An Introduction to Environmental Flows

- The natural flow regime
- Flow alteration
- Environmental flows defined
- Scaling up

Eloise Kendy, Ph.D.
IUCN workshop
Kathmandu, Nepal
5 August 2011
The most threatened species are all in freshwater.
Key Factors Affecting Aquatic Ecosystems

Hydrologic Regime
(surface flow, groundwater, surface inundation, and soil moisture regimes)

Physical Habitat Conditions
(woody debris, riparian canopy, geomorphology, sediment/soil regime)

Biological Composition & Interactions
(energy regime, feeding, 1st & 2nd production, target structure & composition, competition & predation, reproduction, disease & parasitism, mutualism)

Connectivity
(up-down gradient continuity, water-wetland-land connectivity)

Water Chemistry Regime
(salinity, alkalinity, hardness, temperature, dissolved minerals, dissolved gases, turbidity, pH, ORP, radioactivity, organic compounds)
Flow is the Master Variable

Flow Regime
(low flows, high pulses, floods)

- Physical Habitat
- Water Quality
- Connectivity
- Energy Supply
- Species Interactions

Ecological Integrity
Ecosystem Services
Flow is the master variable.
The Natural Flow Paradigm

“The full range of natural intra- and inter-annual variation in hydrologic regimes, and associated characteristics of timing, duration, frequency, and rate of change, are critical in sustaining the full native biodiversity and integrity of aquatic ecosystems.” (Poff et al. 1997)
Hydrological Alteration:

Any anthropogenic disruption to the magnitude or timing of natural river flows

(Rosenberg et al. 2000)
What alters hydrology?

- Dams
- Withdrawals
- Land-Use Change
- Climate Change
The History of Global Dam Development

before 1750

Map shows 23,427 large dams worldwide. Dam data are from Greifswald University, the ICOLD World Register of Dams, the FAO African Dams Database, the U.S. National Inventory of Dams, and The Nature Conservancy.
Map 7.6  World potential and current hydropower production, 2004

- OECD North America
- Brazil
- Other Latin America
- OECD Europe
- Transition economies
- Russia
- Africa
- Middle East
- India
- China
- Rest of developing Asia
- OECD Pacific

= 500 terawatt hours
Economic potential (terawatt hours a year)
Hydropower production in 2004 (terawatt hours)

Source: IEA 2006.
Percentage of economically feasible hydropower potential that has been developed (International Hydropower Association)
Dams

- Disconnect river reaches, preventing migration
- Pond water in reservoirs upstream
- Alter flow patterns downstream for:
  - Water supply
  - Hydropower production
  - Recreation
  - Flood control
- Downstream impacts:
  - Sediment
  - Water quality
  - Temperature
  - Flow
Impacts of reservoir operation for flood control, Yangtze River

Too cold and too early for fish spawning

Natural Daily Inflow
Outflow

Summer Target 6000 m³/s
Withdrawals
Global Water Consumption
Global Water Stress

Stressed out: This map shows stress on the world’s major river basins, comparing the amount of water available to the amount of water humans use.

Source: World Commission on Water in the 21st Century
Ground-water discharge creates wetlands and contributes to surface flows.
Effects of ground-water pumping

Pre-pumping

Well 1

Well 2

Alley et al, 1999, USGS Circular 1186, fig. 13
Streamflow depletion: The inevitable consequence of ground-water withdrawal.

Fuyang Basin, North China Plain
(Kendy, 2002)

See also: WATER FOLLIES by R. Glennon
Land-Use Change

Ground-water flow paths

Winter et al, USGS Circular 1139, fig. 3
Climate Change

MORE FREQUENT DROUGHTS
MORE FREQUENT FLOODS
HIGHER TEMPERATURES
EARLIER SNOWMELT

Eloise Kendy, photos
What are “environmental” flows?

.....vs. “minimum” flows?

.....vs. “instream” flows?

The Brisbane Declaration
Environmental Flow:

Pattern of water flows through a natural river or lake that sustains healthy ecosystems and the goods and services that humans derive from them.
Not just “minimum” flows.

Flow requirements for endangered arctic grayling
Big Hole River at Wisdom, Montana (USA)

Source: Mike Roberts, Montana DNRC
Not just fish.

Ecological Model of the Savannah River

- Prothonotary warbler in Central and South America wintering grounds
  - return migration
  - breeding/nesting
  - fall migration

- Bald cypress peak seed fall
  - seed dispersal
  - germination and growing season
  - seed fall

- River Flow (cfs)
  - American shad adults emigrate
  - egg, larval and juvenile development
  - adults emigrate

- 1944 (pre-dam typical year)
- 1974 (post-dam typical year)

October, November, December, January, February, March, April, May, June, July, August, September
Not just “instream” flows.
Out-of-stream environmental flows in Australia

Murray-Darling, Australia: diversions from instream flows to floodplain to restore flood-dependent gum tree forests

Progressive deterioration of a red gum tree, Murray River, Australia
What are some ecological functions?

For each:

Large flood

Small flood

Extreme low flow

High flow pulse

Low flow

Streamflow (cfs)

Day of Year

Output from TNC’s IHA software
Environmental flow prescription

1. Retain flood magnitude, to scour channel and vegetation, recharge river banks and floodplains
2. Maintain baseflow and thus aquatic habitat in dry season
3. Retain spring flushing flow as cue to life cycles
4. Vary baseflow in wet season, but with removal of some floods

River Flow

Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec

Natural
For ecological maintenance

Postel and Richter, 2003
Low Flow Criteria: 
\[-20\% < Q < +20\%\]

Flood Flow Criteria: 
\[-40\% < Q < +10\%\]

High Flow Criteria: 
\[-30\% < Q < +10\%\]

Richter, 2010
Implementing Environmental Flow Recommendations

(Discussion)

- Dams
- Withdrawals
- Land Use
- Climate Change
Scaling up: from dams to basins
Mitigation at scale of a dam

Can potentially address:

- Seasonal patterns of flow and flow events
- Impacts from peaking operations

However, may be limited by operational constraints.

More difficult to address:

- Migratory fish and longitudinal connectivity
- Sediment
- Temperature and water quality
- Loss of free-flowing river
Limits to sustainability at scale of dam

Spawning habitat

Floodplain fishery
Mitigation Hierarchy

1. Avoid
2. Minimize
3. Offset
Penobscot River Restoration

Energy
- Medway Dam (expanded)
- West Enfield Dam
- Milford Dam
- Stillwater Dam (expanded)
- Orono Dam (added)
- Ellsworth Dam (Union River)

Fisheries
- West Enfield Dam
  - Existing Fish Passage
- Howland Dam
  - Decommission / Innovative Fish Bypass
- Milford Dam
  - New Upstream Fish Passage
- Great Works Dam
  - Decommission / Removal
- Veazie Dam
  - Decommission / Removal
Existing Conditions Veazie Dam

MMI Engineering
Projected Conditions Veazie Dam

MMI Engineering
Penobscot River and Tributaries

Number of Dams Downstream to get to or from the ocean after the PRRP is complete.

Before PRRP

After PRRP

Number of Dams to the Ocean

- 0: Does not include dams not mapped by the state and does not imply free passage up natural barriers or man-made barriers such as road crossings.
- 1
- 2
- 3
- 4
- 5 or more

Penobscot River Watershed
Penobscot example: system planning

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<td>Near zero</td>
<td>1.5 million</td>
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If system planning had occurred in the Penobscot in 1880, which scenario would they have chosen?