HYDROMODIFICATION MODELING

OVERVIEW OF APPROACHES

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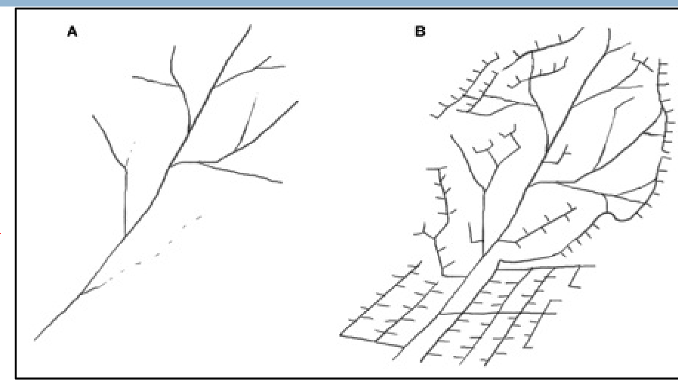
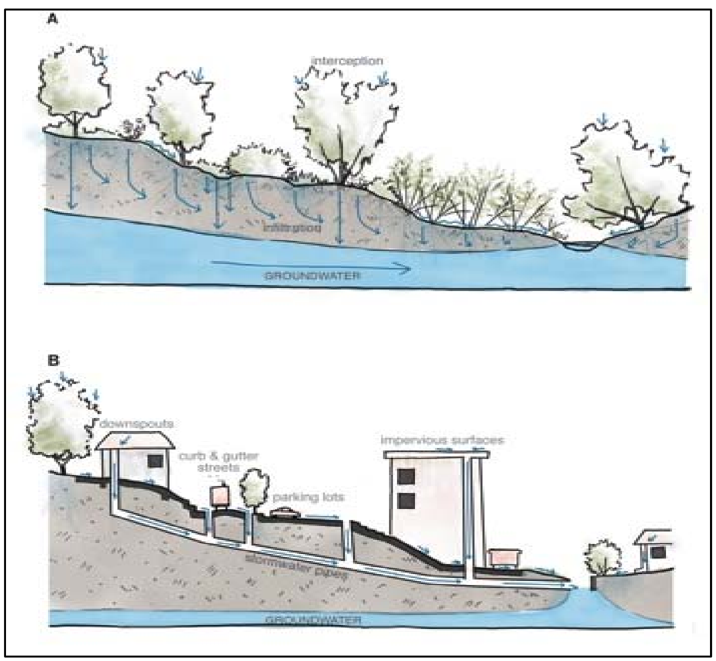
Today's Presentation

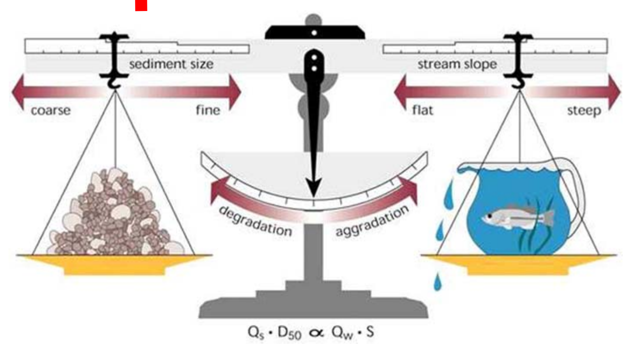
- Hydromodification 101
  - Challenges of Hydromodification Monitoring
- Types of Modeling Approaches
  - examples
- Roadmap for the Day

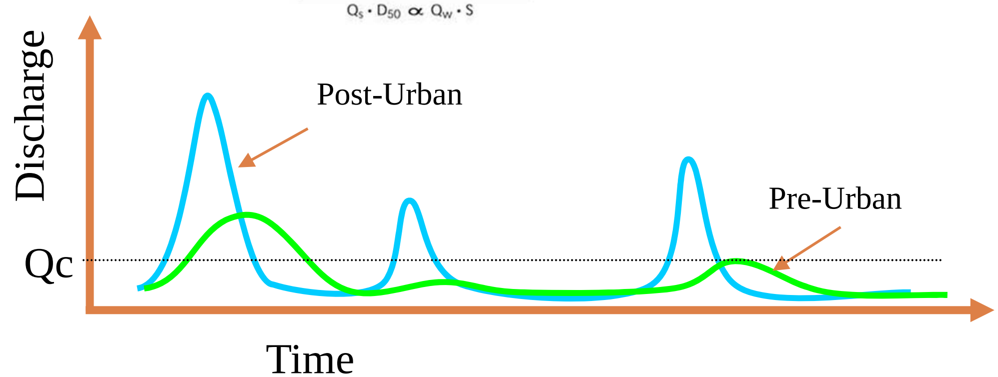
Hydromodification 101

Hydromodification = changes to the runoff hydrograph and sediment supply resulting from land use modifications



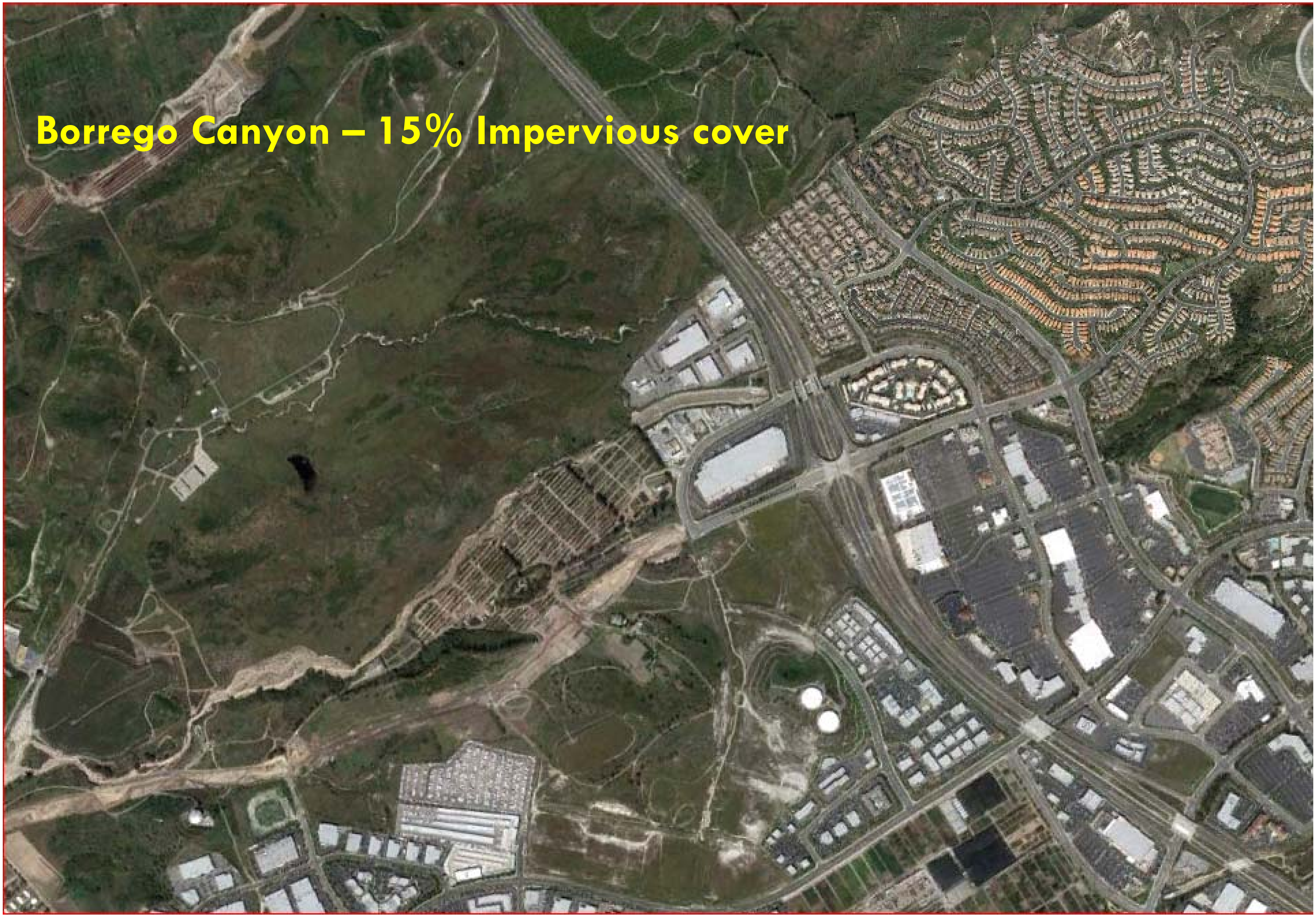


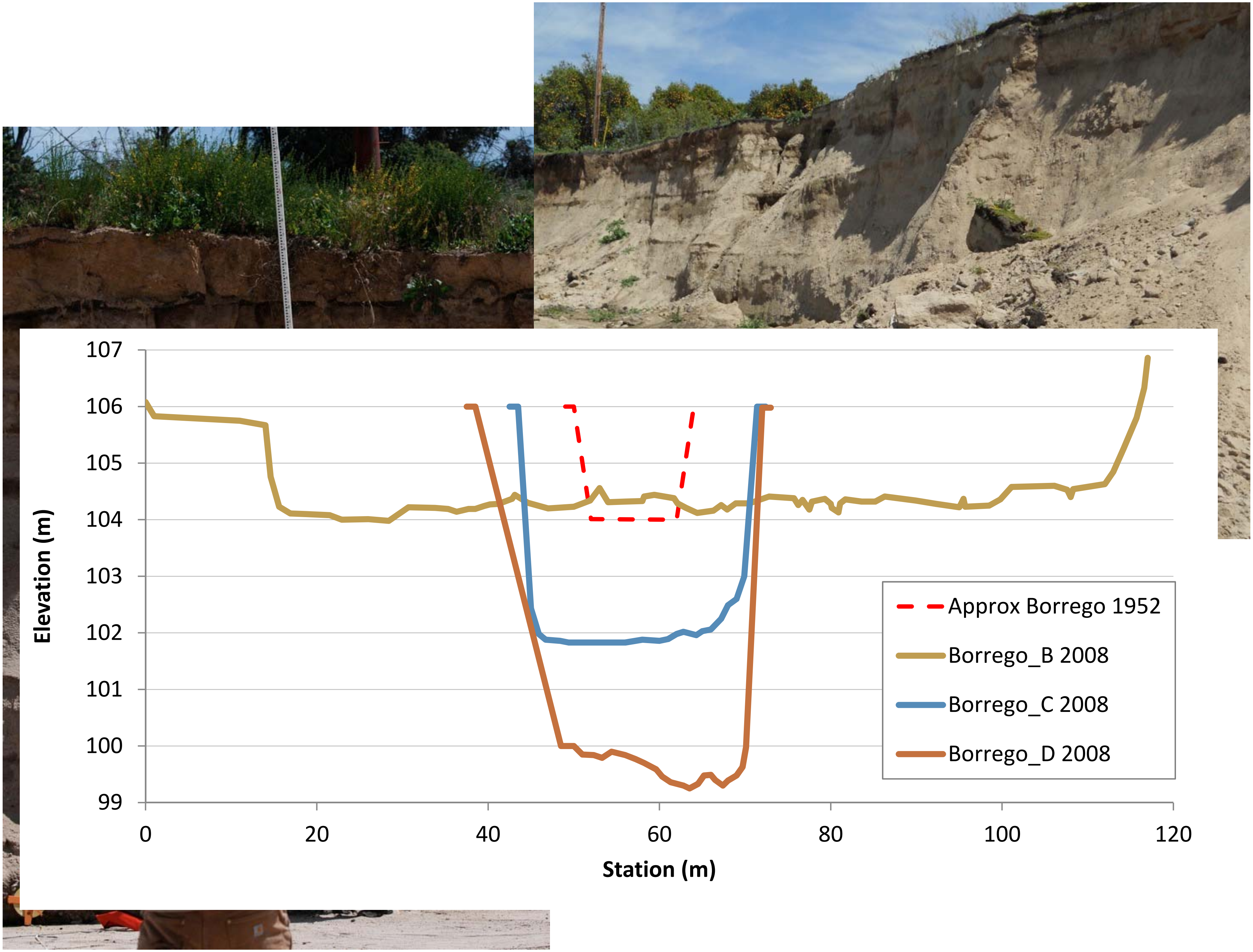




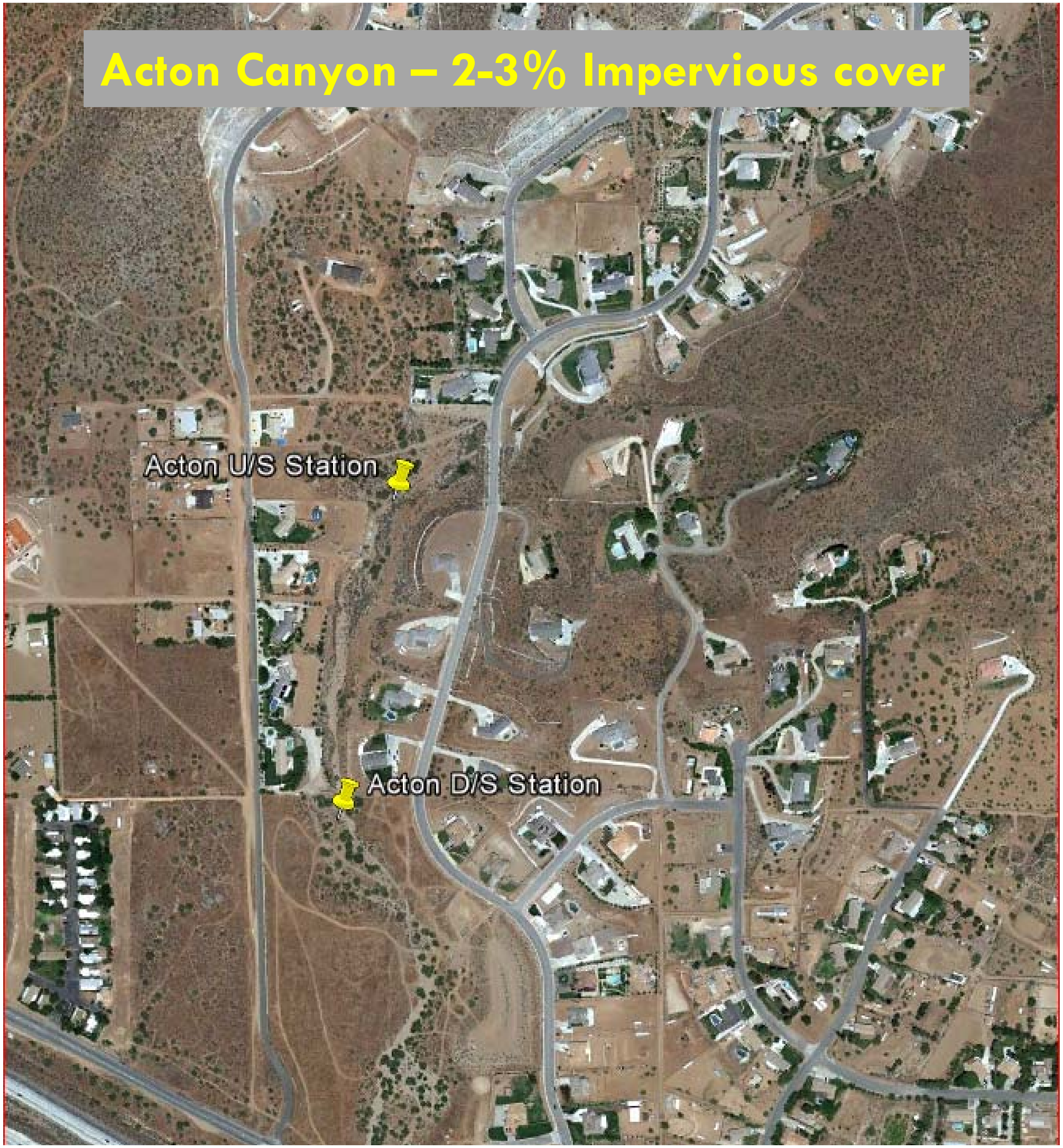
Hydromodification Effects

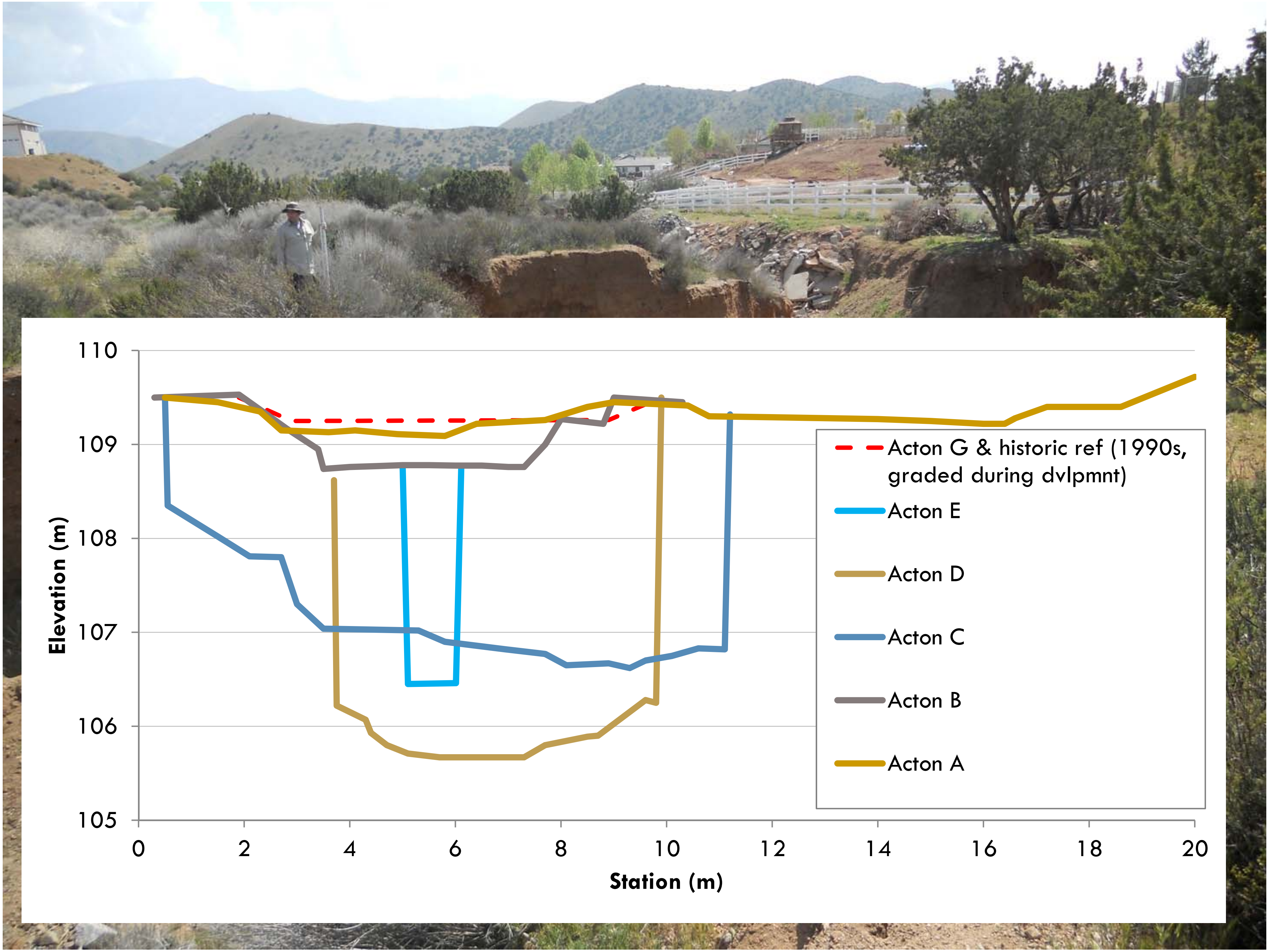
Borrego Canyon – 15% Impervious cover





Elevation (m)
107
106
105
104
103
102
101
100
99
0
20
40
60
80
100
120
Station (m)
Approx Borrego 1952
Borrego_B 2008
Borrego_C 2008
Borrego_D 2008


Acton Canyon – 2-3% Impervious cover
Acton U/S Station
Acton D/S Station



110
109
108
107
106
105
Elevation (m)
0
2
4
6
8
10
12
14
16
18
20
Station (m)
Acton G & historic ref (1990s, graded during dvlpmnt)
Acton E
Acton D
Acton C
Acton B
Acton A

The Challenge of Hydromodification

- Change can occur rap
- Streams are highly vo
- May be dealing with
- Responses are difficult to predic -

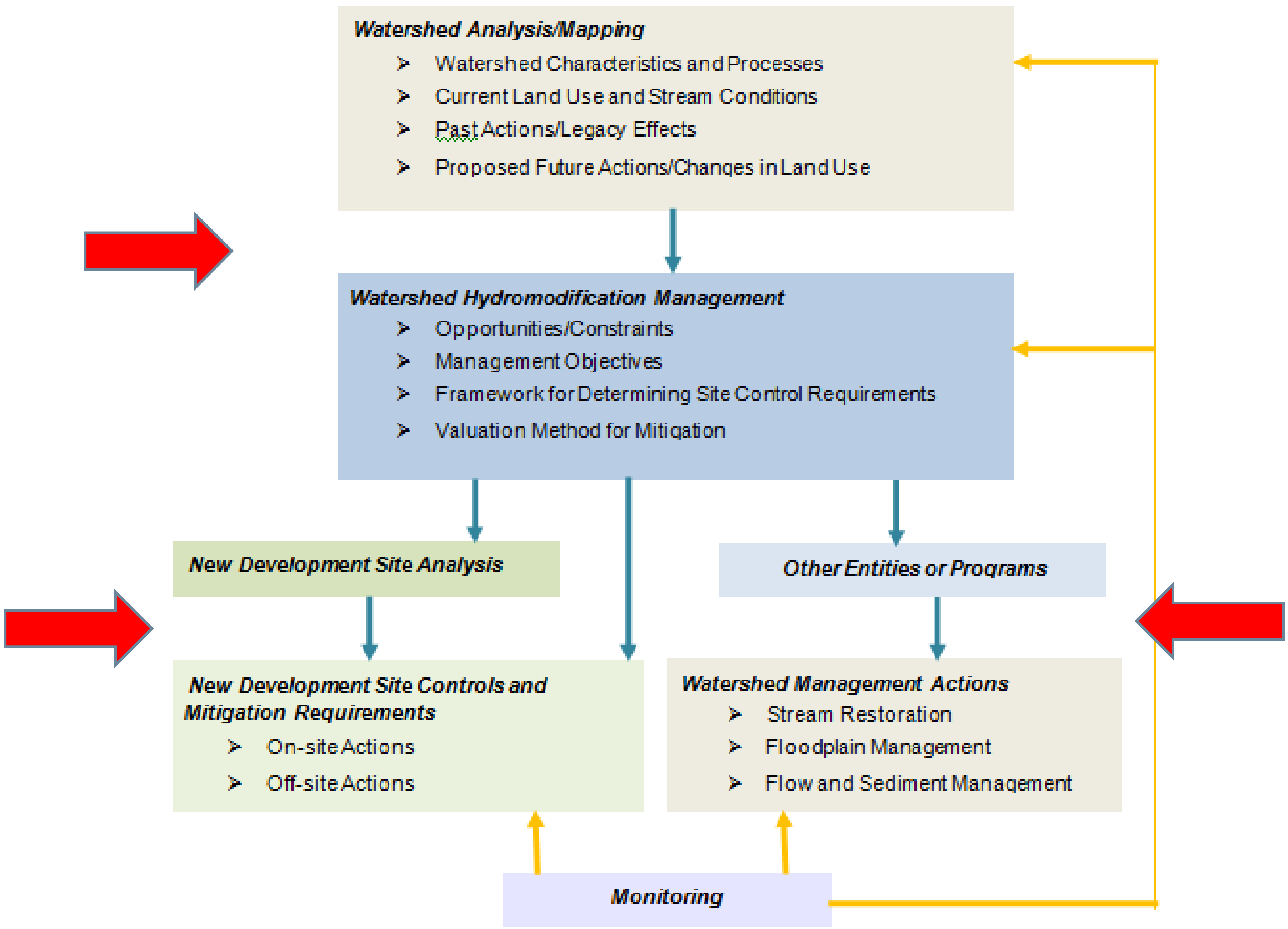
Modeling Tools

Modeling tools have the potential to advance hydromodification management by:

- Providing a physical basis for making predictions of stream response to watershed development.

- Assessing alternative future states of streams under different management scenarios.

- Avoiding one-size-fits-all solutions through:
  - improved prediction of relative magnitude of potential channel change and proximity to response thresholds; and
  - tailoring mitigation strategies to streams with different levels of susceptibility.


Watershed Analysis/Mapping
Watershed Characteristics and Processes
Current Land Use and Stream Conditions
Past Actions/Legacy Effects
Proposed Future Actions/Changes in Land Use
Watershed Hydromodification Management
Opportunities/Constraints
Management Objectives
Framework for Determining Site Control Requirements
Valuation Method for Mitigation
New Development Site Analysis
Other Entities or Programs
New Development Site Controls and Mitigation Requirements
On-site Actions
Off-site Actions
Watershed Management Actions
Stream Restoration
Floodplain Management
Flow and Sediment Management
Monitoring

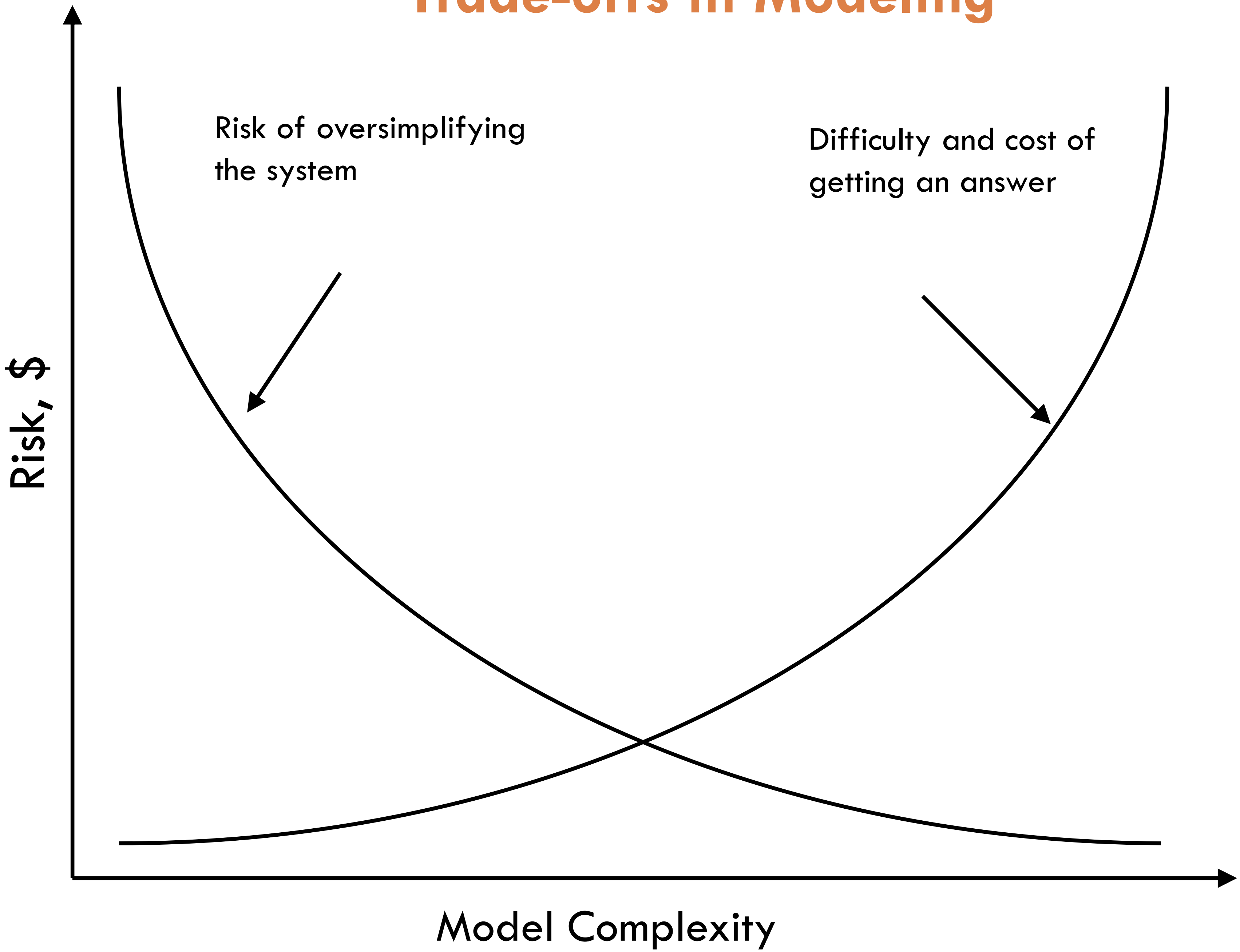
Modeling and Assessment

Modeling tools allow us to predict likely response to change in land use and to evaluate potential effect of management actions

… but there are challenges:

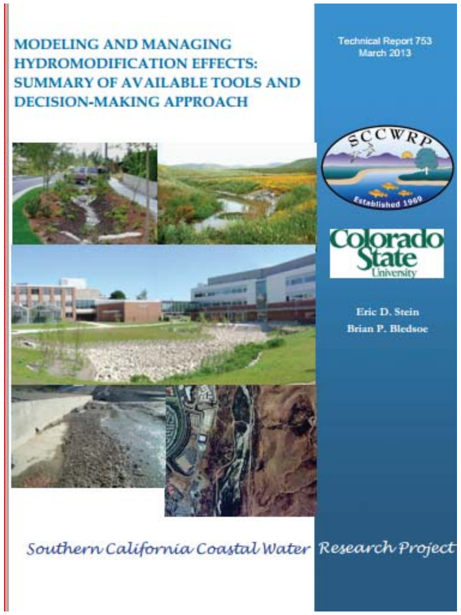
- Geologic heterogeneity
- Unpredictable flow and sediment transport
- Limited calibration data (especially for sediment yield)
- Challenges of modeling mobile bed + mobile bank
- Challenges of split flow and other planform dynamics

Trade-offs in Modeling



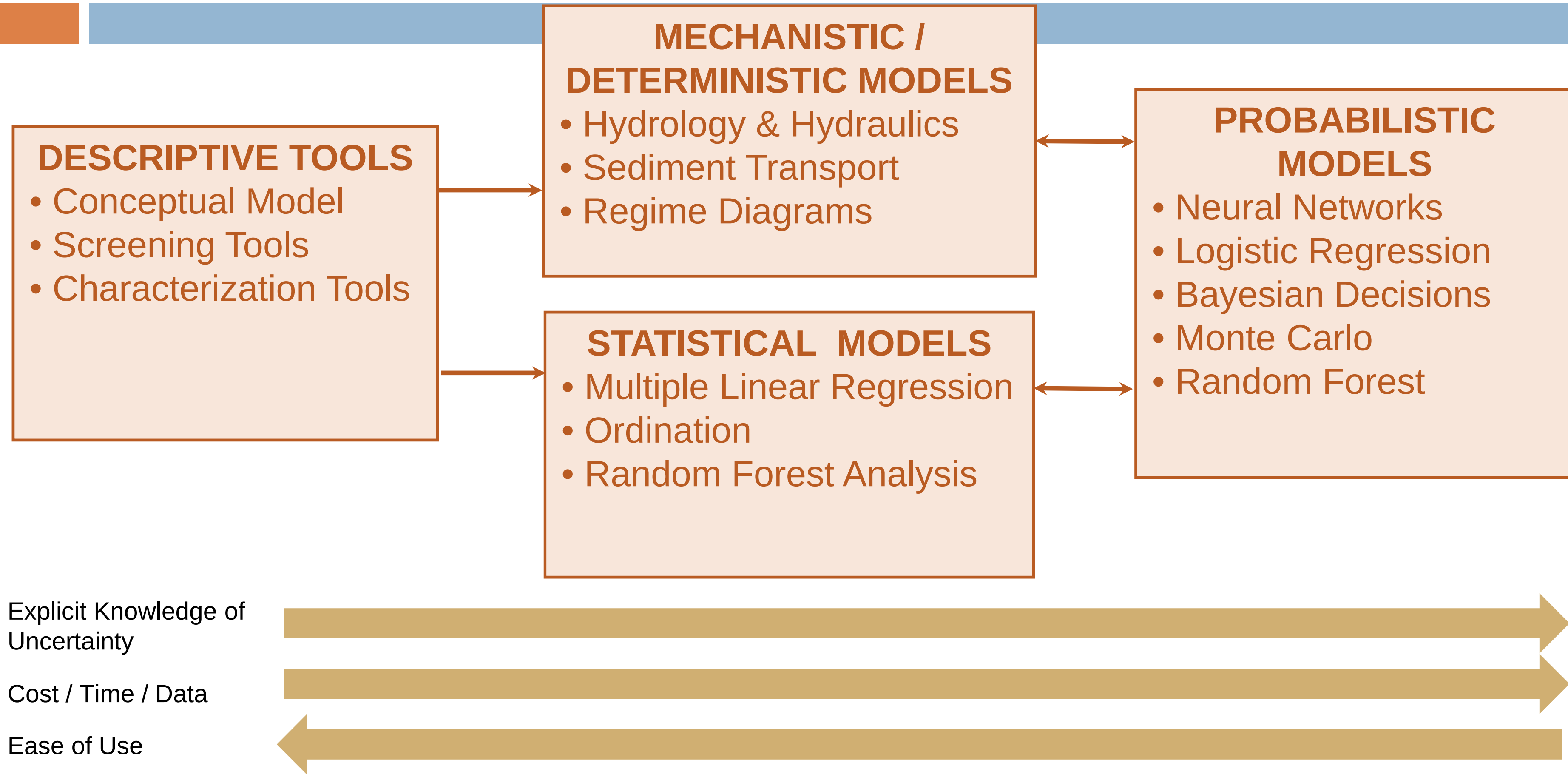
Summary of Modeling Tools

- Report provides summary of modeling tools most relevant to hydromodification management in southern CA



  - Question(s) addressed
  - Scale
  - Relation to other tools
  - Data requirements
  - Relative uncertainty
  - Key considerations / questions in appropriate use

Modeling Tool Box



Appropriate tool or combinations of tools based on information needs, desired level of certainty, data availability etc.

Guidance on Model Selection and Use

- Is this model appropriate for the question(s) at hand?
- What are the key considerations associated with a particular tool (e.g., scale, vintage of data, parameterization, etc.)?
- What are the underlying assumptions about physical and hydrological processes that are used by the model
- What information and data are sufficient to drive the model?
- What is the simplest model that will provide adequate prediction accuracy?
- What is level of certainty associated with the output?

Modeling Tool Box

DESCRIPTIVE TOOLS
- Conceptual Model
- Screening Tools
- Characterization Tools

- Questions of basic condition, susceptibility, etc.
- Once developed, relatively rapid and easy to apply
- Answers are generally qualitative or semi-quantitative
- Appropriate for screening-level decisions
- Inform decisions about need/selection of more intensive models

Explicit Knowledge of Uncertainty

Cost / Time / Data

Ease of Use

Field Screening Tool

Not all streams are created equal

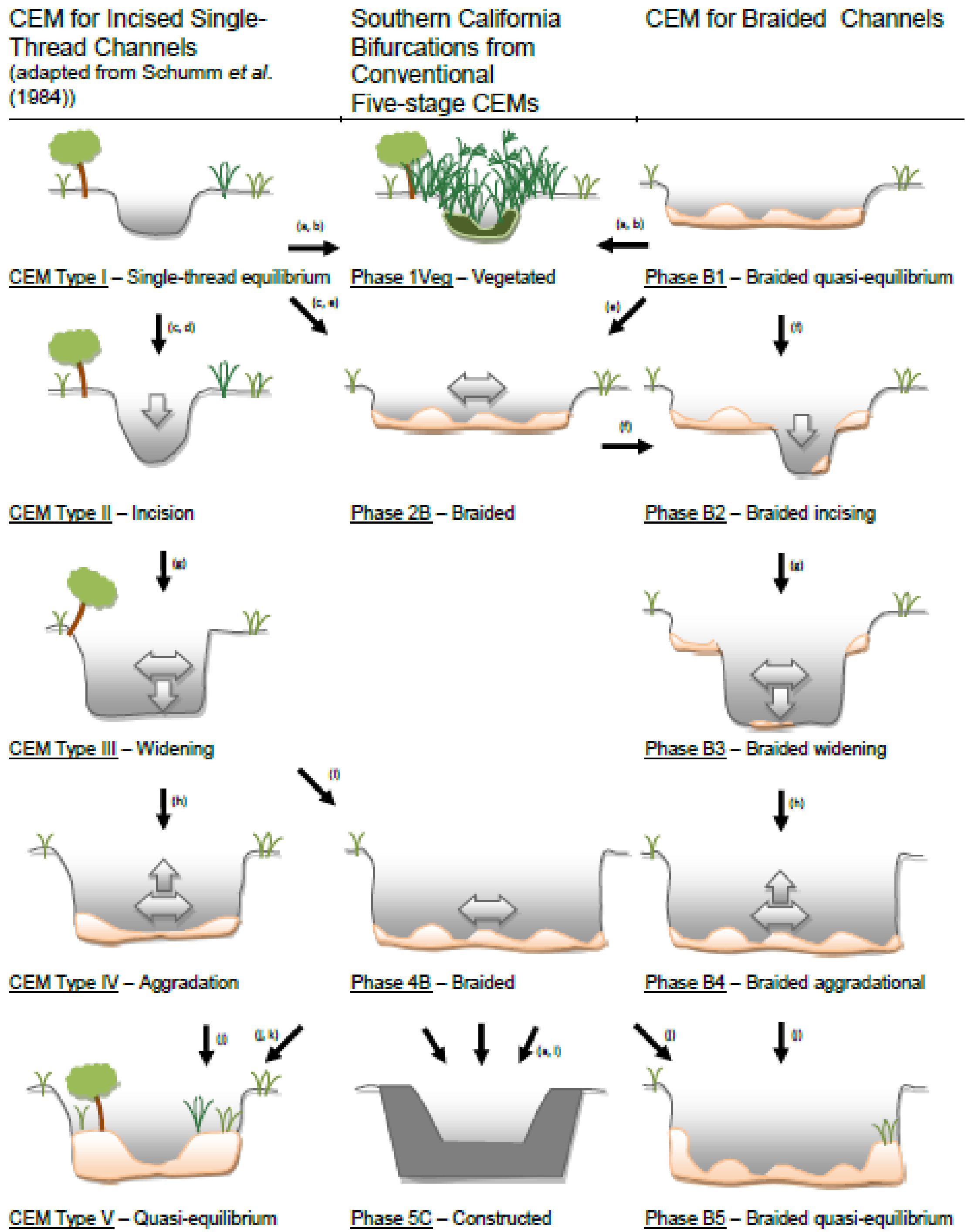
- Classify streams by:
  - Likely severity of response
  - Likely direction of response
- Decision trees
  - Clear endpoints – *very high, high, medium, low*
- Simple to apply field metrics
  - Does not rely on complex field measures
- Locally calibrated
- Rapid - < 1 day in office + 1 day in field

Channel Evolution Model (CEM) Quantification

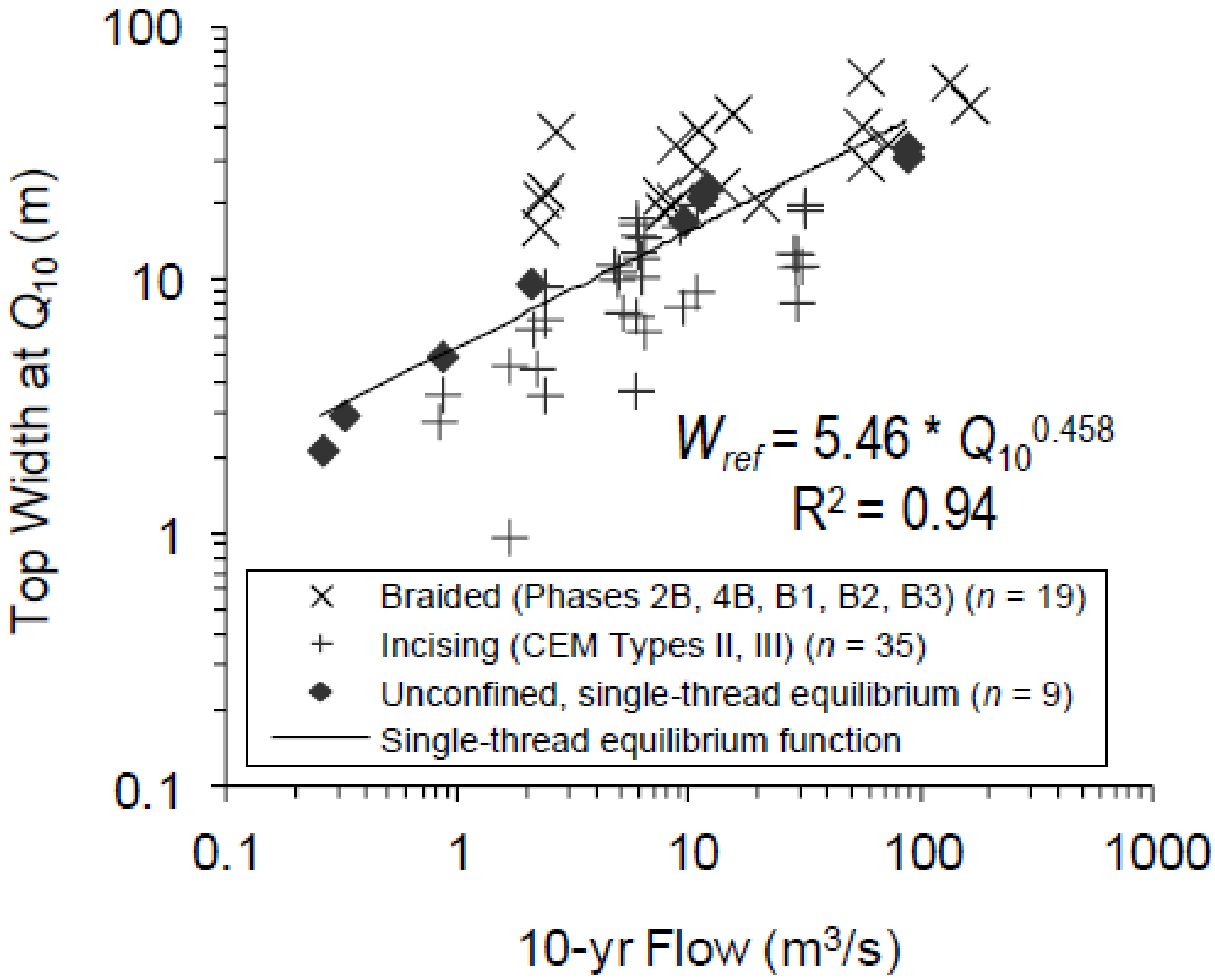
- **Descriptive** but can be quantified using empirical information

- Identifies relationships between driving variables, channel states and geomorphic thresholds

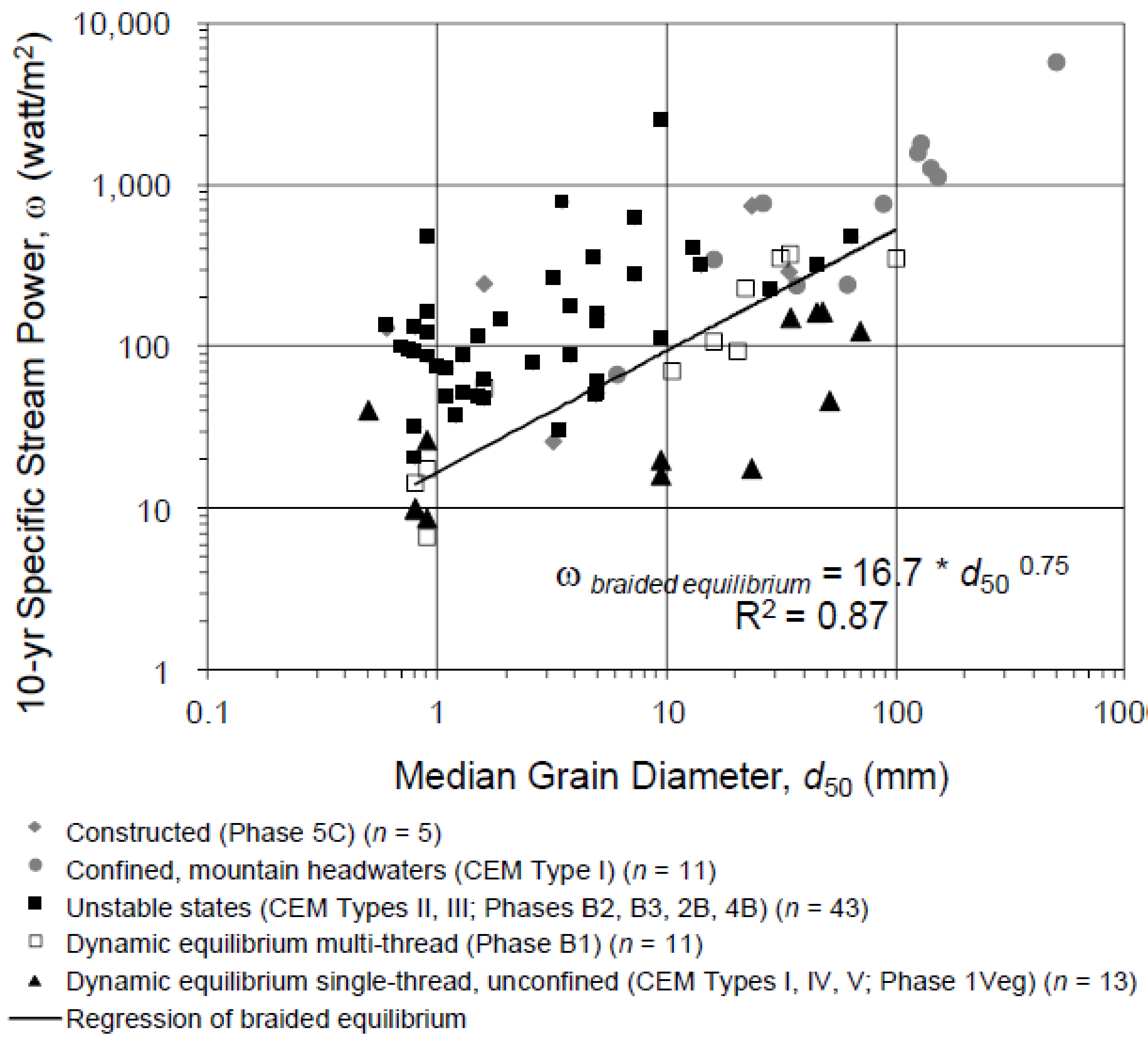
- Provides a framework for:
  - interpreting past and present response trajectories
  - identifying the relative severity of potential response sequences
  - applying appropriate models in estimating future channel changes
  - developing strategies for mitigating the impacts of processes likely to dominate channel response in the future


CEM for Incised Single-Thread Channels
(adapted from Schumm et al. (1984))
Southern California Bifurcations from Conventional Five-stage CEMs
CEM for Braided Channels
CEM Type I – Single-thread equilibrium
Phase 1Veg – Vegetated
Phase B1 – Braided quasi-equilibrium
CEM Type II – Incision
Phase 2B – Braided
Phase B2 – Braided incising
CEM Type III – Widening
Phase B3 – Braided widening
CEM Type IV – Aggradation
Phase 4B – Braided
Phase B4 – Braided aggradational
CEM Type V – Quasi-equilibrium
Phase 5C – Constructed
Phase B5 – Braided quasi-equilibrium

Relationships between CEM Stage, Planform, Q10, and Width



Relationships between CEM Stage, Stream Power, and Grain Size



Modeling Tool Box

MECHANISTIC / DETERMINISTIC MODELS

- Hydrology & Hydraulics
- Sediment Transport
- Regime Diagrams

Expli
Unce
Cost
Ease

- Appropriate for predicting likely responses
- Familiar and commonly used for other water quality analyses
- Quantitative output based on mechanistic understanding
- Potential for fairly high and possibly unknown levels of uncertainty
- May be limited by availability of data to parameterize or calibrate

Mobile Boundary Modeling

- Tested:
  - HEC-6 (now in HEC-RAS)
  - CONCEPTS
  - FLUVIAL-12

- Difficult to apply and high prediction uncertainty
  - Critical flow
  - Split flow conditions
  - Lack of fidelity to complex widening, bank failure, and bed-armoring processes

- May not be sufficient to address all hydromodification management questions

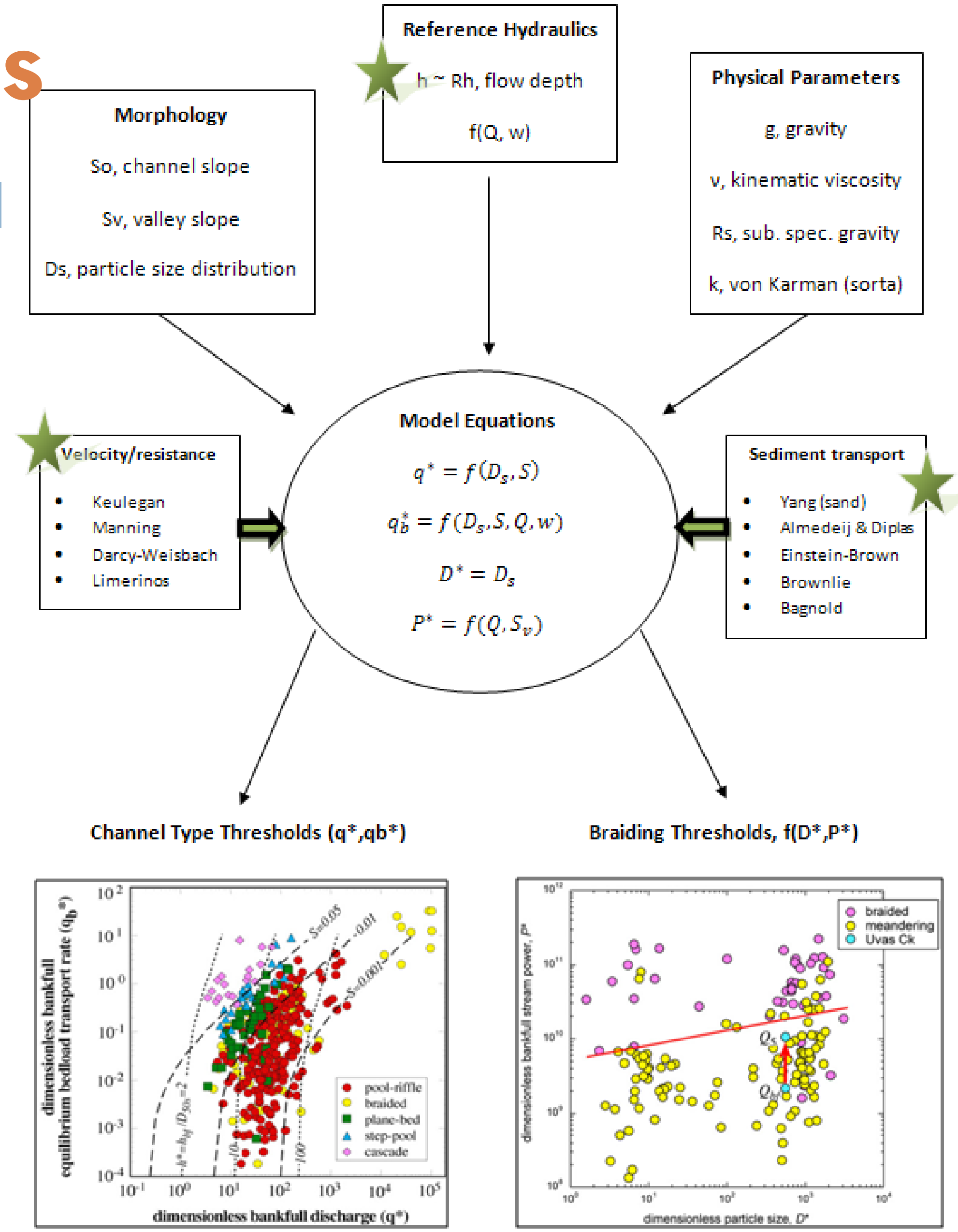
Regime Diagrams Overview

Purpose: assessing potential channel responses to changing Q, Qs

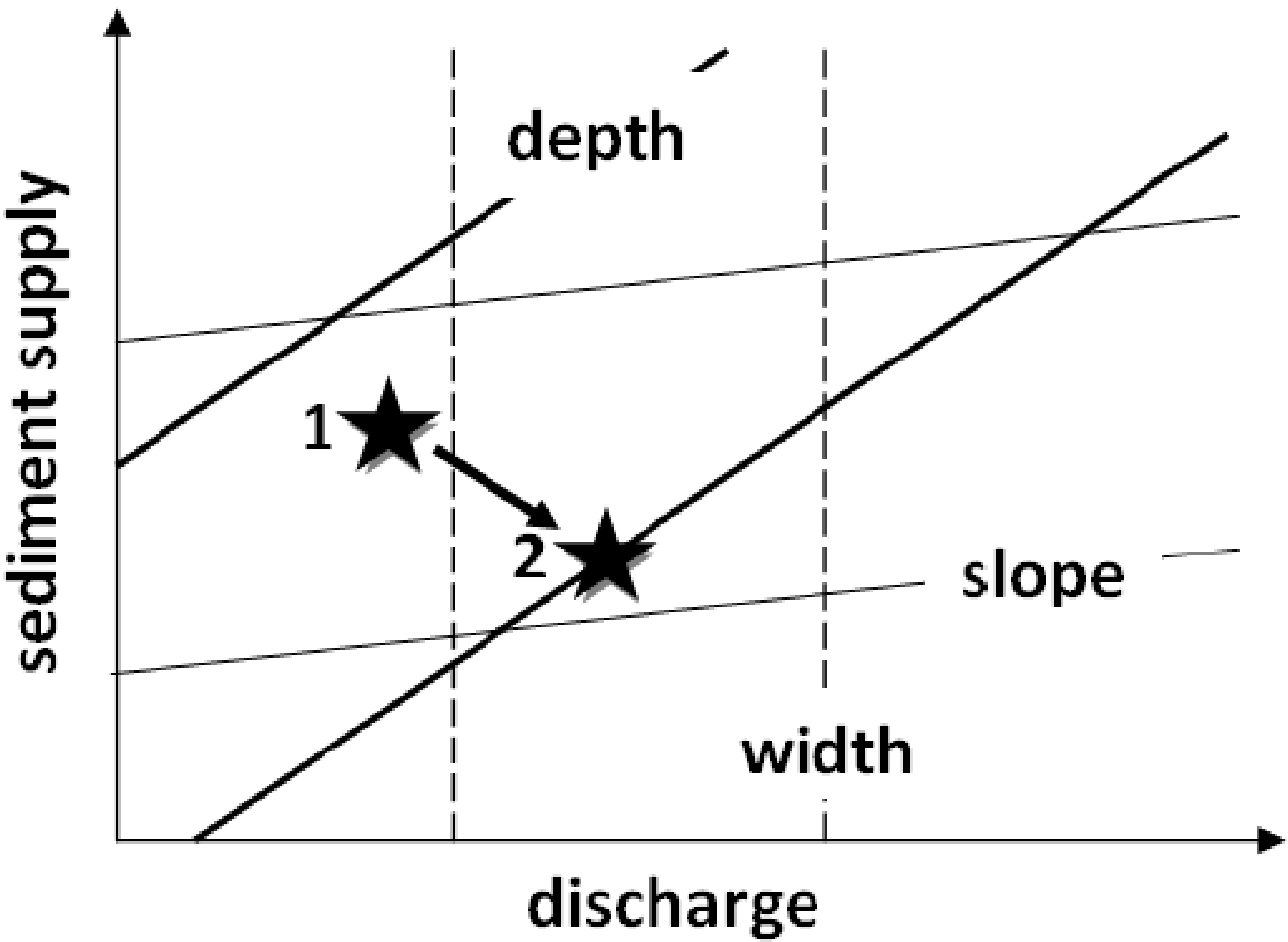
- Plot of physical control variables overlain with isoclines of geometric parameters
- Predict relative or absolute magnitude of potential adjustment in slope, depth, and width
- Mechanistic combination of several governing equations
- Physically-based but provide managers with a relatively simple form of output from analytical channel design models without performing additional modeling

Regime Diagrams

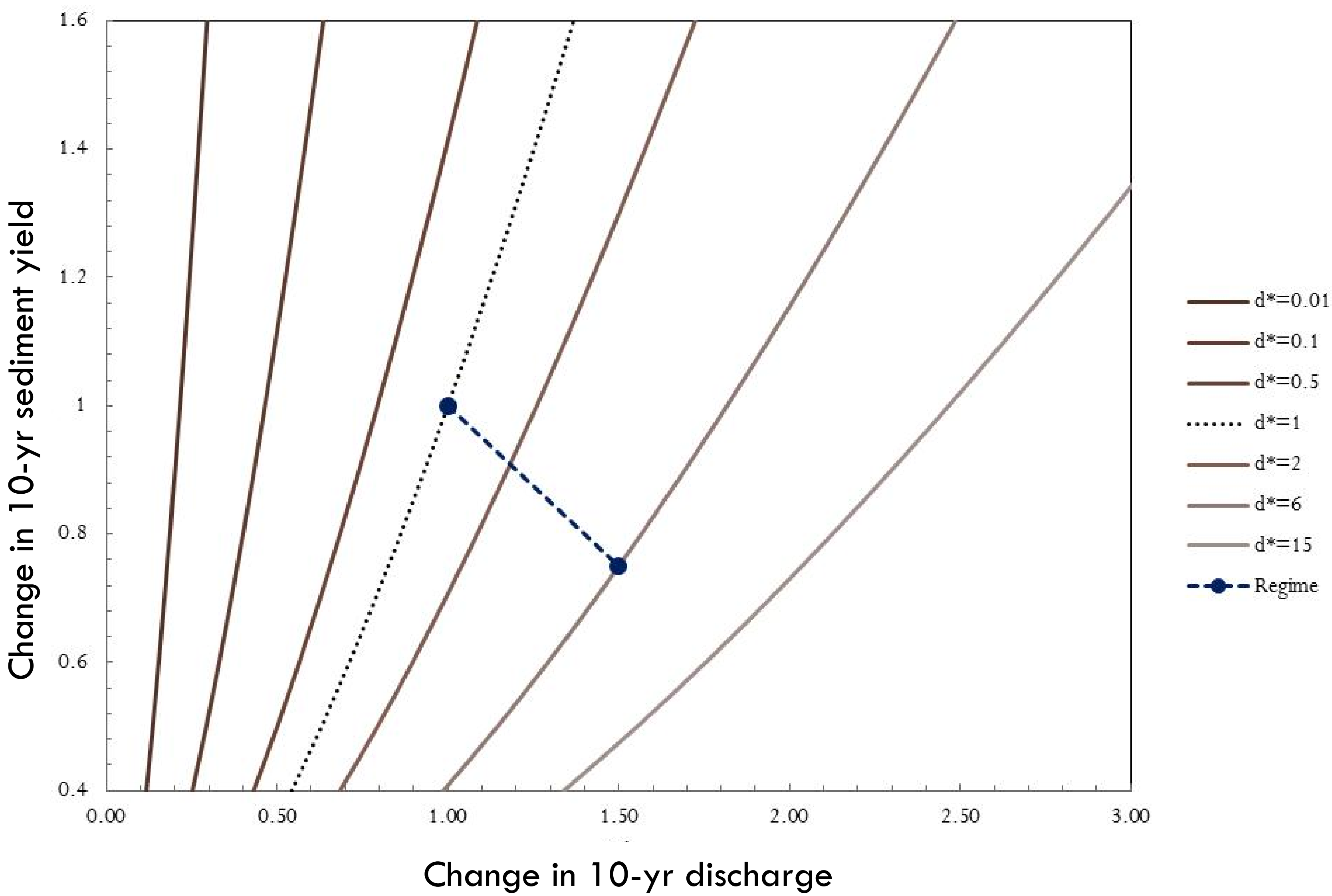
- Predict likely response based on empirical relationships
- Select appropriate equations for local conditions
- Calibrate with local data
- Once developed, easily applied to new situations



Buffington and Parker (2005)


sediment supply
depth
1
2
slope
width
discharge

S. California Derived Regime Diagrams



Diagrams for changes in width, **depth**, slope

Regime Diagrams

- Bracket the maximum lateral or vertical response that might be expected given a particular combination of altered discharge and sediment supply.
- Can provide additional resolution to channel susceptibility ratings by comparing the projected change in discharge of water and sediment based on watershed characteristics between streams in the same susceptibility class
- Should not be used in isolation - difficulties with selecting Q, braiding thresholds, etc.

Modeling Tool Box

- Can be used to predict likely response
- Once developed, relatively rapid and easy to apply
- Based on empirical observations
- Known level of confidence in the relationships
- Do not explicitly represent physical processes or response mechanisms
- Inform need for more detailed analysis

Explicit Knowl
Uncertainty

Cost / Time / D

Ease of Use

STATISTICAL MODELS
- Multiple Linear Regression
- Ordination
- Random Forest Analysis

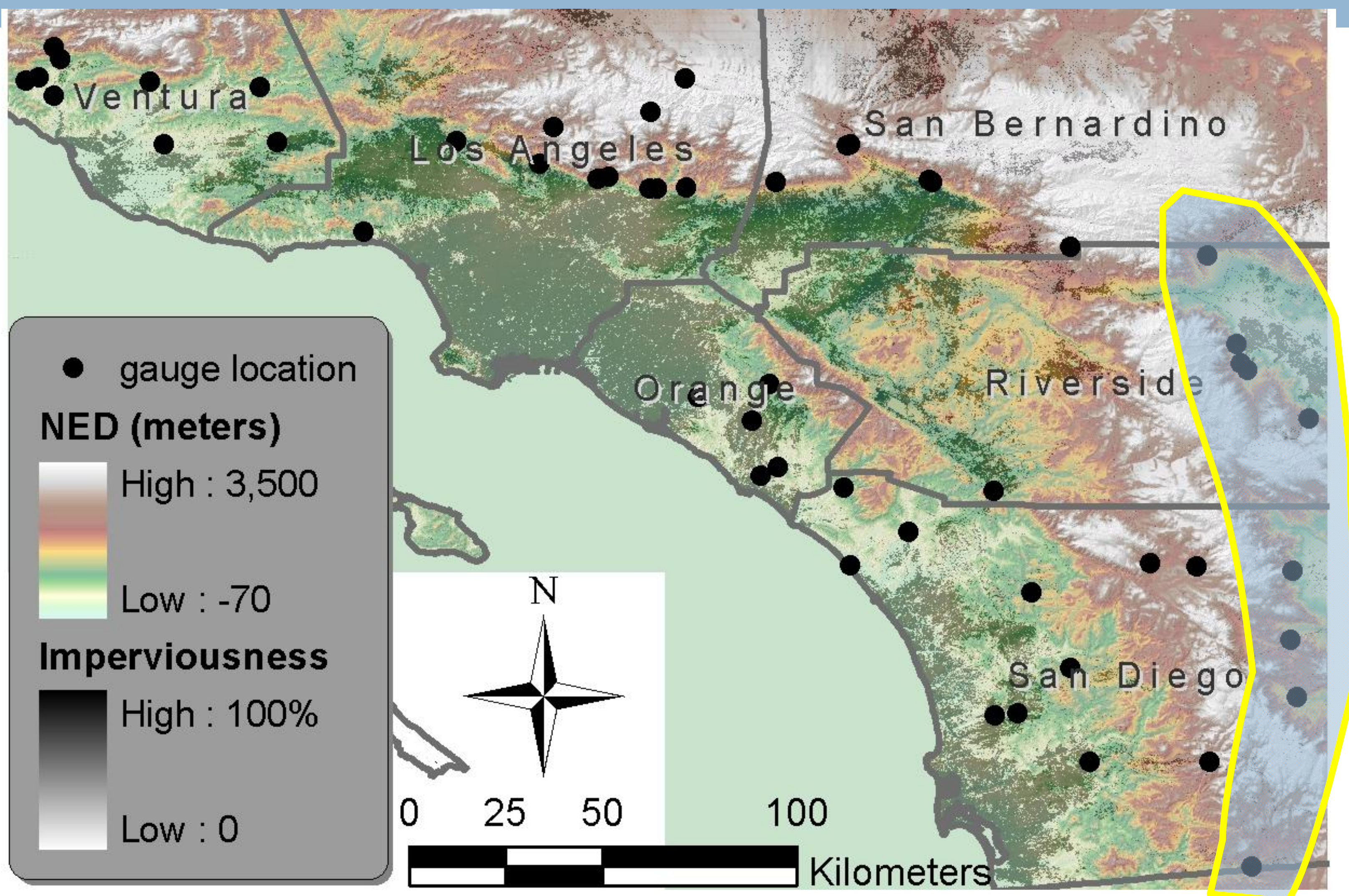
Regional Hydrologic Models

Empirical / statistical models based on regional streamflow data

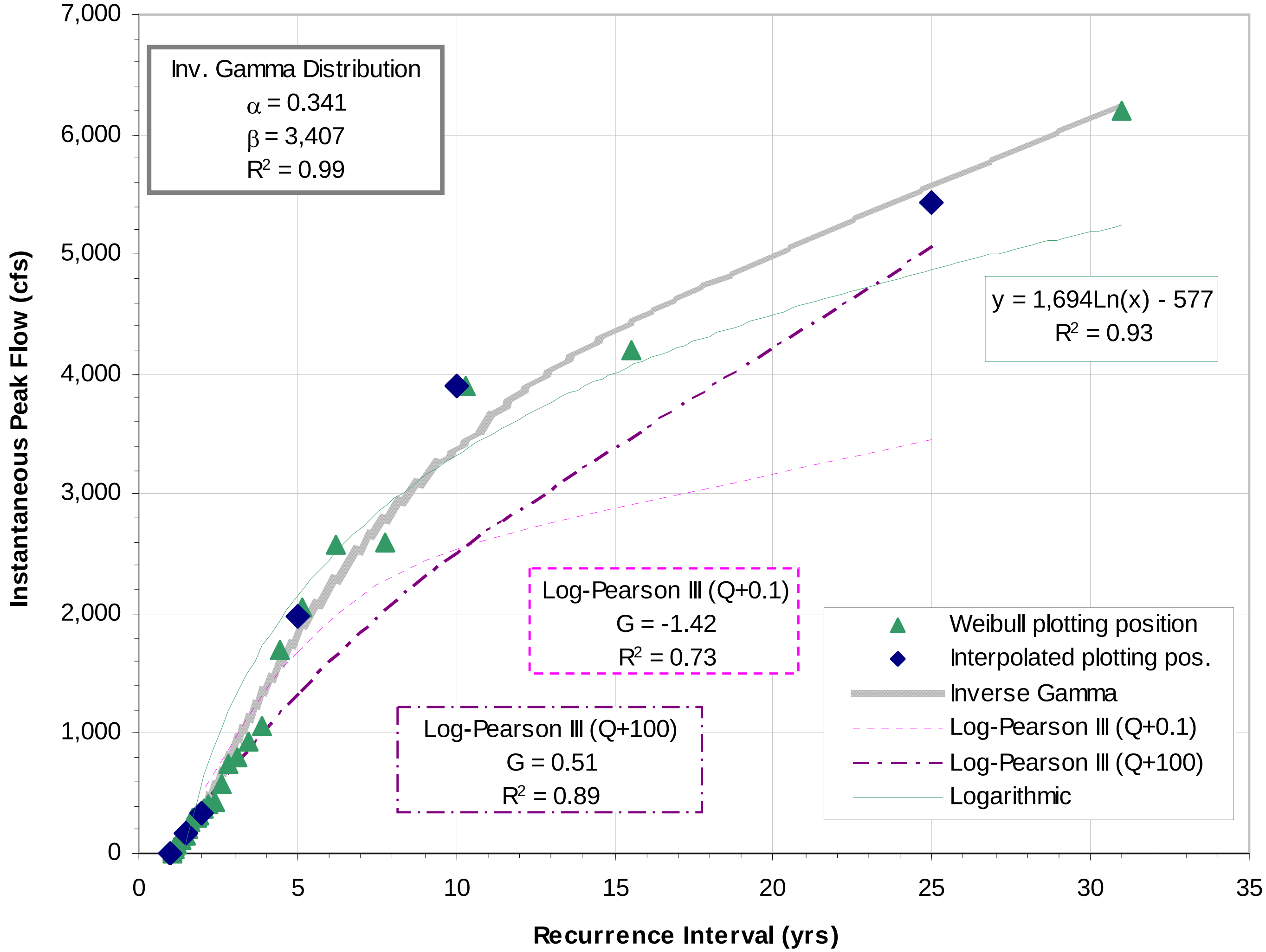
- Improved predictions in ungaged basins compared to USGS regional equations
- Provide both peak flows and flow durations
- Support a variety of geomorphic modeling tools that require projected change in flow peaks and durations

52 unregulated gauges > ~20 yrs.

< ~ 250 km^2 (100 mi^2)

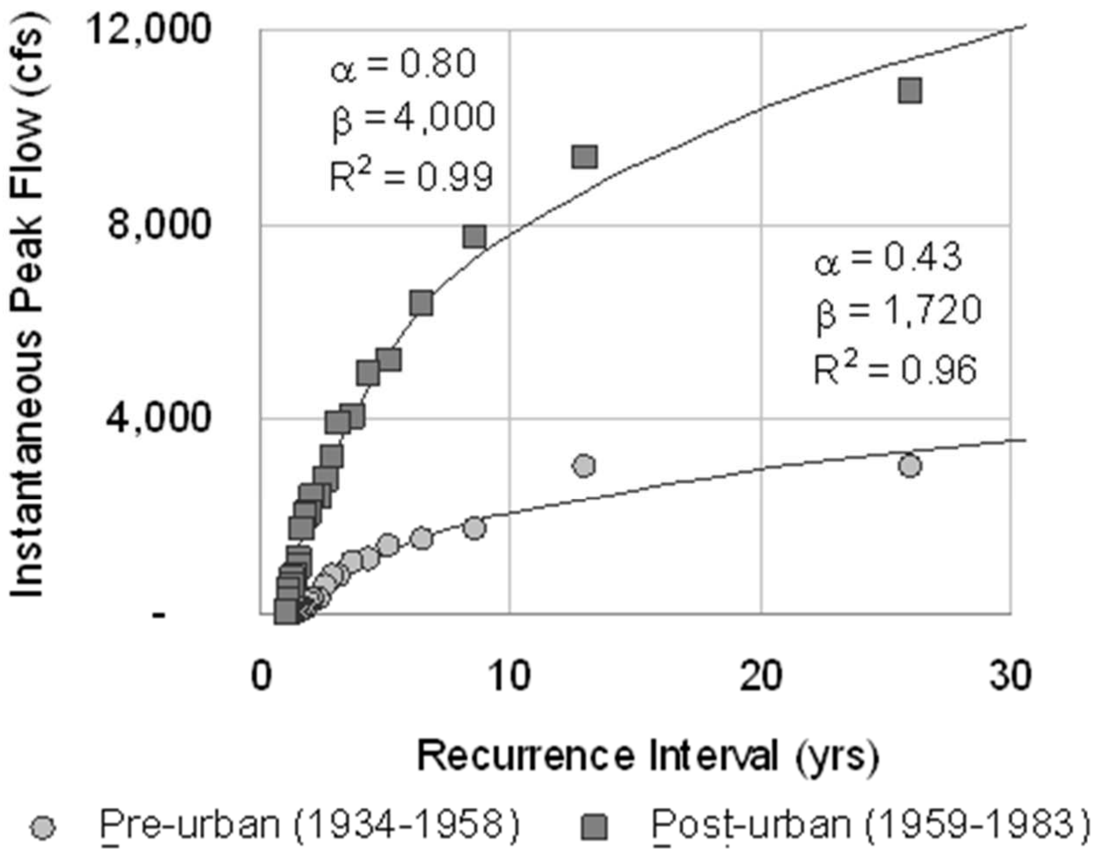


Revised Regional Rating Curve



Hawley and Bledsoe 2011

Effect of Urbanization



1934-1958: Imp_{av} = 2.6%, Imp_{max} = 4.7%

1959-1983: Imp_{av} = 7.3%, Imp_{max} = 8.6%

Modeling Tool Box

- Predict ***probability*** of potential responses
- Incorporate or complement traditional deterministic models
- Account more explicitly for uncertainty
- Better able to accommodate missing or limited input data
- May be more difficult to develop and communicate due to unfamiliarity

PROBABILISTIC MODELS

- Neural Networks
- Logistic Regression
- Bayesian Decisions
- Monte Carlo
- Random Forest

Channel Enlargement Models

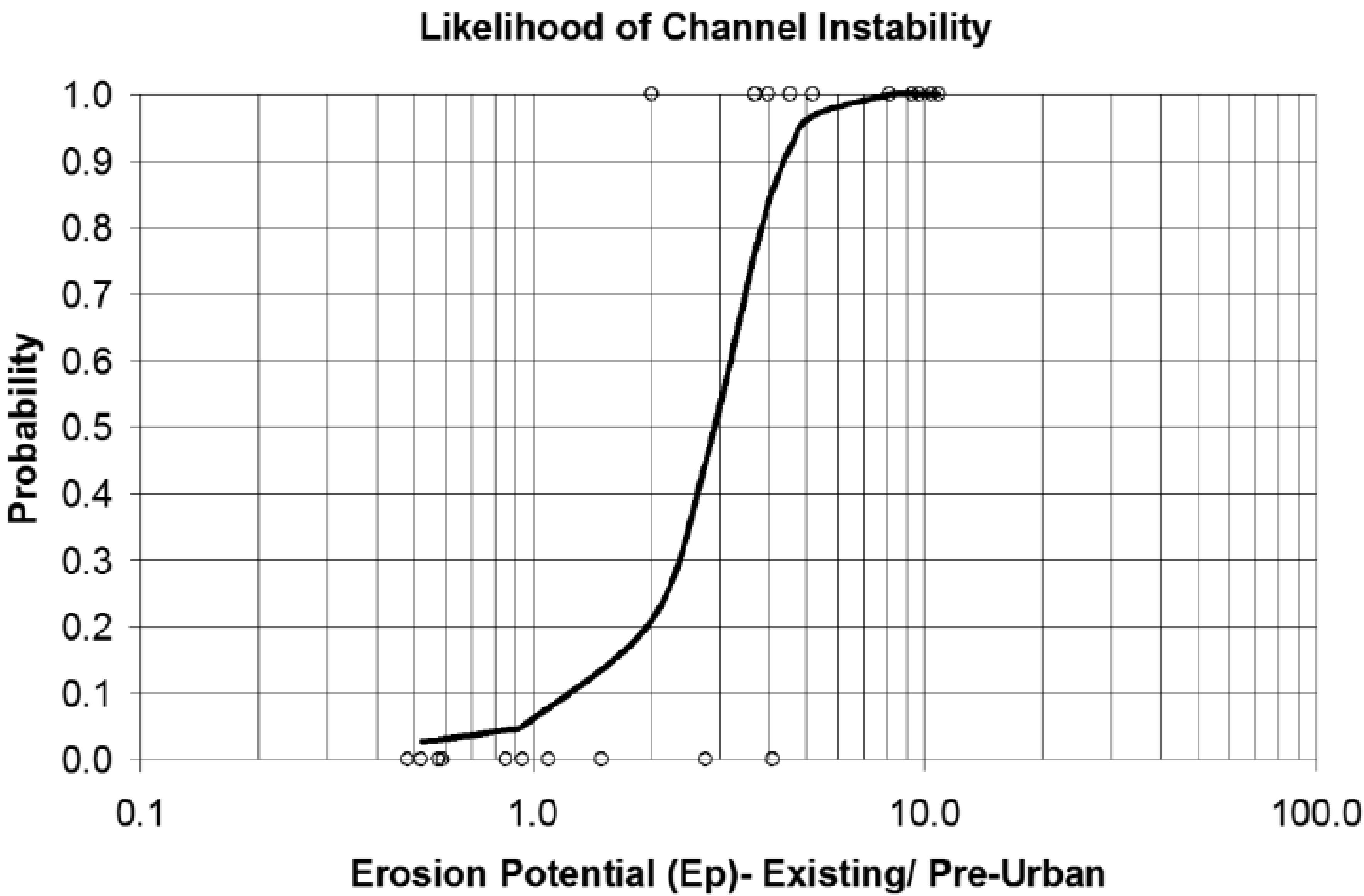
Channel enlargement =

$$\frac{\text{post-development cross-sectional area}}{\text{pre-development cross-sectional area}}$$

- Indicate strong associations between channel enlargement and
  - Erosion potential
  - Bed material size
  - Distance to grade control
  - Increase in Q2

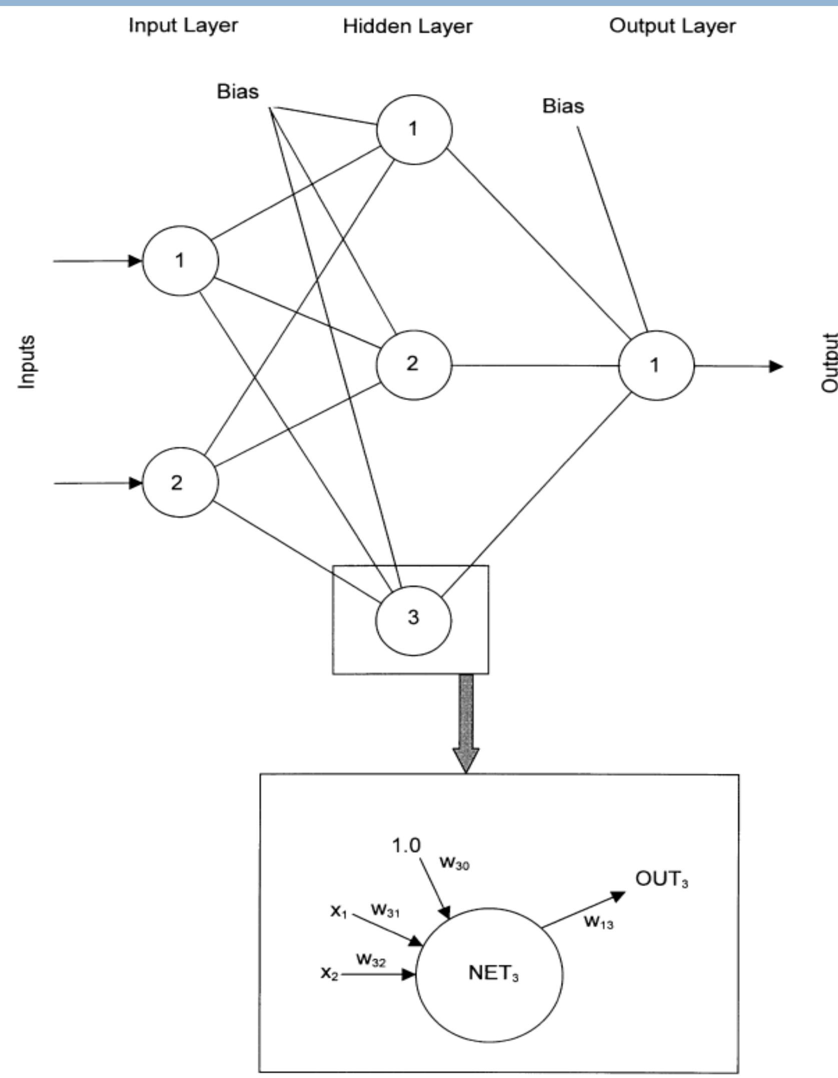
- Importance of balancing the post-development sediment transport to the pre-development setting over the entire range of erosive flows rather than a single flow
  - Load ratio, a.k.a. erosion potential -explained nearly 60% of the variance

Risk of channel shifting to undesirable state based probabilistic model linking field data with erosion potential (Ep)



Artificial Neural Network (ANN)

- Series of iteratively solved equations:
  - Adaptive Learning
  - Ability to model nonlinear relationships
  - Identification of variables that most affect uncertainty in model output
  - Ability to use surrogate variables
  - Easier parameter optimization



Support for Selecting Appropriate Tool(s)

Table I.3. Summary of the models that are currently considered most relevant to hydromodification management.

Tools / Models	Example(s)	Type	Question(s) Addressed	Scale	Relation to Other Tools	Data Requirements	Relative Uncertainty	Key Considerations / Questions in Appropriate Use[3]
Descriptive (D) Tools								
Rapid riparian/wetland assessments	CRAM	D	Level of wetland / riparian function?	reach to segment	Complements geomorphic assessment tools.	Field visit, readily available GIS and desktop data.	Low - Moderate	Were protocols properly followed?
Rapid channel susceptibility assessments	Bledsoe *et al.* (2010, 2012)	D	Relative channel susceptibility to hydromodification High, Medium, or Low?	reach to segment	Complements riparian assessment tools, vertical and lateral rating point to additional modeling tools, suggests in a coarse sense the level of mitigation that may be required.	Field visit, readily available GIS and desktop data.	Low - Moderate	Were protocols properly followed? For relative comparisons of susceptibility.
Geomorphic Landscape Units	Booth *et al.* (2011)	D	Where will development most affect runoff processes? Where are key sources of coarse sediment supply to stream channels? Where are priority areas for restricting development to maintain watershed processes? Where might "over-control" be necessary to mitigation reductions in sediment supply?	watershed - region	Complements channel stability assessments, land use planning.	Readily available GIS data.	Low - Moderate	Were protocols properly followed? For relative comparisons of potential sediment delivery.
Channel Evolution Model	Schumm *et al.* (1984), Hawley *et al.* (2012)	D	What is the sequence of incision and/or braiding that can be expected over decades in disturbed channels? What geomorphic thresholds are most relevant to understanding channel response? How can unstable channels be classified for targeting rehabilitation measures?	reach to watershed	Identifies geomorphic thresholds quantified by braiding/incision predictors, highlights key processes that models of channel response may need to account for.	Field visit, expertise in fluvial geomorphology.	Low - Moderate	Are the predictions of other channel response models consistent with this framework, which processes / thresholds in the CEM are not accounted for in a modeling analysis?
Mechanistic (M) / Empirical-Statistical (E/S)								
Rainfall-runoff models	HSPF, SWMM, HEC-HMS	M	What are the estimated streamflows at an ungaged site? How will different types of land use change affect streamflow? How will peak flows change (single event modeling)? How will the long-term streamflow regime change in terms of magnitude, frequency, duration, flashiness, etc. (continuous modeling)?	watershed	Provide inputs in hydraulic models, shear stress and effective discharge calculators, SIAM, mobile boundary models. Continuous simulation outputs necessary to create flow-duration curves and to estimate important metrics like erosion potential for probabilistic models.	Several watershed GIS layers (e.g., precipitation, land cover, soils), streamflow data needed for calibration - long-term records of precipitation, land use change, calibration data required for continuous simulation.	Low - High, depends on data availability, calibration and testing	Is there match in the spatial and temporal scales and vintage of input data, are infiltration parameters consistent with standardized values for the study region, were 15-min data generated for flashy streams, was the model calibrated and validated?
Regional streamflow regressions	Hawley and Bledsoe (2011)	E/S	What are estimates of streamflow metrics at ungaged sites? How will urbanization affect streamflow at this ungaged site? How will peak flows and flow durations change in response to urbanization?	watershed	Complement rainfall-runoff models by providing an additional estimate of flow characteristics that is relatively straightforward to estimate. Can be used as a check of more detailed hydrology models.	Watershed GIS layers.	Moderate if not extrapolated beyond calibration data	Are the regressions applied within the range of conditions used to develop the model?

Suites of Modeling Tools

- How do tools fit together to provide predictive scientific assessment?

- Use combinations of tools
  - Baseline stability assessment
  - Channel forming discharge
  - Erosion potential
  - Sediment transport analysis

Modeling Tools - Conclusions

- These tools have a clear physical basis; however, their efficacy has not been widely demonstrated for hydromodifcation management
- This underscores the need for carefully designed monitoring and adaptive management programs.
- Models should account for hydraulic characteristics through physically-based metrics that integrate variables like stream power or shear stress (relative to boundary material size) over time.
- This critical information comes at a cost—the tools require more time and effort to apply than has been the norm in hydromodification management.

Modeling Tools - Conclusions

- Deterministic representations (such as those derived from continuous simulation modeling) can mask uncertainties and be misleadingly precise unless prediction uncertainty is explicitly characterized.
- Given the uncertainty associated with predicting hydromodification impacts, development of probabilistic models is recommended.
- Focus should be on the decisions (or objectives) associated with the resource and not on building more-detailed models with the hope that they will provide the answers that elude us.

Roadmap for the Rest of Today

- Flow monitoring and Introduction to Continuous Simulation Modeling
  - Chris Bowles
- Application of Continuous Simulation Modeling for Decision Making and "BMP" Design
  - Judd Goodman
- Application of GLU approach for protecting sediment supply areas
  - Papantzin Cid
- Machine Learning (Beyond Probabilistic Modeling) for Assessing Hydromodification Effects
  - Ashmita Sengupta
- Future Directions for Integrated/Expanded Flow Monitoring
  - Felicia Federico


Thank You
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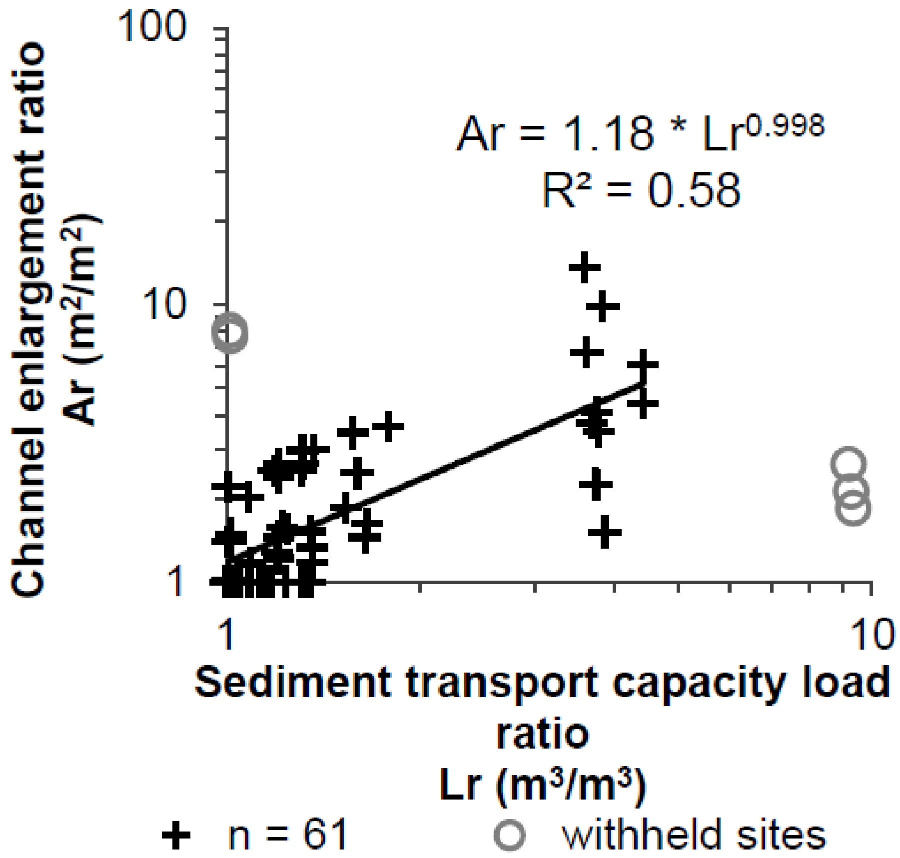
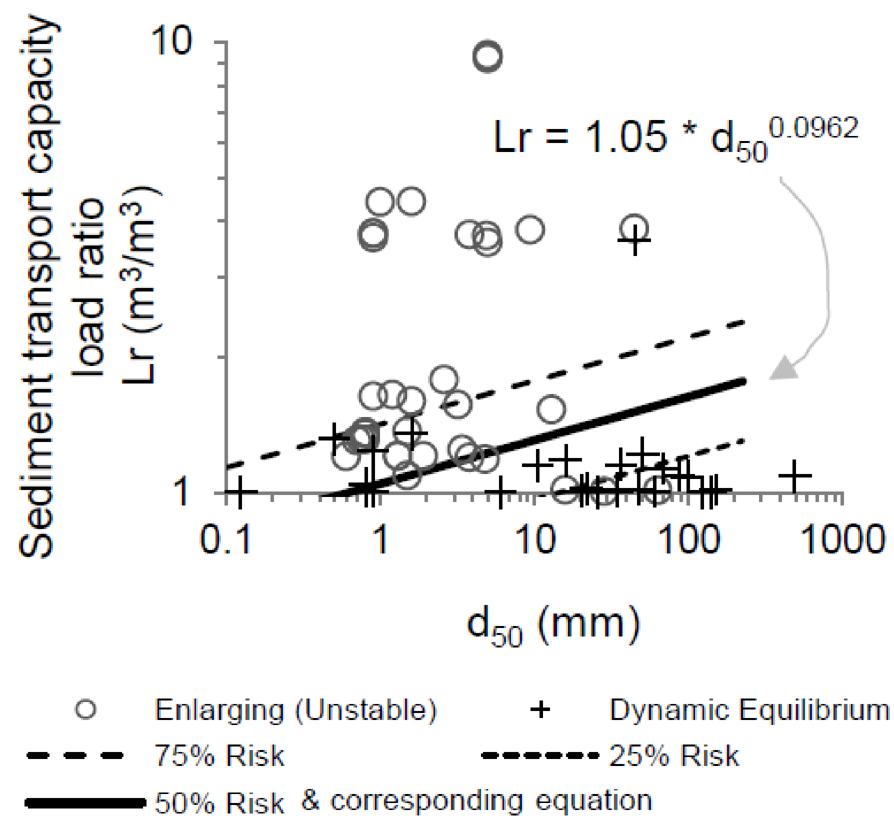
- Potential CART example from bio-objectives

Channel Enlargement Models



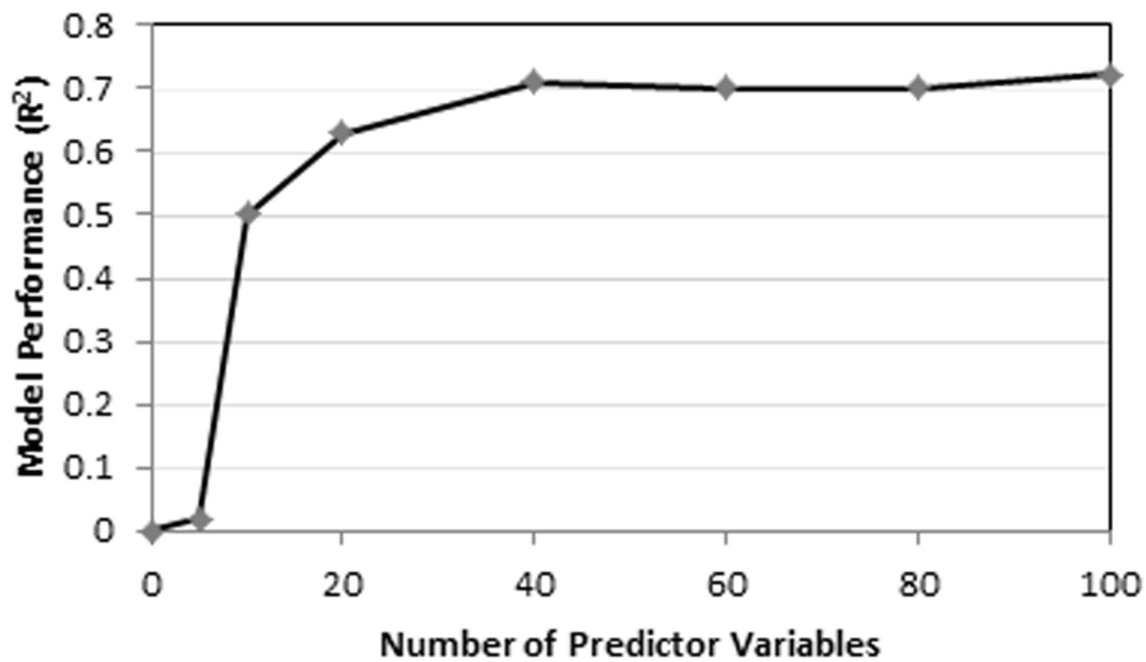
(a) enlargement vs. erosion potential



(b) risk of enlargement associated with d_{50} and erosion potential

Parameter Reduction through ANN

Predictor Variables
Calculated Flow
Bedload Capability
Stability of Cross-section
Total Impervious Area
Stream Power
Bed material Composition
Distance to Hardpoint



Sengupta et al., in review