Selecting Appropriate Methods and Tools for Developing Environmental Flow Recommendations
Eloise Kendy, Jeff Opperman, Colin Apse
The Nature Conservancy

nature.org/freshwater
Environmental flow methods

- Broad categories of methods
- Evolution of approaches
- Overview of holistic approaches
- Environmental flow components
- Framework for method selection
Basic categories of environmental flow methods

_Tharme (2003):_

- **Hydrologic**
  - Tennant (Montana) method

- **Hydraulic**
  - Wetted perimeter method

- **Habitat simulation**
  - PHABSIM (part of IFIM)

- **Holistic**
  - DRIFT, BBM, TNC’s “Savannah Process”

Limitations of methods

Most commonly used methods:

- Seek a single (or a few) discharge values (inherent in method or how method is generally implemented)

- Are not generally designed to incorporate infrequent events and riverine process needs:
  - Tennant
  - Wetted Perimeter
  - PHABSIM

- Are difficult to reconcile with functional riverine and riparian ecosystems and the need for inter- and intra-annual variability
Evolution of environmental flows

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
Evolution of environmental flows

Stable low flows
Instream flows

...vs. a range of flows, including floods
...vs. flows above bankfull

Focused on trout

...vs. focused on riparian veg and sediment transport

and large wood & channel form and invertebrates

and people

People catching trout
Shift from minimum flow to flow regime:
* magnitude, frequency, duration, timing, rate of change
* flow components (low flows, freshes, floods)
Instream Flow Incremental Methodology

PHABSIM

USGS Fort Collins
Holistic Methods Attempt to Better Account for Ecosystem Needs

- Well-developed in South Africa (DRIFT) and Australia (BBM)
- Encompasses variability, a range of flow types, and a range of resources (human & ecological)
- Foundation of The Nature Conservancy’s framework for developing environmental flows for situations ranging from resource- and data-poor to extensive resources and/or data
Protecting Ecological Functions with Environmental Flows

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

## Specialists for inter-disciplinary team

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>River flow</strong></td>
<td>surface &amp; groundwater hydrology, hydraulics, water resources modelling, climate change</td>
</tr>
<tr>
<td><strong>Channel form</strong></td>
<td>geomorphology, sedimentology, physical habitat</td>
</tr>
<tr>
<td><strong>Biota</strong></td>
<td>vegetation, fish, invertebrates, frogs, reptiles, mammals, birds</td>
</tr>
<tr>
<td><strong>Water quality</strong></td>
<td>chemistry, microbiology</td>
</tr>
<tr>
<td><strong>Subsistence users</strong></td>
<td>sociology, anthropology, water supply, public health, animal health</td>
</tr>
<tr>
<td><strong>Economics</strong></td>
<td>resource economist, macro-economist</td>
</tr>
<tr>
<td><strong>Process</strong></td>
<td>co-ordinator, international mentor</td>
</tr>
</tbody>
</table>
Top-down approach: DRIFT
Downstream Response to Imposed Flow Transformation
(Brown and Joubert 2003, King et al 2003)

Module 1
Biophysical

Module 2
Sociological

Module 3
Scenario development

Module 4
Economics

DRIFT output to decision maker:
Biophysical, sociological, economic consequences of each scenario
DRIFT

Scenario development
Evaluation of biophysical and social consequences

Flow Scenario
- Constant minimum release (0.5 m³ s⁻¹)

Biophysical Component
- *Phragmites australis* (reed)

Severity of Predicted Change
- Negative and severe

Direction and % Change
- Increase (60-80%)

Ecological Reason
- Grows only in wet bank zone

Social links
- Medicine, fodder, construction
Bottom-up approach: Building Block Methodology (BBM) (King and Louw 1998)

e.g. BBM site, Sabie River

**LOW FLOW**

2.2 m$^3$ s$^{-1}$; 1.04 m

**Geomorph:**
- Increase riffle biotopes

**Fish:**
- Provide access to nursery areas i.e. marginal veg., NB for cyprininds, *Serranochromis*

**Inverts:**
- Provide natural biotope diversity

**HIGHER FLOWS**

15.0 m$^3$ s$^{-1}$; 1.58 m; 10 days; 1:1 ARI

**Geomorph:**
- Provide scouring of active channel

**Rip. Veg.:**
- Activate wide range of seasonal & perennial channels, maintaining all associated veg.

**Fish:**
- Provide spawning cues for large *Labeo* spp., provide habitat diversity

* Subsistence use
“Savannah approach”

Step 1
Orientation Meeting

Step 2
Literature Review & Summary Report

Step 3
Flow Recommendations Workshop

Step 4
Implementation of Flow Prescription

Step 5
Data Collection & Research Program
Environmental flow workshop structure, using “Savannah process”

- Full Group
- Aquatics (fish, others)
  - Floods/pulses
  - Low Flows
- Riparian Veg & Floodplains
  - Floods/pulses
  - Low Flows
- Unified Floods/pulses
- Unified Low Flows
- Unified Flow Requirements
ENVIRONMENTAL FLOW COMPONENTS

For each:
Magnitude, frequency, duration, timing, rate of change

Output from TNC’s IHA software
WRITE THESE DOWN:

- **Magnitude** (how much flow or what level?)
- **Duration** (how long do certain flows or levels last?)
- **Timing** (when do certain flows or levels occur?)
- **Frequency** (how often do certain flows or levels occur?)
- **Rate of change** (how fast do flows or levels change from one condition to another?)

Magnitude of flow:

- 3520 cfs
- 307 cfs
Duration of flow events e.g. below 400 cfs
Timing of flow events:

- Oct. 23
- Nov. 25
- Dec. 12
Frequency of flow events e.g. above 2200 cfs
Rate of change in flow
Environmental Flow Recommendations
Savannah River, below Thurmond Dam (River-Floodplain)

**Floods**

<table>
<thead>
<tr>
<th>Flow Range</th>
<th>Duration</th>
<th>Frequency</th>
<th>Activities</th>
</tr>
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<tbody>
<tr>
<td>50,000-70,000 cfs</td>
<td>2 weeks</td>
<td>avg every 2 yrs</td>
<td>Create floodplain topographic relief, Provide fish access to the floodplain, Maintain wetlands and fill oxbows and sloughs, Enhance nutrient cycling &amp; improve water clarity, Disperse tree seeds</td>
</tr>
<tr>
<td>&gt;30,000 cfs</td>
<td>5 pulses, &gt;2 days with 2 events of 2 week duration (March and early April)</td>
<td></td>
<td>Maintain channel habitats, Create shallow water habitat for small-bodied fish, Control invasive species, Maintain wetlands and fill oxbows and sloughs, Enhance nutrient cycling &amp; improve water clarity, Disperse tree seeds</td>
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<tr>
<td>20,000-40,000 cfs</td>
<td>2-3 days</td>
<td>1/month</td>
<td>Provide predator-free habitat for birds, Disperse tree seeds, Transport fish larvae, Flush woody debris from floodplain to channel, Floodplain access for fish, Fish passage past NSBLD</td>
</tr>
<tr>
<td>&lt;13,000 cfs</td>
<td>3 successive years, every 10-20 years</td>
<td></td>
<td>Floodplain tree recruitment</td>
</tr>
<tr>
<td>8,000-12,000 cfs</td>
<td></td>
<td></td>
<td>Exchange water with oxbows</td>
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**High Flow Pulses**

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**Low Flows**

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<td>&gt;8,000 cfs</td>
<td></td>
<td>Larval drift for pelagic spawners</td>
</tr>
<tr>
<td>&lt;5,000 cfs</td>
<td></td>
<td>Adequate floodplain drainage, Create shallow water habitat for small-bodied fish</td>
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<tr>
<td>3,000 cfs</td>
<td>3 successive years every 10-20 years</td>
<td>Floodplain tree recruitment</td>
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**Key**

- Wet Year
- Avg Year
- Dry Year

**Legend**

- JAN
- FEB
- MAR
- APR
- MAY
- JUN
- JUL
- AUG
- SEP
- OCT
- NOV
- DEC
Environmental Flow Prescription

Environmental Flow Recommendations

Graph showing flow recommendations for different years.
Holistic methodologies: strengths and weaknesses

+ Whole-ecosystem focus
+ Generates alternative environmental flow scenarios for different ecological and social conditions
+ Use of interdisciplinary expert judgment in structured, consistent process
+ Usable in data rich and data poor contexts (use of available techniques and understanding)
+ Explicit links with characteristics of flow regime and with biological and social responses to flow change

- Reliant on expert judgment
- Difficulties in reconciling opinions of different experts
- Moderate to high resource demands
Three Levels of Comprehensive Environmental Flow Assessment

- **Hydrologic desktop methods** consider range of natural variability linked to key ecosystem processes.
- **Expert-panel approaches** with little or no modeling.
- **Integrated field studies and modeling** encompassing tools such as:
  - Riparian recruitment models
  - Sediment transport
  - Temperature models
  - Instream habitat models
  - Other environmental flow methodologies (e.g., PHABSIM, IBMs)
  - Decision support systems to assist integration.
Three-Level Hierarchy

(1) Strategic resource deployment: methods are matched to the level of certainty required and the level of funding available.

(2) Iterative: information generated at one level provides the foundation for, and identifies the need for, higher levels

(3) Accelerates implementation.
Three Levels of Comprehensive Environmental Flow Assessment

- **Level 1:** Hydrologic analysis
  - *Limited*

- **Level 2:** Expert-panel driven
  - *Moderate*

- **Level 3:** Integrated field studies and modeling
  - *Extensive*

Implementation and Adaptive refinement

- As much a social process as it is a technical approach: foster collaboration to get durable results
- Can be sequential
Level 1: Hydrologic analysis

- Can be first step prior to implementing other levels; screening-level approach

- Precautionary stand-alone approach; over time, augmented with higher level approaches

- Can use tools such as Indicators of Hydrologic Alteration (IHA) that can account for the range of ecological flow components necessary for maintaining river processes
Level 1 example: Hydrologic analysis using IHA

Colorado River at Lees Ferry
Monthly Flow Alteration with RVA Boundaries (1922-2004)
Level 2: Expert-panel driven approach

- Advanced significantly in Australia and South Africa for rivers with few data available

- TNC published “Savannah Process” based on collaborative process for e-flow determination with US Army Corps
Hypotheses, uncertainties

Research, models, methods

Winter/Spring Bankfull Pulses

**Recommendation:**
- Time period: Nov 15 - Mar 15
- Number of events: 1 - 5 depending on precipitation
- Magnitude range: 18,000 – 20,000 cfs
- Duration: mimic unregulated events

**Supports ecosystem functions:**
- Geomorphic processes (sediment transport, reconnection)
- Downstream migration of juvenile salmonids
Level 3: Integrated field studies and modeling

- For systems with extensive existing data or the funding and time to develop new data

- For situations in which greater certainty is desired or required (for example, if lawsuits are likely)

- Can encompass and integrate many existing methods, ideally using decision support system
Level 1
- Initial hydrological assessment/information foundation

Level 2
Expert-panel workshop

Level 3
- Modeling and research
  - Constraints
  - Opportunities
- Flow experiments/monitoring

Initial flow changes
Adaptive management and policy

Year
1  2  3  4  5+

Initial environmental flow recommendations
Adaptive flow regime; formalized in management

Flow recommendations
Study Plan
Modeling, research, problem solving
Level 3 example: Sacramento River Ecological Flows Tool

Steelhead (Oncorhynchus mykiss)

Chinook Salmon (Oncorhynchus tshawytscha)

Green Sturgeon (Acipenser medirostris)

Bank Swallow (Riparia riparia)

Western Pond Turtle (Clemmys marmorata)

Fremont Cottonwood (Populus fremontii)
Decision Support System: SacEFT used to manage data and link different tools/datasets.
1-day max flows

Natural hydrograph

Regulated hydrograph

August low flows

Level 1: Hydrologic desktop analysis
Level 2: Expert panel approach to define initial flow recommendations, framed as hypotheses
Models for meander migration and sediment transport;
Key flow range = 15,000 – 20,000 cfs

Cottonwood recruitment box model (rate of recession)
Data on fish utilization of floodplains (duration for rearing)

Level 3: Using modeling, field sampling and analyses to reduce uncertainties and refine flow needs
Average-year hydrograph to meet flow recommendations

Required 1 in 10 years
Wet-year hydrograph to meet flow recommendations

Required 1 in 10 years
Cost and time comparison

Level 1: Hydrologic analysis
- Months 0 - 5
- $100 - $10,000

Level 2: Expert-panel driven
- Months 6 - 12
- $10,000 - $200K

Level 3: Integrated field studies and modeling
- Years 2 – 5 +
- Often $1,000,000 +

Adaptive refinement
- Requires sustainable budget
Criteria for a Regional Environmental Flow Method

- Addresses many rivers simultaneously
- Explicitly links flow and ecology
- Applies across a spectrum of:
  - Flow alteration types
  - Data availability and scientific capacity
  - Social and political contexts
Ecological Limits of Hydrologic Alteration (ELOHA)

- Quantifies trade-offs between streamflow alteration and ecological degradation
- Informs the determination of environmental flow targets
- Integrates environmental flows into a computerized DSS
Flow Alteration - Ecological Response Curve

Excellent

Good

Fair

Poor

Increasing Hydrologic Alteration

Minimal changes in structure & function of biotic community

Moderate changes in structure & function

Major changes in structure & function

Severe changes in structure & function
SCIENTIFIC PROCESS

Step 1. Hydrologic Foundation
- Baseline Hydrographs
- Hydrologic Model and Stream Gauges
- Developed Hydrographs

Step 2. Stream Classification
- Stream Hydrologic Classification
- Geomorphic Stratification

Step 3. Flow Alteration
- Degree of Hydrologic Alteration
- Hydrologic Alteration by River Type

Step 4. Flow-Ecology Relationships
- Flow - Ecology Hypotheses
- Ecological Data and Indices
- Flow Alteration-Ecological Response Relationships by River Type

SOCIAL PROCESS

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

Monitoring

Adaptive Adjustments
Confidence in Protecting Healthy Rivers

- **TIME AND MONEY INVESTED**
  - Level 1: Desktop
  - Level 2: Experts
  - Level 3: Studies

- **Entire Country**
- **River Type**
- **Single River**

**Confidence Levels**
- **Low**
- **Medium**
- **High**
### Essential Knowledge for Environmental Flows: Situation Analysis

- Natural hydrology, biology, geomorphology
- Rare and endangered species
- Existing and future development
- Degree of controversy
- Water policy framework
- Upstream and downstream constraints
- Stakeholder needs and interests
- Resource and capacity constraints
- Available information
References


http://www.conservationgateway.org/topic/freshwater
<table>
<thead>
<tr>
<th>Period</th>
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<tbody>
<tr>
<td>1950s-60s</td>
<td>Water resource development for society</td>
</tr>
<tr>
<td>1960s-70s</td>
<td>Minimum flows for pollution dilution</td>
</tr>
<tr>
<td>1970s-80s</td>
<td>Minimum flows for fish</td>
</tr>
<tr>
<td>1990s</td>
<td><strong>Environmental flows</strong> for ecosystems</td>
</tr>
<tr>
<td>1990s-2000s</td>
<td>Holistic integration of full range of values of healthy rivers for nature and people</td>
</tr>
</tbody>
</table>