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
Acton Canyon – 2-3% Impervious cover
The Challenge of Hydromodification

- Change can occur rapidly.
- Streams are highly variable.
- May be dealing with legacy effects.
- Responses are difficult to predict.

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

New Development Site Controls and Mitigation Requirements
- On-site Actions
- Off-site Actions

Other Entities or Programs

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

Risk, $

Model Complexity

Risk of oversimplifying the system

Difficulty and cost of getting an answer
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
Explicit Knowledge of Uncertainty

Cost / Time / Data

Ease of Use

Modeling Tool Box

DESCRIPTIVE TOOLS
- Conceptual Model
- Screening Tools
- Characterization Tools

MECHANISTIC / DETERMINISTIC MODELS
- Hydrology & Hydraulics
- Sediment Transport
- Regime Diagrams

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

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

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?
Explicit Knowledge of Uncertainty

Cost / Time / Data

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Modeling Tool Box

• 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
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
Relationships between CEM Stage, Planform, Q10, and Width

\[ W_{\text{ref}} = 5.46 \times Q_{10}^{0.458} \]

\[ R^2 = 0.94 \]
Relationships between CEM Stage, Stream Power, and Grain Size

\[ \omega_{\text{braided equilibrium}} = 16.7 \times d_{50}^{0.75} \]

\[ R^2 = 0.87 \]

- Constructed (Phase 5C) \( (n = 5) \)
- Confined, mountain headwaters (CEM Type I) \( (n = 11) \)
- Unstable states (CEM Types II, III; Phases B2, B3, 2B, 4B) \( (n = 43) \)
- Dynamic equilibrium multi-thread (Phase B1) \( (n = 11) \)
- Dynamic equilibrium single-thread, unconfined (CEM Types I, IV, V; Phase 1Veg) \( (n = 13) \)

Regression of braided equilibrium
Modeling Tool Box

MECHANISTIC / DETERMINISTIC MODELS
- Hydrology & Hydraulics
- Sediment Transport
- Regime Diagrams

STATISTICAL MODELS
- 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)
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

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 km² (100 mi²)
Revised Regional Rating Curve

\[ y = 1,694 \ln(x) - 577 \]

\[ R^2 = 0.93 \]

- **Inv. Gamma Distribution**
  - \( \alpha = 0.341 \)
  - \( \beta = 3,407 \)
  - \( R^2 = 0.99 \)

- **Log-Pearson III (Q+0.1)**
  - \( G = -1.42 \)
  - \( R^2 = 0.73 \)

- **Log-Pearson III (Q+100)**
  - \( G = 0.51 \)
  - \( R^2 = 0.89 \)

- **Weibull plotting position**
  - Interpolated plotting pos.

Hawley and Bledsoe 2011
Effect of Urbanization

1934-1958: \( \text{Imp}_{\text{av}} = 2.6\% \), \( \text{Imp}_{\text{max}} = 4.7\% \)
1959-1983: \( \text{Imp}_{\text{av}} = 7.3\% \), \( \text{Imp}_{\text{max}} = 8.6\% \)
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.

<table>
<thead>
<tr>
<th>Tools / Models</th>
<th>Example(s)</th>
<th>Type</th>
<th>Question(s) Addressed</th>
<th>Scale</th>
<th>Relation to Other Tools</th>
<th>Data Requirements</th>
<th>Relative Uncertainty</th>
<th>Key Considerations / Questions in Appropriate Use?</th>
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<tbody>
<tr>
<td>Descriptive (D) Tools</td>
<td>CRAM</td>
<td>D</td>
<td>Level of wetland / riparian function?</td>
<td>reach to segment</td>
<td>Complements geomorphic assessment tools.</td>
<td>Field visit, readily available GIS and desktop data.</td>
<td>Low - Moderate</td>
<td>Were protocols properly followed?</td>
</tr>
<tr>
<td>Rapid riparian/riparian</td>
<td>Biedso et al. (2010, 2012)</td>
<td>D</td>
<td>Relative channel susceptibility to hydromodification High, Medium, or Low?</td>
<td>reach to segment</td>
<td>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.</td>
<td>Field visit, readily available GIS and desktop data.</td>
<td>Low - Moderate</td>
<td>Were protocols properly followed? For relative comparisons of susceptibility.</td>
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<td>Rapid channel susceptibility</td>
<td>Biedso et al. (2010)</td>
<td>D</td>
<td>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 mitigate reductions in sediment supply?</td>
<td>watershed - region</td>
<td>Complements channel stability assessments, and use planning.</td>
<td>Readily available GIS and desktop data.</td>
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<td>Geomorphic Landscape Units</td>
<td>Booth et al. (2011)</td>
<td>D</td>
<td>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?</td>
<td>reach to watershed</td>
<td>Identifies geomorphic thresholds quantified by broad basin predictions, highlights key processes that modes of channel response may need to account for.</td>
<td>Field visit, expertise in fluvial geomorphology.</td>
<td>Low - Moderate</td>
<td>Are the predictions of other channel response modes consistent with this framework, which processes / thresholds in the GEM are not accounted for in a modeling analysis?</td>
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<tr>
<td>Channel Evolution Model</td>
<td>Schumm et al. (1994), Hawley et al. (2012)</td>
<td>D</td>
<td>What are the estimated streamflows at an unaged 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, flashy, etc. (continuous modeling)?</td>
<td>watershed</td>
<td>Provide inputs in hydraulic models, shear stress and effective discharge calculation, SIAM, mobile boundary models. Continuous simulation outputs necessary to create flow-duration curves and to estimate important metrics like erosion potentials for probabilistic models.</td>
<td>Several watershed GIS layers (e.g., precipitation, land cover, sols), streamflow data needed for calibration - long-term records of precipitation, land use change, calibration data required for continuous simulation.</td>
<td>Low - High, depends on data availability, calibration, and testing</td>
<td>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?</td>
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<tr>
<td>Mechanistic (M) / Empirical-Statistical (E/S) Rainfall-runoff models</td>
<td>HSPP, SWMM, HEC-HMS</td>
<td>M</td>
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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
These tools have a clear physical basis; however, their efficacy has not been widely demonstrated for hydromodification 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.
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