Meander Bends, Landscape Preferences, and River Restoration

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Lack of post-project appraisal holds us back

Each project an experiment from which we can learn

Evidence for cultural preference for channels to be:
stable, single-thread, meandering

Popularity of form-based (cookbook) approach to restoration

The NRRSS Project – comprehensive review of river restoration in US

Post-Project Appraisal

Acknowledge limitations in our predictive capability (humility)

Treat restoration projects as experiments (adaptive management)

My view (for what it’s worth):
If you don’t have funds for monitoring and evaluation, you don’t have enough money for an intervention

Situation improving in some places (eg CALFED), but still a long way to go overall
Elements in Post-Project Appraisal

Clear objectives
- based on sound geomorphic-ecological study, ie “know your patient”

Good baseline data
- Extend record to past through historical analysis

Adequate length of monitoring
- A decade is good rule of thumb, catch Q5-10

Willingness to acknowledge “failures”
- Define learning success, not just meeting objectives
- Requires a change in attitudes (e.g., Cherry)

The quest for the stable channel

- Landowners resist bank channel change,
- We all know Bank erosion is bad!

- Yet bank erosion and bar deposition create and sustain riparian and aquatic habitat
- More sophisticated approach is to understand dynamic river processes, avoid bank stabilization
Channel Migration and Riparian/Aquatic Habitat

Source: McBain and Trush
Rush Ck incised 1 m, former wet meadows now xeric. Channel migrates, erodes xeric upland, builds point bar with high water table, willows colonize Rush Ck “restores” itself.
Rush Ck: first ‘restoration’ project in the Mono Basin “severely eroding banks” treated with “soft armoring”

“Stability” is often seen as a goal – appropriate?

Channel Reconstruction Projects

*The current paradigm:* Stable channel design based on bankfull Q, Rosgen classification scheme

*Endorsed by the NRC 1992!*
TABLE 5.8 Decision Steps for In-Stream Habitat Structures

1. Inventory streams.
2. Classify stream types.
3. Identify limiting factors.
4. Select candidate structures to correct limitations.
5. Make final selection based on suitability for stream type.
6. Utilize engineering criteria.
7. Determine cost-benefit ratios to make final selection.
8. Implement final design.


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TABLE 5.9 Limitations and Discussions of Various Fish Habitat Improvement Structures by Stream Types (stream types refer to Rosgen and Fittante, 1986, Tables 1 and 2)\(^1\)

**REARING HABITAT ENHANCEMENT**

**Low-Stage Check Dam**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Channel Types</th>
<th>Limitations/Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good</td>
<td>C1</td>
<td>Bank erosion due to lateral migration will occur unless bank stabilization is utilized.</td>
</tr>
<tr>
<td>Fair</td>
<td>B3, B4, B5, C3, C4, C5, D1, D2</td>
<td>Low dams must be constructed in conjunction with bank stabilization in these channel types. Use in conjunction with confinement measures and bank stabilization to reduce lateral migration.</td>
</tr>
<tr>
<td>Poor</td>
<td>B1-1, C1-1</td>
<td>Bedrock streambed limits the development of pools.</td>
</tr>
<tr>
<td>N/A</td>
<td>A1, A2, C6</td>
<td>Pools not limiting in these stream types.</td>
</tr>
</tbody>
</table>

**Medium-Stage Check Dams**

<table>
<thead>
<tr>
<th>Rating</th>
<th>Channel Types</th>
<th>Limitations/Discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exc.</td>
<td>B1</td>
<td>No limitations.</td>
</tr>
</tbody>
</table>
But how to apply to the Carmel River in 1983?
Braided, unstable channel due to bank devegetation and instability

Approaching River Restoration
Sound historical-geomorphological analysis of underlying cause of problem – and nature of river behavior to evaluate if there IS a ‘problem’

See the ‘problem’ on larger spatial and temporal scales:
- Catchment instead of reach scale
- Decadal instead of months-years

Understanding of regional differences in climate, geologic influences, etc

A process approach preferable to form-based approach
When possible, buy land and let the river design itself. (Exceptions being low-energy systems)
**Uvas Creek, California Coast Ranges**
A case study of channel reconstruction post Gravel mining

- 1-km reach adjacent to urbanizing Gilroy
- channel form disturbed by historical gravel mining
- objectives: city park, fish habitat (passage)
- City of Gilroy told that permits would flow freely if a Rosgen-type project was built
- Project designed based on Rosgen classification system (by local consultant and Rosgen)
- Construction completed Nov 1995
View downstream from Santa Teresa bridge Jan 1996.  
(Are we in Denmark?) 
Note: symmetrical meander bends, rock weirs and bank 
protection on outside meander bends

View downstream from Santa Teresa bridge, July 1997 
(after washout in Feb 1996)
Structures to protect meander bends were not eroded or outflanked. Uvas Creek cut across artificial meander bends and/or buried structures.

Basis of channel design: excerpts from plan

The channel was once a stable C4 channel (Rosgen, 1985, 1993). C4 channels have well defined point bars and floodplains, which are used as energy dissipating features during high stage, high energy events. Energy is also dissipated by the sinuous meander pattern (Leopold, Wolman, Miller, 1964).

Levee construction, gravel extraction, and ill-fated flood control efforts resulted in a deepening and straightening of the channel. The effects of these activities on channel stability and behavior are to convert the stable channel to F4 and G4c channels. This conversion results in:

- an increase in mean velocity,
- a higher entrenchment ratio (bankfull width to width at 2x bankfull depth),
- an increase in sediment contribution from banks (manifested by bank collapse, lateral channel migration),
- a decrease in fish and wildlife habitat habitat,
Project Plan was 18 pages long, of which 12 were tables, identical except for one column.

Stream Classification Summary

<table>
<thead>
<tr>
<th>Location:</th>
<th>Idealized Cross-section (Post-restoration)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bankfull Discharge (125 year event):</td>
<td>448 cfs</td>
</tr>
<tr>
<td>Bankfull Width:</td>
<td>55 feet</td>
</tr>
<tr>
<td>Maximum Bankfull Depth:</td>
<td>3 feet</td>
</tr>
<tr>
<td>Mean Bankfull Depth:</td>
<td>2.2 feet</td>
</tr>
<tr>
<td>Area</td>
<td>120 sq ft</td>
</tr>
<tr>
<td>Mean Velocity @ Bankfull</td>
<td>3.73 fps</td>
</tr>
<tr>
<td>Floodprone Width (Width @ 2x Max BF Depth):</td>
<td>Minimum of 275 feet</td>
</tr>
<tr>
<td>Entrenchment Ratio (Width, fs/Width, bf):</td>
<td>5+</td>
</tr>
<tr>
<td>Simuosity (Water Slope/Valley Slope):</td>
<td>1.5</td>
</tr>
<tr>
<td>Width-to-Depth Ratio (Wfd/Dbf, Average):</td>
<td>25</td>
</tr>
<tr>
<td>Water Surface Slope:</td>
<td>0.00237</td>
</tr>
<tr>
<td>Stream Type (Rosgen Method):</td>
<td>04-</td>
</tr>
<tr>
<td>Material Size (D50):</td>
<td>26 mm</td>
</tr>
<tr>
<td>Riffle/Pool Ratio:</td>
<td></td>
</tr>
<tr>
<td>Meander Length:</td>
<td>770 feet</td>
</tr>
<tr>
<td>Radius of Curvature:</td>
<td>140-150</td>
</tr>
<tr>
<td>Belt Width (outside to outside):</td>
<td>275 feet</td>
</tr>
<tr>
<td>Meander Length Ratio (NL/Wbf):</td>
<td>14</td>
</tr>
<tr>
<td>Radius of Curvature/Width @ BF:</td>
<td>2.5-2.7</td>
</tr>
<tr>
<td>Meander Width Ratio (Belt Width/Width BF):</td>
<td>5</td>
</tr>
<tr>
<td>Meander Ratio (Belt Width/Meander Length):</td>
<td>0.56</td>
</tr>
<tr>
<td>Bank Erosion Potential:</td>
<td>very high</td>
</tr>
<tr>
<td>R/D8+ (Relative Roughness):</td>
<td></td>
</tr>
<tr>
<td>Roughness Coefficient (Manning's 'n')</td>
<td>0.32</td>
</tr>
</tbody>
</table>
Channel design based on
- Classification as C4 type channel
- Meander geometry relations (e.g., wavelength and amplitude scaled to bankfull channel width)

Historical evidence: channel was not formerly a meandering channel, but braided. 1879 map:
The channel was wide, unvegetated, braided.
1894 photo from Twin Bridges (1 km upstream project)

The project reach was braided in 1939: reflects climate (Mediterranean) and lithology (Franciscan Formation)
C4/C3 Meandering Channels in California
(Some dates below appx, being checked in NRRSS)

<table>
<thead>
<tr>
<th>Year</th>
<th>Location</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>Wolf Ck, Sierra Nevada</td>
<td>Washed out, buried</td>
</tr>
<tr>
<td>1990</td>
<td>Cuneo Ck, Coast Ranges</td>
<td>Washed out</td>
</tr>
<tr>
<td>1993</td>
<td>Mattole Cyn Ck, Coast Ranges</td>
<td>Washed out</td>
</tr>
<tr>
<td>1994</td>
<td>Greenhorn Ck, Sierra Nevada</td>
<td>Washed out</td>
</tr>
<tr>
<td>1995</td>
<td>Jamison Ck, Sierra Nevada</td>
<td>Washed out</td>
</tr>
<tr>
<td>1995</td>
<td>Uvas Ck, Coast Ranges</td>
<td>Washed out</td>
</tr>
<tr>
<td>1996</td>
<td>Cold Ck, Lake Tahoe</td>
<td>Filled then scoured</td>
</tr>
<tr>
<td>1997</td>
<td>West Walker R, Sierra</td>
<td>Rocked meanders</td>
</tr>
<tr>
<td>1999</td>
<td>Bear Ck, Cascades</td>
<td>Channel moved to meadow (success), Many constructed riffles (undulating bed cut into clay) washed out</td>
</tr>
<tr>
<td>2001</td>
<td>Ackerman Ck, Coast Ranges</td>
<td>Washed out</td>
</tr>
</tbody>
</table>
Jamison Ck: State park, goal: improve trout habitat.

Designed C-4 channel drawn over air photo base. Design channel narrower, symmetrical meanders.
Existing channel filled, new channel narrower.
Pool eliminated because it "doesn't belong in a B-type stream"
Cuneo Creek, Tributary to Bull Ck
Humboldt Redwoods State Park

Basin logged in 1950s-60s, high sediment yields.

Aggradation, braided channel
Since 1953, over 7 m aggradation at confluence Cuneo and Bull Creeks, under Cuneo Ck bridge
DOT filled wetlands, needed ‘mitigation’.  
*Money looking for a project!*  
Deep Run channel assumed to be eroding,  
sediment filling in wetland downstream.  
With ‘proper’ geometry, no more erosion!
Narrower, symmetrical C4 channel predicted to be stable.

Existing riparian vegetation removed

Smith (1997) found overbank velocities higher post-project (reduced roughness)
Looking upstream at erosion from overbank flow. No rip veg, low roughness, high overbank velocities

Channel shifted away from protected banks
1908: Flood of record - 49,000 cfs. Overtopped dam, Threatened powerhouse, dam blown up to save powerhouse
Concern now over possible consequences that another large flood could destroy dam, releasing contaminants downstream. Damage to dam in 1986 and 1996 floods.
Overlay of historical channels of Clark Fork
Upstream of Milltown Dam
Why stable, symmetrical meandering channels so popular for design?

Easy to design by cookbook:
standard elements, e.g., such as rootwads, rock weirs.

Classification system predicts they are stable.

Cultural preference for stable, narrow, single-thread channels. (trout streams!)

Cultural Preference for Meanders
Appleton (1975): “deflected vistas” such as paths, rivers, valleys, as line of sight deflected, curved (Ullrich 1983)

Cullen (1961): “anticipation” in analysis of curving city streets, arouse curiosity about what will be at end of street.


18th-19th Century English landscape ideas: The beautiful, picturesque, sublime
A Brownian landscape (above) and the same landscape (below) made picturesque, from Richard Payne Knight, *The Landscape: a didactic poem* (1794)
IN AMERICA

a novel by

RICHARD BRAUTIGAN

Four Seasons Foundation : San Francisco : 1967
There was also a big sign that said:

**USED TROUT STREAM FOR SALE.
MUST BE SEEN TO BE APPRECIATED.**

I went inside and looked at some ship's lanterns that were for sale next to the door. Then a salesman came up to me and said in a pleasant voice, "Can I help you?"

"Yes," I said. "I'm curious about the trout stream you have for sale. Can you tell me something about it? How are you selling it?"

"We're selling it by the foot length. You can buy as little as you want or you can buy all we've got left. A man came in here this morning and bought 563 feet. He's going to give it to his niece for a birthday present," the salesman said.

"We're selling the waterfalls separately of course, and the trees and birds, flowers, grass and ferns we're also selling extra. The insects we're giving away free with a minimum purchase of ten feet of stream."

"How much are you selling the stream for?" I asked.

"Six dollars and fifty-cents a foot," he said. "That's for the first hundred feet. After that it's five dollars a foot."

"How much are the birds?" I asked.

"Thirty-five cents a piece," he said. "But of course they're used. We can't guarantee anything."

"How wide is the stream?" I asked. "You said you were selling it by the length, didn't you?"

"Yes," he said. "We're selling it by the length. Its width runs between five and eleven feet. You don't have to pay anything extra for width. It's not a big stream, but it's very pleasant."

"What kind of animals do you have?" I asked.

"We only have three deer left," he said.

"Oh... What about flowers?"

"By the dozen," he said.

"Is the stream clear?" I asked.

"Sir," the salesman said. "I wouldn't want you to think that we would ever sell a murky trout stream here. We always make sure they're running crystal clear before we even think about moving them."

"Where did the stream come from?" I asked.

"Colorado," he said. "We moved it with loving care. We've never damaged a trout stream yet. We treat them all as if they were china."

"You're probably asked this all the time, but how's fishing in the stream?" I asked.

"Very good," he said. "Mostly German browns, but there are a few rainbows."

"What do the trout cost?" I asked.
and already beginning to gather dust.

I had seen all I wanted of the waterfalls, and now I was very curious about the trout stream, so I followed the sales-
man's directions and ended up outside the building.

O I had never in my life seen anything like that trout stream. It was stacked in piles of various lengths: ten, fif-
ten, twenty feet, etc. There was one pile of hundred-foot

lengths. There was also a box of scraps. The scraps were in odd sizes ranging from six inches to a couple of feet.

There was a loudspeaker on the side of the building and soft music was coming out. It was a cloudy day and seagulls were circling high overhead.

Behind the stream were big bundles of trees and bushes. They were covered with sheets of patched canvas. You could see the tops and roots sticking out the ends of the bundles.

I went up close and looked at the lengths of stream. I could see some trout in them. I saw one good fish. I saw some crawdads crawling around the rocks at the bottom.

It looked like a fine stream. I put my hand in the water. It was cold and felt good.

I decided to go around to the side and look at the animals. I saw where the trucks were parked beside the railroad
**Importance of seeing the river as it really is** –

Not necessarily anything wrong with rivers that don’t meander and are unstable. Avoid imposing cultural ideals on rivers.

Take a larger temporal and spatial scale. Problems usually defined at site scale over short (engineering) scale.

But underlying processes, and thus solutions, are often at catchment and decadal scales.

Emphasize process over form. Distinguish what river can restore from what we must do. (e.g. incised channel ‘feedback’)
An example of a successful project designed with altered process in mind: Schulte Rd project, Carmel River

Water table lowered by well pumping, Die-off of bank stabilizing vegetation, Channel instability in affected reaches.

Restoration project built before water table issue resolved – floodplain and pilot channel built, planted with willow, and irrigated!
**Proposed prioritization:**

Preserve intact processes and forms, let river recreate its own channel. (Passive restoration)

Where processes intact, can restore form (carbon copy)

Restore processes where possible

With irrevocable change in process, design form but account for changed conditions, and approach restoration as experiment

In low-energy, low-sediment systems (e.g., England), where channel “stuck” (eg incised), restore form. Elsewhere, try to leave alone or restore process.

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**Attitudes towards river restoration:**

Heavily colored by cultural preferences, often lack of looking at big picture of basin-scale and long time scales

We need ‘real geomorphology’ and To acknowledge our cultural influences

Join the SOBC League!
No prejudice against braided channels!
eg, affirmative action for BCs in France, example from the Drome River
Watershed change and resulting channel change in two contrasting catchments:

- Pine Ck, Idaho
- Drome R, SE France

Both underwent large changes in bedload sediment yield since 19th century, but in opposite directions.

In both cases, managers seek to “restore” to prior conditions.

Drome River basin drains preAlps, K marl, limestone. Since 19th C, reduced land use pressure, resulting in reduced bedload supply.
Profound landscape change since 19th century: Reduced population density and land use in mountains

Drome River nr Saillans, 1900
Badlands in marl outcrops

Drome River nr Saillans, 1996
(same view as previous slide)
The Drome River:
Reduced bedload yield from catchment + instream gravel mining led to incision, channel narrowing, reduced braiding

Fig. 8. Change in active channel width (m x 10^2), braided index (channel length/valley length), and number of woody islands (per 500 m of channel length) along the Drôme River, as measured from
**Restoration Actions: Drome River**
- Gravel mining outlawed in 1980s
- Sediment no longer removed for routine maintenance, even landslide sources
- Proposals to *increase* bedload by re-activating landslides, removing check dams

Objective: increase bedload supply to recover incised bed

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**Fig. 14.** Diagram illustrating contrasting directions of channel change due to catchment change, and contrasting directions of intended restoration, in Pine Creek and the Drôme River.
Conclusions:

To progress, learn from our experiments (and our projects are experiments!)
Situation improving, but long way to go.

We need real science as a basis for design.

Often the best project is to let the river fix itself.

*Take a braided channel to lunch today!*