.07 - 7.1	0.01 - 1.4	0.00006 - 0.037	0.23 - 4.0	46 - 89
Englund-Hansen (*flume*)	NA	0.19 - 0.93	NA	0.65 – 6.34	0.19 – 1.33	0.000055 – 0.019	NA	45 - 93
Laursen (*field*)	NA	0.08– 0.7	NA	0.068 – 7.8	0.67 – 54	0.0000021 – 0.0018	63 – 3640	32 - 93
Laursen (*flume*)	NA	0.011 - 29	NA	0.7 - 9.4	0.03 – 3.6	0.00025 – 0.025	0.25 – 6.6	46 - 83
Meyer-Peter Muller (*flume*)	0.4 – 29	NA	1.25 – 4.0	1.2 – 9.4	0.03 – 3.9	0.0004 – 0.02	0.5 – 6.6	NA
Tofaletti (*field*)	0.062 – 4.0	0.095 – 0.76	NA	0.7 - 7.8	0.07 – 56.7 (R)	0.000002 – 0.0011	63 - 3640	32 – 93
Tofaletti (*flume*)	0.062 – 4.0	0.45 – 0.91	NA	0.7 - 6.3	0.07 – 1.1 (R)	0.00014 – 0.019	0.8 – 8	40 - 93
Yang (*field-sand*)	0.15 – 1.7	NA	NA	0.8 - 6.4	0.04 – 50	0.000043 – 0.028	0.44 – 1750	32 - 94
Yang (*field-gravel*)	2.5 – 7.0	NA	NA	1.4 - 5.1	0.08 – 0.72	0.0012 – 0.029	0.44 – 1750	32 - 94

d=overall diameter (mm), d_m=median diameter (mm), s=sediment specific gravity, V=avg. channel velocity (ft/s), D=channel depth (ft), S=energy gradient, W=channel width (ft), T=water temperature (°F), (R)=hydraulic radius (ft), NA= data not available

Ackers-White

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- Designed to calculate the TOTAL sediment load, i.e., the bedload and suspended bed material sediment load combined.
- Calibration accomplished using 925 sets of data from 14 investigators. Based on flume data.
- Determines the rate of transport in terms of three dimensionless parameters: size, mobility, and transport.

$$G_{gr} = f\,(F_{gr}, D_{gr})$$

Where: G_{gr} = dimensionless sediment transport rate
F_{gr} = sediment mobility number
D_{gr} = dimensionless sediment size

Ackers-White

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- Suspended load $\propto$ shear velocity, Bedload $\propto$ mean flow velocity
- Hiding function by Proffit and Sutherland (1983) included as an option in RAS
  - Shielding of smaller particles by larger ones tends to decrease transport rate
- Ackers-White performs best for sand bed streams where gradients and velocities are not excessive.

Ackers-White

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$$X = \frac{G_{gr} s d_s}{D\left(\frac{u_*}{V}\right)^n} \quad \text{and} \quad G_{gr} = C\left(\frac{F_{gr}}{A} - 1\right)$$

Where: X = Sediment concentration, in parts per part

G_{gr} = Sediment transport parameter

s = Specific gravity of sediments

d_s = Mean particle diameter

D = Effective depth

u_* = Shear velocity

V = Average channel velocity

n = Transition exponent, depending on sediment size

C = Coefficient

F_{gr} = Sediment mobility parameter

A = Critical sediment mobility parameter

Engelund-Hansen

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- TOTAL load formula
- Best for sandy rivers with significant suspended load
- Based on flume data
- Simple to apply, well-tested

$$g_s = 0.05\gamma_s V^2 \sqrt{\frac{d_{50}}{g\left(\frac{\gamma_s}{\gamma}-1\right)}}\left[\frac{\tau_o}{(\gamma_s-\gamma)d_{50}}\right]^{3/2}$$

Where: g_s = Unit sediment transport

γ = Unit wt of water

γ_s = Unit wt of solid particles

V = Average channel velocity

τ_o = Bed level shear stress

d_{50} = Particle size of which 50% is smaller

Laursen (Copeland)

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- TOTAL load predictor
- Derived based on qualitative analysis, experiments, and other data
- Laursen's formulation extended by Copeland to gravel sizes (0.011 to 29 mm).

$$C_m = 0.01\gamma\left(\frac{d_s}{D}\right)^{7/6}\left(\frac{\tau_o'}{\tau_c} - 1\right) f\left(\frac{u_*}{\omega}\right)$$

Where: C_m = Sediment discharge concentration, in weight/volume

G = Unit weight of water

d_s = Mean particle diameter

D = Effective depth of flow

τ_o' = Bed shear stress due to grain resistance

τ_c = Critical bed shear stress

$f\left(\frac{u_*}{\omega}\right)$ = Function of the ratio of shear velocity to fall velocity as defined in Laursen's Figure 14 (Laursen, 1958).

$g_s = C_m * q$

Laursen (Copeland)

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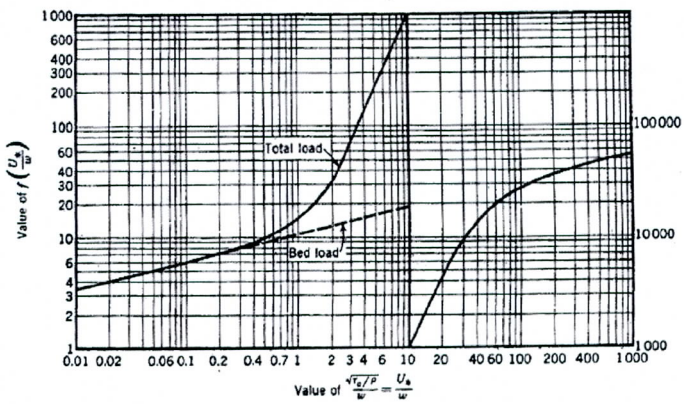

FIG. 2.103.—Function $f(U_*/w)$ for Laursen Formula, Eq. 2.231a

Meyer-Peter & Muller

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- BEDLOAD Formula
- Based on data from experiments in flumes
  - slopes varying from 0.004-0.02
  - water depths from 1 cm-120 cm
  - mean sediment sizes from 0.4 mm-30 mm (medium sand to coarse gravel)
  - little or no suspended loads

$$\left(\frac{k_r}{k_r'}\right)^{3/2} \gamma RS = 0.047(\gamma_s - \gamma)d_m + 0.25\left(\frac{\gamma}{g}\right)^{1/3}\left(\frac{\gamma_s - \gamma}{\gamma_s}\right)^{2/3} g_s^{2/3}$$

Where: g_s = Unit sediment transport rate in weight/time/unit width
k_r = A roughness coefficient
k_r' = A roughness coefficient based on grains
γ = Unit weight of water
γ_s = Unit weight of the sediment

g = Acceleration of gravity
d_m = Median particle diameter
R = Hydraulic radius
S = Energy gradient

Meyer-Peter & Muller

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- k_r/k'_r varies between 1.0 (no bedforms) to 0.5 (strong bedforms).
- Can reduce the formula to

$$\varphi = 8(\theta - 0.047)^{3/2}$$

- The volumetric bedload fluxes per unit width calculated from the equation are integrated across the channel width for each discharge to yield the total mass of bedload discharge as a function of flow discharge.

Toffaleti

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- TOTAL load predictor
- Based on data from 7 "large" rivers and flume expts.
- Four zones defined in a vertical section to represent bed load and three zones of suspended load approximating "Rousian" distribution

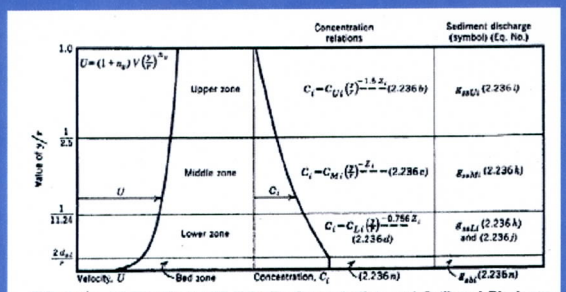

FIG. 2.108.—Toffaleti's (1969) Velocity, Concentration, and Sediment Discharge Relations

Toffaleti

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$$g_{ssL} = M \frac{\left(\frac{R}{11.24}\right)^{1+n_v-0.756z} - (2d_m)^{1+n_v-0.756z}}{1+n_v-0.756z} \quad \text{(lower zone)}$$

$$g_{ssM} = M \frac{\left(\frac{R}{11.24}\right)^{0.244z}\left[\left(\frac{R}{2.5}\right)^{1+n_v-z} - \left(\frac{R}{11.24}\right)^{1+n_v-z}\right]}{1+n_v-z} \quad \text{(middle zone)}$$

$$g_{ssU} = M \frac{\left(\frac{R}{11.24}\right)^{0.244z}\left(\frac{R}{2.5}\right)^{0.5z}\left[R^{1+n_v-1.5z} - \left(\frac{R}{2.5}\right)^{1+n_v-1.5z}\right]}{1+n_v-1.5z} \quad \text{(upper zone)}$$

$$g_{sb} = M(2d_m)^{1+n_v-0.756z} \quad \text{(bed zone)}$$

$$M = 43.2C_L(1+n_v)WR^{0.756z-n_v}$$

$$g_s = g_{ssL} + g_{ssM} + g_{ssU} + g_{sb}$$

Where: g_{ssL} = Suspended sediment transport in the lower zone, in tons/day/ft

g_{ssM} = Suspended sediment transport in the middle zone, in tons/day/ft

g_{ssU} = Suspended sediment transport in the upper zone, in tons/day/ft

g_{sb} = Bed load sediment transport in tons/day/ft

g_s = Total sediment transport in tons/day/ft

M = Sediment concentration parameter

C_L = Sediment concentration in the lower zone

R = Hydraulic radius

d_m = Median particle diameter

z = Exponent describing the relationship between the sediment and hydraulic characteristics

n_v = Temperature exponent

Yang

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- TOTAL load equation
- Streampower (V*S) dominant factor in sediment concentrations
- Developed from field and flume data

Sands

$$\log C_t = 5.435 - 0.286\log\frac{\omega d_m}{\nu} - 0.457\log\frac{u_*}{\omega} + \left(1.799 - 0.409\log\frac{\omega d_m}{\nu} - 0.314\log\frac{u_*}{\omega}\right)\log\left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega}\right)$$

Gravels

$$\log C_t = 6.681 - 0.633\log\frac{\omega d_m}{\nu} - 4.816\log\frac{u_*}{\omega} + \left(2.784 - 0.305\log\frac{\omega d_m}{\nu} - 0.282\log\frac{u_*}{\omega}\right)\log\left(\frac{VS}{\omega} - \frac{V_{cr}S}{\omega}\right)$$

Where: C_t = Total sediment concentration
ω = Particle fall velocity
d_m = Median particle diameter
ν = Kinematic viscosity
u^* = Shear velocity
V = Average channel velocity
S = Energy gradient

Wilcock

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- BEDLOAD transport equation
- Newest equation implemented in RAS
- Variation of Parker's surface-based transport equation
- Based on field measurements and one flume study
- Adjusts critical shear stress with sand coverage of the bed
- Bed material characterized by surface measurements, not bulk samples

A Short List of Sediment Transport Relations

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AUTHOR(S)	DATE	TYPE #	REQUIRED QUANTITIES	BED-LOAD DISCHARGE ONLY	BED-AND SUSPENDED-LOAD DISCHARGES	TOTAL LOAD DISCH. ONLY	SED. DIS.BY SIZE FRACTION	NO. OF FLOWS USED IN QUANTIFICATION	RANGE OF SEDIMENT SIZE (MM)
DUBOYS	1879	BS	τ_0, T_C, D_{50}	x				GILBERT EXPTS.	.1-4.0
SCHOKLITSCH	1934	V_q	q, S, P_1, D_1	x			X	GILBERT EXPTS.	.3-5.0
MEYER-PETER	1934	V_q	q, S, D_{50}	x				NA	3.1-28.6
SHIELDS	1936	BS	$q, S, \tau_0, T_C, D_{50}$	x				NA	1.5-2.5
KALINSKE	1942	P_b	τ_0, T_C, D_{50}	x				40	NA
MEYER-PETER AND MUELLER	1948	Vq	$r_b, V, S, D_{50}, 1_b$	X				NA	.4-30.0
EINSTEIN-BROWN	1950	BS	τ_0, D_{50}, v	X				315	.3-28.6
EINSTEIN (BED LOAD FUNCION)	1950	P_b, BS	$rb, V, S, D_{25}, D_{65}, P_1, D_1, W_1, v$		X		X	-100	.78.26.6
BAGHOLD	1956	E	τ_0, V, D_{50}	X				NA	NA
LAURSEN	1958	BS	$d, V, S, D_{50}, P_1, w_1, D_1, \tau, ci$			X	X	NA	.27-86
COLBY	1964	V	d, V, D_{50}, T, C_1			X		NA	.10-.30
BISHOP, SIMONS, AND RICHARDSON	1965	BS	r_b, S, D_{50}, D_{25}			X		NA	.19-.93
BAGHOLD	1966	E	τ_0, V, D_{50}, w		X			NA	.03-1.0
BLENCH	1966	R	q, S, D_{50}, b, k, m^v			X		GILBERT EXPTS.	.30-7.0

(CONTINUED)

A Short List of Sediment Transport Relations

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AUTHOR(S)	DATE	TYPE #	REQUIRED QUANTITIES	BED-LOAD DISCHARGE ONLY	BED-AND SUSPENDED-LOAD DISCHARGES	TOTAL LOAD DISCH. ONLY	SED. DIS.BY SIZE FRACTION	NO. OF FLOWS USED IN QUANTIFICATION	RANGE OF SEDIMENT SIZE (MM)
ENGELUND AND HANSEN	1967	BS, V	d, V, S, D_{50},			x		-96	.19-.93
INGLIS-LACEY	1968	V	d, V, v, w			x		IRRIGATION CANALS	NA
TOFFALETI	1969	S_m	$r, V, S, T, P_1, D_1, w_1, v, D_{65}$		x		x	621	.30-.93
SHEN AND HUNG	1971	Rg	V, S, w			x		587	NA
YANG	1973	E, Rg	d, V, S, D_{50}, w, v			x		463	NA
ACKERS AND WHITE	1973	Sm, Rg	d, V, S, D_{35}, v			x		925	NA
ENGELUND AND FREDSOE	1976	Sm, Bs	d, V, S, D_{50}, w_s, B		x			-57	.19-7.76
I HR-1 (KARIN AND KENNEDY)	1981	Sm, Rg	q, S, D_{50}, v		x		x	615	.14-28.6
I HR-2 (KARIN AND KENNEDY)	1981	Sm, Rg	q, S, D_{50}, v			x	x	615	.14-28.6
BROWNLIE	1981	Rg	$d, V, S, D_{50}, \sigma g^v$			x		999	.062-1.4
VAN RIJN	1982	Sm, Rg	$d, V, D_{50}, D_{90}, v, r_b, w$		x			730	.09-.56
LAURSEN (MADDEN)	1985		$d, V, S, D_{50}, P_1, w_1, D_1, \tau_c$ ci			x	x		
LAURSEN (COPELAND)	1988		$d, V, S, D_{50}, P_1, w_1, D_1, \tau_c$ ci			x	x		

#BS=BED SHEAR; Vq = VELOCITY AND/OR DISCHARGE; Pb = STOCHASTIC/STATISTICAL Sm = SIMULATION AND/OR THEORETICAL; Rg = REGRESSION WITH DIMENSIONAL DIMENSIONAL ANALYSIS; E = ENERGY; R = REGIME THEORY

(CONCLUDED)

Selection Procedure Suggested by Shen

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IF FIELD DATA IS AVAILABLE:

- Use the Modified Einstein Method to estimate the unmeasured suspended load and bedload based on measured data.
- There is a question of whether Einstein's intensity of bedload transport should be arbitrarily divided by a factor of two.

Selection Procedure Suggested by Shen

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IF FIELD DATA IS AVAILABLE:

- Separate bed material load from washload and analyze them separately.
- Decide which available sediment transport equations best agree with the measured data and use them to estimate the sediment transport load for the design flow, where actual measurement is not available.

Selection Procedure Suggested by Shen

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WHEN NO MEASURED DATA IS AVAILABLE:

- Use Einstein's procedure if bedload is a significant portion of the total bed material load. Otherwise see below.
- Use Colby's method for rivers with flow depth less than or about 10 feet.
- Use Toffaleti's method for large rivers.
- Use Shen and Hung method for flume data and small rivers.

Yang's Suggestions when No Measured Data

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- Use Meyer-Peter and Muller's formula when the bed material is coarser than 5mm.
- Use Yang's sand formula for sand bed laboratory flumes and natural rivers with washload excluded. Use Yang's gravel formula for gravel transportation when the bed material is between 2 and 10mm.

Yang's Suggestions when No Measured Data

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- Use Ackers and White, or Engelund and Hansen's equation for subcritical flow condition in the lower flow regime.
- Use Laursen's formula for laboratory flumes and shallow rivers with fine sand or coarse silt.
- A regime or regression equation can be applied to a river only if the flow and sediment conditions are similar to that from which the equation was derived.

Which is Best?

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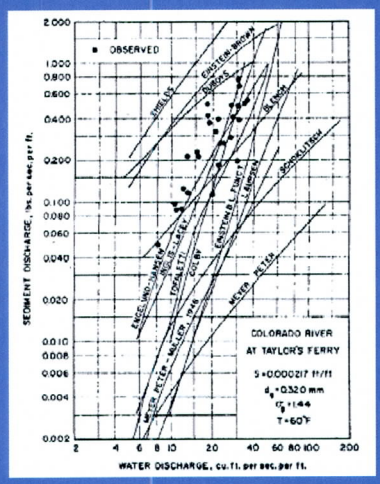

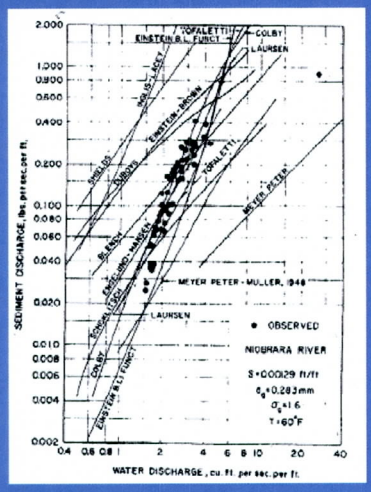

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HEC-6/6T, Sediment Transport Modeling

By WEST Consultants, Inc.

CONDUCTING A SEDIMENT TRANSPORT STUDY: GENERAL SEQUENCE OF STEPS

Adapted from COE EM 1110-2-4000, Chapter 4

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Steps for a **General** Study

1. River Geomorphology

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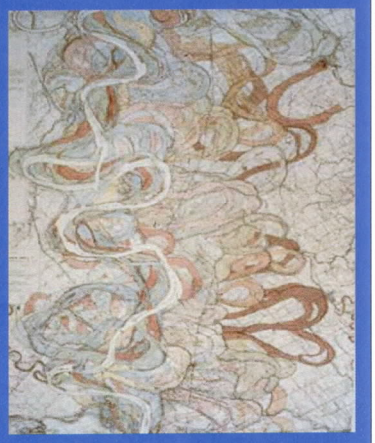
A. Assemble data from all sources.

B. Carefully assess the historical stability of the stream system within the project reach, and look both at approach and exit reaches to the project reach.

C. The period of time of interest is the most recent 20-30 years.



2. Field Reconnaissance

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A. More detailed information on how to conduct a field reconnaissance is presented in another lecture.

B. The study reach should be inspected to determine if it is stable under current conditions. It if is not, a more complete investigation will be needed, and the Sediment Impact Assessment should recommend what level of detail is appropriate.

3. Hydraulic Parameters for Existing Conditions

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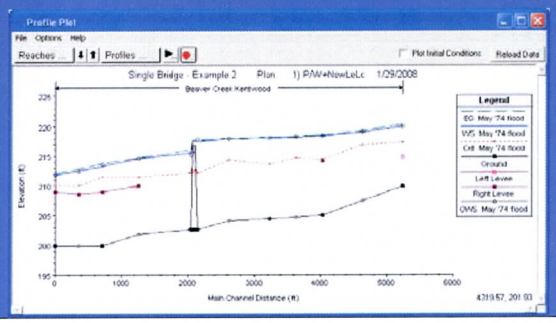
A. Should be obtained from field measurements taken at a standard discharge range.
   - Water velocities, discharges, and water surface elevations needed to confirm the hydraulic calculations.
   - If that source not available, use the measurements made on the field reconnaissance to support the hydraulic calculations.



3. Hydraulic Parameters for Existing Conditions

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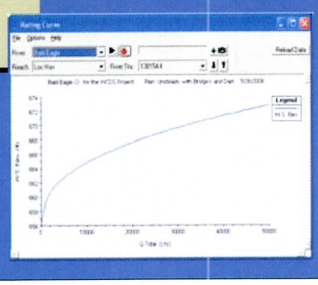
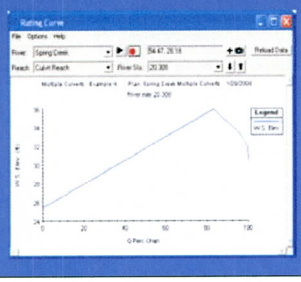
B. In either case the following graphs for the project reach are suggested:

- stage-discharge
- depth-velocity
- depth-slope
- depth-bed shear stress
- depth-percent of total flow in the channel





3. Hydraulic Parameters for Existing Conditions

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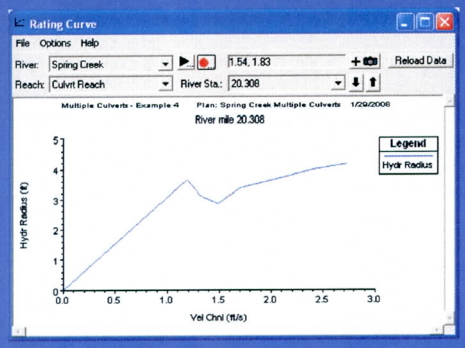
C. Bed roughness.

Use a "bed roughness predictor" to tie the hydraulics to the bed sediment samples taken during the field reconnaissance trip.

Composite this n-value with other roughnesses in the cross section.



Plot a graph of channel velocity vs. hydraulic radius for the range of water discharges through the project design flood discharge.

3. Hydraulic Parameters for Existing Conditions

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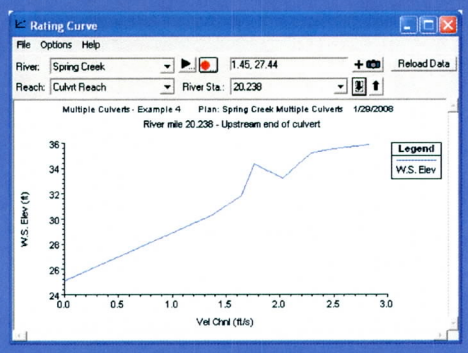
D. Flow distribution between channel and overbanks.

Plot the channel velocity for the full range of water discharges. Should see velocities increasing with depth. If decrease with increasing depth, either justify trend or correct n-values between the main channel and overbanks

Use channel velocity from the bed roughness predictor as an aid in calibrating the distribution between channel and overbanks.



3. Hydraulic Parameters for Existing Conditions

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E. Sensitivity to geometry.

If channel characteristics are so varied that one curve is not representative of the project reach, use RAS to calculate the hydraulic parameters. Make two runs: One with best estimate of n-values from office files; and one using predicted bed-roughness n-values for the channel bed portion of the cross section.

4. Sediment Transport for Existing Conditions

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If measured data are available, separate the total sediment discharge into bed material load and wash load components.

Otherwise, select several (say two) sediment transport formulas (see lecture on selecting sediment transport methods) and calculate a sediment transport relationship for the full range of water discharges (sediment load curve) on the stage-discharge relationship. That will provide bed material discharge curves for existing conditions.

If the curves are drastically different, apply another transport function and select the most consistent one.

5. Plotting of soil borings

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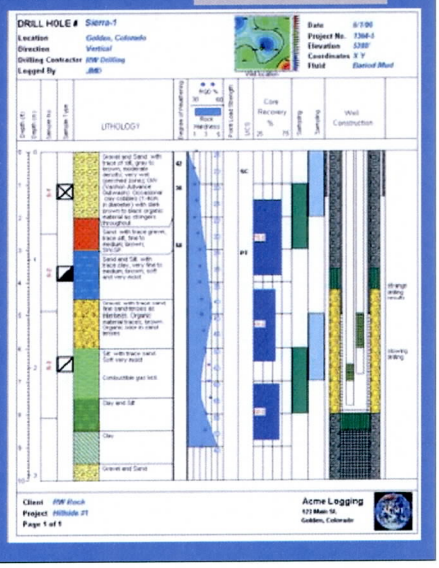
It is very useful to plot the channel boring logs on a channel profile. This allows quick identification of potential problem areas.

It will also allow design channel grades to be set in such a manner that the channel will be imbedded in erosion resistant material, rather than be cut into soils that are easily eroded



6. Develop Proposed Design Features

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"… in erodible materials a river will shape its cross sections in accordance with its flow, slope, bank materials, and alignment, irrespective of its initial cross sections, provided the initial cross sections are not so wide and shallow that the flow does not have sufficient velocities to move sand along the bed and erode the banks. Of practical importance, these test show that in erodible sediments there is not advantage in digging a new channel for a river deeper than is normally found under similar conditions." - Friedkin, 1945

⇒ **If the proposed design cross section is not similar to the regime cross section, sediment problems usually require extensive maintenance to keep the project in operation. This concept is valid for both flood control and navigation channels**

7. Hydraulic Parameters for Project Conditions

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Flow line computations are the only source of this information.

If the channel is prismatic and flow is friction controlled, simple normal depth calculations will be adequate. Otherwise, use a water surface profile program (RAS).

Calculate and plot the same variables as presented for the existing channel. Use the same stage discharge predictor as for the natural channel, but use the bed material gradations at the invert of the proposed channel as well as those from the natural channel and perform a sensitivity study.

8. Preliminary Screening for Sedimentation Problems

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The velocities in the improved channel should not exceed the maximum allowable velocity for the type of material in which the stream is embedded.

If they do, either redesign the channel cross section, include a channel lining, or add design features such as drop structures to flatten the slope.

Improved velocities for low flows should not be so low that deposition will be induced beyond that which occurs under existing conditions

9. Sediment Transport for Project Conditions

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Using the same sediment transport formula, calculate a sediment discharge for the full range of water discharges on the stage-discharge relationship.

Plot the calculated sediment discharges on the graph with existing conditions.

10. Impact of Sedimentation on Proposed Project

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A. General aggradation or degradation.

- Test for general aggradation with a sediment budget analysis.
  - Subtract the sediment yield (based on transport capacity) of the bed material sediment load for project conditions from that for the existing channel.
  - Positive → aggradation is indicated.
  - Negative → check the bed sediment for resistance to erosion.
- The sediment yield is needed for both existing and project conditions.

10. Impact of Sedimentation on Proposed Project

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B. Calculate sediment yield for existing conditions.

- Calculate the average annual sediment yield component and the wash load component.
- Devise a flow-duration curve for the project site, and integrate that with the calculated sediment transport curve for the existing channel.
- The result is average annual yield of bed material sediment.
- Confirm that result with yields determined by other methods and reconcile differences before proceeding.

10. Impact of Sedimentation on Proposed Project

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C. Calculate sediment yield for project conditions.

Use the flow-duration sediment discharge rating curve method and make a sediment yield calculation for project conditions.

D. Calculate the sediment budget.

Subtract the sediment yield for project conditions from the sediment yield for existing conditions.

- Positive = deposition. Using simple geometries and available specific weights, calculate how much time will pass before deposition is sufficiently deep to affect project performance.
- Negative = erosion. Choose design features accordingly.

10. Impact of Sedimentation on Proposed Project

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E. Design flow analysis.

Repeat the sediment budget calculation for the design flow hydrograph also.

F. Local scour.

At this level of study, the approach for estimating local scour potential at bridges and hydraulic structures is to compare this project with similar projects.

G. Bank erosion.

Likewise, the approach for evaluating bank erosion and the need for a protective cover is to compare this project with similar projects.

11. Estimate Long-term Maintenance

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This refers to both local and general scour and deposition in the project reach.

The approach for estimating maintenance to arrest local scour at bridges, hydraulic structures and bank protection sites, is to compare this project with similar, existing projects.

The approach for estimating maintenance for general deposition is to use the sediment budget analysis.

12. Use of Numerical Models

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A numerical sediment model, such as HEC-RAS orHEC-6 will make all those calculations and display the results in a table using as much or as little data as is available. It is not expensive to analyze a few tracer discharges when an HEC-2 or HEC-RAS water surface profile data set exists

13. End Product

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A. Conclude whether the improvements will or will not cause the reach to be unstable.

B. The type and probable locations of design features should be estimated.

13. End Product

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C. If the magnitude of sedimentation problems is important to basic formulation decisions, further study should be recommended.

D. However, if the results of this impact assessment can be changed by a factor of 2 without changing the basic go/no-go decisions about the project, it will probably be acceptable to proceed with formulations, initiate a data collection program, and refine the sedimentation investigation in a detailed sedimentation study.

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Steps for a **Detailed** Study

1. Purposes and General Requirements

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A. The Detailed Sedimentation Study identifies the location and type of project features that will be required to achieve the project purpose with the minimum amount of maintenance.

B. The primary criteria are
   - What is required for the project to function without major sedimentation problems?
   - How will those features affect the stream system?

1. Purposes and General Requirements

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C. The sediment routing is done by particle size using a numerical sediment model.

- Several proven models are available and have been used extensively (HEC-RAS/-6).
- The differences between this application and that presented in the Sediment Impact Assessment are in the breadth and depth of the computations and the amount of data that is available.

D. Flow hydrographs should be used instead of just a few tracer discharges, and the period of simulation should span from a single event to the life of the project.

1. Purposes and General Requirements

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E. Sensitivity runs should be made to test the response of the project to uncertainties in sediment yield, water runoff or downstream controls.

F. These study results will provide a better basis for developing conclusions than other computation techniques can provide.

2. General Steps

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A. Field Reconnaissance.

Another field investigation is recommended to visually verify data collected since the previous one.

B. Data Collection.

Data necessary for the computer program should have been identified and the data collection effort initiated following the Sediment Impact Assessment recommendations. See the HEC-RAS user's manual for specific data requirements.

2. General Steps

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C. Selection of Transport Equation.

The measured sediment data previously collected should be used to select an equation that most closely reproduces the measured data over a wide range of flows. When sufficient data were available, the empirical coefficients in one of the standard transport equations have been calibrated particularly for that study.

2. General Steps

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D. Preparing Data for the Numerical Model.

The data must be organized and input into the computer. One of the largest surprises in sedimentation studies is the amount of time required to manage the large hydrologic data sets, which are required for long-term simulation of a network of streams.

2. General Steps

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E. Confirmation.

Any quantitative analysis should be based on predictive methods that have been confirmed. The confirmation process consists of taking past physical conditions and adjusting the calibration variables until the model will reproduce actual measured changes.

F. Prediction.

Upon completion of the confirmation steps, a prediction of bed aggradation and/or degradation can be made with a reasonable degree of certainty.

2. General Steps

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G. Conclusions.

- The computer output indicates changes in the channel bottom elevation, thereby highlighting potential problem areas.
- While the program prints out specific numbers, the engineer must realize that the numbers can only be used for comparison with each other and represent only the "average" future behavior for the project reach.

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Feature Design
Sedimentation Study

1. Purposes and General Requirements

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A. This type of study is an extension of the Detailed Sedimentation Study to test the final design of the project and relocation features.

B. It is usually conducted at a specific location on a stream where extensive data are available. It includes all of the original data plus all data collected since the Detailed Sedimentation Study was completed.

1. Purposes and General Requirements

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C. Examples:

- depth of both local and general scour at bridges;
- head loss and potential local scour at weirs and drop structures;
- potential deposition in expansions and at inflow points;
- performance of debris basins;
- stability of the channel invert against erosion;
- ability of the approach structure to eliminate head-cuts upstream from the project, local erosion at the approach structure and the changes in tailwater as the result of changes in the exit channel.

2. General Steps

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A. Field Reconnaissance.

A field investigation is necessary to visually verify conditions and data previously collected

B. Confirmation.

At this level of study all hydraulic and sediment parameters will have been confirmed against field data. The process consists of taking past physical conditions and adjusting the input variables to reproduce an actual measured change. After the predictive equation has been confirmed, the process can be verified by applying it to other data sets and verifying the results.

2. General Steps

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C. Prediction.

The major task is to forecast future land use, hydrology loading and sediment loading. The confirmed model can predict future conditions with a reasonable degree of certainty.

CHAPTER 1: Getting Started

THE NUMERICAL FLUME PROBLEM[1]

Introduction

HEC-6/HEC-6T is a one dimensional sedimentation model which includes the hydrologic processes of erosion, entrainment, compaction, transportation and deposition of sediment. Computational modeling of sedimentation is the technology of using the computer to simulate these physical processes. HEC-6T can provide sufficient detail to assist engineers in making decisions about the impact of sedimentation and stream system morphology.

A model such as HEC-6T is not an expert system it is an aid to a person who is trained in river mechanics. It takes the drudgery out of computational details and allows the engineer to focus on understanding the project and the river system.

Certain data requirements must be filled so that HEC-6T will run efficiently and effectively. These data requirements are grouped into three types. They are geometric data, sedimentary data and hydrologic data, and are always placed in that order in the "input file".

The input file contains the following data.

Geometric data set:

1. model network structure
2. the initial cross sections of the model
3. the hydraulic roughness value
4. the size of the bed sediment reservoir

Sedimentary data set:

1. the number of size classes of sediment in the model
2. the specific weight of the sediment deposit
3. the gradation of the bed sediment reservoir
4. the selection of the transport function
5. the water sediment discharge rating curves for all in-flowing points around the model

Hydrologic data set:

1. the water discharge histogram
2. the tail water elevation
3. the water temperature
4. the computation time step
5. program commands

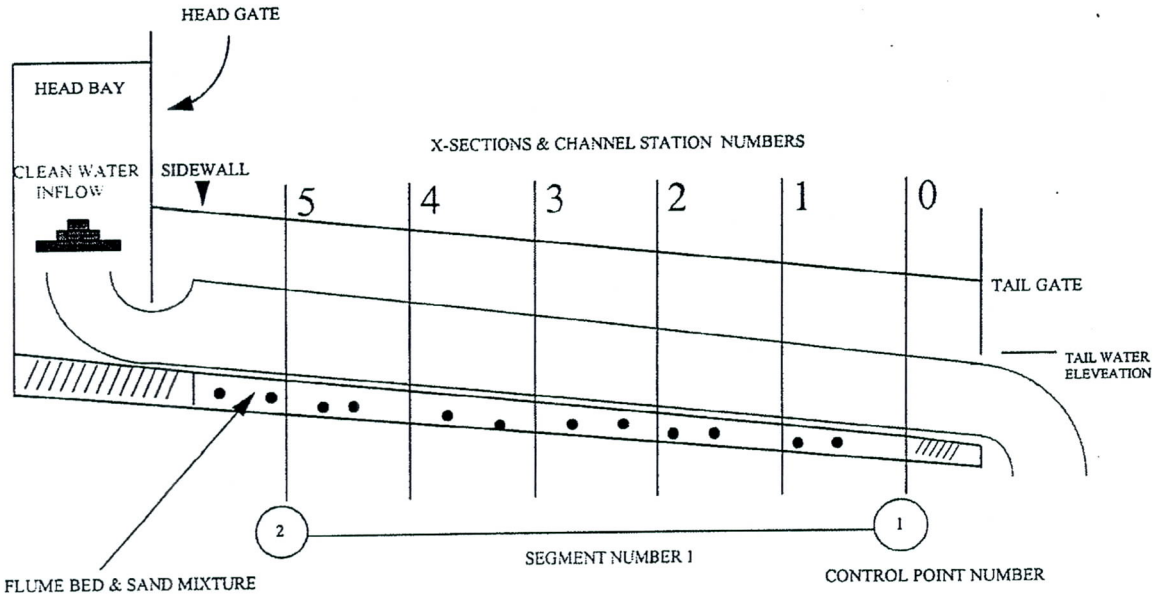
To illustrate data preparation, a series of examples have been included with the program. The first one is a flume problem. It is presented in this chapter.

---

[1]Copied from "Workbook for SEDIMENTATION IN STREAM NETWORKS, (HEC-6T) by William A. Thomas, Mobile Boundary Hydraulics, P.O. Box 264, Clinton, MS 39060.

Problem

The file, flume.t5, is a data set that models a simple flume. Below is a sketch of what the physical model of this flume would look like from a side view. Notice the 6 vertical lines numbered 0 through 5. These are the cross sections and channel station numbers of the flume. The flume has a single inflow at control point 2 and a single outflow at control point 1. The flume sketch shows these control points as circles. Notice that the circles are connected by a line that runs the length of the flume. This is called a "Segment." A segment is comprised of a group of cross section. In this example, a sand mixture has been placed in the bed of this flume. The sketch shows clean water coming from the head bay. This flume will have a single gate across its entire width to insure that the inflowing water is distributed uniformly from one wall to the other. The tailwater elevation will be at normal depth. Since there is no bed material in the inflowing water, one expects erosion to take place as water flows down this flume.



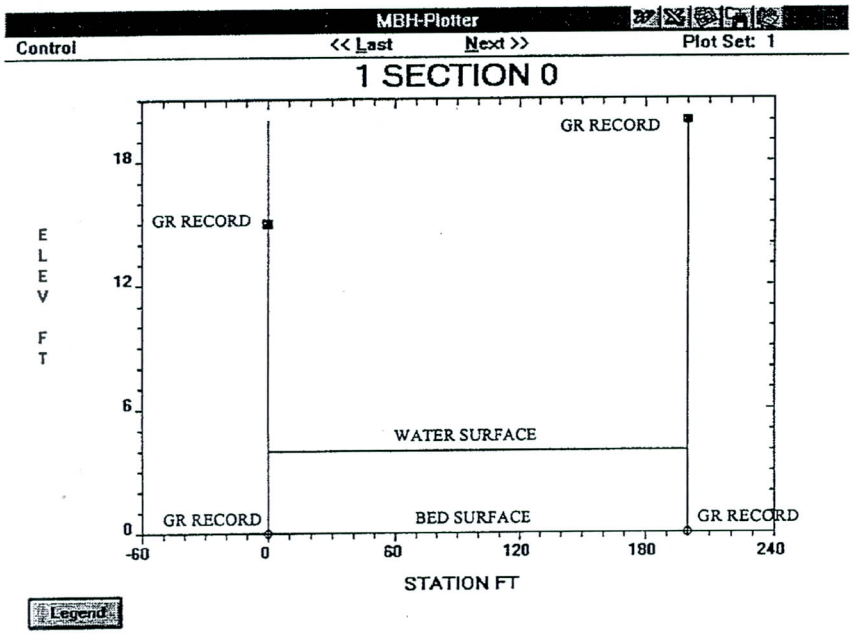
FLUME

Developing the HEC-6T Data File

Now that the physical parameters of our flume have been explained, we can construct what is called a .T5 file for HEC-6T to execute. The .T5 file is all the raw data collected and put in a format the computer can read. A .T5 file looks like this.

```
T1       FLUME TEST
T2       HEC-6T  VERSION 4.00.   4 MARCH 1994,   WA THOMAS
T3
NC  .150     .150     .025
X1     0        6     -.1   200.1       0       0       0
X3    10
GR    10       -1      10     -.1       0       0       0     200      10   200.1
GR    10      201
H      0
X1   100                              100     100     100              .1
X3    10
H    100
X1   200                              100     100     100              .1
X3    10
H    200
PX           100                                2    .001     100     100     100
EJ
T4       SEDIMENT DATA FOR FLUME TEST
T5       BED GRADATION ARE HYPOTHETICAL
T6       NO SEDIMENT INFLOW
T7
T8
I1            10
I4             4       1      11
LQ     Q      10  30000.
LTLTOTAL
LF   VFS
LF    FS
LF    MS
LF    CS
LF   VCS
LF   VFG
LF    FG
LF    MG
LF    CG
LF   VCG
LF    SC
PF                    1.0   128.0    64.0    36.0    32.0    31.0    16.0    28.0
PFC  8.0     27.0     4.0    25.0     2.0    24.0     1.0    19.0     .50    16.0
PFC .250     15.0    .125    13.0
$HYD
*   AB  RUN 1
Q   2000
R      4
T    45.
W     .1
$PLOTP  TITLE="EXAMPLE 1"  8,9,16
$$END
```

The following graph is a digital representation of Cross Section 0 of the flume as it is encoded in the input data file. Certain parts have been labeled for easier identification.



The following table groups records by purpose and annotates the different elements of the input data file.

Table 1-1. Description of Input Records

Input Records	Descritpion
T1 FLUME TEST T2 HEC-6T VERSION 4.00. 4 MARCH 1994, WA THOMAS T3	Title records that describe the contents of this file.
NC .150 .150 .025	Friction Coefficient
X1 0 6 -.1 200.1 0 0 0 X3 10 GR 10 -1 10 -.1 0 0 0 200 10 200.1 GR 10 201 H 0	The first cross section in the model. This is at channel station 0 - coded on X1. The cross section is on GR records. X3 requests ineffective area. The bed sediment reservoir is coded on H record.
X1 100 100 100 100 X3 10 H 100	Reuse GR records from previous cross section.
X1 200 100 100 100 .1 X3 10 H 200	ditto
PX 100 2 .001 100 100 100	Template for extending the model in the upstream direction.
EJ	End of Geometric data.
T4 SEDIMENT DATA FOR FLUME TEST T5 BED GRADATION ARE HYPOTHETICAL T6 NO SEDIMENT INFLOW T7 T8	Title records for the sedimentary data set.
I1 10 I4 4 1 11	Sediment and model parameters.
LQ Q 10 30000. LTLTOTAL LF VFS LF FS LF MS LF CS LF VCS LF VFG LF FG LF MG LF CG LF VCG LF SC	Inflowing water sediment mixture in the water column. (Zero in this case.) The LF records partition the inflow into fractions by size class.

Input Records	Descritpion
PF 1.0 128.0 64.0 36.0 32.0 31.0 16.0 28.0	Sediment gradation in the bed sediment reservoir.
PFC 8.0 27.0 4.0 25.0 2.0 24.0 1.0 19.0 .50 16.0	
PFC .250 15.0 .125 13.0	
$HYD	Hydrologic data set begins.
* AB RUN 1 Q 2000 R 4 T 45. W .1	These records describe the Hydrologic Boundary Conditions. Q - the water discharge in cfs. R - tailwater elevation T - water temperature. W - computation time step in days.
* Q W	After the first event code only *,Q,W until the water temperature or downstream elevation changes.
$PLOTP TITLE="EXAMPLE 1" 8,9,16	Plot parameters: Bed, Water Surface and Cross Section in this Example.
$$END	End of run

Execution

To execute, type "menu6" and the HEC-6 program menu will appear. Follow instructions on the screen to execute the Numerical Flume Data Set. The bottom of the screen shows the $$END record followed by the number of DATA ERRORS DETECTED, and the end of job statistics. This shows that the execution has come to a normal termination. The screen will look similar to this.

```
$$END

        0    DATA ERRORS DETECTED.

 TOTAL NO. OF TIME STEPS READ =          1
 TOTAL NO. OF WS PROFILES =              1
 ITERATIONS IN EXNER EQ =               60

 COMPUTATIONS COMPLETED
 RUN TIME =   0 HOURS,   0 MINUTES &   0.00 SECONDS
```

Printout

Printout is written as the data file is read. This makes it possible to locate errors in the data by searching to the end of the printout file. Printout can be inspected by a viewer named "List" in the HEC-6 menu.

To view the printout file on the screen select menu item number 4 "DISPLAY OUTPUT TO CONSOLE."

Use the arrow keys to navigate through the printout file if there are long lines. If additional help is needed, turn the "Help" screen on by using the question mark key on the computer keyboard. Press the question mark key again to turn the "Help" screen off.

The first image of the printout file is the time and date followed by the HEC-6 Banner. The banner shows the program name, version number, and dates. Just below the banner is a description of the program dimensions. This is to verify that the problem has fit in terms of the number of cross sections and control points.

EXECUTING HEC-6T AND READING THE PRINTOUT FILE

Objective: The student will be able to execute HEC-6T and to locate hydraulic and sedimentation results in the printout file.

1. Problem Statement: Execute **Example3.t5** from the HEC-6T example problems.

Open the MBH Shell program

A. Choose the *Load T5 File* button, then use the file browser to navigate to the directory where the workshop files are stored.

Select the input file **example3.t5**

The press the *Open* button. The dialog should now show the complete file pathname and end with "example3.t5."

B. Select the large *Execute HEC-6T* button. From the Command (DOS) window, answer the following:
Does the simulation run to completion? Y/N
How many fatal errors were detected? 0. 12 non-fatal
What is the output file name? Example3.t12

Press any key to exit this window.

2. Problem Statement: Display **Example3.t6**.

Press the *View Output* button on the bottom right side of the shell dialog.

The shell will open the output file using the text editor software that you selected during configuration of the shell.

A. Notice the HEC-6T Version Number in the Banner at the top of the output file.

B. Go to END OF FILE.

C. Complete the summary information found at the NORMAL TERMINATION of a job in the spaces below this line.

READING INPUT DATA FROM file_name = Example3.t5

PRINTOUT WRITTEN TO file_name = t6

0 FATAL DATA ERRORS

TOTAL NO. OF EVENTS READ = 4

TOTAL NO. OF WS PROFILES = 4

ITERATIONS IN EXNER EQ = 260

WRITE END OF RUN GEOMETRY DATA SET TO file_name = t12

D. Go to the top of the file. Then do a search for "SB-2" and view

TABLE SB-2: SEGMENT 1 STATUS OF THE BED PROFILE AT TIME = 52.00000 DAYS

SECTION ID NUMBER	AVG BED CHANGE (ft)	WS ELEV (ft)	THALWEG (ft)	Q (cfs)	SEDIMENT LOAD (tons/day)
58.000	-0.42	981.85	974.83	1400	554
55.000	0.17	980.66	973.10	1400	502

Notice the TABLE Number, **SB-2**. This string always applies to the Bed Profile Table.

At what COMPUTATION TIME does this "Status of the Bed Profile" Table apply? 52 days

E. Search on the String SB-2 and record the COMPUTATION TIME for each printout in the space below: 0, 53, 54

F. Repeat the search down the file, until the SB-2 table at 54 days is located. The "**BED CHANGE**" column shows positive and negative values. Circle the correct answer in the following sentences.

A negative bed change indicated (deposition, erosion).

If the cross section is in a deposition area, there will be (more, less) sediment transported into the reach than is transported out of it.

Record the two erosion zones using their cross section identification values.

58 and 53 . 32.1 32 15

Close the output file.

3. Problem Statement: Modify **Example3.t5** with a special command and re-run.

From the shell, press the *Edit T5 File* button on the middle left side of the shell dialog.

The shell will open the input file using the text editor software that you selected during configuration of the shell.

D. Search for "$HYD" and then add a line below it. Type the following on the new line (note that the numbers MUST be in the right columns):

```
1234567 1234567 1234567 1234567
$MXMN 3        3        3        3
```

The $MXMN Record will cause the program to save maximum and minimum values as described in the HEC-6T manual.

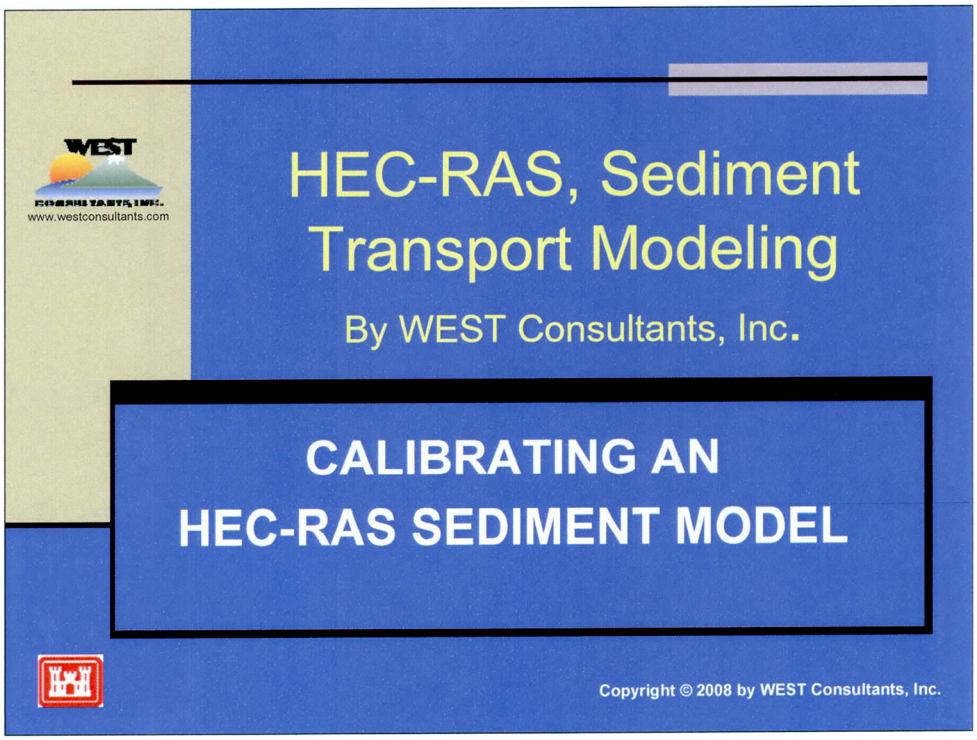
E. Save the file and then re-run from the shell using the *Execute HEC-6T* button.

F. Press the *View Output* button on the bottom right side of the shell dialog.

G. Go to the end of the output file and then scroll up above the names of the input and output files. There are two new tables there. Fill in the blanks in the table below

CHANNEL STATION	WATER DISCHARGE MAXIMUM CFS	WATER DISCHARGE MINIMUM CFS	WATER SURFACE ELEV. MAXIMUM FEET	WATER SURFACE ELEV. MINIMUM FEET	BED SURFACE ELEV. MAXIMUM FEET	BED SURFACE ELEV. MINIMUM FEET
58	1400.00	532.00	_____	978.89	975.25	974.25
55	1400.00	532.00	980.66	977.63	973.10	972.84
53	2050.00	660.00	977.12	974.64	972.20	971.09
44	2050.00	660.00	975.90	974.32	967.74	967.14
42	2200.00	689.00	975.15	974.15	969.80	969.80
35	2200.00	689.00	974.00	_____	963.34	963.30
33.9	2200.00	689.00	970.36	965.50	963.16	962.65
33.3	2200.00	689.00	970.19	964.86	962.62	962.49
33	2200.00	689.00	970.00	963.73	961.33	961.00
32.1	2200.00	689.00	967.61	963.73	_____	_____0
32	2200.00	689.00	966.53	963.12	956.45	956.32
15	2500.00	750.00	965.13	957.67	953.54	953.44
1	2500.00	750.00	965.00	956.00	945.98	945.06

How would you find out at what time a maximum or minimum occurred?



References:

- HEC, 1993. "Guidelines for the Calibration and Application of HEC-6." Training Document No. 13. The Hydrologic Engineering Center, Davis, CA
- ASCE Manual of Practice 110, *Sedimentation Engineering: Processes, Measurements, Modeling and Practice*, Chapter 14, "Computational Modeling of Sedimentation Processes"
- J.A. Cunge, F.M. Holly, and A. Verwey, 1980, *Practical Aspects of Computational River Hydraulics*

Calibration:

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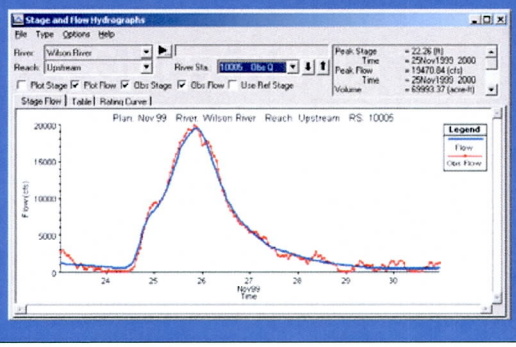
The adjustment of a model's uncertain parameters, such as roughness, sediment properties, and coefficients, so that it reproduces observed data to an acceptable accuracy.



Note that calibration is not the same as verification. Verification demonstrates that the calibrated model will match prototype data during a period of time that was not used in calibration. Calibration and verification are often performed using a “split sample” approach.

Outline

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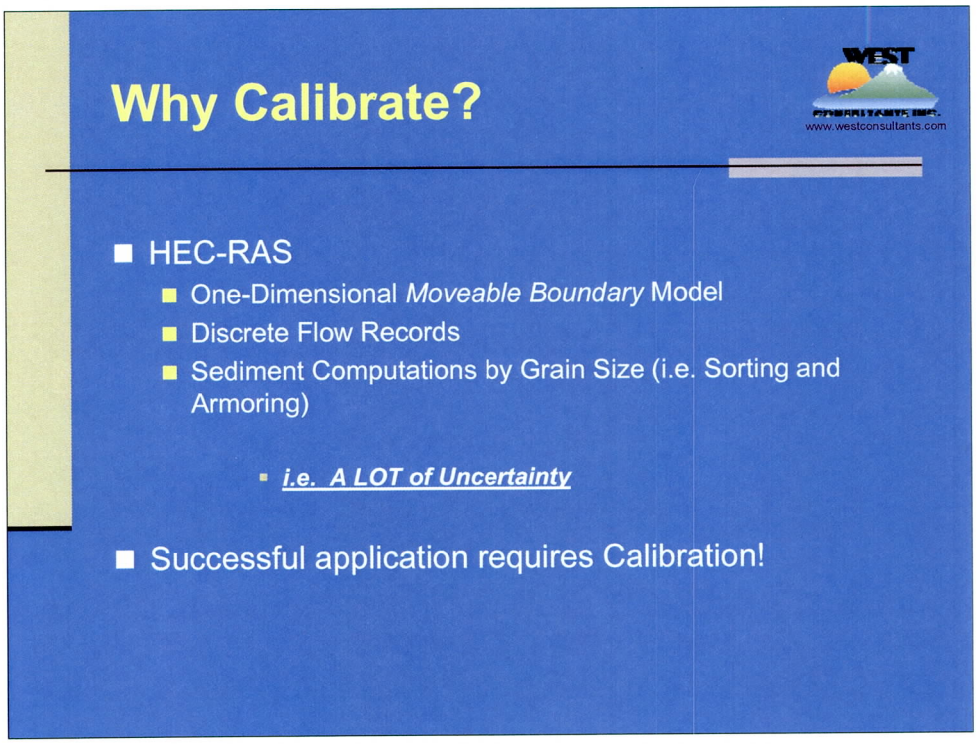
- Why calibrate?
- Historical Stream Behavior
- Data Requirements for Calibration
  - Types
  - Model Input
  - Sources
- Calibration
  - Geometric
  - Sediment
- Base/Alternatives Test
- Sensitivity Test

Topics to discuss



Manual 110 differentiates between *Computational Modeling*, where calibration data is available, and *Computational Analysis*, where it is not.

Historical Stream Behavior

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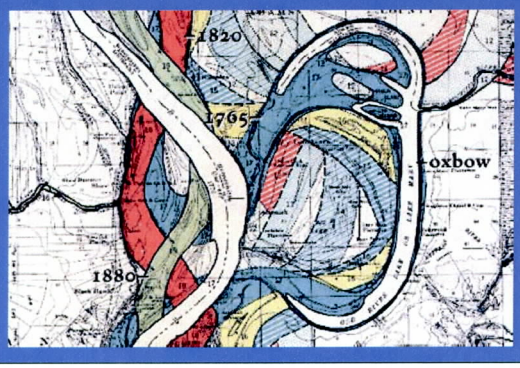
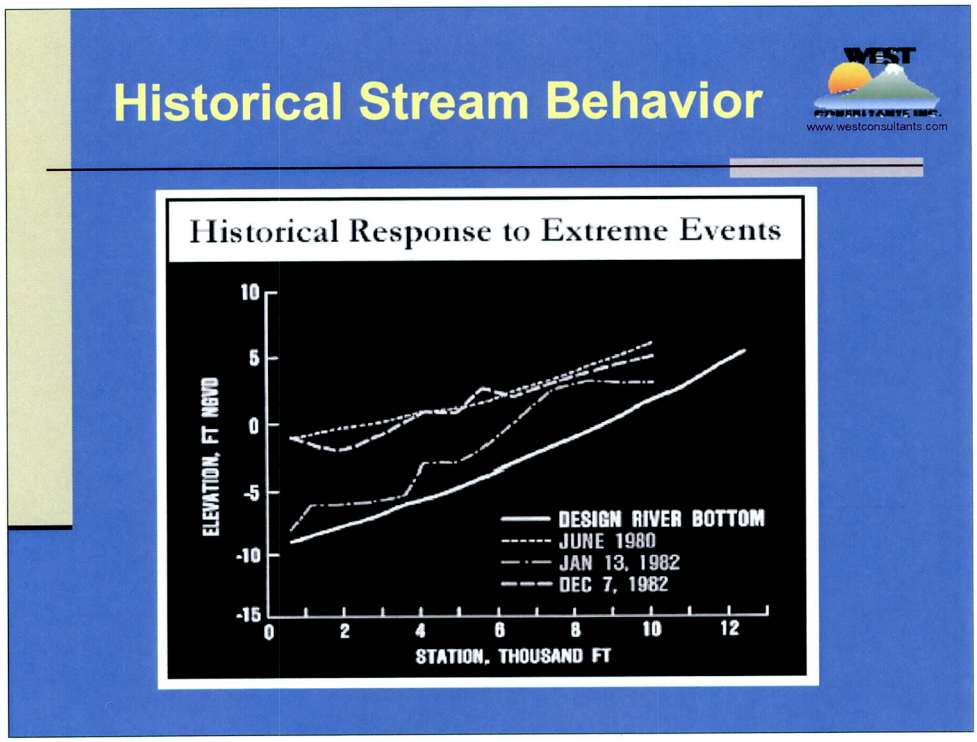
- Know your stream's history!
  - Recent *AND* Geologic
  - Can you gage future responses by examining past responses?





San Lorenzo River, Santa Cruz, California

Historical Stream Behavior

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- Examine Extreme Flow Events
- Estimate the Response Time of the System
- Evaluate the Impacts from any Impoundments
- Establish an Understanding of Past Behavior
- Locate Irregularities in stream characteristics
- Locate and date Stream Activity
- Locate flood paths to Overbanks

Then…

Historical Stream Behavior

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- Refine the Study Objectives based on your Findings
- Identify Missing Data-What must we Measure?
- Identify Locations of Significant and Permanent Scour/Deposition during a given Flood Event
- Locate Geologic Controls (i.e. bedrock) that control vertical movement of the bed.

Also…

Historical Stream Behavior

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- Investigate Sediment Characteristics on Point Bars
  - Grain Size
  - Sand Deposits
  - Sudden Change in Gradation
- Bed Roughness
  - Grain vs. Form
  - Vegetation – Seasonal
  - Temperature – Seasonal
  - Others?

Field Reconnaissance

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- Photograph locations that support conclusions in the geomorphology study
- Identify landforms with dominant processes
- Utilize a Channel Evolution Model as an aid
- Collect sediment samples from the bed and banks
- Record features that illustrate basic sedimentation processes: scour and deposition zones, bank instability, geological controls, structures (dams, bridges, levees)

Basic Features

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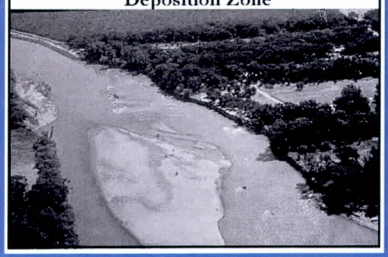
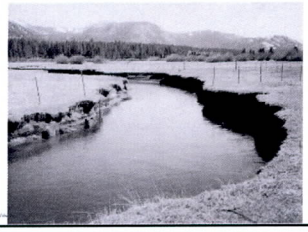
Deposition Zone



Tributary Inflow

Bank Instability

Stability of Channel Width



Basic Features

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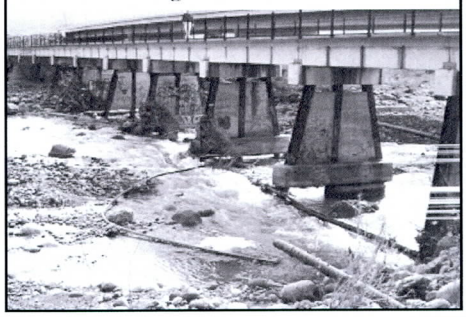
Knick Point – Temporary Bed Control

Degradation Zone



Data Requirements

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Study Area:

- Model Boundaries
  - Free from influence of alternatives
  - Dynamic Equilibrium
- Hydraulic Controls can make Good Boundaries
  - Dams/Reservoirs
  - Natural Drops
- Consider Available Gage Stations
- Include all Sediment-Producing Tributaries

Data Requirements

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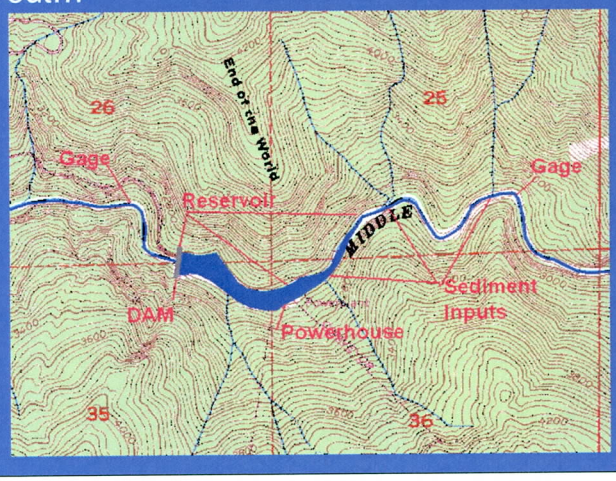
Study Area:

- Map it out…



Data Requirements

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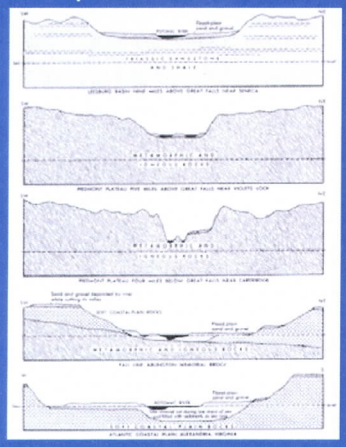
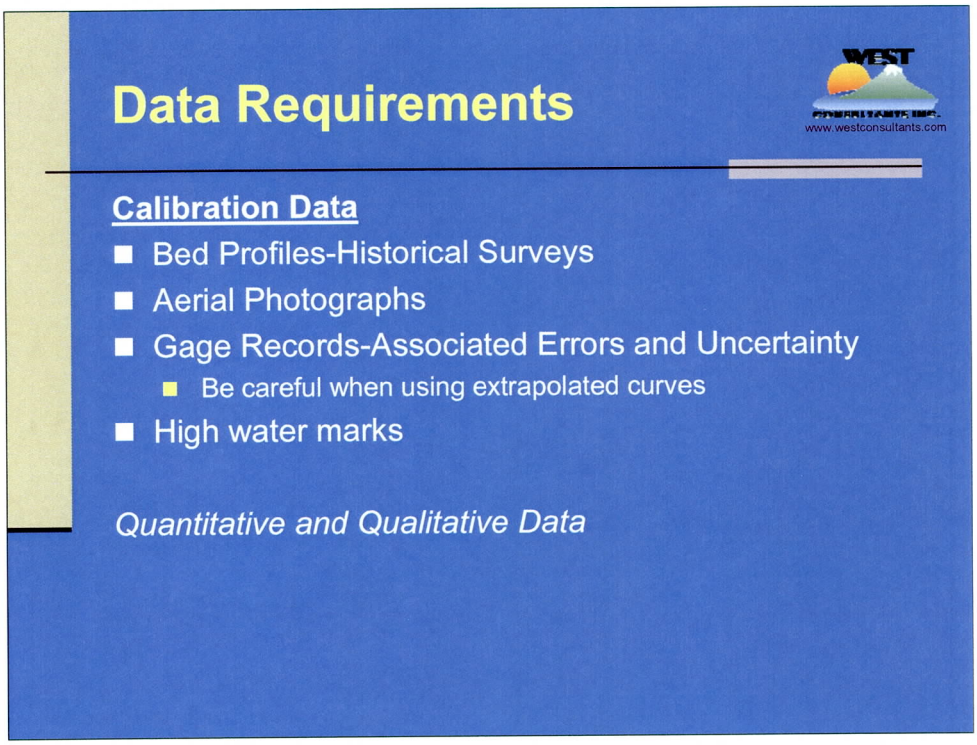
Two Types

- Calibration Data (i.e. prototype data)

- Input Data





Any type of prototype data that can also be extracted from model results can be useful. For example, the amount of sediment removed from a mining pit or dredged from a depositional area after a certain period of time can be compared to modeled sediment volumes deposited in the reach over the same period of time.

Data Requirements

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Model Input

- Geometric Data – Cross Sections
  - Spacing: Study needs and Accuracy

    "Develop input data that yield model results that reconstitute the historical behavior of the bed profile and also capture key features of the flow and the boundary movement."
  - Directly Proportional with Time Step
  - Be careful with cross sections developed for Fixed Bed Studies.
    - May be biased towards constrictions over reach-typical sections.
    - May fall on apex of bends or junctions.
    - Try to use more "Reach-Typical" cross sections

Data Requirements

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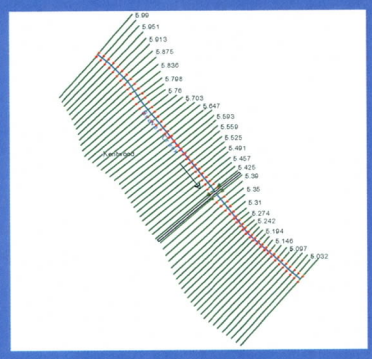
- Geometric Data – Cross Sections
  - Locations
    - Major Changes in Bed Profile
    - Changes in Channel or Valley Width
    - Tributaries
    - Changes in Roughness
    - Structures
    - Geologic Controls (Bedrock)
    - Where Calculated Results are Required



Data Requirements

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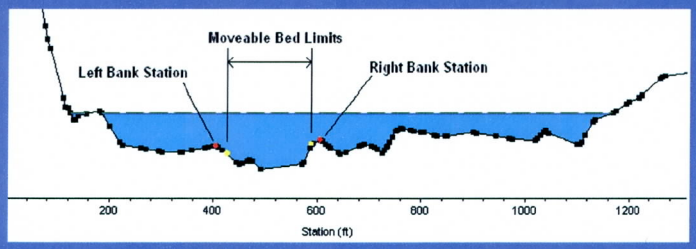
- Geometric Data – Cross Sections
  - Moveable Bed Limits
    - Typically just inside the left and right bank stations
    - May be adjusted during the calibration procedure.



Data Requirements

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- Manning's n Values
  - May be different for a Moveable Bed Model versus Fixed Bed
  - n Values can change with Discharge and Temperature
  - Calibrate to Fixed Bed Model first, then adjust to match Real Events with significant bed changes
  - Do not use unrealistic n values
  - Use Moveable Boundary Roughness Predictors for the moveable portion of the cross section
    - Brownlie, Limerinos, etc.
  - Use Calibrated Photographs for fixed bed portions.
    - Chow, Barnes, etc.

Data Requirements

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Model Input

- Sediment Data
  - Accurate Sediment Data and Inflowing Sediment Curve are ESSENTIAL
  - Reservoir Studies-Accurate Relationship between Discharge and Inflowing Sediment Load
  - River Studies-Accurate Relationship between Discharge and Inflowing Sediment Load and Gradation
    - The Total Load and the Distribution must be adjusted until a Representative Curve is Established
    - The Representative Curve, when applied over an annual hydrograph, should produce the proper Volume of Sediment

Data Requirements

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Sediment Data

- Sediment Inflow Rating Curves (Load Curves)
  - *IF* available, use Suspended Sediment Concentration Measurements

    -OR-
  - Calculate with Transport Theory
    - Select Upstream Boundary Carefully
    - Dynamic Equilibrium
    - Sample the Bed Surface-focus on Point Bars and Alternate Bars
    - Use Appropriate Transport Function
    - Will probably require Adjustment during Calibration

Data Requirements

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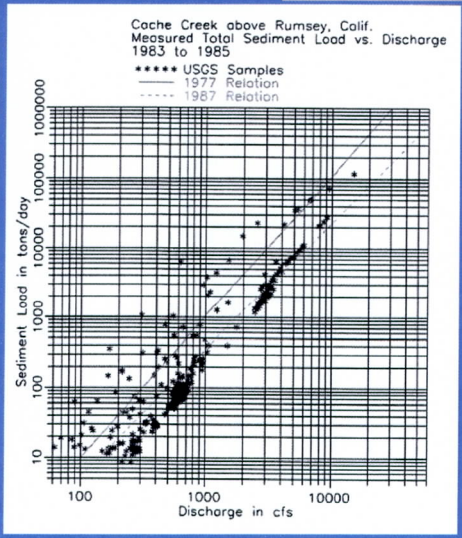
Sediment Data

- Sediment Inflows

Example plot of Suspended Sediment Samples and resulting Sediment Load Rating Curve



Data Requirements

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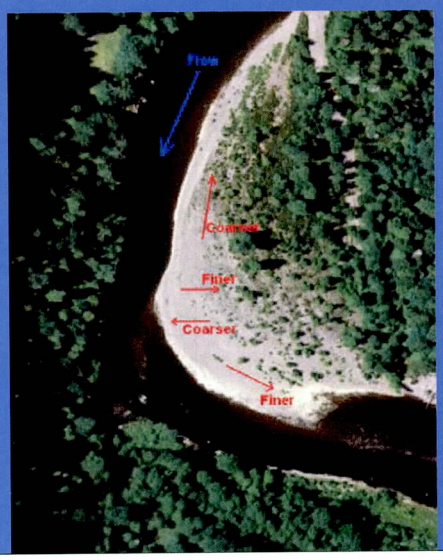
Sediment Data

- Bed Material Sampling

General Rule: Always seek "Representative Samples"

- Avoid Anomalies
- Avoid Samples near Bridges or Other Structures



Data Requirements

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Sediment Data

- Transport Functions
  - How was it derived? Is it Applicable?
  - Past Usage. Successes
  - Different functions will produce Different Results.
  - SAM-AID, Applicability Index (Williams and Julien, 1989)

Transport Function: Ackers-White

- Ackers-White
- England-Hansen
- Laursen (Copeland)
- Meyer Peter Muller
- Toffaleti
- Yang
- Wilcock

Data Requirements

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Hydrologic Data

- Computation Interval
  - Can be variable-Quasi Unsteady Flow Editor
    - Short Time Steps during periods of Rapid Changes
    - Long Time Steps during Low Flow periods
  - Generally speaking, Smaller XS spacing = Smaller Time Steps
  - Multi-year Simulations: 1 Day to 1 Month Time Step
  - May be most Convenient to use 1 Day Time Steps with Mean Daily Flow Records

Data Requirements

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Model Input

- Hydrologic Data
  - Water Inflows for Main stem, Tributaries and any local inflows/outflows
  - Stage Hydrograph, Rating Curve, Normal Depth, Critical Depth at the Downstream Boundary
  - Water Temperatures
  - **Preserve the Total Volume of Water in the Observed Hydrograph**

Data Requirements

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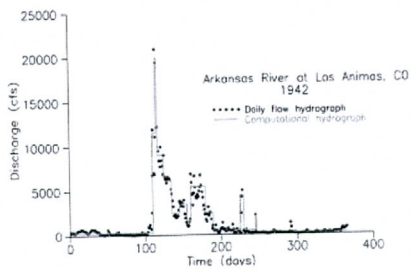
Hydrologic Data

- Water Inflows
  - Period of Record flows
    - Reproduce Observed
    - Predict Future Conditions
  - Length of Study
    - Study Objectives
    - Computational Time
    - Data Compression
  - Tributary Inflows
    - All contributions (gaged AND ungaged) to the study are should be included



Flow Data Compression.

Data Requirements

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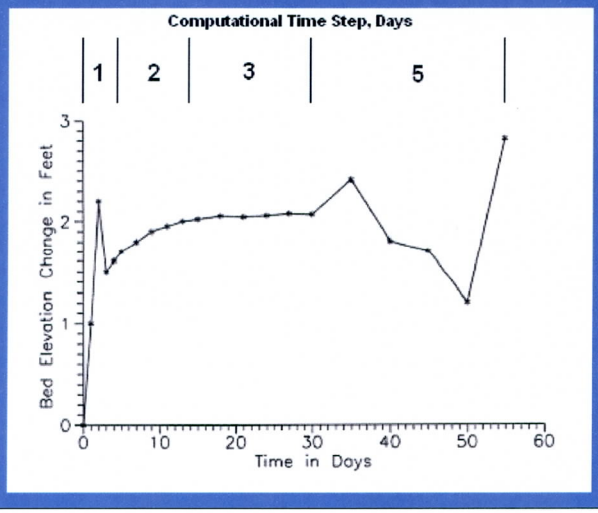
Time Step Test



Data Requirements

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Preparations for a Good Model

- Preserve Total Volume of Water in Hydrograph
- Preserve Total Volume of Sediment during hydrograph period
- Increase Computation Interval, yet maintain stability
- Provide a "Warm-up" period at the beginning of the simulation
- Preserve the flood peaks in the flow records-that's where the majority of the sediment moves

Data Requirements

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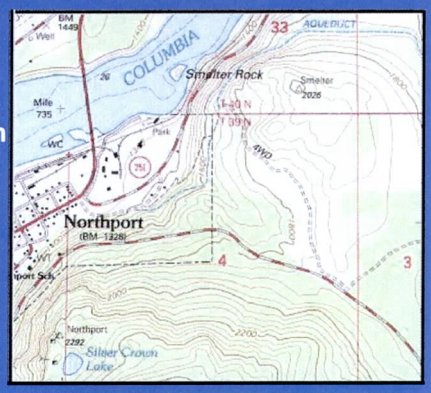
Data Sources

- USGS
  - Topo Maps
  - DEM
  - Mean Daily Discharges-can request 15-minute
  - Rating Curves
  - Occasionally Suspended Sediment and grain size available.
  - Rarely bed load information



Data Requirements

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Data Sources

- NWS
  - Rainfall Data
- NRCS/ARS
  - Historic Land Use
  - Land Surface Erosion
  - Sediment Yield
  - Soil Maps/Aerial Photos
  - Reservoir Sedimentation Reports
- Farm Service Agency (FSA)
  - Formerly Agricultural Stabilization & Conservation Service
  - Historic and updated Aerial photography of croplands
- COE

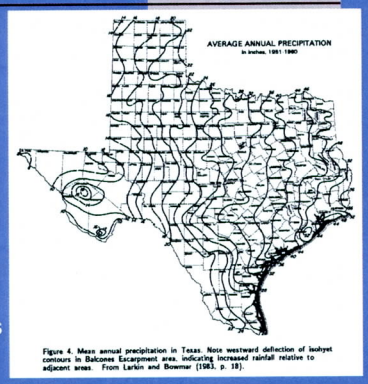

Figure 4. Mean annual precipitation in Texas. Note westward deflection of isohyet contours in Balcones Escarpment area, indicating increased rainfall relative to adjacent areas. From Larkin and Bowmar (1983, p. 18).

Data Requirements

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Data Sources

- COE
  - Older Hydraulic and/or Sediment Studies
  - Reservoir Discharge Information
  - Survey Data, Aerial and Ground Photography
  - Channel Cross Sections
- State and Local Agencies
- Local Universities, Consultants, Businesses, and Residents

Calibration

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- *Calibration is the adjustment of a model's parameters, such as roughness, hydraulic structure coefficients, and inflowing sediment load, so that it reproduces observed data to an acceptable accuracy*

2-Stage Process

1. *Selection* of Uncertain Parameters
2. *Verification* of Uncertain Parameters

Calibration

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Calibrating Geometric Data

- Start with Fixed-Bed Simulations
- Check n-values and other geo parameters using 3 distinct discharges
  - Bank-Full, typically near the 2-year return interval
    - Plot water surface, velocities, depths, widths in profile. Look for abrupt changes-may require ineffective flows.
    - Look for high velocities at bends. Remove these XSs?
    - Check for correct reproduction of overbank flow
  - Low Flow
    - Minimum Q anticipated
    - Changes in velocity, depth, width.
  - High flow
    - Maximum Q anticipated
    - Flow Distributions (channel to overbanks), Widths, Velocities

Calibration

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Calibrating Geometric Data

- Single Discharge, Moveable Bed Test
  - Bank-full flow
    - Dominant Discharge, little Aggradation/Degradation
  - First check Manning's n values
    - Appropriate for Moveable Bed?
  - Be careful with the start of the simulation
    - Large amounts of available fines to transport
    - Transport Rates will initially be higher
  - Balance the sizes of the inflowing bed material load with the transport potential and bed gradation

Calibration

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Calibrating Sediment Data

- Rating Curve "Drift"
  - Indicator of behavior of a stream reach with regard to General scour or deposition
  - Make sure the gage is not within influence of local scour/deposition.

Calibration

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Calibrating Sediment Data

- +-0.5 ft typically satisfactory
- Focus on Change in XS Area, rather than Average Bed Elevation
- Focus more on reach-wide comparisons between model and prototype, rather than specific XS's.
- 1-D Model vs. 3-D process.
- **Base Calibration Effectiveness on Processes which will impact Decision Making.**

Calibration

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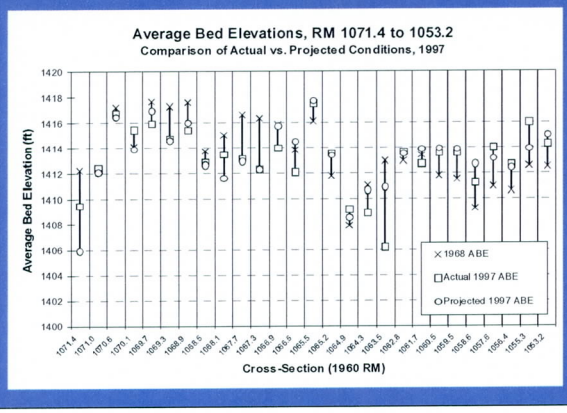
Calibrating Sediment Data

- Variable vs. Elevation at Selected Cross Sections
  - Example: Compare Calc. Stages with Observed Rating Curve(s).



Calibration

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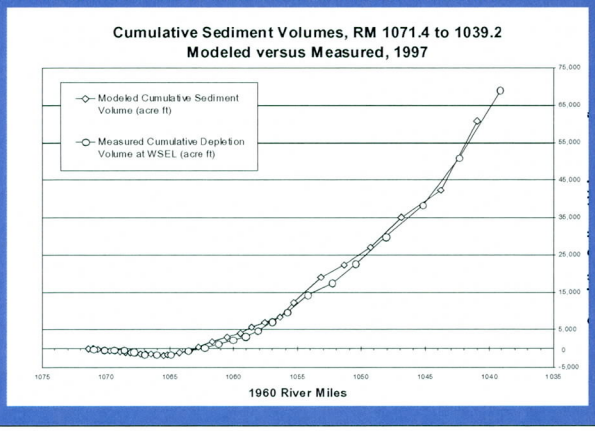
Calibrating Sediment Data

- Variable vs. Distance
  - Example: Water Surface and Bed Surface Profiles



Calibration

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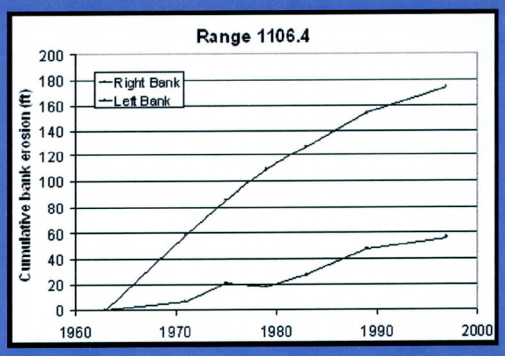
Calibrating Sediment Data

- Variable vs. Time at Selected Cross Sections



Calibration

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- Data Adjustment
  - "The Art of Reproducing a 3-D effect with a 1-D model"
  - Adjust uncertain parameters within their realistic bounds to better reproduce results
    - Manning's n Values
    - Inflowing Load
    - Bed Gradation
    - Ineffective Flow Limits
    - Mobile Bed Limits
    - Bridge/Culvert Coefficients
  - DO NOT FORCE A CALIBRATION USING <u>UNREALISTIC</u> VALUES!!!

Calibration

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Steps in Correcting Model Performance

1. Check Numerical Stability.
2. Ensure the upstream and downstream boundaries are located in a Stable region and that the model reproduces this.
3. Fix Hydraulic problems from Downstream to Upstream.
4. Fix Sediment problems from Upstream to Downstream.

Calibration

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Steps in Correcting Model Performance

5. Make sure the Bed Sediment Depths and Gradations match the prototype.
6. If Calculated Transport Rates are too High, check for prototype armor layers in the vicinity.
7. If Deposition is too high, or Erosion is too low, check Bank Elevations and Ineffective Flow Limits to ensure the model is not allowing too much flow in the overbanks.
8. If none of the above helps, try adjusting the Inflowing Sediment Load. If rotating the curve, stay within the scatter of the data.

Base/Alternatives Test

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- Base Test
  - A "No Action" Future
  - Should show little net scour or deposition if the existing stream is in Dynamic Eq.
  - Serves as a Method for Comparison of Alternatives
- Alternatives Tests
  - Results should always be presented as a *Change from the Base Test*, not as absolute values

Sensitivity Test

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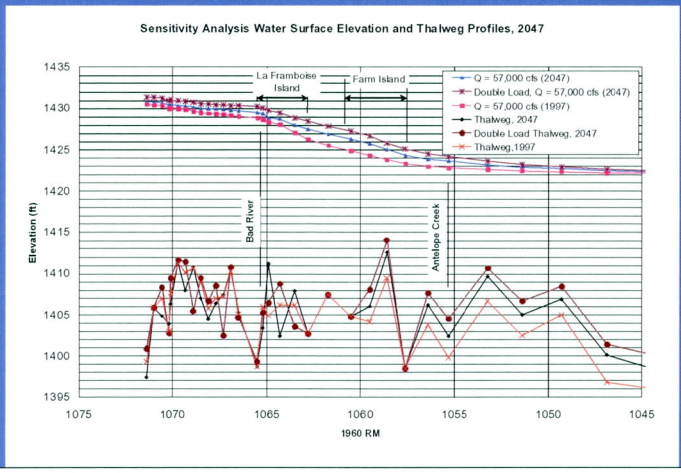
Necessary to understand the prototype's behavior and to have a Credible Model



Sensitivity Test

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- Particularly important when measured data are not available
- Establish limits of uncertainty
- Test effect of each variable on results
  - Roughness coefficient
  - Movable bed limits
  - Inflowing sediment load and fraction of size classes
  - Initial bed gradation

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Troubleshooting an HEC-RAS Sediment Model

Objective: This lecture will discuss common sources of error and troubleshooting techniques for HEC-RAS Sediment Models

1

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Topics to Discuss

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- Boundary Conditions
- Interpolation
- Fixed Bed Issues
- Hydraulic Property Weighting
- Output Issues

- Guidelines

2

In this lecture we'll discuss Boundary Conditions, Interpolation of Bed Sediment Gradation, Fixed Bed issues, Hydraulic Property Weighting, and Output Issues. We'll finish with a discussion of guidelines for troubleshooting sediment models.

Boundary Conditions

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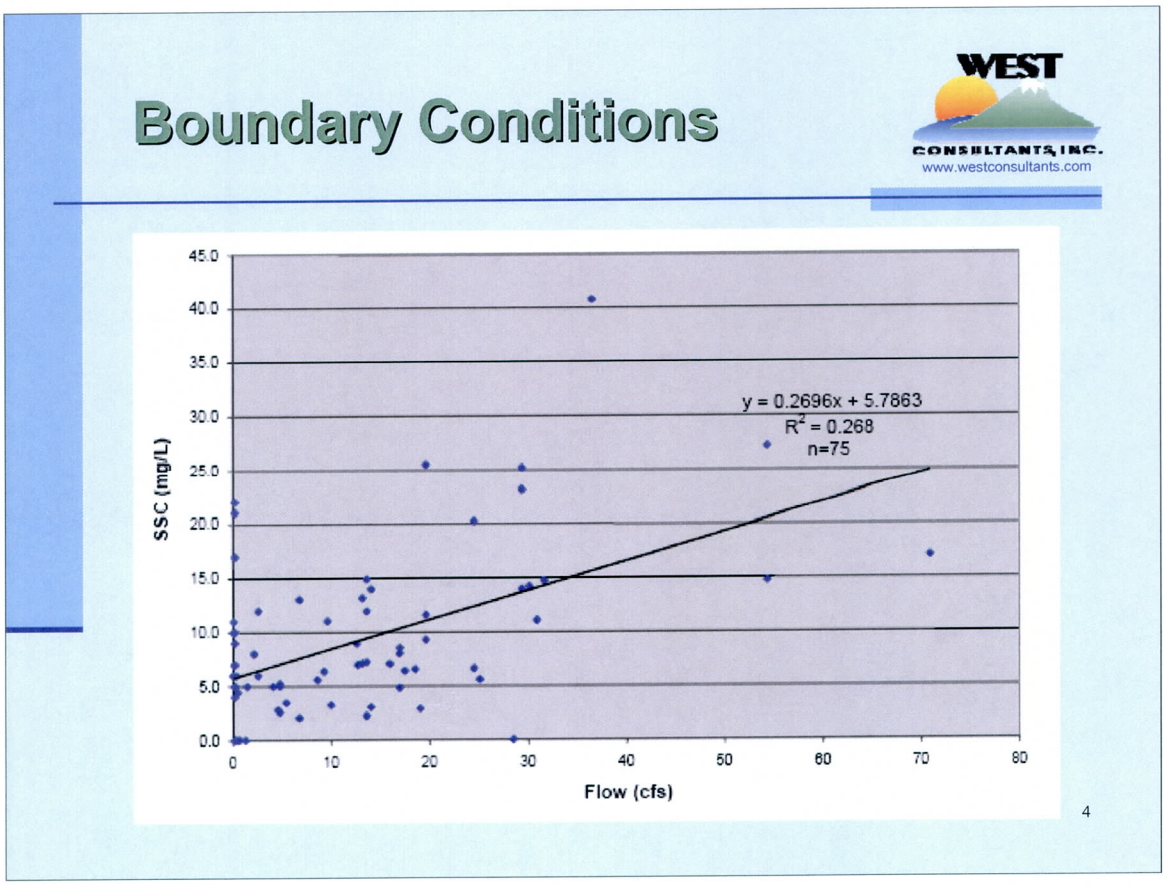
- Flow/Load or Sediment Rating Curves
  - Data is scarce
  - Difficult to assemble
  - Data is skewed towards the smaller particle sizes
    - Samples collected during Low Flows only
    - Samples may not include Bed Load
  - What Flow levels/sediment movement is doing most of the work?

3

Flow-Load data or "Sediment Rating Curves" are required at the upstream end of a reach. This data is very difficult to come by in the field, and even more difficult to assemble into useful information. Transforming a sediment sample, or sampling effort, into a sediment rating curve requires a lot of subjective assumptions. A lot of times the data is skewed towards smaller particle sizes because the samples were collected at low flows only, and the curve fitting and extrapolation methods may not be adequate. Commonly, sediment sampling does not include bed gradation, and some assumption must be made as too how much of the sediment load is bed load.

The question to ask is What flows are doing most of the work? What percentage is bed load, suspended load. Are all sediment fractions accounted for?



This figure illustrates the difficulty in simply predicting the sediment load for a wide range of flows. Most of the data points are at low flows and the curve fitting leaves little confidence. So here, we are off to a bad start. Then trying to further break this down into a distribution of particle sizes can add even more uncertainty and error into the model.

Boundary Conditions

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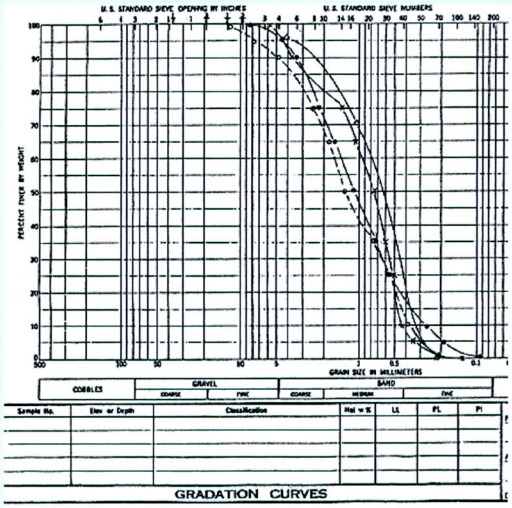
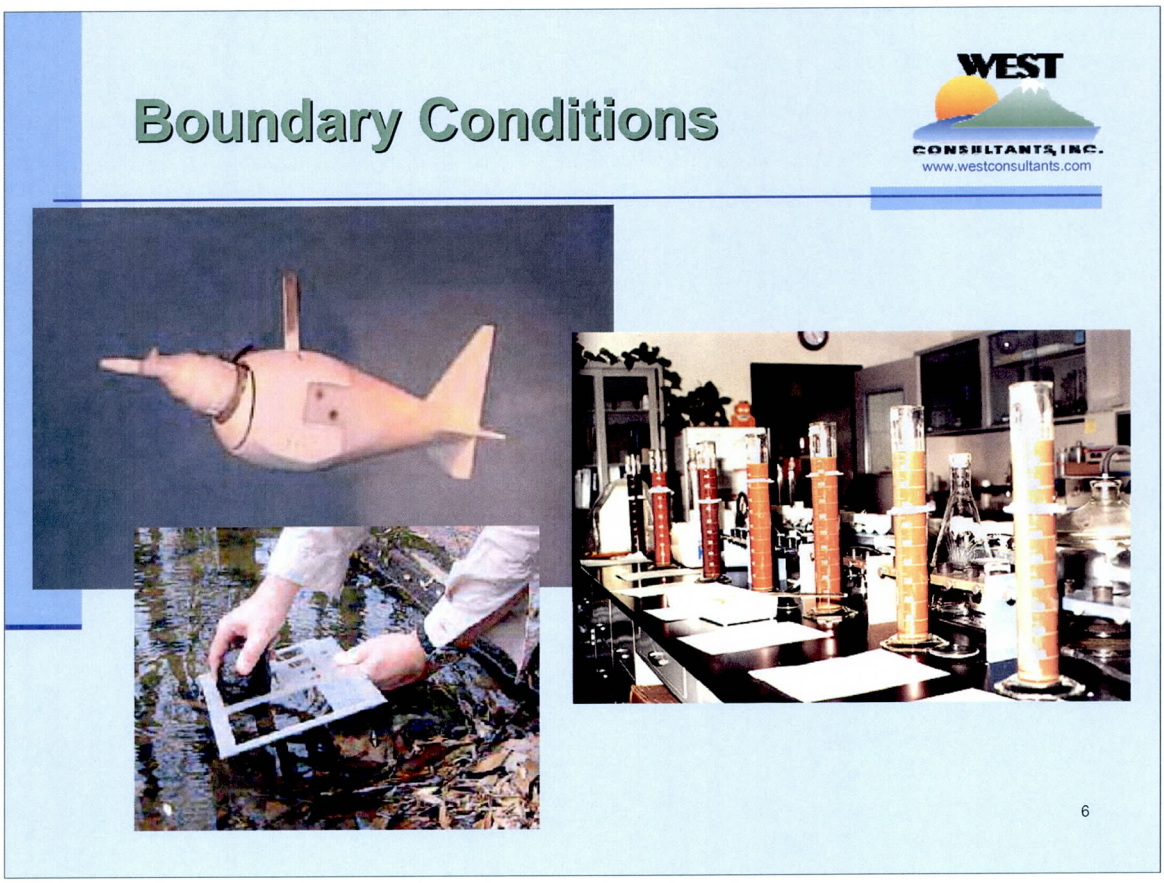
- Site Visit
- Compare representative Bed Material with the Flow/Load curve
- Does it make sense?



A site visit to the sampling location is always beneficial. Does the bed sediment match up with the gradation curves. How about the sediment load/rating curve? In this example the actual bed sediment is much larger than that which is plotted on the gradation curve. It is likely that the sediment load sampling effort did not include bed load sampling.



The upper left hand picture is an example of a suspended load sampler. Hydrometer tests (on the right) would be used to develop a gradation of the collected sample. At higher flows, larger sediment will be mobilized, but will not be collected in the sampler. A gravelometer (lower left) can be used to get an idea of the grain size distribution of the bed load. Some approximation of contribution of bed load to the overall sediment load must be made (if it cannot be determined from field tests). Einstein suggests 10% of the sediment load is bed load, but this is a very broad statement and the amount can vary from Less than 1% to near 100%.

Boundary Conditions

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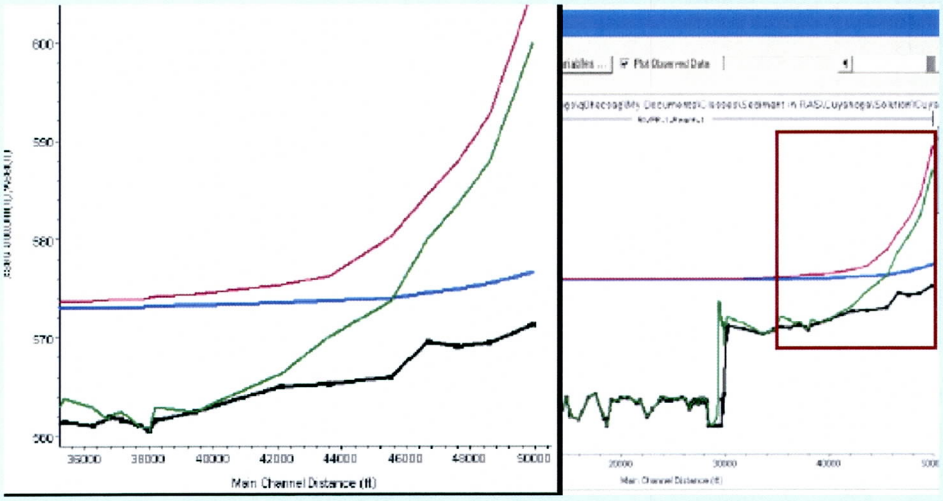
- Overestimating the Bed Material Size…



7

Conversely, if the sediment load gradation is overestimated (or skewed towards larger particle sizes), the deposition at the upstream end may be grossly overestimated. This figure shows an example. If this is seen in the output of the spatial plot, make sure the inflowing sediment load is not too coarse.

Boundary Conditions

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- Stable Boundary Conditions
  - Both upstream and downstream boundaries should be located at geomorphically stable locations
    - Dynamic Equilibrium
    - Bedrock
    - Reservoirs

8

Stable boundary conditions are essential for sediment transport models. This adds confidence to the model and lets the modeler know that outside influences (outside of the system being modeled) are not having an effect on the area of interest. Ideal places to place boundaries indclude locations that can be confirmed to be in dynamic equilibrium, bedrock areas, or sufficiently large reservoirs (constant sink).

Boundary Conditions

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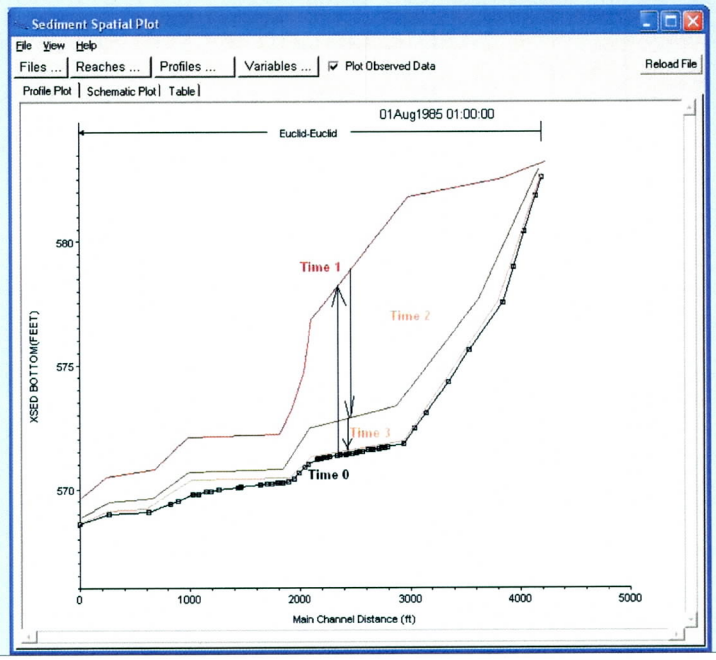
- Initial Sediment Pulses
  - Warm up period?



Initial sediment pulses may happen as the model "warms up." If the pulses diminish fairly quickly in the simulation, they can be ignored. However, if these pulses are affecting the results, a warm-up period should be used to push the model towards a stable starting condition.

Boundary Conditions

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- Get the Hydraulics Correct
  - Downstream boundary
    - Normal depth?
    - Rating Curve?
    - Stage Series?
  - Upstream boundary
    - Flows and Durations

10

The hydraulics need to be correct before sediment transport work can be done. If the hydraulics are wrong, little confidence can be had in the sediment transport results.

Bed Interpolation

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- How are the "few" sediment sample gradations applied to the entire model (i.e. each cross section)?
  - Interpolation?
  - Association?

11

How can we assign bed gradations for all of the cross sections when only a few samples are available. We can assign by "Interpolation" or by "Association." Interpolation will actually interpolate the gradation curves for cross sections located between two samples. Association simply assigns the bed gradation for one sample to a series of near-by cross sections. Which one do we use???

Bed Interpolation

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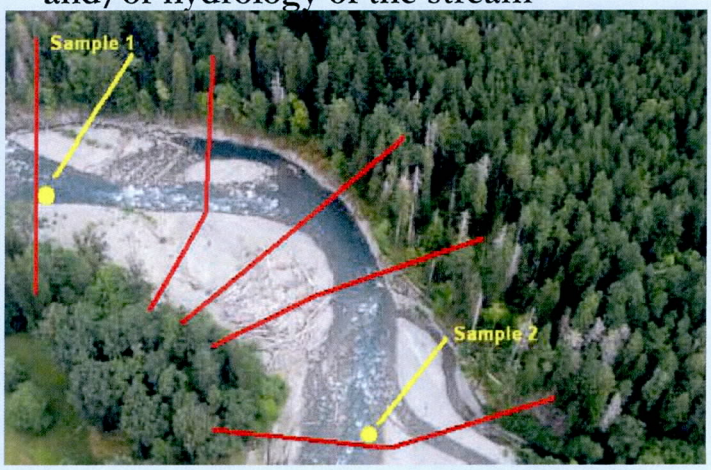
- Interpolation
  - When samples are separated by relatively consistent substrate. No significant changes in geometry and/or hydrology of the stream



12

This example shows a relatively consistent looking stream. It can be reasonably assumed that there are no significant geologic or hydrologic effects that could drastically change the makeup of the bed sediment reservoir. In this case, interpolation between the two samples is warrented.

Bed Interpolation

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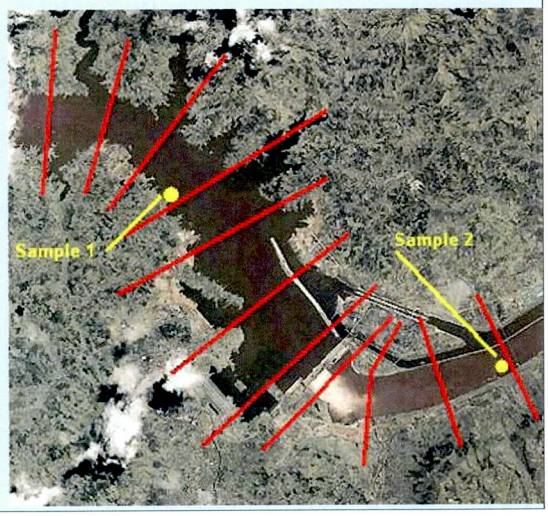
- Association
  - When there is a distinct hydrologic or geological boundary between the samples
    - Tributary inflow
    - Grade Break
    - Active Bank Erosion



In this rather obvious example, there is a large dam in between the two samples. Interpolation would not be adequate here, since there is most likely a sharp difference in the bed sediment distribution above the reservoir versus below the reservoir. The reservoir is going to have a lot more fine material than downstream of the dam. In this case, Sample 1 could be applied (Associated) to all the cross sections in the reservoir, and Sample 2 could be applied to the cross sections downstream of the dam.

Fixed Bed Issues

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- What is a Fixed Bed?
  - No Sediment Reservoir.
  - No scour (at least initially)
  - Concrete Channels
  - Bedrock Streams

14

This canal is a good example of a fixed bed. Sediment can enter this reach and even deposit, but there is initially no bed sediment reservoir to work with. This can lead to oscillations as the fast moving canal transitions from a lot of deposition to a lot of scour from one section to the next over the simulation.

Fixed Bed Issues

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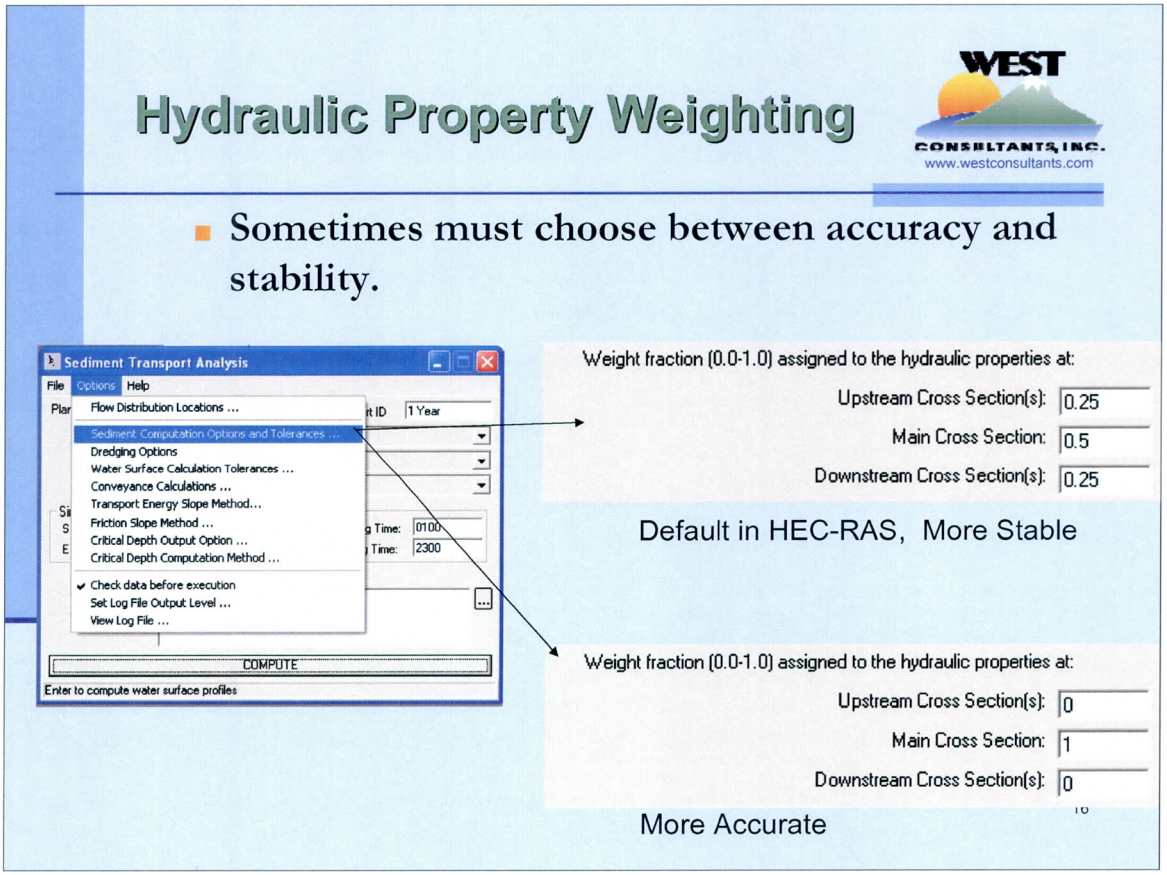
- Can lead to numerical oscillations
  - No sediment reservoir leads to 0 transport potential
    - First time step everything is deposited
  - Fixed Bed typically means High Velocity
    - Next time step, everything is scoured.
  - This oscillation effect moves downstream and can lead to instabilities in the results.
- What to do???
  - Smaller Computational Interval
  - Tighter Cross Sections

15

To remedy this situation, smaller time steps and tighter cross sections may do the trick.



Hydraulic property weighting can add stability to a model, but does so at the expense of some accuracy.

Hydraulic Property Weighting

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- Consider Upstream Boundary and Downstream Boundary Independently.
  - More sensitive to weighting effects.
  - Only one other Cross Section to "weight" with

17

Hydraulic Property Weighting

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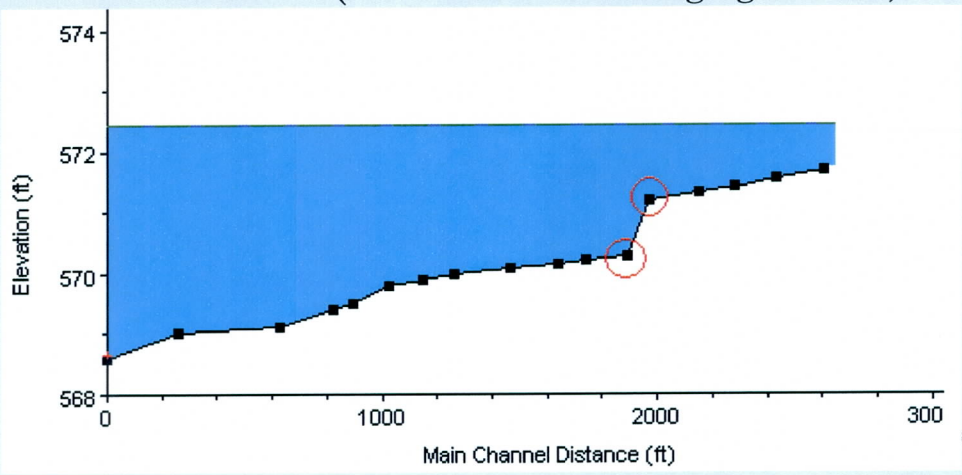
- Can lead to problems if…
  - Significant changes in depth from one cross section to the next (i.e. interface to a dredging channel)



8

Hydraulic Property Weighting

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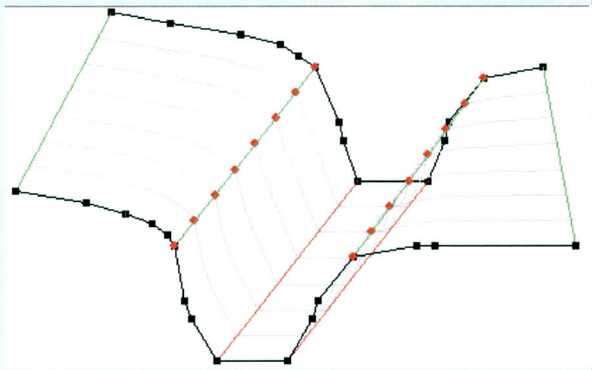
- Cross Section Interpolation
  - Interpolation gives more weight to individual cross sections. Therefore, a more accurate weighting scheme will more easily work. The cross section interpolation helps to transition hydraulic characteristics through the reach.



19

Geometric interpolation of cross sections can add stability to sediment models by smoothing the transition of the hydraulic characteristics over a reach.

Output Issues

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- Know how to read the output.
  - Sediment Spatial Plot
  - Sediment Time Series Plot

20

It is very important to know what exactly the output is telling you, to be able to adequately troubleshoot a model. The two most common output graphics to view for sediment transport modeling are the Spatial Plot and the Time Series Plot.

Output Issues

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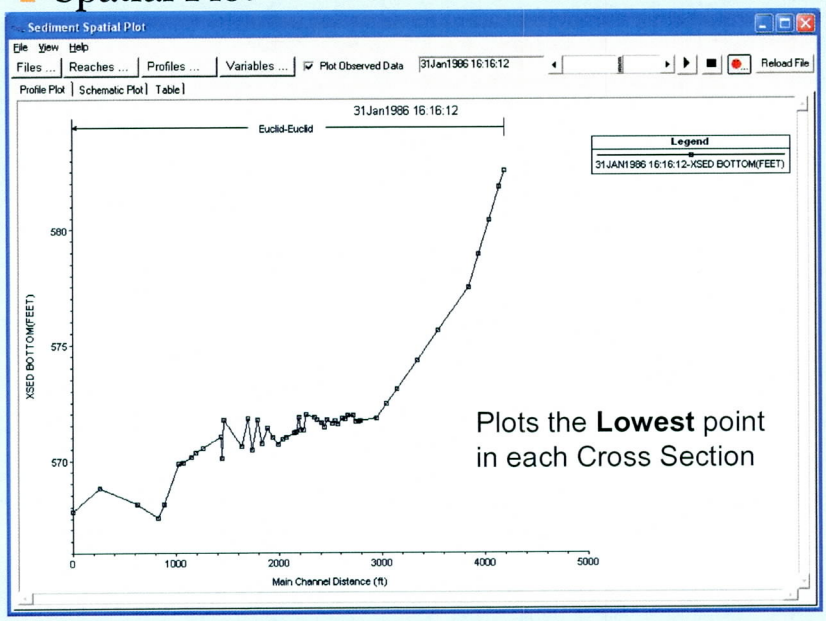
- Spatial Plot



Plots the **Lowest** point in each Cross Section

21

The Spatial Plot shows the elevation of the channel thalweg for the entire reach at a given timestep. Animating through the timesteps can give an idea as to how sediment is moving through the system.

Output Issues

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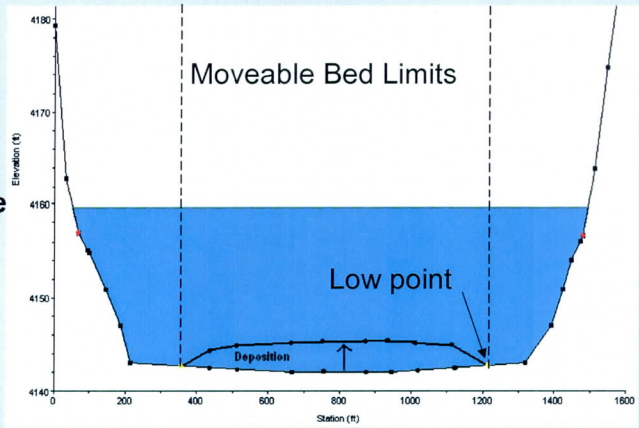
- Spatial Plot

  - **Does the thalweg spatial plot accurately depict the deposition/scour of sediment for the entire cross section?**

    - **Location of Bed Change Limits**



22

Keep in mind the spatial plot only shows the minimum elevation node for each cross section. As a result, a depositional zone may not be captured correctly in that plot, if the mobile bed stations are missplaced. This example shows the mobile bed limits placed low in the channel. As the bed aggrades, the low point moves out to the mobile bed limit and remains constant throughout the simulation. The Sediment Spatial plot will indicate the cross section is stable, when in reality it is depositing a lot of sediment. A check of the mass plot will help to figure this out.

Output Issues

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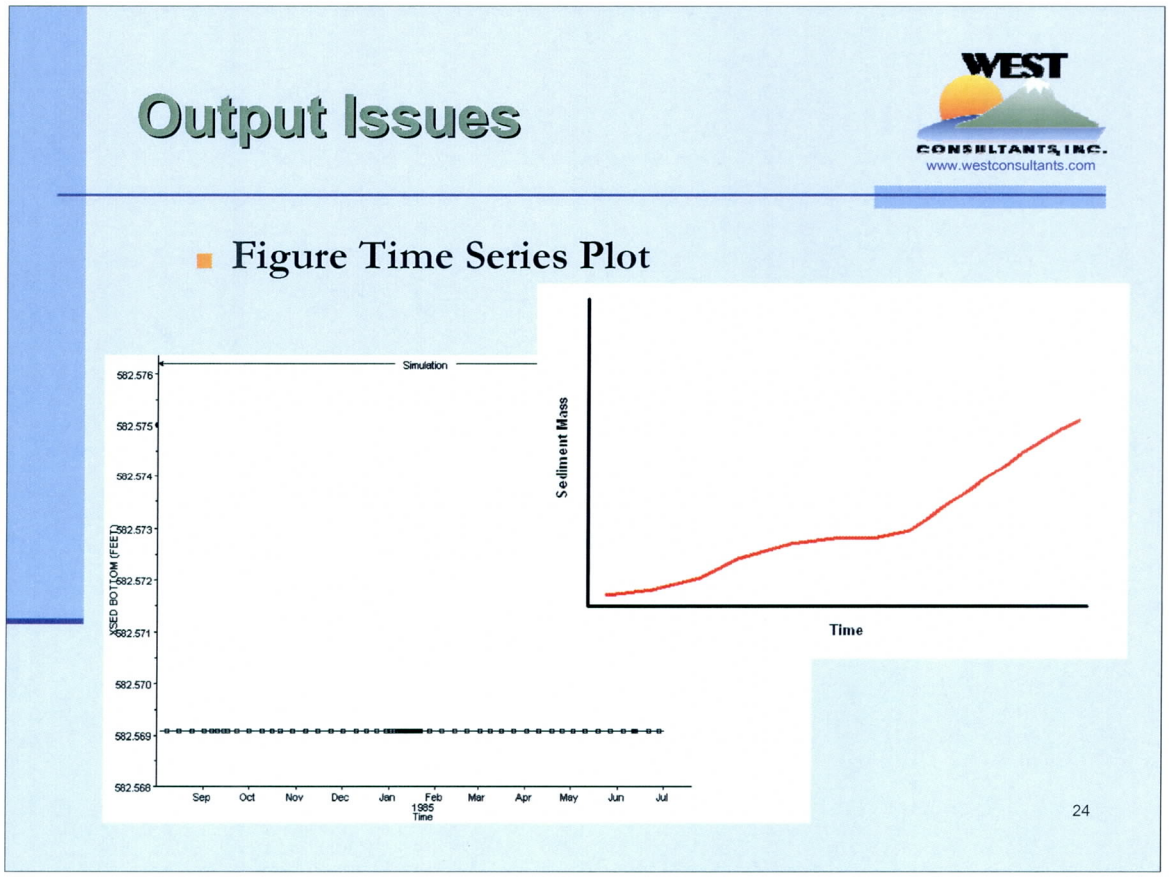
- Don't forget about the Mass Balance
  - Check the Time Series Plot for all Cross Sections
  - If any of them are very stable, and can't be explained, check the consistency with the Mass Plot
  - If the cross section is stable in the Time Series Plot, the Mass Plot should show a corresponding stability.



Here's an example of a (seemingly) very stable cross section. However, examination of the mass plot indicates the deposition is not being shown at this cross section in the spatial plot.

Guidelines for Troubleshooting

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- Computational Time Steps
  - Too large?
    - Look for stability
    - Look for reasonableness of results
  - Want changes to happen gradually
    - Cross section must have room to adjust both its hydrodynamic properties and it transport potential

25

Probably the most common issues for models not working properly are too coarse of time steps and cross section spacing. Keep in mind that numerically, we don't want too refined time steps and spacings either. There is a sweet spot. Look for stability in your model output. Does the data look reasonable. Does is look more reasonable with smaller time steps/smaller cross section spacing? We want to make sure that changes in the hydraulics and sediment transport happens gradually from one time step to the next and from one cross section to the next.

Guidelines for Troubleshooting

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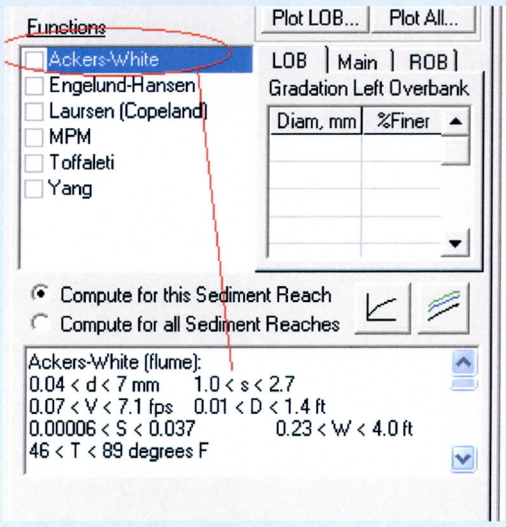
- Pick the correct Transport Function!
  - How was it developed?
  - What assumptions were made?
  - What range of material was examined?
  - Does this work for your system?



26

Make sure that the transport function that you choose is applicable to your hydraulics and sediment properties. Look at how the transport function was developed and what assumptions were made. What range of sediment sizes were examined. The Sediment Tranport Capacity window in the Hydraulic Design area of HEC-RAS provides a well documented description of each transport function that is available. Check your conditions with that which is listed in the model. Or better yet, find the original research done by the developer of the transport function you want to use.

Guidelines for Troubleshooting

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- Some functions will grossly overpredict transport capacity for sediment sizes outside the range of applicability.
- i.e. Ackers-White

27

Some of the transport functions in HEC-RAS will grossly overpredict transport capacities for grain sizes outside its applicable range. Ackers-White is a good example of a transport function that does this. If you find that transport capacities for some of the finer grain sizes are abnormally large, this may be the problem.

Guidelines for Troubleshooting

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- Get the Hydraulics Right!
  - Run a series of steady flow runs, representing important (if not all) flows in your Boundary Flow Series
  - Check overbank to main channel flow consistency
    - Standard Table 2.
  - Transitions. Ineffective Flow Areas.
  - Do the hydraulics make sense? (i.e. flow cannot take 90 turns or instantaneously jump from one sub section to another.
  - Hydraulics happen Gradually! Even during dynamic events. Don't fight it. Use it!

28

Get the Hydraulics Right. Everything else will be wrong, if the hydraulics are wrong. Run some steady flow runs first and concentrate on getting the hydraulic solution to look reasonable for the range of flows. Keep in mind that hydraulics in natural rivers happen Gradually. This is actually a gift to us a hydraulic modelers, because the numerical techniques used in hydraulic modeling like when things happen gradually. Therefore, if flow distributions are jumping around, or hydraulic parameters are changing rapidly, it's not only difficult for the model to solve, but most likely it is wrong to begin with. Try to fix these issues before embarking on the sediment transport modeling.

Guidelines for Troubleshooting

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- Get the Hydraulics Right!
  - Do NOT force unrealistic Manning's n-values or other coefficients.
  - Be sure the flows are representative of the system.

29

Guidelines for Troubleshooting

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- Mobile Bed Limit Placement
  - Hydraulics in addition to bed characteristics should be considered
  - Again, gradual changes in mobile bed widths and placements (relative to bank stations) are advantageous.
  - If something looks odd, or out of place on the spatial plot, check the cross section and make sure both bed limits and banks stations are correctly placed.

30

Mobile Bed Limits are a common cause of bad, or misinterpreted data. Make sure you get these correct.

Guidelines for Troubleshooting

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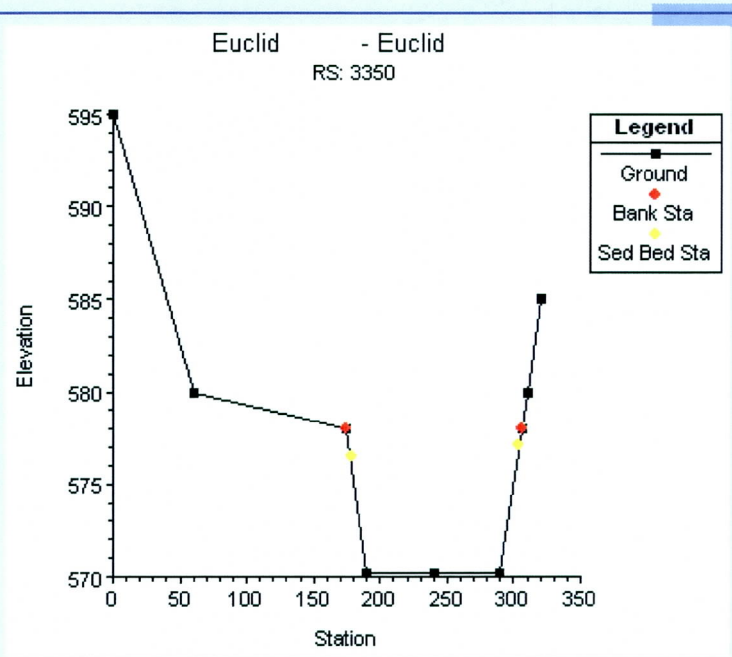

31

Guidelines for Troubleshooting

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- When examining Hydraulic Issues, Work from Downstream to Upstream.
- When examining Sediment Transport issues, Work from Upstream to Downstream.

32

For most natural rivers, hydraulic information is passed from node to node in the upstream direction. Water levels are a function of the discharge and what's happening downstream (for the most part). That's why it is always a good idea to troubleshoot the hydraulic results from downstream to upstream. Conversely, sediment is constantly moving in the downstream direction (assuming it is moving at all). Therefore, troubleshoot the sediment issues from upstream to downstream.

Guidelines for Troubleshooting

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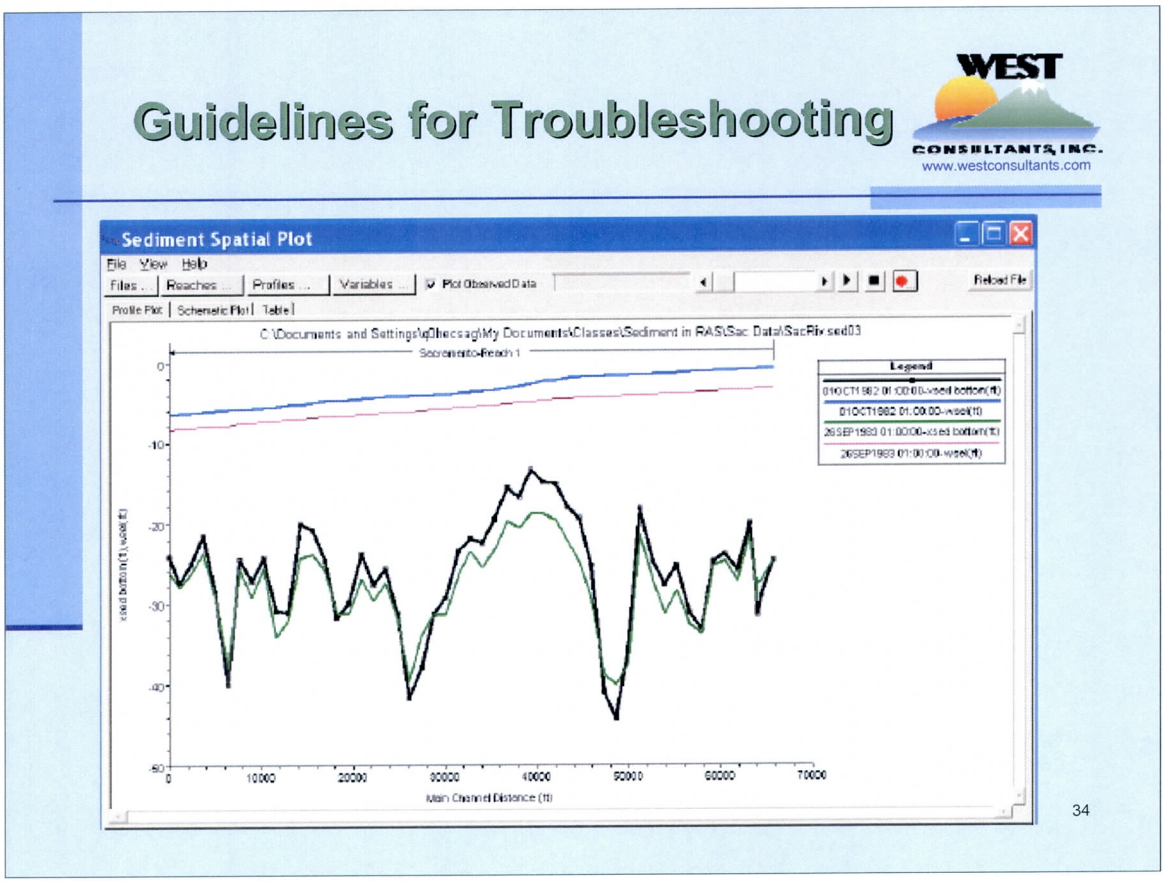
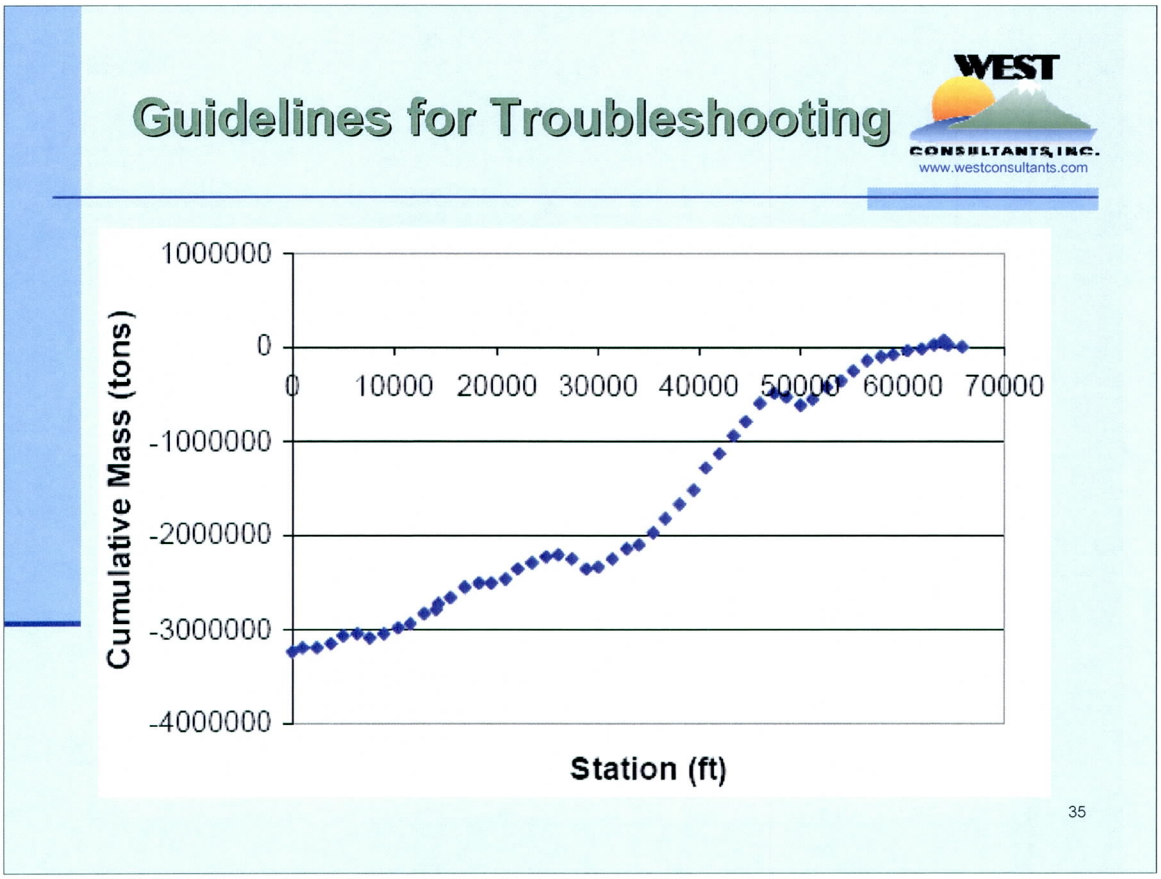
- Look at the Mass Balance in your system. Examine from Upstream to Downstream.
  - Does it make sense?
  - Does the Spatial Profile Plot show the same trend in scour or deposition as the Cumulative Mass Plot

33

It's always a good idea to check your spatial and time series plots against a mass balance plot. It's quite possible that for cross sections spaced far apart, or with wide mobile bed limits (or both), a large amount of sediment addition to its reach may show up as a very small increase in bed elevation. The sediment is effective spread out over a large area.



This plot shows a reach that is generally degradational. There are some aggradational sections, but overall, it is degradational.



The mass plot confirms that the reach is dominated by erosion. A closer look at the plot confirms consistency with the spatial plot at station 47000. This is a small section of the reach that is deposition over the simulation period.

Guidelines for Troubleshooting

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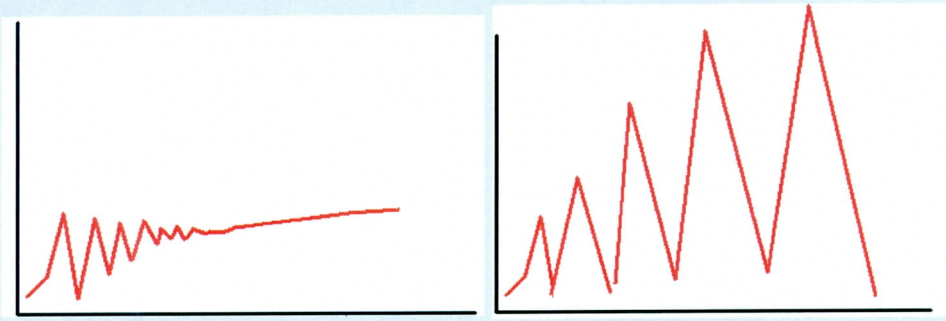
- Is it an Oscillation or an Instability
  - An Oscillation will dampen over time with constant boundary conditions.
  - An Instability will continue to grow over time with constant boundary conditions.



36

It is good to understand the difference between an natural oscillation in the movement of sediment through a reach and an instability generated by the numerical techniques used. Genarlly, oscillations will dampen out naturally under constant (steady-state) conditions. An instabilty can continue to grow and lead to very erroneous data or a simulation crash.

Guidelines for Troubleshooting

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- Try to AVOID…
  - Using a flow series that is not representative of the real hydrology.
  - Using artificially high Manning's n values in an effort to meet calibration objectives
  - Failing to allow enough time for boundary condition changes to affect sedimentation processes for the entire model.

37

This is a list of things to try to avoid when running your sediment transport model.

Sediment Investigation and Stable Channel Design for the Lower Mud River

A Case Study

Martin J. Teal, P.E., P.H., D.WRE
WEST Consultants, Inc.

This case study is of a project performed for USAED Huntington by WEST Consultants, Inc.

Introduction

- Background
- Stable Channel Design
- Sediment Analyses
- Conclusions

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Background

- U.S. Army Corps of Engineers, Huntington District Project
- Location – West Virginia, tributary to Ohio River

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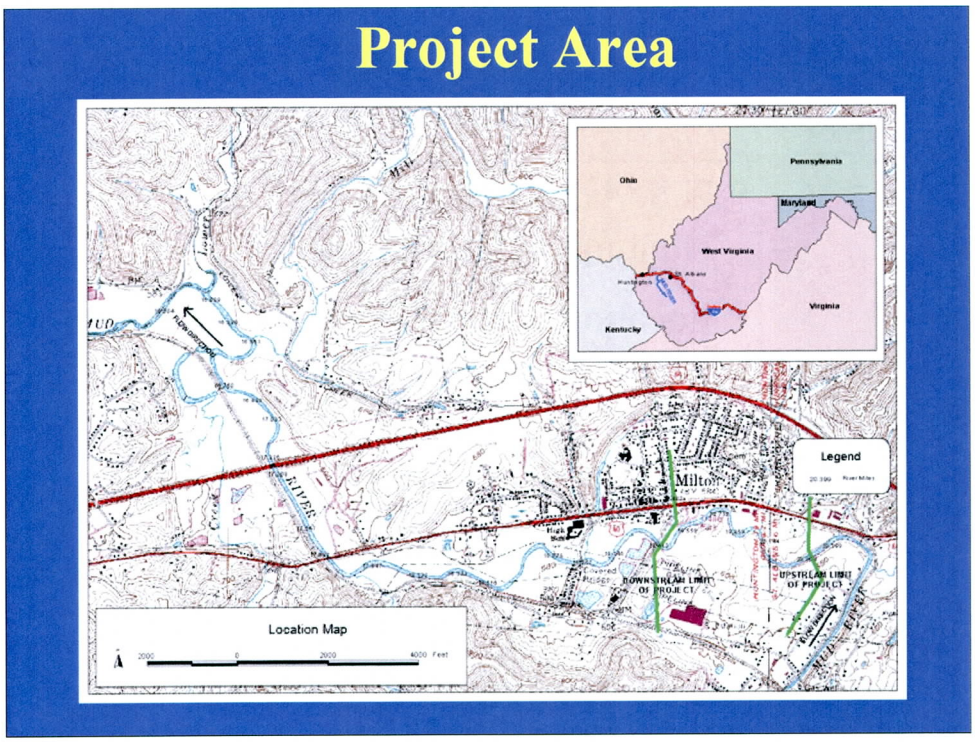

The project limits are indicated on the figure. As we will see later, the model limits were located a significant distance both up- and downstream of the project limits.

View of the Lower Mud River near the upstream project limit during higher than normal flow. In general, the Lower Mud River appears to be a fairly stable river with little signs of active aggradation or degradation. Bank erosion was almost nonexistent.

Background

- U.S. Army Corps of Engineers, Huntington District Project
- Location - West Virginia, tributary to Ohio River
- Purpose – Local Flood Protection for City of Milton
- Approach - Hydraulic and Sediment Transport Modeling, Geomorphic and Stable Channel Analysis

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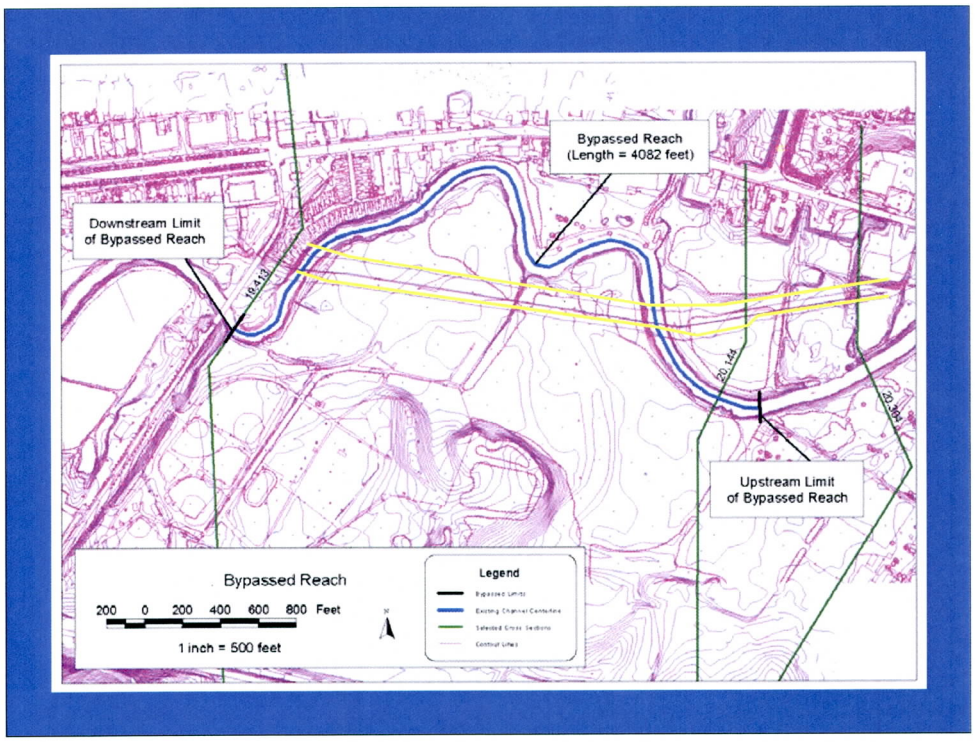
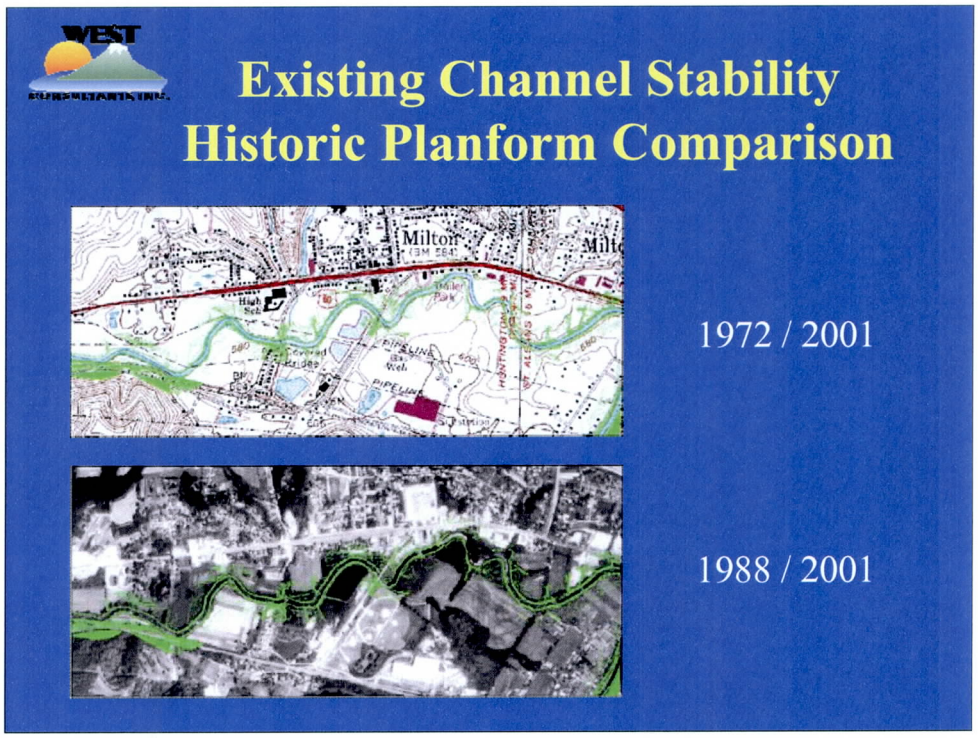
Background - Preferred Alternative

- New levee, 250-year level of protection
- Re-aligned river reach within project limits

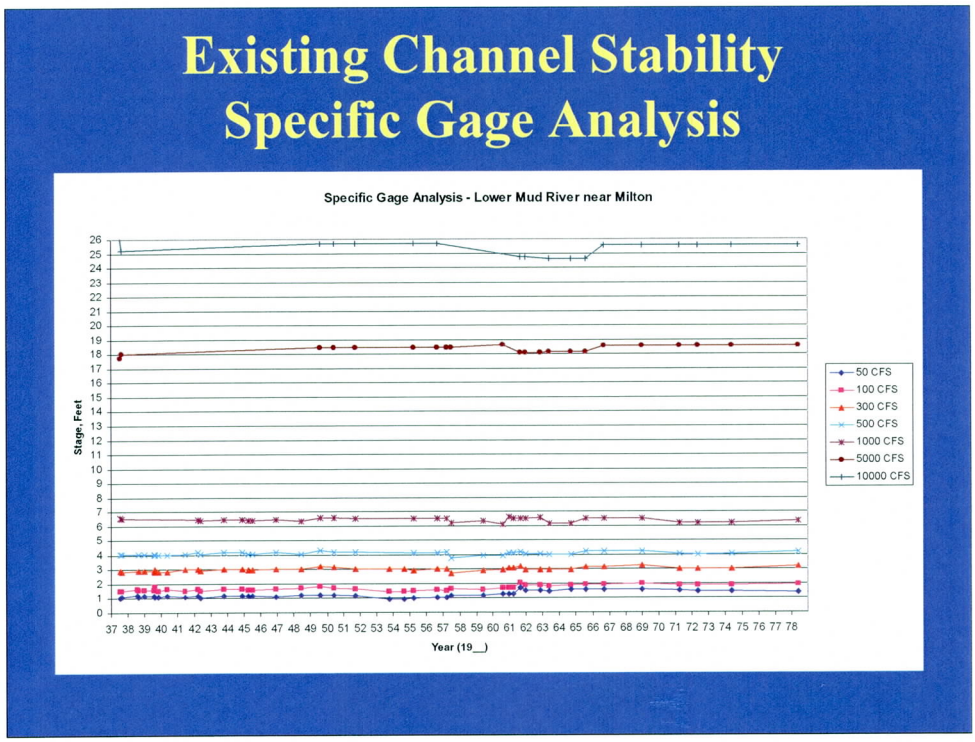
The levee level of protection was determined by Huntington District based on economic analyses and benefit/cost ratios of alternatives. The levee footprint for the preferred alternative was also provided by the District.



A straight-line connection between the upstream and downstream bends would be about 2400 feet, only half of the existing channel reach length.

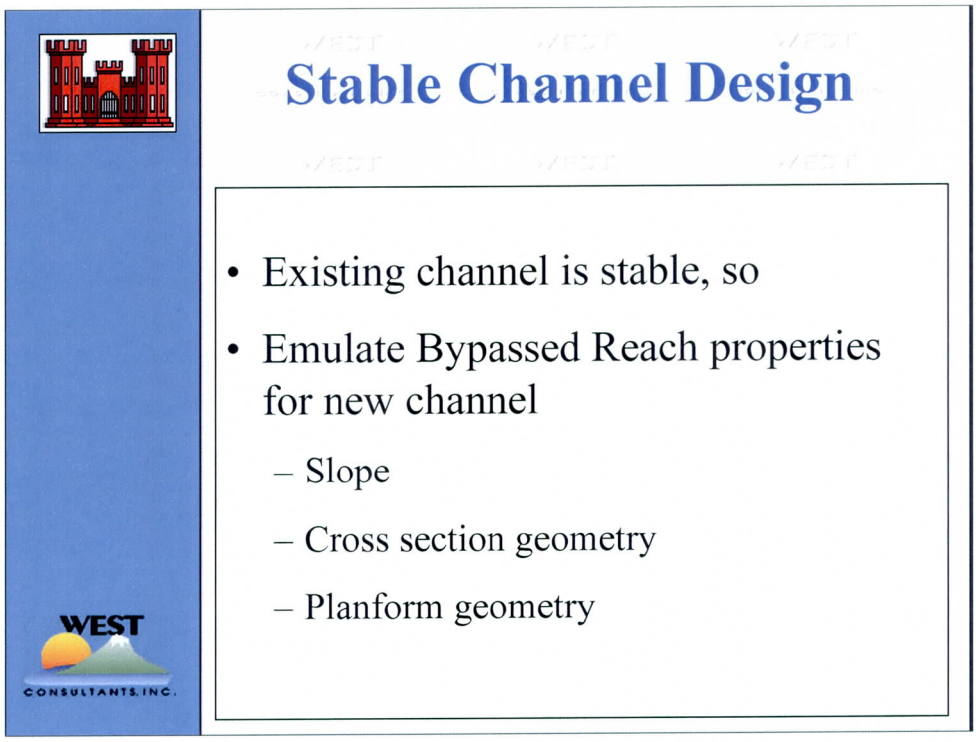


Almost no change was observed between 1972 and 2001.



USGS gage number 03204500 was located near a bridge near the Zoar Baptist Church, about 5 miles upstream of Milton. The site of the gage was visited during the field reconnaissance and no hydraulic controls were noted at the site. Forty-four rating curves were obtained from the COE which cover the time period 1938 to 1978. Each rating curve was examined to determine the stage over time for a series of given flows: 50, 100, 300, 500, 1,000, 5,000, and 10,000 cfs.

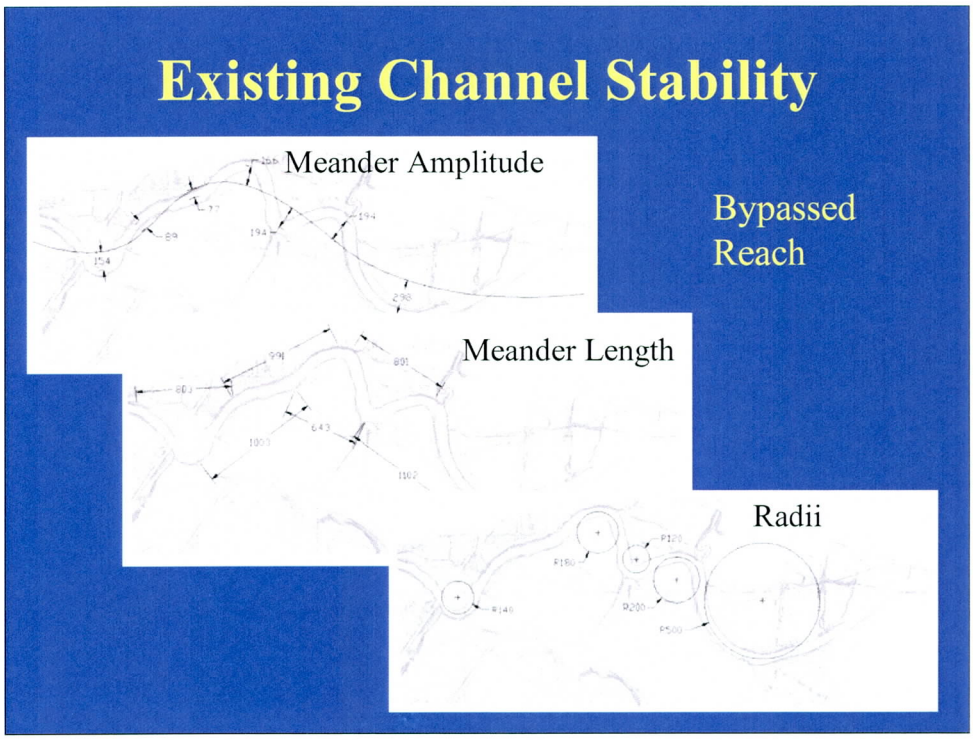
The results of the specific gage analysis suggest that the Mud River near Milton was relatively stable between 1937 and 1980 (42 years). Minor variations in stage, as seen in the plot, are usually within the measurement accuracy that may be expected for this type of analysis.



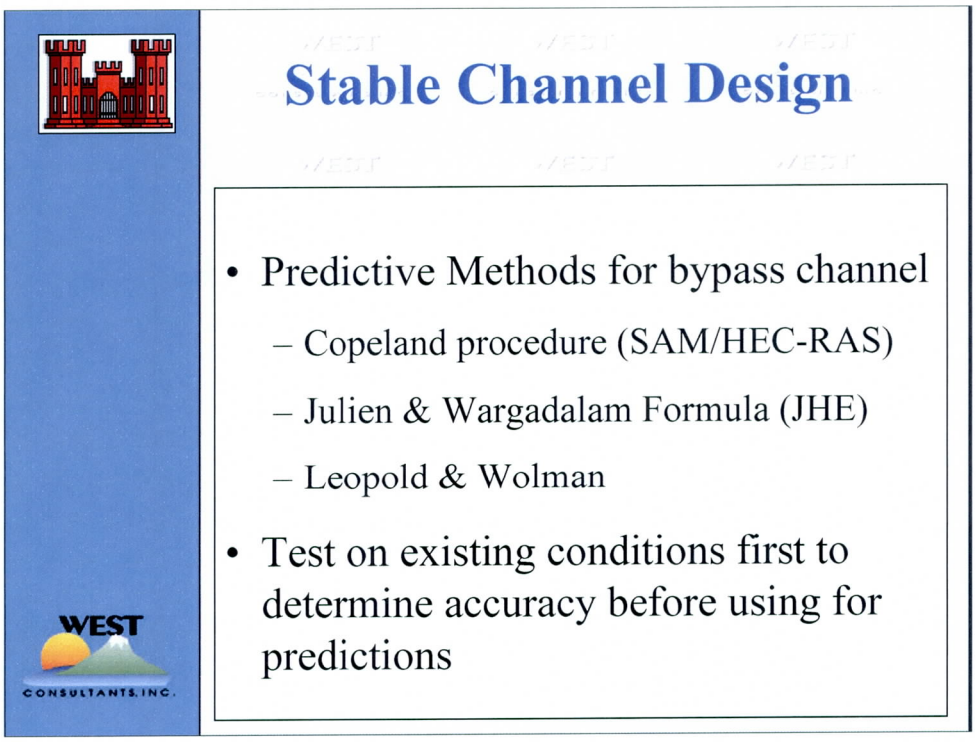
Because the bypassed reach is apparently stable, the primary objective of the design of the new reach was to duplicate the parameters in the bypassed reach. For ease of design and analysis, a trapezoidal cross section was used for the new reach. Observation of cross sections from the HEC-RAS model shows that existing sections can also be reasonably approximated by a trapezoid.

The design of the new reach had the primary objectives of preserving the length and slope of the bypassed reach, and preserving the approximate channel geometry of sections in the bypassed reach. Secondary objectives were duplication of meander lengths and meander amplitudes of the existing channel. Another objective was that the meanders should maintain the left-right alternation found in natural channels. This last objective required, for example, that the first meander at the upstream limit of the new reach turn to the right since the previous upstream meander turned to the left.

The by-pass channel initial design was based on geomorphic principles – sediment transport analyses would be used later to examine channel stability over time.



DGN files for current site conditions and the preferred alternative were supplies by the District. These and other coverages such as aerial photography and contours were brought into GIS to perform measurements.



Predictions of stable dimensions for channel width, depth, and longitudinal slope were generated using two "regime" methods. The first method is Copeland's procedure (Copeland, 1994), which balances inflowing and outflowing sediment transport to predict stable channel dimensions. Although computations for this study used SAM, this method has since been implemented in HEC-RAS. The second method is Julien and Wargadalam's method (Julien and Wargadalam, 1995), which uses a series of equations to predict channel dimensions. Predictions of meander length and amplitude were made using formulas developed by Leopold and Wolman, which predict these parameters based on channel width (Leopold and Wolman, 1960).

Stable Channel Design
Channel Forming Discharge

- Q_{cfd} estimated via Bankfull Discharge
  - 1.5-year (Dunne & Leopold) – 1.1-yr = 5480 cfs
  - 0.6% exceedance of mean daily Q's (Nixon) = 4080 cfs
  - HEC-RAS – 3500 to 4500 cfs
- Adopted $Q_{bf} = Q_{cfd}$ =4080 cfs

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The use of regime equations or SAM/HEC-RAS to predict channel geometry requires specification of a channel-forming discharge. This discharge is a single representative flow that will theoretically produce (for stable rivers in regime) the same bankfull dimensions as the natural sequence of flow events. This discharge is also known as the dominant discharge.

Biedenharn et al., (2000) describe three ways to estimate channel-forming discharge. The first estimate is the bankfull discharge, the maximum discharge a stream can convey without overflowing its banks. This can be estimated by recurrence interval flows, hydraulic modeling and field reconnaissance.

The second estimate of channel-forming discharge described by Biedenharn et al., is based on flood recurrence intervals, generally being between the 1-year and 5-year floods. It can be difficult to make a precise estimate from this very wide range of discharges.

The third estimate of channel-forming discharge suggested is the effective discharge. which is that discharge which transports the largest fraction of the average annual bed-material load.

The most practical approach, and the most common practice, is to use bankfull discharge to estimate the channel-forming discharge. That approach was adopted here.

For this reach of the Lower Mud River, the 1.5-year flood (as suggested by Dunne & Leopold [1978] to estimate bankfull) was not calculated, but the 1-year flood is 5,481 cfs and the 5-year flood is 11,259 cfs. However, even the 1-year flood caused most of the cross sections in the bypassed reach to overtop their banks in the HEC-RAS model. The hydraulic model results indicated that discharges somewhere between 3,500 to 4,500 cfs resulted in a bankfull condition at most cross sections. The exceedance percentage method of estimating bankfull showed that the 0.6% exceedance discharge equaled 4,080 cfs. Because both the HEC-RAS model and the exceedance discharge method indicate a lower channel-forming discharge than the 1.5-year flood method, these results were considered more reliable. The 4,080 cfs bankfull discharge obtained from the exceedance method was in the range of the bankfull discharges observed from the HEC-RAS model, and was adopted as the bankfull discharge and the channel-forming discharge for the purposes of this study.

Stable Channel Design
Copeland Method

- Family of slope-width-depth solutions for stable channel using Brownlie sediment transport method
- Input: discharge, roughness, channel shape, inflowing concentration
- Excellent agreement with observed conditions

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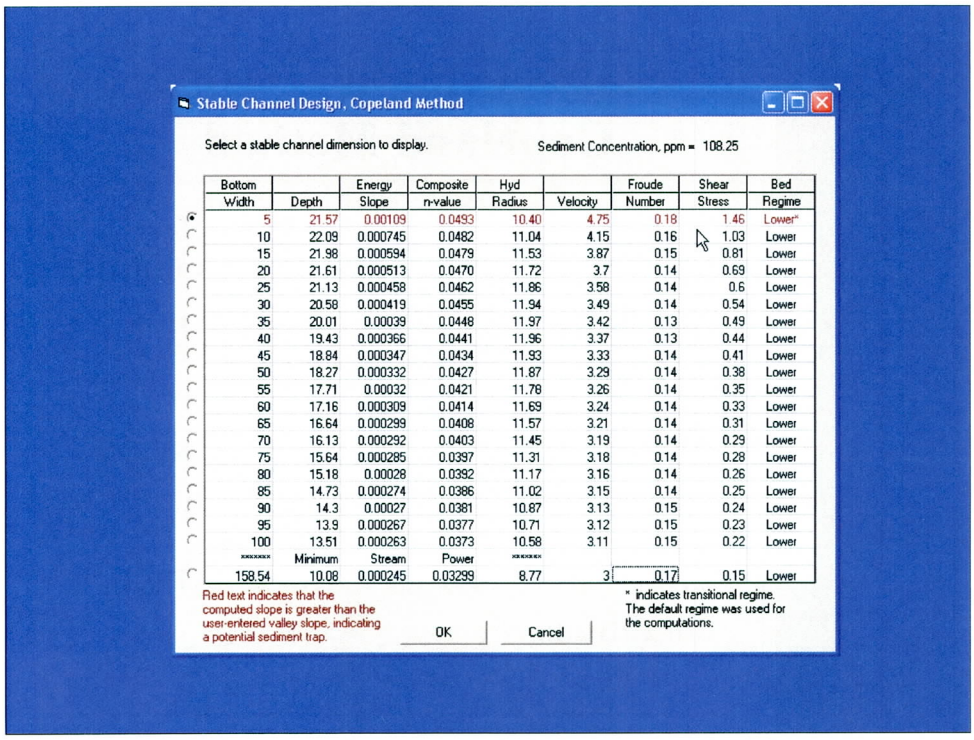
The agreement between cross section parameters in the bypassed channel reach and the SAM predictions is excellent. However, this is to be expected. The HEC-6T model was used to generate the sediment transport rates used as an input into SAM. It is therefore not surprising that SAM predicts stable channel parameters which are similar to the actual cross sections found in the bypassed reach. The SAM results are useful, however, for verifying the trapezoidal dimensions and slopes which provide similar sediment transport rates to the natural channel in the bypassed reach.



Stable Channel Design, Copeland Method

Select a stable channel dimension to display.

Sediment Concentration, ppm = 108.25

Bottom Width	Depth	Energy Slope	Composite n-value	Hyd Radius	Velocity	Froude Number	Shear Stress	Bed Regime
5	21.57	0.00109	0.0493	10.40	4.75	0.18	1.46	Lower*
10	22.09	0.000745	0.0482	11.04	4.15	0.16	1.03	Lower
15	21.98	0.000594	0.0479	11.53	3.87	0.15	0.81	Lower
20	21.61	0.000513	0.0470	11.72	3.7	0.14	0.69	Lower
25	21.13	0.000458	0.0462	11.86	3.58	0.14	0.6	Lower
30	20.58	0.000419	0.0455	11.94	3.49	0.14	0.54	Lower
35	20.01	0.00039	0.0448	11.97	3.42	0.13	0.49	Lower
40	19.43	0.000366	0.0441	11.96	3.37	0.13	0.44	Lower
45	18.84	0.000347	0.0434	11.93	3.33	0.14	0.41	Lower
50	18.27	0.000332	0.0427	11.87	3.29	0.14	0.38	Lower
55	17.71	0.00032	0.0421	11.78	3.26	0.14	0.35	Lower
60	17.16	0.000309	0.0414	11.69	3.24	0.14	0.33	Lower
65	16.64	0.000299	0.0408	11.57	3.21	0.14	0.31	Lower
70	16.13	0.000292	0.0403	11.45	3.19	0.14	0.29	Lower
75	15.64	0.000285	0.0397	11.31	3.18	0.14	0.28	Lower
80	15.18	0.00028	0.0392	11.17	3.16	0.14	0.26	Lower
85	14.73	0.000274	0.0386	11.02	3.15	0.14	0.25	Lower
90	14.3	0.00027	0.0381	10.87	3.13	0.15	0.24	Lower
95	13.9	0.000267	0.0377	10.71	3.12	0.15	0.23	Lower
100	13.51	0.000263	0.0373	10.58	3.11	0.15	0.22	Lower
******	Minimum	Stream	Power	******				
158.54	10.08	0.000245	0.03299	8.77	3	0.17	0.15	Lower

Red text indicates that the computed slope is greater than the user-entered valley slope, indicating a potential sediment trap.

OK

Cancel

* indicates transitional regime. The default regime was used for the computations.

Stable Channel Design in HEC-RAS Hydraulic Design Functions output showing the family of stable channel curves.

Stable Channel Design
Julien & Wargadalam

- Three predictor equations for average water depth, width, and slope
- Input: discharge, median grain size, Shields Number
- Excellent agreement for slope, predicts a slightly wider and shallower channel than observed.

Julien and Wargadalam's formulas provide a more independent prediction of stable channel parameters than the Copeland method, since they do not depend on sediment transport rates calculated externally (HEC-6T or HEC-RAS). The predicted channel slope of 0.00045 is very close to the actual slope of about 0.00042 to 0.00046 (depending on which upstream limit is used to calculate the slope). The Julien and Wargadalam method, however, predicts a somewhat wider and shallower channel than found in the bypassed reach. The actual average depth is about 10 feet versus a predicted 7.2 feet. The actual widths range from below 100 feet to about 145 feet, versus a predicted 187 feet. One possible reason why the existing channel is narrower and deeper than the method's predictions may be the presence of cohesive bank material along much of the Lower Mud River (cohesive material is not considered in the method).

Stable Channel Design
Leopold & Wolman

- Two predictor equations for meander length and amplitude
- Input: channel width
- Good agreement for meander length
- Predicted amplitude much higher than observed

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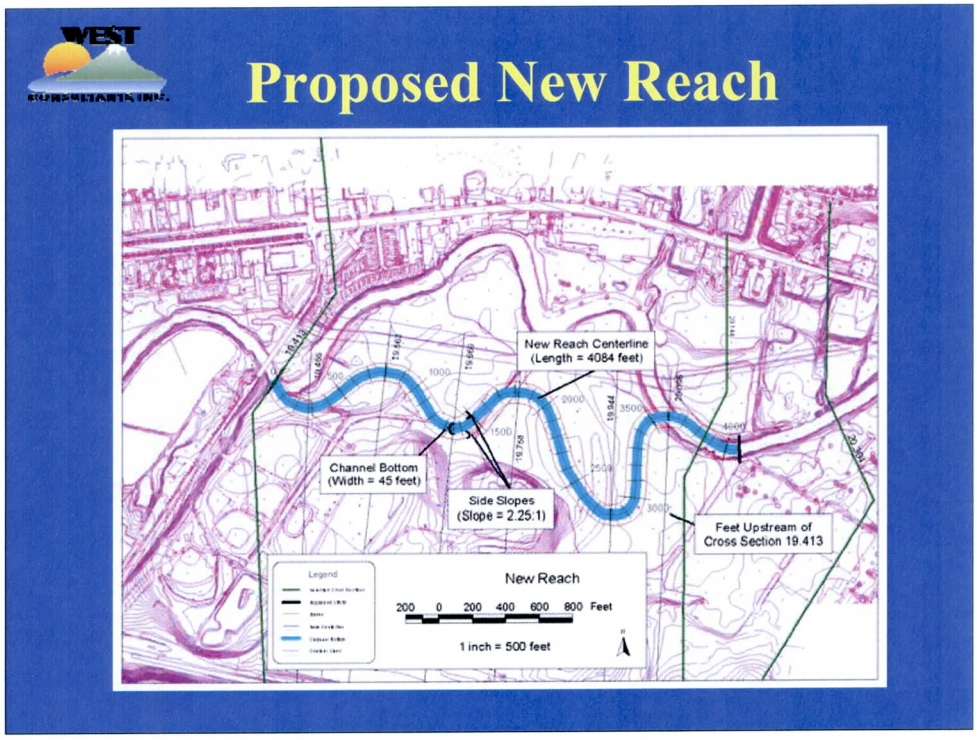
The average existing meander length is 937 feet. The predicted stable meander length of 1234 feet is reasonably close to this value.

The meanders in the bypassed reach have amplitudes of 77, 89, 154, 166, 194, and 298 feet. The average of these is 163 feet. The predicted meander amplitude of 466 feet is considerably higher than the existing values.



The design of the new reach had the primary objectives of preserving the length and slope of the bypassed reach, and preserving the approximate channel geometry of sections in the bypassed reach. Secondary objectives were duplication of meander lengths and meander amplitudes of the existing channel. Another objective was that the meanders should maintain the left-right alternation found in natural channels.

In addition to duplicating the previously measured parameters of the bypassed reach, the vertical position of the new channel needed to be established. The cross section of the existing (bypassed) channel at river mile 20.144, near the upstream limit of the bypassed channel, was used to establish the elevation of the new channel. This cross section is fairly regular and has an average bottom elevation of about 560.0 feet.

For simplicity, the longitudinal slope of the new reach was set to a constant value, as was the bottom width and sides slopes. This was reasonable, as the existing slope of the bypassed reach is also more or less constant.

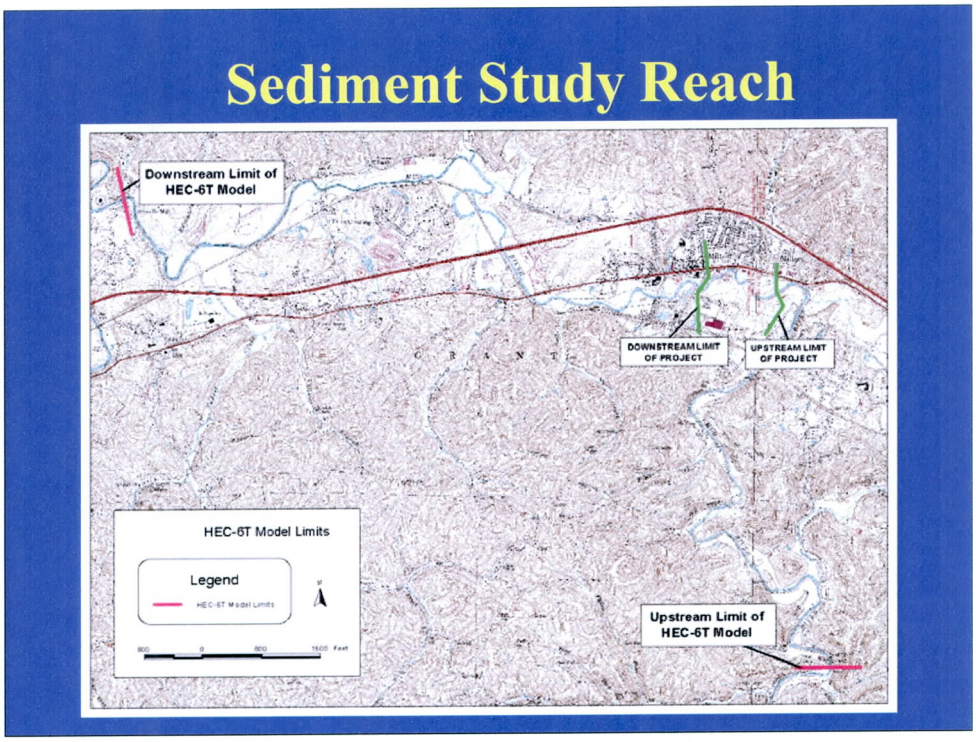
The available corridor for the new reach is bounded to the north by the proposed levee. In addition, the alignment incorporated a 100-foot buffer zone from the toe of the proposed levee to the top of bank of the new channel. The corridor is bounded to the south by hills.

The proposed alignment is shown in this slide. This alignment is based on a 0.00045 longitudinal slope, 45 foot bottom width, 2.25:1 side slopes, and an elevation of 560.00 where the channel centerline intersects cross section 20.144. The bank lines shown are based on where the side slopes would intersect the existing topography, assuming that the bypassed channel is filled in where it does not overlap the new channel. The closest the right bank of the new channel gets to the toe of the proposed levee is 96 feet at one of the bends. The right bank at the other bends is 100 feet or more away from the levee toe.

Sediment Transport Analysis

- Purpose: Evaluate stability of future without project and future with project
- Long-term: Historic data used for fifty year simulation period
- Single Event: Largest recorded hydrograph scaled up for 100-year flood event
- Employed HEC-6T model

The original study used HEC-6T, but some input/output has been recreated with the sediment functions in HEC-RAS for this presentation.



The extents of the HEC-6T model are from RM 105.09 at the downstream end to RM 109.73 at the upstream end. This reach of river is included in the HEC-RAS model and was chosen because it contains the project area and allows sufficient river length both upstream and downstream to show potential project effects and resolve instabilities typically associated with model boundaries. The proposed project is located upstream of the Fairgrounds Road Bridge (~RM 19.4) and extends upstream to approximately RM 20.3.

The downstream boundary of the model is at the Howell's Mill weir. This location was chosen because it provides a grade control for the channel. A rating curve was computed at the weir based on a previous model of the Mud River provided by the District (that model had its downstream limit at the Guyandotte River). The upstream boundary was chosen at the site of the former USGS gage. This location was chosen because both water and sediment inflows were developed from data originally collected at this gage.

Sediment Transport Analysis Topics

- Geometry and Hydraulic Model
- Erosion & Deposition limits
- Sediment Sampling & Testing
- Inflowing Sediment Load & Gradation
- Sediment Transport Equation

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Each of these topics will be covered in subsequent slides.

Sediment Transport Analysis Topics (cont'd)

- Hydrology
- Fixed-bed Calibration
- Sediment Model Calibration
- FWOP Results
- Sensitivity Analysis
- Preferred Alternative Results and Comparison with FWOP Results

Each of these topics will be covered in subsequent slides.

Sediment Transport Geometry & Hydraulics

- Hydraulic model based on FIS (HEC-2), later modified by the District (HEC-RAS)
- Roughness acceptable, later subjected to sensitivity
- Cross sections re-aligned, ineffective flow limits modified as necessary

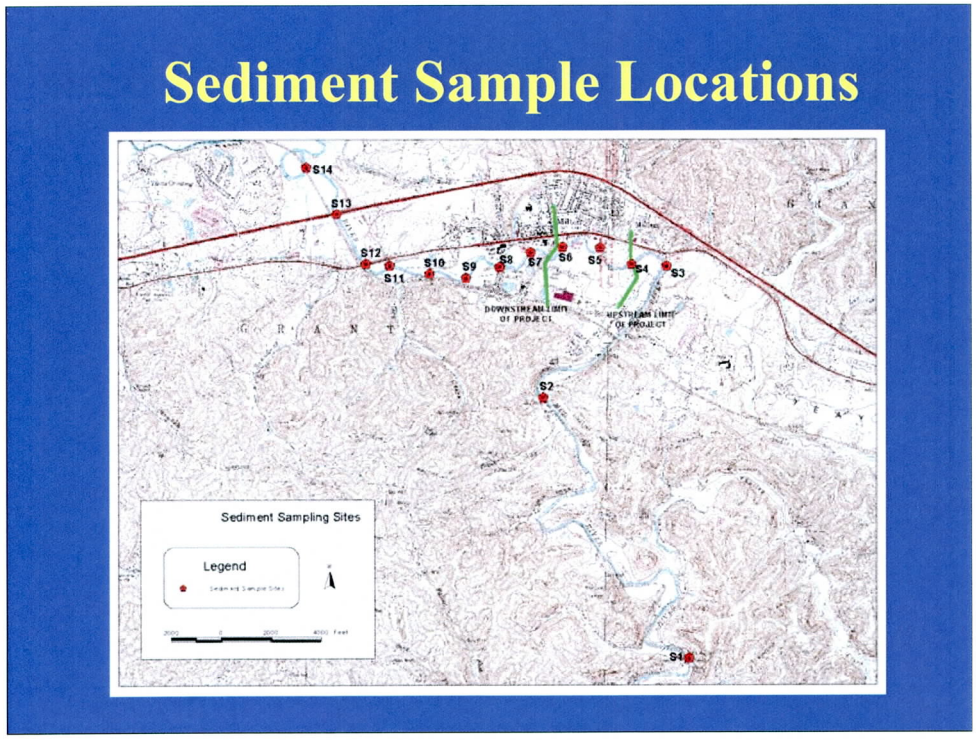
Roughness (Manning's 'n') values for the reach were developed for the original FIS model (FEMA, 1987) and subsequently slightly modified by the District. Because assignment of roughness values is somewhat subjective and the values from the previous model were, in our judgment, not outside of reasonable limits, the original 'n' values were not modified. Sensitivity of sediment transport model results to roughness were, however, examined (addressed later).

Cross section locations were not changed from the previous study, although several cross sections were re-aligned to be normal to the flow direction. Ineffective flow limits were checked and adjusted as necessary, and "slivers" (small openings left under bridge abutments) were removed. Depressions in the overbanks that are not representative of flow conveyance were also removed in two cases.

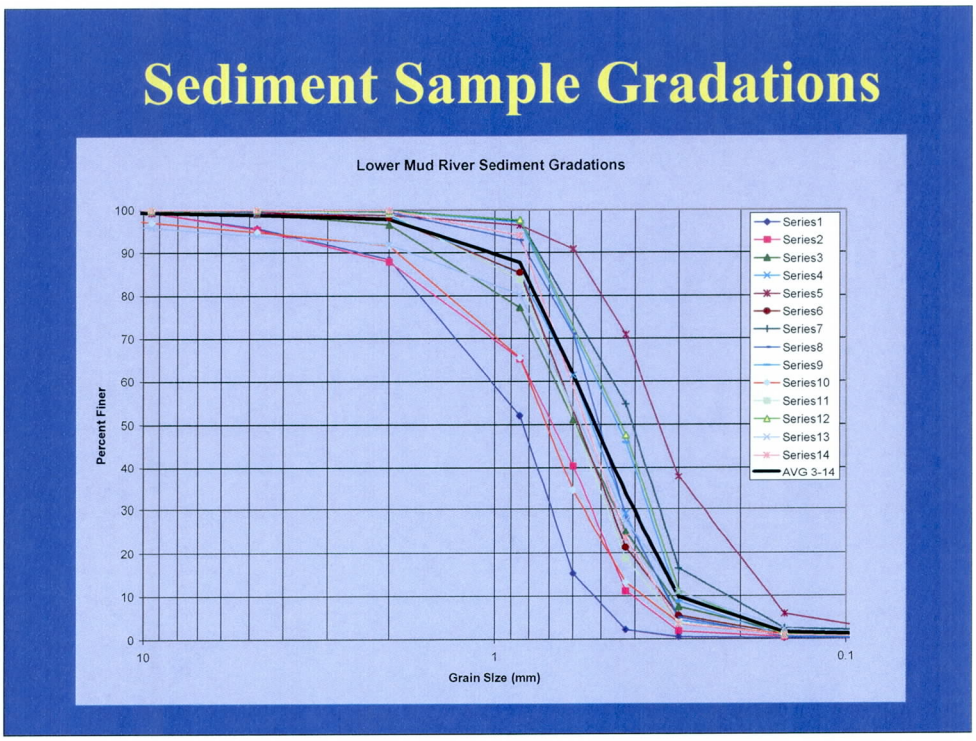
Erosion and Deposition Limits

- Determined from field reconnaissance and cross section plots
- Erosion generally limited to within main channel limits
- Deposition allowed anywhere in wetted cross section for most sections
- Erosion limited at weirs

From the field reconnaissance and plots of the cross sections, the lateral limits of erosion and deposition were determined and input to the HEC-6T model. The model assumes that scour is uniform between the erosion limits for wetted portions of the cross section. Deposition can occur anywhere inside the deposition limits within the wetted portions of the cross section. In general, the erosion limits are within what is termed the □active bed□ and are often located just within the main channel limits. All cross sections were allowed to erode with the exception of those located at the Howell's Mill weir and the City of Milton water supply weir.

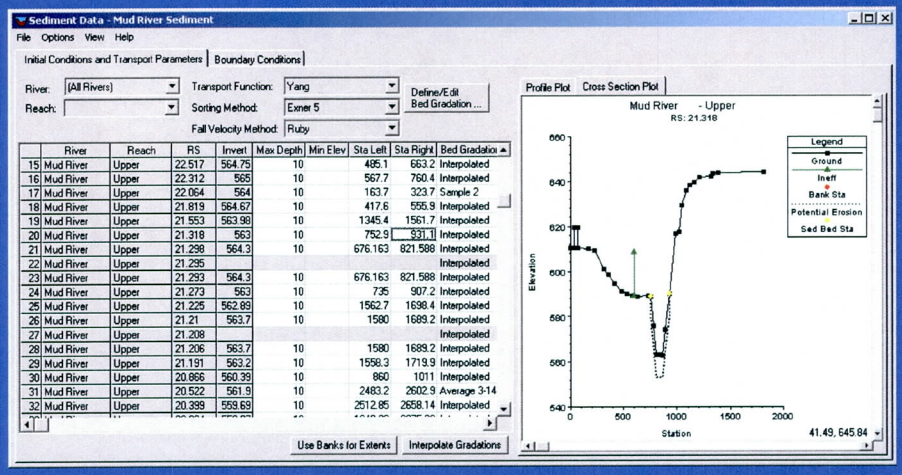


Bed material samples were collected at various locations along the Lower Mud River to examine gradations at various locations for modeling purposes. Fourteen grab samples were collected from the channel bottom using a Wildco petite ponar and were brought to a lab for development of size distribution information per ASTM D 421 (Sieve Analysis).



Bed sediment gradations within the study reach are a required input for sediment transport modeling. At cross sections that do not have sample gradations available, the upstream and downstream cross section gradations are linearly interpolated (using a logarithmic scale) to produce a representative gradation. This interpolation is performed automatically. The Sample 1 gradation was used for the two most upstream cross sections in the model (RM 25.862 and 25.617) as it was judged representative of the coarser material found near the bridge marking the upstream limit of the model. The Sample 2 gradation was used at the cross section at RM 22.064, the approximate location at which it was collected. For cross sections upstream of this point, but downstream of the section at RM 25.617, the program was allowed to interpolate the gradations between those of Sample 2 and Sample 1. At the location of Sample 3 (~RM 20.522), and at all cross sections downstream of that point, a representative gradation taken from the average of Samples 3-14 was used (shown as the curve labeled "AVG 3-14"). At cross sections between RM 25.617 and RM 20.522 the program was allowed to interpolate gradations.

Sediment Input

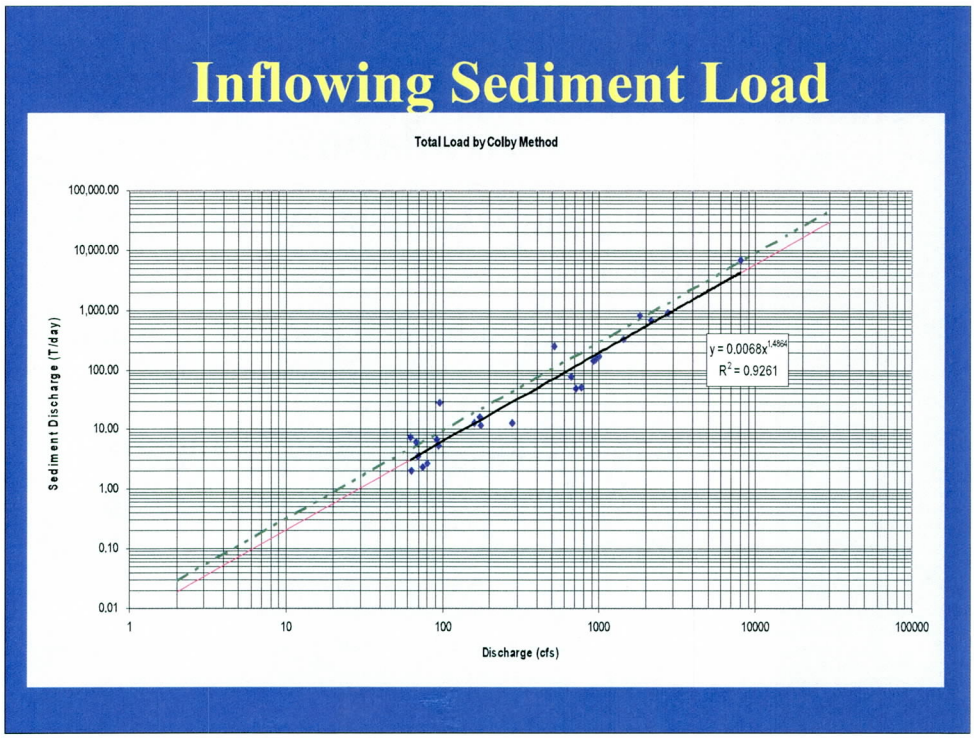


	River	Reach	RS	Invert	Max Depth	Min Elev	Sta Left	Sta Right	Bed Gradatio
15	Mud River	Upper	22.517	564.75	10		485.1	663.2	Interpolated
16	Mud River	Upper	22.312	565	10		567.7	760.4	Interpolated
17	Mud River	Upper	22.064	564	10		163.7	323.7	Sample 2
18	Mud River	Upper	21.819	564.67	10		417.6	555.9	Interpolated
19	Mud River	Upper	21.553	563.98	10		1345.4	1561.7	Interpolated
20	Mud River	Upper	21.318	563	10		752.9	931.1	Interpolated
21	Mud River	Upper	21.298	564.3	10		676.163	821.588	Interpolated
22	Mud River	Upper	21.295						Interpolated
23	Mud River	Upper	21.293	564.3	10		676.163	821.588	Interpolated
24	Mud River	Upper	21.273	563	10		735	907.2	Interpolated
25	Mud River	Upper	21.225	562.89	10		1562.7	1698.4	Interpolated
26	Mud River	Upper	21.21	563.7	10		1580	1689.2	Interpolated
27	Mud River	Upper	21.208						Interpolated
28	Mud River	Upper	21.206	563.7	10		1580	1689.2	Interpolated
29	Mud River	Upper	21.191	563.2	10		1558.3	1719.9	Interpolated
30	Mud River	Upper	20.866	560.39	10		860	1011	Interpolated
31	Mud River	Upper	20.522	561.9	10		2483.2	2602.9	Average 3-14
32	Mud River	Upper	20.399	559.69	10		2512.85	2658.14	Interpolated

Inflowing Sediment Load and Gradations

- 43 suspended samples available for 3-8,000 cfs
- 31 samples indicated percent of wash load
- Using average wash load, computed total bed material load using Colby Method

Forty-three suspended sediment samples were collected by the USGS at the Milton gage for flows ranging from approximately 3 to 8,000 cfs. Thirty-one of the samples had a recorded value for percent of material finer than 0.062 mm. The percent of the suspended samples consisting of wash load (finer than 0.062 mm) ranged from 25 to 100 percent, with an average of 73 percent (78 percent for samples for flows greater than 200 cfs). The Colby method (Vanoni, 1975, pp. 218-220) was used to estimate total bed sediment discharge based on the stream measurements of suspended discharge. The values of mean channel velocity, stream width, and mean depth, necessary input for the method, were taken from the HEC-RAS results for the cross sections at RM 25.847 and 25.862. In order to use the information for samples where the percent of fines was not measured, these were assigned a value of 73% wash load for flows less than 200 cfs and 78% for flows greater than 200 cfs based on the averages presented previously. Only measured data collected when the computed channel velocity was greater than 1 ft/s were used (27 points) because this is the low velocity threshold for the Colby method.



A power equation was fit to the data using the method of least squares and is presented along with the computed points in the figure. Initial inflowing sediment load to the model reach was computed using the equation, Qs = 0.007*Q^1.49 (solid line) for all modeled flows.

During the model calibration process it became apparent that the inflowing load was not sufficient to maintain the quasi-stable channel observed in the field and discussed in the previous chapter of this report. The inflowing sediment load was therefore increased by 50% at all discharges. This line (dashed) is also shown in the slide.

Inflowing Sediment Load and Gradations (cont'd)

- Once load obtained, gradations computed using SEDDISCH program
- Capacity by size class computed using Laursen, Engelund & Hansen, Colby, Yang formulas
- Yang (sand and gravel) gave results closest to rating curve, used for inflowing load in each size fraction

The sediment size distribution for the inflowing sediment load was determined with the aid of the sediment transport program SEDDISCH (Stevens and Yang, 1989). Hydraulic parameters from cross sections at RM 25.862 and 25.847 at flows of 1, 100, 1,000, 10,000 and 30,000 cfs were used as input to the program. Total sediment transport and transport by size class were computed at each of these discharges using the Laursen, Engelund and Hansen, Colby, Yang (sand), and Yang (sand and gravel mixture) sediment transport formulas. As the Yang sand and gravel formula gave total transport results closest to those computed using the rating curve discussed in the previous section, those results were used to describe the percentage of inflowing sediment in each size fraction.

Inflowing Sediment Input

Load Specification for Mud River Upper 25.862

Number of flow-load points: 5 sets

	Flow (cfs)	1	100	1000	10000	30000
	Total Load (tons/day)	0.01	2.09	310.1	9584.9	49266
1	Clay					
2	VFM					
3	FM					
4	MM					
5	CM					
6	VFS	0.95	0.03746	0.01528	0.01775	0.01877
7	FS	0.04	0.05049	0.02339	0.02474	0.02556
8	MS	0.01	0.48941	0.29139	0.29196	0.29562
9	CS	0	0.42264	0.47786	0.46312	0.46028
10	VCS	0	0	0.19192	0.20135	0.19893
11	VFG	0	0	0.00016	0.00044	0.00029
12	FG	0	0	0	0.00046	0.00038
13	MG	0	0	0	0.00018	0.00014
14	CG	0	0	0	0.00002	0.00003
15	VCG					
16	SC					
17	LC					
18	SB					

OK Cancel

Sediment Transport Equation

- Williams method used to rank four commonly used sand transport functions
- Best (Brownlie) gave unrealistic results, second (Yang) was chosen
  - Good results in many sand-bed streams
- Sensitivity examined later

Williams (1995) developed a methodology based upon four dimensionless parameters to determine which of four commonly used sand transport formulas gives the most accurate results under different situations. The four parameters are dimensionless grain size, dimensionless mobility number (also referred to as the grain Froude number, a form of the Shields parameter), dimensionless flow depth, and dimensionless stream power. The four transport formulas compared were Ackers-White, Brownlie, Engelund-Hansen, and Yang. Using the Williams method with input from the HEC-RAS model, the identified best method was that of Brownlie, followed by Yang, and then Engelund-Hansen. Based on this ranking, the Brownlie method was selected for use in the Lower Mud River models.

However, initial results showed that the program was not functioning correctly using the Brownlie relation. Although the geometric standard deviation, σ_g, is between 1.4 and 1.9 for the bed samples, HEC-6T generated many warnings that this value was outside the range of data upon which the Brownlie relation is based and would therefore be set to the maximum value of 5. Because of these warnings and the dubious results produced by the model, the second best method, that of Yang, was tried. Because this method produced reasonable results, and because of WEST's experience using this method in many other sand bed stream across the United States, the Yang method was adopted as the preferred transport equation.

An additional transport relation was also examined as part of the sensitivity analysis described later in the report.

Hydrology

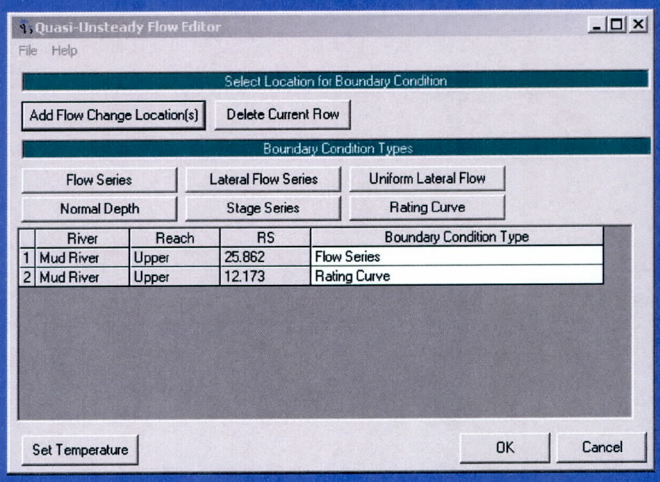
- Long-term and single-event considered
- 50 years of record developed from gage data
- 1% flood hydrograph developed by scaling up largest recorded event

Hydrologic data included both long-term flow data with a period of record equal to the 50-year design life of the project and a single event flood hydrograph. The long-term data are used to develop an understanding of the long-term trends in aggradation/degradation that should be expected as a result of the project. The single event data are used to understand the potential magnitude of aggradation/degradation associated with large flood events and what impact this may have on the hydraulics of the channel during a flood.

The long-term and single event hydrographs were discretized into one-day and one-hour increments, respectively, and used for input to the sediment transport models. For the long-term simulation, only flows greater than 2 cfs were modeled. Flows below this threshold were judged to move negligible amounts of sediment. Water and sediment contributions from tributaries along the model reach were considered to be minor for this system and were not included in these analyses.

The short-term impact from a flood was estimated using the flood hydrograph from the April 1978 flood. Although this flood is not the largest on record, this is the largest flood for which detailed flow records were readily available (at one-hour increments). Ordinates of the 1978 hydrograph were scaled up by the ratio of the peak flows (27,498/6,060) to create the 100-year flood hydrograph.

Quasi-Unsteady Flow Editor

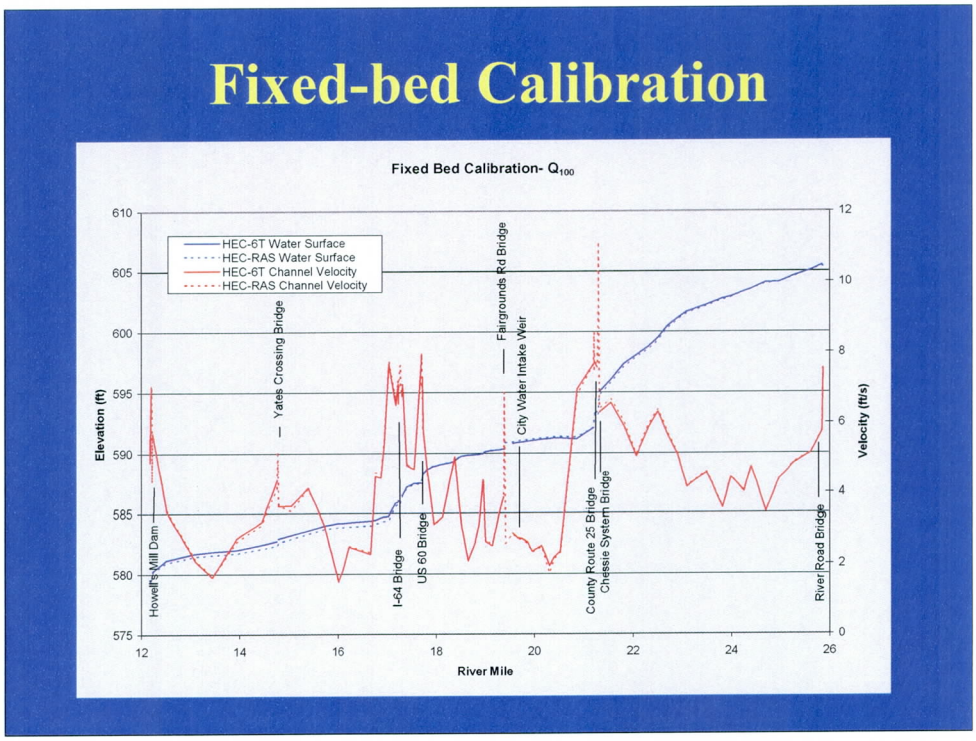


Fixed-bed Calibration

- Necessary to ensure that HEC-6T hydraulics match those from HEC-RAS
- This step no longer necessary with sediment transport in RAS

Typically one wants the HEC-6T hydraulic results to match the HEC-RAS model results as the latter model is more sophisticated in handling hydraulic calculations, especially around bridges. With the advent of sediment transport in RAS this calibration step will probably no longer be necessary.

Hydraulic calibration for this study was achieved by running the HEC-6T model in fixed bed mode (which allows for computation of channel hydraulics without the input of sediment or changes in the channel geometry) and making adjustments to model parameters such as roughness values. HEC-6T does not model bridges in the same manner as HEC-RAS. Therefore, bridges in HEC-6T are typically modeled by changing the hydraulic roughness such that the computed water surface elevations and velocities are approximately equal to the results obtained from the HEC-RAS model. Water surface elevations and mean channel velocities were compared for the 1-, 5-, 20-, and 100-year floods. The results from on profile are shown on the next slide.



Computed water surface elevations for the future without project HEC-6T model compared very well with the HEC-RAS model results for all discharges. The differences between results from the two models were less than 2% for nearly all cross sections. Channel velocity results also compared well. Differences in channel velocities between the HEC-6T and HEC-RAS model results were typically on the order of +/-5%. Expected discrepancies were obtained at the bridges due to the difference in computational algorithms between the two models. Manning's 'n' values were adjusted to vary with elevation at most bridges in order to correctly model backwater created by the structure.

Sediment Model Calibration

- No historic cross section data available
- No historic bed profiles found
- Indicators that planform stable over time
- Specific Gage Analysis shows bed stability over time at one location
- No real calibration possible

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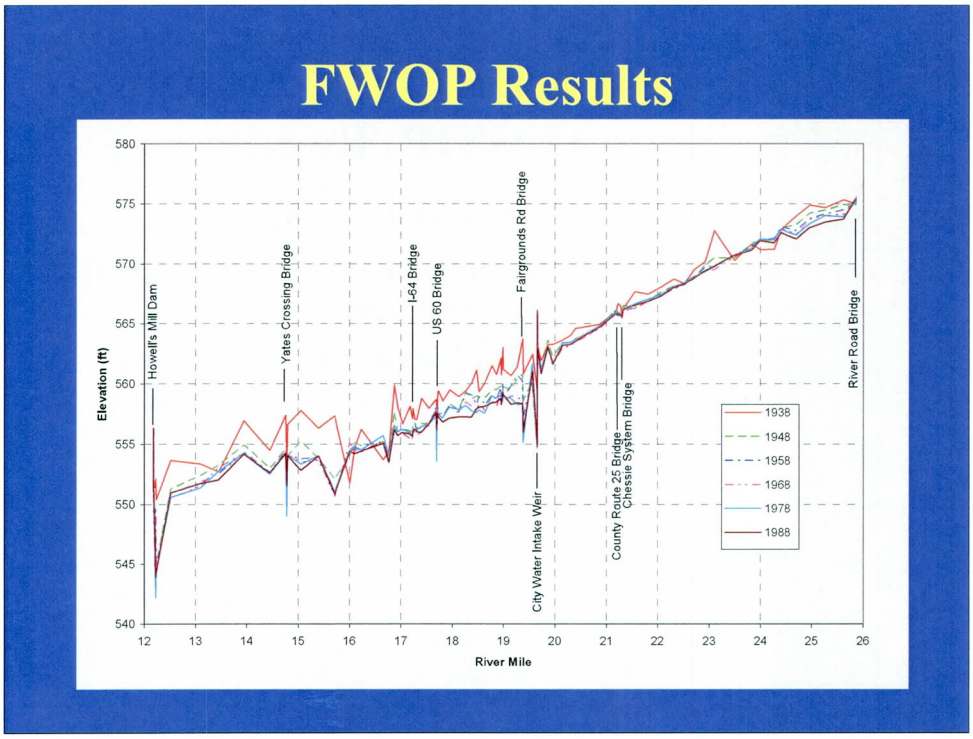
The goal of the existing conditions sediment transport model was to duplicate the quasi-equilibrium observed in the field and from historic data – that is the best that could be achieved in terms of calibration. However, the overall purpose of the study was to compare future without project to future with project conditions. Because we are interested in the relative difference between these two conditions rather than absolute numbers, the lack of calibration becomes less of an issue.

Future without Project (FWOP) Results

- Long-term Simulation (50 years)
  - ∆t = 1 day, adjusted down where needed to acheive convergence
  - Average Bed Elevation and Thalweg profiles, cross section shapes checked every decade
- 1% Event Simulation
  - ∆t = 1 hour
  - Profiles and cross sections checked at peak and at end

The hydraulically calibrated HEC-6T model was used for a long term simulation assumed to represent "future without project" conditions. Sediment and hydrologic data were added to the geometric data set to create the model. Time steps were adjusted downwards from the daily value as needed (usually for larger flows) to allow the model to converge to reasonable solutions.

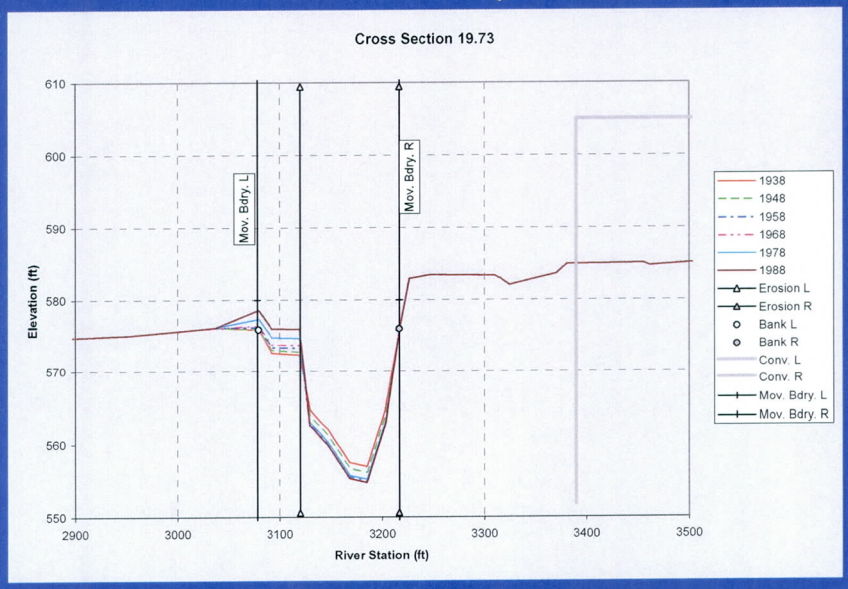
Because the bed sediment gradations are often not "in-sync" with the flow rates at the beginning of the simulation, a warm-up period was used for all models. Half of the channel forming discharge identified previously was run through the model for five days in order to allow sorting of the bed gradation for each cross section in the model. The end of the warm-up period is the simulation start time used for all the predictive sedimentation models.

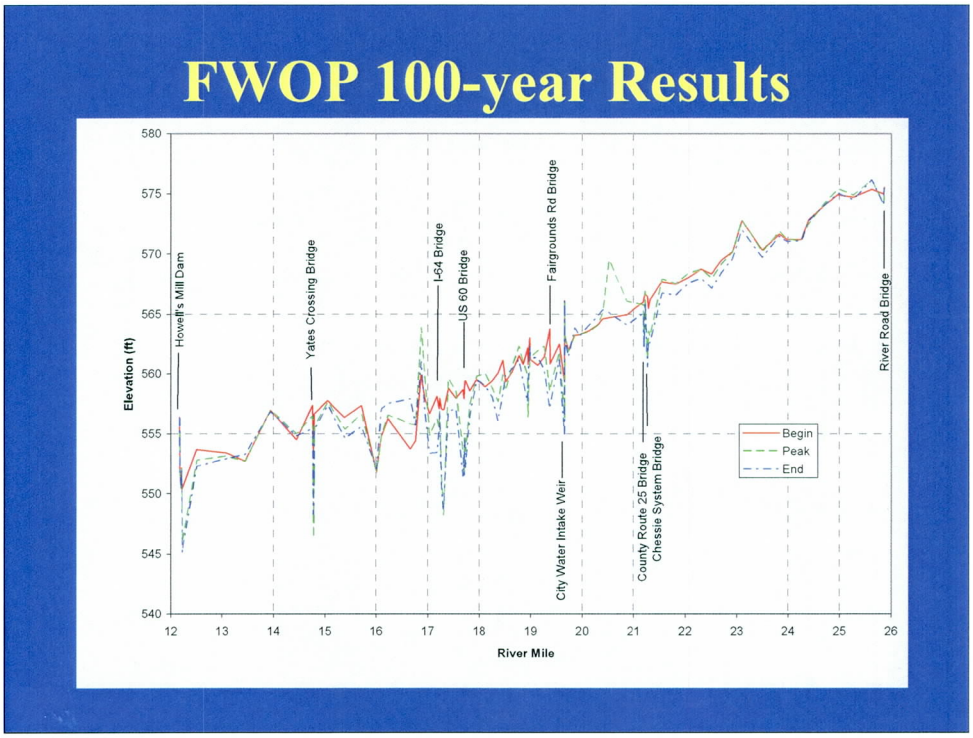


Bed elevations are shown at ten year intervals. Note the highly distorted scale which increases the vertical resolution of the results. Also, the labels for each plot (1938-1988) refer to the years used in the synthetic hydrologic record. Consider the 1938 plot as existing conditions with the other results corresponding to 10, 20, 30, 40 and 50 years into the future.

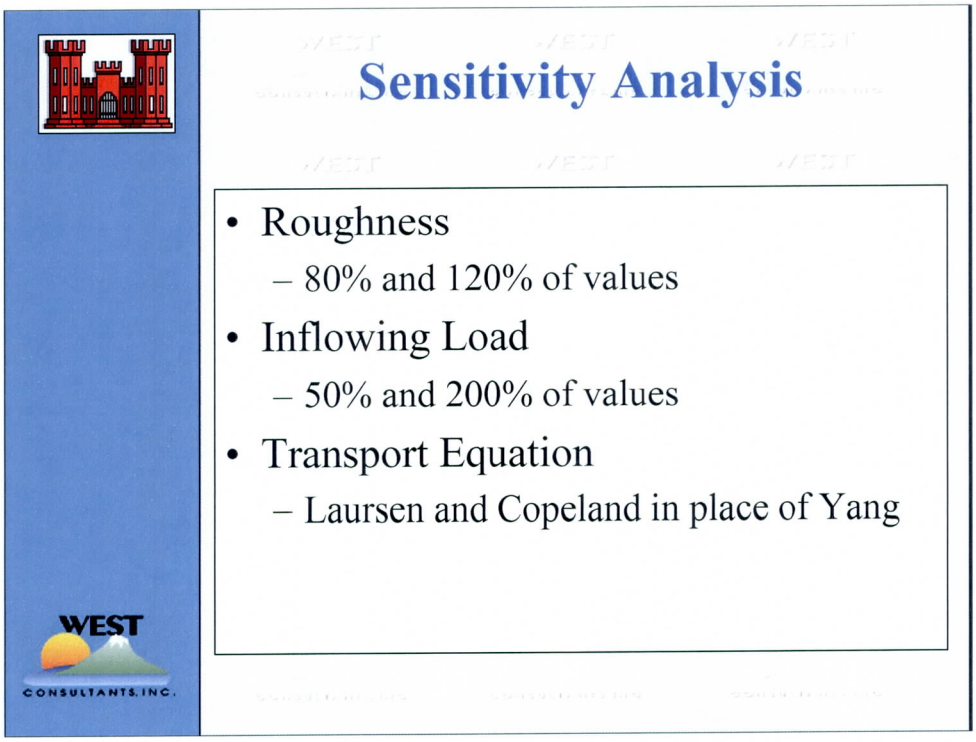
It can be seen in the figure that the model reach is predicted to be slightly degradational for the first one and a half river miles (25.9 – 24.4) downstream from the former gage location at the upstream limit of the model. The following four and a half miles (24.4 to RM 19.9) are predicted to be relatively stable over time. The area located just downstream of this point is affected by the City of Milton water intake weir. This feature is easily discernable on the plot near RM 19.6. The high bed elevation of the weir section is followed by an eroded section immediately downstream of the weir. Another erosional "dip" is located at RM 19.3 and is the result of high velocities created by the Fairgrounds Road Bridge. The next several river miles in the downstream direction (to the confluence with Mill Creek at ~RM 16.7) are predicted to be slightly degradational over time. The downstream part of the model reach, from RM 15.7 to Howell's Mill at RM 12.173 is also predicted to be largely degradational. The combination of the weir structure and bridge crossing at the downstream end of the model produces the erosion seen near RM 12.2, and the effect of the Yates Crossing Bridge can also be seen near RM 14.8.

FWOP Results (XSection)

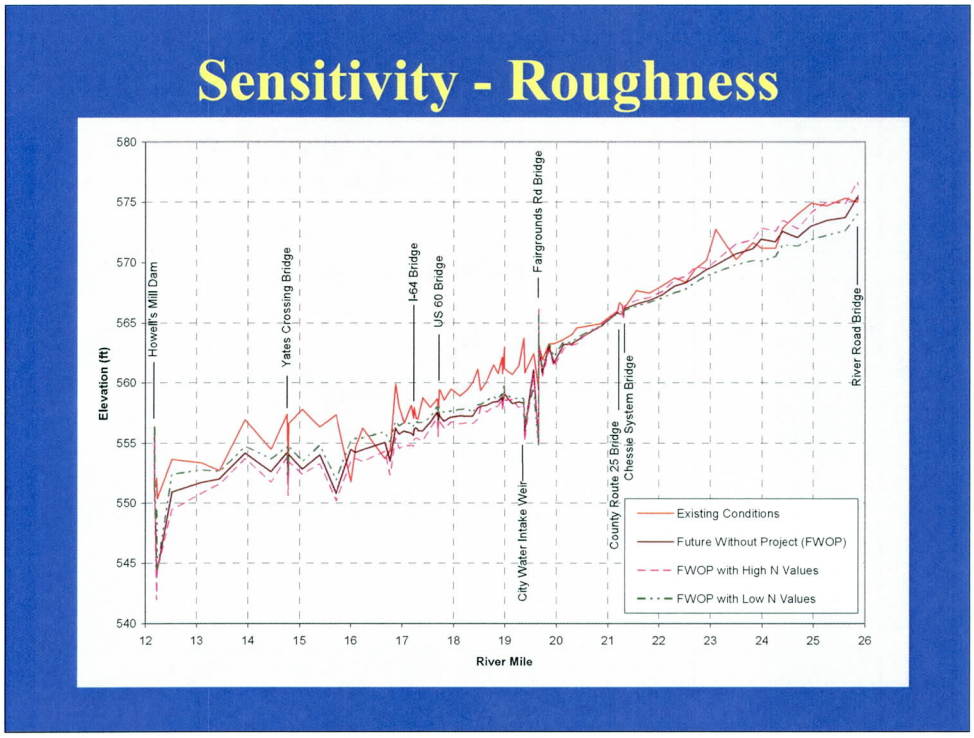




Degradation is seen to occur at most of the bridges (RM 21.295, 21.208, 19.384, 17.703, 17.266, 14.772, and 12.215) and at a few other constrictions (e.g., RM 18.371). Some deposition is noted at a few locations at the peak flow (RM 16.87, 20.52) but the deposited sediment is removed by the end of the event. Some deposition is predicted during the receding limb of the hydrograph in the area between the confluence with Mill Creek (~RM 16.7) and Lower Creek (~RM 16.1). This area has relatively wide floodplains compared with reaches immediately up- and downstream.

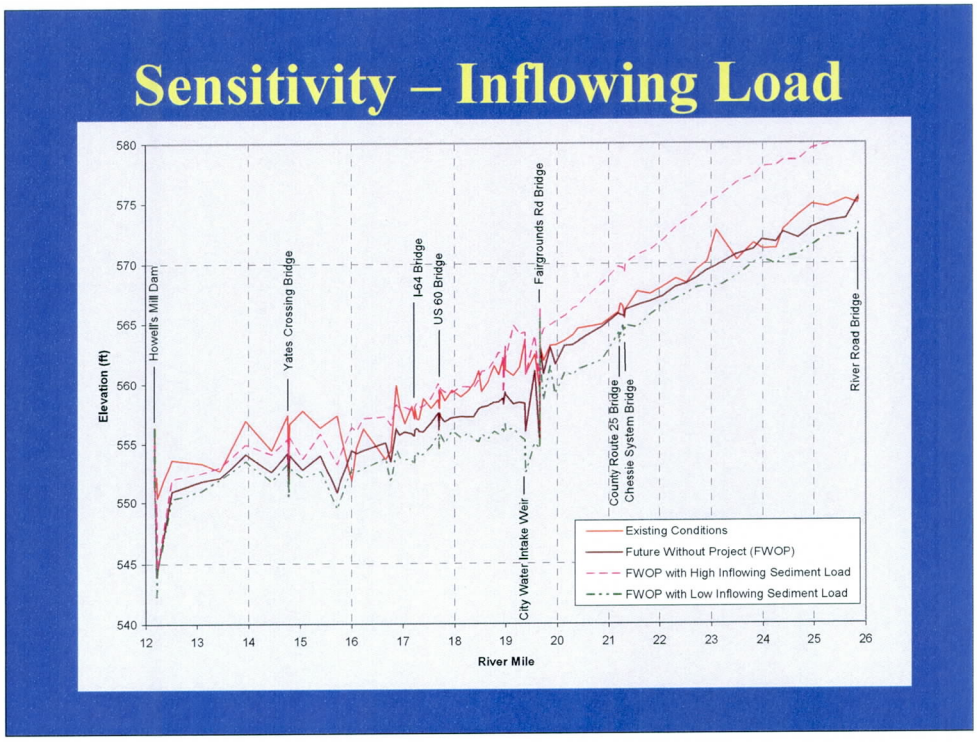


There is a great deal of uncertainty in sediment transport modeling. In order to quantify the affects of several assumptions upon model results, a sensitivity analysis was performed. Departure of model results from the Future without Project (FWOP) solution was analyzed for variation of the following parameters: Manning's 'n', inflowing sediment load, and transport equation.



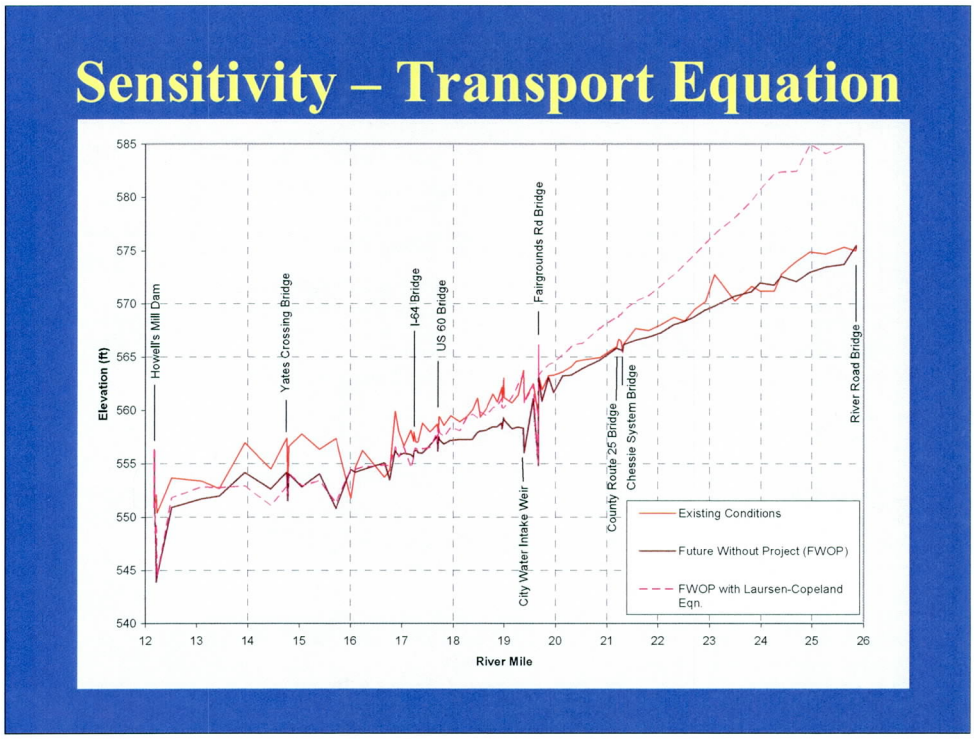
Simulations were performed for "low" Manning's 'n' (80% of the values used in the base model) and "high" Manning's 'n' (120% of the values used in the base model). Results after a simulation time of 50 years are shown.

Higher roughness values promote more deposition in the reach upstream of RM 21 which results in a lack of sediment supply (and resulting erosion) in the reach downstream of the Fairgrounds Road Bridge (RM 19.41). Lower roughness values have exactly the opposite effect, with increased erosion in the upstream part of the model reach and increased deposition downstream of RM 19.4. Possibly due to the stabilizing influence of the City of Milton water intake weir, changes in 'n' values have very little effect in the project reach (RM 19.4 – RM 20.3).



Because of inherent uncertainties in estimating the inflowing sediment rating curve, the sensitivity of model results to adjustments in this parameter was studied. Fifty year simulations were performed using one-half and double the inflowing load for the base model. Results of the simulations are shown.

The high inflowing load greatly increases deposition in the reach upstream of the City of Milton weir, maintains a relatively constant ABE in the reach from RM 19 to 16 (compared to 1938 conditions), and shows slight degradation in the remaining downstream part of the model reach. The low inflowing load results show more degradation throughout the model reach when compared with the FWOP results.



The Yang sand and gravel transport equation was chosen for use in the base model upon the considerations described previously. However, model results are usually sensitive to the particular equation used for a given study. Because the Laursen & Copeland (LC) method was one of the recommended equations from the SAM program (USACE, 1998), the base model was executed using this method in place of the Yang method. Results of the simulation are shown.

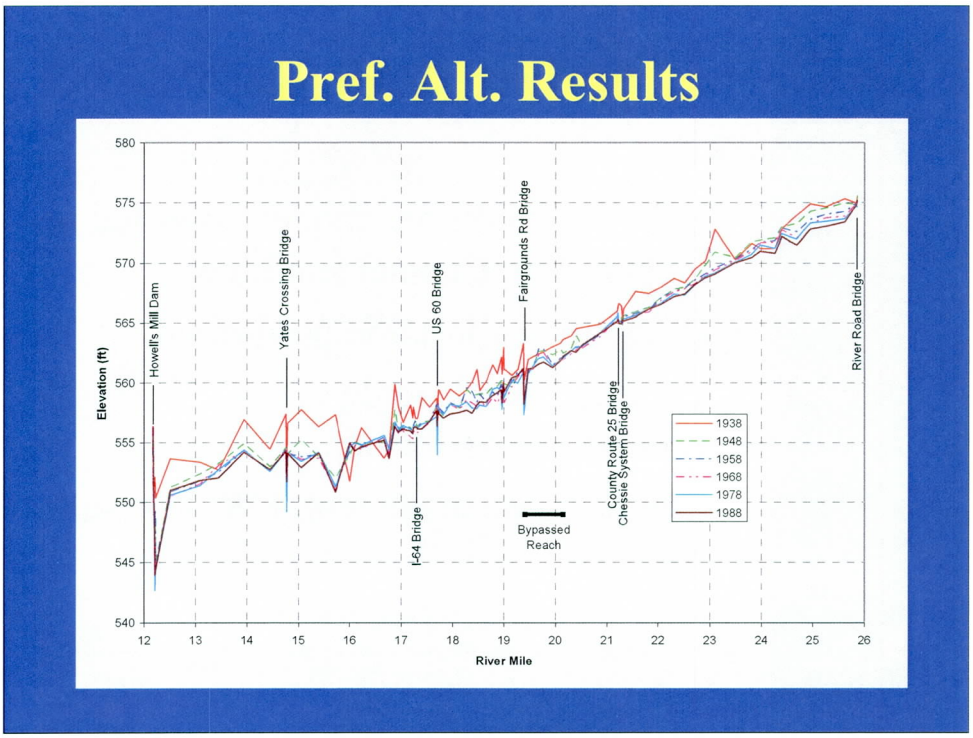
Use of the LC transport equation results in a much greater deposition of material in the upstream part of the model reach. Below the City of Milton water intake weir, the LC results still show increased deposition when compared with the FWOP results. The ABE's are roughly the same as for existing conditions between RM 19.4 and 18.2. Downstream of RM 18, the LC results are approximately the same as the FWOP results.

Preferred Alt. Results

- Existing conditions models adjusted to include new channel and levee
- Hydraulic calibration performed
- Long-term and single event simulations performed
- Comparisons made with FWOP results

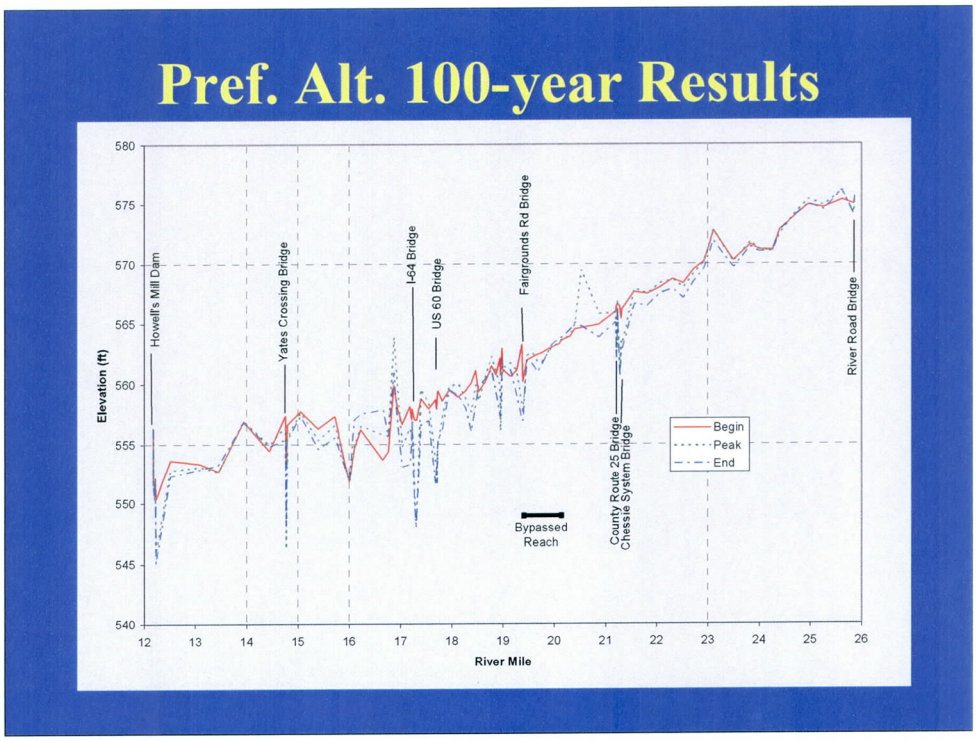
The existing conditions models (HEC-RAS and HEC-6T) were adjusted to reflect the addition of the new channel and levee. Cross sections falling between RM 19.45 and RM 20.2 in the old model were replaced by new cross sections.

Water surface elevations and velocities in HEC-6T were calibrated to the HEC-RAS results.

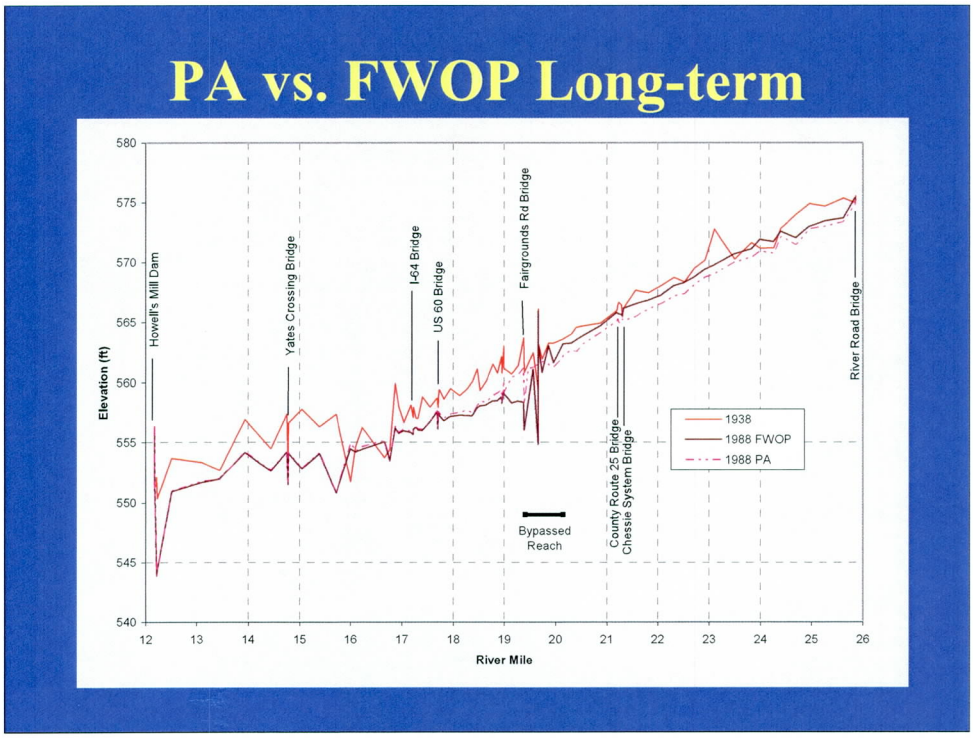


The 50-year synthetic hydrology record was used with the preferred alternative geometry to create the preferred alternative HEC-6T model. It can be seen that, similar to the FWOP results, a general lowering trend is predicted for the bed in the model reach and in the project reach.

It should be noted that the bed gradations in the new reach were assumed to be unchanged from those of the bypassed reach. In reality, the new channel will probably cut through layers of sands, silts, and clays as indicated on a single boring log found for the new channel alignment. As noted, there will most likely be a period of adjustment as fine materials are transported downstream leaving the larger bed material to be mixed with sand supplied from upstream reaches.

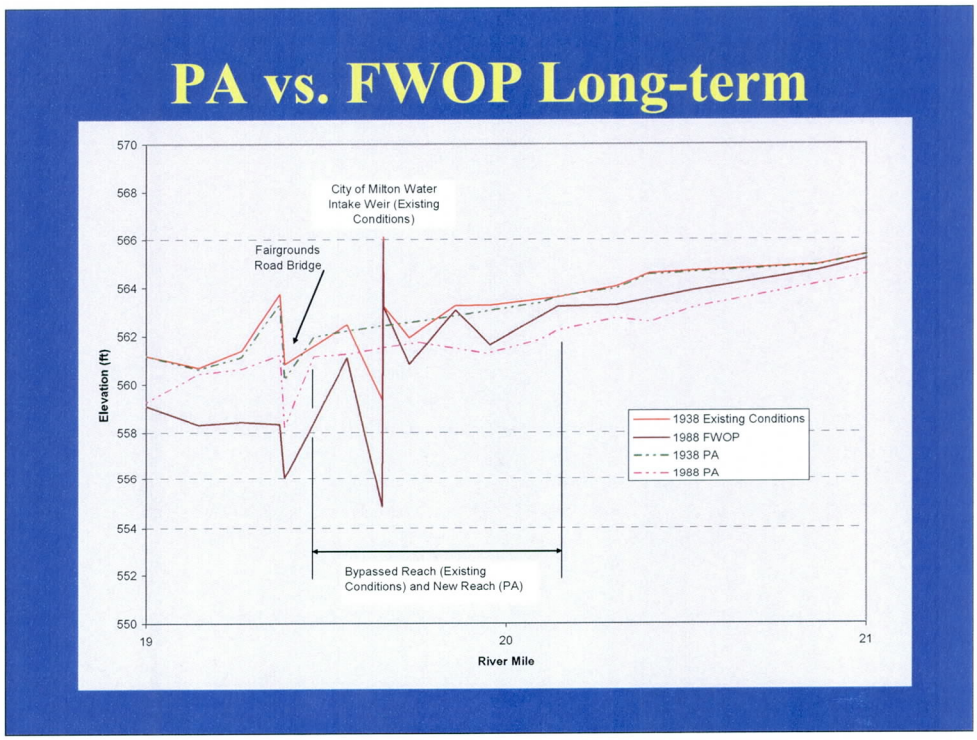


The preferred alternative model was also executed using the 100-year flood hydrograph described previously. Bed elevations at the beginning, time of peak flow, and end of the hydrograph are shown. The results closely resemble those found for the existing conditions single event model.

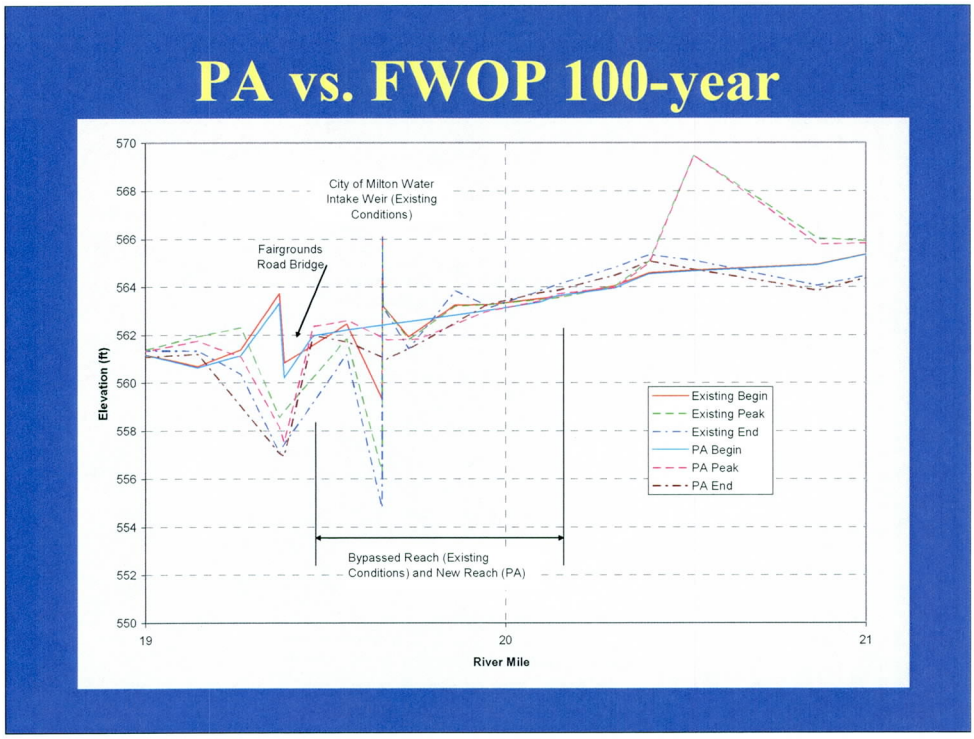


The key to anticipating effects of the project lies in comparing the Preferred Alternative (PA) results to the Future without Project (FWOP) results.

The difference in bed elevations between PA and FWOP results is shown. It is apparent that the City of Milton water intake weir located at RM 19.658 plays a major role in the difference between the FWOP and PA results after 50 years of simulation time. Below RM 19, the results from the two alternatives are nearly identical. Upstream of that point, removal of the weir (which acts as a grade control) results in aggradation downstream and degradation upstream of the weir location when comparing the PA results to the FWOP results. However, both sets of results show an overall degradational trend in the model reach when compared to the existing conditions ("1938") results.



The foregoing results imply that the weir affects the local stability of the river. A "close-up" of the area between RM 19 and RM 21, which includes the project reach, is shown. The maximum lowering of the bed elevation upstream of the weir between the FWOP and PA alternatives is approximately 1.6 feet. The effects of the weir removal appear to propagate several river miles in the upstream direction.



The only area where PA and FWOP results differ for this event is between RM 19 and RM 21, shown in the slide.

The difference in the results lies in the absence of the weir in the PA model. The existing conditions results in the figure are dominated by the effects of the weir. At the time of the peak flow the PA results show deposition just upstream of the Fairgrounds Road Bridge (RM 19.465 to 19. 563) due to backwater, and erosion upstream of that area (RM 19.67 decreasing in magnitude up to RM 20.096) due to the constricting effects of the levee. Some reduction of the deposition area and, to a lesser extent, filling of the eroded area is noted at the end of the hydrograph (where the flow is still 500 cfs). Low flows present in the channel for a large part of the year would be expected to gradually rework the sediments and further fill the eroded area.

Conclusions

- The Mud River near Milton appears to be in quasi-equilibrium based upon historic data, specific gage analysis, and field observations
- New bypass channel was designed using geomorphic and engineering methods – expected to be stable
- Sediment transport modeling confirms same trends for Preferred Alternative as FWOP over 50 years

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Recommendations

- Protect levee at bends, especially before vegetation is established
  - Consider toe-down, overbank flows using model results
- Establish sediment ranges for monitoring

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Acknowledgments

- USAED Huntington
  - Phillip E. Anderson
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  - Jerry Webb (HQ)
  - Eric Dolly
  - Steve Foster
  - Janet Cody
- Triad Engineering (Sediment Testing)

Questions ?

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Stable Channel Analysis with HEC-RAS

Objective: This lecture will discuss the stable channel analysis capabilities of HEC-RAS

1

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Topics to Discuss

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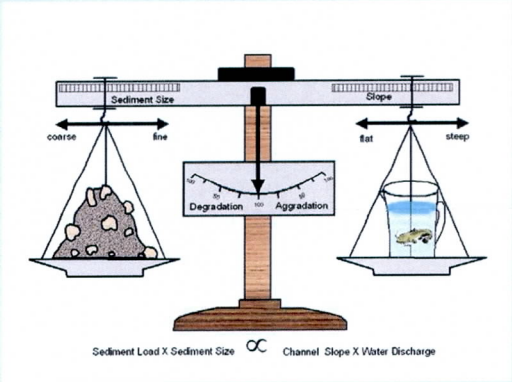
- General Guidelines
- Uniform Flow Computations
- Stable Channel Design
- Sediment Transport Capacity



2

The figure presented in this slide is of "Lane's Balance." Lane's Balance illustrates the balance required between sediment load, discharge, channel size, bed gradation, and channel slope to maintain a dynamically stable channel. Such a channel is often referred to as being in "Dynamic Equilibirum"-equilibrium in the sense that there is no appreciable reach-wide aggradation or degradation over time, but the channel is still able to move laterally (scouring bends and developing point bars, for example).

General Guidelines

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- Based on SAM Hydraulic Design Package.
- General approach used in SAM has been altered to fit within the HEC-RAS framework.
- Can aid in the Design of Stable Channels.
  - *Compute the necessary hydraulic parameters within HEC-RAS, then use the Channel Design Features to design a stable channel and determine its sediment transport capacity.*

3

The Stable Channel Design methods in HEC-RAS are based on the SAM Hydraulic Design Package for Channels, developed by the U.S. Army Corps of Engineers Waterways Experiment Station. These tools can be used to help in the design and analysis of stable channels.

Uniform Flow

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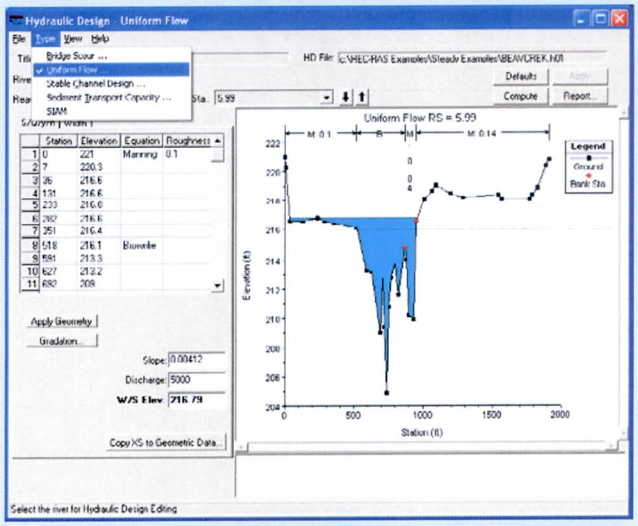
- Preliminary Channel Sizing and Analysis for a given Cross Section
- Solves the Steady-State, Manning's Equation for Uniform Flow.

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



4

Manning's Equation for Steady-State Uniform Flow (English Units form. For SI, the 1.49 in the numerator is 1.0). Q = Discharge, n = Manning's n value, A = Cross Section Area, R = Hydraulic Radius, and S = Energy Slope. For uniform flow conditions, the energy slope = the water surface slope = bed slope.

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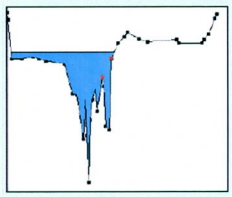
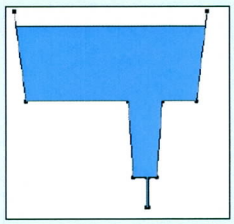
- **Provide 4 parameters, HEC-RAS solves for the 5th.**

$$Q = f(A, R, S, n)$$

, for Irregularly Shaped Channels.



- **When solving for Width, a compound section with up to 3 trapezoidal templates must be used. Provide Depth, Side Slope, Bed Slope and n, HEC-RAS solves for Width.**



$$Q = f(Y, W, z, S, n)$$

, for Trapazoidal Shaped Channels.

5

The user can solve for Discharge, Stage, Slope, or Manning's n values for all cross sections. Both Area and Hydraulic Radius are functions of Stage. Alternatively, a width can be solved for, however a compound shape (with up to three trapezoidal templates) will be constructed when this method is chosen.

Uniform Flow

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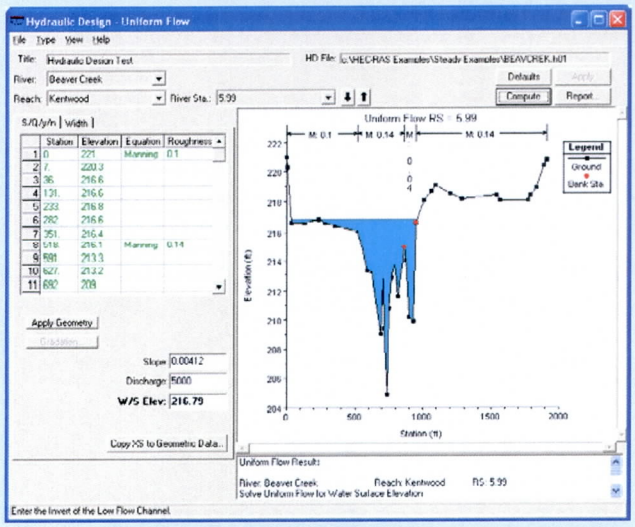
- Select a River Station
- Provide a Slope and a Discharge.
- Click Compute. HEC-RAS solves for the W/S elevation.

- Alternatively provide Slope and W/S Elevation and solve for Discharge

  -or provide Discharge and W/S Elevation and solve for Slope.



6

First, select a River Station to work with. Once selected, it will show up on the graphic. Then you can:

Enter a Slope and Discharge and solve for W/S Elevation or

Enter a Slope and W/S Elevation and solve for Discharge or

Enter a Discharge and W/S Elevation and solve for Slope.

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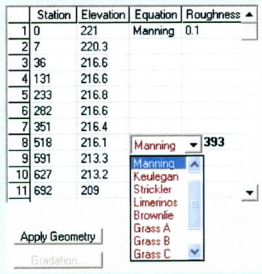
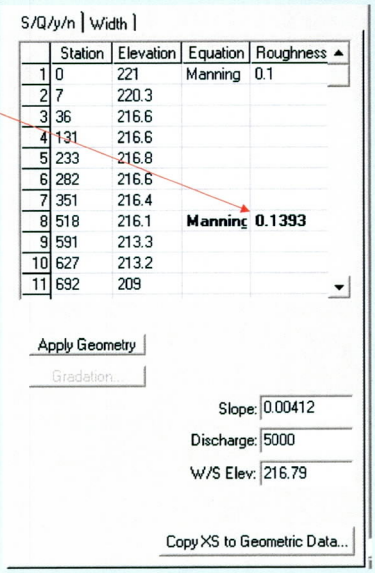
- Or provide all 3 Standard Variables and solve for an "n" value by leaving it blank.
- When solving for Manning's n values, Manning's, Keulegan, and Strickler can be used.
- When solving for Slope, Discharge, or W/S Elevation, any of the roughness equations can be used.





7

Alternatively, you can provide all three of the variables Slope, Discharge and WS Elevation, leave a Roughness Value blank and solve for the required roughness value to meet Manning's Equation.

Within the Uniform Flow Editor, HEC-RAS allows the user to define roughness by other equations in addition to Manning's n values. Roughness values solved for using other equations are converted to Manning's n values for the computations.

When solving for the Roughness Value (i.e. the roughness value cell is left blank, and Slope, Discharge, and W/S Elev. are input), only Manning's, Keulegan, and Strickler can be used. When solving for the other variables, any of the roughness equations/methods can be used.

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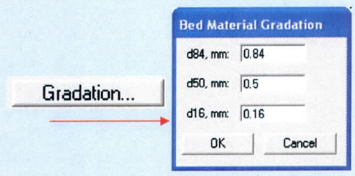
- Roughness Equations.
  - *The selected equation is used in the computations, and an equivalent Manning's n value is back-calculated.*
  - Manning's – Uses the provided n value.
  - Keulegan – Requires Temperature Data (for viscosity)
  - Strickler – Requires a k_s value (in the Roughness Column)
  - Limerinos – Requires a d84 particle size (Gradation Button)
  - Brownlie – Requires d16, d50, and d84 and particle specific gravity.
  - SCS Grass Curves – Consult Table 12-1 in Reference Manual to determine appropriate Grass Curve (A through E).



8

Manning's: When choosing the Manning equation method, one n value or a range of n values is prescribed across the cross section and then the Manning's equation is used to solve for the desired parameter.

Keulegan: Applicable for Rigid Boundary channel design. Based on boundary layer theory. Applicable for Froude Numbers between 0.2 and 8.0 and for relative roughness values (R/ks) less than 3. See the HEC-RAS Hydraulic Reference Manual for a detailed description of this method.

Strickler: Uses the "Strickler Function" = 0.0342 for natural channels, 0.0342 when performing velocity and stone size computations for riprap design, and 0.038 for discharge computations in riprap design. N = S.F. * ks^(1/6), where the equivalent sand roughness, ks, can be represented by the d50 of the bed material.

Limerinos: Good for larger grain sizes. Can only be used in the upper flow regime (grain-related), which means the inertial effects on the grains dominate over the gravitational effects – in other words, swift-moving streams. See the HEC-RAS Hydraulic Reference Manual for a detailed description of this method.

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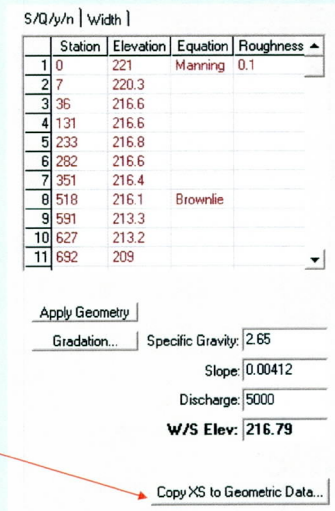
- Geometry can be adjusted to meet parametric requirements.
  - *i.e. Alter the cross section geometry until a required water surface is met for a given slope and discharge.*
  - *Copy the new geometry to the geometry file.*



9

The Uniform Flow Editor is compatible with the geometry file. In other words, any changes you manually make to the Station/Elevation table, including roughness value and equation, can be copied into the regular geometry as a replacement to an existing cross section or as an entirely new cross section.

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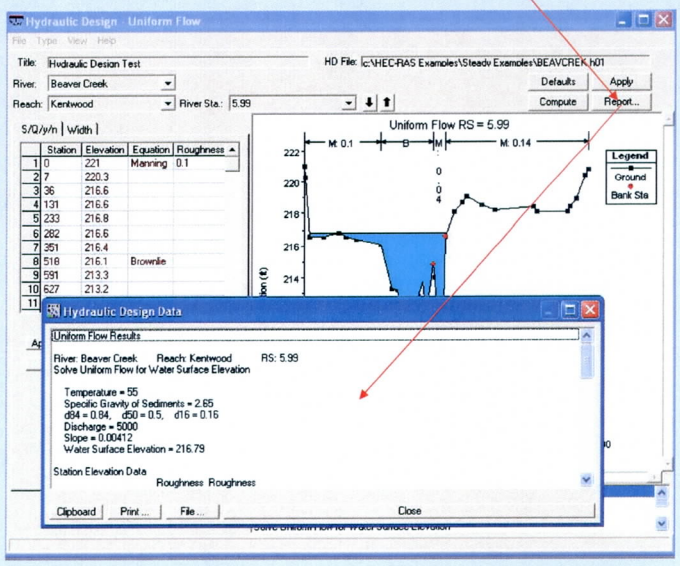
- View the Report for more detail…



10

The Report provides a text file with most of the input and output data resulting from your Uniform Flow Analysis. This data can easily be copy and pasted into other documents or printed.

Uniform Flow

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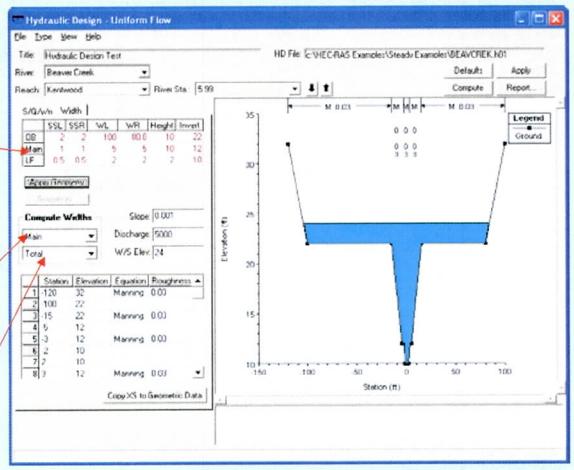
- Computing Widths
  - *First, fill out the channel template table for an initial cross section.*
  - *Apply the geometry and adjust Roughness as necessary.*
  - *Then enter a slope, discharge, and w/s elev.*
  - *Compute the width in either the main channel or the overbanks.*
  - *Can compute the width by applying to the right of centerline, left of centerline, or both.*



11

When determining uniform width, a trapezoidal compound channel must be used. The compound channel can have up to 3 trapezoidal templates, a low flow, a main channel, and an overbank channel. An initial channel shape is first provided in the upper table. Then, once the Slope, Discharge, and W/S Elev. is entered, a width is solved for. You can either solve for the main channel width, or the overbank width required to satisfy Manning's equation. That width can then be applied to the left side, the right side, or equally to both sides of center.

Uniform Flow

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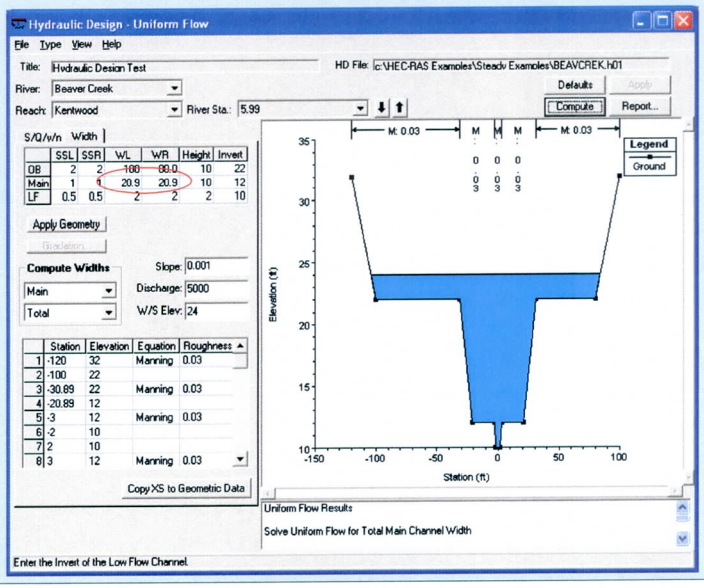
- Computing Widths
  - A new main channel width that satisfies Manning's equation is determined…



The new channel is automatically updated in the graphic.

Stable Channel Design

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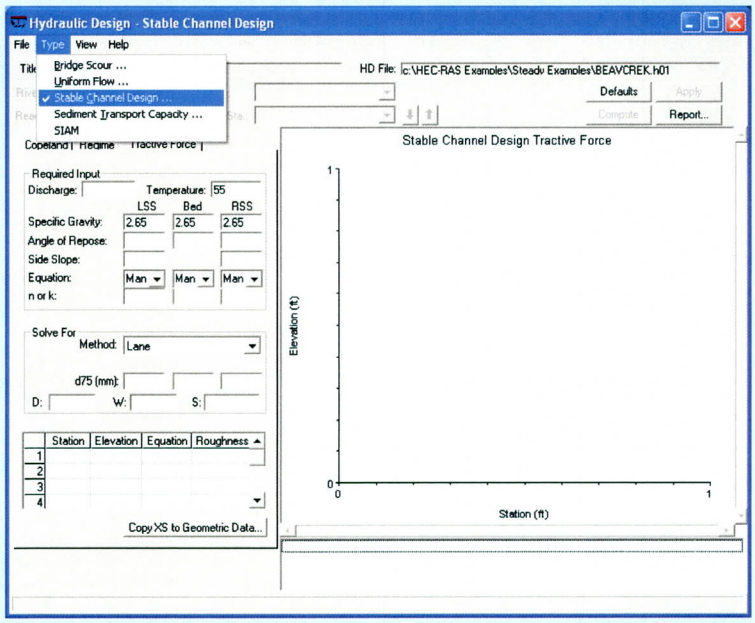
- Can be used to design a stable channel based on 3 different methods…



Stable Channel Design

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- Copeland – Stability defined as "Sediment Inflow = Sediment Outflow" for a given reach.

- Regime – Stability defined as "No net annual scour or deposition" for a given reach.

- Tractive Force – Stability defined as "No appreciable bed load movement" for a given reach.

14

Stable Channel Design

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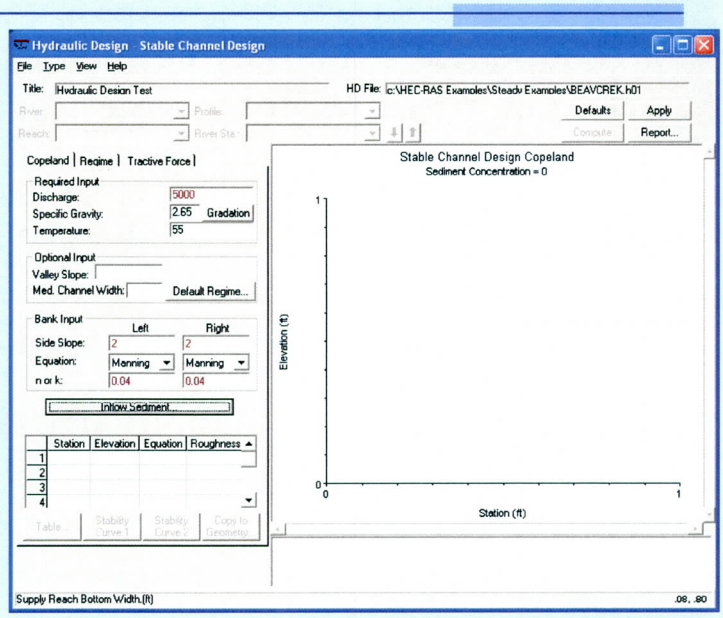
- **Copeland**
  - Discharge
  - Specific Gravity
  - Temperature
  - Gradation
  - Side Slopes
  - N-value
  - Optional
    - Valley Slope
    - Med Channel Width



15

Developed by Dr. Ronald Copeland of WES, the Copeland method is primarily analytical, with some empirically-derived equations. It uses Brownlie's equations for depth and discharge and will solve for a stable depth and slope. No bed load movement above the banks. Since Copeland's method defines stability as Sediment Inflow = Sediment Outflow, an inflowing sediment load must be established. This can either be done by providing a sediment concentration, or by allowing HEC-RAS to compute the sediment concentration by the geometric and sediment properties of an upstream reach.

Stable Channel Design

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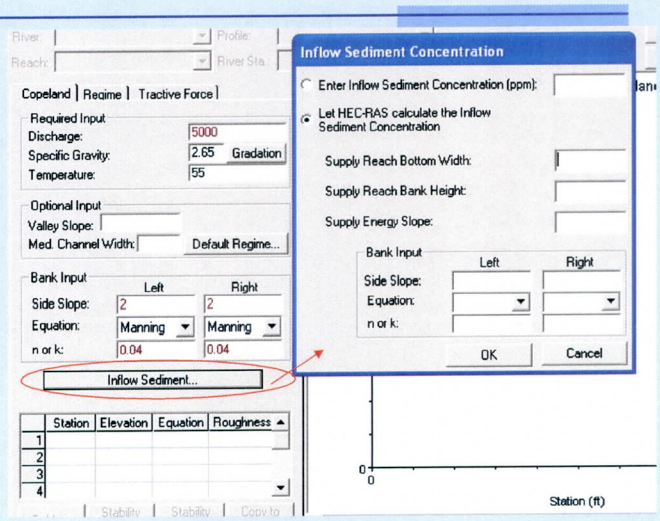
- **Copeland**
  - Must Provide information about the inflowing sediment.
  - Enter the Inflowing Sediment Load Concentration or-
  - Have HEC-RAS Compute it.



16

Since Copeland's method defines stability as Sediment Inflow = Sediment Outflow, an inflowing sediment load must be established. This can either be done by providing a sediment concentration, or by allowing HEC-RAS to compute the sediment concentration by the geometric and sediment properties of an upstream reach.

Stable Channel Design

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Copeland-Output

Stable Channel Design, Copeland Method

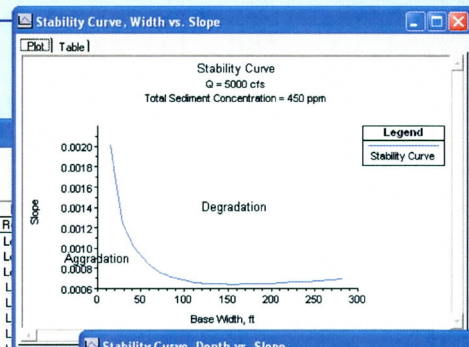
Select a stable channel dimension to display. Sediment Concentration, ppm = 450

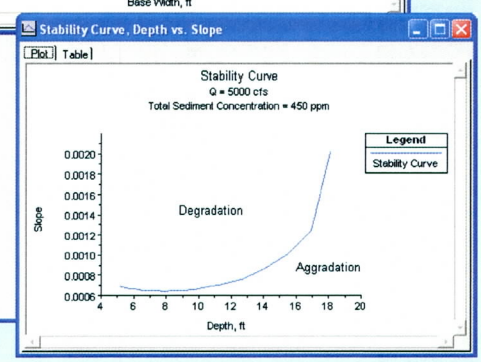
Bottom Width	Depth	Energy Slope	Composite n-value	Hyd Radius	Velocity	Froude Number	Shear Stress	Ri
14	18.07	0.002011	0.0545	9.57	5.52	0.23	2.27	L
28	16.94	0.001236	0.0510	10.08	4.77	0.2	1.31	L
42	15.5	0.001006	0.0498	10.13	4.42	0.2	0.97	L
57	13.94	0.000846	0.0472	9.91	4.23	0.2	0.74	L
71	12.64	0.00076	0.0448	9.54	4.11	0.2	0.6	L
85	11.51	0.000707	0.0428	9.11	4.02	0.21	0.51	L
99	10.55	0.000679	0.0411	8.63	3.94	0.21	0.45	L
113	9.73	0.000659	0.0396	8.17	3.87	0.22	0.4	L
127	9.02	0.000648	0.0387	7.79	3.81	0.22	0.36	Lower
141	8.42	0.000643	0.0379	7.41	3.76	0.23	0.34	Lower
156	7.86	0.000641	0.0373	7.05	3.71	0.23	0.31	Lower
170	7.4	0.000643	0.0366	6.71	3.66	0.24	0.3	Lower
184	6.99	0.000645	0.0363	6.44	3.61	0.24	0.28	Lower
198	6.63	0.000648	0.0354	6.14	3.57	0.24	0.27	Lower
212	6.3	0.000654	0.0350	5.88	3.53	0.25	0.26	Lower
226	6.02	0.00066	0.0346	5.65	3.49	0.25	0.25	Lower
240	5.76	0.000667	0.0343	5.44	3.45	0.25	0.24	Lower
255	5.5	0.000675	0.0340	5.22	3.41	0.26	0.23	Lower
269	5.29	0.000683	0.0337	5.04	3.38	0.26	0.23	Lower
283	5.09	0.000691	0.0334	4.87	3.35	0.26	0.22	Lower
*******	Minimum	Stream	Power	*******				
155.78	7.87	0.000642	0.03766	7.09	3.71	0.23	0.32	Lower

Red text indicates that the computed slope is greater than the user-entered valley slope, indicating a potential sediment trap.

OK Cancel

* indicates transitional regime. The default regime was used for the computations.





The output provided by Copeland's method is an array of stable width/depth/slope combinations. These can be illustrated with stability curves as shown in this slide. The curve on the plot defines channel stability over a range of depths, widths, and slopes. Above the curve, you can expect degradation in your channel. Below the curve, you can expect Aggradation. A minimum Stream Power solution is also provided which corresponds to the vertex of each of the stability curves.

Stable Channel Design

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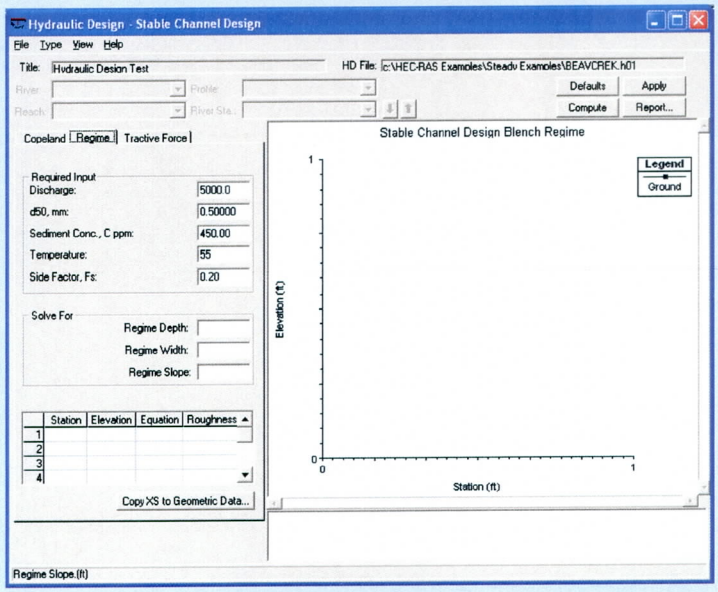
- **Regime**
  - Discharge
  - D50
  - Sediment Concentration
  - Temperature
  - Side Factor
    - 0.1 to 0.3 for "Friable" to "Tough" banks



The Regime Method is based on the concept that there is no net annual scour or deposition in the channel in order to be defined "Stable". Equations by Blench (Blench, 1970) are used in HEC-RAS and are intended for use in channels with sand beds. Discharge, d50, Sediment Concentration, Temperature and a Side Factor are required inputs. A stable regime Depth, Width and Slope are then solved for. Blench suggests certain channel characteristics that his regime equations work best for. They are presented in the Hydraulic Reference Manual. Unless your channel meets all of these characteristics, this technique is better used as a method to obtain approximate results.

Blench, T., 1970. "Regimne Theory Design of Canals with Sand Beds." Journal of the Irrigation and Drainage Division, ASCE, Vol. 96, No. IR2, Proc. Paper 7381, pp 205-213.

Stable Channel Design

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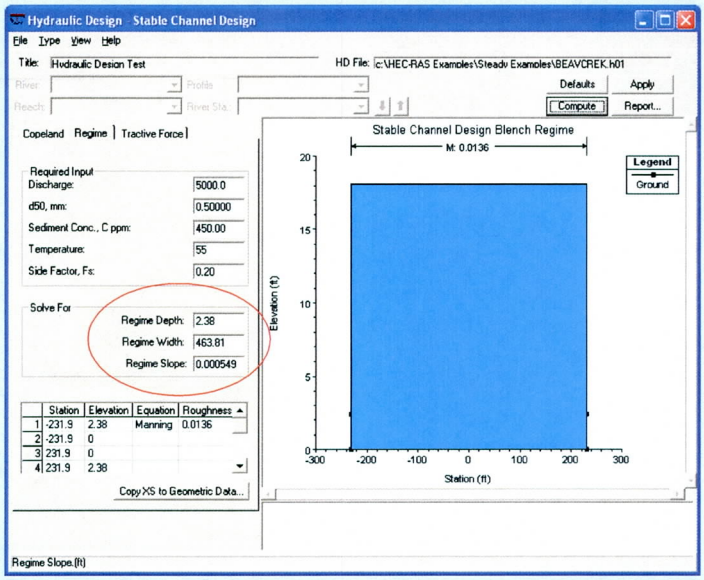
- **Regime**
  - Depth, Width and Slope are solved for.



Stable Channel Design

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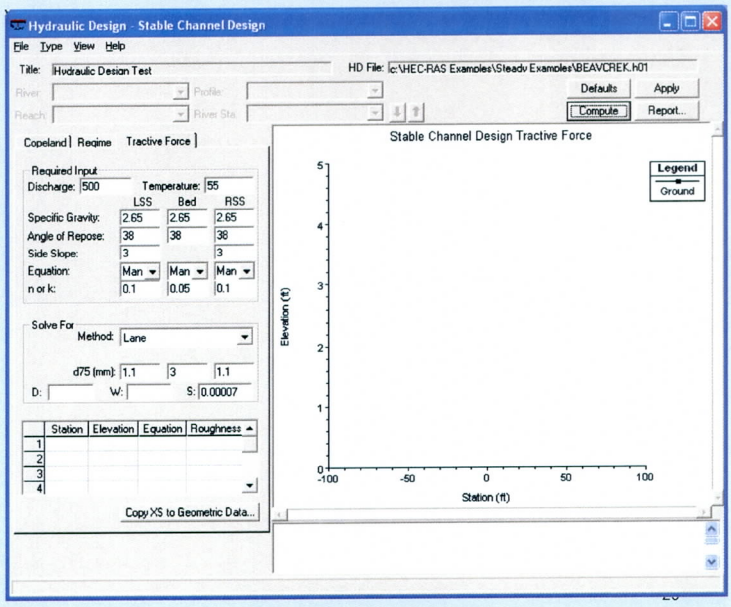
- **Tractive Force**
  - Discharge
  - Temperature
  - Specific Gravity
  - Angle of Repose
  - Side Slope
  - Manning's n
  - Pick 2 of:
    - D75
    - Depth
    - With
    - Slope
  - HEC-RAS solves the other 2.



The Tractive Force method is an analytical approach to channel stability, that defines stability as no appreciable particle movement in a given reach. Consequently, this will not work well in a natural sand-bed stream. Essentially, HEC-RAS determines a critical shear stress and compares it to the computed shear stress. If the critical shear stress is exceeded, then the bed particles are moving and the bed is not stable. Lane and Shields can be used to determine the critical mobility parameter. Alternatively, the user can enter in the critical mobility parameter manually, if neither Lane nor Shields is adequate. The procedure is documented in the HEC-RAS Hydraulic Reference Manual.

Stable Channel Design

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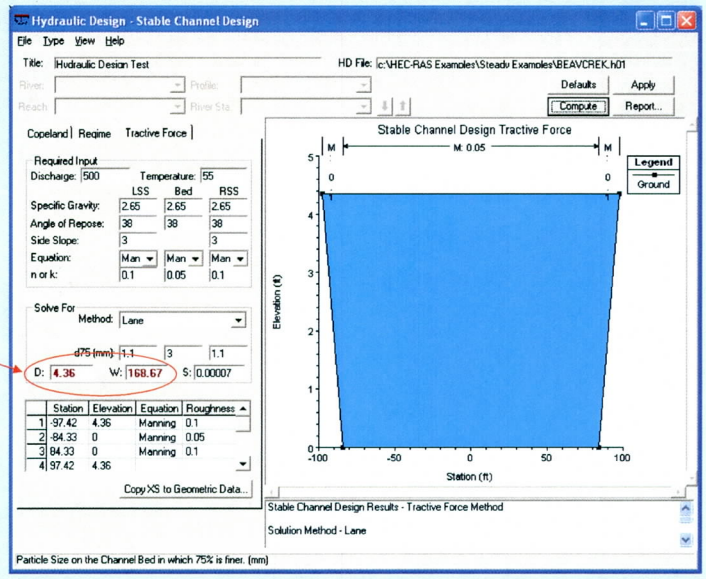
- **Tractive Force**
  - Pick any 2 of the 4 Variables. HEC-RAS solves for the other 2.
  - In this case Depth and Width were solved for.



21

Stable Channel Design

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- **Tractive Force**
  - 3 Tractive Force Methods Available
    - Lane's $\tau_{cr} = 0.4 d_{75}$
    - Shield's $\tau_{cr} = \Theta_{cr}(\gamma_s - \gamma) d_{50}$

      Θ_{cr} is solved for using Shield's Diagram.
    - User's $\tau_{cr} = \Theta_{cr}(\gamma_s - \gamma) d_{50}$

      Θ_{cr} is entered by user.

22

Lane's critical shear is based on the sediment d75.

Shields uses a critical mobility parameter and the d50. The critical mobility parameter can be determined from Shield's Diagram, however, in hydraulically rough flow, the sediment particle properties dominate and constant critical mobility parameter of 0.055 could be used. Shield's curve is based on "permanent grain movement" at all locations within the reach. In other words, designing a channel using Shield's may lead to occasional particle movement, but reach-wide movement should not be expected.

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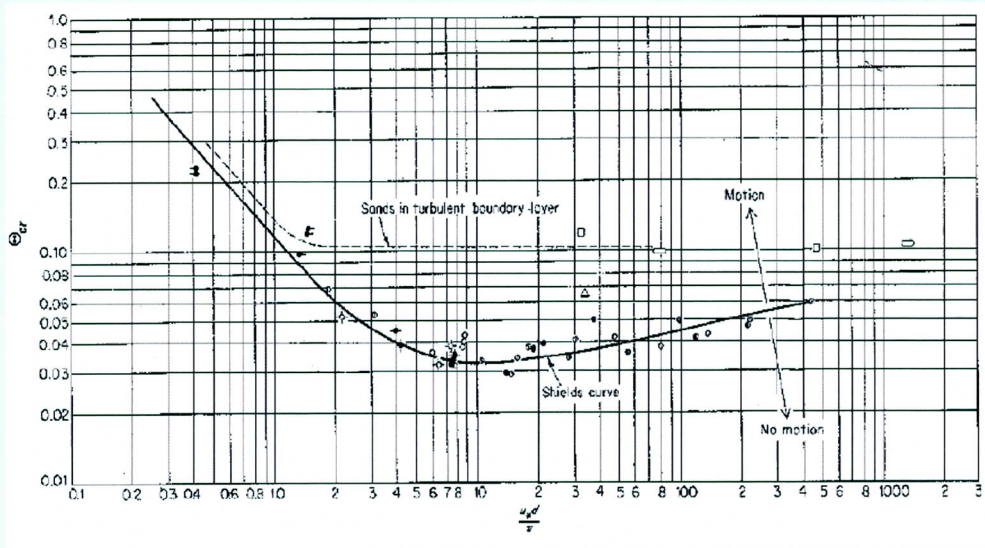

Shield's Diagram (Graf, 1971)

23

Shield's Curve (Graf, 1971). Above the curve indicates permanent grain movement at all locations throughout the reach. Notice that the curve levels off at a critical mobility parameter of 0.055 when the flow becomes hydraulically rough.

Graf, Walter Hans. 1971. "Hydraulics of Sediment Transport." McGraw Hill, Inc.

Stable Channel Design

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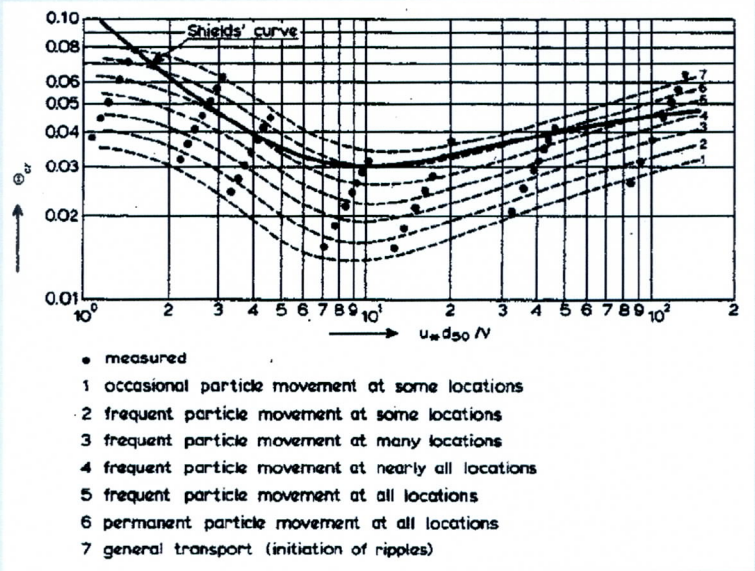

Initiation of Motion and Suspension for a Current Over a Plane Bed (Delft Hydraulics, 1972)

24

An alternative to Shield's Diagram, this set of curves better defines the type of particle movement. If no particle movement at all is desired, then curve #1 should be used and the channel should be designed to fall below this curve. Notice that Shield's Curve falls between curves 5 through 7. This would indicate that Shield's provides a stable channel that may have significant particle movement at times. Consequently, HEC-RAS allows the user to enter in their own Critical Mobility Parameter to account for this, if so desired.

Figure from *Van Rijn, Leo C. 1984. "Sediment Transport, Part I: Bed Load Transport," Journal of Hydraulic Engineering, ASCE, Vol 110, No. 10, pp 1412-1430.*

Sediment Transport Capacity

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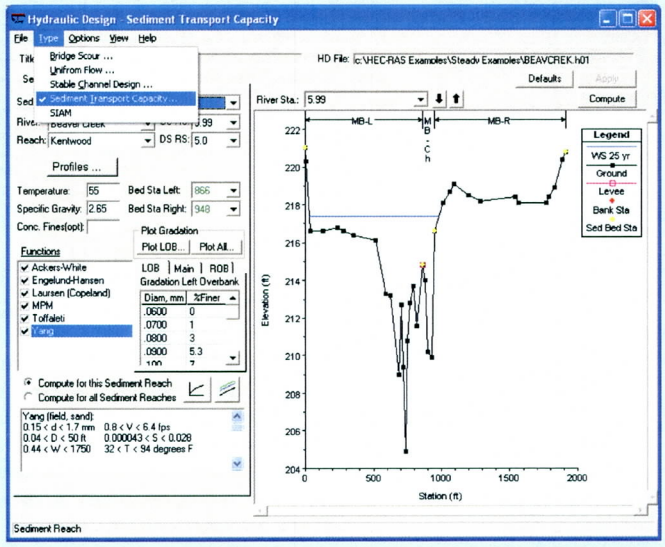
- Can predict sediment transport ***capacity*** for non-cohesive sediment at one or more cross sections based on hydraulic properties and known bed sediment properties.



25

This utility within HEC-RAS can solve for the capacity of a given channel (or reach) to transport material. Since we don't know what is coming into the reach, we cannot compute long term scour or deposition using this tool. However, this is a great tool for developing sediment rating curves, or for predicting responses to sediment transport capability based on geometric changes to the cross section(s).

Sediment Transport Capacity

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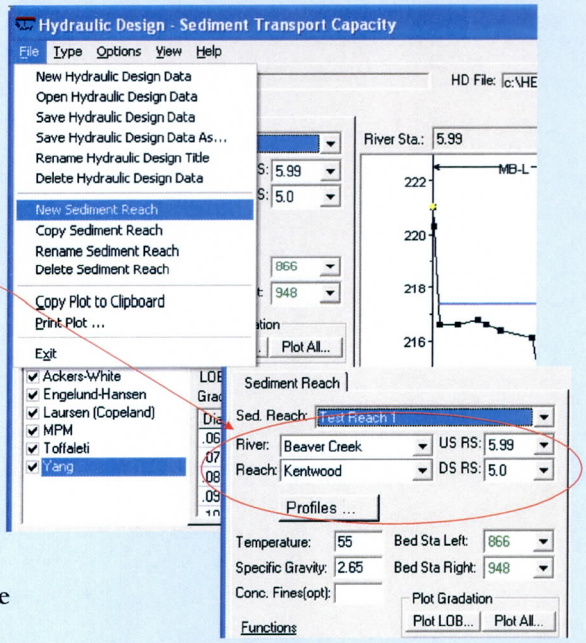
- First Create a New Sediment Reach.
- Then Define the New Sediment Reach and select the W/S profiles (from a steady flow run) that you wish to use.
  - A sediment reach
    - should have similar geometric and sediment properties.
    - Cannot span multiple Rivers
  - Multiple sediment reaches are allowed.



HEC-RAS allows the user to combine river stations into Sediment Reaches. A Sediment Reach should have similar geometric, discharge, and sediment characteristics. A reach cannot span multiple rivers, but multiple reaches can be created in one HEC-RAS reach. A Sediment reach can be as small as one cross section.

Sediment Transport Capacity

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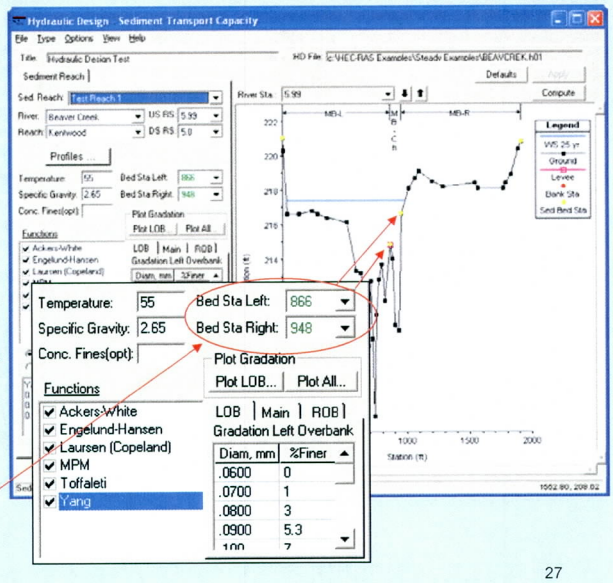
- Enter Temperature, Specific Gravity and Concentration of Fines.
- Select the Transport Function to use (one or more)
- Enter Sediment Gradation for the Left and Right Overbanks and the Main Channel.
- Define the Bed Stations (shown in yellow).



27

The Bed Stations split the cross section into 3 transport sub-sections similar to how HEC-RAS splits up a cross section into 3 hydraulic sub sections. A left overbank, right overbank, and main channel transport sub-section is defined. Commonly these will line up with the bank stations, but not always. A significant change in bed gradation is a good indicator of where the bed station should be located within a cross section.

Sediment Transport Capacity

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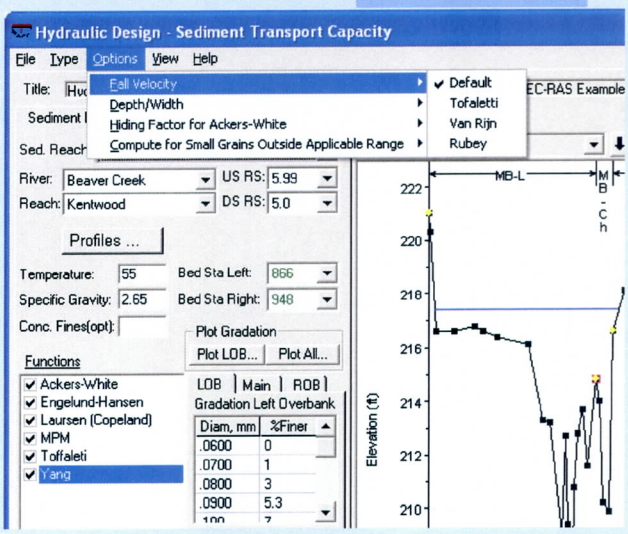
- Fall Velocity
  - Default uses the method used in the development of each individual Transport Function.



28

Fall velocity is used to determine if there is enough boundary layer turbulence to overcome a particles weight and project it into suspension. Many of the transport equations compute fall velocity, but there are a few different ways to do it in HEC-RAS. By selecting the "Default" option, HEC-RAS will automatically use the method that was used for each transport functions' development, respectively. A detailed description of each method is provided in the HEC-RAS Hydraulic Reference Manual.

Sediment Transport Capacity

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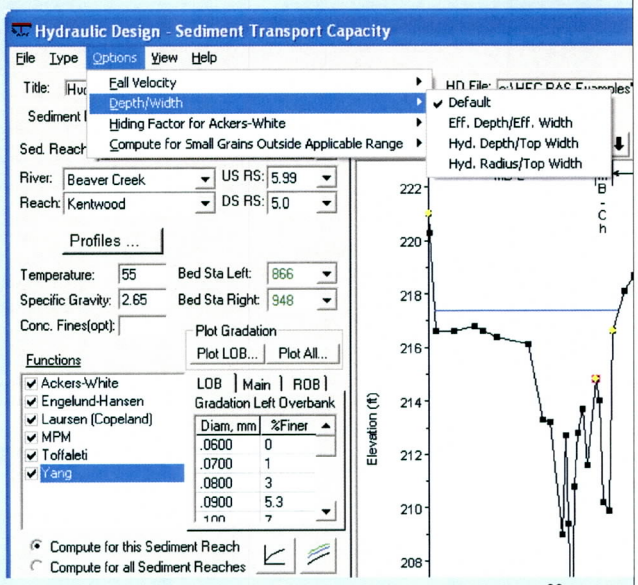
- Depth/Width Definition
  - Eff. Depth/Width

$$EFD = \frac{\sum_{i=1}^{n} D_{avg} a_i D_{avg}^{\frac{2}{3}}}{\sum_{i=1}^{n} a_i D_{avg}^{\frac{2}{3}}} \qquad EFW = \frac{\sum_{i=1}^{n} a_i D_{avg}^{\frac{2}{3}}}{EFD^{\frac{5}{3}}}$$

  - Hyd. Depth/Top Width
  - Hyd. Radius/Top Width



Because natural streams have irregular shaped cross sections, a standard for defining "width" and "depth" must be applied. As with Fall Velocity, selecting the default option tells HEC-RAS to use whatever method was used in the development of each respective transport function. The Effective Width and Effective Depth (as used in HEC-6) are presented on the slide. Hydraulic Depth is simply the cross section area divided by the Top Width. The Hydraulic Radius is the cross section area divided by the wetted perimeter.

Sediment Transport Capacity

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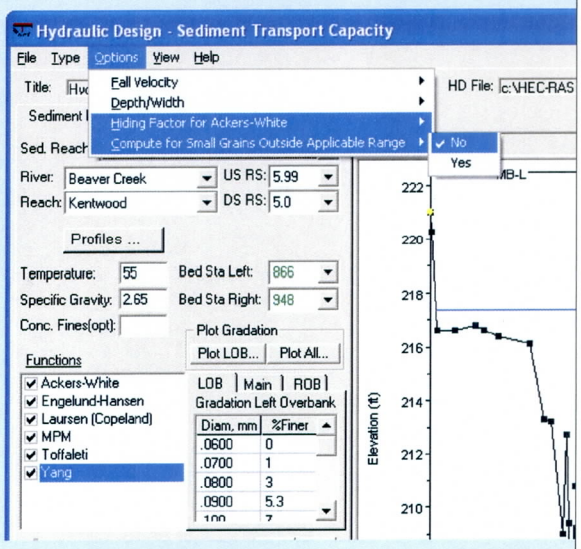
- Hiding Factor
  - Only for Ackers-White
  - Good when large range of sediment sizes is used.
- Compute for Small Grains
  - Only grain sizes that fall within the applicability range of a given Transport Function
  - Computing outside the applicability range can grossly *overestimate* the transport capacity



30

When using Ackers-White, a hiding factor can be applied. The hiding factor is an adjustment to include the effects of a masking of the fluid properties felt by smaller particles due to shielding by larger particles. When the bed gradation has a large range of sizes, the hiding factor can be useful in obtaining a more accurate result.

Some of the transport functions will over-estimate the transport capacity (sometimes quite significantly) if particle sizes outside the applicability range of that transport function are used. The user can select to ignore those sizes.

Sediment Transport Capacity

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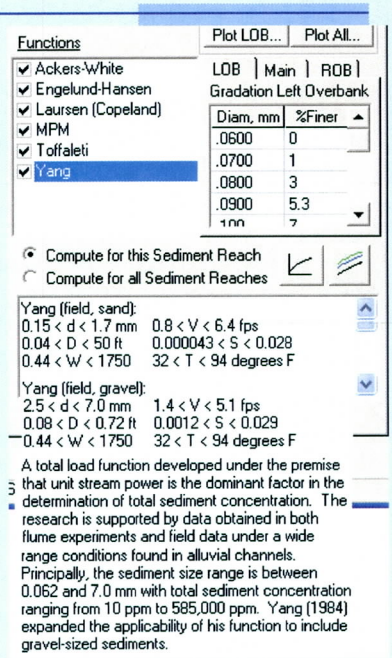
- Description Box
  - Indicates the range of parameters over which the selected Transport Function was developed
  - Provides a brief description of its development and applicability.
  - Use the Description Box to verify the applicability of the selected Transport Function to your sediment reach.



Sediment Transport Capacity

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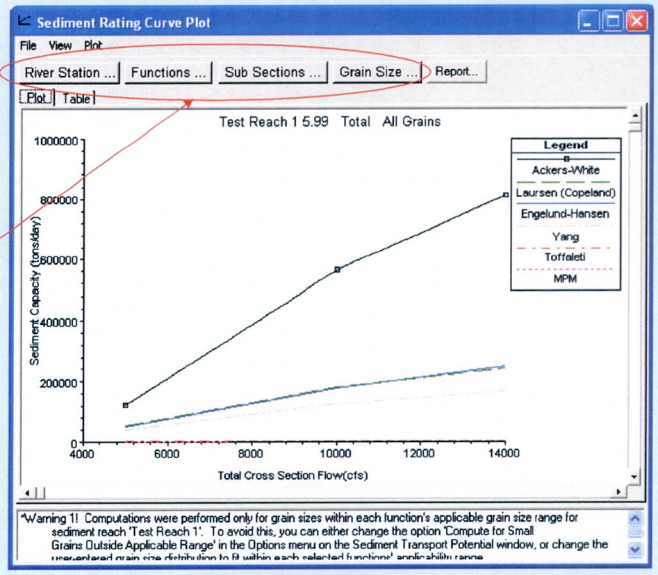
- Output
  - Sediment Rating Curve

Choose which River Station, Transport Function(s), Sub-Section(s) and Grain Size(s) to represent on the plot.



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Sediment Transport Capacity

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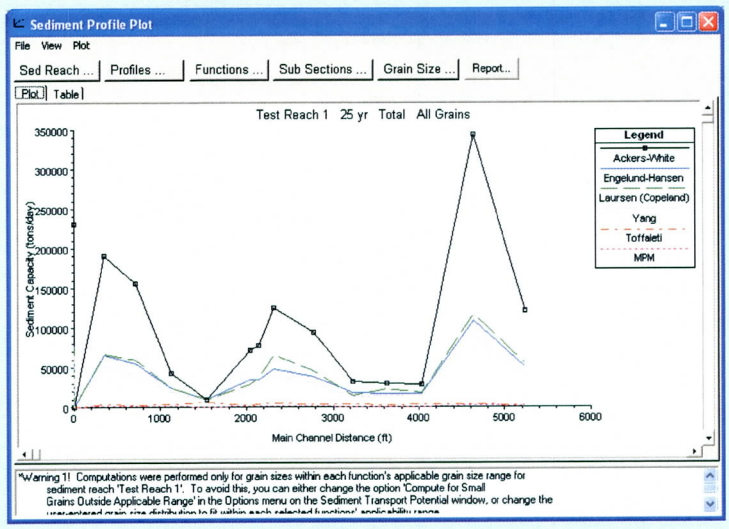
- Output
  - Sediment Profile



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Sediment Transport Capacity

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- Output
  - Report

Hydraulic Design Data

d90	1.40	1.40		1.40
d84	.982	.982		.982
d50	.473	.473		.473

Bed Material Fraction by Standard Grade Size

Class	dm (mm)	Left	Main	Right
1	.003	0.000	0.000	0.000
2	.006	0.000	0.000	0.000
3	.011	0.000	0.000	0.000
4	.023	0.000	0.000	0.000
5	.045	0.009	0.009	0.009
6	.088	0.092	0.092	0.092
7	.177	0.177	0.177	0.177
8	.354	0.243	0.243	0.243
9	.707	0.330	0.330	0.330
10	1.41	0.110	0.110	0.110
11	2.83	0.026	0.026	0.026
12	5.64	0.014	0.014	0.014
13	11.3	0.000	0.000	0.000
14	22.6	0.000	0.000	0.000
15	45.1	0.000	0.000	0.000
16	90.5	0.000	0.000	0.000
17	181	0.000	0.000	0.000
18	362	0.000	0.000	0.000
19	724	0.000	0.000	0.000
20	1448	0.000	0.000	0.000

Sediment Transport Potential (tons/day) Test Reach 1 5.99 Total All Grains (tons/day)

	Sed Reach	RS	Profile	Function	All Grains
1	Test Reach 1	5.99	25 yr	A-W	121400
2	Test Reach 1	5.99	25 yr	E-H	49960
3	Test Reach 1	5.99	25 yr	Laur	54860
4	Test Reach 1	5.99	25 yr	MPM	1021
5	Test Reach 1	5.99	25 yr	Toff	2333
6	Test Reach 1	5.99	25 yr	Yang	39480
7	Test Reach 1	5.99	100 yr	A-W	565700
8	Test Reach 1	5.99	100 yr	E-H	177600
9	Test Reach 1	5.99	100 yr	Laur	181900
10	Test Reach 1	5.99	100 yr	MPM	2522
11	Test Reach 1	5.99	100 yr	Toff	3186
12	Test Reach 1	5.99	100 yr	Yang	125800
13	Test Reach 1	5.99	May '7...	A-W	812300
14	Test Reach 1	5.99	May '7...	E-H	246700
15	Test Reach 1	5.99	May '7...	Laur	240000
16	Test Reach 1	5.99	May '7...	MPM	3210
17	Test Reach 1	5.99	May '7...	Toff	3635
18	Test Reach 1	5.99	May '7...	Yang	165800

Clipboard Print ... File ... Close

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HEC-RAS Sediment Transport Modeling

By WEST Consultants, Inc.

SEDIMENT COMPUTATION OPTIONS AND TOLERANCES

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Topics

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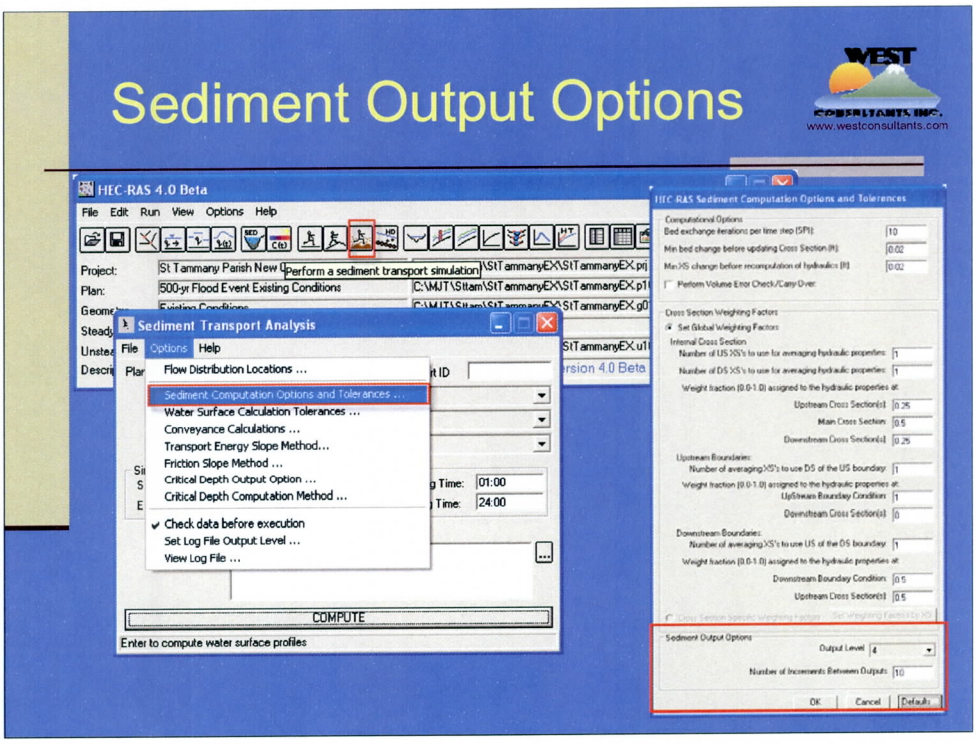
- Sediment Output Options
  - Output Level Variables, Increments
- Computational Options
  - Sediment Exchange Increment (SPI)
- Cross Section Weighting Factors
- Transport Slope Method



The user can define the number of output variables (Output Level) and the increment at which they are written (Number of Increments…). Choosing 1 will give the least amount of output while 6 will give the most.

Output Level Variables

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Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Bed Elevation	Bed Elevation	Bed Elevation	Bed Elevation	Bed Elevation	All From Level 4 and 5 and…
	WSE	WSE	WSE	WSE	Slope
	Observed	Observed	Observed	Observed	Cumulative XS Mass Out (All)
	Δ Bed	Δ Bed	Flow	Flow	Time Step XS Mass Out (All)
		Velocity	Velocity	Velocity	Cumulative Δ Bed (All)
		Flow	Δ Bed	Δ Bed	Time Step Δ Bed (All)
		Shear	Shear	Shear	Transport Capacity (All)
		XS Mass Out Tot	XS Mass Out Tot	XS Mass Out Tot	Sediment Discharge (T/d) Tot
			XS Weight Out Cum	d50 Cover	Channel Manning's n
			XS Weight Residue	d50 Surface	Channel Froude #
			Slope	d50 Inactive	U Star
			XS Mass Bed Delta Tot	Mass Cover (All)	d90
			XS Mass Bed Data Culm Tot	Mass Surface (All)	Effective Depth
			XS Mass Capacity tot	Mass Inactive (All)	Effective Width
				Armor (All)	

(All) = This variable is output as a total for all materials and separately for each of the 20 grain classes
Tot = Only total for all grain sizes combined
WSE = Water Surface Elevation
Bottom Delta = Change of bed elevation

Default Output Level is 4, detailed number of increments is 10

Output files can grow extremely large if a detailed output level is selected and variables are written frequently. There is no way to turn off the output or request it only at certain times (Feb 2008). The output file size can be reduced by specifying a less detailed output level or increasing the Number of Increments Between Outputs (this will also reduce run times).

Computational Options

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HEC-RAS Sediment Computation Options and Tolerences

Computational Options

Bed exchange iterations per time step (SPI):	10
Min bed change before updating Cross Section (ft):	0.02
Min XS change before recomputation of hydraulics (ft):	0.02

☐ Perform Volume Error Check/Carry Over:

Computational Options

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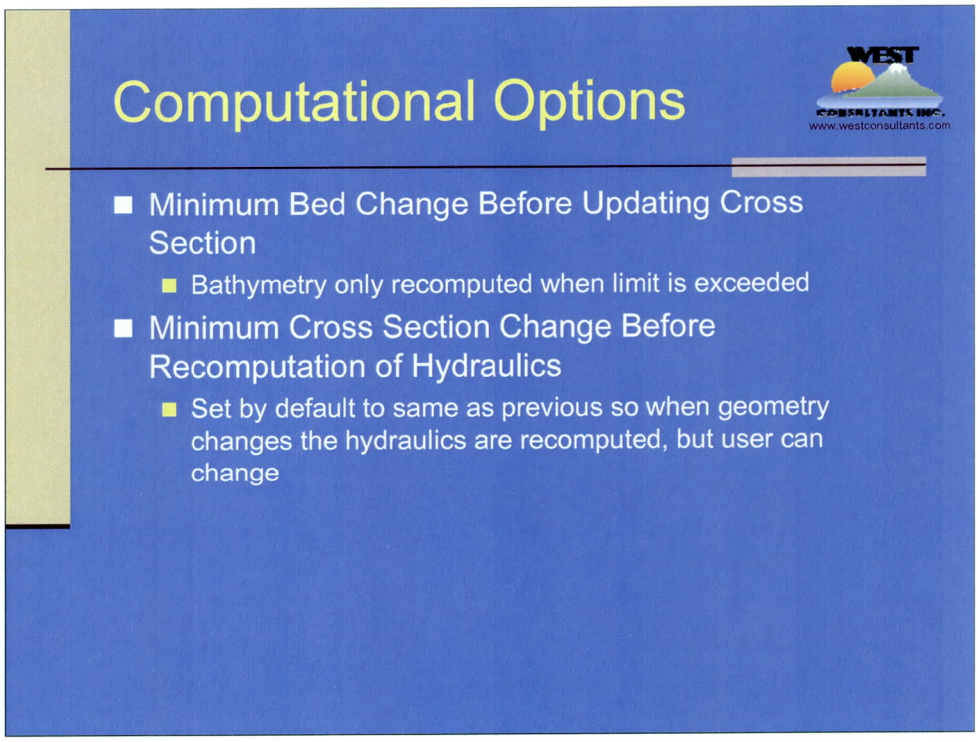
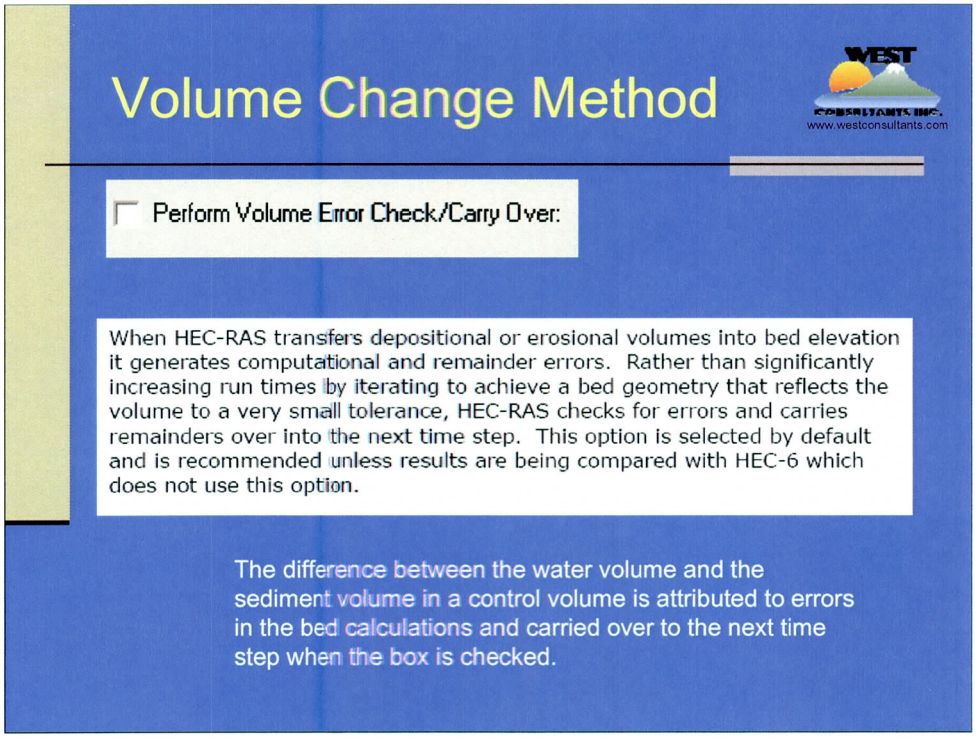
- The Bed Exchange Iterations variable is the same as the SPI factor in HEC-6
- Number of iterations the sorting and armoring algorithms will perform per computation increment to account for changes in bed material availability
- Bathymetry and Transport Potential is unchanged throughout the bed exchange iterations
- Transport Capacity is re-calculated at the beginning of each exchange increment based on the updated active layer composition

SPI=(V dt)/dx. Because the continuity equation is being solved for a control volume (no advection-diffusion), the time step dt should be chosen to approximate the time it takes for a particle to move through a control volume. This is analogous to maintaining the Courant conditions for hydraulic calculations.



Minimum Bed Change Before Updating Cross Section – In order to decrease run times HEC-RAS does not update the cross sections at every computational increment. Instead, erosion or deposition is tracked until the minimum bed change is achieved. When the threshold is exceeded the bathymetry is recomputed. The tolerance can be increased to lower run times or decreased to make the model more sensitive to bed change.

Minimum Cross Section Change Before Recomputation of Hydraulics- In order to conserve computational resources, hydraulic parameters are not automatically computed after each computational increment unless one of the cross sections has undergone appreciable change.



Example: At the end of a computation interval, the cross section in question has 1000 cu ft of material to be deposited which corresponds to a bed change of 0.017 ft. Because this is less than the tolerance of 0.02 ft, the cross section is not adjusted. During the next computation interval the cross section has 1300 cu. ft. more material to be deposited for a total of 2300 and a computed bed change of 0.04 ft. The cross section is adjusted and the difference in water volume is determined to be 2280 cu. Ft. (2300-2280 gives 20 cu ft of carryover). During the next computational interval, 1200 cu ft is deposited plus the 20 cu ft of carryover for a total of 1220 resulting in a bed change of 0.025 ft.

Cross Section Weighting Factors

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Cross Section Weighting Factors

Set Global Weighting Factors

Internal Cross Section

Number of US XS's to use for averaging hydraulic properties: 1

Number of DS XS's to use for averaging hydraulic properties: 1

Weight fraction (0.0-1.0) assigned to the hydraulic properties at:

Upstream Cross Section(s): 0.25

Main Cross Section: 0.5

Downstream Cross Section(s): 0.25

Upstream Boundaries:

Number of averaging XS's to use DS of the US boundary: 1

Weight fraction (0.0-1.0) assigned to the hydraulic properties at:

UpStream Boundary Condition: 1

Downstream Cross Section(s): 0

Downstream Boundaries:

Number of averaging XS's to use US of the DS boundary: 1

Weight fraction (0.0-1.0) assigned to the hydraulic properties at:

Downstream Boundary Condition: 0.5

Upstream Cross Section(s): 0.5

Cross Section Specific Weighting Factors Set Weighting Factors by XS

Default values shown

Cross Section Weighting Factors

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- Sediment transport calculations can be very sensitive to local changes in hydraulics, generating instabilities
- Can dampen abrupt changes by averaging hydraulic properties of several cross sections when considering a control volume
- Specify
  - Number of U/S Xsecs, Number of D/S Xsecs
  - Weighting for U/S, D/S, main cross sections
  - For boundaries, only use BC plus closest Xsec(s)
- Using more cross sections or different factors can increase stability at the expense of accuracy

Transport Slope Method

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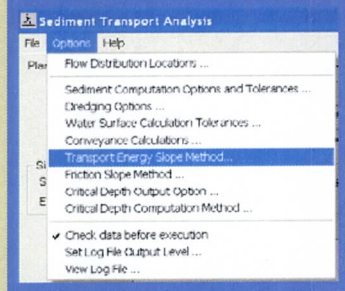

- Energy slope used in transport equations for shear stress and transport potential
- Choose between average and instantaneous
  - Default depends on which version of the program that you are using

Transport Slope Method

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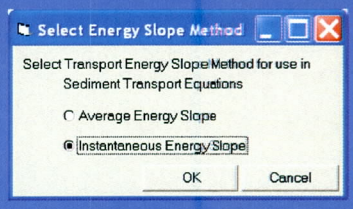

$Q = A\ R^{2/3}\ S_f^{1/2}$

$Q = K\ S_f^{1/2}$

$S_f = (Q/K)^2$

- Uses Manning's Equation to determine energy slope at any given time at any given cross section

Transport Slope Method

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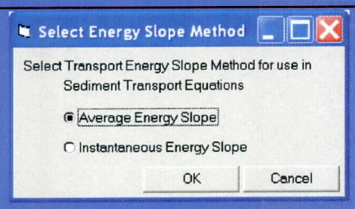
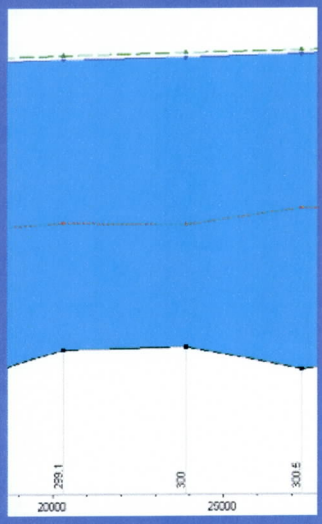


- Average of upstream EG slope and downstream EG slope

S = (change in EG) / (cross section distance)

$S_{avg} = (S_{u/s} + S_{d/s}) / 2$



Transport Slope Method

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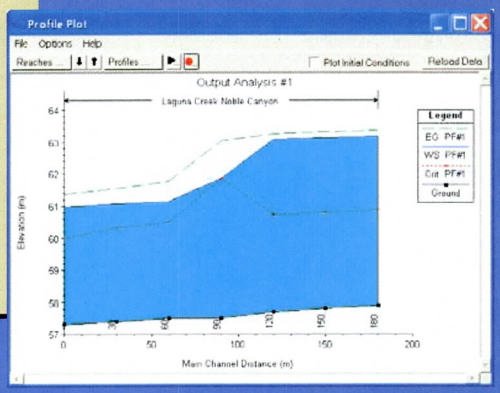

- Average method is generally more representative
- Average method can give wild results
- Default method depends on version of program
  - Web version Feb 2008 – Average
  - HEC version - Instantaneous

The average method is generally better, especially for mild sloped systems. However, where there are abrupt changes in energy (see profile above) the average energy results can be too high at multiple cross sections and resulting in high shear stress and large sediment transport potential. In the above example, the instantaneous method would give high shear at a single cross section but may result in more realistic sediment transport calculations.

Agenda:

October 17th, 2011

08:30 - 09:00	Welcome, General Instructions and Introductions
09:00 - 10:00	Lecture - Sediment Transport in Natural Streams
10:00 - 10:15	Break
10:15 - 11:00	Lecture - Introduction to HEC-6T and HEC-RAS
11:00 - 12:00	Demonstration - Executing HEC-RAS, Reading Output
12:00 - 13:00	Lunch
13:00 - 14:00	Workshop - The Flume Problem with HEC-RAS
14:00 - 14:15	Break
14:15 - 15:30	Lecture - Sediment Properties and Sediment Modeling
15:30 - 16:30	Lecture - Selection of Sediment Transport Relations

October 18th, 2011

08:30 - 09:00	Lecture - Steps in Performing Sediment Studies/Field Reconnaissance
09:00 - 10:00	Workshop - The Flume Problem with HEC-6T
10:00 - 10:15	Break
10:15 - 11:15	Demonstration - Executing HEC-6T, Reading Output
11:15 - 12:00	Lecture - Calibration and Verification Techniques
12:00 - 13:00	Lunch
13:00 - 13:45	Lecture - Calibration and Verification Techniques, continued
13:45 - 14:00	Break
14:00 - 15:00	Lecture - Trouble Shooting an HEC-RAS Sediment Model
15:00 - 16:00	Example - Lower Mud River Study
16:00 – 16:30	Stable Channel Design in RAS

WORKSHOP SOLUTION

HEC-RAS SEDIMENT WORKSHOP NO. 1-4
THE FLUME WORKSHOP PROBLEM

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Objective: To prepare and execute a basic sediment transport model and view the results.

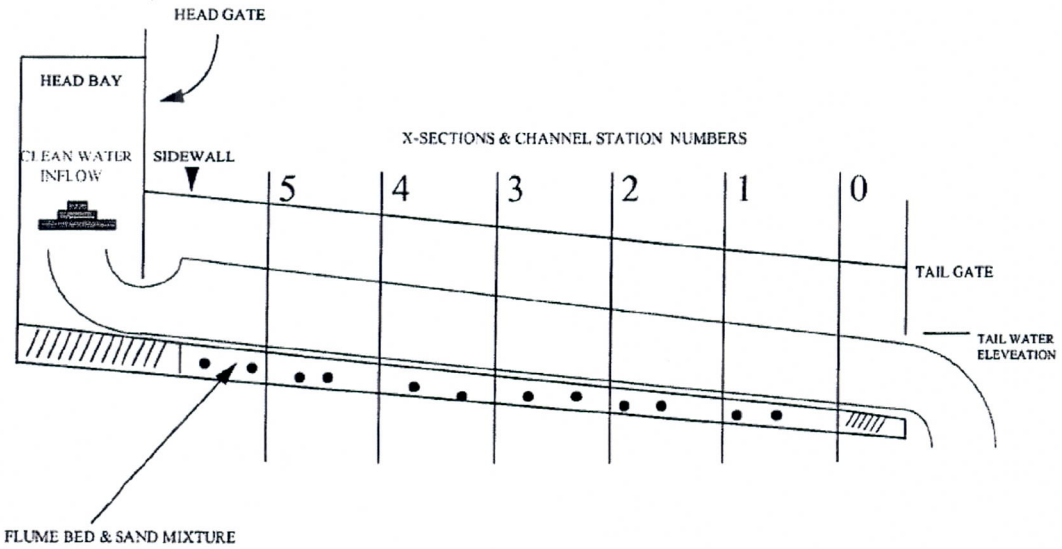
Time to Complete: 1 hour

The data files used for this workshop were developed for pedagogic purposes. The model and results of this workshop do not represent current or future conditions for any particular river.

Intro

Introduction

The HEC-RAS file, flume.prj, is a data set that models a simple flume. Below is a sketch of what the physical model of this flume would look like from a side view. Notice the six vertical lines numbered 0 through 5. These are cross sections and channel station numbers of the flume. The flume has a single inflow at the upstream end (cross section 5) and a single outflow at the downstream end (cross section 0). In this example, a sand mixture has been placed in the bed of this flume. The sketch shows clean water coming from the head bay. This flume will have a single gate across its entire width to insure that the inflowing water is



FLUME

distributed uniformly from one wall to the other. The tailwater elevation will be at normal depth. Since there is no bed material in the inflowing water, one expects erosion to take place as water flows down this flume.

Steps to Enter Sediment Data and Run Sediment Transport Simulation

Step 1 **Entering Sediment Data**

1. Open the HEC-RAS file: flume.prj

2. Click the Sediment Boundary Condition Data button.

3. On the Initial Conditions and Transport Parameters Tab, enter the following in the table:

   a. Max Depth = 10 (all cross sections)

   b. Min Elev field left blank

   c. Click the "Use Banks for Extents" button at bottom of page to populate left and right movable bed limits (Note: if the button is not visable, try changing the window size).

4. Now click the Define/Edit Bed Gradation ... button to define the gradation.

   a. Create a new gradation by clicking the button, and name the gradation "Sample#1."

   b. Enter the following gradation, then click OK:

5. Select the "Sample#1" gradation at each cross section.

Class	diam (mm)	% Finer
Clay	0.004	
VFM	0.008	
FM	0.016	
MM	0.032	
CM	0.0625	
VFS	0.125	13
FS	0.25	15
MS	0.5	16
CS	1	19
VCS	2	24
VFG	4	25
FG	8	27
MG	16	28
CG	32	31
VCG	64	36
SC	128	100
LC	256	
SB	512	
MB	1024	
LB	2048	

6. Define the sediment transport function as Yang

7. Click the Boundary Conditions tab, click in the white box next to cross section 500, then click the Rating Curve button, and without entering any data click OK.

8. To save the Sediment Data entered in the steps above, select "Save Sediment Data As…" from the File menu and name the Sediment Data Completed Sediment

Step 2 Entering Quasi-unsteady Flow Data

1. From the Main HEC-RAS window, click the Quasi-unsteady flow data button.

2. Click in the white box next to cross section 0, then click the Normal Depth button and enter a friction slope of 0.001.

3. Now click in the white box next to cross section 500, then click the Flow Series box and enter the following data:

Flow Duration (hours)	Computation Increment (hours)	Flow (cfs)
6	1	2000

4. At the bottom of the dialog box, click the Set Temperature ... box and enter the following data then "OK.":

Duration (hours)	Temp (F)
24	45

5. To save the Quasi-unsteady Data, select "Save Quasi-Unsteady Flow File…" from the File menu and name the file QU2000cfs

Step 3 Perform the Simulation

1. To run the simulation, click the Perform Sediment Transport Simulation button from the main HEC-RAS window.

2. Enter the following in the simulation time window:

Simulation Time Window			
Starting Date:	01MAR2008	Starting Time:	2400
Ending Date:	02MAR2008	Ending Time:	0559

3. To save the Sediment Transport Analysis plan data, select "Save Plan As…" from the File menu and name the file Flume with 2000cfs w sediment and name the short ID as flume w sed

4. Click COMPUTE to run the simulation

Step 4 Evaluate the Output

1. From the main HEC-RAS window, select "Sediment Spatial Plot…" from the View menu and select the Profile Plot tab.

2. The default variable plotted is "Ch Invert El" (channel invert elevation). Click the Profiles … button to select profile number 7. By clicking on the line, enter the final thalweg elevation at cross section 200 for profile 7:

0.15 feet

3. Now click on the Table tab and provide the final thalweg elevation at cross section 200, profile 7, to four significant digits (just because we can):

0.1492 feet

4. How much degradation occurs at cross section 200 for profile 7? (hint: change Variables … from "Ch Invert El" to "Invert Change")

0.05 feet

5. Which cross section degraded the most and to what depth?

depth of 0.13 feet at cross section 500

6. How much scour occurs at cross section 400 after the third hour? (hint: turn on profile 4 and the "Invert Change" variable)

0.05 feet

7. From the main HEC-RAS window, select "Sediment Time Series Plot…" from the View menu.

8. Based on the results of this simulation, what shear stress (rounded up to the nearest 0.01 lbs/ft^2) would you select for designing erosion countermeasures? (hint: change Variables ... to shear stress and view the chart and/or table for each cross section; watch out for boundary condition effects)

approximately 0.18 lbs/ft^2

9. Which cross section has its minimum velocity occur at hour 1, and what is that velocity? (hint: change Variables ... to velocity and view the chart and/or table for each cross section)

Cross section 0

3.63 fps

End of Workshop