Towards a basis for designing backwater restorations

F. Douglas Shields, Jr., Scott S. Knight
US Dept of Agriculture Agricultural Research Service
National Sedimentation Laboratory
John M. Stofleth
PWA, Ltd. Sacramento
The importance of off channel habitats (Junk et al. 1989)

- Flood pulse concept
- “Moving littoral”
- “Aquatic terrestrial transition zone
- Intermediate disturbance
The importance of off channel aquatic habitats

- Secondary channels
- Side channels
- Braids
- Anastomosed channels
- Sloughs
- Backwaters
- Floodplain lakes and borrow pits
- Inundated floodplain

Frequency and duration of main channel connection and current
Backwater areas tend to be negatively impacted by

- Flow regulation
- Flood control
- Levees
- Diversions
- Channel incision
- Nonpoint source pollution
- Cutoffs
- Channelization

Generally, the trend is toward an overall simplification of the river corridor and loss of off-channel habitats of all types.
Key problems associated with river restoration

- Setting restoration targets
- Measuring success
- Attack symptoms or underlying problems
- Restoring form or process
- Sustainability
All of these problems apply to backwater restoration

- Perhaps more difficult than “in channel” projects
- Should backwater/side channel features be included at all?
- Does the type of feature we envision “belong” in the historic/present/future landscape?
Setting goals for backwater management projects

Restoration = an attempt to return an ecosystem to its historic (pre-degradation) trajectory (SER 2002)
Setting goals for backwater management projects

- Habitat quantity
- Habitat requirements for selected species
- Emulation of physical conditions within a reference system
Emulation of reference physical conditions

- Sacramento River, California
- Kissimmee River, Florida
- Levee setbacks
- Dam reduced floods
- Levees prevent overbank flow
- Channelization, cut off meander bends
- Reopening of blocked meanders

Kondolf et al. 2006
Can this framework be applied to backwater restoration?

Ideally, backwater restoration projects should be evaluated at the river reach scale (say >100 W), but this is logistically difficult.
Natural trajectory of a single backwater

Trajectories for backwaters in perturbed systems are similar, but faster. Also, new backwaters are not continuously formed.

Restoration = an attempt to return an ecosystem to its historic (pre-degradation) trajectory (SER 2002)

As channel migration processes isolate old backwaters, they form new ones.

Hydrologic Variability

Unchanging water level or dry

Continuous variation in response to main channel and local inflows

Episodic variation in water levels and velocities

Additional sedimentation, channel migration

Sedimentation

Lateral Connectivity

low

high
Emulation of reference—hypothetical degraded backwater

Prior Condition—when backwater was first isolated from main channel

Selection of rehabilitation target governed by what is attainable and what is sustainable
## Setting goals for backwater management projects

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<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
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Real world example 1

- Severed meander bends, Tennessee-Tombigbee Waterway
- 39 cutoffs constructed 1976-1984
- System perturbed by navigation dams as well as cutoffs
- Cutoff bends provided valuable backwater habitats
- Total length > 130 km
- Area ~ 17 km²
- Sediment loaded (fully alluvial) system
Sport fish habitat value of cutoff bends

12 cutoff bends yielded 25 to 47 species each

Mean Percent of Catch by Weight

- Largemouth Bass: 15.5
- White Crappie: 14.4
- Bluegill: 3.7

Bendways
Navigation Channels

1985-86 USFWS All Gear Types All Seasons
How should cutoff bends be managed to maximize ecosystem services?

- Concerns expressed by plaintiffs in environmental litigation about water quality degradation in cutoff bends due to “stagnant” conditions
- Studies of cutoff bends on the Tombigbee and the adjacent Alabama River suggested that biological diversity was greater if some current was maintained within the cutoff bendway. Retention of point bar habitats
- Recreation access provided when bends were kept open to river
- Connectivity......
However, leaving bends open at both ends put them on a steep trajectory.

Deposition As Of 1987

Estimated $11 \times 10^6$ m$^3$ in 39 bends by 1987
Tennessee-Tombigbee Cutoff Bends—Restoration Tactics

- Limited dredging to remove deposited sediments
- Blockage embankments were constructed at the upstream end of 13 bendways to retard sediment transport from the main channel into the bend
Tenn-Tom bendways - outcome

- Connectivity sacrificed for sustainable habitat quantity
- Reduction in area of connected bendways
- Increase in area of disconnected bendways
- 44% decrease in connected bendway area

*(Spencer and Schramm 2007)*
Tenn-Tom bendways--outcome

Tennessee-Tombigbee Waterway Habitat Area Change 1985-2003

Main Channel
Primary Backwater
Secondary Backwater
Embayment
Connected Bendway
Disconnected Bendway
Tributary
Canal

Change in aquatic habitat, km²

(Spencer and Schramm 2007)
Tenn-Tom bendways-outcome

- Low Hydrologic Variability
- Low Lateral Connectivity

“Connected bendway”

- Blocked at upstream entrance
- Floodplain lake or wetland

- Dredging

Hydrologic Variability

Low          High
Example 2—Selected species

- Sunrise side channel, American River, Sacramento, CA
- Sediment starved, highly regulated system
- Minimize steelhead salmon redd stranding by deepening an existing side channel—*increasing quantity* of side channel habitat
- Allow channel to be inundated during lower flows, thus providing favorable conditions more frequently during spawning season
Example 2—American River side channel

- Formerly channel was inundated only when flows exceeded 110 m$^3$/s (4000 cfs).
- This level of flow is usually not sustained very long.
Example 2—American River side channel

- Maintain flowing water depth > 10 cm over redds in side channels when Q > 25 m³/s.
- Maintain steep side slopes on side channel to deter spawning on easily dewatered channel edges.
- Eliminate the need to import gravel.
- Spread excavated material on bar to fill stranding areas.
American River side channel--design components

- Qualitative assessment of the need for upstream grade control to prevent main channel avulsion through side channel
- Shields analysis for frequency of bar movement and redd scour
- Design life of 20 years estimated based on return frequency of sediment-transporting events
American River side channel—design components

Rule of thumb for maximum gravel size for redds: 10% of female fish length

$0.1 \times 640 \text{ mm} = 64 \text{ mm}$

*Kondolf and Wolman (1993)*
American River side channel--
design components

- UNET outputs for high flow boundary conditions
- HEC-RAS model for impacts on high flow stages
- MIKE 21C 2D for habitat assessment
- Model calibration using ADCP data
Habitat Improvement at 65 m$^3$/s
American River side channel--outcome

- Recent survey – 25 chinook redds
- Prolonged period of low flows.

Discharge, m3/s

American River at Fair Oaks, CA
American River side channel--outcome

- Bar system prior to dam closure
- Side channel immediately after restoration
- Side channel prior to restoration

Future vector?

Low Hydrologic Variability High

Low Lateral Connectivity High
Example 3—Cutoff bend, Coldwater River

The weir was located here to divert most agricultural runoff away from lake cell.
Example 3—cutoff bend

Coldwater River

In this case we quantify connectivity and variability.
Coordinates for Kondolf diagram

- Both quantities were defined for a given water year
- Connectivity
  - Total duration of connection for a given year
- Variability
  - Standard deviation of mean depth
    - Mean depth computed at each time step = water vol/surf area
    - Compute std dev of time series of mean depths
Coldwater cutoff—Current conditions

Typical Cross Section Showing Sediment Depth, CC2

Stage Duration Curve Affected by Incision and Sedimentation
Coldwater cutoff—current conditions

High flows attenuated by upstream reservoir. Rise and fall times are brief, leading to generally low variability.

Backwater stage in MSL

Jan

56
55
54
53

52

08/16/2005
Example 3—no information about prior condition
Reference site as a surrogate for pre-degradation condition
Coldwater cutoff—design for rehabilitation

- The weir is operated to simulate a very long natural “flood pulse”
Backwater simulation model

- Inputs include river hydrograph, precipitation, description of system geometry, control structures, hydraulic resistance
- Outputs include flows in/out of backwater (4 pathways), evaporation
- Timestep = $10^{-4}$ day.

Water surface elevation m MSL for “current condition”
Coldwater Cutoff

Low Lateral Connectivity

Current Condition

SD of mean depth = 0.12 m, total 51 days/yr

Reference Condition

SD of mean depth = 0.20 m, total 77 days/yr

Rehabilitated Condition

Low Hydrologic Variability High

???
**SD mean depth = 0.12 m**
Total duration of connection = 51 days

**SD mean depth = 0.20 m**
Total duration of connection = 77 days

**SD mean depth = 0.39 m**
Total duration of connection = 5.7 days
Coldwater cutoff—predicted outcome

Performance based on simulation of median year
Coldwater cutoff--outcome

- Based on simulation of median year, rehabilitation project was expected to result in higher levels of variability but lower lateral connectivity.
- The project was constructed in 2006
Coldwater cutoff--outcome

Backwater Stage, m NGVD

Total duration of connection = 19 days

Reference Site Stage

Total duration of connection = 75 days
Coldwater cutoff--outcome
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<th>Example</th>
<th>Years</th>
<th>Outcome</th>
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<td>Coldwater River backwater</td>
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Towards better backwater rehab—conclusions

- Kondolf diagram a useful construct for assessing status and setting goals.
- Application of Kondolf diagram should consider sustainability—trajectory velocity of system.
- Deeper understanding of backwater processes and functions is needed to support design and management.