Ecologically Informed Water Management

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What are Ecological Flows?
It is not sufficient to just avoid this.
The Natural Flow Regime

A paradigm for river conservation and restoration

N. LeRoy Poff, J. David Allan, Mark B. Bain, James R. Karr, Karen L. Prestegaard, Brian D. Richter, Richard E. Sparks, and Julie C. Stromberg

Humans have long been fascinated by the dynamism of free-flowing waters. Yet we have expended great effort to tame rivers for transportation, water supply, flood control, agriculture, and power generation. It is now recognized that human activities have significantly altered river systems and their ecological communities. The ecological integrity of river ecosystems depends on their natural dynamic character. A Database and Meta-Analysis of Ecological Responses to Stream Flow in the South Atlantic Region

The ecological limits of streamflow alterations (ELOSA): a new framework for developing regional environmental flow standards


Emerging Science

Evaluating Ecological Flows

The Nature Conservancy

Protecting nature. Preserving life.

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Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows

N. LeRoy Poff and Julie K. H. Zimmermann

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The Nature Conservancy, Bethesda, MD, U.S.A.

SUMMARY

1. In an effort to develop quantitative relationships between various kinds of flow alteration and ecological responses, we reviewed 168 papers published over the last four decades, with a focus on recent papers. Our aim was to determine if general relationships could be drawn from disparate case studies in the literature that might inform environmental flows science and management.

2. For all 168 papers we characterized flow alteration in terms of magnitude, frequency, duration, timing and rate of change as reported by the individual studies. Ecological responses were characterized according to taxonomic identity (macroinvertebrates, fish, riparian vegetation) and type of response (abundance, diversity, demographic parameters). A'qualitative' or 'qualitative' summary of the reported results strongly corroborated previous, less comprehensive, reviews by documenting strong

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Relating streamflow characteristics to specialized insectivores in the Tennessee River Valley: a regional approach

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ABSTRACT

Analysis of hydrologic time series and fish community data across the Tennessee River Valley identified three hydrologic metrics essential to habitat suitability and food availability for insectivorous fish communities in streams of the Tennessee River Valley: constancy (flow stability or temporal invariance), frequency of moderate flooding (frequency of habitat disturbance), and rate of streamflow recession. Initial datasets included 1100 fish community sites and 300 streamgages. Reduction of these datasets to sites with coexisting data yielded 33 sites with streamflow and fish community data for analysis. Identification of critical hydrologic metrics was completed using a multivariate correlation procedure that maximizes the rank correlation between the hydrologic metrics and fish community resemblance matrices. Quantile regression was used to define thresholds of important hydrologic metrics for stream values of the hydrologic metrics. Impacts of management and
Ecosystem Flow Recommendations for the Susquehanna River Basin

- Used Ecological Limits of Hydrologic Alteration (ELOHA) framework to develop flow recommendations
- Project area: Susquehanna River has six major subbasins and spans three major physiographic provinces

Ecosystem Flow Recommendations for the Upper Ohio River Basin in Western Pennsylvania

- Used Ecological Limits of Hydrologic Alteration (ELOHA) framework to develop flow recommendations
- Project area: Upper Ohio River basin in western Pennsylvania (mainstem of the Three Rivers and all tributaries)
Warm, small river: South Fork Tenmile Creek at Jefferson, PA (180 sq mi)

- Flood (2 yr rec): 3,510 cfs
- High Pulse (≥ Q10): 491 cfs
- Seasonality (monthly median):
  - March: 294 cfs
  - Sept: 9 cfs
- Low Pulse (≤ Q90): 4.1 cfs

Graph showing daily discharge variability over the years.

- 10th to 90th percentile range of Average Daily Discharge
- Median daily discharge

Graphs and tables showing the life cycle stages of mussels, fish, and vegetation:

- Mussels:
  - Moderate, small
  - Moderate to swift
  - Low gradient
  - Spawning: Glochidia, Spawning, Spawning, Brooding

- Fish:
  - Slow, spring
  - Riffle obligates: Spawning, Egg and larval development, Juvenile growth
  - Riffle associates: Migration and spawning, Adult growth, Juvenile growth
  - Nest builders: Nest building and spawning

- Vegetation:
  - Sub/Emergent: Permanent to semi-permanent inundation
  - Herbaceous: Severe flood and ice scour, Vegetation growth
  - Forest/Shrub: Moderate to severe flood and ice scour, Seed dispersal
The ELOHA Framework
(reproduced from Poff et al. 2010)
Hydroecological Integrity Assessment Process for Missouri Streams

Application of the Hydroecological Integrity Assessment Process for Missouri Streams

By Jonathan S. Kemnitz, James A. Humlau, John Heasley, Brian S. Gute, and James W. Tompkins

Open-File Report 2009-1138

U.S. Department of the Interior
U.S. Geological Survey

Gages
- Intermittent
- Perennial runoff
- Perennial groundwater

Central Plains
Ozark Highlands
Osage Plains/Flint Hills
MS Alluvial Basin
The ELOHA Framework
(reproduced from Poff et al. 2010)

**Scientific Process**

**Step 1. Hyrdologic Foundation**
- Baseline
- Flow Data and Modeling
- Developed Hydrograph

**Step 2. River Classification (for each analysis node)**
- Baseline Hydrograph
- Geomorphic Subclassification
- River Type

**Step 3. Flow Alteration (for each analysis node)**
- Analysis of Flow Alteration
- Measures of Flow Alteration

**Step 4. Flow-Ecology Relationships**
- Flow – Ecology Hypotheses *for each river type*
- Ecological Data for each analysis node
- Flow Alteration – Ecological Response Relationships

**Social Process**

- Implementation
- Environmental Flow Standards
- Acceptable Ecological Conditions
- Societal Values and Management Needs

Adaptive Adjustments
Ecologically Informed Water Management

• Flow-ecology relationships
Ecologically Informed Water Management

- Flow-ecology relationships
- Flow alteration – ecological response relationships
- Changes in fish community as function of changes in flow regime
Applying Biological Data

- The biological condition gradient
  - Davies and Jackson 2006

<table>
<thead>
<tr>
<th>Stressor Gradient</th>
<th>Biological Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Native or natural condition</td>
</tr>
<tr>
<td></td>
<td>Minimal loss of species; some density changes may occur</td>
</tr>
<tr>
<td></td>
<td>Some replacement of sensitive-rare species; functions fully maintained</td>
</tr>
<tr>
<td></td>
<td>Some sensitive species maintained but notable replacement by more-tolerant taxa; altered distributions; functions largely maintained</td>
</tr>
<tr>
<td></td>
<td>Tolerant species show increasing dominance; sensitive species are rare; functions altered</td>
</tr>
<tr>
<td>High</td>
<td>Severe alteration of structure and function</td>
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</table>
Applying Biological Data

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<th>Flow Alteration</th>
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<tr>
<td>Low</td>
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Davies and Jackson, 2006

Severe alteration of structure and function
Ecological Flow Assessment in Missouri

Use Existing Data to Examine Fish Community Changes Due to Stream Flow Alterations:

- Accumulated data on flow alterations (ArcGIS 10.2, RivEX)
Using a consistent set of biological data (wadeable streams)

Resource Assessment and Monitoring (RAM) Program

- **Fish collection**
  - MDC’s Resource Assessment and Monitoring Program
  - Random samples from late May – early October (2000-2016)
  - Single pass electrofishing and seining of a block-netted reach

- **Richness and Diversity**
  - Number of native fish species

- **Habitat Preference**
  - Number of native benthic species

- **Trophic Ecology**
  - Proportion of native insectivorous cyprinid individuals
  - Proportion of native omnivorous/herbivorous individuals

- **Reproductive Ecology**
  - Number of native lithophilic species

- **Sensitivity to Disturbance**
  - Proportion of native tolerant individuals
  - Proportion of non-native individuals
Stream Network Analyses

- Working downstream from each headwater segment, we used RivEX software to accumulate values:
  - Impoundment (Dams)
  - Withdrawal (Losing Catchments)
  - Springs
  - Baseflow Capture Area
  - Baseflow Big Losses
  - Runoff Big Losses
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Applied to every fish community sampling site
Estimating hydrology at fish sample sites

- Missouri’s hierarchical aquatic classification system
  - Aquatic Subregion
    - Ecological Drainage Unit (EDU)
    - Aquatic Ecological System Type (AES)
      - Stream Size Classification
      - Valley Segment Type (VST)
Estimating hydrology at fish sample sites

Sowa, et. al (2005) developed Aquatic Ecological System Types for Missouri via a cluster analysis of geology, soils, slope, and spring density (approximately = hydrology).

Reference (least disturbed) Flow Duration Curves (FDC) can be synthesized for reaches based on:

- Regressions of gage discharge vs. drainage area for FDC groups
- Regression of percent zero flow days vs. drainage area for FDC groups
- FDC groups are primarily based on hydrologically similar AES Types. Some AES Types were split based on gage data, which reflected geologic differences not captured in the AES cluster analysis
- Reach specific adjustments based on accumulated springflow and losing stream data
Available Data - Missouri

- RAM Fish Community Data
- Estimates of Mean/Median Annual Flow (from Flow Duration Curves)
- Impoundment Metrics:
  - Degree of Regulation – will relate to High Flow Alterations
  - Percent Reservoir Area – will relate to Low Flow Alterations
- Withdrawals (Losing Streams):
  - Percent Reduction of Median Flow
Study Regions and Spatial Framework

- Central Plains
- Ozark Highlands
- Osage Plains/Flint Hills
- MS Alluvial Basin
Study Regions – Hydrologic Alterations

Grand and Chariton Rivers –
• Impoundments

Neosho and Big Sugar Rivers –
• Withdrawals (Losing Stream Effects)
Study Regions and Spatial Framework

- Grand and Chariton Rivers - Impoundments
  - 1,442 Dams
  - 192 RAM Sites
  - 27 USGS Stream Gages
  - 14,037 Stream Segments
  - 10,572 mi² Drainage Area of Stream Catchments (MoRAP)
Impoundments (≈ 5,500 within Missouri)

- Multitude of purposes
  - Flood Control
  - Food and Drinking Water Supply
  - Crop Irrigation
  - Hydroelectricity
  - Navigation (Freight transport)
  - Grade Stabilization
  - Recreational Opportunities
  - Fish and Wildlife Ponds
Flow normally limited to principal spillway pipe

Auxiliary spillway (grass waterway) intended to rarely have flow

Flood control dams have more storage between principal and auxiliary spillways

Peaks of runoff events are clipped, but events are released over a few days, so no seasonal shift of flow

Low flows affected by seasonal or drought periods when evaporation exceeds precipitation and by any water withdrawals
Impoundment Metrics (NID, MODNR, NABD)

Use as Surrogates for Hydrology

- Cumulative Reservoir Storage (MAX STOR)
- Cumulative Reservoir Area (RES AREA)
- Mean Annual Flow (from regression equation of 37 gages)
- **Degree of Regulation**: Cumulative Storage/ Mean Annual Flow
- **Percent Reservoir Area**: Cumulative Reservoir Area/Drainage Area
Grand and Chariton Rivers

Degree of Regulation

Number of Native Benthic Species

Number of Native Lithophilic Species

Number of Native Fish Species
Grand and Chariton Rivers
Percent Reservoir Area/ Drainage Area
Study Regions and Spatial Framework

- Neosho and Big Sugar Rivers – Withdrawals (Losing Stream Effects)
  - 3,362 Stream Segments
  - 297 Springs
  - 95 RAM Sites
  - 14 USGS Stream Gages
  - 2,800 mi² Drainage Area of Stream Catchments (MoRAP)
  - 509 mi² of Losing Stream Catchments
Using losing streams as a surrogate for withdrawals

- High flows are channel forming flows and create the habitat template. Losing streams like withdrawals have little effect on channel forming flows.

- Withdrawals and losing streams do reduce the baseflow and thus the amount of the habitat template that is wet.

- Assumed no baseflow contribution from local catchment of losing streams.

- Have to account for measured flow losses found in specific reaches during USGS and DNR studies.

- Have to account for springflow which can compensate for losing streams and can in some cases dominate the baseflow.

- Need to accumulate the losing stream and springflow data for each fish sampling site.
Percent reduction of median flow

- Estimated median daily discharge can be calculated using a regression equation (non-springflow discharge vs non-losing drainage area) plus estimated spring flow. (karst median)

- The same regression equation can be used assuming no karst features to calculate full drainage area median. (non-karst median)

- \((1-\text{karst median}/\text{non-karst median}) \times 100\%\) will be used as a surrogate for percent reduction in median flow.
Neosho and Big Sugar Rivers

Estimated Reduction of Median Discharge

Number of Native Fish Species

Number of Native Lithophilic Species

Number of Native Benthic Species

Native Fish Species Richness

Estimated Reduction of Median Discharge (%)
Estimated Reduction of Median Discharge

Neosho and Big Sugar Rivers

Proportion of Native Insectivore Cyprinid

Proportion of Native Omnivorous/Herbivorous

Estimated Reduction of Median Discharge (%)

[Graph with data points showing correlation between estimated reduction of median discharge and proportions of native fish species.]
Continued Work…

• **Improvements and future directions**
  
  • Apply process of flow estimation and impoundment and withdrawal metrics to the rest of the state
  
  • Incorporate additional fish community data
  
  • Address the influence of different purposes for impoundments
  
  • Determine how USGS gages sit in respect to impoundment metrics
  
  • Incorporate macroinvertebrate data for water quality screening of RAM sites
  
  • Target new sampling locations to fill in gaps in the gradient of flow alteration
  
  • Validate flow estimation process and incorporate as tool to link with other datasets in Missouri
Acknowledgments

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