Stream Restoration

What Works and What Doesn't Work

A one-hour webinar by **F. Douglas Shields, Jr.**
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1

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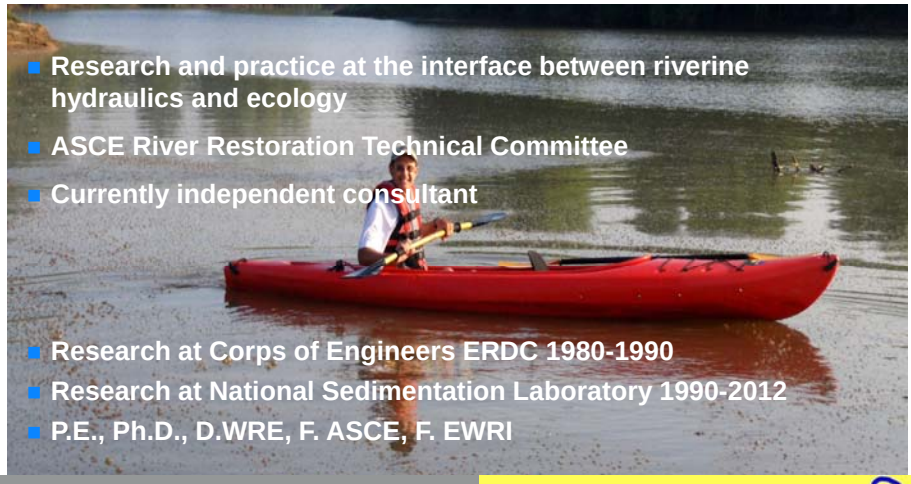
Your instructor



- Research and practice at the interface between riverine hydraulics and ecology
- ASCE River Restoration Technical Committee
- Currently independent consultant
- Research at Corps of Engineers ERDC 1980-1990
- Research at National Sedimentation Laboratory 1990-2012
- P.E., Ph.D., D.WRE, F. ASCE, F. EWRI

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Introduction

Overview and objectives

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3

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Webinar overview

- Introduction, overview, objectives
- Where's the beef? What research studies on restoration benefit delivery have shown
- Shooting fish in a barrel: some things that almost always work
- Snake oil for sure: some things that hardly ever work
- Ideas someone should try

Sad, but true

"If you want to loose weight, you have to eat fewer calories than you burn."

"There is no Santa Claus."

"You will have to pay taxes on that."

"In investing, risk and reward are inversely proportional."

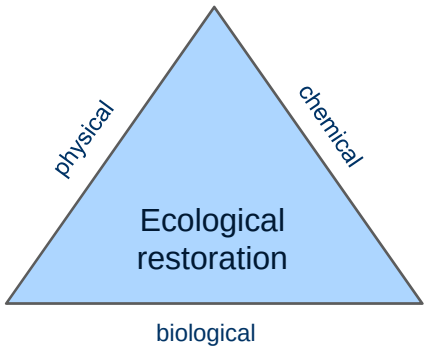
"There is no free lunch."

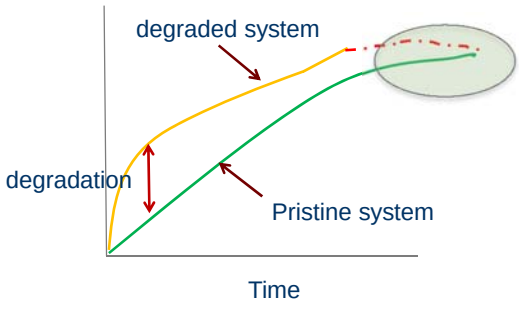
Stream restoration is complicated.

- There are no approaches or techniques that always work.
- There are no approaches or techniques that always fail.
- There are no easy recipes.

What does "working" restoration look like?

Return to a pre-restoration trajectory…

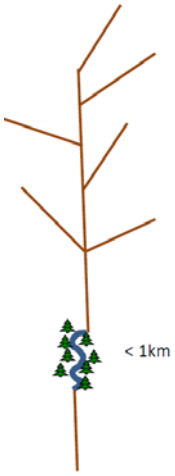




Webinar objectives

Pay close attention, and you should be able to…

- Identify key factors that contribute to stream restoration project success
- Be able to list several proven stream restoration techniques
- Be able to identify "promising" but not yet proven approaches
- Be able to develop semi-quantitative project risk assessments



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Quiz time

- For purposes of this webinar, how is stream restoration success defined?
- What are the perils/difficulties associated with this definition?
- Your questions?

Where's the beef?

Recent findings of research on stream restoration benefit delivery

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What works and what doesn't….most projects are not evaluated

- Only < 10% of stream restoration projects are monitored (Palmer et a. 2007, NRRSS)

National River Restoration Science Synthesis

- Your friends won't tell you.
  - Telephone interviews of 317 stream restoration project managers revealed that 2/3 felt their project had been "completely successful." (Bernhardt et al. 2007)
  - 89% of project contacts reported success, but only 11% ….because of the response of a specific ecological indicator (39 projects in Midwest, Alexander and Allan 2007)

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Stream restoration and physical integrity

- Median length = 1,117 ft
- Median drainage area = 224 ac

Too many restoration projects are "small actions in small streams"

- Median stream power = 14 ft lb/s-ft = 62 W/m
- Deep, narrow, straight channels
- Riffles stable, filled with fines, colonized by wetland plants
- Many sites had extremely poor soil quality

Some projects don't even pass the visual test

Mecklenberg and Fay (2011) performed physical post-project assessments for 51 stream mitigation projects in Ohio that included **physical reconfiguration**

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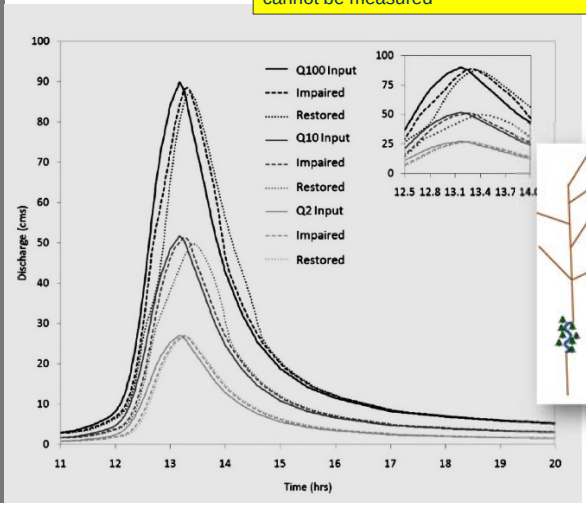
Stream restoration and physical integrity

Short reach projects have such small influence on peak discharge that it cannot be measured



Minimal flood peak attenuation

Sholtes and Doyle (2011) modeled flood wave passage through hypothetical impaired and restored reaches using HEC RAS and median channel dimensions from 20 North Carolina stream restoration projects. Reach length ~1 km, channel slope ~0.005, bankfull width 14-16 m, Q_{bf} = 28-49 m^3/s

Stream restoration and water quality

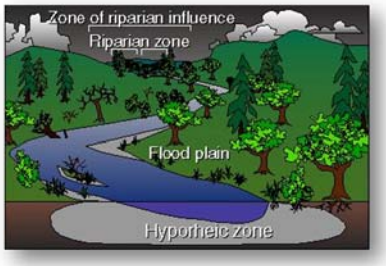
☺ Riparian zones can trigger significant denitrification in shallow groundwater,

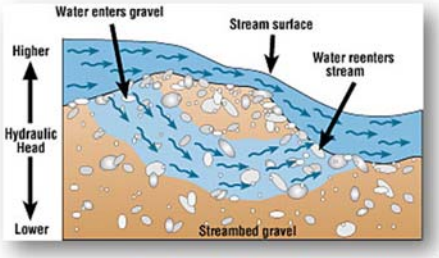
but….

☹ Typical types of restoration often improve hyporheic retention,

but…

☹ this impacts only a tiny fraction of total flow in streams that do not have very coarse beds (Kasahara and Hill 2006, Stofleth et al. 2008)





Recent findings of research on stream restoration benefit delivery

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Stream restoration and macroinvertebrates

- Two large meta-analyses
  - Palmer et al. 2009
  - Miller et al. 2010
- Some overlap between the two meta-analyses
  - 78 projects, 18 different author groups
  - 24 studies (out of initial list of 53 papers)
    - 18 reported both density and richness estimates
    - 6 only richness or density

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Stream restoration effects--macroinvertebrates

- Palmer et al. 2009
  - "….across the 78 independent restoration projects monitored by the 18 sets of studies we evaluated, only two of the 78 (.026) projects resulted in increases in invertebrate diversity sufficient for the authors to conclude that the project was a biological success."
  - Increase in physical diversity (habitat heterogeneity) did not produce increase in biological diversity

Stream restoration effects--macroinvertebrates

- Miller et al. 2010
  - Results highly variable
  - Richness mean response = 2.3 genera or 10% (p = 0.08)
  - Density mean response = 660 individuals (per m^2?) or 23% (p = 0.24)
  - Richness levels did not return to target or minimally impacted conditions
  - LW >> Boulder additions

Stream restoration and fish

Widely variable results, but higher rates of success with salmonids than warmwater species

Instream structures and salmonids

- Two major meta-reviews (17 and 211 studies) Whiteway et al. (2010), Stewart et al. (2009)
- Both used statistical techniques to combine data sets
- A wide range of typical interventions
  - ✓ Weirs
  - ✓ Deflectors, vanes, groins
  - ✓ Cover structures
  - ✓ Boulder placement
  - ✓ LW
  - ✓ Ramps, riffle creation
  - ✓ Re-meandering

Instream structures and salmonids

- Widely variable results
- No control for confounding factors such as degraded water quality
- Structures associated with a statistically significant increase in salmonid abundance/biomass
- Structures appear to be more effective in smaller (i.e., narrower) streams

Instream structures and warmwater fishes

Compilation of study results by Roni et al. (2008)

"Little positive benefit [of instream structure placement] has been documented for nonsalmonids…"

Quiz time

- What fraction of stream restoration projects are monitored?
- How would you characterize findings of recent research regarding effects of stream restoration on benthic macroinvertebrates?
- Your questions?

The "field of dreams" myth

In real life, if you restore physical habitat, the animals may NOT come, and water quality may NOT improve.

Shooting fish in a barrel

Some things that almost always work

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Shooting fish in a barrel: some things that almost always work

- Roni et al. (2008) Global review of stream habitat rehabilitation
- 325 studies reviewed (1937 – 2006) , most in Western US and Canada
- Qualitative synthesis rather than quantitative meta-analysis
- Focused on fishes and to a lesser extent on macroinvertebrates

Some things that almost always work

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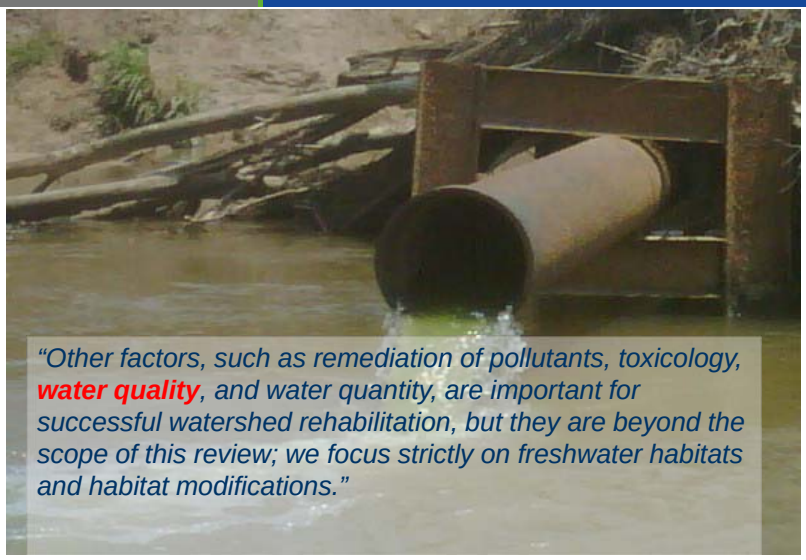
24

Roni et al. did not cover…



*"Other factors, such as remediation of pollutants, toxicology, **water quality**, and water quantity, are important for successful watershed rehabilitation, but they are beyond the scope of this review; we focus strictly on freshwater habitats and habitat modifications."*

Verbal synthesis for each major intervention category

Roni et al. (2008)

- ✓ Road improvement (removal, stabilization, culverts…..)
- ✓ Riparian rehabilitation (fencing, planting….)
- ✓ Floodplain connectivity and rehabilitation
  - dam and levee removal
  - beaver reintroduction
  - meander creation
  - flow modification
- ✓ Instream habitat improvement (LW, rock, gravel)
- ✓ Nutrient addition

Some things that almost always work

Some things that almost always work...low risk, high percentage plays

- **Roni et al. (2008) findings regarding "most promising techniques"**
  - Reconnection of isolated habitats (side channels, ponds, lakes, wetlands…)
  - Floodplain rehabilitation (creation of floodplain ponds, channels, lakes; flooding, beaver reintroduction)
  - Placement of instream structures
- "When implemented properly , these techniques can produce dramatic improvement of physical habitat and biota…."
- "Little positive benefit [of instream structure placement] has been documented for nonsalmonids"
- "The most successful projects…. create large changes in physical habitat and mimic natural processes…."
- Several techniques (e.g., riparian rehabilitation, dam removal…) have shown promise, "but no long-term studies documenting their success have yet been published."

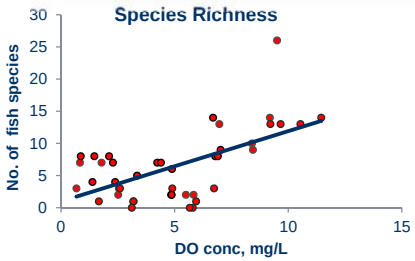
Process, process, process

- Watershed scale
  - Surface erosion
  - Mass wasting
  - Surface and subsurface hydrology
  - Nutrient processing and delivery
- Reach scale
  - Sediment transport and storage
  - Stream flow and storage, flooding
  - Channel migration, floodplain and backwater formation
  - Sediment sorting and pool formation
  - Root reinforcement of banks, shading, LW supply
  - Primary and secondary biomass production
  - Habitat formation by beaver

Address water quality issues

Shields and Knight (2011)

- Basic water quality problems like temp and DO issues are common
- In such cases, manipulation of habitat structure alone not adequate for ecological restoration
- But history shows water quality improvement can be a major first step towards restoration



Quiz time

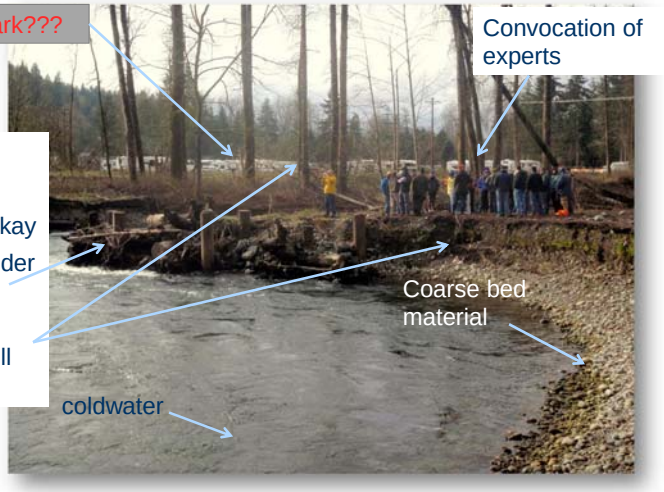
- East v. west
- Coldwater v. warm
- Gravel/cobble bed v. sand/fines
- Salmonids v. non salmonids
- Less developed watershed v. short reach urban
- Large stream v. small
- Process v. natural channel design

Location, location, location

- East v. **west**
- **Coldwater** v. warm
- **Gravel/cobble bed** v. sand/fines
- **Salmonids** v. non salmonids
- **Less developed watershed** v. short reach urban
- Large stream v. **small**
- **Process** v. natural channel design

This should work

This should work



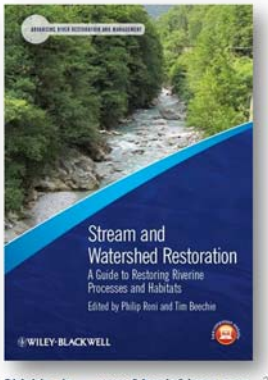
- Pacific NW
- Salmonid stream
- Hydrology and WQ okay
- Large wood and boulder addition to create instream structures
- Natural processes still active

It's complicated

Factors that lead to success

- Target root causes of degradation
- Tailor restoration actions to local potential
- Restoration scale = process scale
- Define expectations, including time
- Adapt, adjust, maintain

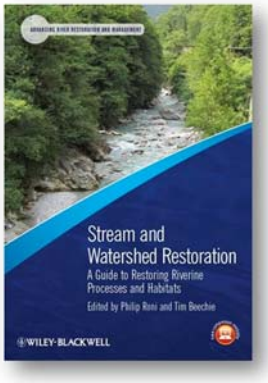
- Channel modifications
- Point source water pollution
- Dams
- Grazing
- Deforestation
- Agriculture
- Roads
- Urbanization



Factors that lead to success

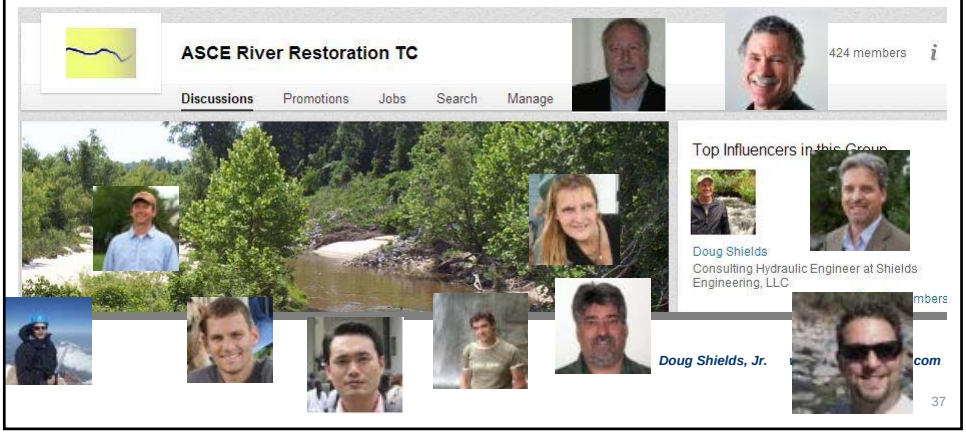
Obsess about process

- Hydrology
- Sediment transport
- Riparian functions
- Connectivity
- Nutrient cycling



Linkedin discussion

- ASCE River Restoration Technical Committee Linkedin Group
- Discussion…. *Overly simplistic question:* ***what commonly-used restoration approach is most likely to produce ecological benefits****?*



What commonly-used restoration approach is most likely to produce ecological benefits?

Lots of verbiage, discussion, qualification…but…these emerged

- Barrier removal and fish passage (dams, culverts, etc.)
- Address water pollution
- Large wood
- Set back levees
- Floodplain regulation, preserve riparian corridors, fencing, give the river room to do its thing…

Linkedin discussion of best approaches

Words of wisdom

In addition to identifying the most effective stream restoration approaches, the group offered sage advice…

- No single approach or technique is best—very system dependent
- Restore natural processes and functions
- How much time are you buying for your buck? “Accelerate natural recovery...”
- Dam or barrier removal can open up “miles” of rivers, but…
- Dam removal/levee breaching can also trigger instability

Quiz time

- Which project is **more** likely to produce a **positive** ecological response?

Both projects consist of placement of LW structures along 2 miles of channel

Rural, pastoral stream in Ohio. Previously channelized for drainage, riparian veg retained on one bank. Elevated nutrients and susp sediment.

Forested watershed, Vermont. Relocated due to highway construction.

Some things that almost always work

Snake oil for sure

some things that hardly ever work

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41

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Installing plant materials…

Without thinking very much about soils…

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Plants need

- Sunlight
- Water
- Nutrients
- Air in root zone

Designing for today and not for tomorrow….

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Ensuring restoration project failure

Bond and Lake (2003). Local habitat restoration in streams: Constraints on the effectiveness of restoration for stream biota

- Ignoring barriers to colonization
- Designing for today (and not for tomorrow)….needs of all life stages, high flow and drought refugia
- Introduced species. These may benefit disproportionately from restoration
- Long-term and large-scale physical processes such as legacies of previous disturbances and ongoing disturbances at watershed and larger scales
- Restored area is much smaller than the critical range or patch size for target species

some things that hardly ever work

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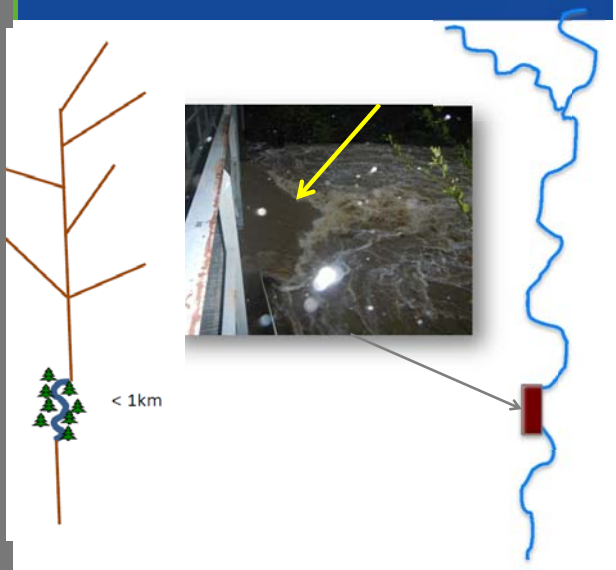
Ignoring barriers to colonization

The field of dreams hypothesis



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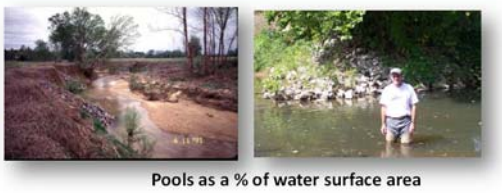
A "take home" message

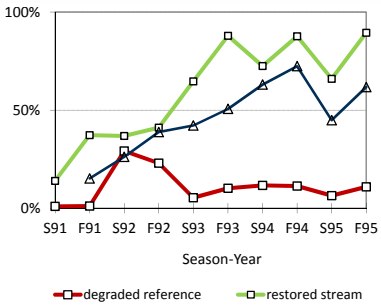
- A completed project may look "natural"
- It may withstand high flows and floods
- Vegetation may survive

But….

- Ecological functions may not be restored

Species richness, fish numbers and fish biomass all showed slight declines…(Shields et al. 1998, 2007)





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Thinking you are smarter than exotics

Kudzu smothers willow plantings

Introduced species

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Ignoring long ter and large-scale processes

Also known as…..

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Ignoring long term and large-scale processes

For example, watershed scale channel incision

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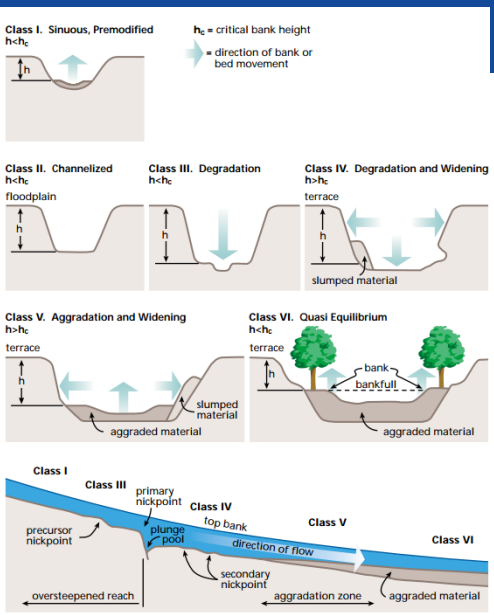
Conceptual model of incised channel evolution

See FIWRG (1998) for introduction to this tool



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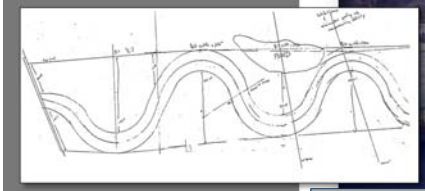
Ignoring long term and large-scale processes

Imposing a new channel form without considering processes that determine channel form



Kondolf (2006)

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Ignoring long term and large-scale processes

Imposing a new channel form without considering processes that determine channel form

1-3 years after

Kondolf (2006)

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In hindsight….

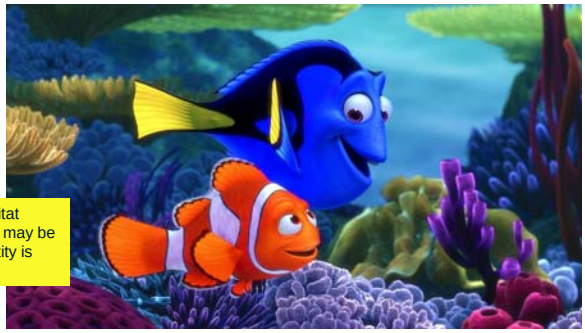
- No adequate geomorphic assessment
- Design did not answer the "core questions" (Wilcock 2004)
  - What is the water discharge Q(t) and sediment supply rate Qs(t) and grain size D(t) delivered to the upstream end of the design reach?
  - How will the available flow move the supplied sediment through the design reach?

Inappropriate scales for restoration

Also known as the aquarium syndrome

"The spatial extent of restoration is rarely set from the perspective of target species or communities, instead being driven more often by human perceptions…or by issues of economic and social convenience." *Bond and Lake (2003)*

A great job of habitat quality restoration may be ineffective if quantity is inadequate



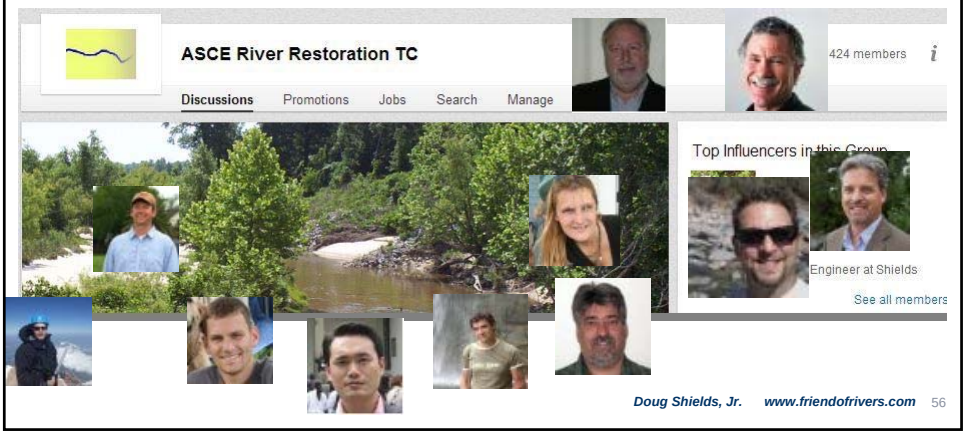
Inappropriate scales for restoration

In some ways, bigger is better. For sure, there is a minimum size below which restoration is ineffective….

- Water quality processes are dependent on scales of physical features
  - Width of buffers (nonpoint controls)
  - Length of shaded reaches (temperature)
- Flood peak mitigation is similarly scale dependent

"the dumbest restoration move I ever made (saw)…"

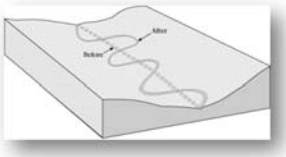
- ASCE River Restoration Technical Committee Linkedin Group
- Discussion…. **What restoration strategies/tactics/techniques do you find the least effective?**



Least effective approaches (per group)

- Instream structures that have no natural analog
  - J-hook vanes
  - Rootwads
  - Gabions
  - "Stonemason" structures

- Designing channels with excessive uniformity
  - Perfect sine curves for meander planform
  - Uniform channel widths (riffles tend to be wider, bend apices narrower)
- Designing channels to be excessively stable
  - Extra large riffle stone
  - Bed immobility up to Q_{10}
  - No channel changes allowed!



- Generally ignoring geomorphic context

some things that hardly ever work

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Least effective approaches (per group)

- Inadequate hydrologic design basis
  - Using rainfall/runoff relations for groundwater dominated systems
  - Considering only single Q, such as bankfull
  - Placing wood or other aquatic habitat features at unrealistically high elevations
  - Sizing channels based on Q_{peak} rather than considering floodplain inundation duration and frequency

some things that hardly ever work

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Least effective approaches (per group)

- Sediment or soils mistakes
  - ☹ Underestimating erodibility
  - ☹ Overestimating erodibility
  - ☹ Designing single thread channels that cannot transport supplied Q_s
  - ☹ No consideration of scour
  - ☹ No consideration of channel evolution

Quiz time

- Which project is riskier?

Project A http://www.pmcl.com/mmdl/CorpsCaseStudies.asp?ID=45	Project B http://www.ecologyandsociety.org/vol13/iss2/art54/
Urban, Great Plains	Rural (mixed cover), Southeast
Gravel and rubble bed, trout stream	Deeply incised, sand bed, warmwater. Minimal game fish populations
Mean daily flow = 29 cfs, slope = 0.005	Mean daily flow = 5 cfs, slope = 0.002
Basic water quality OK, but water too shallow and warm for trout	High sediment concentrations and temperatures
4.9 mi reach treated with instream structures made of 1-3 ft rock and designed to narrow baseflow channel	3000 ft reach treated with large wood and willow plantings to scour pools, provide cover

Factors that lead to failure (recap)

- Not addressing the root cause of habitat or water quality degradation
- No recognizing upstream processes or downstream barriers to connectivity
- One size fits all
- Inappropriate prioritization or sequencing of projects
- Poor project design
- Inadequate stakeholder support
- Inadequate monitoring

some things that hardly ever work

Ideas someone should try

Maybe you have?

Ideas someone should try

- Developing [radically] more efficient **native** plant propagation systems

"rotary stinger"

Photos from S&K Environmental Restoration, Inc., Arlee, MT used by permission.

Also see brochures and video at www.brackeforest.com

Ideas someone should try

- A "riparian zone arbor day"----with thousands involved

Ideas someone should try

- Develop a suite of tools for managing beaver
  - Attraction
  - Propagation
  - Repulsion
  - Population control

Review

- Most projects are not monitored, and most that are monitored have disappointing performance with respect to ecological targets.
- Approaches that focus on restoring process and function have greater likelihood of success than those that focus on form (the way things look)
  - Potential project effects are inversely proportional to stream size
  - Projects in less altered watersheds are more likely to succeed
  - Coldwater restorations (salmonids) are less risky that warmwater restorations
  - Geomorphic context and sediment transport analysis are quite important
- Bigger is often better as far as project size goes, but we can reduce failure risk of reach-scale restorations by looking up- and downstream
  - Consider watershed scale processes
  - Start with a good geomorphic assessment
  - Look for barriers

Restoration handbooks

(1) Stream Restoration Design Handbook (NEH 654), USDA.
You can either download individual chapters of NEH 654 or request a free cd. There are no paper copies.
(I) Download the book chapter by chapter from http://policy.nrcs.usda.gov/index.aspx
navigate to Handbooks, Title 210 - Engineering, National Engineering Handbook, Part 654 - Stream Restoration Design
(II) To request a CD, go to http://landcare.nrcs.usda.gov/ and search for NEH-654. The CD version is free and includes navigation bookmarks, is fully searchable with keywords, and has high quality files for selective printing.

(2) Federal Interagency Stream Restoration Working Group (FISRWG). 1998. Stream Corridor Restoration: Principles, Processes and Practices . Also on the aforementioned CD.

(3) RiverRat www.restorationreview.com. Skidmore, P. B., C. R. Thorne, B. Cluer, G. R. Pess, J. Castro, T. J. Beechie, and C.C. Shea. In review 2009. Science base and tools for evaluating stream engineering, management, and restoration proposals. U.S. Dept. Commerce, NOAA Tech. Memo. NMFS-NWFSC.

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Stream restoration—what works and what doesn't work

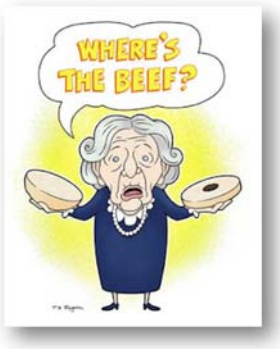
Bonus slides

Stream restoration and physical integrity

- Instream habitat often responds quickly to instream structures, channel reconstruction, etc.
- ☹ But this is usually measured at base flow.
- ☹ And some types of projects have poor records of physical habitat effects….(Miller and Kochel 2010, Mecklenberg and Fay 2011)
- Channel stability and sediment load are hard to measure.
- ☹ Some projects actually trigger erosion and contribute sediment (Buchanan et al. 2010)
- Effects of increased shade on water temperature are significant when treatment is applied over long reaches.

Where's the beef?

- Growing number of reports that restoring channel form (meandering planform, pool and riffle morphology, riparian vegetation) is not sufficient to restore ecological function.
- Similarly, claims of positive impacts on flood conveyance and downstream water quality appear untrue or unsubstantiated.
- In fact, some projects have demonstrably degraded environmental resources.
  - Disturbance due to earthmoving, clearing
  - Structural failure

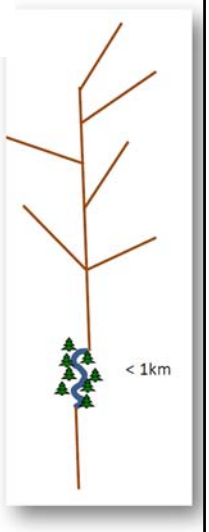


Ecological Applications, 21(6), 2011, pp. 1926–1931

River restoration: the fuzzy logic of repairing reaches to reverse catchment scale degradation

Emily S. Bernhardt[1,4] and Margaret A. Palmer[2,3]

"….there has been little empirical evaluation of whether restoration projects individually or cumulatively achieve the legally mandated goals ……..New efforts to evaluate ***river restoration projects that use channel reconfiguration*** *….are* ***finding little evidence for measurable ecological improvement****. While designed channels may have less-incised banks and greater sinuosity than the degraded streams they replace, these reach-scale* ***efforts do not appear to be effectively mitigating*** *the physical, hydrological, or chemical alterations that are responsible for the loss of sensitive taxa and the declines in water quality ……"*



Stream restoration and macroinvertebrates—German and NC studies

- Sunderman et al. (2011) German studies
  - 3/25 (.120) of the restored sites showed "good ecological quality" Diversity, dominance and evenness did not vary between control and restored reaches No relationship between restoration success and costs, length of restored section or elapsed time since restoration
  - Later work showed distance from sources of potential colonists to be critical
- Tullos et al. (2006 and 2008) NC studies
  - No difference in specialists between control and restored reaches
  - Taxa tolerant of disturbance were characteristic of restored reaches

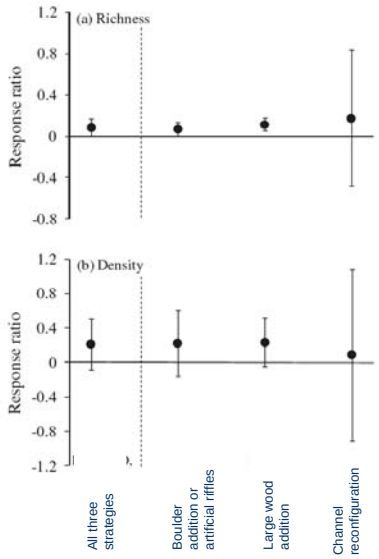
Results from Miller et al. (2010)

$$Response\ ratio = \ln\left(\frac{\overline{X}_E}{\overline{X}_C}\right)$$

Response ratio = ln (mean for restored site/mean for control)

Response ratio = 0.1 implies that ratio of means is 1.1

Response ratio = 0.2 implies that ratio of means is 1.2



Ignoring long term and large-scale processes

For example, working at the short-reach scale when channel incision via headcutting is occurring throughout the watershed.

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Long-term and large-scale processes

More examples…

- Bank stabilization in reach with unstable bed
- Reach scale habitat structures in urbanizing watershed with perturbed hydrology…or similar issues due to deforestation, agriculture, etc.
- Ignoring effects of upstream impoundment on bed sediments
- Floods and droughts (restoration delay)
- Climate change