Perspectives on river restoration science, geomorphic processes, and channel stability

Stream Restoration Forum: Science and Regulatory Connections

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Overview

• Reconfiguration vs reconnection restoration
• Channel stability
  – Vertical vs lateral stability
  – Flow and sediment regimes
  – Structures as means to manipulate channel stability
• Modelling approaches to evaluating stability
• Other perspectives on river restoration
Reconfiguration restoration

- Reach-scale
- Create stability
- Increase habitat heterogeneity
  - Ecological benefits?
Form-based restoration: extreme cases no longer the norm
Common approaches to creating stability:
• Bank structures to prevent lateral movement
• Boulders or large logs in bed to prevent vertical movement
• Plantings along banks and floodplain to provide cohesion

Conceptual model:
• Prevent channel movement during ~1st decade to allow riparian vegetation establishment
• Subsequently bank stabilizing materials will decompose, allowing dynamic channel
Reconnection restoration: Floodplain connectivity

Provo River, UT

Mareit River, Italy

Sacramento River, CA

Kootenai River, ID

Kissimmee River, FL

Aerials of 2000 project before construction (left), and after in 2001

Maps and images illustrating the restoration projects.
• Stability of stream restoration practices and elements of practices
  – Research is needed to better understand why and when stream restoration practices “fail” in order to reduce “failures” and increase “successes.”
  – We recognize that there is no standard definition of “failure,” definition of “stability,” or agreed upon tolerance for movement of stream materials within or from a project.
“Stream stability is morphologically defined as the ability of the stream to maintain, over time, its dimension, pattern, and profile in such a manner that it is neither aggrading or degrading and is able to effectively transport the flows and sediment delivered to it by its watershed. Morphologic stability permits the full expression of natural stream characteristics.”
Sediment Balance in Channel Restoration Design

The core questions:
• What is the supply of water and sediment?
• What do you want to do with it?

More precisely:
1. What is the water discharge $Q(t)$ & sediment supply rate $Q_s(t)$ and grain size $D(t)$ delivered to the upstream end of the design reach?
2. How will the available flow move the supplied sediment through the design reach?

(P. Wilcock)
Wohlet al. 2015, *BioScience*
Conservation of sediment mass

\[ I - O = \Delta S \]
\[ \text{Input (of sediment)} - \text{Output (of sediment)} = \text{Change in (sediment) storage} \]

**Sediment balance:**

- If \( I = O \), then \( \Delta S = 0 \)
  - Bed elevation \( (z) \) does not change

- If \( I > O \), then \( \Delta S \uparrow \)
  - Bed aggrades \( (z \uparrow) \)

- If \( I < O \), then \( \Delta S \downarrow \)
  - Bed scours \( (z \downarrow) \)

\[
(1 - \lambda_p) \frac{\partial z}{\partial t} = - \frac{\partial q_s}{\partial x}
\]

- \( \lambda_p \): bed porosity
- \( z \): bed elevation
- \( q_s \): sediment transport rate (per unit width)

- Sediment transport \( \rightarrow \) channel change
- Quantifying sediment balance provides a basis for predicting channel behavior
Lateral stability harder to predict than vertical stability

- Driving & resisting forces more complex
- Local & non fluvial influences
- Biotic & abiotic influences
The core questions:
• What is the supply of water and sediment?
• What do you want to do with it?

Often, instead of answering the core questions, we:
• Replace them with assumptions:
  – *Channels are unstable*
  – *Sediment inputs are from bank erosion*
  – *There is a predictable “dominant discharge”*
• Use structures as a substitute
  – *Grade control*
  – *Bank protection*

The core questions are difficult to answer
• But we cannot wish them away
• Ignoring them is basis for project failure
• Large uncertainty ≠ unpredictable
• Uncertainty must be incorporated in channel design

(P. Wilcock)
Restoration success vs failure

• Objectives
  – A necessary (but not sufficient) quantitative performance measure: sediment balance, averaged over all flows

• Perception that restoration synonymous with stability
  – In contrast to ecological restoration

• What is failure?

• In what conditions can we
  – Build restoration projects without reliance on structures?
  – Relax the need to quantify sediment balance?

• Communication critical
CB Trust Restoration Research

- What are the flow conditions
  - Local hydraulics (metrics: velocity, shear stress)?
  - Flood recurrence interval?
  - How to generalize?

- under which different in-stream channel structures (e.g., vanes, step pools, constructed riffles, large woody debris)
  - Cross-site comparison of specific type of structure?
  - Pooled study of all types of structures?

- or approaches (e.g., RSC, NCD, stream valley restoration/legacy sediment removal) function and remain stable?
  - Cross-site comparison of specific approach?
  - Pooled study of all approaches?

- What are the energy tolerances beyond which the structures or approaches begin to fail?
  - How to define failure?
  - How to quantifying energy tolerance?

LITTLE IS KNOWN ABOUT ANSWERS TO THESE QUESTIONS!

[Craig Hill, after Rosgen, 2006, NRCS 2007]
Damage States Framework

- Damage scores assigned for
  - Infrastructure protection
  - Structural integrity
  - Bank stability and migration

- Damage scores from none to complete
  - Flood hazard
  - Vertical stability
  - Wood & sediment transport
  - Bank vegetation

Miller and Kochel 2010, *Env. Earth Sci*

Jones and Johnson, 2015, *JAWRA*
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• How well can various modelling approaches predict the structural “success” or “failure” for the various stream restoration techniques and structures?
  – What variables must be included in the models to make accurate predictions for stream restoration “success” or “failure” at the site?

• Possible Elements of the Experimental Design: Compare 1D and 2D model predictions with real life “success” or “failure” (i.e., degree of sediment movement, degree of loss of materials), including enough replicate study sites to capture variability.
Physical modelling

Velocity in bendway weir fields (Kinzli and Thornton, 2010)

Rock vane failure hydraulics (Kang and Sotiropoulos 2015, *JHR*)
Numerical modelling

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<thead>
<tr>
<th></th>
<th>1D</th>
<th>2D</th>
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</thead>
<tbody>
<tr>
<td>Required topography input</td>
<td>Cross sections</td>
<td>High-resolution topography</td>
</tr>
<tr>
<td>Output</td>
<td>Cross-section averaged flow conditions</td>
<td>Depth-averaged flow conditions</td>
</tr>
<tr>
<td>Industry standard?</td>
<td>Yes, HEC-RAS</td>
<td>No</td>
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<tr>
<td>Cost</td>
<td>Lower</td>
<td>Higher</td>
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Applicability depends on objectives & complexity of flows being modelled
Regardless, calibration & judgment required. Garbage in, garbage out!
Comparison of 1D and 2D model results for ecohydraulic analysis: Yuba R., CA (Gibson and Pasternack 2015, RRA)

Bendway weir design, North Raccoon River, Iowa (Claman 2014)
Trends in stream restoration

- Accounting for climate change
- Ivory tower-practitioner common ground
- Restoration education & training
- New approaches & tools
Reconnection restoration: Longitudinal connectivity

- Environmental flow releases
- Dam removal
- Sediment management

US dam removals 1916-2015 (American Rivers)

Controlled flood, Glen Canyon Dam, Colorado River

Gravel injection, Yuba River, CA, Englebright Dam (G. Pasternack)
Alternative frameworks

RiverRAT: Science base and tools for analyzing stream engineering, management, and restoration proposals (NOAA, P. Skidmore)

River Styles Framework (G. Brierley, K. Fryirs)
Concluding thoughts

• Reconfiguration vs reconnection focused restoration
• Sediment balance, channel stability, & stream restoration
• Research needed to better predict stability of stream restoration projects
• Little generalizable knowledge about effectiveness of various structures & approaches
• Modeling becoming more effective & accessible
• Reasons for optimism!

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Translation Slides
What does this mean for me?

• Understanding sediment supply and transport is critical in the overall success of a stream restoration project.

• Vertical Stability – flood plain connectivity is critical to the overall success of a stream restoration project.

• Lateral Stability – maintaining lateral stability until vegetation establishes is critical to the overall success of a stream restoration project. Use of wood is best since it will decompose over time and allow for natural channel movement.

• Little research information exists regarding best stream restoration practices, structures or design approaches to achieve quasi-equilibrium. Regardless of how restoration occurs, success will always be compromised if sediment balance is not addressed.

• Modelling – 1D v.s. 2D modelling. 1D less effort and less detail than 2D modelling. Which model is best depends on objectives of project. However, 2D modelling is becoming easier and less expensive to use.
What does this mean for me?

• **What might I take from this if I am a practitioner:**

  Let’s make sure to address sediment budget in design process and use wood for structures as much as possible and when appropriate.

• **What might I take from this if I am a regulator:**

  Let’s make sure sediment analysis is addressed as part of design process and that an appropriate level of stability analyses and/or modelling are conduct to demonstrate design quasi-equilibrium.