Sustainable Hydropower Development Alternatives for the Mekong:

Maintaining the Flows that Nourish Life

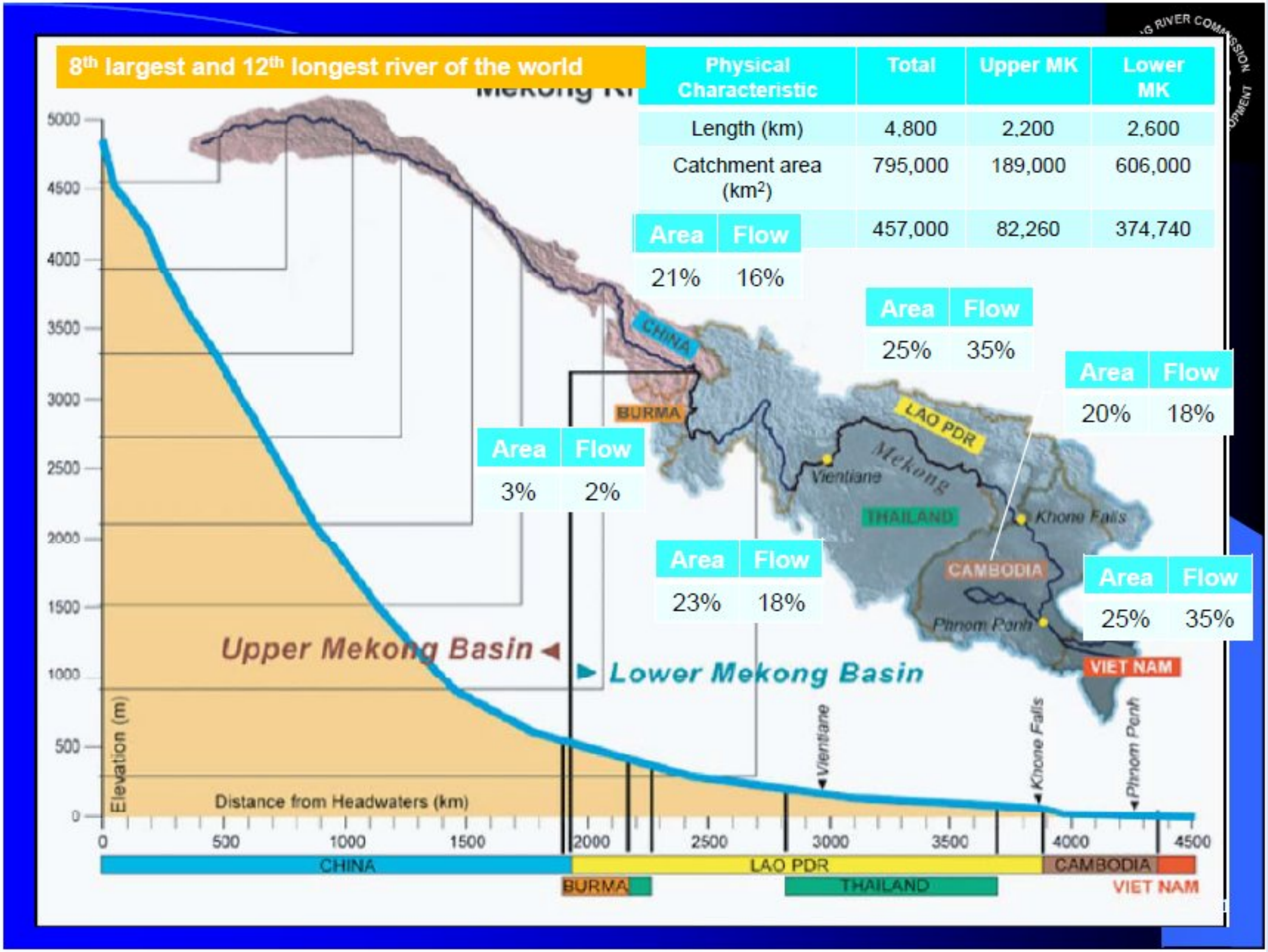
Boy in basin navigates through floating village in Tonle oto: Sitha Som, Conservation International
.

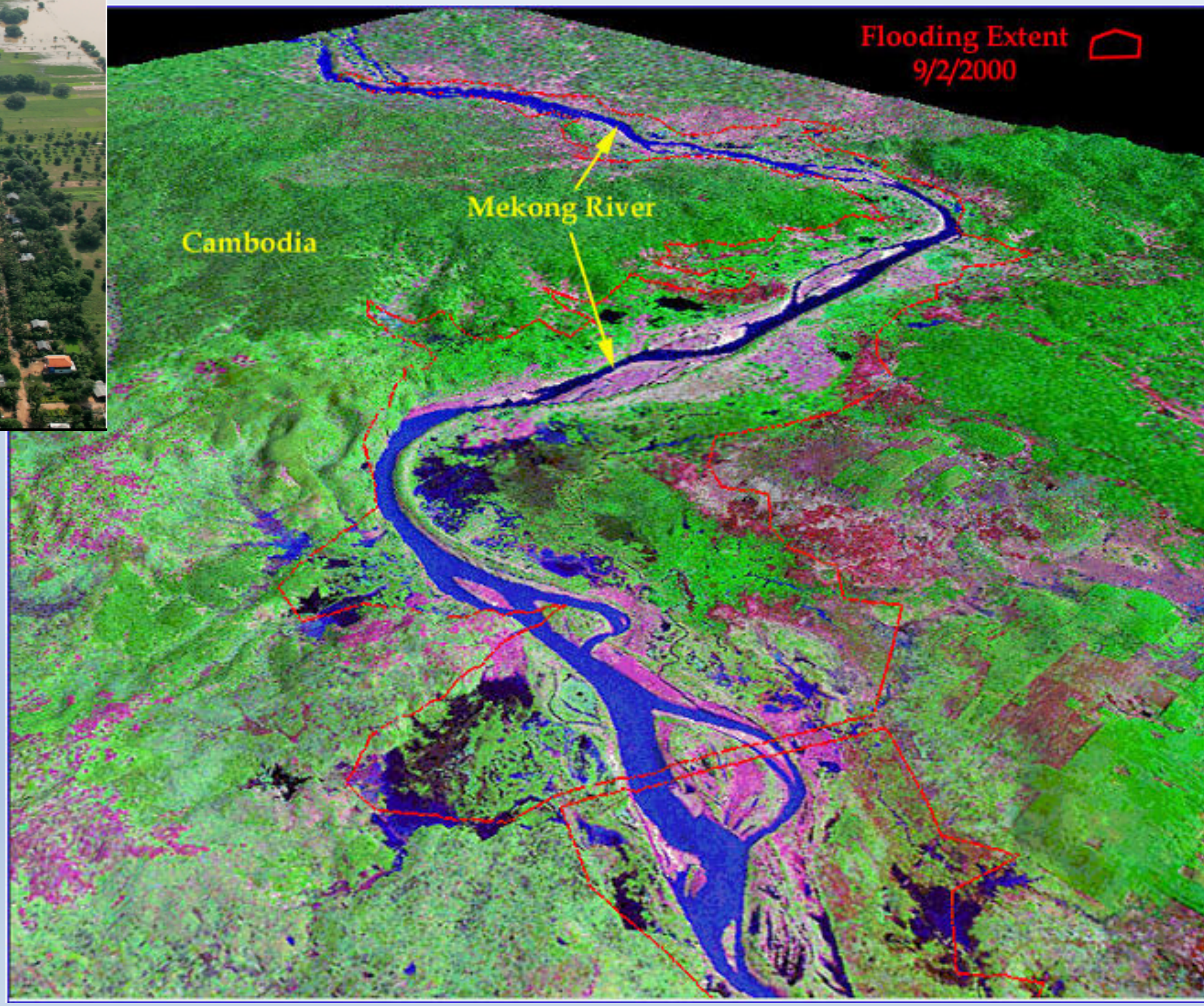
Mekong River in Laos. Photo: Andi Mezger

13 July 2018

8th largest and 12th longest river of the world

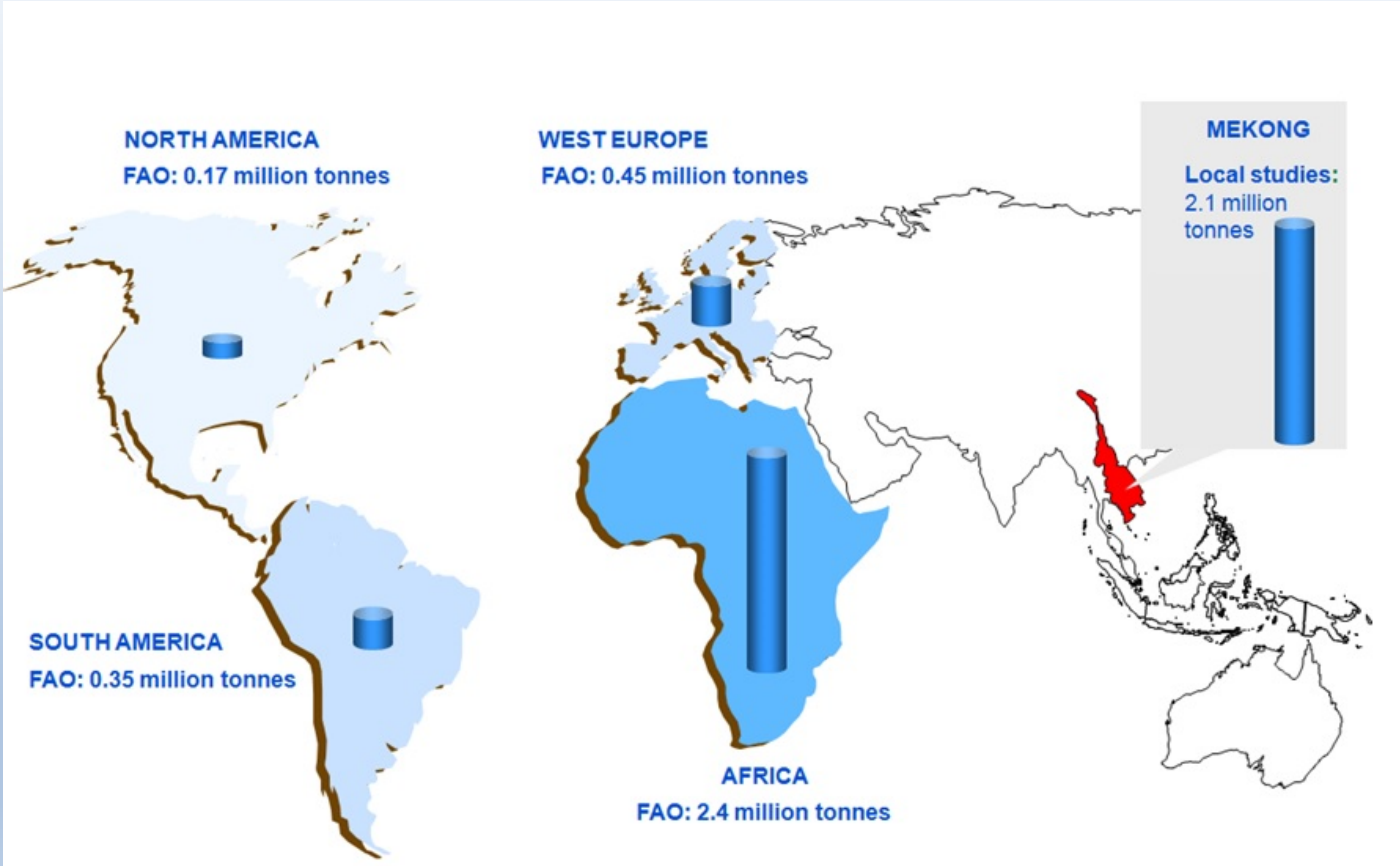
Physical Characteristic	Total	Upper MK	Lower MK
Length (km)	4,800	2,200	2,600
Catchment area (km²)	795,000	189,000	606,000
	457,000	82,260	374,740




Flooding Extent
9/2/2000
Mekong River
Cambodia

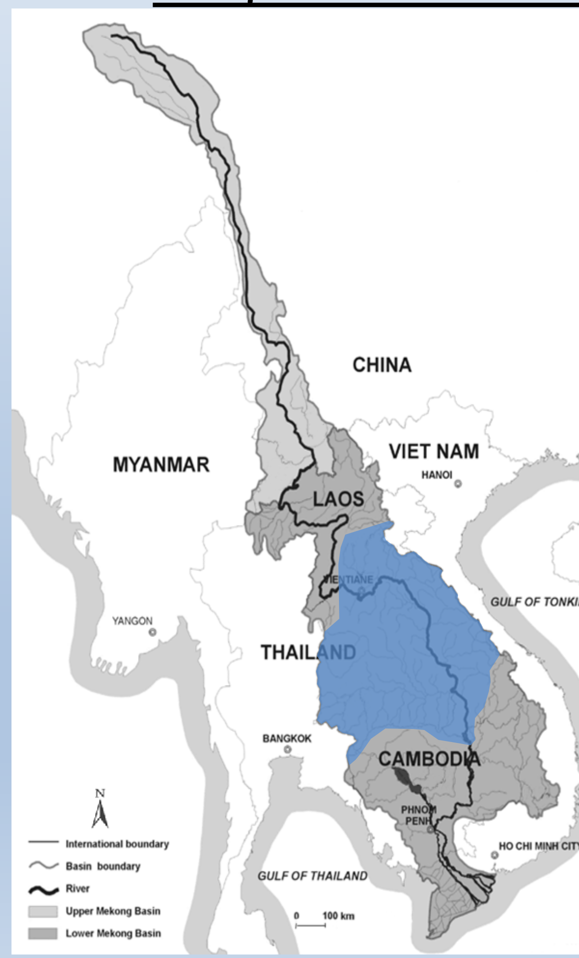


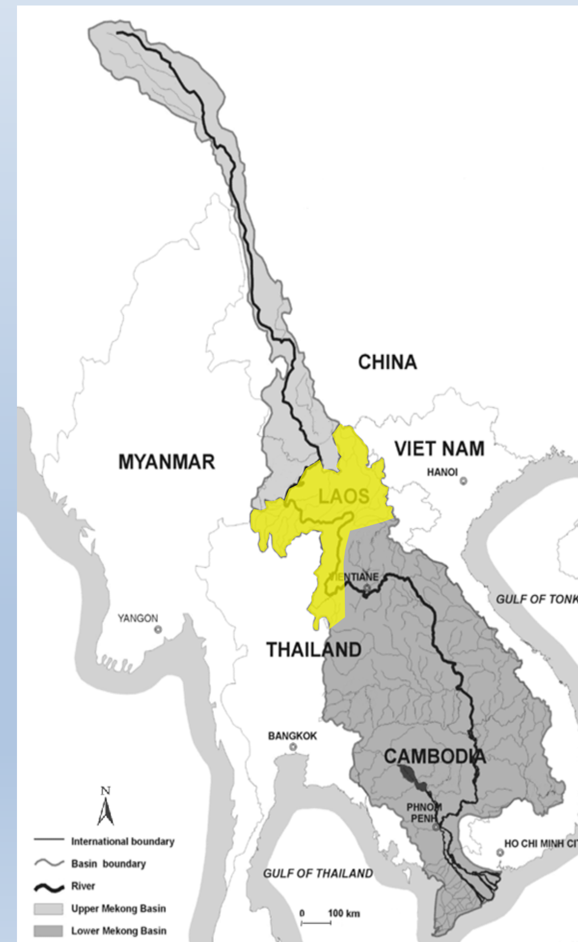

Why focus on fish?



Mekong Fisheries

Lower Mekong	Middle Mekong	Upper Mekong
1-1.4 million tonnes	0.9-1.2 million tonnes	60,000 tonnes
US$ 1,700 million	US$970 million	US$37 million

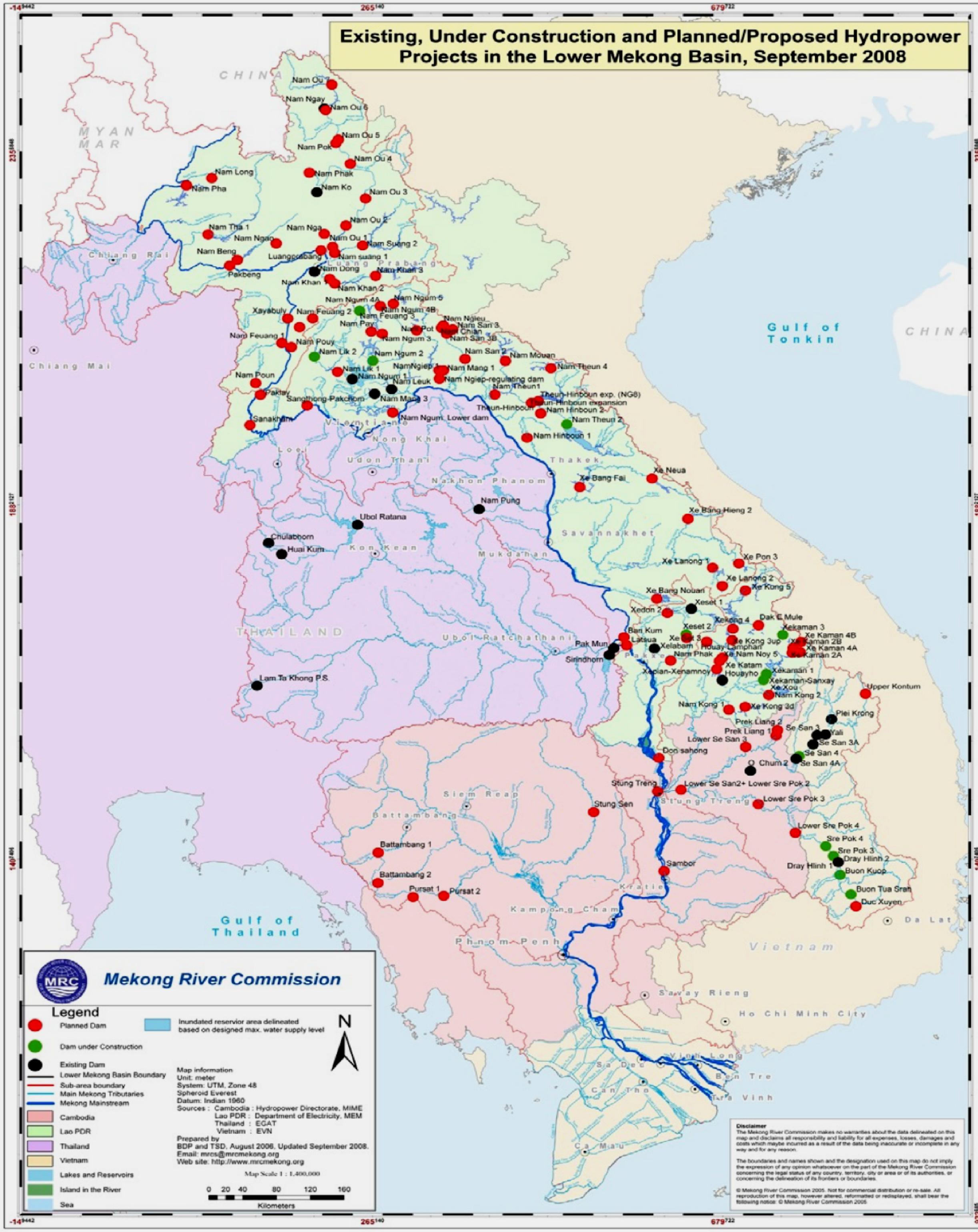


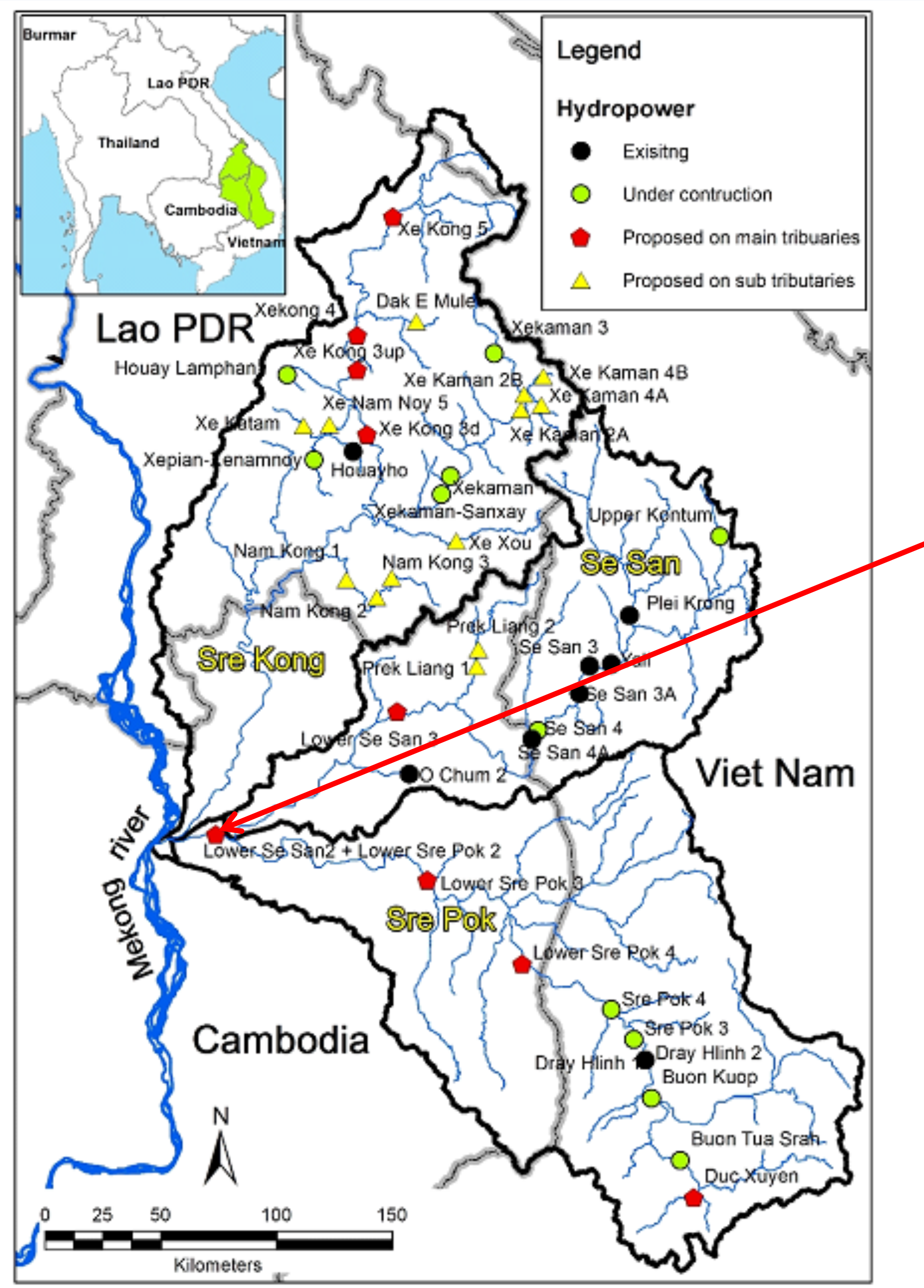


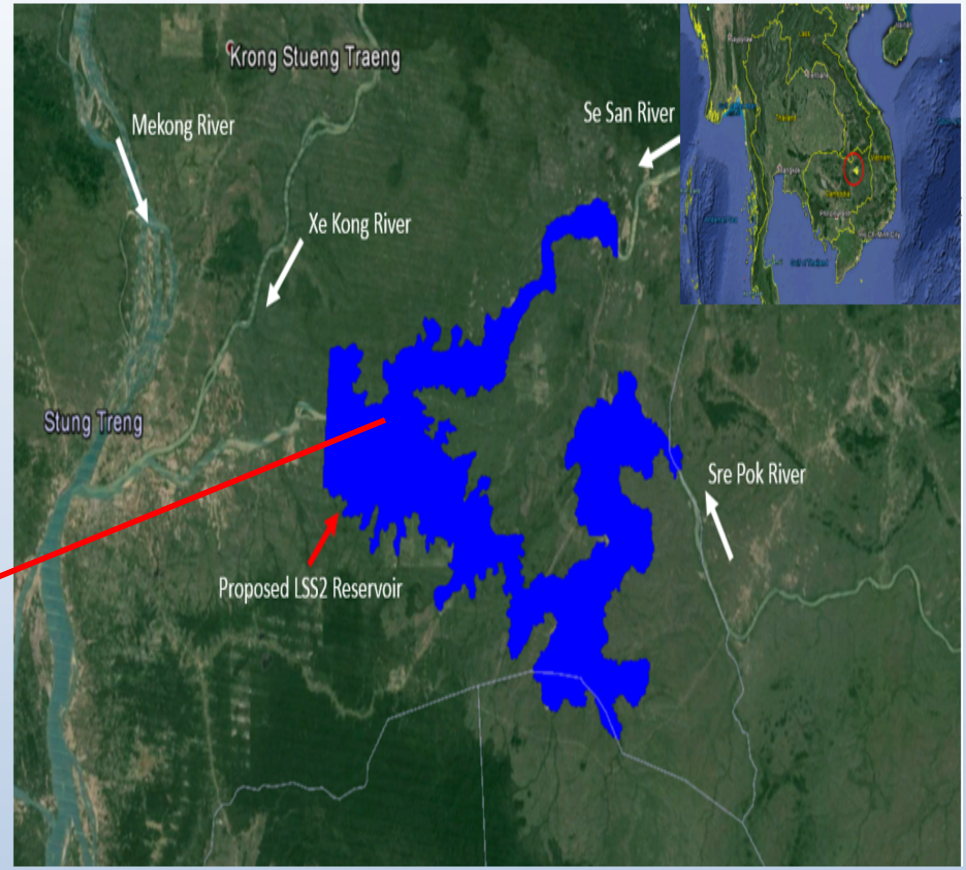
Source: MRC 2007

- 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)

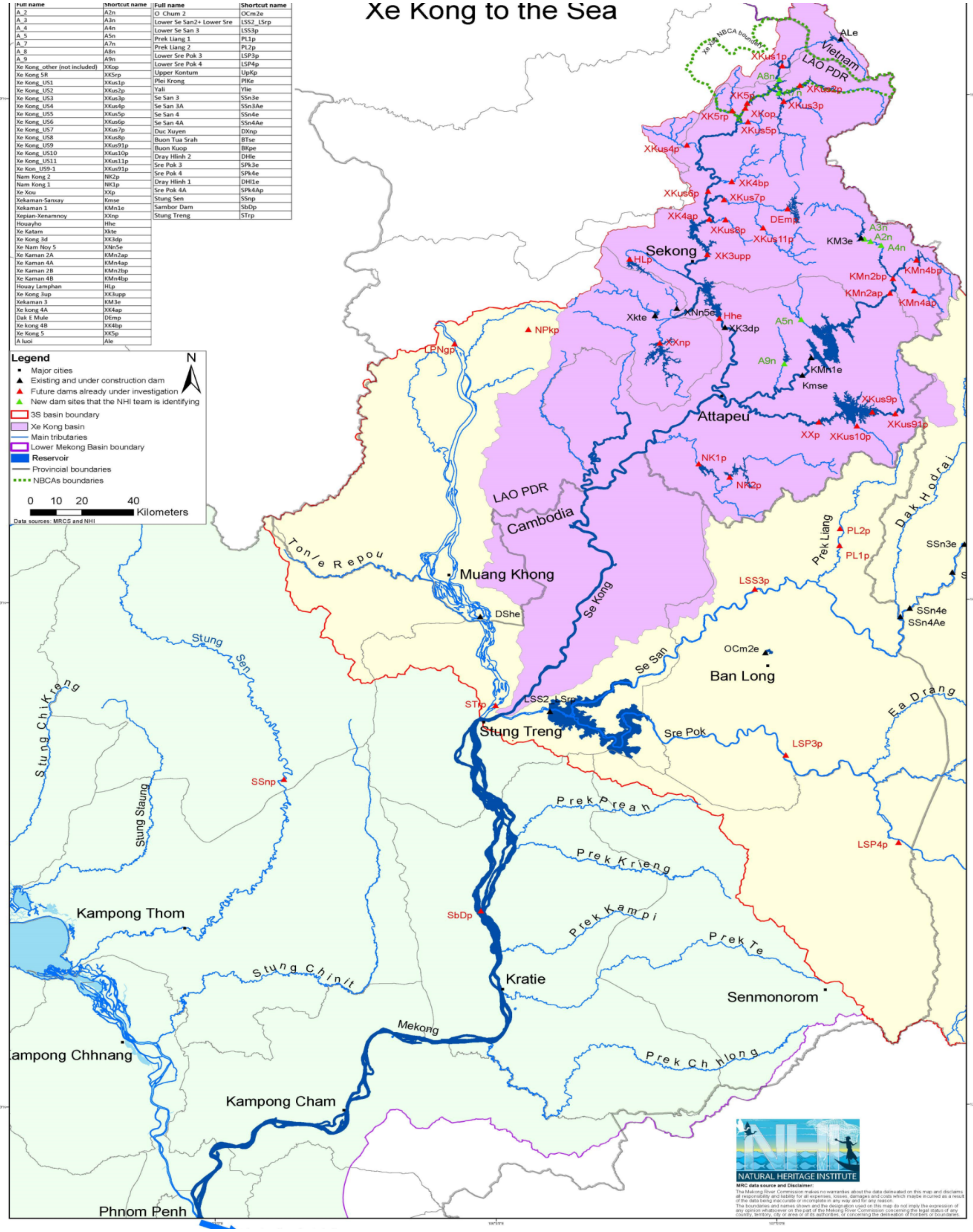

Existing, Under Construction and Planned/Proposed Hydropower Projects in the Lower Mekong Basin, September 2008
Mekong River Commission
MRC
Legend
Planned Dam
Dam under Construction
Existing Dam
Lower Mekong Basin Boundary
Sub-area boundary
Main Mekong Tributaries
Mekong Mainstream
Cambodia
Lao PDR
Thailand
Vietnam
Lakes and Reservoirs
Island in the River
Sea
Inundated reservior area delineated based on designed max. water supply level
Map information
Unit: meter
System: UTM, Zone 48
Spheroid Everest
Datum: Indian 1960
Sources : Cambodia : Hydropower Directorate, MIME
Lao PDR : Department of Electricity, MEM
Thailand : EGAT
Vietnam : EVN
Prepared by
BDP and TSD, August 2008, Updated September 2008.
Email: mrcs@mrcmekong.org
Web site: http://www.mrcmekong.org
Map Scale 1 : 1,400,000
0 20 40 80 120 160
Kilometers
N
CHINA
MYANMAR
THAILAND
Gulf of Tonkin
Gulf of Thailand
Vietnam
Chiang Mai
Chiang Rai
Vientiane
Nong Khai
Udon Thani
Nakhon Phanom
Savannakhet
Kon Kean
Mukdahan
Ubol Ratchathani
Siem Reap
Battambang
Stung Treng
Kratie
Kampong Cham
Phnom Penh
Svay Rieng
Ho Chi Minh City
Da Lat
Ben Tre
Tra Vinh
Can Tho
Ca Mau
Nam Ou
Nam Ngay
Nam Ou 6
Nam Ou 5
Nam Pok
Nam Ou 4
Nam Long
Nam Pha
Nam Phak
Nam Ko
Nam Ou 3
Nam Ou 2
Nam Tha 1
Nam Nga
Nam Ngao
Nam Ou 1
Nam Suang 2
Nam Beng
Luangprabang
Pakbeng
Nam Dong
Nam Khan 3
Nam Khan 2
Xayabuly
Nam Feuang 2
Nam Feuang 3
Nam Feuang 1
Nam Pouy
Nam Lik 2
Nam Lik 1
Nam Ngum 2
Nam Ngum 5
Nam Ngum 4B
Nam Ngum 3
Nam San 3
Nam San 3B
Nam San 2
Nam Mouan
Nam Theun 4
Nam Mang 1
Nam Ngiep-regulating dam
Nam Theun 1
Theun-Hinboun exp. (NG8)
Theun-Hinboun expansion
Theun-Hinboun
Nam Hinboun 2
Nam Theun 2
Nam Hinboun 1
Nam Poun
Paklay
Sanakham
Sangthong-Pakchom
Nam Ngum 1
Nam Leuk
Nam Mang 3
Nam Ngum Lower dam
Xe Neua
Xe Bang Fai
Nam Pung
Ubol Ratana
Chulabhorn
Huai Kum
Lam Ta Khong P.S.
Xe Bang Hieng 2
Xe Pon 3
Xe Lanong 1
Xe Lanong 2
Xe Kong 5
Xe Bang Nouan
Xeset 1
Xedon 2
Xeset 2
Xekong 4
Dak E Mule
Xekaman 3
Xe Kaman 4B
Xe Kaman 2B
Xe Kaman 4A
Xe Kaman 2A
Ban Kum
Latsua
Pak Mun
Sirindhorn
Xelabam
Houay Lamphan
Nam Phak
Xe Nam Noy 5
Xe Katam
Houayho
Xepian-Xenamnoy
Xekaman 1
Xekaman-Sanxay
Xe Xou
Nam Kong 2
Upper Kontum
Nam Kong 1
Xe Kong 3d
Plei Krong
Prek Liang 2
Prek Liang 1
Se San 3
Yali
Se San 3A
Lower Se San 3
Se San 4
Don sahong
O Chum 2
Se San 4A
Stung Treng
Lower Se San2+ Lower Sre Pok 2
Lower Sre Pok 3
Stung Sen
Lower Sre Pok 4
Sre Pok 4
Sre Pok 3
Dray Hlinh 2
Dray Hlinh 1
Buon Kuop
Buon Tua Srah
Duc Xuyen
Sambor
Battambang 1
Battambang 2
Pursat 1
Pursat 2
Disclaimer





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



Full name	Shortcut name
A_2	A2n
A_3	A3n
A_4	A4n
A_5	A5n
A_7	A7n
A_8	A8n
A_9	A9n
Xe Kong_other (not included)	XKop
Xe Kong 5R	XK5rp
Xe Kong_US1	XKus1p
Xe Kong_US2	XKus2p
Xe Kong_US3	XKus3p
Xe Kong_US4	XKus4p
Xe Kong_US5	XKus5p
Xe Kong_US6	XKus6p
Xe Kong_US7	XKus7p
Xe Kong_US8	XKus8p
Xe Kong_US9	XKus91p
Xe Kong_US10	XKus10p
Xe Kong_US11	XKus11p
Xe Kon_US9-1	XKus91p
Nam Kong 2	NK2p
Nam Kong 1	NK1p
Xe Xou	XXp
Xekaman-Sanxay	Kmse
Xekaman 1	KMn1e
Xepian-Xenamnoy	XXnp
Houayho	Hhe
Xe Katam	Xkte
Xe Kong 3d	XK3dp
Xe Nam Noy 5	XNn5e
Xe Kaman 2A	KMn2ap
Xe Kaman 4A	KMn4ap
Xe Kaman 2B	KMn2bp
Xe Kaman 4B	KMn4bp
Houay Lamphan	HLp
Xe Kong 3up	XK3upp
Xekaman 3	KM3e
Xe kong 4A	XK4ap
Dak E Mule	DEmp
Xe kong 4B	XK4bp
Xe Kong 5	XK5p
A luoi	Ale

Full name	Shortcut name
O Chum 2	OCm2e
Lower Se San2+ Lower Sre	LSS2_LSrp
Lower Se San 3	LSS3p
Prek Liang 1	PL1p
Prek Liang 2	PL2p
Lower Sre Pok 3	LSP3p
Lower Sre Pok 4	LSP4p
Upper Kontum	UpKp
Plei Krong	PlKe
Yali	Ylie
Se San 3	SSn3e
Se San 3A	SSn3Ae
Se San 4	SSn4e
Se San 4A	SSn4Ae
Duc Xuyen	DXnp
Buon Tua Srah	BTse
Buon Kuop	BKpe
Dray Hlinh 2	DHle
Sre Pok 3	SPk3e
Sre Pok 4	SPk4e
Dray Hlinh 1	DHl1e
Sre Pok 4A	SPk4Ap
Stung Sen	SSnp
Sambor Dam	SbDp
Stung Treng	STrp

Sambor Hydropower project in the Lower Mekong Basin

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January 2018

Photo credits: Andy Mezger, Martin Mallen-Cooper, Prince Royce

Policy on Sustainable Hydropower Development

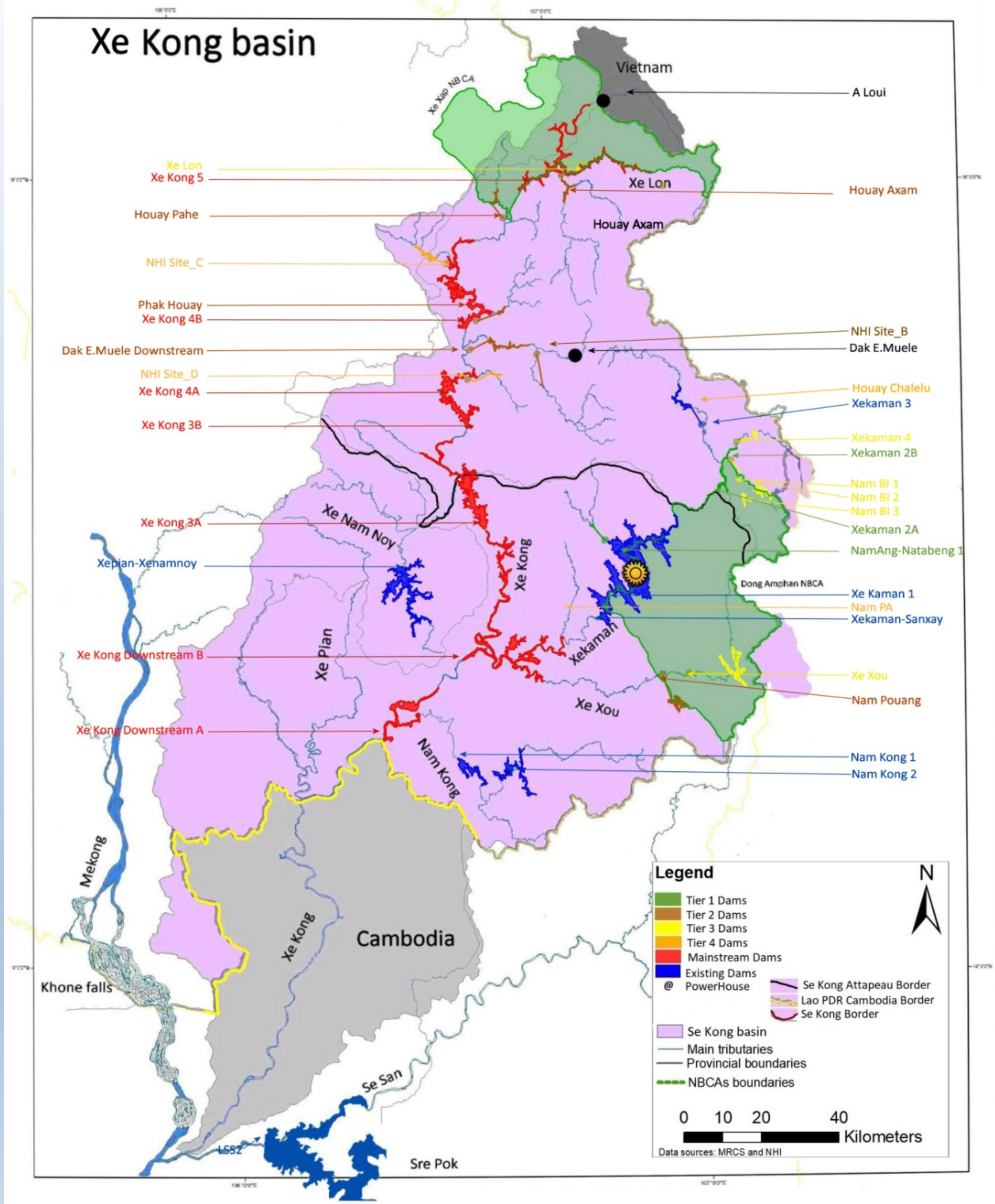
12 January 2015

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

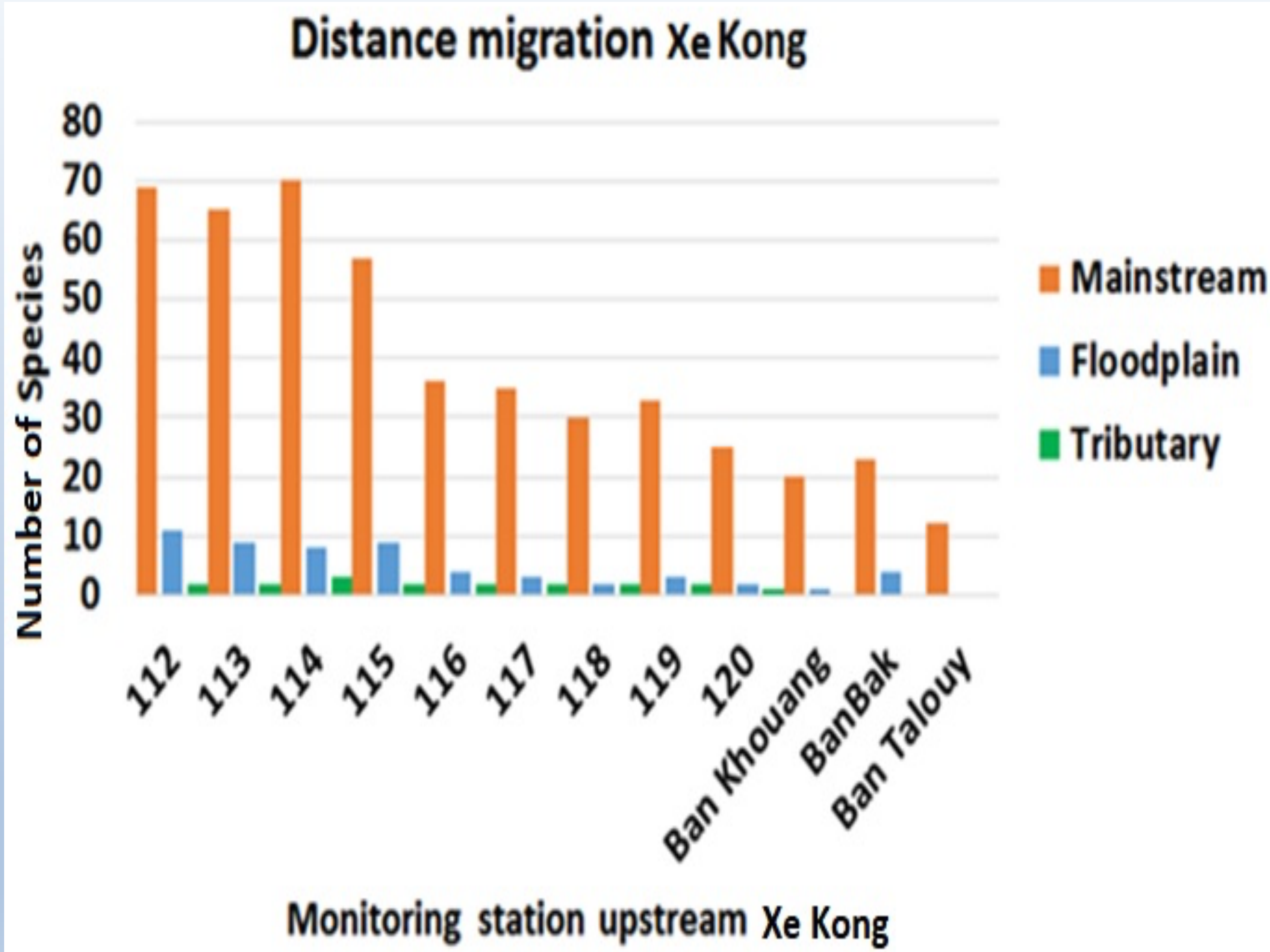
***Goals*:** **Ministries and project developers instructed to prevent and mitigate any potential risks to the natural resources and the environment**

***Procedures*:** **Comprehensive Environmental and Social Impact Assessment including cumulative and transboundary impacts**

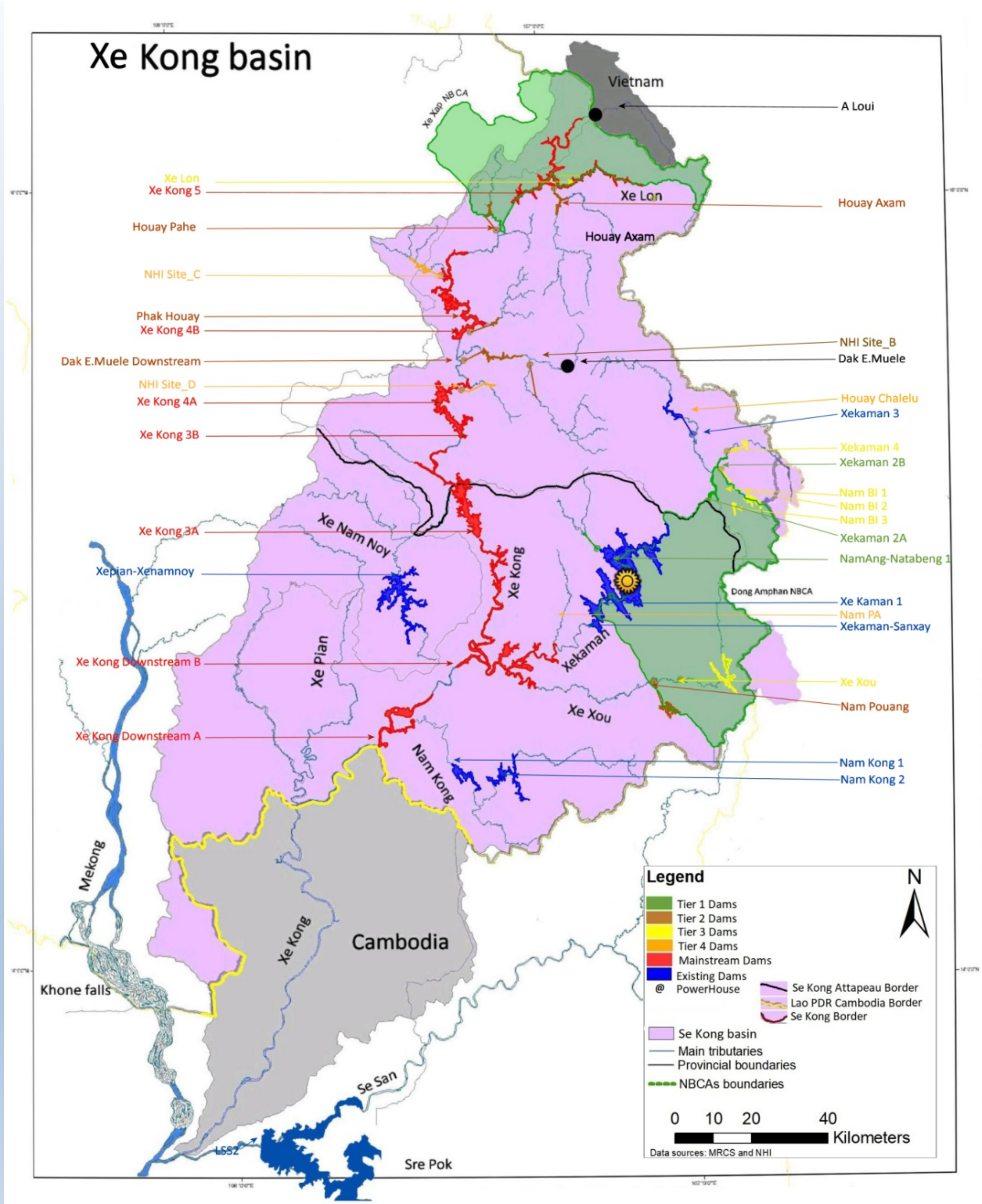
Counteract impacts→→ Aspects of project ↓↓↓	Barrier to migratory fish & Innundation of habitat	Trapping of sediments and nutrients	Alteration of natural flows
Siting	1. Above existing barriers to migration Avoid inundation of critical habitat for endemic native species	2. Deeper canyons in headwaters	3. Re-regulation of altered flows for hydropeaking at or below terminal dam
Design	4. Fish pass facilities, low-impact turbines, fish screens	5. Low level or radial gates for discharge	6. Low capacity factors of power-plant to accommodate variable discharges; Pumped storage
Operation	7. Maintain minimum velocities through reservoirs to maintain larval drift	8. Flushing, sluicing, density current discharges	9. Run of River operations



Xe Kong basin
Vietnam
A Loui
Xe Xap NBCA
Xe Lon
Xe Kong 5
Houay Pahe
NHI Site_C
Phak Houay
Xe Kong 4B
Dak E.Muele Downstream
NHI Site_D
Xe Kong 4A
Xe Kong 3B
Xe Kong 3A
Xepian-Xenamnoy
Xe Kong Downstream B
Xe Kong Downstream A
Xe Lon
Houay Axam
Houay Axam
NHI Site_B
Dak E.Muele
Houay Chalelu
Xekaman 3
Xekaman 4
Xekaman 2B
Nam Bl 1
Nam Bl 2
Nam Bl 3
Xekaman 2A
NamAng-Natabeng 1
Dong Amphan NBCA
Xe Kaman 1
Nam PA
Xekaman-Sanxay
Xe Xou
Nam Pouang
Nam Kong 1
Nam Kong 2
Xe Nam Noy
Xe Kong
Xekaman
Xe Pian
Xe Xou
Nam Kong
Mekong
Khone falls
Xe Kong
Cambodia
Se San
LSS2
Sre Pok
Legend
Tier 1 Dams
Tier 2 Dams
Tier 3 Dams
Tier 4 Dams
Mainstream Dams
Existing Dams
PowerHouse
Se Kong Attapeau Border
Lao PDR Cambodia Border
Se Kong Border
Se Kong basin
Main tributaries
Provincial boundaries
NBCAs boundaries
N
0 10 20 40
Kilometers
Data sources: MRCS and NHI



Distance migration Xe Kong
Number of Species
80
70
60
50
40
30
20
10
0
112
113
114
115
116
117
118
119
120
Ban Khouang
BanBak
Ban Talouy
Mainstream
Floodplain
Tributary
Monitoring station upstream Xe Kong



Xe Kong basin
Vietnam
A Loui
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Dak E.Muele
Dak E.Muele Downstream
NHI Site_D
Xe Kong 4A
Houay Chalelu
Xekaman 3
Xe Kong 3B
Xekaman 4
Xekaman 2B
Nam BI 1
Nam BI 2
Nam BI 3
Xekaman 2A
NamAng-Natabeng 1
Xe Kong 3A
Xe Nam Noy
Xe Kong
Xepian-Xenamnoy
Dong Amphan NBCA
Xe Kaman 1
Nam PA
Xekaman-Sanxay
Xekaman
Xe Pian
Xe Kong Downstream B
Xe Xou
Nam Pouang
Xe Xou
Xe Kong Downstream A
Nam Kong
Nam Kong 1
Nam Kong 2
Mekong
Xe Kong
Cambodia
Khone falls
Se San
LSS2
Sre Pok
Legend
N
Tier 1 Dams
Tier 2 Dams
Tier 3 Dams
Tier 4 Dams
Mainstream Dams
Existing Dams
PowerHouse
Se Kong Attapeau Border
Lao PDR Cambodia Border
Se Kong Border
Se Kong basin
Main tributaries
Provincial boundaries
NBCAs boundaries
0 10 20 40
Kilometers
Data sources: MRCS and NHI

Strategy?

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

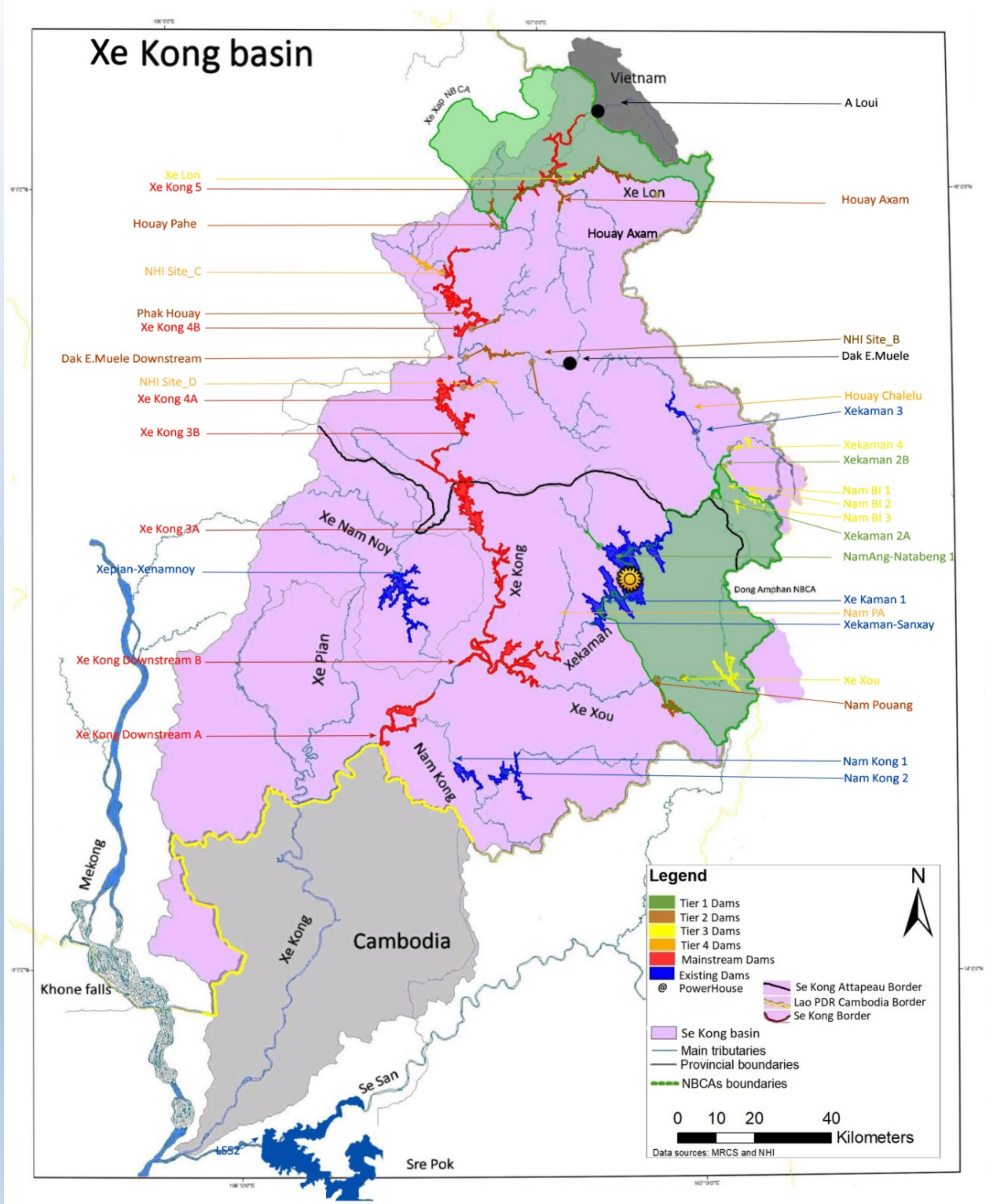
Four Tiers of *Sustainable* Replacement Dams

	Tier 1		
Item	Xe Kaman 2A	Xe Kaman 2B	Nam Ang-Natabeng 1
(Lat /Long.)	15°15.01'N 107°26.33'E	15°16.52'N 107°27.00'E	15.115740N 107.116887E
Province	Attapeu	Attapeu	Xekong
River	Xe Kaman	Xe Kaman	Xe Kaman
Estimated power (GWh/yr)	160	664*	183
Installed capacity (MW)	64*	185	58*
Rated head (m)	48.6	78.8	640
Design discharge (m3/s)	155	90	20.7
Full supply level (m)	280	370	640
Catchment area (km2)	1970	1740	203
Mean annual flow (m3/s)	77.5	68.4	10
Total reservoir volume (mill m3)	20.8	333	

	Tier 2					
Item	Houay Axam	Houay Pache	Phak Houay	Dak E. Mule Downstream	Nam Pouang	NHI Site B
(Lat /Long.)	16.014786N 107.044092E	15°56.70'N 106°52.51'E	15°54.11'N 106°55.94'E	15°30.80'N 106°50.84'E	15°41.50'N 107°18.84'E	15°28.80'N 106°58.94'E
Province	Xekong	Xekong	Xekong	Xekong	Attapeu	Attapeu
River	Houay Axam	Xekong	Xekong	Xekong		
Estimated power (GWh/yr)	518	86	110	253	90	102
Installed capacity (MW)	152	21	27	62	22	25
Rated head (m)	566	172	240	160	145	300
Design discharge (m3/s)	78.2	16	14	49	19	11
Full supply level (m)	566	450	420	330	330	730
Catchment area (km2)	784	186	170	582	229	126
Mean annual flow (m3/s)	39	9	9	29	11	6
Total reservoir volume (mill m3)						

	Tier 3			
Item	Xe Lon	Xe Xou	Nam Bi 1+2+3	Xe Kaman 4
(Lat /Long.)	15°58.83'N 107°18.84'E	14°44.74'N 107°22.20'E	15°13.46'N 107°31.57'E	15°20.83'N 107°32.15'E
Province	Xekong	Attapeu	Xekong	Xekong
River			Xe Kaman	Xe Kaman
Estimated power (GWh/yr)	441*	236	550	305*
Installed capacity (MW)	150*	58	130	100*
Rated head (m)		120	423.6	459.1
Design discharge (m3/s)	70	62	26.0	18.4
Full supply level (m)	550	300	860	865
Catchment area (km2)	829	726	265	712
Mean annual flow (m3/s)	41	36	10	29.6
Total reservoir volume (mill m3)			16.5	141.5

	Tier 4			
Item	Houay Chalelu 1	Nam Pa	NHI Site C	NHI Site D
(Lat /Long.)	15.406373N 107.408824E	14.941010N 107.054225E	15°58.64'N 106°42.60'E	15°30.80'N 106°50.84' E
Province	Xekong	Xekong	Xekong	Xekong
River	Xe Kaman	Xe Kaman		Xekong
Estimated power (GWh/yr)	40	29.	65	47
Installed capacity (MW)	12	7	16	14
Rated head (m)	20	48	134	190
Design discharge (m3/s)	62.8	14.3	15	9
Full supply level (m)	420	200	350	350
Catchment area (km2)	841	140	173	108
Mean annual flow (m3/s)	42	7	9	5
Total reservoir volume (mill m3)				



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Xe Kaman 1
Nam PA
Xekaman-Sanxay
Xe Pian
Xekaman
Xe Kong Downstream B
Xe Xou
Nam Pouang
Xe Xou
Xe Kong Downstream A
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Nam Kong 1
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Mekong
Xe Kong
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N
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Kilometers
Data sources: MRCS and NHI

Endorsed by Prime Minister

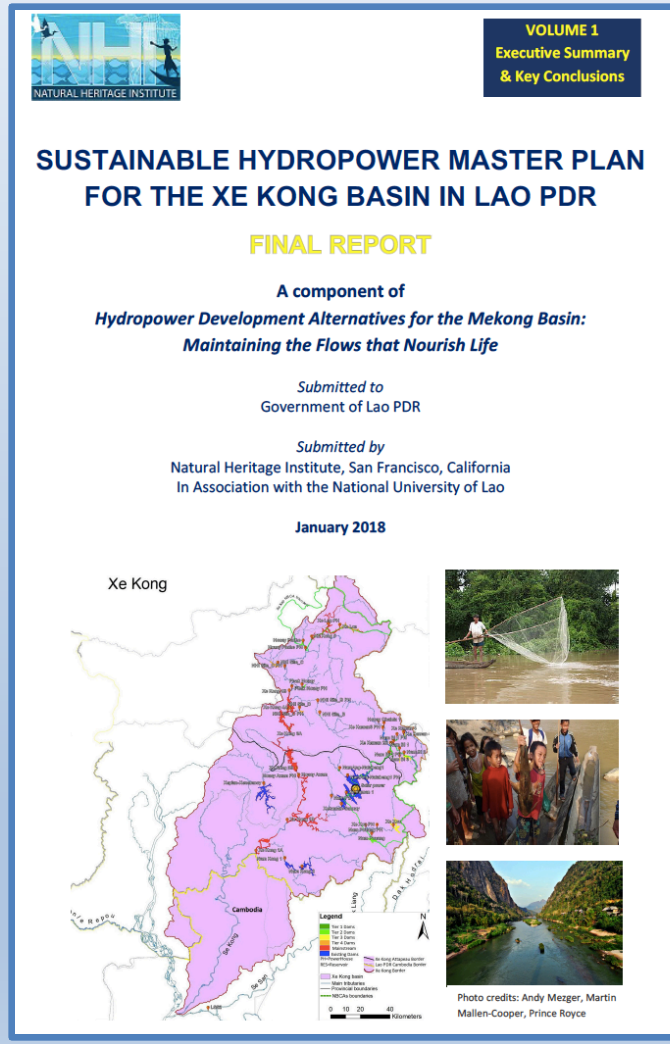

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Photo credits: Andy Mezger, Martin Mallen-Cooper, Prince Royce

NATURAL HERITAGE INSTITUTE

VOLUME 1
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SAMBOR HYDROPOWER DAM ALTERNATIVES ASSESSMENT

FINAL REPORT

[INCLUDES COMPARISON OF DAM AND "NO-DAM" ALTERNATIVES]

A component of
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Submitted to
Royal Government of Cambodia

Submitted by
Natural Heritage Institute, San Francisco, California

December 2017

Photos by Gregory A. Thomas, NHI

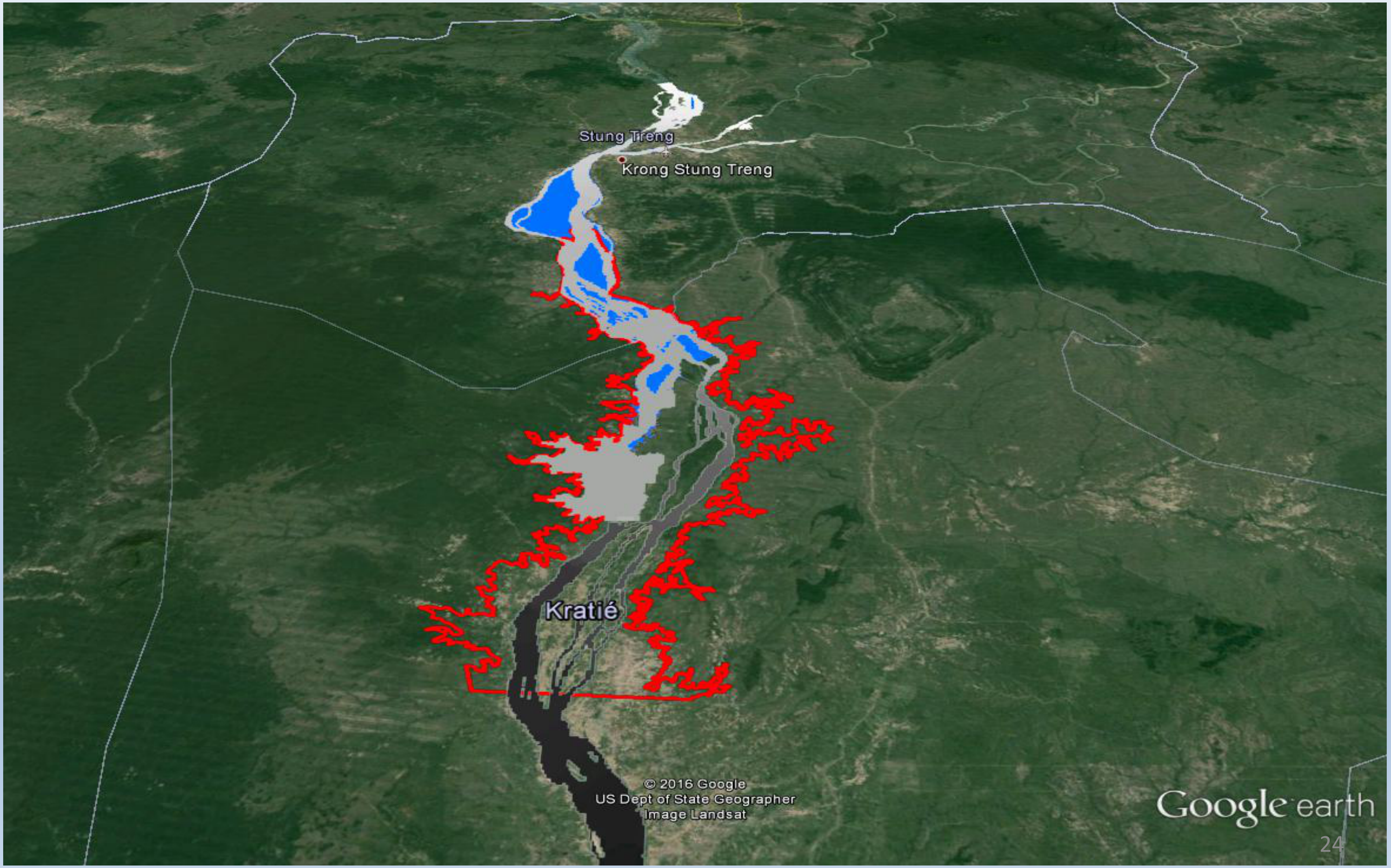
Scope of MoU

→ 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

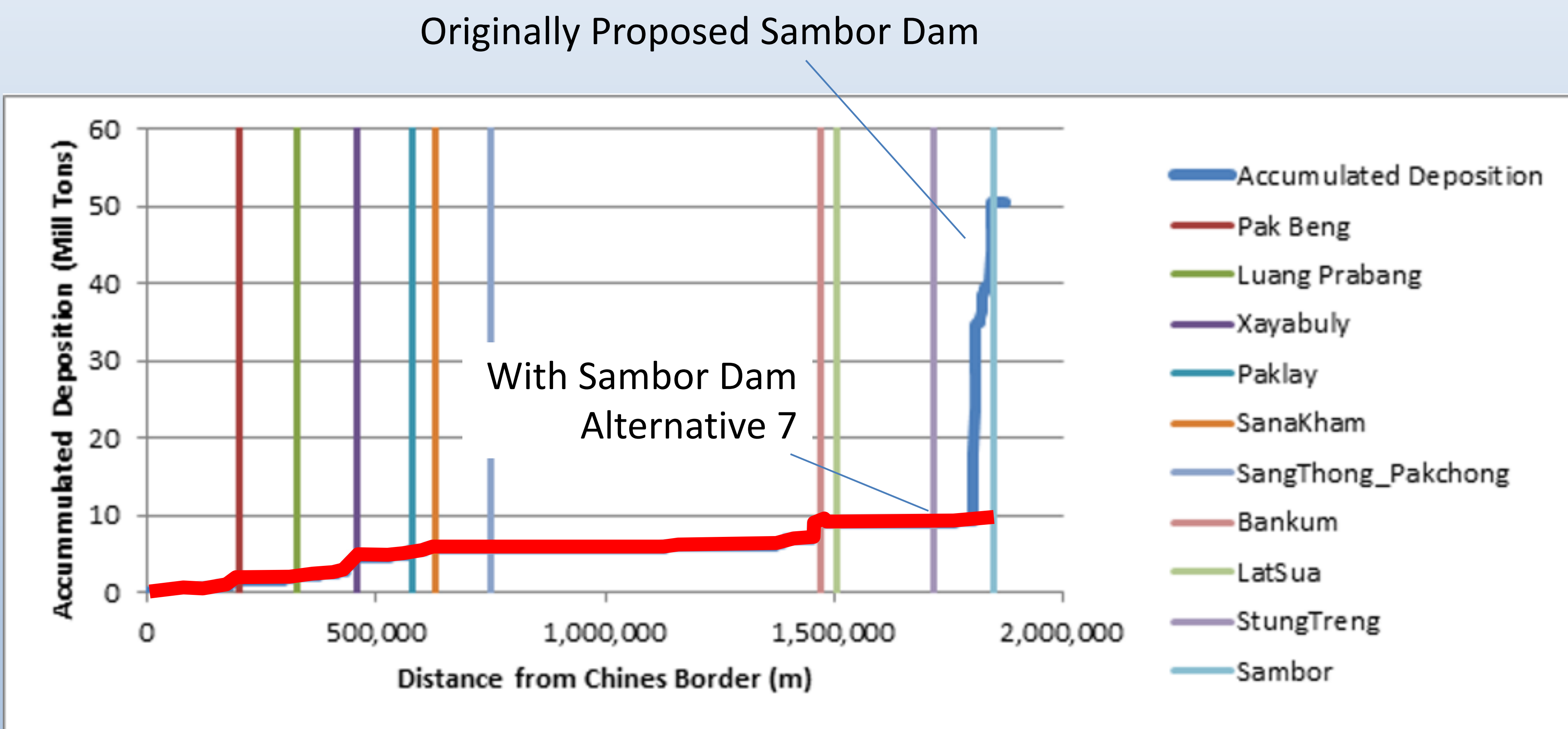
→ Migratory corridor that experiences the largest movement of biomass on the planet every year

→ 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

Mekong Area of Sambor

Sediment Deposition of Main Stream Dams

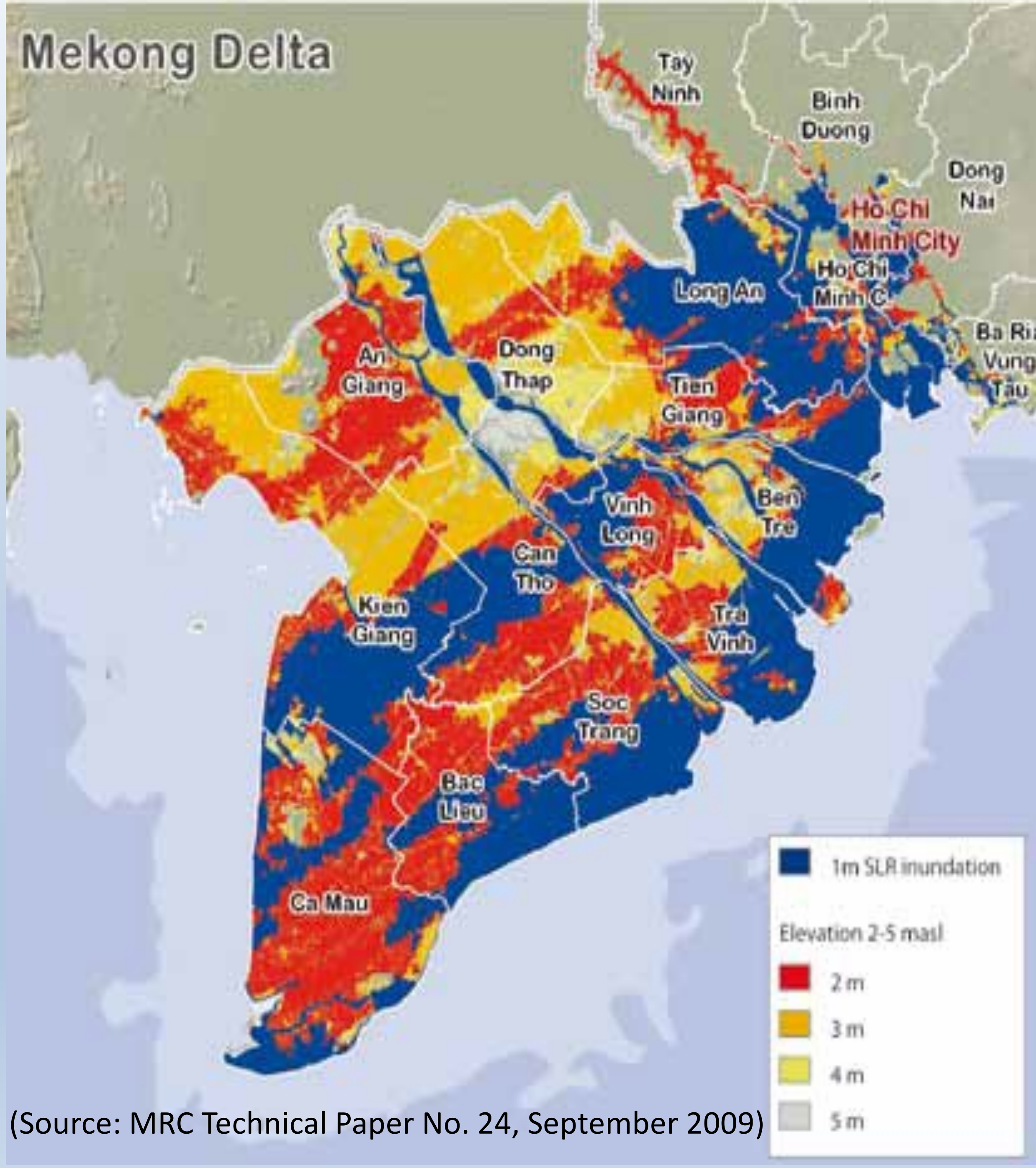


Sediment Management Techniques Considered

Technique	Feasible?
Dredging	No
Hydrosuction (HSRS)	No
Dry Excavation	No
Sluicing	No
Bypassing	No
Drawdown Flushing	No

Amount of sediment retained in long term:
4,580 million m^3 to 4,790 million 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

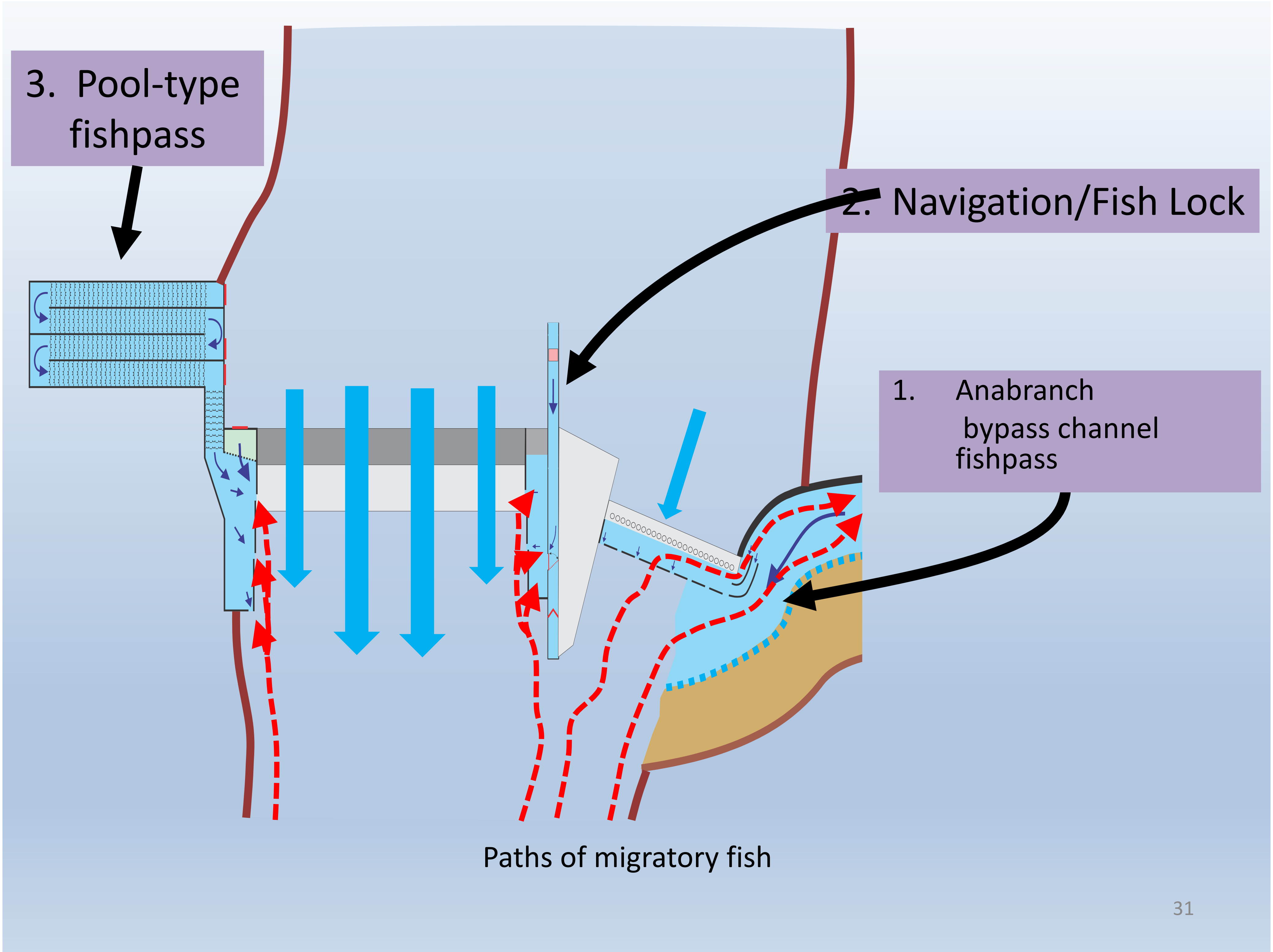
- Identify Impacts
  - Social, Fisheries, Sediment
- Develop Environmental Performance Criteria
  - Integral part of Design Criteria
- Optimize Design
  - Concurrently Consider all Objectives
- **Result – Optimized Solution**
  - Balanced Design by Integrating:
    - Fish Passage
    - Sediment Passage
    - 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 $\geq$ 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

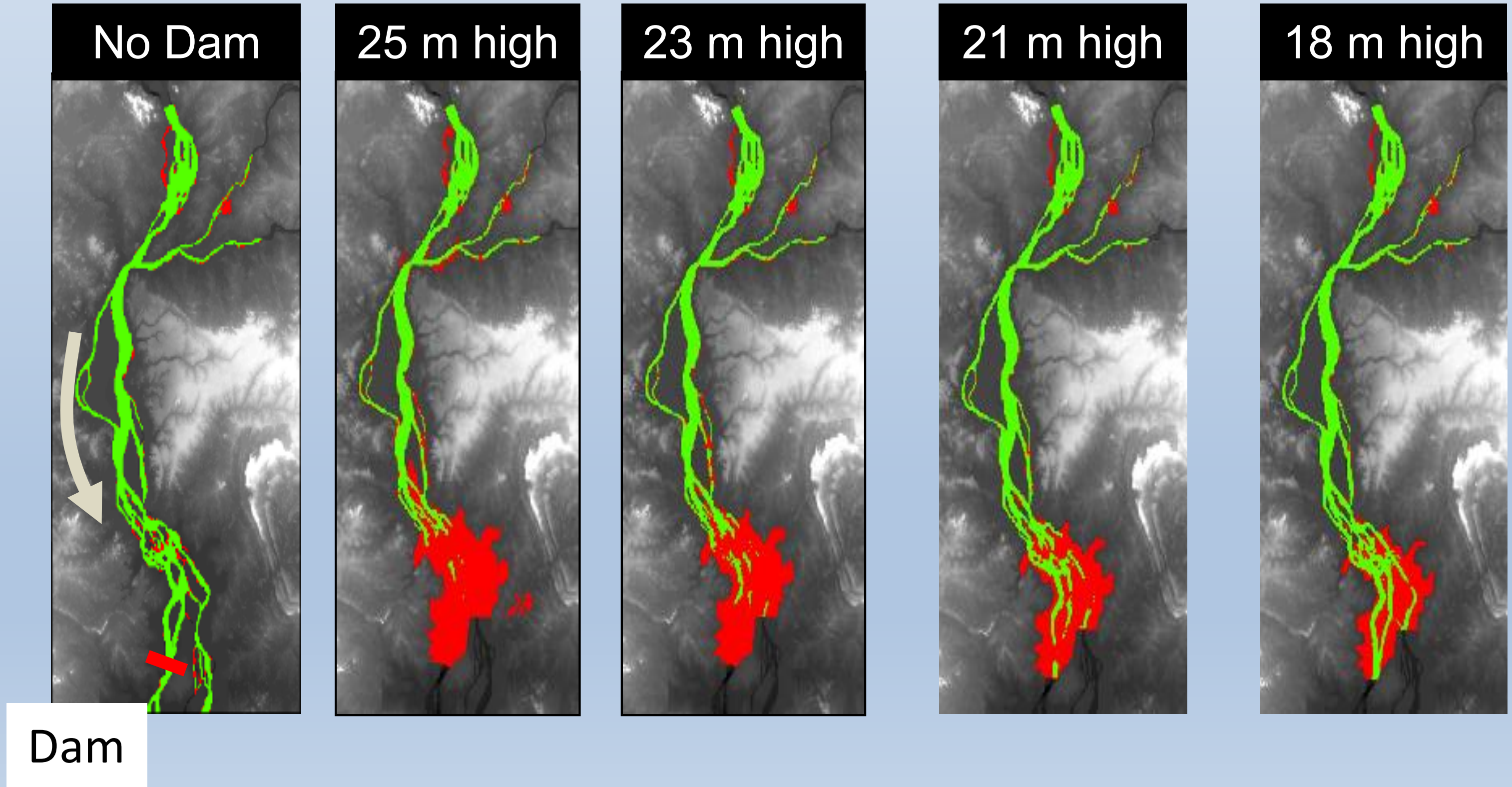
- Relocation
  - Minimize the Number of People to be relocated
  - Use 100-year Flood as Criterion
  - No Additional Flooding of Stung Treng


3. Pool-type fishpass
2. Navigation/Fish Lock
1. Anabranch bypass channel fishpass
Paths of migratory fish

Downstream larval drift

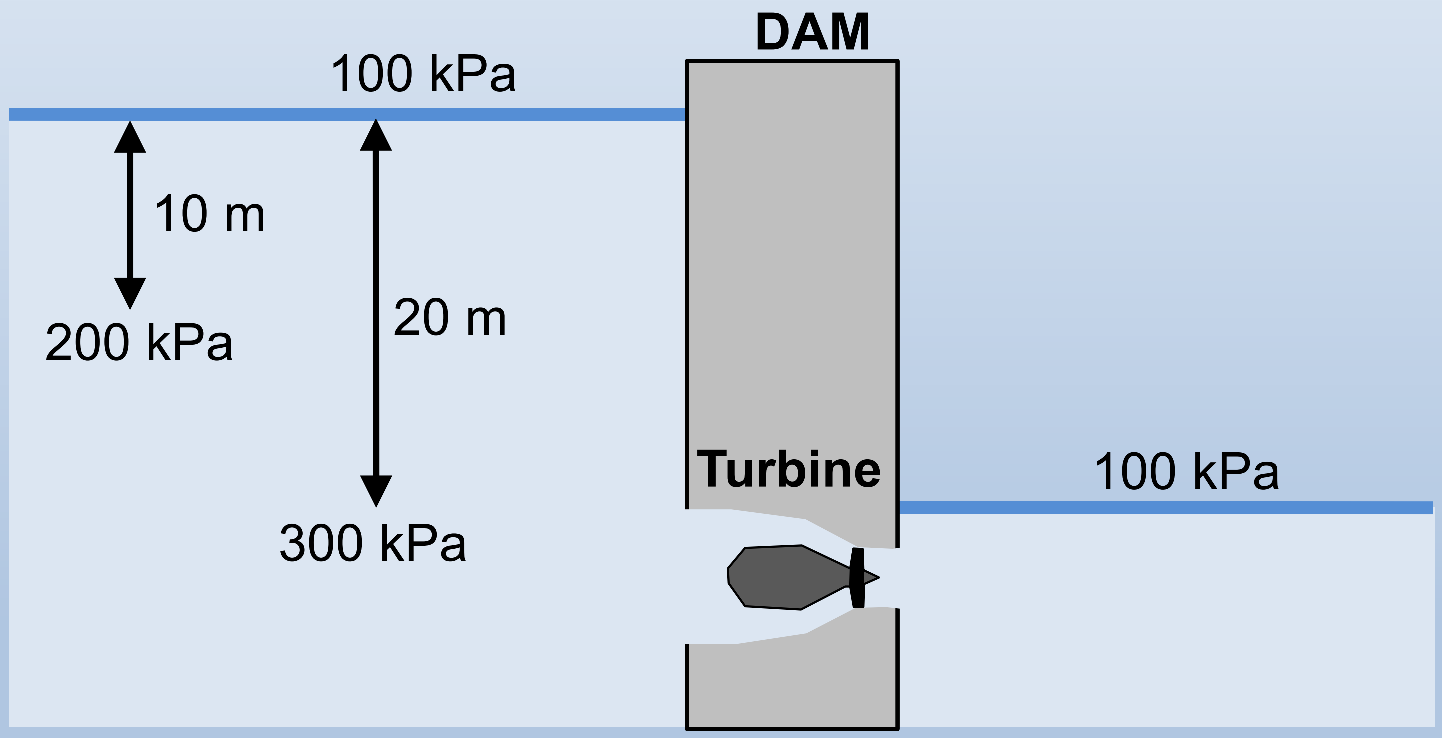
> 0.3 m/s (water velocity to maintain larvae drifting)

< 0.3 m/s (larvae stop drifting and die)



DOWNSTREAM FISH PASSAGE EFFECTS OF PRESSURE ON FISH

Barotrauma



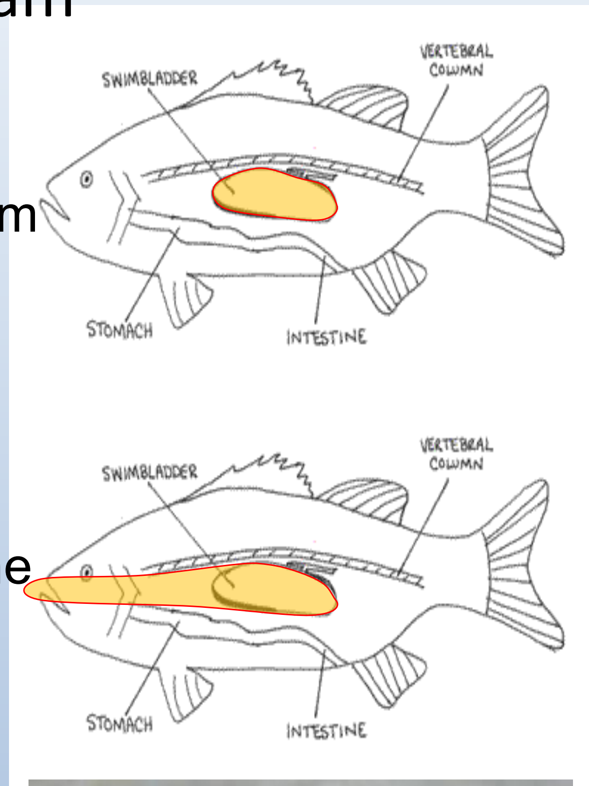
Impacts of pressure change (barotrauma)

e.g. 20 m dam

Upstream

↓

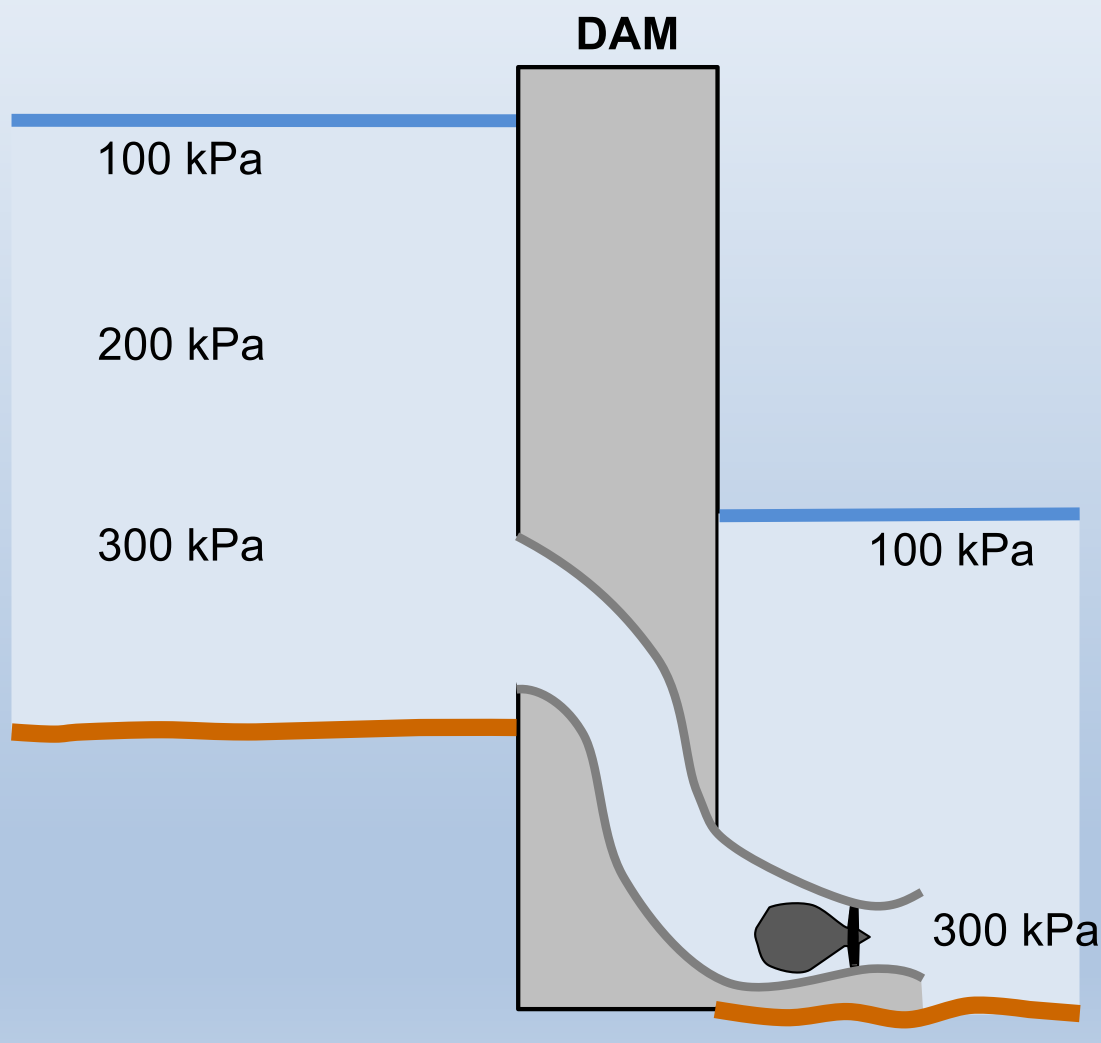
In turbine



Swim bladder
approx. 3X volume

Photograph courtesy of Luiz Silva

MITIGATING BAROTRAUMA

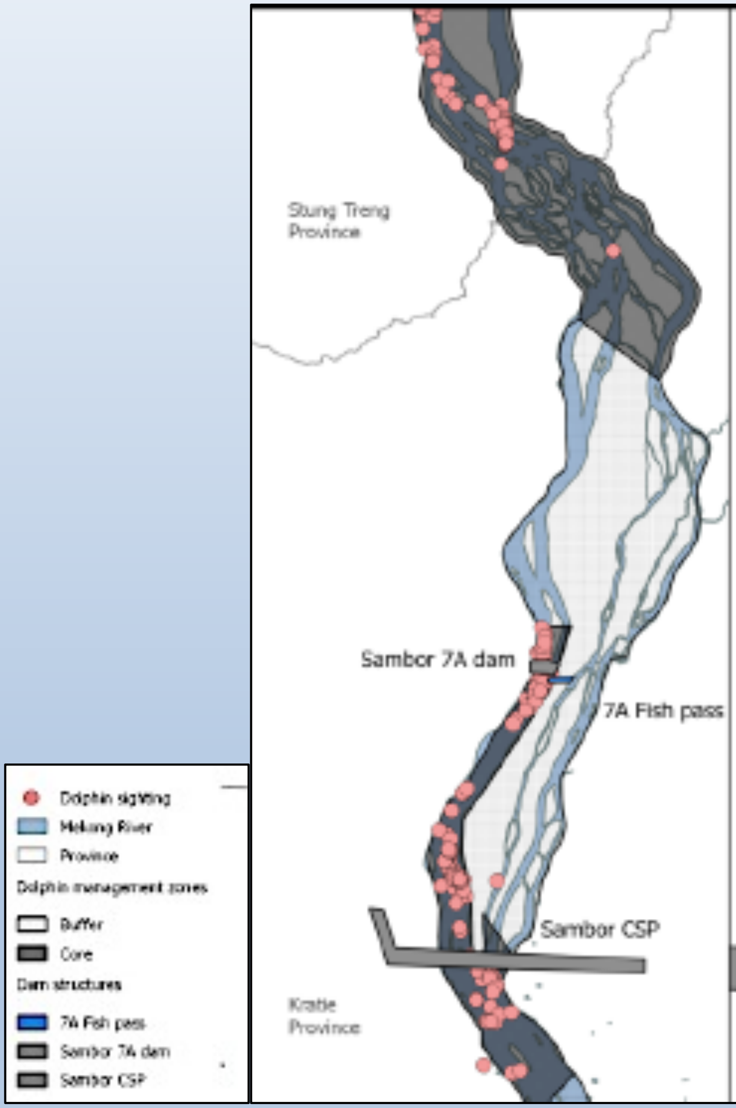


. . . but also need to consider shear and blade strike

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)



Photo, above: Roland Seitre, WWF. https://futureoceans.com/10-things-you-might-not-know-about-irrawaddy-dolphins/

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.

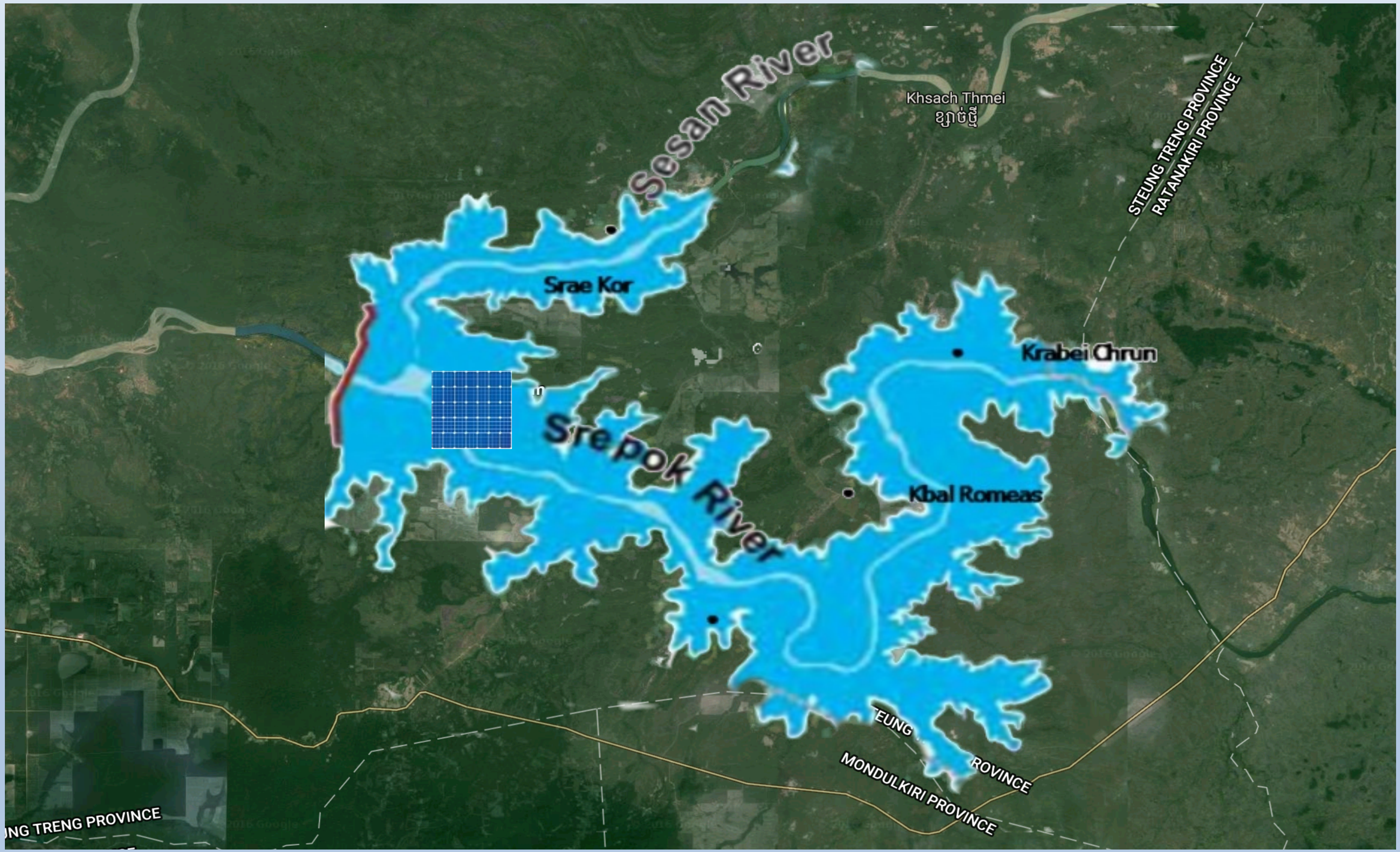
Potential Impact on Irrawaddy Dolphins (2)

- **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

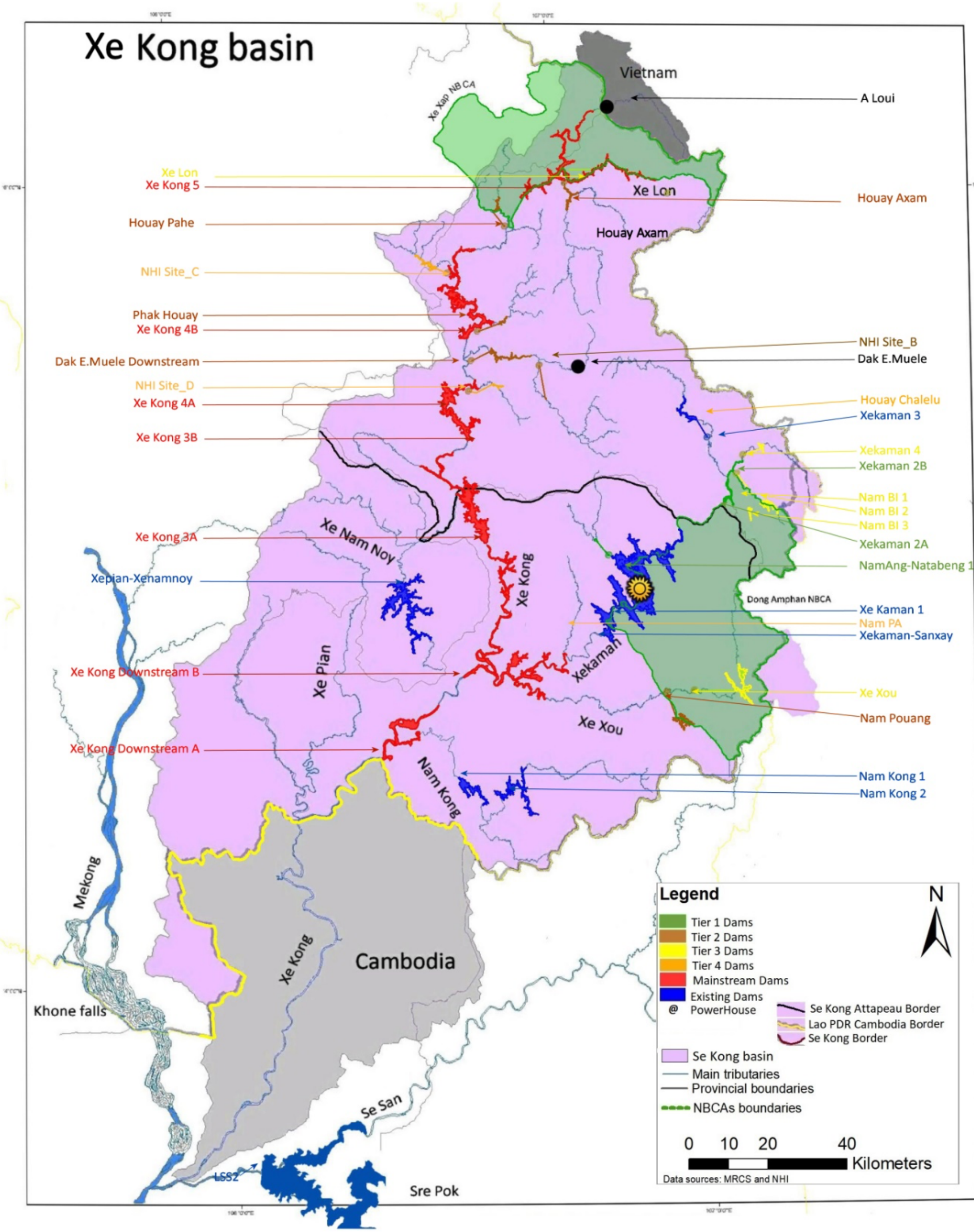
Findings and Conclusions

Alternative	Result	Reason
1. Small dam on side channel (Alt. 6A)	Not **financially** feasible	Dam backs up water into main channel so not enough water goes through turbines
2. Large dam on main channel (Alt 7A) with all mitigation measures including fish screens	Not **financially** feasible	Large costs of the fish screens
3. Large dam on main channel (Alt. 7A) with all mitigation measures except fish screens	Substantial risk to productivity of fishery	1. Mitigation measures untested + 2. Uncertainties in fish behavior
4. Solar power augmentation of existing hydro	**Only option that provides a positive net economic benefit**	Cost competitive with no impacts on fishery

Hydro/Solar Hybrid Power

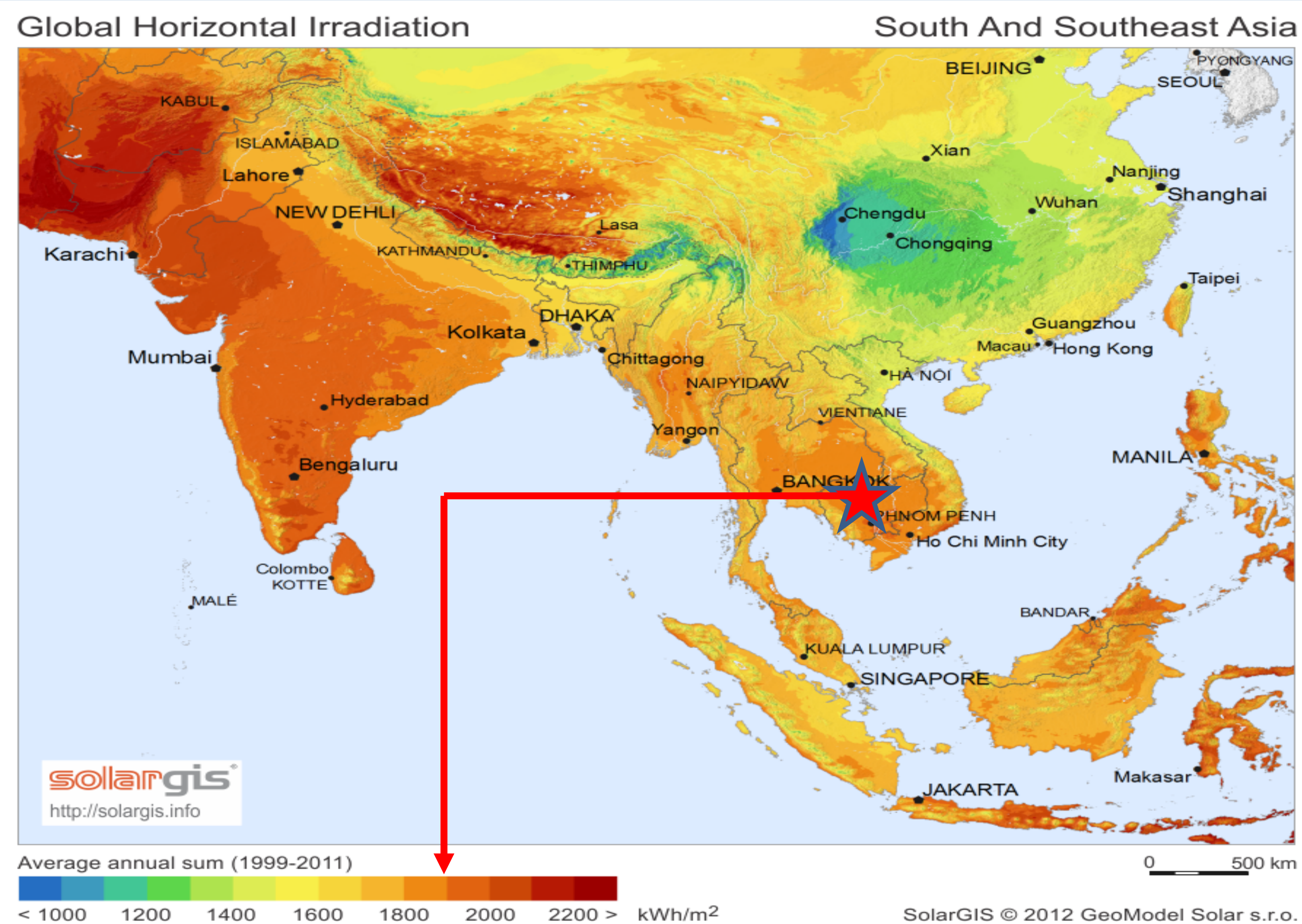


Lower Se San II Hydropower Project


Xe Kong basin
Vietnam
A Loui
Xe Xap NBCA
Xe Lon
Xe Kong 5
Houay Axam
Xe Lon
Houay Pahe
Houay Axam
NHI Site_C
Phak Houay
Xe Kong 4B
NHI Site_B
Dak E.Muele
Dak E.Muele Downstream
NHI Site_D
Houay Chalelu
Xe Kong 4A
Xekaman 3
Xe Kong 3B
Xekaman 4
Xekaman 2B
Nam Bl 1
Nam Bl 2
Nam Bl 3
Xekaman 2A
Xe Kong 3A
Xe Nam Noy
NamAng-Natabeng 1
Xepian-Xenamnoy
Xe Kong
Dong Amphan NBCA
Xe Kaman 1
Nam PA
Xekaman-Sanxay
Xe Pian
Xe Kong Downstream B
Xekaman
Xe Xou
Nam Pouang
Xe Xou
Xe Kong Downstream A
Nam Kong
Nam Kong 1
Nam Kong 2
Mekong
Cambodia
Xe Kong
Khone falls
Se San
LSS2
Sre Pok
Legend
N
Tier 1 Dams
Tier 2 Dams
Tier 3 Dams
Tier 4 Dams
Mainstream Dams
Existing Dams
PowerHouse
Se Kong Attapeau Border
Lao PDR Cambodia Border
Se Kong Border
Se Kong basin
Main tributaries
Provincial boundaries
NBCAs boundaries
0 10 20 40
Kilometers
Data sources: MRCS and NHI

Cambodia: High irradiance resource

Average annual insolation: 1,893 kWh/m^2



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

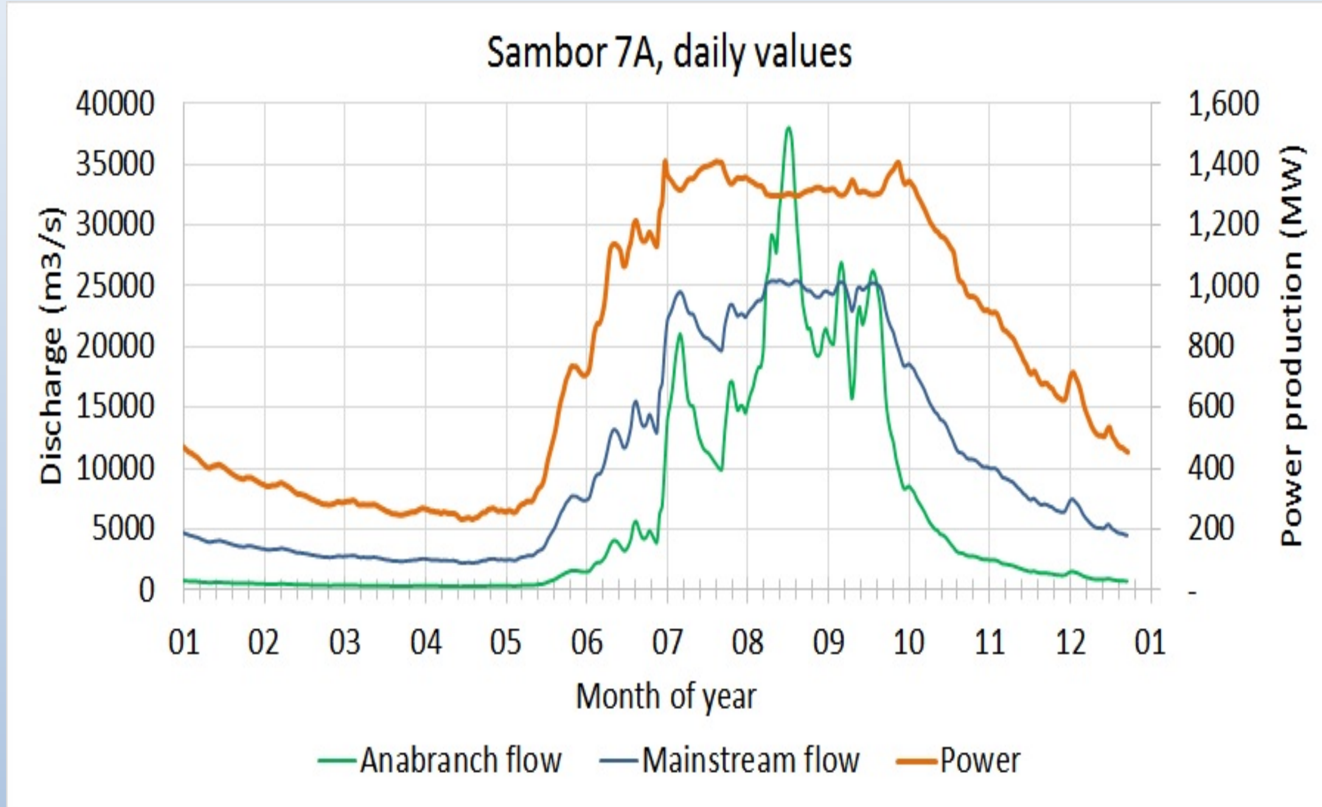
Power grid operators care about:

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



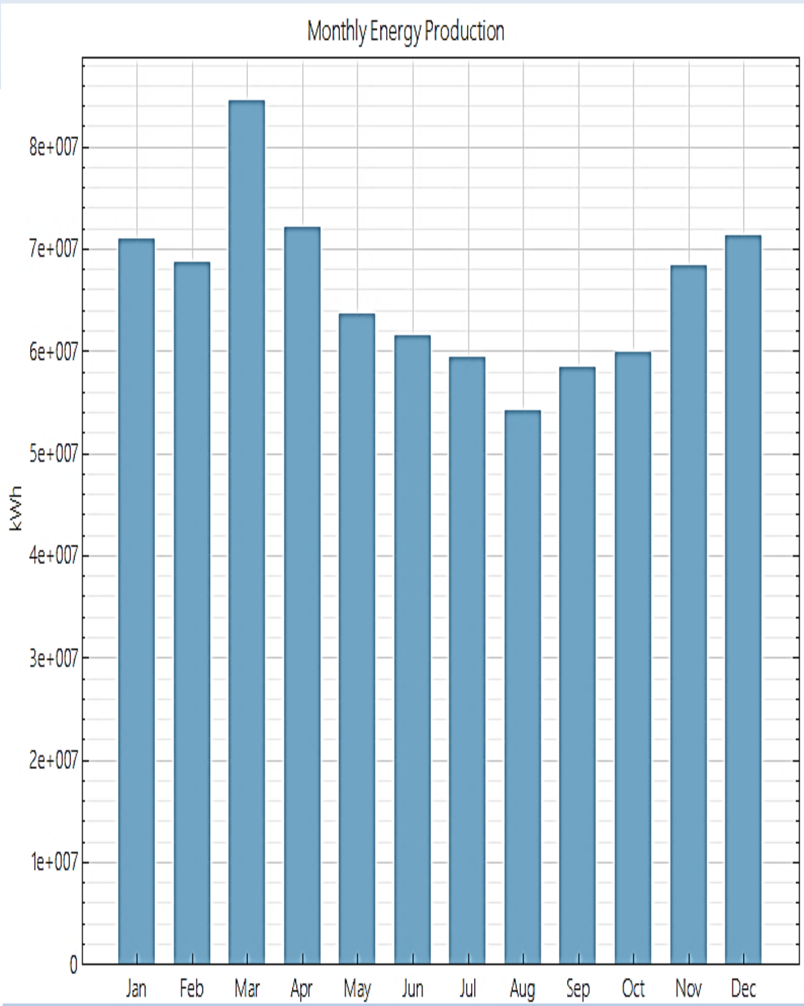
Power production at Sambor Alternative 7A. The power production follows the mainstream flow. During the wet season the reservoir spills additional water into the Anabranch, increasing the flow above normal. The operational rule keeps low water level at flow <20,000m^3/s.

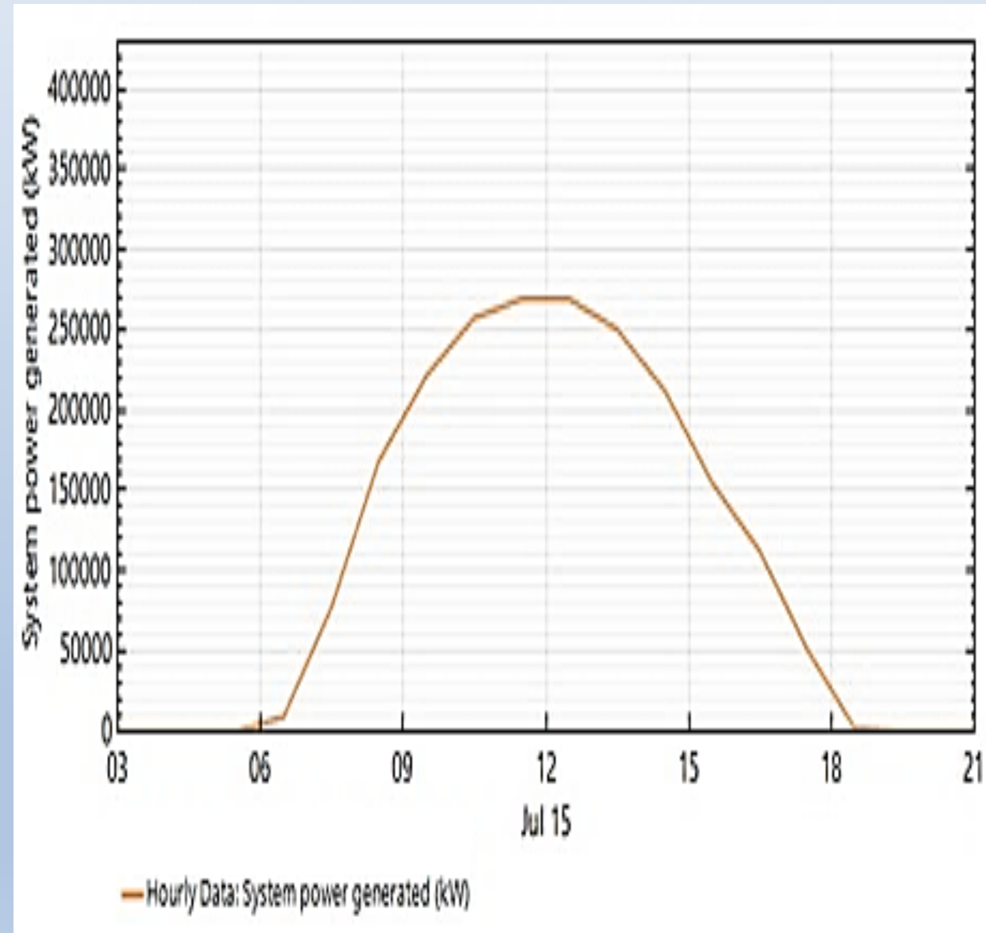
Estimated power production potential by time of day and time of year from solar PV arrays (total 10 km^2 area)

80,000,000

50,000,000

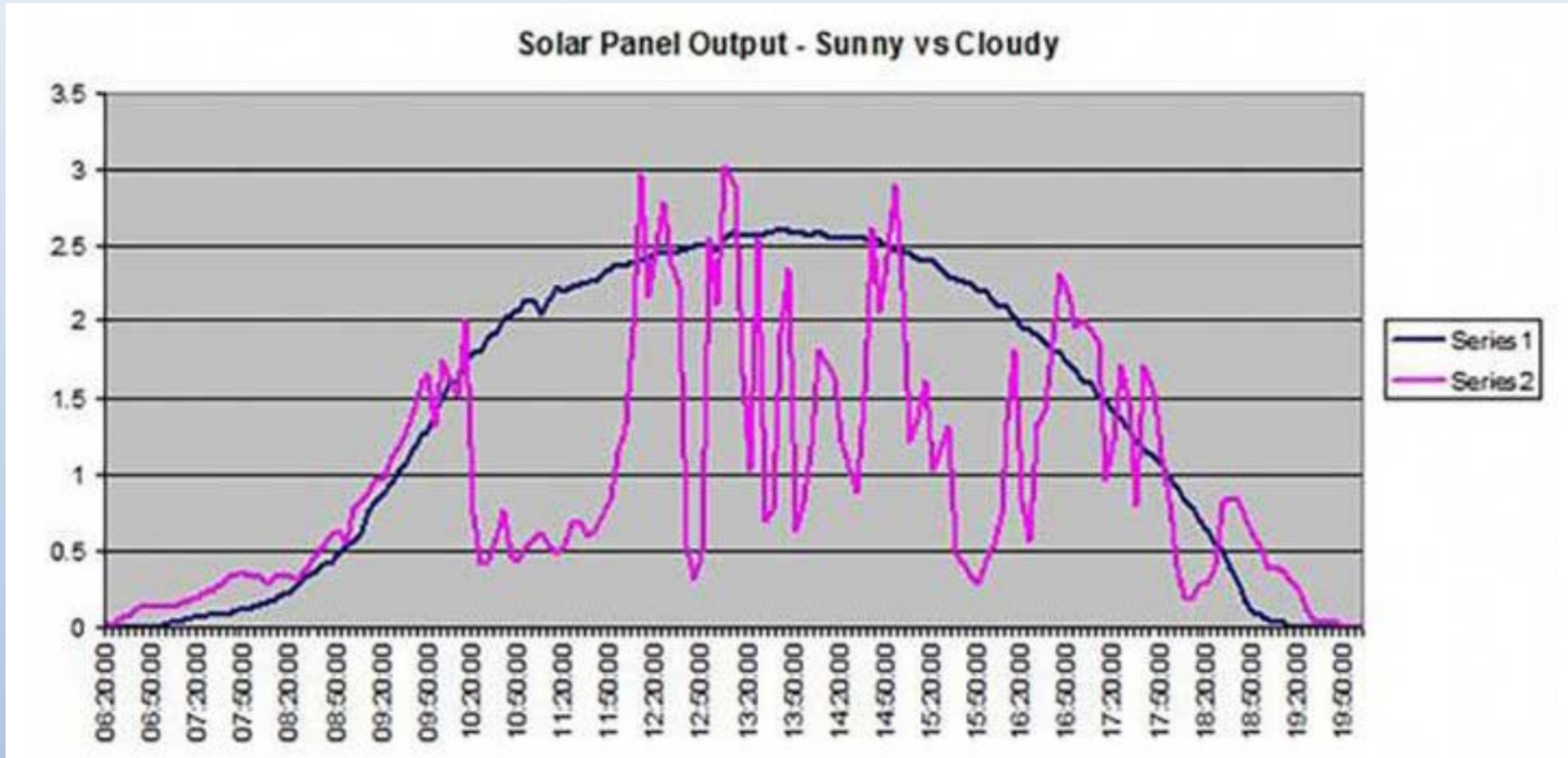
10,000,000





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.

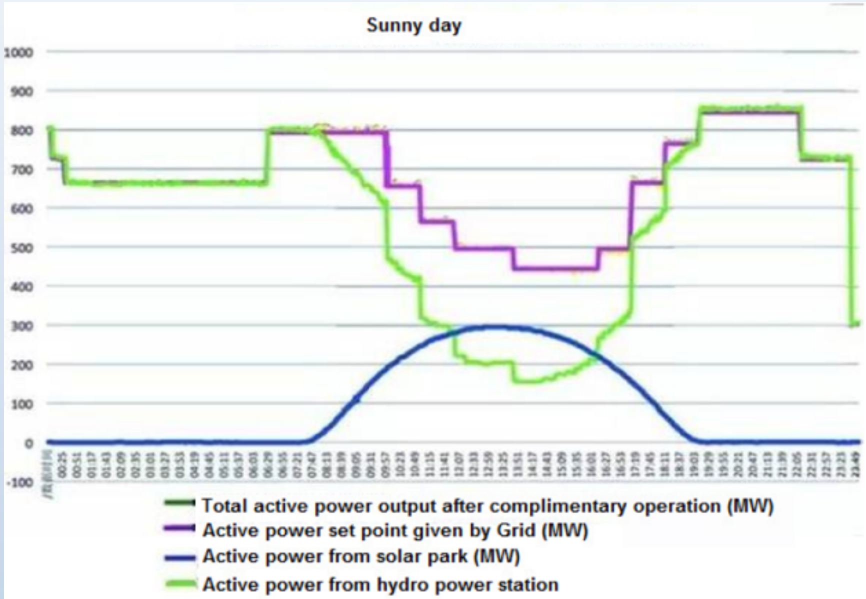
Source: http://www.cat.com/en_US/articles/white-paper-hybrid-microgrids-the-time-is-now.html

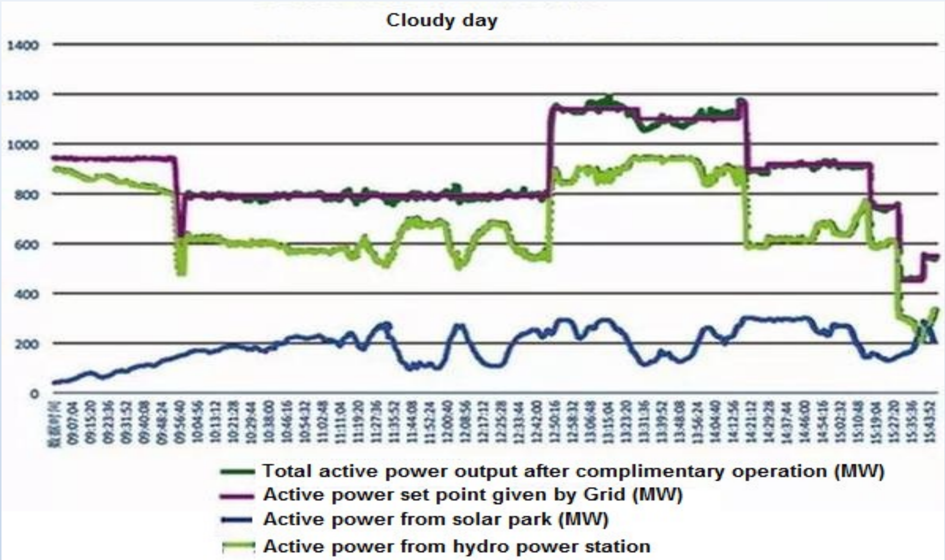
Complimentary PV and Hydro Operation

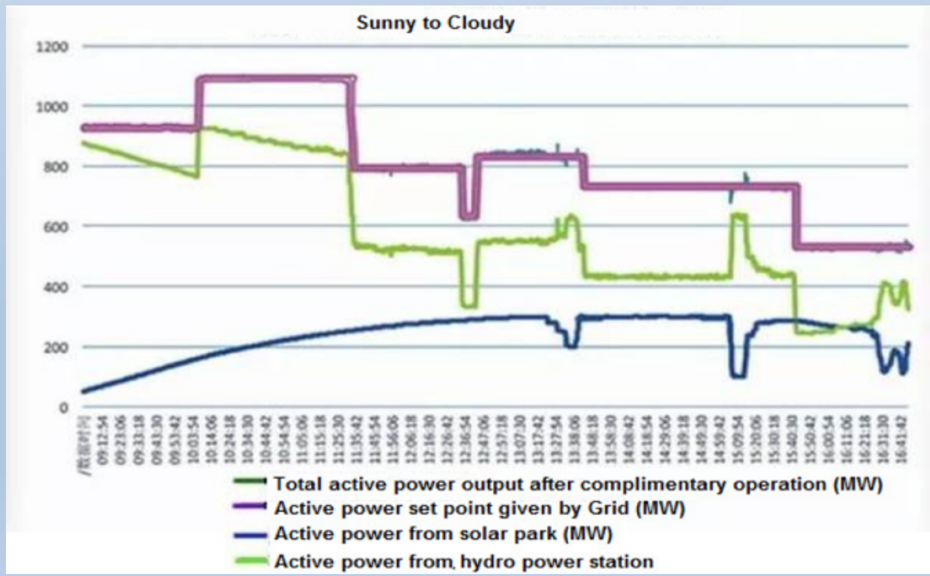
<u>Longyangxia hydropower plant</u>

- Commissioned in 1989
- Installed capacity: 1,280MW (4× 320MW)
- Electricity production: 5,942GWh/year
- Reservoir area: 380 km^2
- Normal storage water level: 2600m; Dead water level: 2530m
- Regulation storage: 193.5×108m^3

Complimentary PV and Hydro Operation







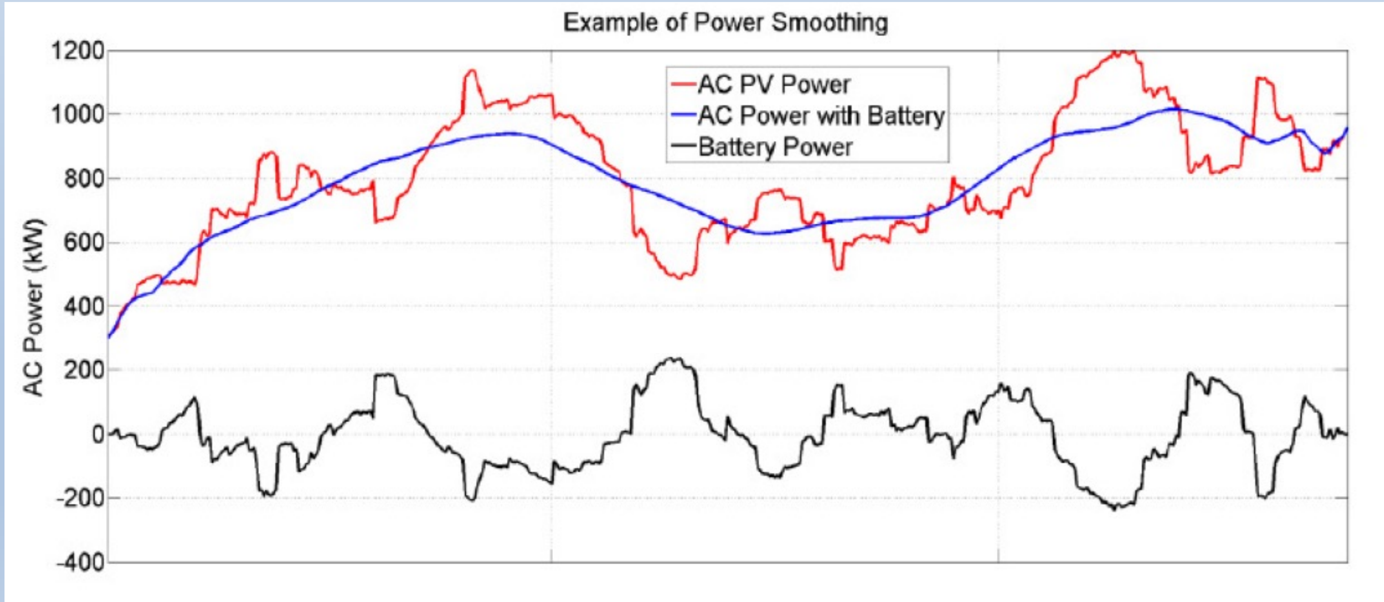
Complimentary operation:

- 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

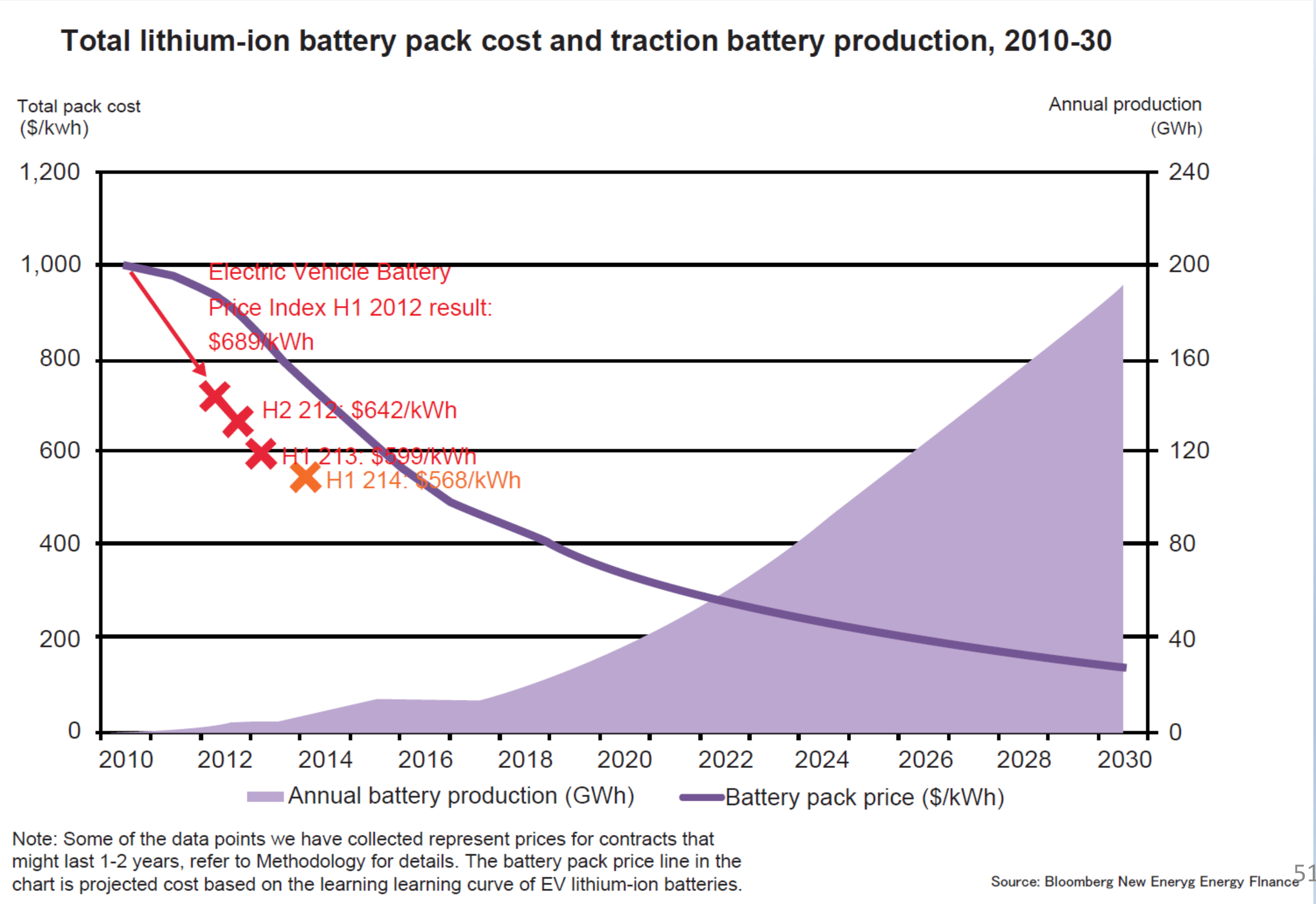
Battery storage to counteract fluctuations due to cloud cover

- 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

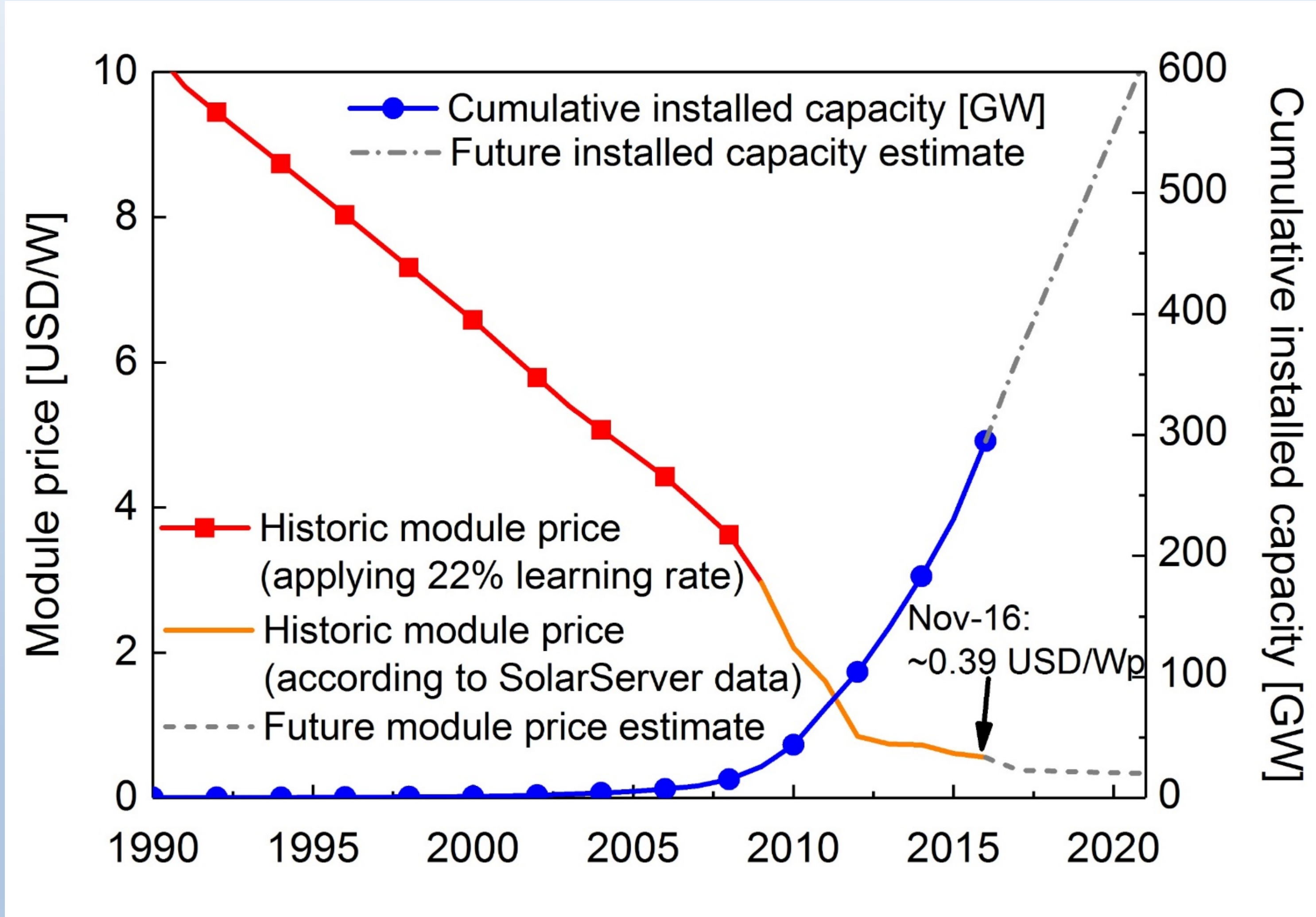
Cost reductions much faster than anticipated



COST

PV market and price developments

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



Data source: SERIS market research, SolarServer: PVX spot market price index for Chinese manufactured modules, latest data as of October 2016, EnergyTrend, Pvinsights for November 2016, MAS for exchange rate data.

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)

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

- 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???

LSS2		Xe Kaman 1	
Hydro:	400 MW	Hydro:	290 MW
Solar:	400 MW	Solar:	400-500 MW

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 km^2
- Commission year: 2016

⇒ **Construction time: 8 months !**

FINANCIAL RISK FACTORS

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

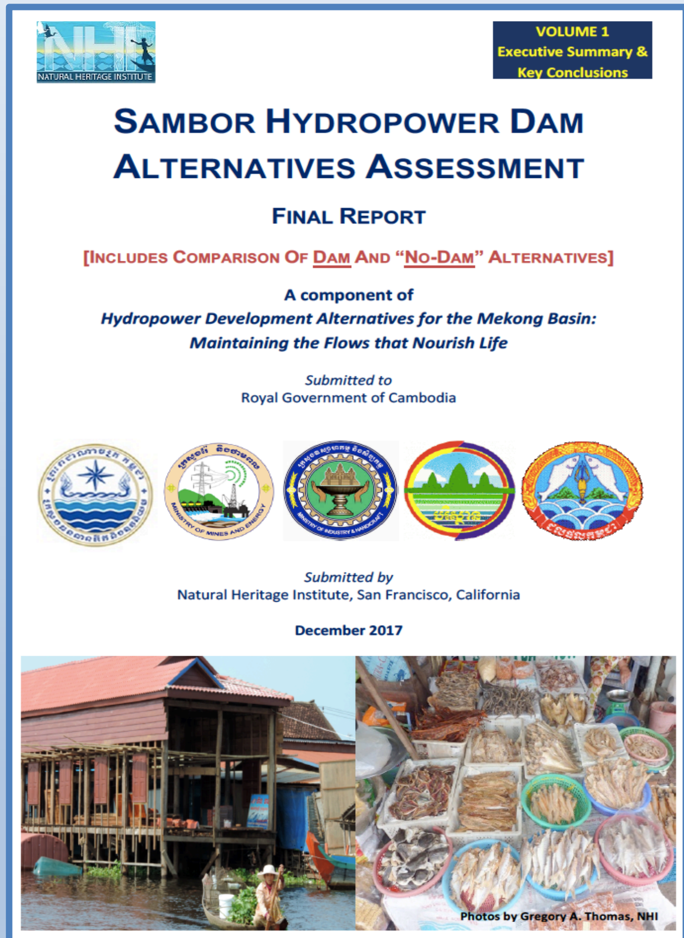
Photo: http://charismaticplanet.com/the-greatest-amazon-river-is-home-to-several-extremes/

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


VOLUME 1
Executive Summary & Key Conclusions

SAMBOR HYDROPOWER DAM ALTERNATIVES ASSESSMENT

FINAL REPORT

[INCLUDES COMPARISON OF DAM AND "NO-DAM" ALTERNATIVES]

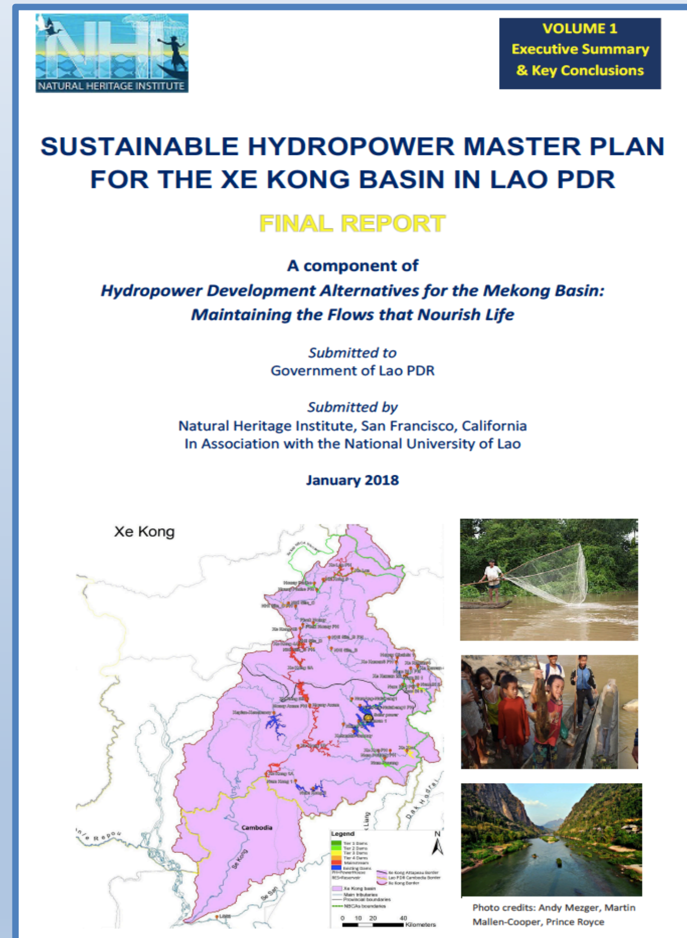
A component of
Hydropower Development Alternatives for the Mekong Basin: Maintaining the Flows that Nourish Life

Submitted to
Royal Government of Cambodia

Submitted by
Natural Heritage Institute, San Francisco, California

December 2017

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


VOLUME 1
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SUSTAINABLE HYDROPOWER MASTER PLAN FOR THE XE KONG BASIN IN LAO PDR

FINAL REPORT

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