The Importance of Boundary Conditions in Channel Stability and Ecology (why vegetation matters)

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Trees have been around for about 350 million years during which time they have had a significant impact on landscape evolution and sedimentary geology.
Historic changes have occurred in forest distribution but in the characteristics of individual trees.

Humans have reduced forest cover from about 35% to about 12%. Similar to the exploitation of other biologic resources (e.g., fisheries), many forests are characterized by younger, smaller trees.
Most Current riparian forests bear little if any resemblance to their historic conditions:

Can you identify the trees below and where they were found?

Washington

Indiana
Riviere des Moustiques Mapou Tree, Haiti
States of Local Streams
Root cohesion and roughness in Manoa Stream

Manoa Stream, O'ahu 5-19-08
Loss of vegetation and sediment input, right bank of Manoa Stream

Manoa Stream, O’ahu 5-19-08
Waimalu Stream, O‘ahu 5-19-08
Waimalu Stream, O'ahu 5-19-08
Some basic fluid mechanics
Velocity and Roughness

\[ \tau_b = ku^2 \quad \text{Chezy (1769) assumption - bed shear stress proportional to the square of velocity (k is a proportionality constant)} \]

\[ u^2 = \rho g/k \ (RS) \quad \text{substitute for } \tau_b \text{ and } R \]

\[ C = (\rho g/k)^{0.5} \quad \text{Chezy Friction Coefficient} \]

\[ u = C(RS)^{0.5} \quad \text{Chezy Equation} \]

\[ C = R^{1/6}/n \quad \text{empirical relation (Manning 1889)} \]

\[ u = k_1R^{2/3} \ S^{1/2}/n \quad \text{Manning’s Equation} \]

Manning’s \( n \) reflects the net effects of all variables contributing to flow resistance.
Shear Stress Partitioning

The force available to transport sediment is that component not dissipated by roughness.

\[ \tau' = \tau_b - (\tau_g + \tau_f + \tau_{s(1)} + \tau_{s(2)} + \ldots) \]

where \( \tau' \) is the force available to do work (sediment transport, bank erosion, etc.). Losses can be up to 90\% in rough channels.
LWD covering less than 2% of the streambed can provide 50% of the total roughness or flow resistance. This results in a finer streambed substrate.

Buffington and Montgomery 1999, WRR 36, 3507-3521
Manga and Kirchner, 2000, WRR 36, 2373-2379.
Rough shoreline:

High velocity flowline is offset by boundary roughness provided by woody vegetation, reducing shear stress along the channel shoreline.
Natural Bank Roughening

Chilkat River, Klukwan, Alaska
Root Cohesion
Trees:
- add cohesion to bank materials
- lower pore pressures by ET
- increase roughness
- add surcharge
- armor unconsolidated banks

Coal Creek, WA 08-02
Influence of roughness on river stage

Brummer, Abbe and others 2006
Hypothesis for collapse of beach spawning habitat

Wood

Boundary conditions of river draining lake

In-stream flows and river stage

Water elevation (stage) in Lake Ozette

Nearshore wave energy along lake

Beach substrate grain-size and vegetation encroachment
Increasing channel & bank roughness reduces flood wave celerity & increases diffusion. Reduced conveyance thereby increasing water elevations, but in downstream reaches this is moderated by reduced discharges.
Head differential due to wood accumulation in Deschutes River, WA
\[ \Delta H = f(Q) \]
Model Results

**Pre-clearing conditions**

**Post-clearing**

![Graph showing model results with pre-clearing and post-clearing conditions.](image)
Influence of vegetation on bank erosion
Map illustrating stability of Wooded Banks upon the Mississippi River 1870-1879

"View on the Missouri, Alluvial Banks Falling in, 600 Miles above St. Louis" George Catlin, 1832. National Museum of American Art, Smithsonian Institution.
Central Sacramento River channel migration rates

(Agricultural erosion rates) = 2 * (Forest erosion rates)

Normalized Eroded Areas by Riparian Vegetation Type

Vegetation influences fluvial ecosystems across multiple scales.

- cm: substrate & cover
- km: planform & floodplain

Base flows  
Moderate flows  
Flood flows

Q vs. t graphs illustrate the changes in flow dynamics under different conditions.
Patterns of wood accumulation throughout a basin
Bar Apex Jam, Allyn River, New South Wales, Australia
An anabranching channel system loaded with wood

Taiya River, Alaska
Removing wood reverses the morphologic complexity created by wood and simplifies rivers.
Human development has dramatically reduced the size and quantity of wood debris. The result is a significant change in channel geomorphology.
Sediment discharge resulting from channel clearing

Consequences of removing wood debris from Colorado River of Texas

Sediment deposited in Matagorda Bay between 1909 and 1941 = 42,809,700 m³
An average sediment discharge of 1,297,264 m³ yr⁻¹
Illustration of the importance of channel roughness versus discharge in creating habitat within a channel reach downstream of a major flow diversion
Flow Regulation in Bypass Reach

[Graph showing discharge in cfs from Jan-92 to Dec-92, with lines representing Combined, Diversion Canal, and Bypass Reach.
River confinement due to levees or incision disconnects floodplain and side channels from main channel.

Unconfined river reach with floodplain & side channel connectivity
Levee constrained or incised river

Unconstrained river

Q1 < Q2 < Q3 < Q4
Simulated flow inundation areas Lower Reach, RM 7 to RM 10.
Simulated flow inundation areas in Middle Reach, RM 10 to RM 13.

Intact unconfined reach
Model results showing relations between bank length and discharge in the three subreaches.
Model Results (field calibrated)

Middle Subreach 2005 Model
Focused Study Reach 2007 Model
Change in habitat quantity per 100 cfs of diverted water for low-flow conditions in the bypass reach

<table>
<thead>
<tr>
<th>Subreach</th>
<th>Change in channel length/100 cfs</th>
<th>Flow range (cfs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper &amp; Middle (uncalibrated)</td>
<td>1 mile (6%)</td>
<td>600 - 3,100</td>
</tr>
<tr>
<td>Middle (field calibrated)*</td>
<td>6 miles (38%)</td>
<td>200 - 600</td>
</tr>
</tbody>
</table>

*Even more side channels observed in field than predicted by model.
What about downstream discharge and stage?

a) Relief
b) Vegetation
c) Type of input hydrograph
d) Channel form
e) Channel slope

Recent work by Gordon B. Anderson provides new perspective on the influence of vegetation on flood routing.

(Anderson, G.B. 2006. Quantifying the interaction between riparian vegetation and flooding from cross-section to catchment scale. University of Melbourne, Australia)
Flood wave celerity

\[ c = \frac{dQ}{dA} = \frac{1}{B} \frac{dQ}{dy} \]

Hydraulic diffusion

\[ D = \frac{Q}{2BS_o} \]

Applying Manning Equation to link discharge to stage:

\[ c_A = \frac{5}{3} \frac{R^{2/3}S_o^{1/2}}{n} \]

\[ D_A = \frac{1}{2} \frac{R^{5/3}}{nS_o^{1/2}} \]
Varying channel geometry (Anderson, BG. 2006 Figure 6.13)
Anderson, BG. 2006.
Anderson (2006, p.417) concludes:

This research shows that the impact of riparian vegetation on flooding has been overstated in the past as the impact of catchment-scale flood wave attenuation was not considered. Therefore, the argument for blocking riparian rehabilitation for fear of exacerbating flooding is flawed."
Flooding in Manoa Stream
O‘ahu, HI
Tree removal off right bank of Manoa Creek after Halloween Flood of 2004
Putting roughness back
July 2003
January 2004
Upstream grade control site
July 2003
August 2003
November 2003
Looking upstream at downstream end of project reach

Before

After
Mahalo