Sustainable Hydropower Development
Alternatives for the Mekong:
Maintaining the Flows that Nourish Life

Boy in basin navigates through floating village in Tonle oto: Sitha Som, Conservation International

Mekong River in Laos. Photo: Andi Mezger

13 July 2018
Why focus on fish?

- **North America**: FAO: 0.17 million tonnes
- **West Europe**: FAO: 0.45 million tonnes
- **South America**: FAO: 0.35 million tonnes
- **Africa**: FAO: 2.4 million tonnes
- **Mekong**: Local studies: 2.1 million tonnes
Mekong Fisheries

Lower Mekong
1-1.4 million tonnes
US$ 1,700 million

Middle Mekong
0.9-1.2 million tonnes
US$970 million

Upper Mekong
60,000 tonnes
US$37 million

Source: MRC 2007
103 species are long-distance migrants

Long distance migrants represent at least 39% of the fish yield (i.e. 800,000 tonnes per year)

Sources:
Ziv et al. 2012
Strategic Assessment 2010
MRC 2004 (map)
Lower Se San II Hydropower Project

Located at the confluence of two of the largest tributaries that pour into the Mekong mainstream just above the Tonle Sap Lake and Delta
Sambor Hydropower project in the Lower Mekong Basin
SUSTAINABLE HYDROPOWER MASTER PLAN FOR THE XE KONG BASIN IN LAO PDR

FINAL REPORT

A component of

Hydropower Development Alternatives for the Mekong Basin:
Maintaining the Flows that Nourish Life

Submitted to
Government of Lao PDR

Submitted by
Natural Heritage Institute, San Francisco, California
In Association with the National University of Lao

January 2018
Policy on Sustainable Hydropower Development
12 January 2015

➔ States **Goals** and **Procedures**, not **Substantive Criteria** or Standards—E.g:

**Goals:** Ministries and project developers instructed to **prevent and mitigate** any potential risks to the natural resources and the environment

**Procedures:** Comprehensive Environmental and Social Impact Assessment including **cumulative and transboundary impacts**
<table>
<thead>
<tr>
<th>Counteract impacts</th>
<th>Barrier to migratory fish &amp; inundation of habitat</th>
<th>Trapping of sediments and nutrients</th>
<th>Alteration of natural flows</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siting</td>
<td>1. Above existing barriers to migration&lt;br&gt;Avoid inundation of critical habitat for endemic native species</td>
<td>2. Deeper canyons in headwaters</td>
<td>3. Re-regulation of altered flows for hydropeaking at or below terminal dam</td>
</tr>
<tr>
<td>Design</td>
<td>4. Fish pass facilities, low-impact turbines, fish screens</td>
<td>5. Low level or radial gates for discharge</td>
<td>6. Low capacity factors of power-plant to accommodate variable discharges; Pumped storage</td>
</tr>
<tr>
<td>Operation</td>
<td>7. Maintain minimum velocities through reservoirs to maintain larval drift</td>
<td>8. Flushing, sluicing, density current discharges</td>
<td>9. Run of River operations</td>
</tr>
</tbody>
</table>
1. **Siting** future hydropower dams in locations that do not inundate or block fish passage into the habitats for migratory species.

2. **Designing** the dams to efficiently pass sediments and nutrients;

3. **Operating** the dams to maintain a semblance of the natural flow patterns.
# Four Tiers of Sustainable Replacement Dams

<table>
<thead>
<tr>
<th>Item</th>
<th>Tier 1</th>
<th>Tier 2</th>
<th>Tier 3</th>
<th>Tier 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Xe Kaman 2A</td>
<td>Xe Kaman 2B</td>
<td>Nam Ang-Natabeng 1</td>
<td>Houay Axam</td>
</tr>
<tr>
<td>(Lat./Long.)</td>
<td>15°15.01'N 107°26.33'E</td>
<td>15°16.52'N 107°27.00'E</td>
<td>15°11.57'N 107.16887'E</td>
<td>16°01.47'60N 107.0440092E</td>
</tr>
<tr>
<td>Province</td>
<td>Attapeu</td>
<td>Attapeu</td>
<td>Xekong</td>
<td>Xekong</td>
</tr>
<tr>
<td>River</td>
<td>Xe Kaman</td>
<td>Xe Kaman</td>
<td>Xe Kaman</td>
<td>Houay Axam</td>
</tr>
<tr>
<td>Estimated power (GWh/yr)</td>
<td>160</td>
<td>664*</td>
<td>183</td>
<td>518</td>
</tr>
<tr>
<td>Installed capacity (MW)</td>
<td>64*</td>
<td>185</td>
<td>58*</td>
<td>152</td>
</tr>
<tr>
<td>Rated head (m)</td>
<td>48.6</td>
<td>78.8</td>
<td>640</td>
<td>566</td>
</tr>
<tr>
<td>Design discharge (m³/s)</td>
<td>155</td>
<td>90</td>
<td>20.7</td>
<td>78.2</td>
</tr>
<tr>
<td>Full supply level (m)</td>
<td>280</td>
<td>370</td>
<td>640</td>
<td>566</td>
</tr>
<tr>
<td>Catchment area (km²)</td>
<td>1970</td>
<td>1740</td>
<td>203</td>
<td>784</td>
</tr>
<tr>
<td>Mean annual flow (m³/s)</td>
<td>77.5</td>
<td>68.4</td>
<td>10</td>
<td>39</td>
</tr>
<tr>
<td>Total reservoir volume (m³)</td>
<td>20.8</td>
<td>333</td>
<td></td>
<td>16.5</td>
</tr>
</tbody>
</table>
SUSTAINABLE HYDROPOWER MASTER PLAN
FOR THE XE KONG BASIN IN LAO PDR

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January 2018
Sambor Hydropower Dam Alternatives Assessment

Final Report

[Includes Comparison Of Dam And “No-Dam” Alternatives]

A component of

Hydropower Development Alternatives for the Mekong Basin: Maintaining the Flows that Nourish Life

Submitted to
Royal Government of Cambodia

Submitted by
Natural Heritage Institute, San Francisco, California

December 2017
Scope of MoU

→ Assess alternative dam sites, designs and operations to achieve specified environmental and social performance objectives

→ Assess “no-dam” alternative that will achieve of exceed net benefits of dam alternatives
No Downstream drift of larvae through 82km reservoir

Catastrophic decline (e.g. $>80\%$) of fish productivity
Sambor Reach of Mekong River

→ Migratory corridor that experiences the largest movement of biomass on the planet every year

→ Fish move from Delta and Tonle Sap into Cambodian floodplains, 3-S basin and through Khone Falls

→ Value of fishery to Cambodia: $1.4 billion/yr
Sediment Deposition of Main Stream Dams

Originally Proposed Sambor Dam

With Sambor Dam Alternative 7
## Sediment Management Techniques Considered

<table>
<thead>
<tr>
<th>Technique</th>
<th>Feasible?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dredging</td>
<td>No</td>
</tr>
<tr>
<td>Hydrosuction (HSRS)</td>
<td>No</td>
</tr>
<tr>
<td>Dry Excavation</td>
<td>No</td>
</tr>
<tr>
<td>Sluicing</td>
<td>No</td>
</tr>
<tr>
<td>Bypassing</td>
<td>No</td>
</tr>
<tr>
<td>Drawdown Flushing</td>
<td>No</td>
</tr>
</tbody>
</table>

Amount of sediment retained in long term: 4,580 million $\text{m}^3$ to 4,790 million $\text{m}^3$
Area Inundated in the Mekong Delta (Sea Level Rise = 1m)

(Source: MRC Technical Paper No. 24, September 2009)
Sambor 7A - Sustainable Hydropower
NEW DESIGN PARADIGM

Conventional Approach

• Select Dam Site
  – Maximize Energy Production
  – Design Hydropower Facility
• Identify Impacts
• Develop Mitigation Measures

• Result
  – Non-Optimized Solution
  – Mitigation inadequate for sustainability standard
  – Risk of Knowledge Gaps not explained

New Approach

• Identify Impacts
  – Social, Fisheries, Sediment
• Develop Environmental Performance Criteria
  – Integral part of Design Criteria
• Optimize Design
  – Concurrently Consider all Objectives

• Result – Optimized Solution
  – Balanced Design by Integrating:
    • Fish Passage
    • Sediment Passage
    • Relocation Needs
    • Site Selection
    • Energy Production
  – Communicate Risk of Knowledge Gaps
Environmental Performance Criteria

• Fisheries
  – Fish Survival: 95% at Sambor
  – Fish Passage
    • Up- and Downstream
  – Larval Drift
    • Downstream Passage
    • Through Reservoir
    • Flow Velocity ≥ 0.3m/s
  – Minimize Barotrauma Potential
    • Power House
    • Spillway
  – Minimize Turbine Mortality
    • Blade Strike
    • Shear

• Sediment
  – Pass ~95% of Suspended Sediment
    • Nutrients – Sustain Fisheries
    • Mekong Delta – Agriculture & Food Security
  – Maintain Reservoir Storage
    • Design Dam to remove deposited Bed Load
  – No Significant Deposition in Deep Pools

• Relocation
  – Minimize the Number of People to be relocated
  – Use 100-year Flood as Criterion
  – No Additional Flooding of Stung Treng
1. Anabranch bypass channel fishpass

2. Navigation/Fish Lock

3. Pool-type fishpass

Paths of migratory fish
> 0.3 m/s (water velocity to maintain larvae drifting)

< 0.3 m/s (larvae stop drifting and die)
DOWNSTREAM FISH PASSAGE EFFECTS OF PRESSURE ON FISH

Barotrauma

DAM
Turbine

100 kPa

200 kPa

300 kPa

10 m

20 m

100 kPa
Impacts of pressure change (barotrauma)

e.g. 20 m dam

Upstream

In turbine

Swim bladder approx. 3X volume

Photograph courtesy of Luiz Silva
MITIGATING BAROTRAUMA

. . . but also need to consider shear and blade strike
Impacts on Potential Yield

• If fish passes are 95% efficient, potential yield predicted to decline by -13% to -30%.

• If fish passes were 60% efficient, potential yield could decline by as much as 70%.

• Potential yield would fall to zero if fish pass efficiency was less than 45% - 50%.
Potential Impact on Irrawaddy Dolphins (1)

Dolphin sightings and management zones in relation to the proposed Sambor CSP and Sambor Alt_7 dam. Sightings based on Beasley and colleagues (2012), Ryan and colleagues (2010) and Beasley unpublished data.

Potential Impact on Irrawaddy Dolphins (2)

• Findings and Conclusion:
  – Dolphins are threatened with extinction
  – All Sambor Dam options substantially increase this risk
  – Original Sambor would certainly fragment the populations, greatly increasing the risk
  – Efficacy of Sambor Alt_7? No current evidence that dolphins use the anabranch channel but may adapt
## Findings and Conclusions

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Result</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Small dam on side channel (Alt. 6A)</td>
<td>Not <strong>financially</strong> feasible</td>
<td>Dam backs up water into main channel so not enough water goes through turbines</td>
</tr>
<tr>
<td>2. Large dam on main channel (Alt 7A) with all mitigation measures including fish screens</td>
<td>Not <strong>financially</strong> feasible</td>
<td>Large costs of the fish screens</td>
</tr>
<tr>
<td>3. Large dam on main channel (Alt. 7A) with all mitigation measures except fish screens</td>
<td>Substantial risk to productivity of fishery</td>
<td>1. Mitigation measures untested + 2. Uncertainties in fish behavior</td>
</tr>
<tr>
<td>4. Solar power augmentation of existing hydro</td>
<td><strong>Only option that provides a positive net economic benefit</strong></td>
<td>Cost competitive with no impacts on fishery</td>
</tr>
</tbody>
</table>
Sustainable Hydropower Development Alternatives for the Mekong River Basin to Maintain the Flows that Nourish Life

Hydro/Solar Hybrid Power

Lower Se San II Hydropower Project
Cambodia: High irradiance resource

Average annual insolation: 1,893 kWh/m²

Picture source: SolarGIS; Irradiance source: Meteonorm
Objective:

⇒ The Challenge:

Present a “No-Dam” alternative comparable or superior to Proposed Hydropower Projects with respect to relevant decision factors for Governments and investors:

✓ Power Reliability
✓ Cost of Power Generation
✓ Power Output
✓ Timeline for Deployment
✓ Financial Risk Avoidance
Reliability

Power grid operators care about:

1. Reliability of power to meet demands as they occur

2. Cost of power

Photo source: http://beprojectidea.blogspot.com/2014/11/electrical-power-transmission-of-bulk.html
Seasonal variability in hydropower generation

Power production at Sambor Alternative 7A. The power production follows the mainstream flow. During the wet season the reservoir spills additional water into the Anabranth, increasing the flow above normal. The operational rule keeps low water level at flow <20,000m³/s.
Estimated power production potential by time of day and time of year from solar PV arrays (total 10 km² area)

Source: NREL SAM modeling tool for a 500MW installation. Bangkok meteorological data.
Example: Daily PV power fluctuations

- PV fluctuations on a sunny day (Series 1) and on a cloudy day (Series 2). Fluctuations can be handled by AGC’s as HP adjustments.
- Short fluctuations <10MW and <8 sec are not handled by AGC’s at LongYangXia, where such short fluctuations are not reported to be a problem.

Complimentary PV and Hydro Operation

**Longyangxia hydropower plant**
- Commissioned in 1989
- Installed capacity: 1,280MW (4×320MW)
- Electricity production: 5,942GWh/year
- Reservoir area: 380 km²
- Normal storage water level: 2600m; Dead water level: 2530m
- Regulation storage: 193.5×108m³
Complimentary PV and Hydro Operation

Complimentary operation:
- Solar PV is treated as an additional non-adjustable unit of hydropower station
- Automatic regulation of the hydro output to balance solar resource’ variability before dispatching to the grid

龚传利，王英鑫，等，“龙羊峡水光互补自动发电控制策略及应用”，水电站机电技术，Vol.37 No.3
Battery storage to counteract fluctuations due to cloud cover

- May need additional battery storage to even out fluctuations due to changes in cloud cover
- But performance is predictable (unlike performance of fish ladders)
Utility-scale battery systems
Cost reductions much faster than anticipated
COST
PV market and price developments

Dramatic cost reduction of PV modules led to a boom in installations

Cost of Solar: Lower tariffs than the best Sambor Hydro

- Tariff for Sambor Alternative = 11-12 USc/kWh (expensive because of mitigation measures)

- Tariff will depend on financing package – concessionary finance hard to obtain because of impacts on Vietnam (need letter of no objection)

- Typical tariff for Floating PV: 6.5-10 USc/kWh which will decrease over time
PV on LSS II: Potential investments
Initial system cost estimation for Option 1 (matching LSS II output)

<table>
<thead>
<tr>
<th></th>
<th>1,000 MWp site [million USD]</th>
<th>USD/Wp*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module</td>
<td>340</td>
<td>0.34</td>
</tr>
<tr>
<td>Inverter</td>
<td>90</td>
<td>0.09</td>
</tr>
<tr>
<td>Electrical work</td>
<td>196</td>
<td>0.20</td>
</tr>
<tr>
<td>Total PV equipment</td>
<td>626</td>
<td>0.63</td>
</tr>
<tr>
<td>Floating structure</td>
<td>169</td>
<td>0.17</td>
</tr>
<tr>
<td>Anchoring</td>
<td>42</td>
<td>0.04</td>
</tr>
<tr>
<td>Total floating PV</td>
<td>837</td>
<td>0.84</td>
</tr>
<tr>
<td>Grid connection cost</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>210</td>
<td>0.21</td>
</tr>
<tr>
<td>Total investment cost</td>
<td>1,047</td>
<td>1.05</td>
</tr>
</tbody>
</table>

Based on those assumption and the available solar resources, the cost of solar electricity would be in the range of: USD-cents 7.5 / kWh (compared to 6.9cts / kWh for LSSII hydro)

Note: NOT including subsidized or concessional financing opportunities
POWER OUTPUT
How Much Additional Power From Solar Augmentation Without Curtailments???

<table>
<thead>
<tr>
<th></th>
<th>LSS2</th>
<th>Xe Kaman 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydro:</td>
<td>400 MW</td>
<td>290 MW</td>
</tr>
<tr>
<td>Solar:</td>
<td>400 MW</td>
<td>400-500 MW</td>
</tr>
</tbody>
</table>
ISSUE CONFRONTING POWER SECTOR PLANNERS TODAY AND TOMORROW:

At any given time, what is the next least-cost option for meeting the next increment of demand in the system or export opportunity?

Answer Today: The next facility to commission is not Sambor—but solar component at LSS2.

Answer Tomorrow: Other solar or solar/hybrid ? ? ?
TIMELINE FOR DEPLOYMENT
Example: Utility-scale solar PV projects

- Kamuthi Solar Power Project
- India
- 648 MW, 10 km²
- Commission year: 2016

⇒ Construction time: 8 months!
Advantage of Solar PV: Modular

➢ No scale economies – no need to build giant projects

➢ Can be built in small increments

➢ Increments can match growth of demand: if demand grows faster, build a larger increment

➢ if demand grows slower than expected, build a smaller increment
Where to go from here?

Implementation/Propagation Phases

1. Technical support to national governments

2. Continued engagement at highest levels of national governments

3. Equip Gov. of Vietnam to influence choices by upstream riparians

4. Video-Animation of Tools and Techniques

5. Harvest and propagate lessons into other settings with high resource values and intense development pressure
For instance: Amazon Basin

- 3500-5000 aquatic species
- 142 major hydropower dams
- 160 proposed new dams (loss of 50% of connectivity in Napo, Maranon, Ucayali, Veni, Mamore)
- Build Rapid Assessment Tool to identify best prospects for solar hybrid retrofit—large storage dams with high irradiance
- Supplant highly impactful projects in Andean tributaries

Photo: http://charismaticplanet.com/the-greatest-amazon-river-is-home-to-several-extremes/
Other Targets of Opportunity

• Himalayan Headwaters:
  – Nepal and Bhutan exports to India
  – Ganges
  – Indus

• Headwaters of the Nile in Ethiopia

• Okavango Headwaters in Angola

• Zambesi Delta—Kariba and Cahora Bassa Dams

• Niger Basin and Delta
THANK YOU FOR JOINING TODAY’S WEBINAR!
For more information, or to request NHI’s project reports, send a request to jessnagtalon@n-h-i.org

https://drive.google.com/open?id=1ldxGigFOoids-UUk1bkpTQdh2YvZd2HOa

https://drive.google.com/open?id=1Z51P-28TJ_6KbrbC_wdQrFPvZ1MseyXJ