Environmental Flows in River Basin Management: Methodologies for Assessment

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Outline

- Environmental flow determination
  - Broad considerations
  - Hierarchy for methodology application
  - Examples of types of methodologies
  - Strengths and limitations

- Environmental flow implementation
  - IWRM and RBM context
  - Factors for successful strategy
  - Policy toolbox
Broad considerations

- Societal vision and objectives for region/catchment and future condition of river(s)
- Ecosystem importance (ecological, social), current status, resilience
- Basin flow management – integration with land management
- Social dependencies and value for people - ecosystem services for livelihoods
- Basin context - highly regulated (closed) to undeveloped (open)
- Water governance - national policies provide guiding frameworks - but implementation at catchment level
- Capacity – institutional, technical
Methodologies to support environmental flow management

(Tharme 2003)
Hierarchical application of methodologies

1. **Planning / Reconnaissance Level**
   - **Hydrology-based**
     - planning estimates, regional analyses, low priority systems

2. **Intermediate or Comprehensive Level**
   - (a) Habitat simulation
   - (b) Holistic
     - high priority systems, allocation tradeoffs
(1) Planning level hydrological methodologies: strengths and deficiencies

- Simple, rapid, inexpensive
- Low data needs (desktop), primarily flow data
- Suitable for water resource planning
- Potential for regionalization for different river ecotypes
- Simplistic, inflexible, low confidence and resolution
- Dynamic nature of flow regime seldom addressed
- Unsuitable for high profile, negotiated cases
- Ecological links weak - recent advances in ecological relevance of flow indices used to set flow targets
Evolution of holistic approach to environmental flows

- **Flow as key driver of ecosystem** – “natural flow paradigm” (Poff et al. 1997)

- **Hydrological variability**
  - Magnitude
  - Frequency
  - Duration
  - Timing
  - Rate of change

- **Shift from minimum flow to flow regime**
Range of Variability Analysis

- Indicators of Hydrologic Alteration (IHA) software
- 33 annual statistics
- Ecologically-relevant
- Targets for management

(Richter et al. 1996, 1997)
Environmental Flow Components
34 additional flow statistics

ENVIRONMENTAL FLOW COMPONENTS

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

Output from TNC's IHA software

Deschutes River at Olympia
(2) Intermediate/Comprehensive level methodologies: Holistic type

1. Retain flood peak - scour channel & recharge banks & floodplain
2. Maintain low flow - aquatic habitat in dry season
3. Retain spring fresh - cue for fish life cycles (e.g. migration)
4. Vary low flow in wet season, but with removal of some floods
### Specialists for inter-disciplinary expert panel

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Areas of Expertise</th>
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<tbody>
<tr>
<td><strong>River flow</strong></td>
<td>surface &amp; groundwater hydrology, hydraulics, water resources modelling, climate change</td>
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<tr>
<td><strong>Channel form</strong></td>
<td>geomorphology, sedimentology, land use</td>
</tr>
<tr>
<td><strong>Biota</strong></td>
<td>vegetation, fish, invertebrates, frogs, reptiles, mammals, birds</td>
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<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>
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<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>
## Construction of e-flow regime:
**ecological and social motivations (e.g. BBM)**

### e.g. BBM site, Sabie River

#### FEBRUARY

<table>
<thead>
<tr>
<th>LOW FLOW</th>
<th>HIGHER FLOWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2 m³ s⁻¹; 1.04 m</td>
<td>15.0 m³ s⁻¹; 1.58 m; 10 days; 1:1 ARI</td>
</tr>
</tbody>
</table>

### Geomorph:
- Increase riffle biotopes

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

### Inverts:
- Provide natural biotope diversity

### 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**
Tools to assist with construction of environmental flow regime

Environmental Flow Recommendation
Savannah River, below Thurmond Dam (River-Floodplain)

- **Floods**:
  - Maintain wetlands and fill oxbows and sloughs
  - Larval drift for pelagic spawners
  - Adequate floodplain drainage
  - Control invasive species

- **High Flow Pulse**:
  - >8,000 cfs; 5 pulses, 2 days with 2 events of 2 week duration (March and early April)
  - Provide predator-free habitat for birds
  - Disperse tree seeds

- **Low Flows**:
  - ≤3,000 cfs; 3 successive years every 10-20 years
  - Floodplain tree recruitment
  - Exchange water with oxbows

- **Dry Year**
  - ≤3,000 cfs
  - Floodplain tree recruitment

- **Wet Year**
  - >30,000 cfs; 5 pulses, 2 days with 2 events of 2 week duration (March and early April)
  - Maintain wetlands and fill oxbows and sloughs
  - Disperse tree seeds

- **Avg Year**
  - 3,000 cfs, 3 successive years every 10-20 years
  - Floodplain tree recruitment
Comprehensive methodology (e.g. ESWM)

Suite of tools:
- PHABSIM
- Temperature models
- Biotope mapping
- Sediment transport
- Riparian dynamics

- Orientation meeting
- Review & summary report
- Implementation of flow prescription
- Monitoring and research program
- Flow recommendation workshop
- RPT used here
- IHA used here

Richter et al. 2006
Physical habitat modelling for target species (e.g. PHABSIM)

(A) Flow through sections 1 and 2

(B) Habitat suitability curves for target sp.

(C) Habitat area (WUA) over time

- Adult
- Juvenile

- Existing
- Proposed
Environmental flow framework (e.g. DRI FT)

(1) Biophysical
Describe the nature and functioning of the river
Develop predictive capacity of flow related changes

(2) Sociological
Identify PAR
Describe river use and health profiles
Develop predictive capacity of social impacts of river changes

(3) Scenario development
Identify possible future scenarios and describe biophysical consequences of each

(4) Economic
Calculate compensation and mitigation costs for PAR

Output to decision-maker

(King et al. 2003)
Integration of environmental flows in water resources planning and management

- Implications of alternative scenarios
- Tradeoff analysis for water allocation across sectors
- Operation procedures & reoptimization of water management system
- E-flow standards & rules - supply assurance and risk
- Siting of storage & flow control structures
- Protection of natural flow regimes in key tributaries
Holistic methodologies: strengths and deficiencies

- Whole-ecosystem integrity
- Alternative e-flow regimes / scenarios for different ecological and social conditions
- Interdisciplinary team in rigorous science-based process
- Data rich and data poor contexts
- Uses ecologically relevant flow regime characteristics
- Addresses biological and social responses to flow alteration
- Reliant on expert judgement
- Difficult to reconcile opinions of different experts
- Moderate to high resource demands
- Site specific
ELOHA
Ecological Limits of Hydrologic Alteration
A new regional desktop method
Environmental Flow Prescriptions by River

Rivers for which environmental flows prescribed
SCIENTIFIC PROCESS

Hydrologic Foundation

Baseline Hydrographs

Hydrologic Model and Stream Gauges

Developed Hydrographs

Stream Hydrologic Classification

Degree of Hydrologic Alteration

Hydrologic Alteration within Class

Monitoring

Flow - Ecology Hypotheses

Biotic Data and Indices

Flow - Ecology Curves by Hydrologic Class

SOCIAL PROCESS

Implementation

Environmental Flow Standards

Acceptable Ecological Conditions

Societal Values

Adaptive Adjustments
Gracias

Thank you

IHA software & resources   www.nature.org/freshwaters

HEC-RPT software   www.hec.usace.army.mil
Integration of e-flows in IWRM / RBM: Conditions for success

• Harmonized policy and regulations with explicit recognition of e-flows principles
  ➢ at basin level, preferably also at national/regional level
  ➢ across all sectors - optimization for multiple benefits
• Reliable, credible knowledge base - information systems, monitoring, infrastructure
• Technical expertise and tools
  ➢ e-flows determination (incl. strategic targeting of river systems for protection)
  ➢ yield analyses and water allocation tradeoffs
  ➢ infrastructure operating rules
Conditions for success cont.

• Transparent, robust decision-making arrangement – stakeholder inclusion

• E-flows integrated in basin management plans and linked to other drivers of change (e.g. land use)

• Institutional capacity for implementation, monitoring, refinement

• E-flows process connected with national plans - IWRM strategy, poverty reduction strategy, MDGs, etc.

• E-flows included in water resource investments and policy reforms
Field sampling, analyses, modeling, experimental flow releases to reduce uncertainties and refine e-flow recommendations

- 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)
- Required 1 in 10 years

- H2O Temp Models
- Spawning surveys
- Fish passage models
Criteria for 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
Indicators of Hydrologic Alteration (IHA) 7 software

67 ecologically-relevant flow statistics (daily flow data) used to:

- Characterize the natural flow regime
- Assess how flow regime has changed over time
- Analyze flows provided by different management scenarios
- Aid in developing e-flow recommendations (in conjunction with ecological information)

(Richter et al. 1996, 1997)
**Indicators of Hydrologic Alteration (IHA) 7 software**

IHA Annual Statistics (33 indices)

- Monthly average flows
- Magnitude of annual extremes (1-, 3-, 7-, 30-, and 90-day minimums and maximums)
- Timing of annual extremes (1-day max and min)
- Zero flow days
- Frequency and duration of high and low pulses
- Rates of flow changes and reversals
- Base flow index (7-day minimum flow / mean annual flow)
Expert panel approach to define initial flow recommendations, framed as hypotheses.
Environmental Flow Recommendations
Savannah River, below Thurmond Dam (*River-Floodplain*)

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

**Key**
- Wet Year
- Avg Year
- Dry Year

*Really?... Monitoring, Research, & Adaptive Management*
Water and environment sectors

- E-flow provision is a water resources management and environmental issue - should be addressed concurrently in:
  - environmental sector and
  - water sector
- EIAs for water resource development projects - opportunities to introduce e-flows, but insufficient to ensure implementation
- E-flows need to be addressed in strategic water resource planning at basin level:
  - Water management options for basin as a whole
  - Siting of storage and flow control structures
  - Protection of natural flow regimes in key tributaries
Implementation strategy

- Allow transitional period –
  - preliminary determinations of e-flows to support evaluation of individual licence applications, updated later
  - range of approaches, from desktop to comprehensive
- Design integrated basin-level plans
  - e.g. protection of natural flows in key tributaries
- In currently over-allocated catchments, develop interim objectives and timeframes – e.g. formalised in Catchment Management Strategies
- Adaptive management approach
  - monitor initial implementation of e-flow allocation and feed back results into
    - improved ecosystem understanding
    - better estimates of e-flows
Policy toolbox

- Resource directed measures
  - Classification system, Reserve, resource quality objectives (i.e. quality of all aspects of water resource: flow, water quality, habitat and biota)
- Source directed controls
  - Standards, BMP, licensing, EIA
- Economic instruments
  - Tariffs, charges, penalties
- Information systems
  - National monitoring networks, catchment-level monitoring
- Institutional arrangements
  - New water management institutions at catchment level, central government has policy and regulatory role
A framework for developing environmental flows

Time/Resource Investment and Level of Certainty

Level I
Holistic hydrological analysis
Range of variability
Environmental flow components
Foundation for seeking funding and support to move toward

Level II
Holistic; expert panel approach

Level III
Initiate flows and monitoring to move toward

Level IV
Holistic; field studies and modeling
Adaptive refinement