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Managing Water in the West

SIAM

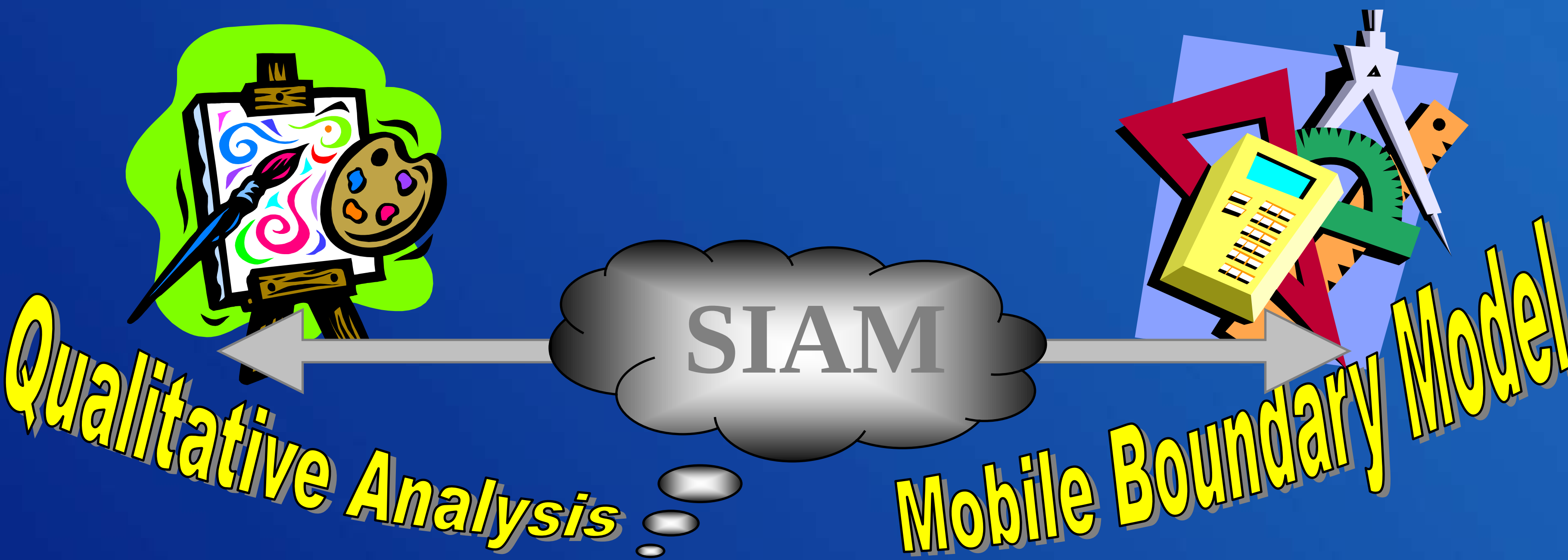
Sediment Impact Analysis Methods

U.S. Department of the Interior
Bureau of Reclamation

Overview

- Part I
  - Purpose and Uses of SIAM
  - SIAM Computations
    - Local Accounting
    - Sediment Source Tracking
    - Equilibrium Estimates
    - Network-Wide Impacts
  - Applicability and Limitations
- Part II
  - Input and Output
  - Model Parameters
  - Big Picture

What is SIAM?



SIAM provides a framework to quantitatively evaluate rehabilitation strategies on a watershed scale from a sediment continuity perspective.

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Why Another Sediment Tool?

How can planners and managers evaluate and optimize options for sediment objectives?

- SIAM facilitates incorporating sedimentation issues into river engineering.
- Unique features include:
  - Source to Impact Linkages
  - Scale Simplification
  - Option Simplification
  - Risk and Uncertainty
- SIAM provides a screening level rapid assessment. Final designs should use more precise tools.

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Applications

- Organize watershed sediment data and geomorphic processes
  - Locate and Quantify Geomorphic Instabilities
  - Assess Infrastructure Risk
  - Identify Distributed Causes and Impacts
  - Reduce Detailed Modeling Efforts to Key Reaches
- Evaluate and Control Sediment Sources
  - Track Sediment Sources
  - Assess Sediment Yields
  - Reservoir Sedimentation and Reach Aggradation
  - Pollutant Transport Related to Sediment
- Determine Rehabilitation Needs and Options
  - Structural Stream Modifications
  - Identification of Causes
  - Alternate Scenario Comparisons

Key SIAM Concepts

- Streams respond to the hydrologic and hydraulic regime by balancing sediment inflow with sediment outflows.
- Sediment continuity connects the geomorphic behavior within a particular reach or portion of a watershed with the larger channel network.
- For a rapid assessment screening tool, we can simplify processes and make inferences base on principles of geomorphic adjustment.

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Inputs

- SIAM groups a channel network into lengths of homogeneous reaches and assigns properties on a reach by reach basis.
- SIAM Inputs define the input and movement of material through a watershed.
- The types of data required by SIAM mirror many of the requirements to perform a geomorphic assessment.
- Input includes bed material, hydrology, hydraulics, transport potential, sediment properties, and sediment sources.

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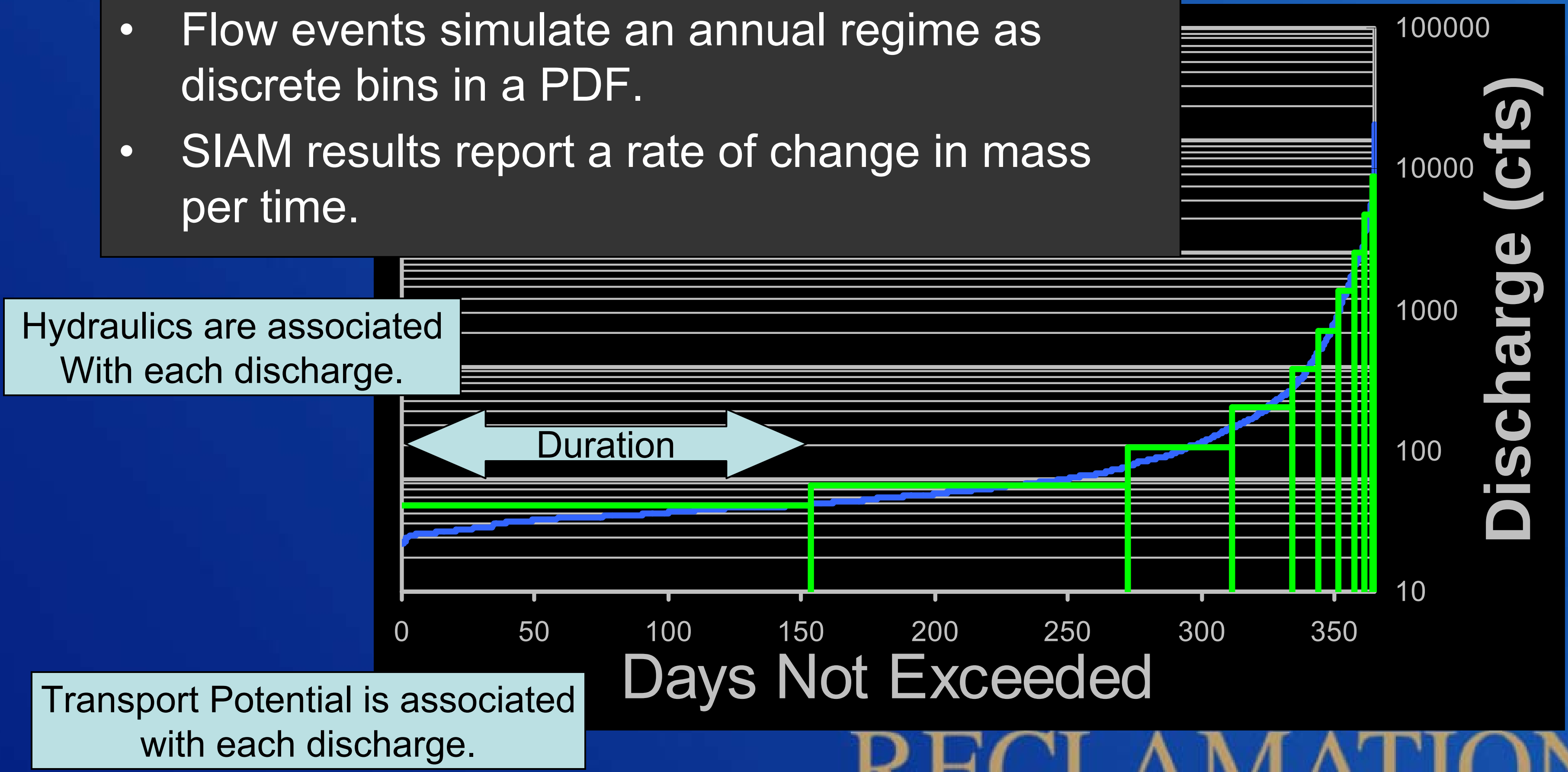
Regime Representation

- A regime consists of the range of flows, hydraulics, and sediment transport potential experienced over the analysis time frame.
- Flow events simulate an annual regime as discrete bins in a PDF.
- SIAM results report a rate of change in mass per time.



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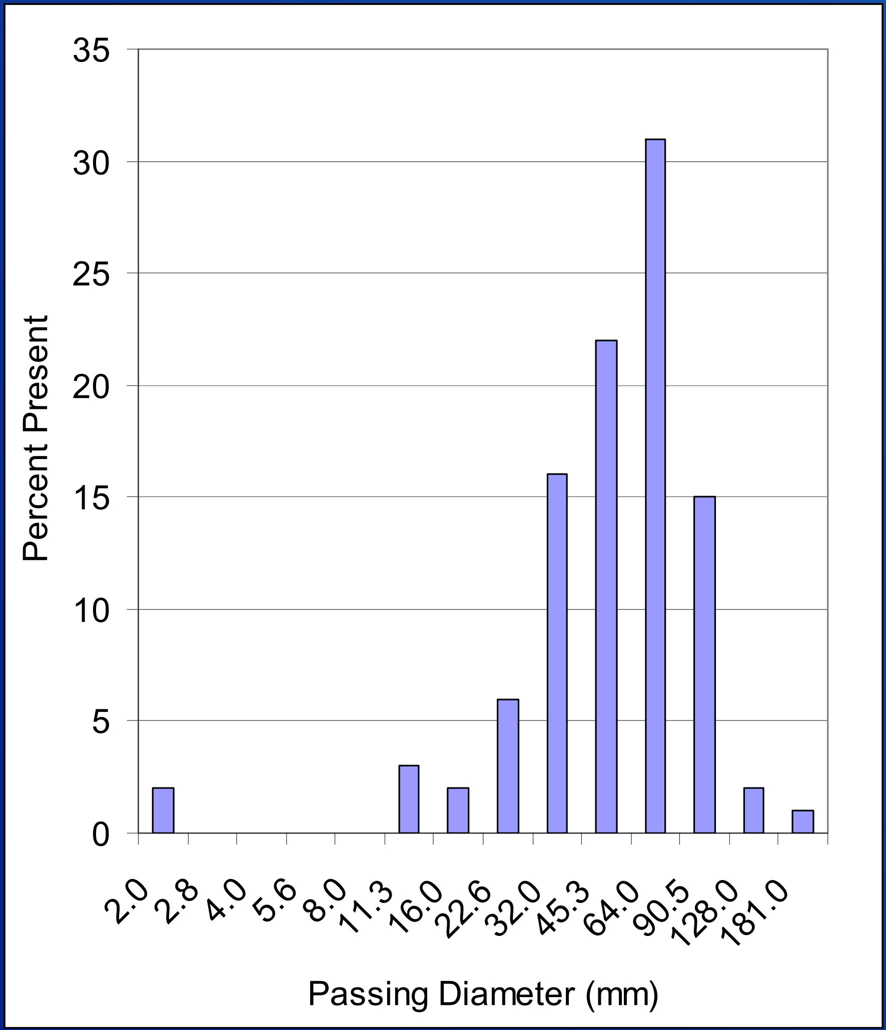
Grain Classes and Sediment Properties



- SIAM divides grain classes into bins with a representative diameter for each bin.
- Bed Material
  - Global Grain Classes
  - Representative Diameter
  - Fraction Present
- Wash Load Threshold Diameter
  - Material not present in the bed in significant quantities
  - These smaller diameters pass without channel interaction
- Cohesive Threshold Diameter
- Armor Control Discharge
  - Larger diameters on the surface shield smaller diameters.

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Local Sources

- Local sources include features supplying sediment.
- Types of Local Sources
  - Boundary Conditions
  - Surface Erosion
  - Unincorporated Tributaries
  - Bank Failure
  - Gullies
  - Land Slides
  - Roads
  - Industry
  - And More!
- Local sources exclude material freed through scour of modeled reaches.

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Calculation Framework

- A SIAM model consists of reaches linked in a dendritic network.
- Each reach contains a wash material reservoir and a channel material reservoir.
  - **WASH** material passes through the system and does not interact with the channel boundaries, but contributes to sediment yield.
  - **CHANNEL** material interacts with channel boundaries and can cause geomorphic change.
  - **TRANSITIONING** material shifts from moving as wash material in one part of the network to channel material in another part or vice versa.
- Different reaches in a system are connected through either a wash reservoir or channel reservoir linkage.
- SIAM considers **SUPPLY** (inflow) minus **TRANSPORT** (outflow).

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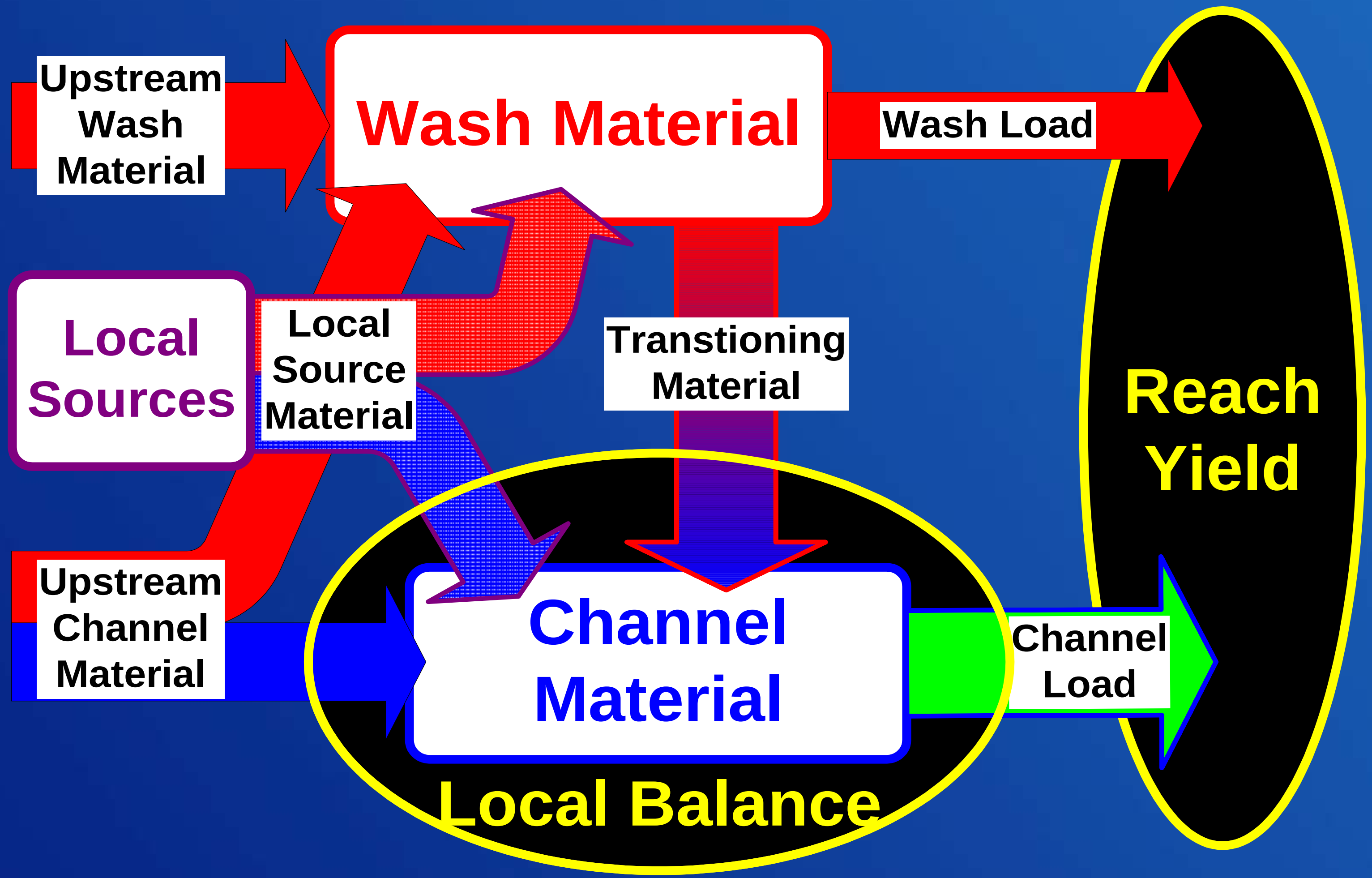
Reach Unit



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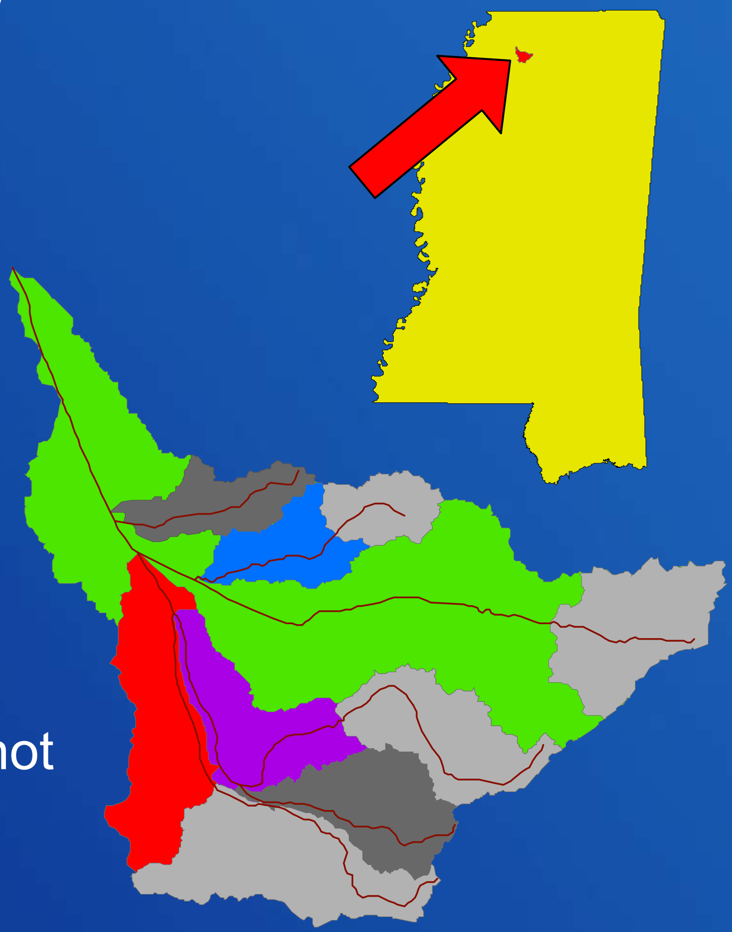
Demonstration Basin - Hickahala, MS

- Hickahala Basin, Mississippi (220 mi^2)
- Channelization in the 1960s
- Hickahala suffered from excessive sedimentation in a downstream reservoir.
  - Degradation and Aggradation
  - Surface Erosion, Bank Failures, and Gullying
  - Flooding and Loss of Land
- A comprehensive rehabilitation plan reduced watershed yield.
- Treatments targeted multiple causes not just symptoms.
- The scope and breadth of data and treatments made an ideal test case.



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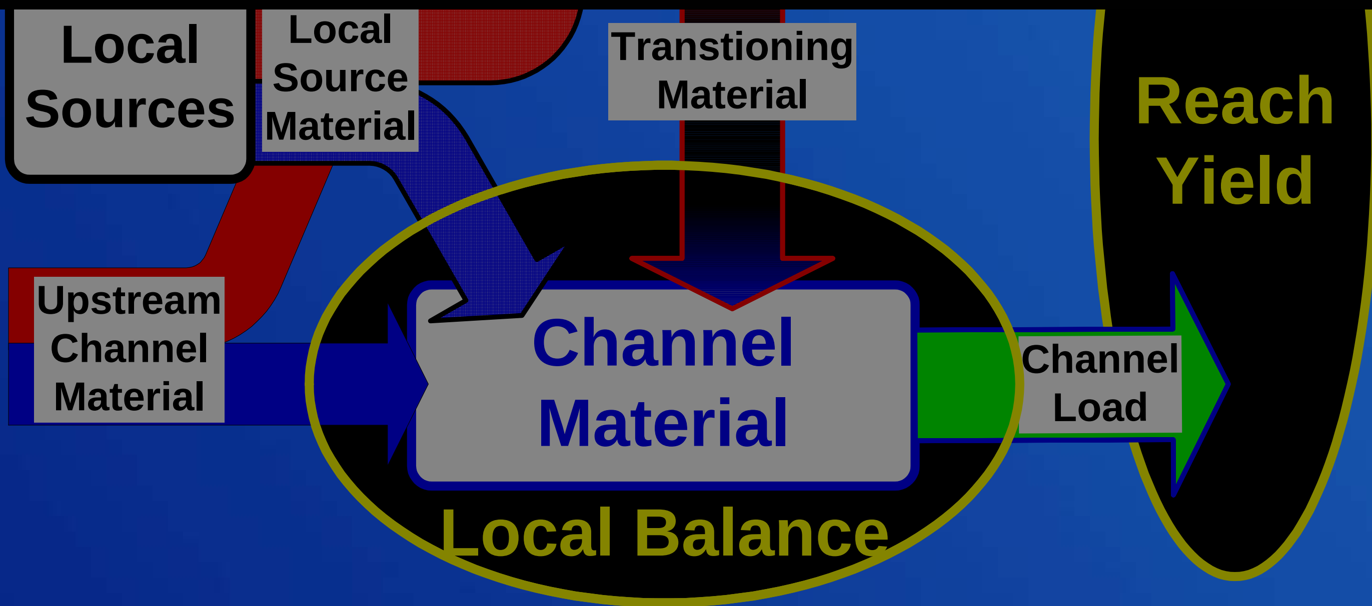
Local Balance of Channel Material

- Local balance subtracts the outflow of material from the inflow.
- Positive values represent aggradation, negative show degradation.
- Transitioning material connects the local balance to the entire upstream network through wash material linkages.
- Local balances include channel material only from immediately adjacent upstream reaches.
- The local balance represents an "immediate" conditions.



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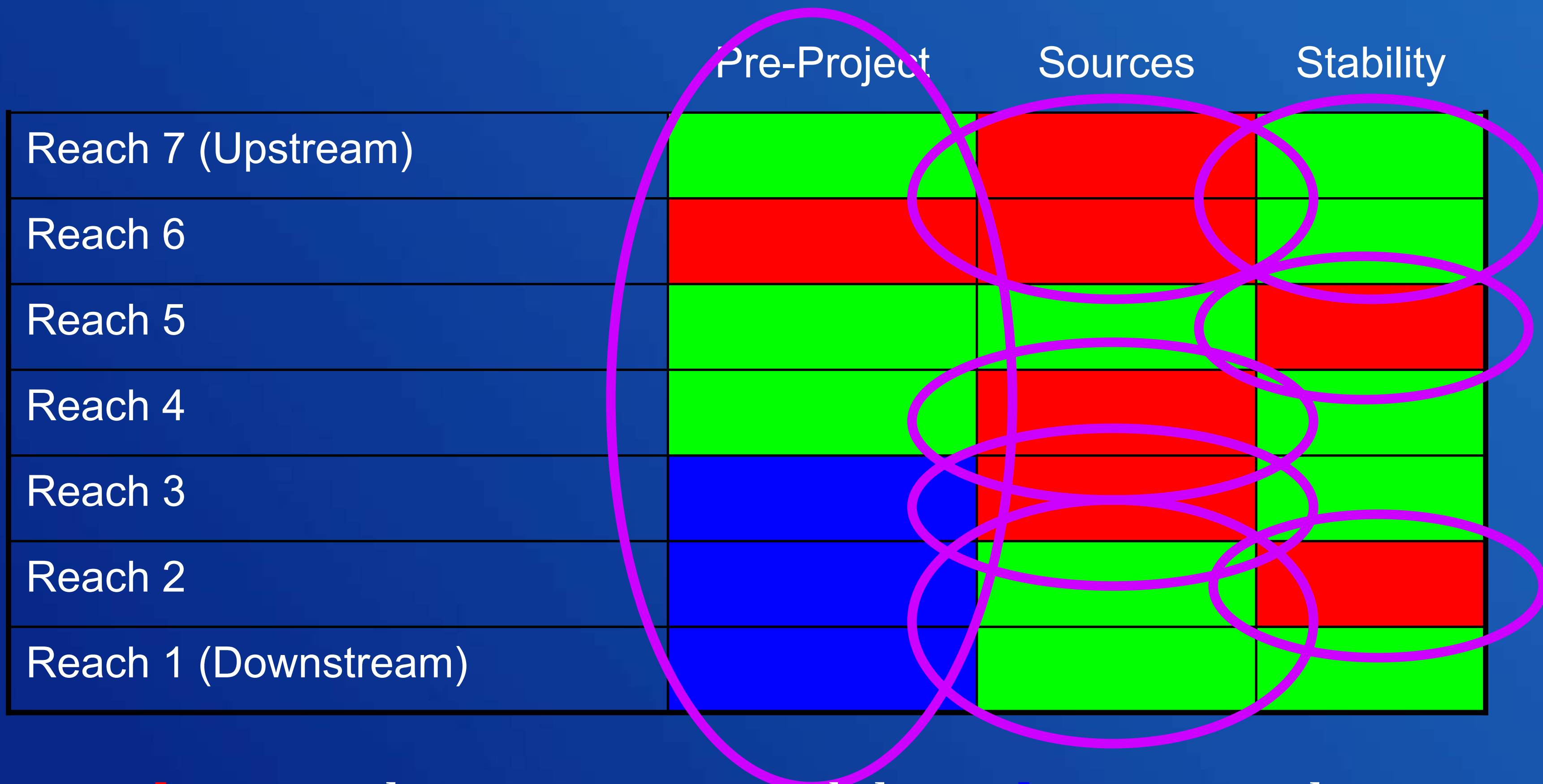
Channel Stability (Senatobia Creek)

Local Balance Answer Quilt



Red = Degradation, **Green** = Stability, **Blue** = Aggradation

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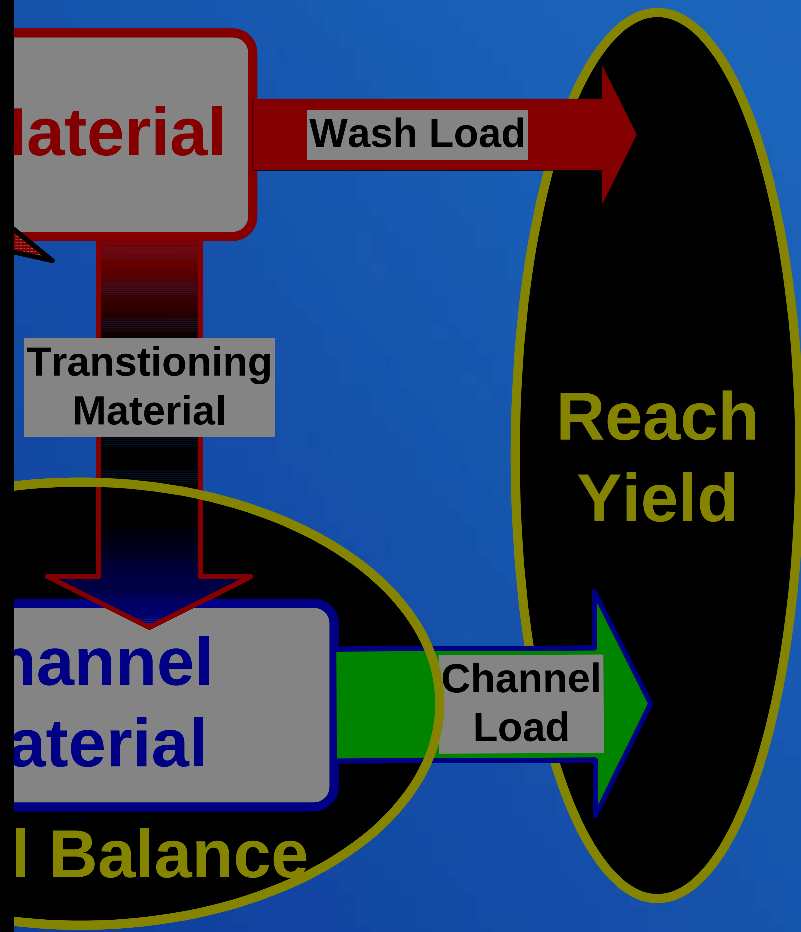
Comparison of Geomorphic Problem Areas

- A field study and a mobile boundary model of the Hickahala Basin identified stable and unstable reaches.
- Comparison of SIAM local balances to prior evaluation agreed in 25 reaches
- 5 reaches showed discrepancies with the mobile boundary study. Resolution of differences included:
  - Reach length (1 case);
  - Inclusion or exclusion of tributaries (3 cases); and
  - 1 unresolved case.
- Particle sieve analysis showed finer material in the depositional areas.

Sediment Yields

- Sediment yield measures the total outflow of material under present conditions.
- Includes all sources connected through wash material reservoir linkages
  - Local sources
  - Channel degradation releasing wash classes
- Includes channel load from the current reach.
- Transitioning material is excluded.



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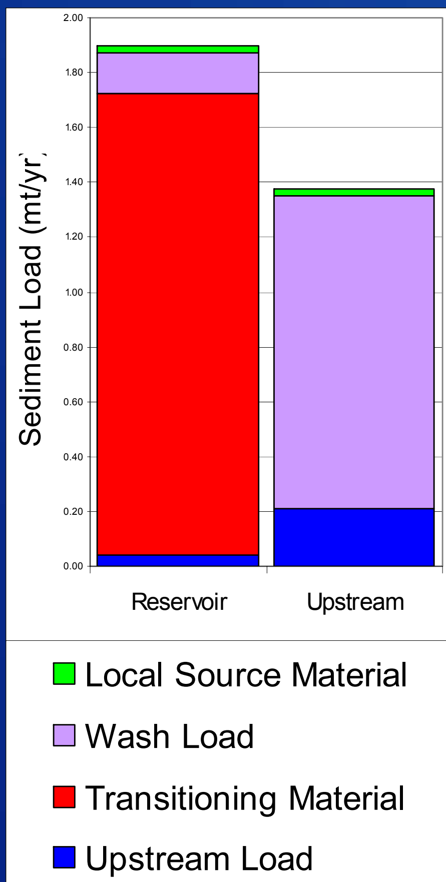
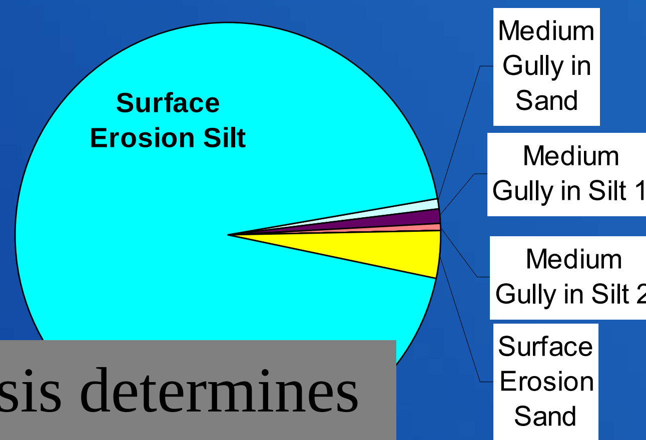
Sediment Yields (Senatobia Creek)

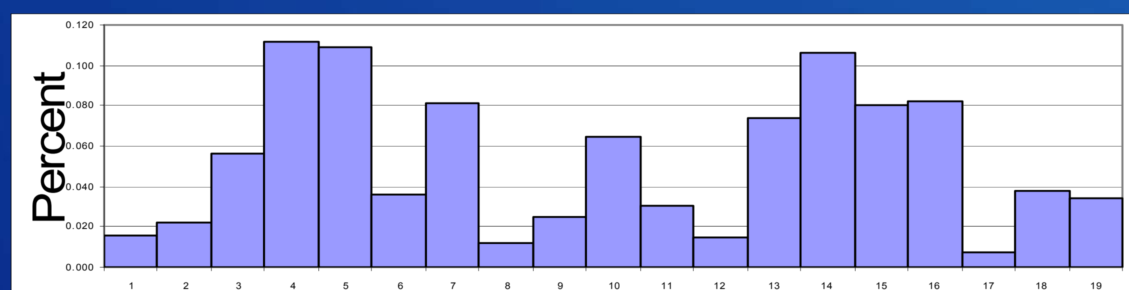
1. Sediment yield identifies processes creating problems.





2. Source analysis determines the significant contributors.

3. Source distribution locates the source.



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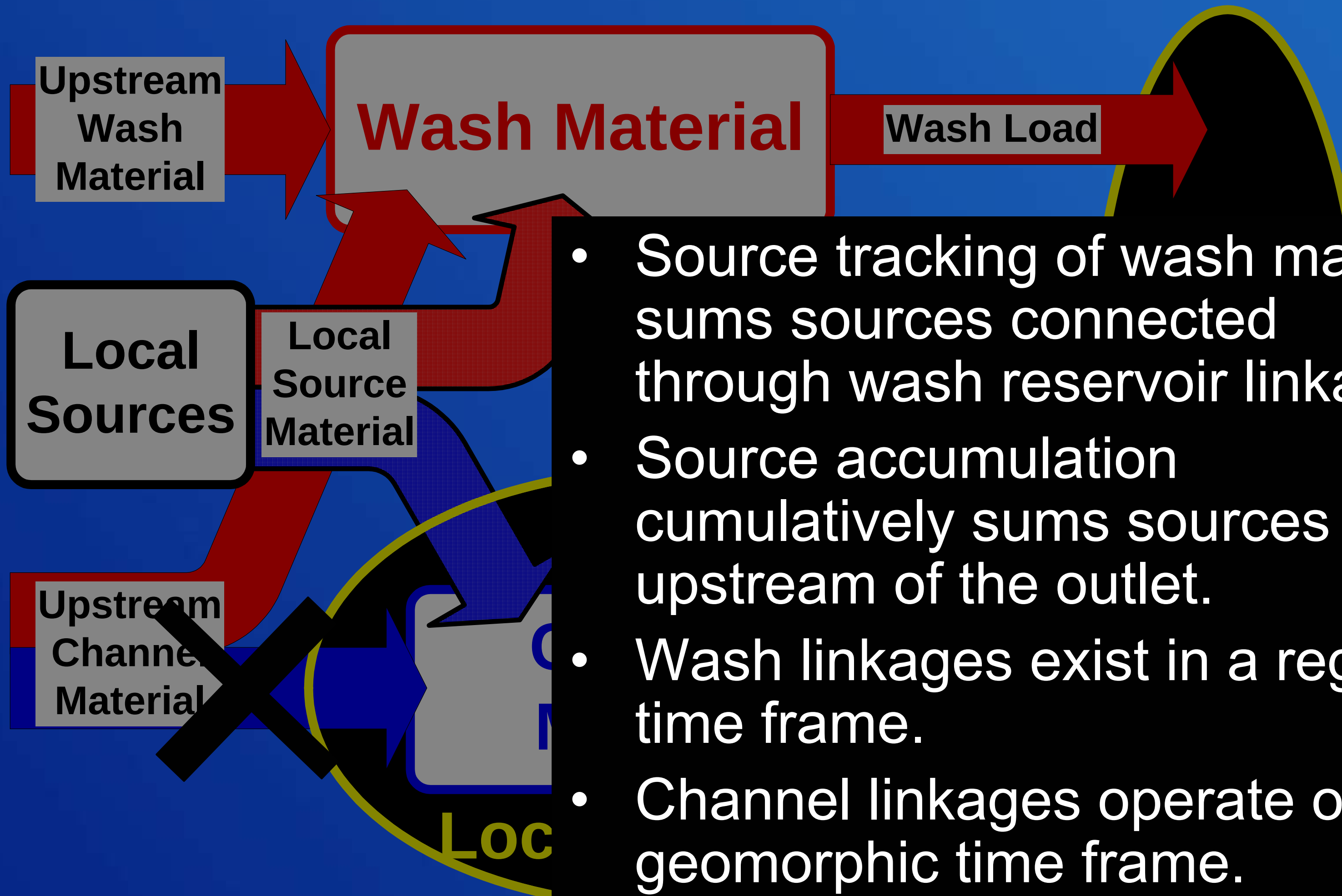
Source Tracking



- Source tracking of wash material sums sources connected through wash reservoir linkages.
- Source accumulation cumulatively sums sources upstream of the outlet.
- Wash linkages exist in a regime time frame.
- Channel linkages operate on a geomorphic time frame.

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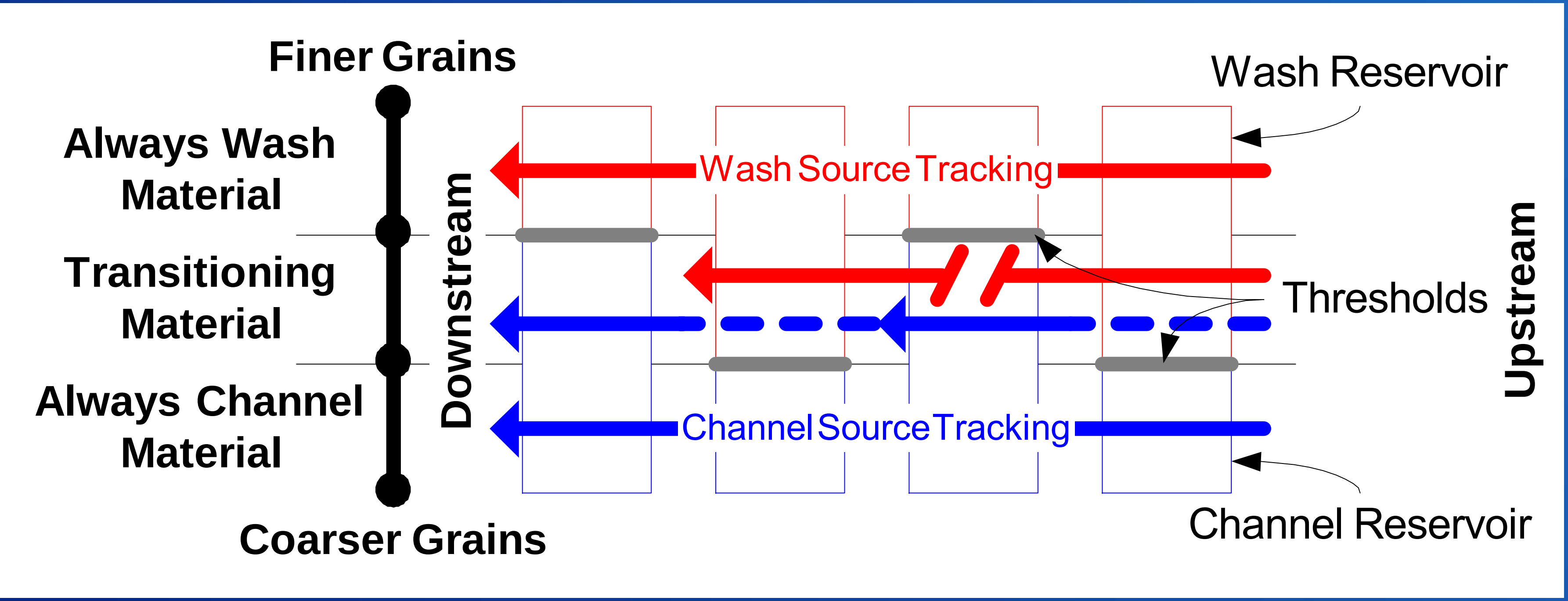
Source Material Reservoir Linkages



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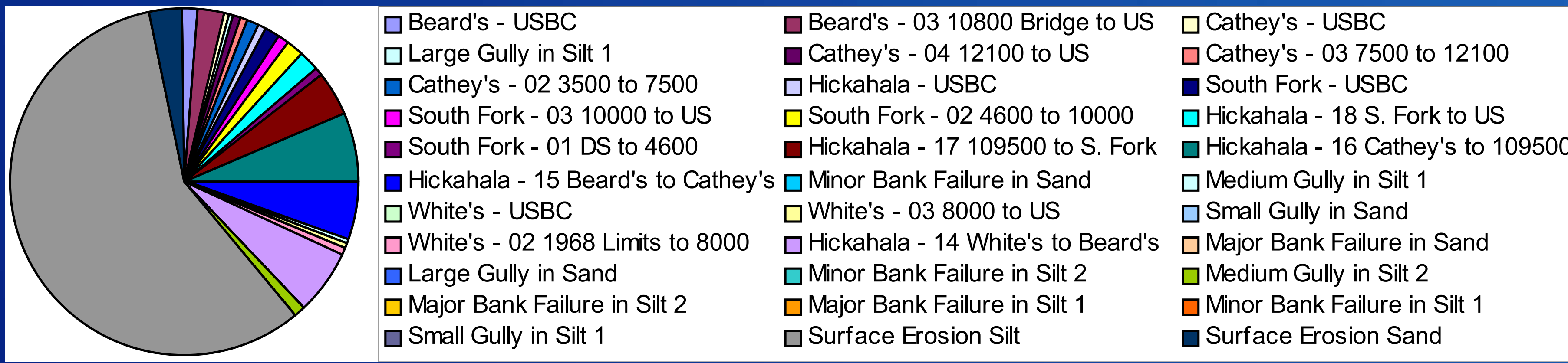
Sediment Yield and Source Tracking

- The Hickahala Basin contained many degrading reaches and load templates.
- Yield was primarily composed of wash material.
- Tracking provides the potential to target an approach
- Significant contributors include:
  - Surface erosion through silty soils
  - Degradation in upstream reaches



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Applied Energy

- Lane's Balance (Discharge, Slope, Transport, Material)

$$Q * S \sim Q_s * d_s$$

- R.A. Bagnold (1966) used concepts of work, power, and energy to describe sediment transport.
- An efficiency term describes the amount of total energy in the stream applied towards moving material.
- Applied energy methods provides a means of simplifying geometry, hydraulic, and transport feedback processes.

$$\Pi = \sum [e_b * (R*S*V*P) * t]$$

- e_b = efficiency, R = hydraulic radius, S = friction slope, V = velocity, P = wetted perimeter, and t = duration.

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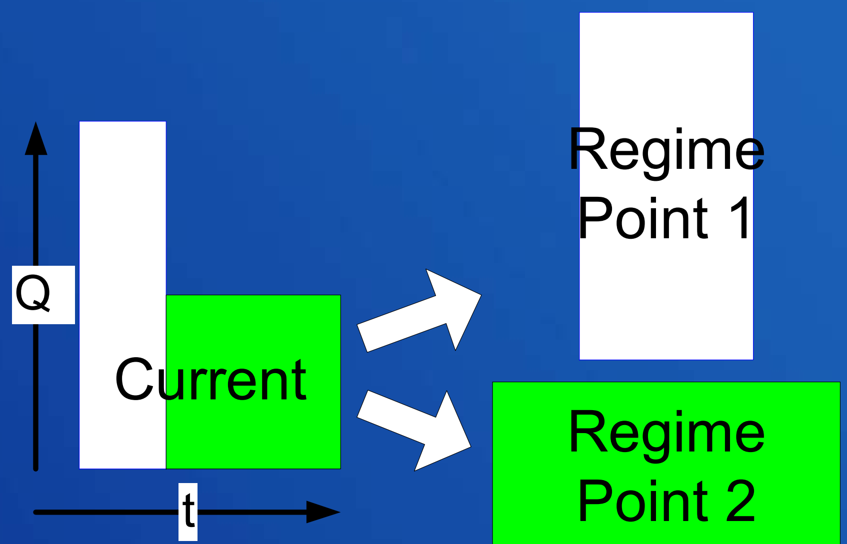
Hypothetical Regime Curve

- SIAM uses existing conditions to estimate a relationship between yield and work.
- Each flow event is treated as an entire regime. Discharge remains equal, but the duration is increased to pass the entire volume of the original regime.
- The regime curve shows the target applied work required to obtain a specific sediment yield.



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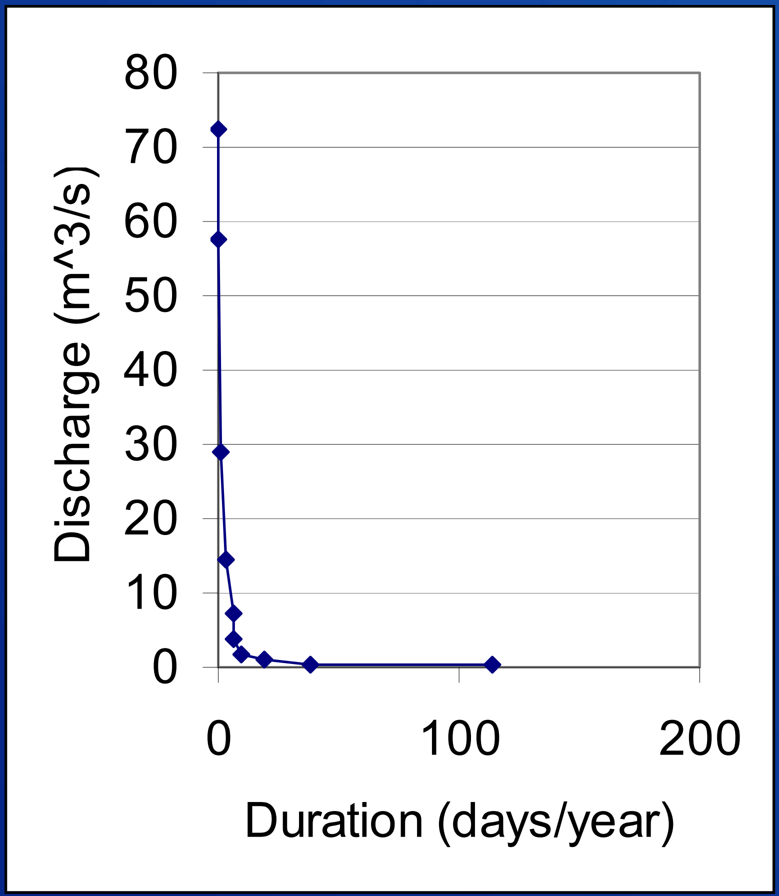
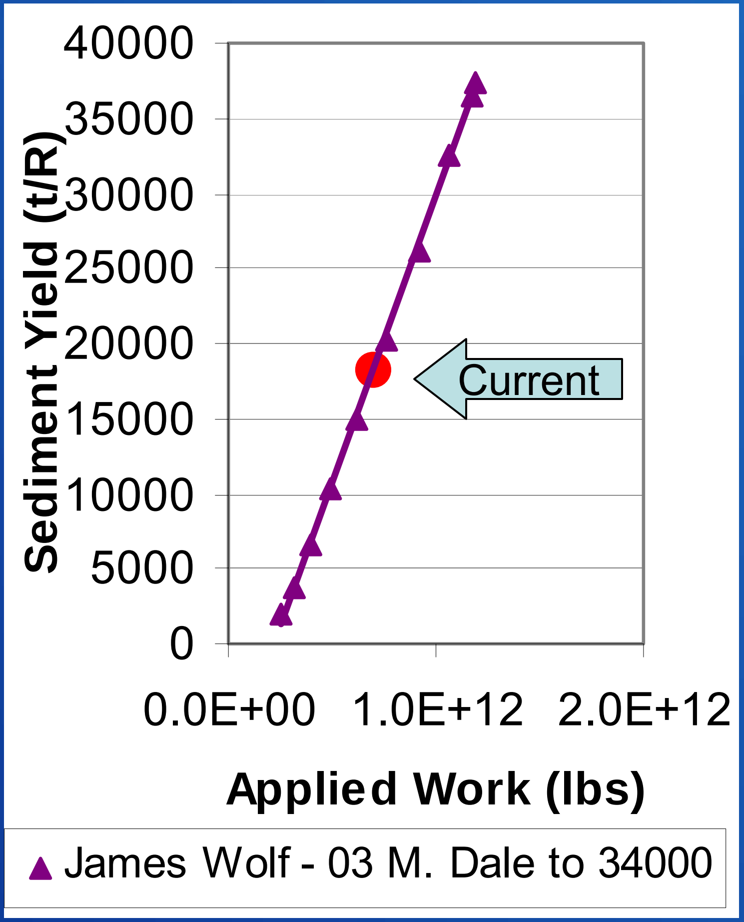
Hickahala Hypothetical Regime Curves





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Empirical Validation

- 84 Reaches on Hickahala Creek
  - Average R^2 value of 0.95
  - Standard Deviation of Residuals 14%
- Reservoir Effects Reduced the Goodness of Fit
- Reaches outside of the reservoir
  - $R^2 = 0.99$
  - Standard Deviation of Residuals = 12%

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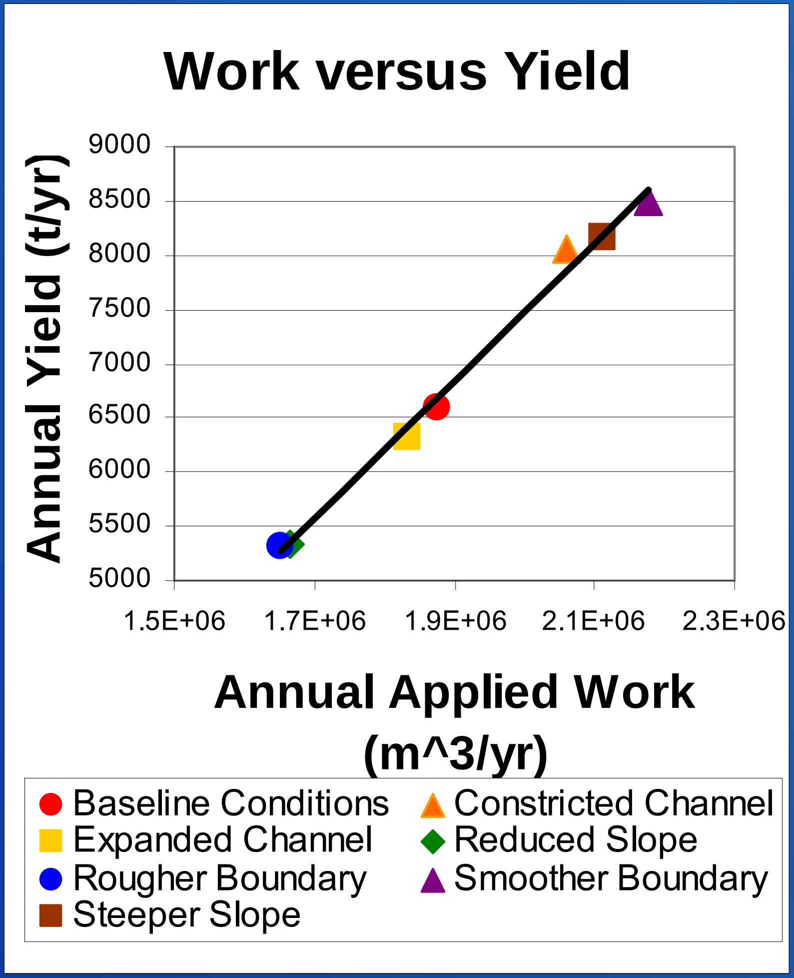
Applied Work using Geometry

- Applied annual work captures the relationship between channel modifications and the resulting sediment yield.
- Inside SIAM, hydrology, hydraulic, and transport records estimate the work relationship.
- Channel designers select a desired sediment load and then modify the channel to obtain the correct amount of work.



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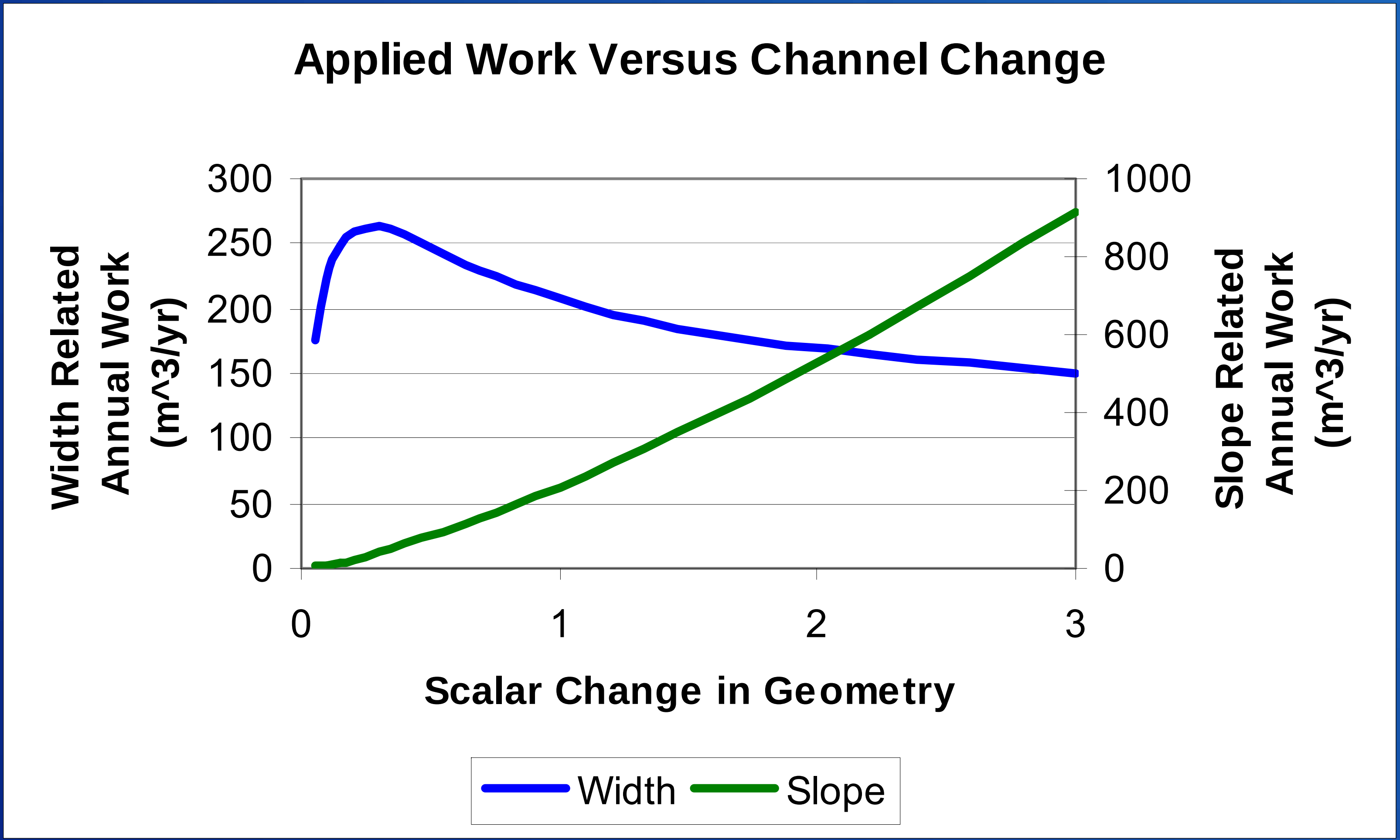
Applied Work and Hydraulics



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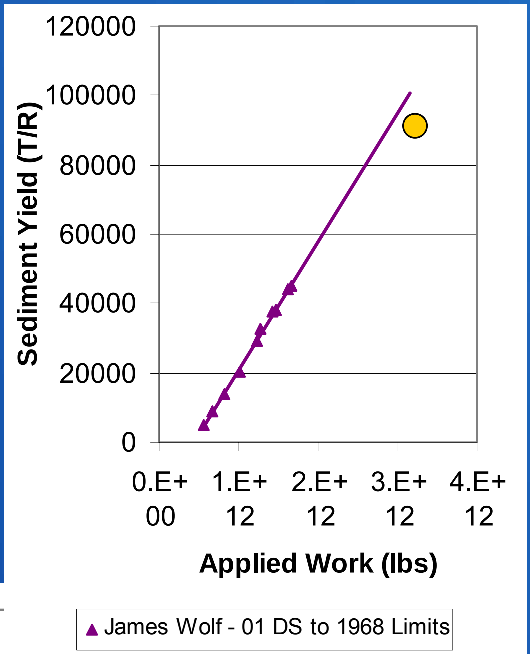
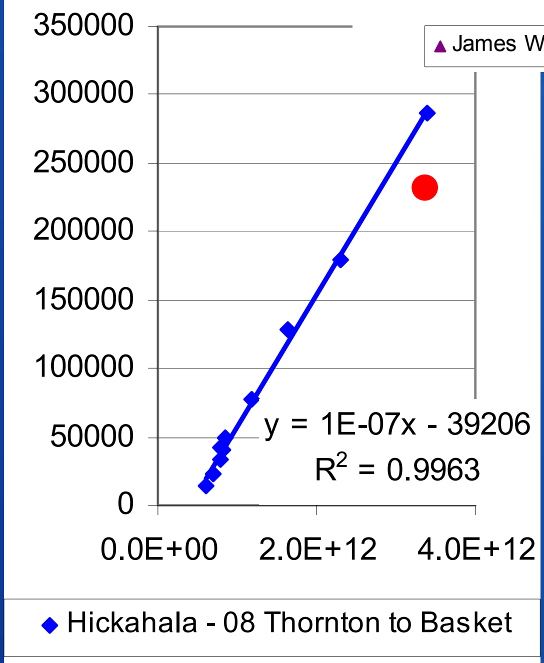
Hickahala Applied Work

- All reaches
  - Mean Error of 10%
  - Standard Deviation of Errors equal to 100%
- Reaches Outside the Reservoir
  - Standard Deviation of Errors equal to 30%
- Order of magnitude accuracy.





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Applied Energy Cautions

- Changes in bed material composition will change the regime curve.
  - Backwater Areas
  - Fining or Coarsening of Material
- The difference between the existing and equilibrium work indicates the magnitude of adjustment, but not the method.

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Network Balance

- Channel material classes interact with the boundaries of the stream to create the form.
- Streams adjust to balance sediment inflow and outflow of material.
- Changes to one part of a stream network may influence other areas both upstream and downstream.

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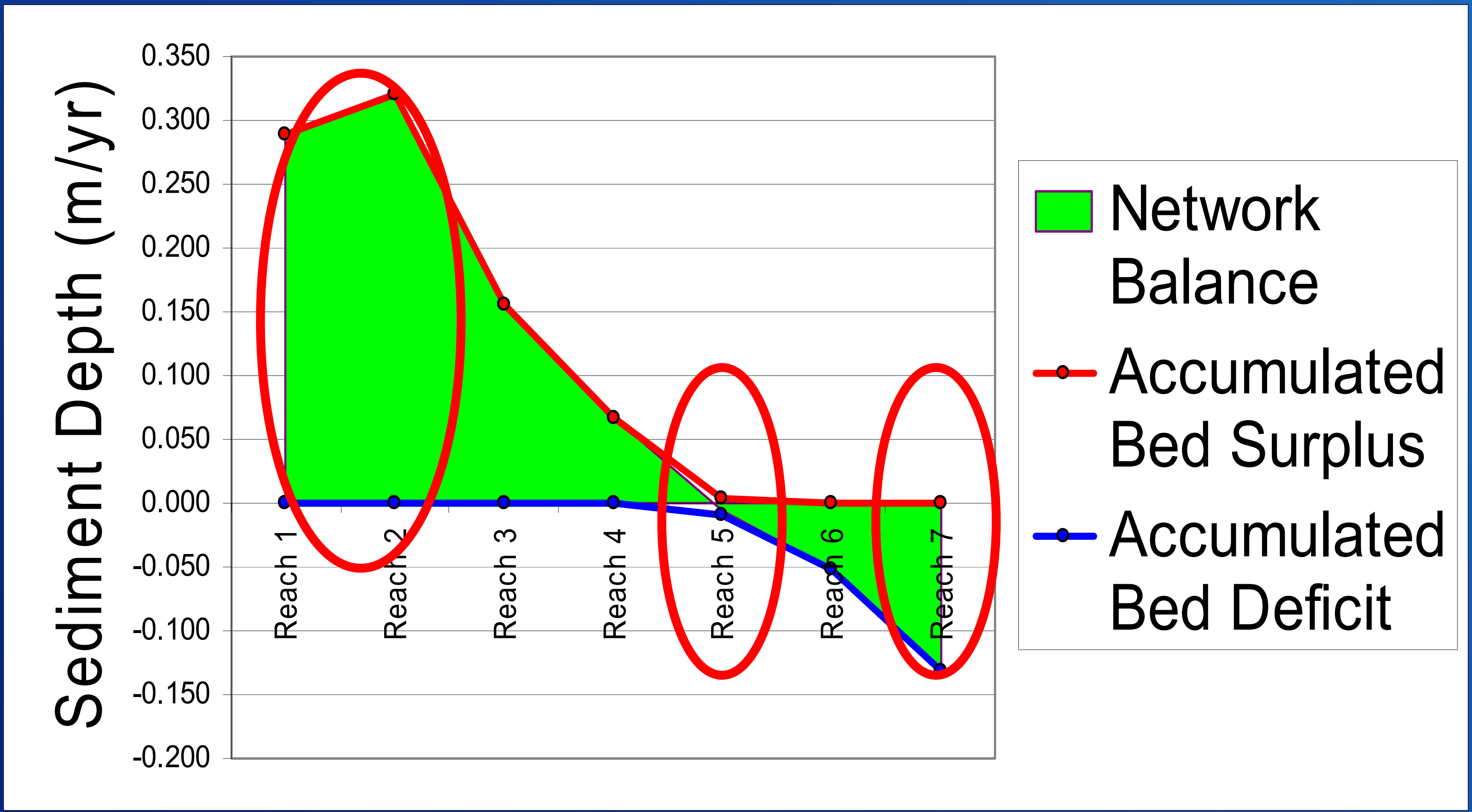
Network Balance (Senatobia Creek)



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Responsiveness (Relative Influence)

- Responsiveness measures how quickly a stream changes transport from a change in applied power.
- RSVP Channel Hydraulics
  - Hydraulics Radius
  - Slope
  - Velocity
  - Wetted Perimeter
- Efficiency Parameter, V/ω (Channel velocity versus particle fall velocity)
- Hydrology Parameter, t (Duration of an event)
- Reach Length, X (Longitudinal distance)

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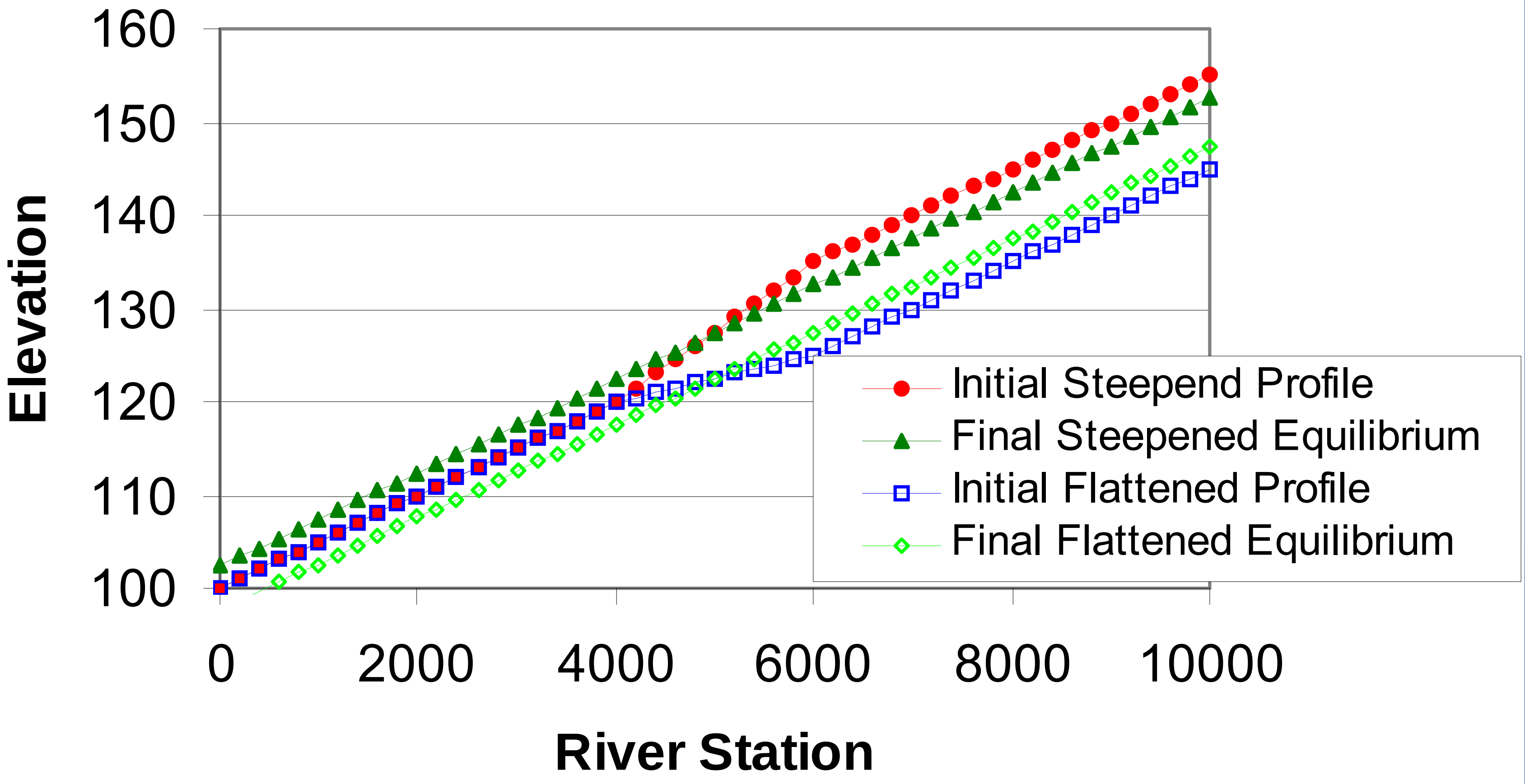
Imbalances from Channel Geometry



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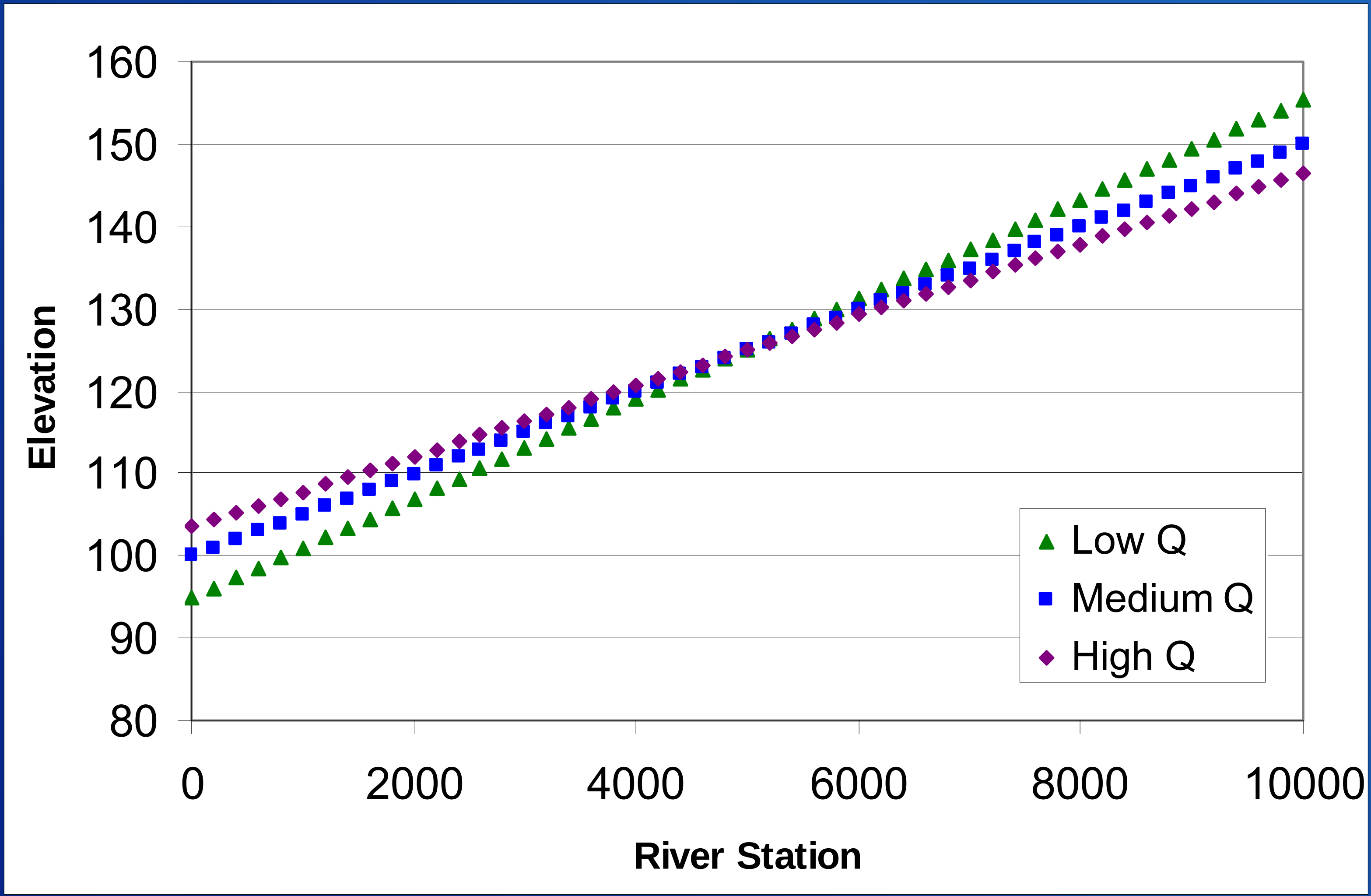
Changes in Capacity or Supply



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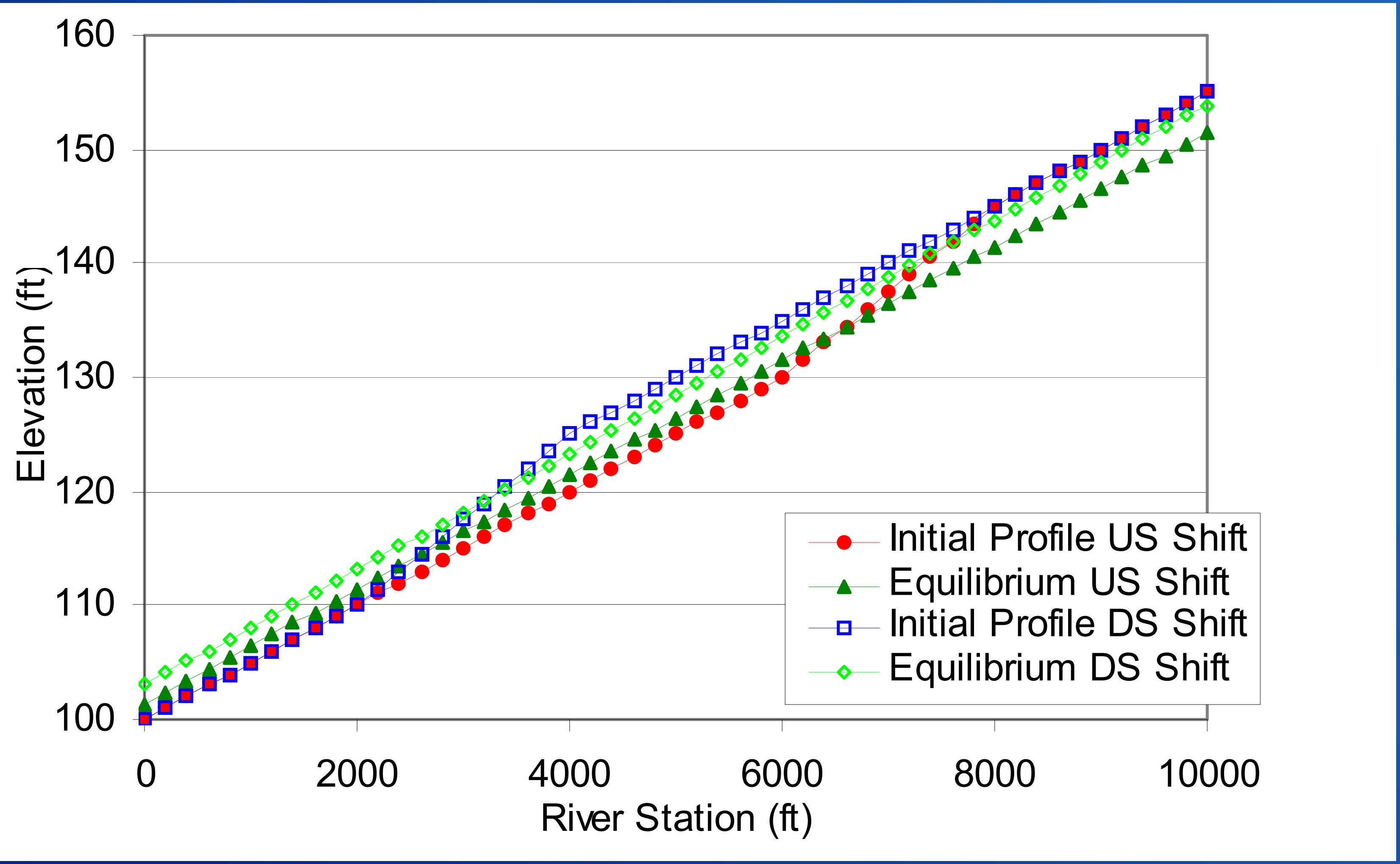
Location of Imbalance



Pivot Points

- Adjustments to the channel can be conceptualized as pivots with upstream and downstream as rotating arms.
- The location of a pivot depends on the responsiveness of the upstream and downstream reaches.
- More responsive reaches adjust more than less responsive reaches.

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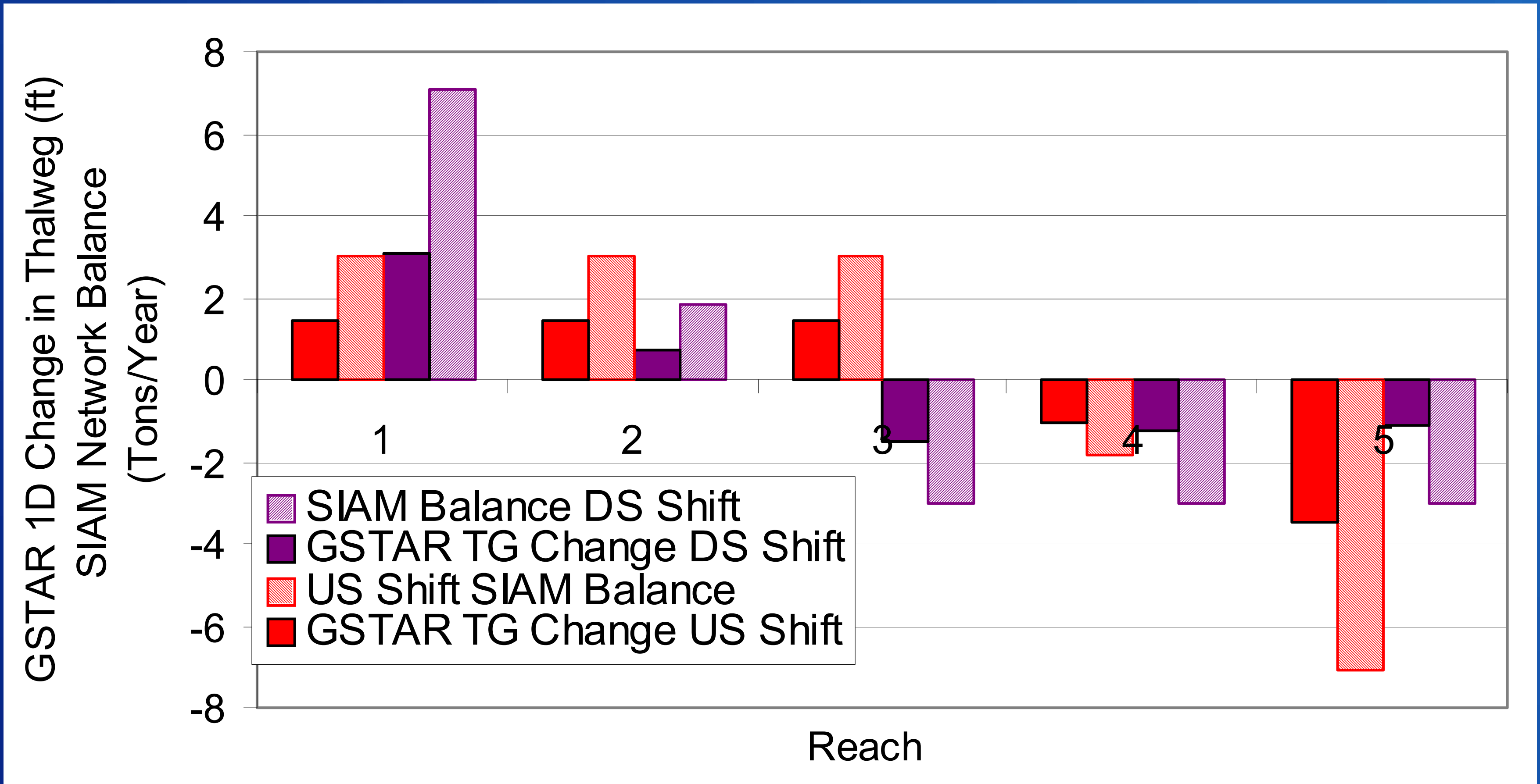
SIAM versus Mobile Boundary



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SIAM versus Sediment Budget

- SIAM integrates a range of flows.
- Source tracking links impacts to identify the greatest contributors of sediment.
- Applied energy provides prescriptive results.
- The network balance identifies the future impact due to geomorphic change.

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SIAM versus Mobile Boundary Input

Mobile Boundary	SIAM
Spatial layout based on cross sections	Reach averaged properties
Input time series of discharges and sediment inflows	Annual regime PDF of discharge and sediment sources, no time frame
Local sources are lumped into a single boundary supply	Sources separated by type
Internal backwater and sediment transport routines	Data provided externally using case specific techniques

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SIAM versus Mobile Boundary Concepts

Mobile Boundary	SIAM
Adjusts cross sections and updates hydraulics to provide intermediate and final states	Measures trends based on known conditions at a single point in time, no adjustment
Lumps sediment sources and focuses on routing	Tracks individual sediment sources and focuses on watershed processes
Analysis tool to evaluate the impact of a project	Synthesis tool to assemble data and provide design guidance

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SIAM versus Mobile Boundary Application

- Use SIAM to:
  - Organize geomorphic information and watershed processes
  - Evaluate and control sediment sources
  - Determine rehabilitation needs and develop options
  - Rapidly assess and screen design alternatives

- Use Mobile Boundary to:
  - Obtain intermediate and final channel profiles
  - Estimate adjustment time frames
  - Verify final design alternatives

Limitations

- Reach Scale: SIAM applies where processes larger than individual bars, riffles, and other local features represent average sediment transport.
- Trend Methods: SIAM cannot model intermediate states or adjustment timeframes.
- Simplified Processes: When time and budget permit, more precise modeling such as mobile boundary simulation can provide information tied to processes.

Part II: Gritty Details

- Input Format
- Input Development
- Channel Load Control
- Calibration and Verification
- Iterative Scenarios
- Sensitivity Studies
- Role

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Input and Output Files

- Fields are the individual pieces of data in a record.
- Records group fields.
- Tables are groupings of records.

<Global Grain Classes>

<Table Definition>

Headings: Name, Diameter, Fall Velocity, Comment

Units: text, mm, m/s, text

</Table Definition>

<CSV Data>

Sand, 0.22, 0.004, 0.0625mm to 2 mm

</CSV Data>

</Global Grain Classes>

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Global Grain Classes

- Global grain classes specify the breakdown of material.
- Each class includes:
  - Name
  - Representative Diameter
  - Fall Velocity
- More classes result in more control of how different sized material moves through a watershed.

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Hydrology, Hydraulics, and Transport Potential

- Hydrology (Discharge and Duration)
  - Rainfall-runoff models
  - Gage records
  - Regional relationships
- Hydraulics (Velocity, Radius, Perimeter, Slope)
  - HEC-RAS
  - Normal Depth
  - Regime Equations
- Sediment Transport (Mass per Time)
  - Transport Equations
  - Rating Curves
  - Reference Reaches

Local Sources

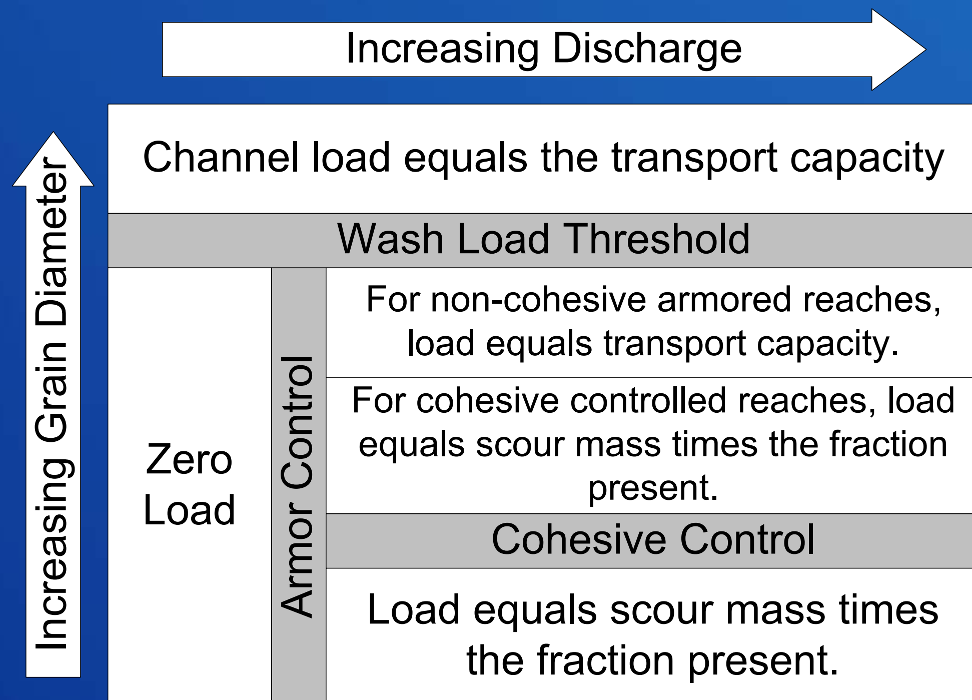
- Load templates describe a type of source.
- Local source records reference a template and include a multiplier.
- Methods for Quantifying Local Sources
  - Aerial Photography
  - Field Reconnaissance
  - RUSLE for overland flow
  - Geotechnical bank stability methods
  - Many, many more.

Sediment Properties

- Transport Mode Controls:
  - Wash Threshold: The largest diameter for wash load material
  - Cohesive Control: The largest diameter of material subject to significant cohesive forces (0.0625 mm, Silts and Clays)
  - Armor Control: The discharge at which bed material begins to move
- Non-Cohesive Substrates: Material scours according to the transport potential and the fraction present in the bed
- Cohesive Substrates: All bed material scours according to the potential of the cohesive grain classes
- Armored Substrates: No scour occurs until exceeding the discharge threshold

Channel Load and Sediment Properties

- Wash Load Threshold
- Armor Control
- Cohesive Control
- Substrates
  - Mixed Sand and Gravel
  - Armored
  - Cohesive Material
  - Bedrock



Calibration and Verification

- Calibration occurs first at the input level.
- Present day conditions can use field verification.
- Modeling of historic conditions and comparing to the present state checks the results.
- SIAM is largely a synthesis tool for organizing and combining river systems sediment information.
- Extrapolating from trends is always tricky.

Wash Deposition Tables

- Wash deposition tables show where the assumption of supply limited conditions no longer apply.
- Non-zero values indicate an improperly assigned wash load threshold or transport calculation.
- Non-zero values could indicate a shift in the current wash load threshold.
  - Cohesive Reaches
  - Armored Reaches
- Developing a SIAM model may require several iterations to simulate conditions.
- Additional global grain classes may be required to define wash versus channel material.

Multiple Scenario – Iterative Process

- Preliminary Model of Base Conditions
- Deposition Check
- Final Model of Base Conditions
- Preliminary Model of Alternative Scenarios
- Deposition Check
- Final Model of Alternative Scenarios

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Sensitivity Exploration

- The modeled was designed to accommodate an incomplete picture with multiple levels of detail.
- The limits of what we can measure is sometimes poorly understood as well.
- The uncertainty surrounding the inputs will determine the certainty of the model.
- With SIAM we can predict responses for many variations in input data.
- A sensitivity study allows for a more complete expression of what we know and suspect.

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SIAM Advantages

- Simple conceptual model
- Process oriented
- Single state analysis
- Rapid comparison between alternatives

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Benefits

- Scalable Input Generation and Modeling Effort
  - Minimal modeling effort for a broad picture
  - Focused detail on problem areas
  - Identification of hot spots for further effort
- Quantitative Networked-Based Sediment Budgets
  - Identifies areas creating problems
  - Identifies impacts from local projects on the system as a whole
- Intermediate Analysis Stage
  - Quantitative results with lower modeling effort
  - Identification of areas for further effort
- Management Scenarios and Prescriptions
  - Low modeling effort allows for multiple runs
  - Prescriptions identify options to explore
  - Design ranges accommodate multiple objectives

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Unique Capabilities

- Sediment Source Tracking
  - Targeted Rehabilitation Efforts
  - Optimization of Rehabilitation Techniques
- Network Trend Analysis
  - Quantitative Comparison of Scenarios
  - Distributed Impacts from Point Effects
  - Few Numerical Difficulties
- Prescriptive Design Results
  - Changes in Flow Regime
  - Slope and Width Criteria
  - Integration with Other Objectives
- Full Flow Range Analysis

SIAM Limitations

- Some output cannot be generated
  - Ultimate channel profiles
  - Time frame for channel effects
- Developing the quantity of input information can be daunting.
- Uncertainty in the input quantification processes can prevent concrete conclusions.
- Interpretation requires a background in stream processes to understand the results.

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Yakima Storage Study, WA

- The Yakima Storage Study is investigating alternatives for increasing water availability.
- A habitat modeling effort will quantify existing and future fish populations.
- Some of the habitat metrics include bed material, annual scour, and deposition of fines.
- SIAM is being used to perform the sediment study for various hydrographs.

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Methow Salmon Recovery, WA

- The Methow Basin has been identified as an area for stream restoration to increase salmon habitat.
- A geomorphic study is incorporating a range of features to identify candidate sites.
- SIAM is providing a screening tool to check sediment transport and current areas of aggradation and degradation.
- Future efforts may include SIAM to check for changes as a result of projects.

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Rio Grande Morphology, NM

- The Rio Grande river has undergone a wide range of anthropogenic modifications.
- SIAM has been proposed to look at management alternatives to address aggradation and bank migration.

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Model Development

- FY '06 Grain sorting and gradation specific calculation
- FY '07 Proposing links between energy and physical channel dimensions
- Continuing visualization and data assembly techniques

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Conclusions

- SIAM encourages the collection of geomorphic information to provide a better understanding of the processes within a watershed.
- SIAM improves the correlation and synthesis of geomorphic information by tying data to quantitative design guidelines.
- A better understanding of the processes in the watershed can optimize efforts and provide better chances of success.
- The systems perspective design reduces the risk of negative interaction both from individual projects and between multiple restoration efforts.

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Questions

http://www.usbr.gov/pmts/sediment

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