ISH0306 - Consultancy for the Development of Guidelines for Hydropower Environmental Impact Mitigation and Risk Management in the Lower Mekong Mainstream and Tributaries

Carina Seliger, Stefan Schmutz, Bernhard Zeiringer

ISH0306 Training
Fisheries and Aquatic Ecology
Mitigation approach
(as discussed in previous presentations)

• Understand the river ecology in relation to abiotic parameters (hydromorphology!)

• Identify values and risks (define indicators!)

• Define appropriate mitigation measures and measure their efficiency on the basis of previously defined indicators
Understand river ecology (examples)
Important functions of natural discharge dynamics

Natural discharge and sediment characteristics provide important ecological functions and habitats

Lateral connectivity
Longitudinal connectivity

Channel form
Habitat complexity $\rightarrow$ biotic diversity
Patch disturbance

Aquatic organisms have evolved with the natural flow regime and are highly adapted to it!

(Bunn and Arthington, 2002)
Important functions of natural discharge dynamics

Productivity of Cambodian floodplain (incl. Tonle Sap and Great Lake System) depends highly on the

- timing
- duration and
- magnitude of high flows
Distribution of important habitats e.g. deep pools, rapids, floodplains...

Rapids

Important as main habitat, spawning areas, dry season shelter, thermal refuges, hiding place, ...

Deep pools

BDP Atlas, MRC 2011
Migration systems
(seasonal patterns)

Migrations = movements that result in an alternation between two or more separate habitats, occur with a regular periodicity, and involve a large proportion of the population.

Active migrations of adults vs. passive drift of larvae/eggs

(Poulsen et al. 2002, Baran 2006)
Migration guilds (based on migratory behaviour)

Rough

- Migratory (white)
- Non-migratory (black)
- Intermediate (grey) guild


More detailed (MRC 2009)

1. Rithron resident;
2. Migratory main channel (& tributaries) resident guild;
3. Migratory main channel (& tributaries) spawner guild;
4. Migratory channel refuge seeker guild;
5. Generalist guild;
6. Floodplain resident guild;
7. Estuarine resident guild;
8. Semi-anadromous guild;
9. Catadromous guild;
10. Marine guild (enters estuaries opportunistically)
Identification of values and risks & definition of suitable mitigation measures
## Values and risks

<table>
<thead>
<tr>
<th>Value</th>
<th>HP Risk</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>River connectivity</td>
<td>Fragmentation (barriers, flow alteration, …)</td>
<td>Maintain connectivity</td>
</tr>
<tr>
<td>Natural habitats</td>
<td>Alteration of hydrologic cycle (seasons, short-term)</td>
<td>Retain seasonality and reduce artificial variability</td>
</tr>
<tr>
<td>Natural functions (e.g. passive drift, spawning trigger)</td>
<td>Alteration of sediment processes (sedimentation and erosion processes)</td>
<td>Retain seasonality and distribution of sediment delivery</td>
</tr>
<tr>
<td>Overall productivity &amp; biodiversity</td>
<td>Alteration of habitats and ecological functions</td>
<td>Minimize impacts, ensure minimum level of required habitats (quality &amp; quantity)</td>
</tr>
</tbody>
</table>
### 1st order: Alteration of abiotic parameters

- Seasonal flow alterations
  - Volume
  - Seasonality (onset, duration)
  - Min/max flows
- Sub-daily flow alterations
  - Characteristics of peaking
- Impoundment
  - Seasonal flow velocities
  - Sed. transport
  - Sed. flushing
- River fragmentation

### 2nd order: Alteration of habitats and ecological functions

- Change/loss of seasonal habitats
- Loss of ecological triggers
- Alteration of shoreline area and floodplains
- River dimensions (depth, width)
- Sed./nutrient concentr.
- Blocked/reduced fish migration
- Blocked sediment transport
- Rapid habitat alterations (flow, velocities, temperature...)
- Support of passive drift
- Blocked/ reduced fish migration

### 3rd order: Alteration of aquatic biodiversity and biomass

- Loss of ecological functions (e.g. triggers)
- Reduced spawning success
- Limited feeding areas
- Stranding of larvae/eggs
- Drift of small fish and larvae
- Reduction in macrophytes
- Reduction in algae
- Reduction in benthic invertebrates
- Loss due to flushing events
- Loss/ reduction of migratory species

### Complex ecosystem

> any changes may cause impacts on aquatic organisms

- Habitat alterations
- Loss of ecological functions
- Impacts via food web

---

**Fish biomass and diversity**

**Indirect effects via food web**
1st order: Alteration of abiotic parameters

- Seasonal flow alterations
  - Volume
  - Seasonality (onset, duration)
  - Min/max flows

- Sub-daily flow alterations
  - Characteristics of peaking

- Impoundment
  - Seasonal flow velocities
  - Sed. transport
  - Sed. flushing

- River fragmentation

2nd order: Alteration of habitats and ecological functions

- Change/loss of seasonal habitats
- Loss of ecological triggers
- Alteration of shoreline area and floodplains
- River dimension (depth, width)
- Loss of important habitats (deep pools, rapids…)
- Rapid habitat alterations (flow, velocities, temperature…)
- Support of passive drift
- Quality/quantity of habitats (deep pools, rapids, hot spots)
- Sed./nutrient concentr.
- Blocked sediment transport
- Blocked/reduced fish migration

3rd order: Alteration of aquatic biodiversity and biomass

- Loss of ecological functions (e.g. triggers)
- Reduced spawning success
- Limited feeding areas
- Stranding of larvae/eggs
- Reduction due to limited habitat availability
- Drift of small fish and larvae
- Reduction in macrophytes
- Reduction in algae
- Reduction in benthic invertebrates
- Loss due to flushing events
- Loss/reduction of migratory species
- Limited feeding areas

Indirect effects via food web
<table>
<thead>
<tr>
<th>1st order: Alteration of abiotic parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seasonal flow alterations</td>
</tr>
<tr>
<td>- Volume</td>
</tr>
<tr>
<td>- Seasonality (onset, duration)</td>
</tr>
<tr>
<td>- Min/max flows</td>
</tr>
<tr>
<td>Sub-daily flow alterations</td>
</tr>
<tr>
<td>- Characteristics of peaking</td>
</tr>
<tr>
<td>Impoundment</td>
</tr>
<tr>
<td>- Seasonal flow velocities</td>
</tr>
<tr>
<td>- Sed. transport</td>
</tr>
<tr>
<td>- Sed. flushing</td>
</tr>
<tr>
<td>River fragmentation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2nd order: Alteration of habitats and ecological functions</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Change/loss of seasonal habitats</td>
</tr>
<tr>
<td>• Loss of ecological triggers</td>
</tr>
<tr>
<td>• Alteration of shoreline area and floodplains</td>
</tr>
<tr>
<td>• River dimension (depth, width)</td>
</tr>
<tr>
<td>• Loss of important habitats (deep pools, rapids...)</td>
</tr>
<tr>
<td>• Rapid habitat alterations (flow, velocities, temperature...)</td>
</tr>
<tr>
<td>• Support of passive drift</td>
</tr>
<tr>
<td>• Quality/quantity of habitats (deep pools, rapids, hot spots)</td>
</tr>
<tr>
<td>• Sed./nutrient concentr.</td>
</tr>
<tr>
<td>• Blocked sediment transport</td>
</tr>
<tr>
<td>• Blocked/reduced fish migration</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3rd order: Alteration of aquatic biodiversity and biomass</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Loss of ecological functions (e.g. triggers)</td>
</tr>
<tr>
<td>• reduced spawning success</td>
</tr>
<tr>
<td>• limited feeding areas</td>
</tr>
<tr>
<td>• Stranding of larvae/eggs</td>
</tr>
<tr>
<td>• Reduction due to limited habitat availability</td>
</tr>
<tr>
<td>• Drift of small fish and larvae</td>
</tr>
<tr>
<td>• Reduction in macrophytes</td>
</tr>
<tr>
<td>• Reduction in algae</td>
</tr>
<tr>
<td>• Reduction in benthic invertebrates</td>
</tr>
<tr>
<td>• Loss due to flushing events</td>
</tr>
<tr>
<td>• Loss/reduction of migratory species</td>
</tr>
</tbody>
</table>

Mitigation measures
- Sediment flushing
- Fish pass
- Minimum flow
- Peaking limitations
- No mitigation
Discussion of key risks/impacts & mitigation measures

Manual & Guidelines are structured on the basis of following five main impacts

(I) Seasonal flow changes
(II) Daily/ short-term flow changes
(III) Loss of connectivity
(IV) Impoundments
(V) Diversion/ intra basin transfer
(I) Seasonal flow changes
→ Key risks & impacts

Changes in seasonality (e.g. delayed floods, increase of dry and decrease of wet season flows)

- Changes in seasonality (e.g. delayed floods, increase of dry and decrease of wet season flows)
- Habitat alteration/loss related to increased erosion (river bed incision, bed armouring, bank erosion etc.)
- Habitat alteration/loss related to water quality changes (e.g. temperature, water clarity, salinity (relevant for the Delta), nutrient transport
- Loss of ecological functions (e.g. migration/spawning triggers)
  Loss of productivity due to reduced flood pulse (increase in permanently flooded areas and decrease in seasonally flooded areas)
(I) Seasonal flow changes

→ Loss of flood pulse / productivity

"Floodplain before the dam"
- Dry season water level
- Wet season water level

"Floodplain after the dam"
- Area not flooded any more in the wet season
- New area permanently flooded in the dry season
- Areas characterized by loss of productivity (by loss of flood pulse)

Tonle Sap

Baran 2010

https://en.wikipedia.org/wiki/Tonlé_Sap
(I) Seasonal flow changes

Mitigation

• Changes occur as sum-effect of storage dams in the catchment
  (e.g. China and LMB tributaries in Mekong basin)

• Mitigation only possible by development and application of large-scale (regional) environmental flow rules and joint operation

• Avoidance of additional impacts!
Discussion of key risks/impacts & mitigation measures

(I) Seasonal flow changes
(II) Daily/ short-term flow changes
(III) Loss of connectivity
(IV) Impoundments
(V) Diversion/ intra basin transfer
(II) Daily/ short-term flow changes

→ Key risks & impacts

Fast increase of flow

- High drifting rate of fish and macroinvertebrates, loss of food sources, offset of migration triggers, stress for aquatic organisms

Fast decrease of flow

- Stranding/ loss of fish and macroinvertebrates, stress for aquatic organisms

Morphological alterations

- Increased erosion and river bed incision causes habitat degradation (see also Table 3.3.)

Thermopeaking

- Unnatural (fast changing) temperature regime, stress for aquatic organisms, offset of migration triggers
(II) Short-term flow changes

→ Fast increase/ decrease of flow (hydropeaking)

Risk of stranding in dewatered habitats of juvenile fish
(II) Short-term flow changes
→ Fast increase/ decrease of flow (hydropeaking)
(II) Short-term flow changes

→ Mitigation

- Avoidance of hydro-peaking operations (operation mode)
- Interposition of equalization/compensation basins (or use most downstream dam in cascade as re-regulation dam)
- Reduction of peak demands and/or coordination (joint management) for up- and downramping events
- Reduction of the amplitude (increased baseflow)
- Deceleration of the rise and fall of the discharge (i.e. ramping rates) based on natural flow variations

<table>
<thead>
<tr>
<th>Location</th>
<th>decreasing water level (≈60% of the time)</th>
<th>increasing water level (≈30% of the time)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1% percentile</td>
<td>5% percentile</td>
</tr>
<tr>
<td>Luang Prabang</td>
<td>-0.030</td>
<td>-0.020</td>
</tr>
<tr>
<td>Sanakham Dam</td>
<td>-0.025</td>
<td>-0.015</td>
</tr>
<tr>
<td>Vientiane</td>
<td>-0.022</td>
<td>-0.013</td>
</tr>
<tr>
<td>Paksane</td>
<td>-0.020</td>
<td>-0.013</td>
</tr>
</tbody>
</table>

- Improvement of river morphology

19.01.2018
Discussion of key risks/impacts & mitigation measures

(I) Annual/ inter-annual flow changes
(II) Daily/ short-time flow changes
(III) Loss of connectivity
(IV) Impoundments
(V) Diversion/ intra basin transfer
(III) Barriers/ loss of river connectivity

→ Key risks & impacts

Disconnect between flow, sediment and nutrient delivery

• Habitat loss related to morphological alterations, offset of migration triggers, reduced productivity with regard to nutrient trapping and limited delivery downstream

Habitat fragmentation

• Blocked/ reduced spawning and feeding migrations, potential isolation of sub-populations

Turbine passage/ spillflow passage

• Stress, fish damage and kills

Water quality changes

• E.g. oxygen supersaturation
(III) Loss of connectivity
→ Migrations at different life stages

Halls & Kshatriya (2009)
(III) Loss of connectivity
→ Basin connectivity

Dams and impoundments cause loss of longitudinal, lateral and vertical connectivity

Continuity interruptions cause disconnection of

- spawning and nursing grounds
- seasonal habitats (wet-/dry season habitats)
- feeding grounds
- populations

Species might not be able to fulfil their life cycle!
Declining stocks cause loss in fisheries yield!

(Grill et al. 2014)
(III) Loss of connectivity

- Cumulative effects in chains of impoundments

Passive drift of eggs and larvae no longer supported if $v < 0.2 \text{ m/s}$

Reduced orientation if $v < 0.3 \text{ m/s}$

Upstream passage efficiency

Downstream risk of injuries and fish kills

Small species
- 2-15% turbine mortality
- 5% spillway mortality

Large species
- 35-80% turbine mortality
(III) Loss of connectivity
→ Siting (sensitive locations)

Important for avoidance and prioritisation of restoration activities!
(III) Barriers

Fish pass types

Upstream
- Nature-like: Bypass channels & rock ramps
- Technical: Vertical slot fish passes

Downstream
- Fish protection: Screens
- Fish passage: Bypasses
- Fish-friendly turbines
- Spill flow

Large scale bypass systems
(III) Loss of connectivity

Mitigation: Temporary shutdown & low level gates

- Design of spillways and low level gates are of high relevance but need to be considered already in the planning phase
  
  e.g. flow velocity at Xayaburi too high for safe passage

Design of spillways which

- return river to its natural (free flowing) state and
- enhance sediment transport

Example: Pak Mun Dam opened for 4 months during wet season but still questionable if conditions support migrations of all species.
Discussion of key risks/impacts & mitigation measures

(I) Annual/ inter-annual flow change
(II) Daily/ short-time flow changes
(III) Loss of connectivity
(IV) Impoundments
(V) Diversion/ intra basin transfer
(IV) Impoundments → Key risks & impacts (1)

Trapping of sediments

• Morphological alteration and habitat loss.
• Upstream: sedimentation, possibly filling up of deep pools, reduced vertical connectivity, change of choriotopes (fish, benthic invertebrates), degradation of shoreline habitats;
• Downstream: loss of habitat structures (e.g. sand bars), reduced habitat quality (e.g. change of choriotopes, river bed armouring), reduced connectivity to tributaries and floodplains (related to river bed incision)

Loss of free flowing river sections

• Delay/deposition of drifting eggs & larvae
• Loss/reduction of fish species adapted to free flowing rivers
• Loss of orientation for upstream migrating fish
(IV) Impoundments
→ Key risks & impacts (2)

Increased visibility, stratification & temperature changes

- Algae growth, stress due to water quality changes (temperature, oxygen)

Water level changes within impoundment

- Stranding of fish and macroinvertebrates, degradation of shoreline habitats

Reservoir flushing

- Flushing of benthic organisms and fish, potentially high losses related to high turbidity, destruction of habitats
(IV) Impoundments

→ Potential loss of deep pools & rapids

Deep pools and rapids

![Graph showing pool area and depth across river km]

- Pool area in ha
- Pool depth in m
(IV) Impoundments
→ Loss of ecological functions (passive drift)

Passive drift of eggs and larvae no longer supported if $v < 0.2 \text{ m/s}$

Red areas highlight sections with velocities too low for passive transport (i.e. $<0.2 \text{ m/s}$)

(0.3 m/s = rheoactive velocity required by upstream migrating adults for orientation!)
Reservoir flushing

Potential risks

- physico-chemical effects
  - effects on benthic invertebrates
  - direct effects on fish
  - indirect effects on fish

- biocoenotic effects
  - lethal effects
  - reduced food supply
  - reduced visibility
  - stress, pathogenic effects
  - emigration
  - fish kills
  - loss of habitats for reproduction and juveniles

- hydro peaking
- turbidity, deposition of fine sediments
- O₂-deficit, toxic load
- increased drift
- retreat into the hyporheic interstitial
(IV) Impoundments

→ Mitigation

- In general: **measures aiming for a more natural hydromorphology** (e.g. sediment transport, seasonal/ sub-daily flow distribution) can also be considered as **beneficial for aquatic organisms**

- Many Mekong fish are **substrate spawners** and therefore rely on a natural substrate composition

- Most fish species’ life cycles are connected to the **hydrologic cycle** (e.g. trigger for migrations, seasonal availability of habitats)

- **Weakening/slowing down the erosional wave** brings benefits on a large scale
  - Longitudinal (along the Mekong mainstream)
  - Lateral (towards the floodplains and confluences with tributaries)
Discussion of key risks/impacts & mitigation measures

(I) Annual/ inter-annual flow changes
(II) Daily/ short-time flow changes
(III) Loss of connectivity
(IV) Impoundments
(V) Diversion/ intra basin transfer
(V) Diversion or intra-basin transfers

→ Key risks & impacts

Reduction of river dimension

• Reduced productivity, species alteration (e.g. loss or large species), reduced depth may impact connectivity, water quality changes

Homogenisation of flows

• Armouring of beds and bars due to reduced sediment transport, habitat loss

Increased flow in receiving basin

• Increased bank erosion and bed incision to accommodate increased flow

Water quality changes

• Stress
(V) Diversion
→ Mitigation: Environmental flow

Definition and terms

→ discharges of a particular magnitude, frequency and timing, which are necessary to ensure that a river system remains environmentally, economically and socially healthy (Gupta, 2008).
(V) Diversion

Mitigation: Environmental flow

- Prior assessment of migration routes/preferences
- Dam height: 20m
- Dam length: 2.9km
- Impoundment: 35km
- Possibly 2nd fish pass at diversion weir required
- Sufficient flow (attraction, depth)

Considerations for Sambor

Detailed habitat modelling in free-flowing channel to ensure sufficient flow for sustaining:

- Natural flow dynamics,
- Natural sediment distribution,
- Natural temperature regime,
- Sufficient depth (large species),

(Annandale 2014)
(V) Diversion

Conclusions & open questions

- Environmental flow (EF) relevant for different situations
  - Diversion hydropower plants
  - Alteration of flow distribution between parallel channels (e.g. Don Sahong, Sambor)
  - Storage hydropower plants (release downstream)
- EF has to be “designed” for local conditions
  - Detailed assessments are required for the respective location
- EF is always a trade-off between economic, social and ecological interests
  - Multi-criteria assessment
- In the Mekong region, EF should also incorporate flows which are suitable for sustaining floodplain habitats
Avoidance > Minimisation > Compensation

Master plans!

Favorable locations – “WHERE”

Danube basin-wide framework

Technical solutions – “HOW”

Not legally binding but serving as a guidance for national application

Transparent, structured, reproducible and criteria based approach on two levels

National/Regional Level

Regional assessment, classifying the potential appropriateness of water bodies for hydropower use, independently from individual application

> Hydroelectric potential
> Ecological and landscape value

Project-Specific Level

Project-specific assessment of the individual application by weighing all pros and cons

> Results of the regional assessment
> Project-specific criteria
> Further socio-economic aspects

Not only at dam site, but in entire impact section!

(ICPDR, 2013)
Thank you for your attention!

Carina Seliger
Institute of Hydrobiology and Aquatic Ecosystem Management
University of Natural Resources and Life Sciences Vienna

Gregor-Mendel-Strasse 33, A-1180 Vienna
Tel.: +43 1 47654-81218, Fax: +43 1 47654-81217
carina.seliger@boku.ac.at
www.boku.ac.at/ihg