Physical-Biological Feedbacks and Limits of Predictability for Managing Rivers and Wetlands

Jud Harvey
and
Laurel Larsen
U.S. Geological Survey
Reston, Virginia
“The Natural Flow Regime”

Poff et al., Bioscience, 1997
Four Reasons a Natural Flow Regime Matters

- creates a complex assemblage of aquatic and riparian habitats
Flood Pulse Facilitates Fish Spawning, Plant Germination, and Nutrient Exchange

Junk et al., 1989
Four Reasons a Natural Flow Regime Matters

- creates a complex assemblage of aquatic and riparian habitats

- supports diverse habitat requirements for aquatic and riparian plants, macro invertebrates, amphibians, and fish while maintaining pathways of animal migration and gene flow
Flood Pulse Facilitates Fish Spawning, Plant Germination, and Nutrient Exchange  Junk et al., 1989
Four Reasons a Natural Flow Regime Matters

- creates a complex assemblage of aquatic and riparian habitats

- supports diverse habitat requirements for macro invertebrates, amphibians, and fish, including nursery areas, and maintains pathways of animal migration, gene flow, and biodiversity

- maintains hydrologic connectivity through the main-channel and between the main channel and off-channel environments.
Retention/Transformation Facilitated by Hydraulic Exchange with Off-Channel Areas

Nutrient Spiraling Concept - Newbold et al., 1982, Stream Solute Workshop, 1990
Four Reasons a Natural Flow Regime Matters

- creates a complex assemblage of aquatic habitats

- supports diverse habitat requirements for macro invertebrates, amphibians, and fish, including nursery areas, and maintains pathways of animal migration, gene flow, and biodiversity

- maintains hydrologic connectivity through the main-channel and between the main channel and off-channel environments

- resupplies storage areas with labile carbon and oxygen at levels supporting decomposition, nutrient mineralization, food webs
Aquatic Food Webs Depend on Groundwater-surface Water Interactions
Statistical Approach to Define Ecological Limits of Hydrologic Alteration - E.L.O.H.A.

Arthington et al., Freshwater Biology, 2007
also see Poff et al., Freshwater Biology, 2008
Physical and Biological Process Feedbacks Not Considered in ELOHA

Flow-related stress (e.g., decreased flood frequency)

Ecological health indicator (e.g., wetland vegetation abundance)
“The Natural Flow Regime - Updated”

by incorporating feedback interactions between fluvial, biological, and geomorphic processes
The Everglades – A Self-Organized Ridge and Slough Floodplain Ecosystem

Flow Redistributes Particulate Organic Matter

Can Degradation Be Reversed by Restoring Flow?

Differential Rates of Peat Accretion

Models by Larsen et al., 2007
Larsen and Harvey, 2010, 2011; Cohen et al., 2011; Cheng et al., 2012; Heffernan et al., in prep
Stepwise Increase in Velocities o Historic Pre-drainage Levels in Experimental Flume
Harvey et al., Geomorphology, 2011

<table>
<thead>
<tr>
<th>Flow velocities (cm/s)</th>
<th>0.3</th>
<th>1.7</th>
<th>3.2</th>
<th>5.3</th>
<th>5.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stem Reynolds numbers</td>
<td>3</td>
<td>19</td>
<td>36</td>
<td>58</td>
<td>63</td>
</tr>
</tbody>
</table>
Semi-arid Headwater Stream

Everglades, Fl

Pinal Creek, AZ
Removal of Metals in Hyporheic Zone of Pinal Creek, AZ
Enhanced Metal Uptake in Hyporheic Zone

Fuller and Harvey, ES&T, 2000

MANGANESE, MILLIMOLAR

COBALT, MICROMOLAR

NICKEL, MICROMOLAR

ZINC, MICROMOLAR

MEASURED METAL CONCENTRATION

CALCULATED NON-REACTIVE METAL CONC

Br TRACER CONCENTRATION

Fuller and Harvey, ES&T, 2000
Removal of Metals Increased Over Five-Year Period

Dissolved Manganese (Mg/L)

Downstream Distance (km)

June 1995

Mixing only
With reactions
Biophysical Feedbacks Created an Alternative Stable Stream Type

Flow-related stress (decreased flood frequency)

1995 1999
Removal of Metals Increased Over Five-Year Period

Dissolved Manganese (Mg/L)

Downstream Distance (km)

June 1995

Mixing only
With reactions

USGS
science for a changing world
Climate-driven Decrease in Summer Monsoon Floods

Harvey, Conklin, and Koelsch, AWR, 2003
Sustainable Management of Water Resources

Human influences. Dramatic changes in runoff volume from ice-free land are projected in many parts of the world by the middle of the 21st century (relative to historical conditions from the 1900 to 1970 period). Color denotes percentage change (median value)

Milly et al., “Stationarity is dead: Whither water management?” Science, 2008
Multiple Scales

- Regional-National Modeling
- Watershed Monitoring and Modeling
- River Reach Monitoring and Modeling
- Stream Tracer Experiments
- Fine-scale Field Measurements
- Computational Modeling
- Laboratory Flumes

Cumulative Effects

Hydroecological Perspective

Controlling Processes