MRC SEA OF MAINSTREAM HYDROPOWER:
HYDROLOGY & SEDIMENT BASELINE

SEA Regional baseline workshop

Phnom Penh, 27-28 January 2010

outline

1. Scope
2. Temporal and spatial framework
3. Overview of the hydro-ecological zones
4. current hydrology & sediment regime of the Mekong River
5. Impacts of Chinese mainstream dams on the LMB
6. Trend analysis of key features in the hydrological regime

Scope

Key Strategic Questions

- Will the construction of mainstream hydropower alter the fundamental hydrological processes of the Mekong River?
    - Changes to the hydrological seasons of the Mekong River
    - Changes to the flood regime
    - Tonle Sap connectivity
    - Saline intrusion

- How will the mainstream dams influence the fate and transport of sediment through the Mekong River and what are the geomorphologic implications of this?
    - Sediment load & transport
    - In-channel erosion & deep pools
    - Dynamics of marine sediment plume

Temporal Framework

- Based on the BDP "baseline" and "Definite future" scenarios

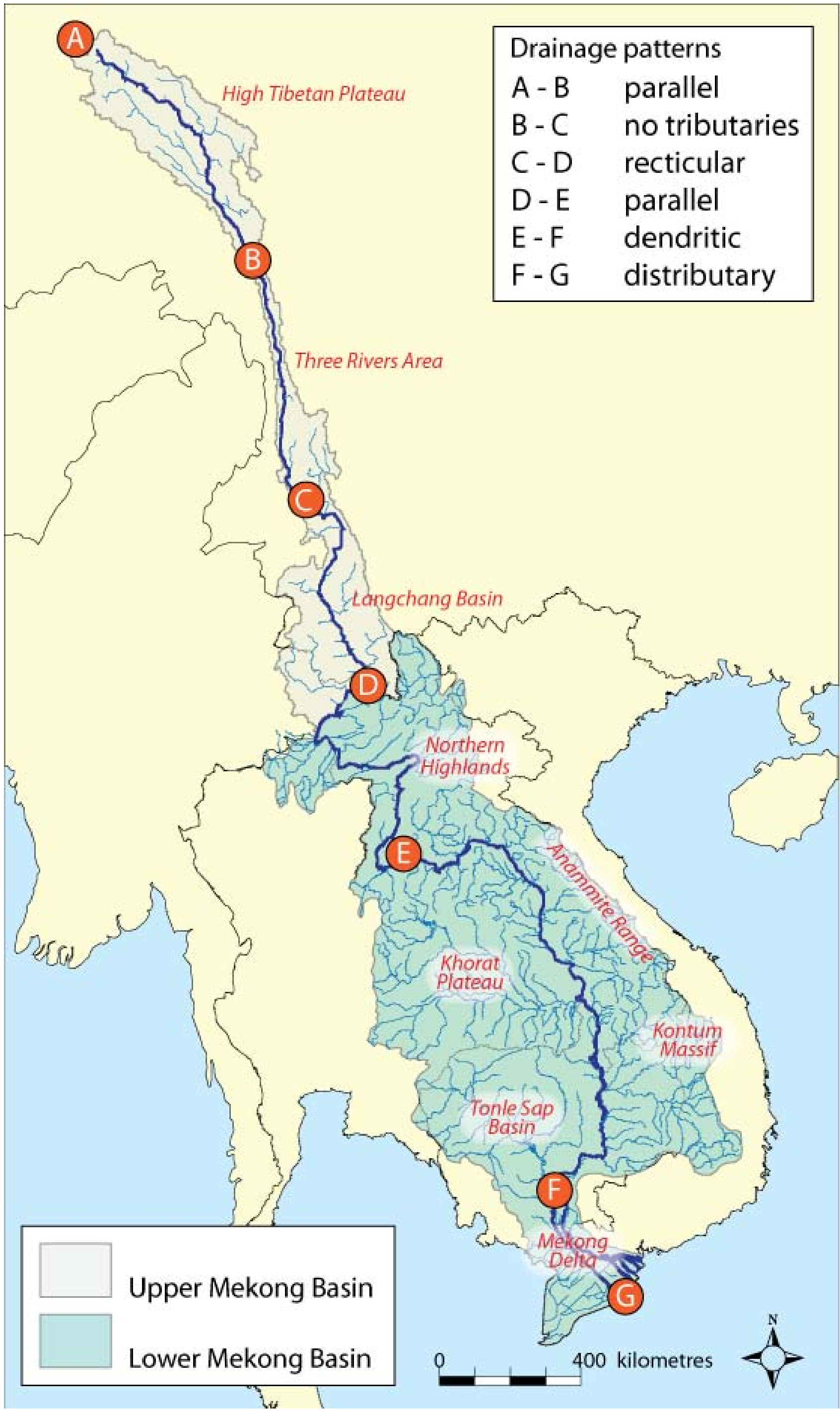
SEA past & current situation	SEA future without LMB mainstream
BDP BASELINE SCENARIO	**BDP DEFINITE FUTURE SCENARIO**
• Takes 2000 as the baseline • Includes 11 hydropower dams, but does not include: (i) Manwan in China, and (ii) 5 small Thai dams (Huai Luang Lam Phra, Nam Oon, Nam Pao, also existing in 2000) with a total installed capacity of 1,620MW • Includes 3.8 x10^6 ha of irrigated land • 1,620 x10^6 m^3 for water supply	• 35 dams overall, includes: (i) 11 from the baseline, (ii) 6 mainstream Chinese dams, (iii) 18 tributary dams existing or under construction in 2009, with a total installed capacity of 21,053 • 4 x10^6 ha of irrigated land (increase of 5.3% from the BDP baseline) • 2,938 x10^6 m^3 for water supply (increase of 81.4%)

Spatial Framework

- The Mekong River is 4,880km long

- Suitable zoning is required to understand the hydrological and geomorphological implications of future development

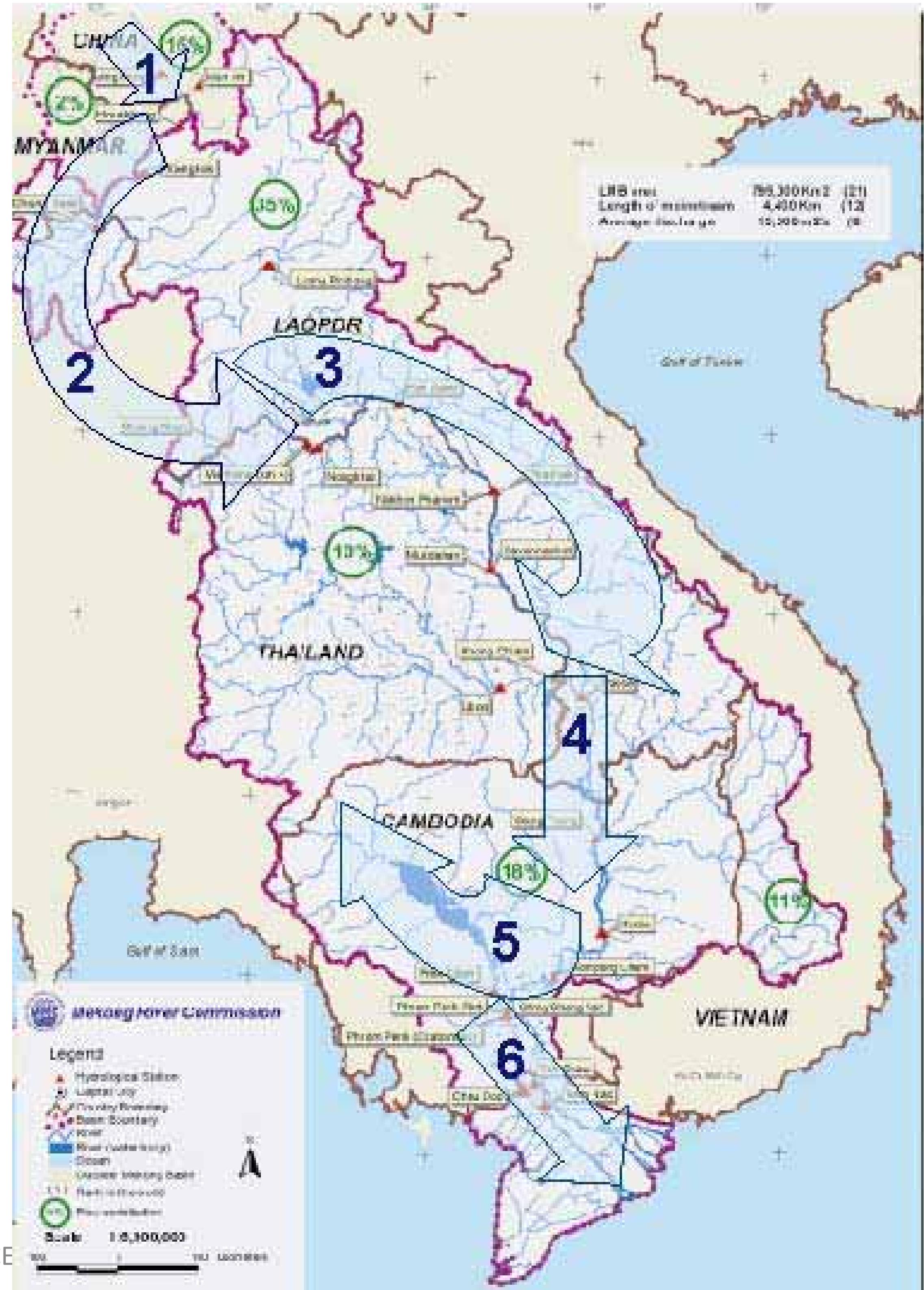
  - Political boundaries (UMB & LMB)?
  - Zones based on drainage patterns?
  - Geological zones
  - MRC hydro-ecological zones represent the most comprehensive and multivariate zoning applied in the LMB



Source: MRC. 2010. State of the Basin Report

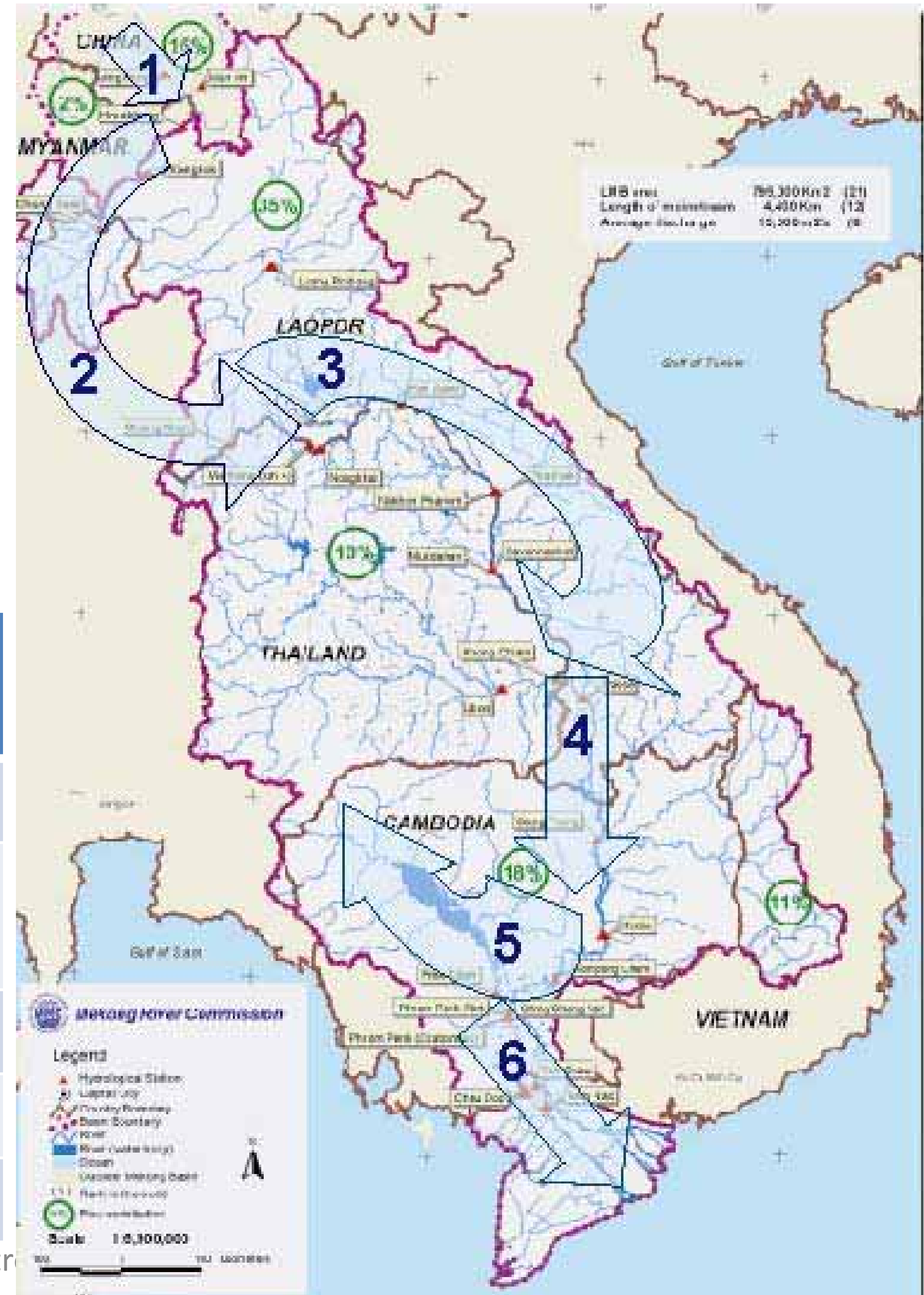
Overview of the hydro-ecological zones

1. UMB
2. Chiang Saen – Vientiane
3. Vientiane – Pakse
4. Pakse – Kratie
5. Kratie – Phnom Penh
6. Phnom Penh – South China Sea



Zone 1 Upper Mekong Basin (UMB)

- **Zone of sediment production**
- Narrow steep gorges with confined single-thread channel
- Some glaciers in the headwaters of the catchment
- Geologic zones: Gorges, Ailao Shan Shear Zone



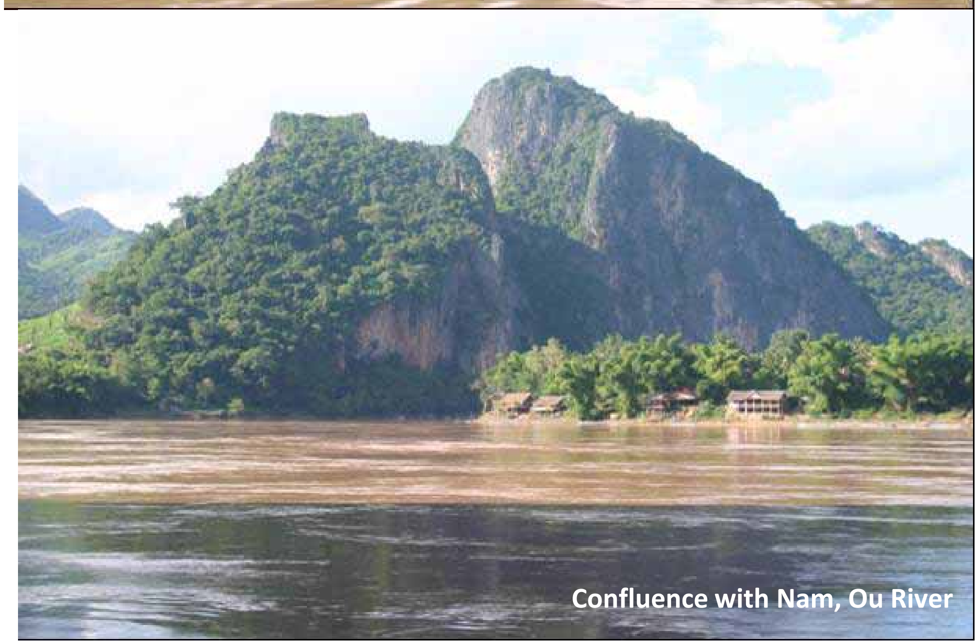
characteristic	UMB contribution
Mekong average annual flow	16%
Mekong average annual sediment load	40-43%
River length	44%
fall	90%

MRC Initiative for sustainable hydropower & ICEM - International Centr

Zone 2 Chiang Saen to Vientiane

- **Zone of sediment transport**
- Mountainous, large areas of remaining forest
- bedrock confined single-thread channel
- large-flow, low-sediment tributaries on the left-bank
- significant meander in the planform
- In-channel islands, sand /gravel bars & deep pools concentrated around bed-rock out crops.
- silt terraces up to 25m above lowest bed level,
- sand bars 5-10m above bed level typically abut from terraces
- Shifting position of channel features
- Lowest level of development in the LMB
- shared riverbank

Surveyors Camp at proposed Pak Beng site



Confluence with Nam, Ou River

Zone 3 Vientiane to Pakse

- **Zone of sediment transport** (minimal production)
- Increasing influence of tributaries to flow
- Reduction in meander and channel slope
- Alluvial channel with (5-15m) in channel deposition
- widening cross-section becoming braided in some reaches
- Formation of larger flat-topped channel islands which migrate by progressive accretion
- Channel becomes increasingly bed rock confined near Pakse
- Channel shared riverbank between Lao PDR and Thailand

Zone 4 Pakse to Kratie

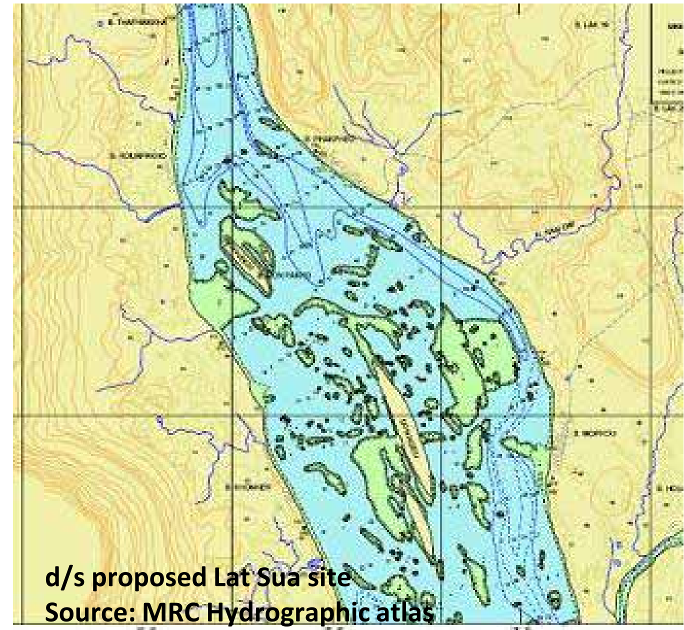
- **Mixed zone of sediment transport, production & deposition**
- 3S contributions (>25% of total annual flow volume for Mekong)
- Upper reaches are bedrock confined

Upstream of Khone Falls:

- flat topography & scattered bedrock outcropping induces a complex of anabranching channels
- Khone falls drops the channel bed

Downstream of Khone Falls

- River shifts to floodplain
- salient hydrological features become water level rather than flow driven



d/s proposed Lat Sua site
Source: MRC Hydrographic atlas

Simphandon in flood
Source: MRC Annual Flood Report 2008

Zone 5: Kratie to Phnom Penh

- **Zone of sediment deposition**

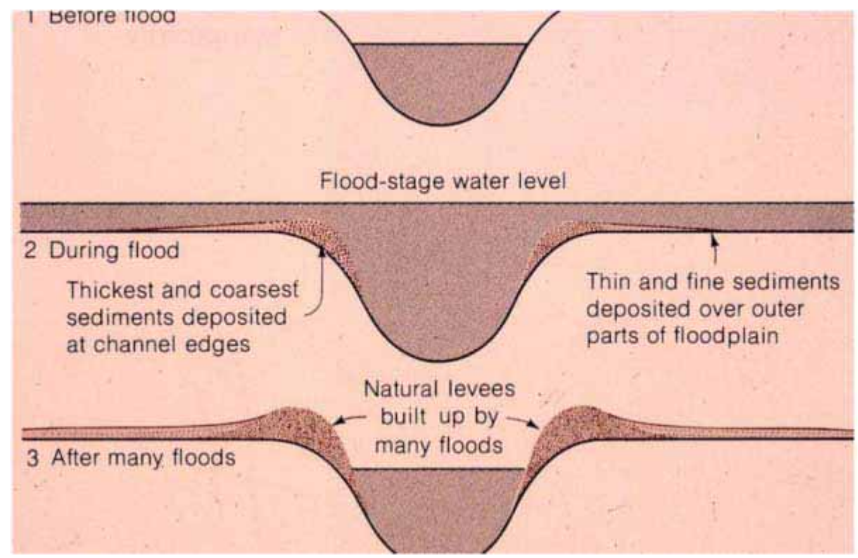
Cambodian floodplain and the Tonle Sap system

- River becomes braided and in parts resumes anastomosed reaches,
- Significant migration of channel reaches and channel features.
- Overbank siltation process builds natural levees preventing return flow of floodwaters on the falling limb of the flood peak
- Tonle sap flow reversal : 8m seasonal variation in Mekong water levels

Downstream of the Tonle Sap

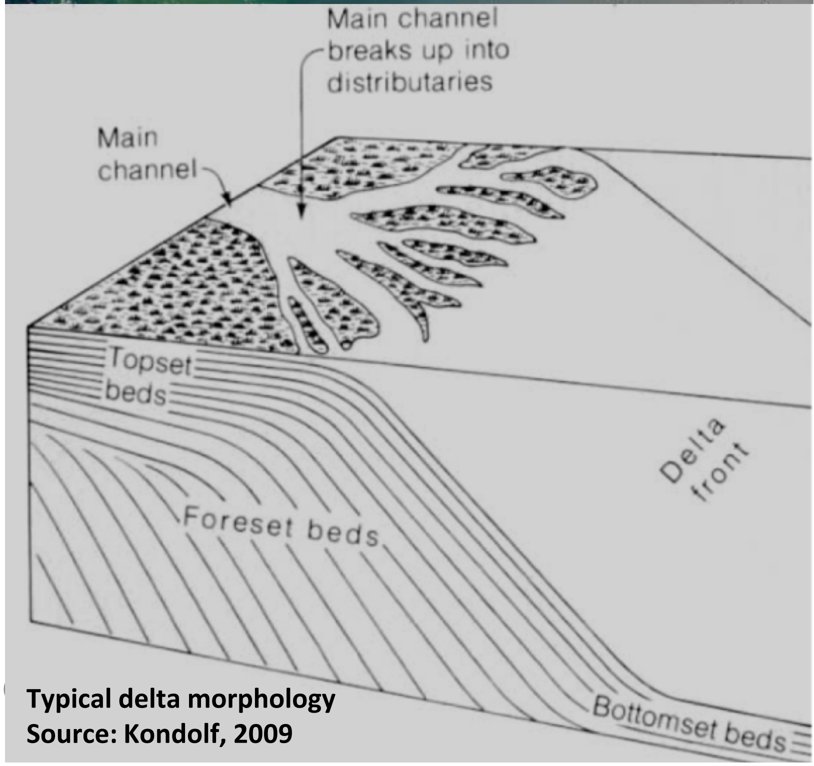
- The Mekong divides into two channels

Cambodian flood plain
Source: MRC Annual Flood Report 2008



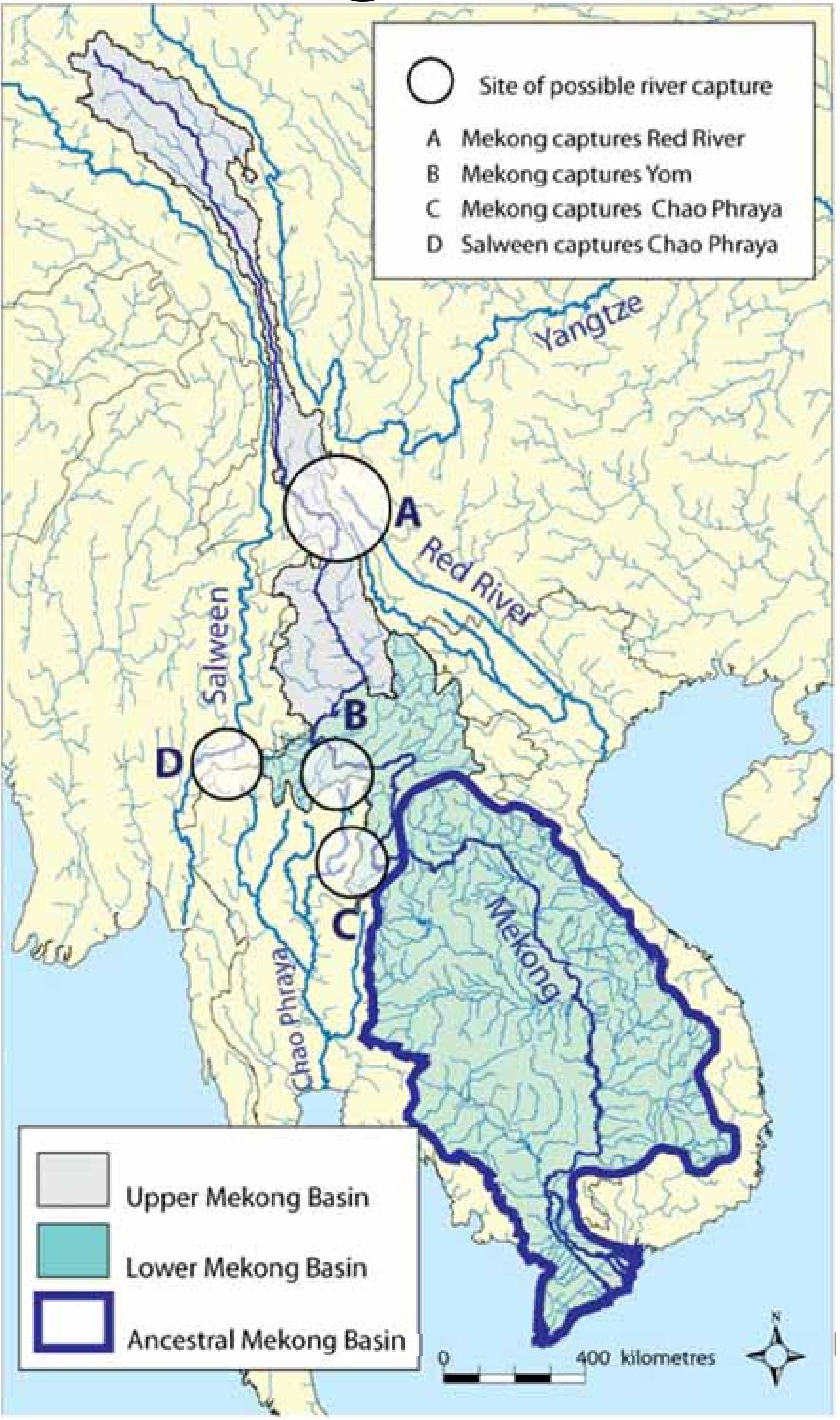
Zone 6: Phnom Penh to South China Sea

- **Zone of deposition**
- Deltaic environment: Braiding of the mainstream and complex network of canals
- River fans out into a network of distributaries with high levels of siltation in between
- Overland flow during the flood season
- Overbank siltation traps flood waters with pockets of remnant wetlands
- Extensive flooding (max. depth of 4m)
- Dry season saline intrusion: affects half of Vietnam's delta.
- High levels of erosion



Typical delta morphology
Source: Kondolf, 2009

Change in the Mekong Basin



- Over geologic time, the Mekong basin has undergone major change
- Ancestral Mekong Basin was centered around the Khorat Plateau & central highlands
- ~6,000yrs ago the South China Sea was almost at Phnom Penh
- Since then the Mekong Basin has reached a dynamic equilibrium with the climate and landscape

Which means:

- No drivers of change within the natural system
- Very consistent & predictable annual hydrograph
- Change to the hydrology & sediment regime is human induced

Drivers of change to the hydrograph

3 types of human-induced change:

1. Changes to the run off regime
   – Land clearing & deforestation

2. Change to surface water volumes
   – Water abstraction for human use (irrigation & water supply)

3. Change to basin storage capacity
   – hydropower

Land clearing, deforestation & changes to run off

Land clearing & deforestation → **Changes to the run off regime**

1960 – 2000

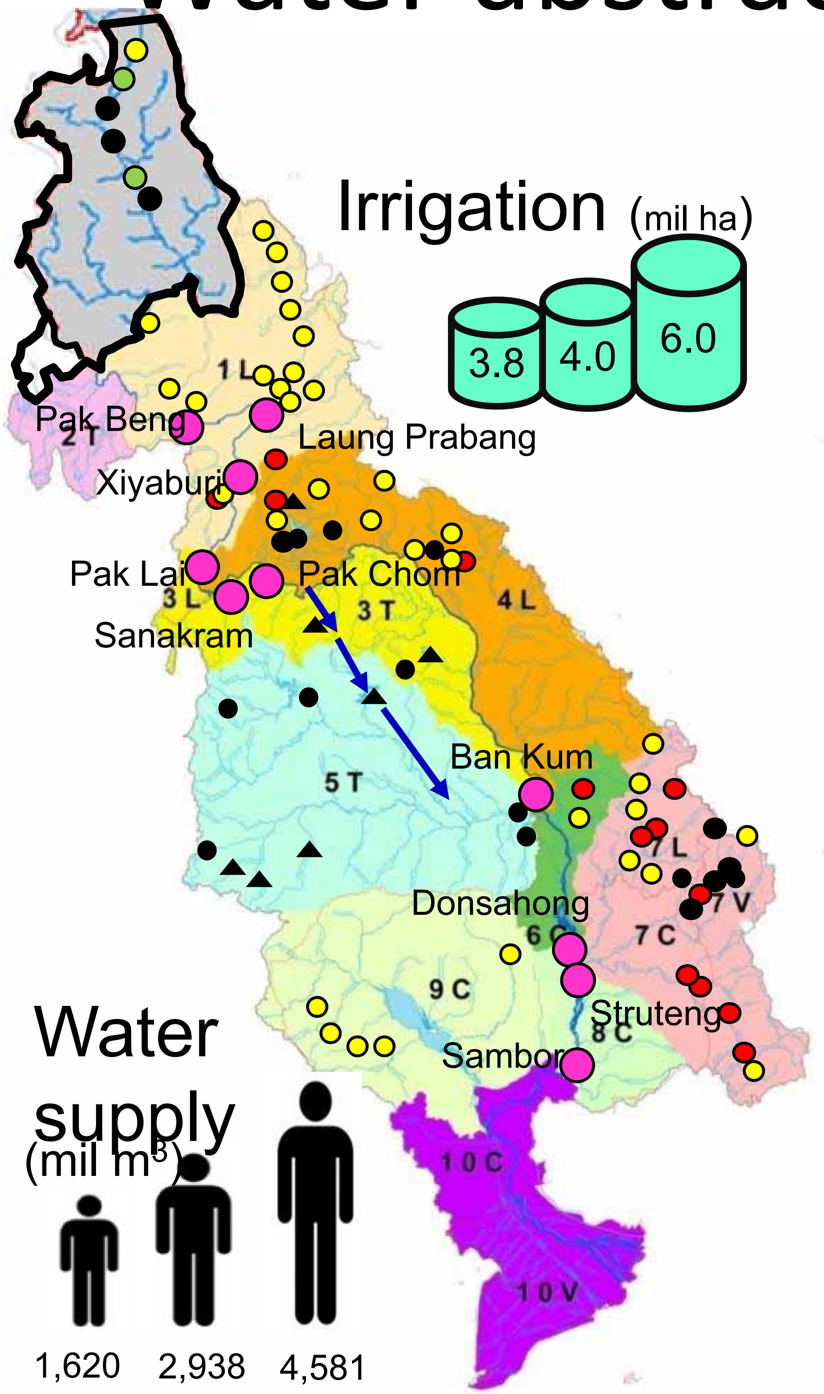
- National deforestation rates
  - Yunnan province from 55% to 33%
  - Thailand from 53% to 29%
  - Lao PDR 60% to 41%
  - Cambodia 70% to 53%
  - Vietnam 42%to 30%

Changes to the run off regime

- Change in land cover can affect runoff/infiltration balance
- Land clearing has seen significant local/tributary impacts
- needs to be at very large scales to affect regional hydrology

- ~17-20% of the Mekong basin has been cleared since the 1960s and this is likely to increase
- Will continue to have impacts on tributary and localised run off volumes
- The size of the basin means this is not likely to change regional hydrology

Water abstraction for human use



Source: MRC, 2009

- Applied irrigation accounts for 5% of mean total volume of basin run off
  - An order of magnitude lower than forest evapotransiration
- Domestic & industrial use is another order of magnitude below this
- Only mega-irrigation projects are likely to be a strategic issue for mainstream

Potential mega-irrigation projects

- Loei-Chi-Mun scheme
- Nam Ngum diversion
- UMB inter-basin water transfer

Hydropower development

Change to basin storage capacity:

- Has been considered for more than 60years (e.g. Nam Pung 1965)
- Becoming more attractive
- 35 projects are planned for completion by 2020
- Hydropower is the only type of development which can influence basin hydrology on a project by project basis
- The biggest reservoir storage projects are the UMB

No	Country	Project Name	MW	Completion
1	China	Dachaosan	1350	2003
2	China	Gonguoqiao	750	2008
3	China	Jinghong	1500	2010
4	China	Manwan	1500	1995
5	China	Nuozhadu	5850	2017
6	China	Xiaowan	4200	2013/2012
7	Laos	Houayho	150	1999
8	Laos	Nam Leuk	60	2000
9	Laos	Nam Lik 2	100	2010
10	Laos	Nam Mang 3	40	2004
11	Laos	Nam Ngum (1)	155	1971
12	Laos	Nam Ngum 2	615	2013
13	Laos	Nam Ngum 5	120	2011
14	Laos	Nam Song	60	1996
15	Laos	Nam Theun 2	1070	2010
16	Laos	T. Hinboun	210	1998
17	Laos	Xekaman 1	322	2014
18	Laos	Xekaman 3	250	2010
19	Laos	Xekaman 2	53	
20	Laos	Xeset 2	76	2010
21	Thailand	Chulabhorn	40	1971
22	Thailand	Nam Pung	6	1965
23	Thailand	Pak Mun	136	1997
24	Thailand	Sirindhorn	36	1968
25	Thailand	Ubol Ratana	25	1966
26	Vietnam	Buon Kuop	280	2008
27	Vietnam	Ban Tou Srah	86	2008
28	Vietnam	Plei Krong	120	2008
29	Vietnam	Se San 3	273	2006
30	Vietnam	Se San 3A	96	2006
31	Vietnam	Se San 4	360	2009
32	Vietnam	Se San 4A	255	2008
33	Vietnam	Sre Pok 3	300	2011
34	Vietnam	Sre Pok 4	100	2009
35	Vietnam	Yali	720	2000
	TOTAL		21264	

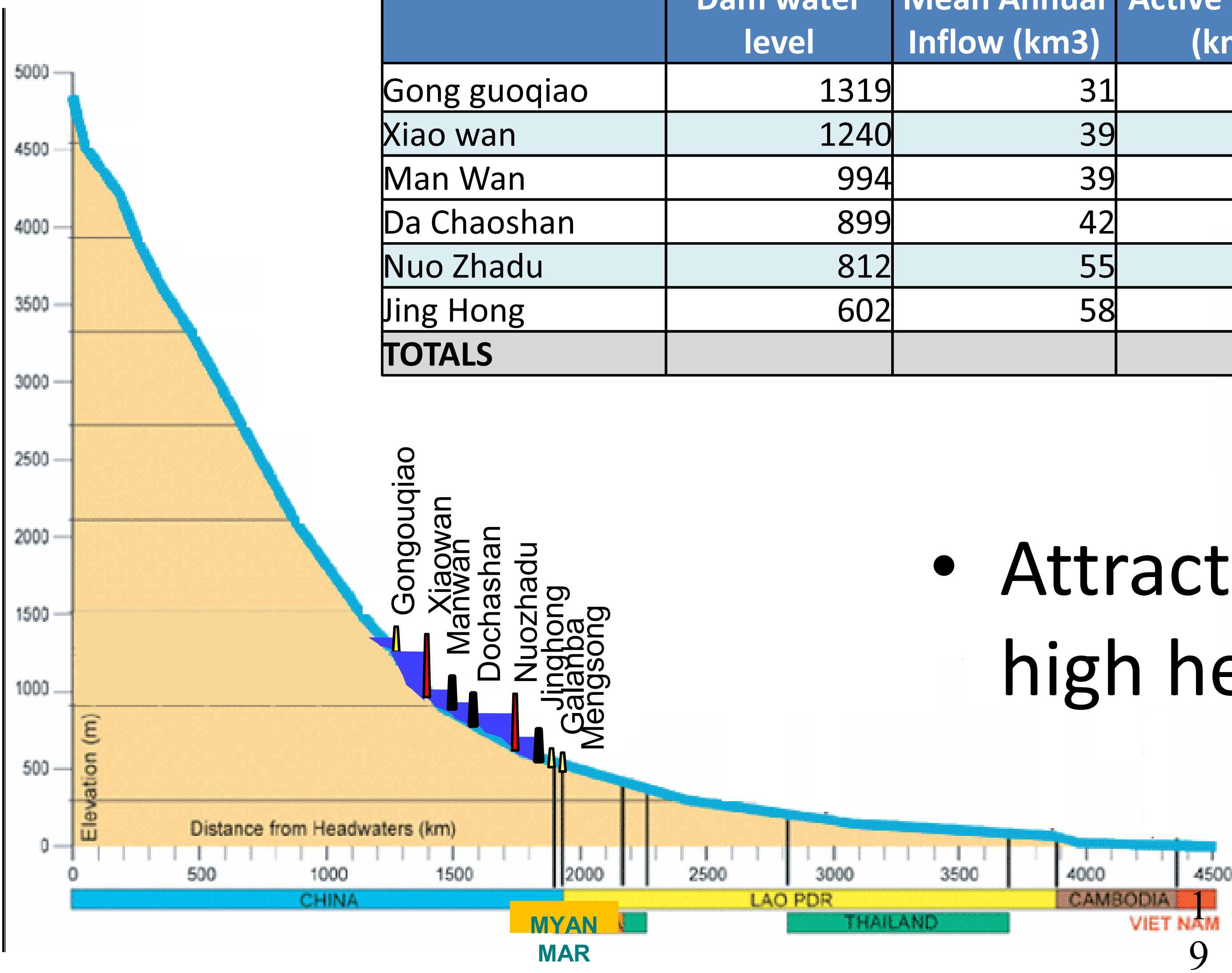
The Yunnan Cascade

- Cascade of 8 dams (16,460MW)
- Using 828m of head
- Part of China's national energy demand strategy & state policy to reduce greenhouse gas emissions
- Cascade is in the lower Lancang River
- Coordinated operation between the dams

STATUS	UMB MAINSTREAM PROJECT
Operational	Manwan, Dachaoshan, Jinghong
Construction started 2002 (reported to be filling)	Xiaowan
Construction started 2004	Nuozhadu
Under design	Gongguoqia, Ganlanba
postponed	Mengsong (due to predicted impacts on fish migration)

Yunnan cascade: Salient features

	Dam water level	Mean Annual Inflow (km3)	Active storage (km3)	Head (m)	TE1 (%)	TE2 (%)
Gong guoqiao	1319	31	120	750	39	30
Xiao wan	1240	39	9,900	4,200	93	98
Man Wan	994	39	344	1,500	60	60
Da Chaoshan	899	42	467	`1,350	64	66
Nuo Zhadu	812	55	12,300	5,500	92	98
Jing Hong	602	58	577	1,500	62	64
TOTALS			**23,708**			



- Attractive because of high head potential

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Yunnan contribution to Mekong flows

Main flow sources:

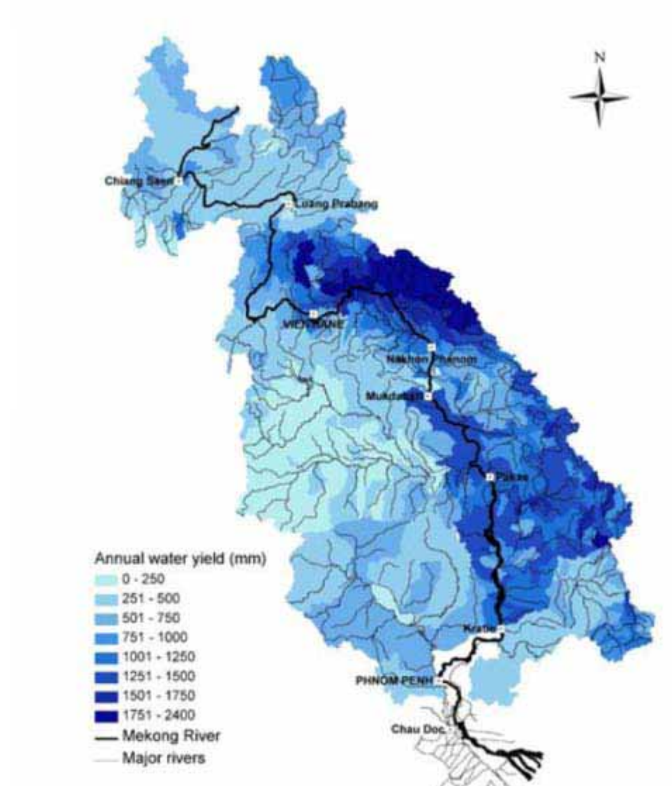
- left bank tributaries in northern Lao PDR
- Central highlands (Nam Theun, Nam Ngum, 3S river basins)

Tributary influence

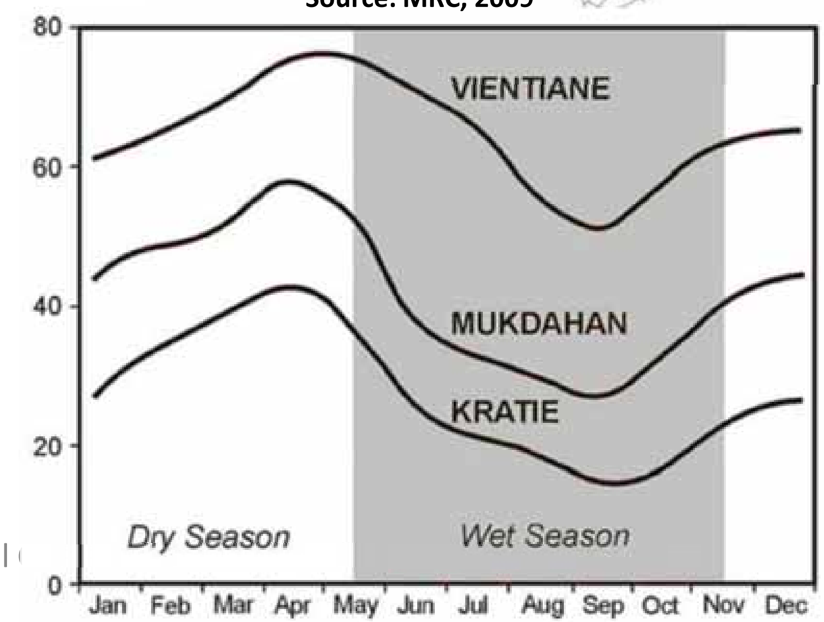
- concentrated on the wet season, and is the key driver of the flood pulse

UMB influence

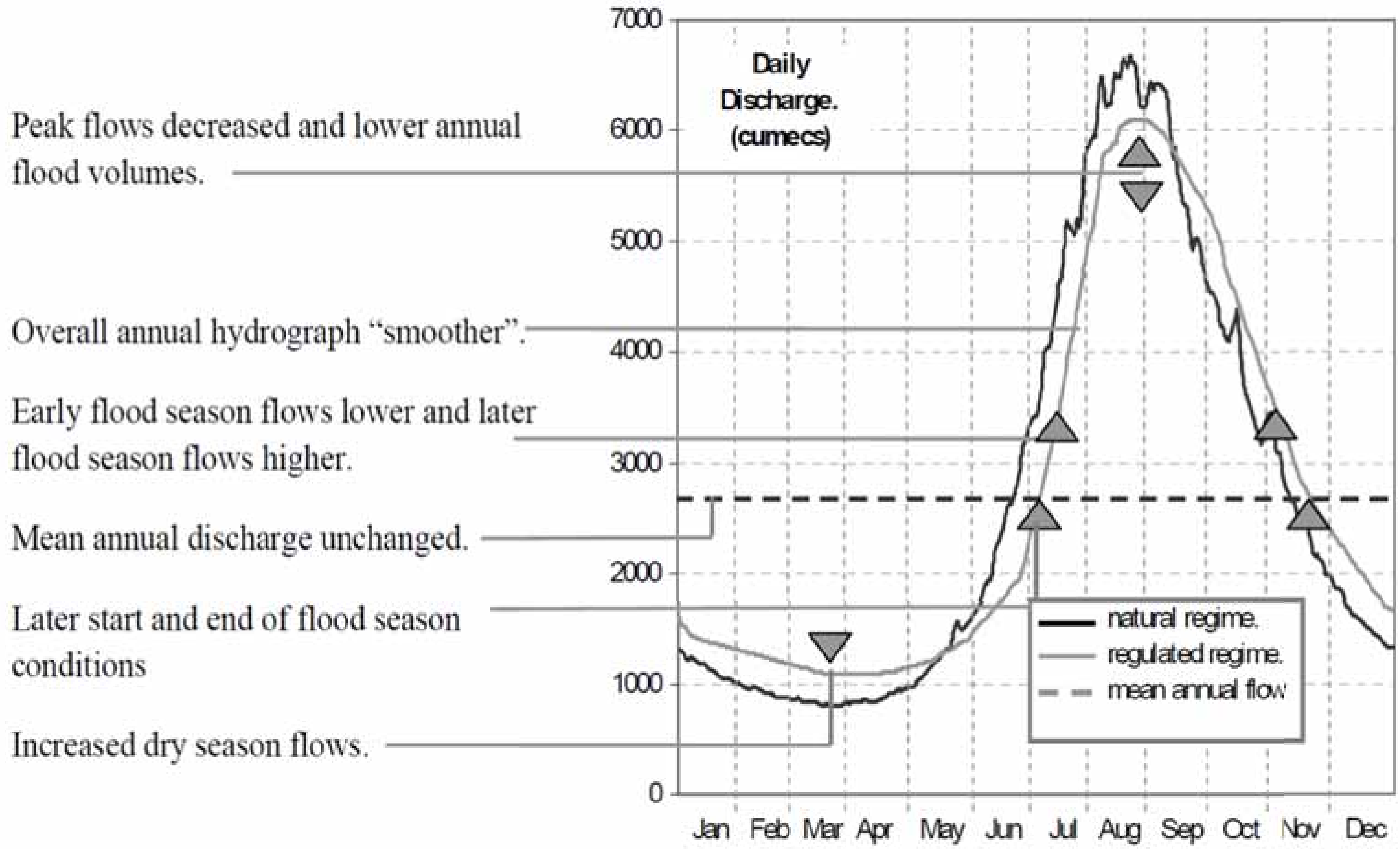
- critical in the dry season because of glacial & snow melt in the late spring provides significant dry season contribution
- UMB: ~16% of total annual flow
- UMB: up to 40% dry season flow at Kratie



Source: MRC, 2009



Typical hydrograph response to hydropower regulation

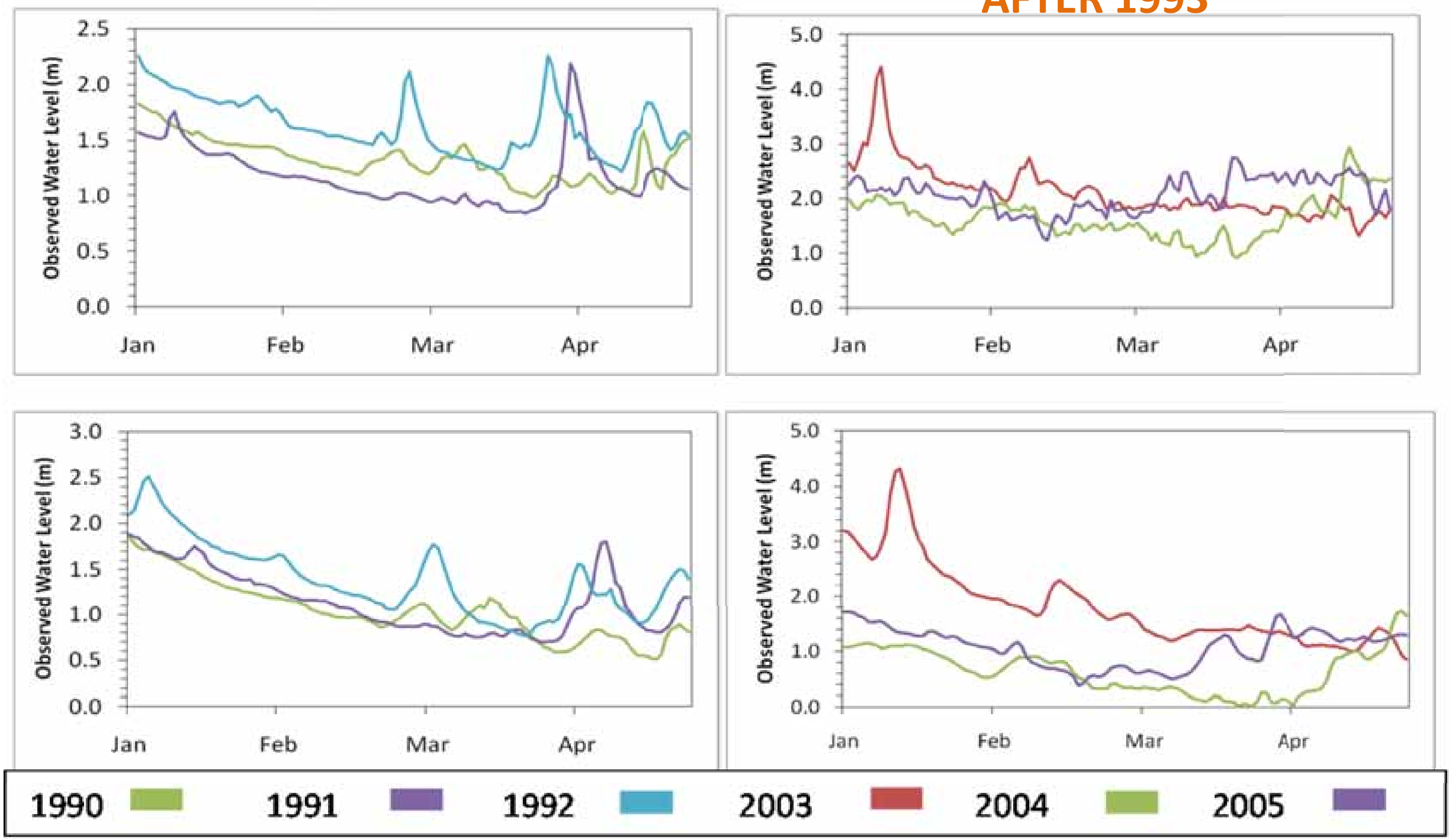


Source: MRC, 2009

- Regulation affects the timing, amplitude & variability of the hydrograph

Observed dry season Impacts from Manwan: Hydrology

BEFORE 1993 **AFTER 1993**

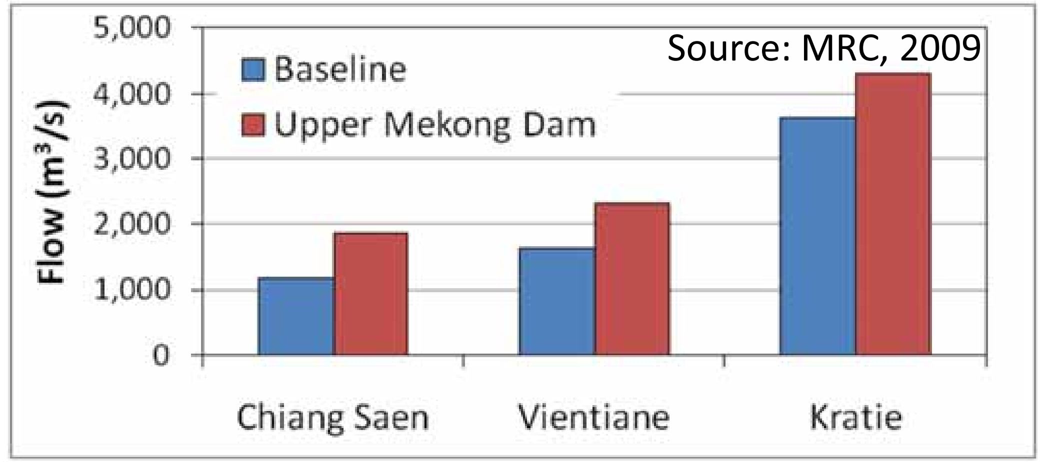


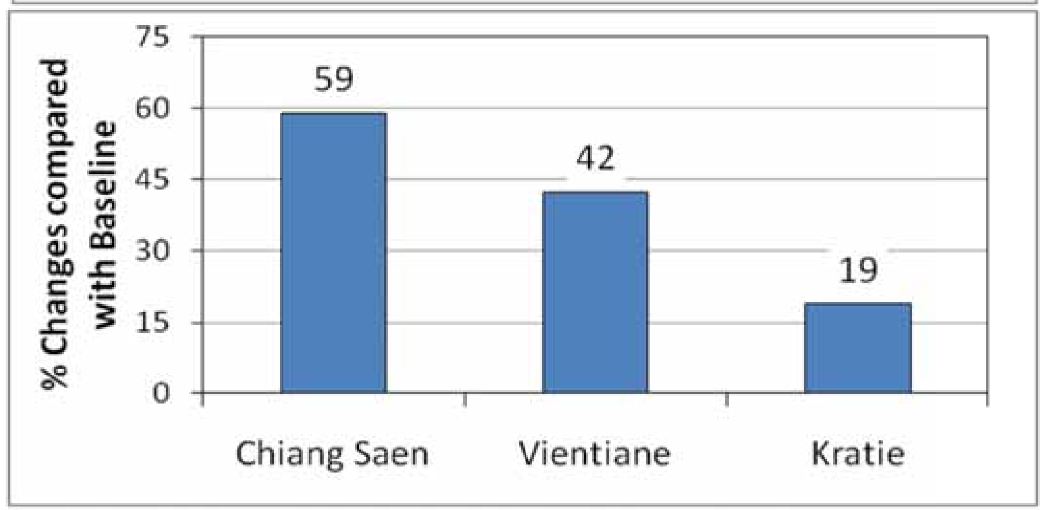
Chiang Saen

Vientiane

- increase in daily dry season water levels at both the Chiang Saen and Vientiane sites, with greater inter-annual variability at the site further downstream

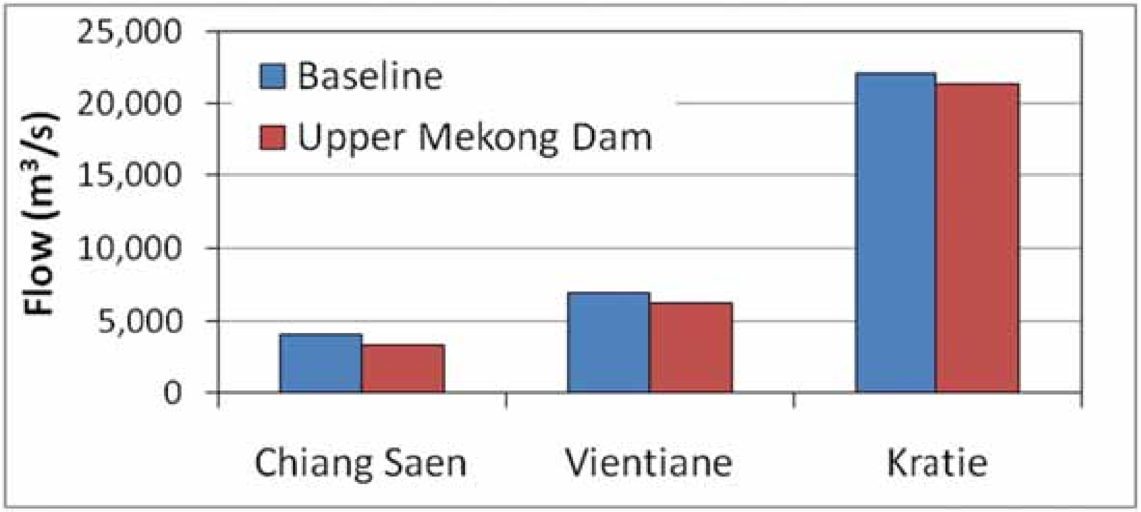
Modelled changes in dry season flows

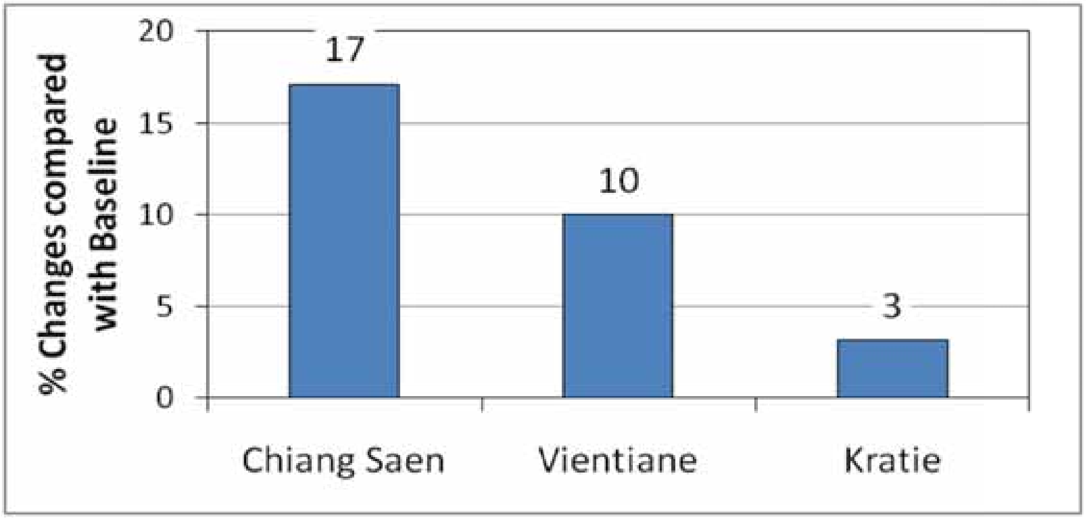




- Dry season flow will increases ~ 690 m^3/s
- Influence will extend down to Kratie

Modelled changes in wet season flows

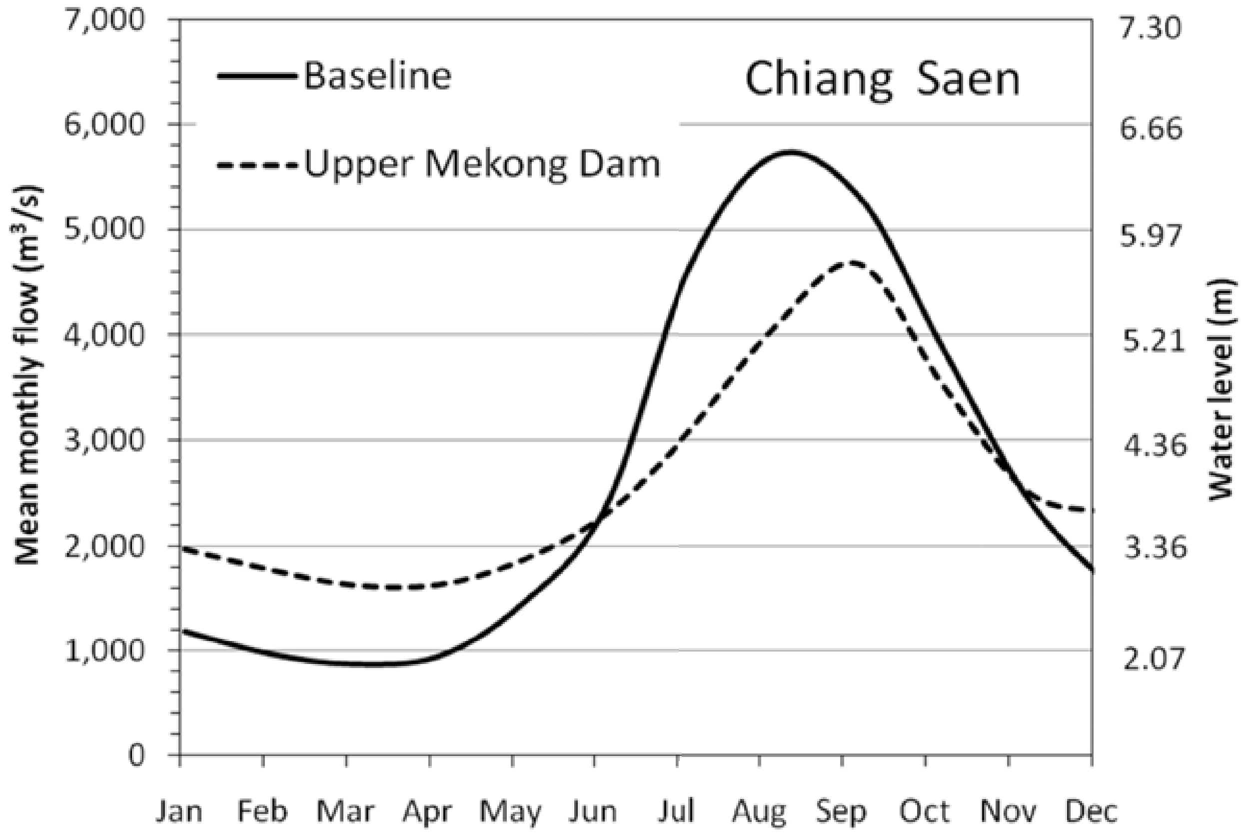




- Wet season flow will decrease ~ 700 m^3/s

Modelled changes to the Mekong annual hydrograph

- Decrease in the flood peak
- Delay in the flood peak
- Increase in dry season low flow
- Shortening of flood season
- Effect will diminish downstream
  - But still reduce flood duration by up to 2weeks in Cambodian flood plain



Mekong Sediment

Drivers of Sediment transport

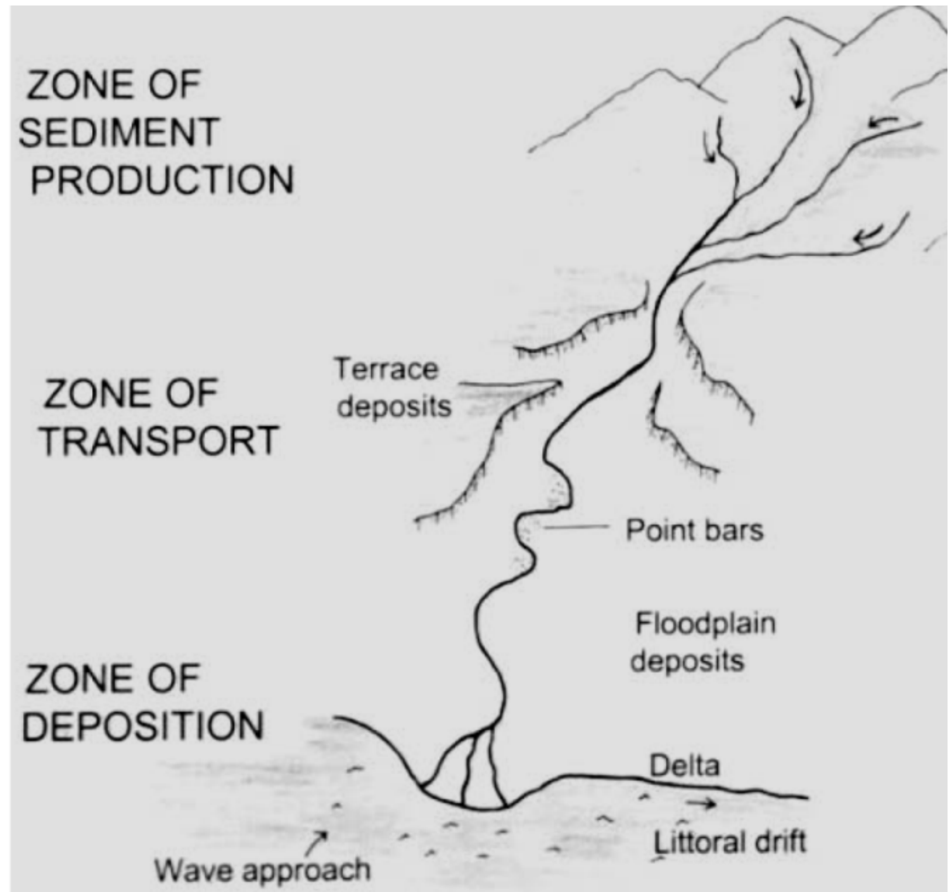
- Sediment load
- Sediment transport capacity

Sediment transport capacity:

- Ability of the river to suspend and carry sediments from zone of production to zone of deposition
- Yunnan dams will reduce peak flows but will not see a significant reduction in transport capacity

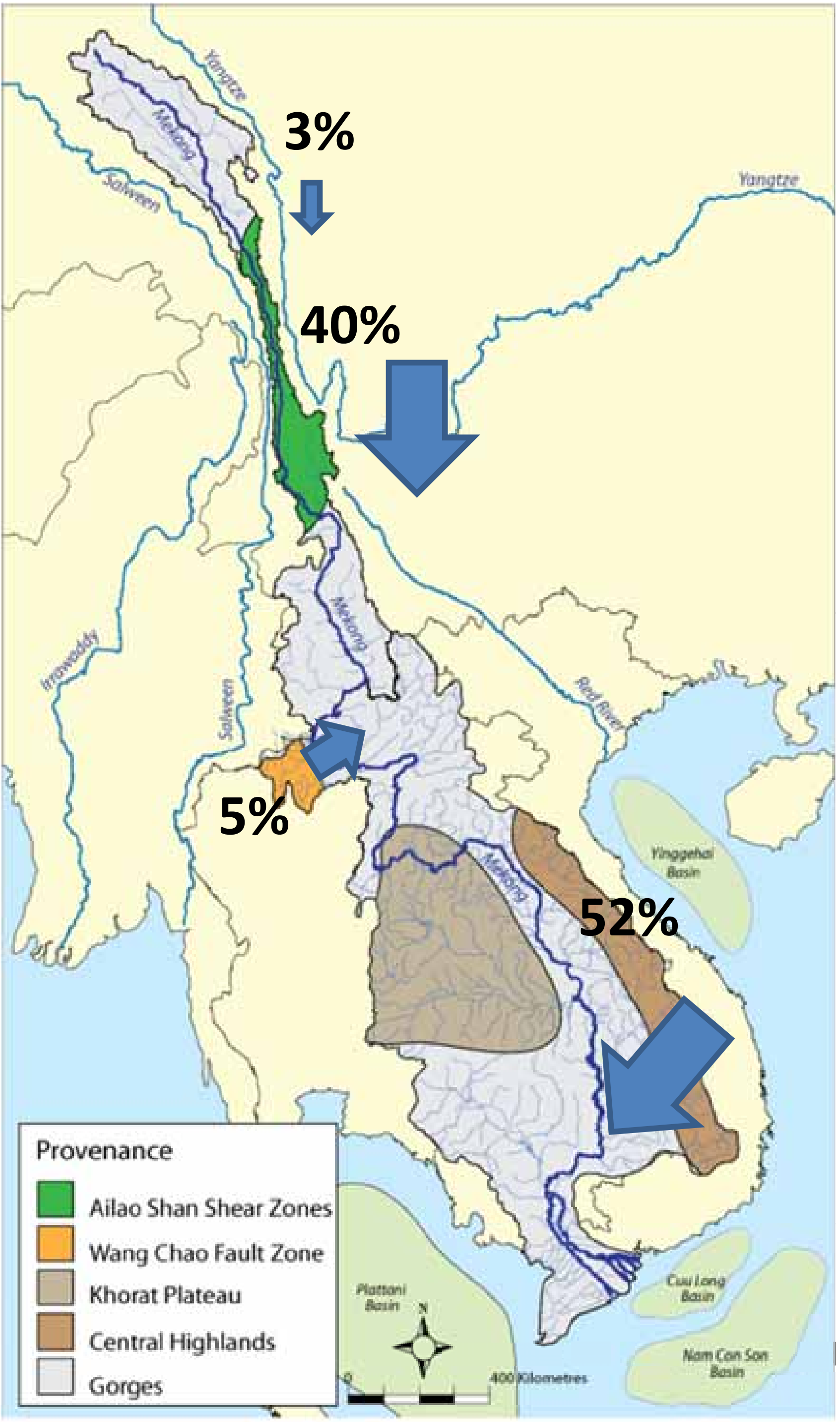
Sediment load:

- Current sediment load ~150 – 190 $x10^6 m^3$
- Yunnan dams will reduce sediment load
- But how much?

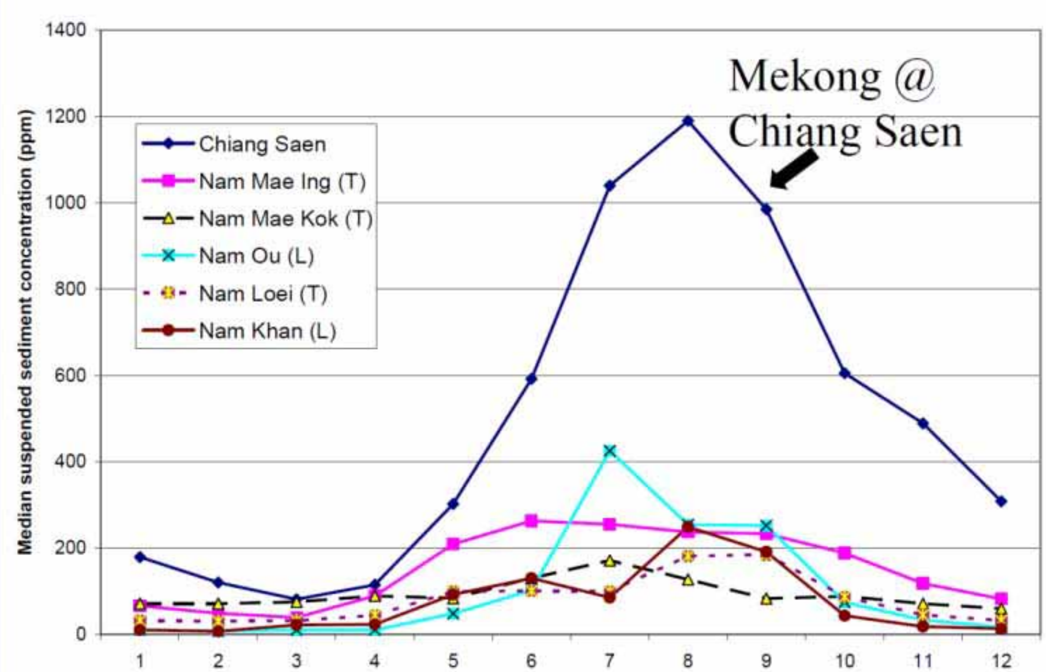


Source: Kondolf, 2009

Source of sediment

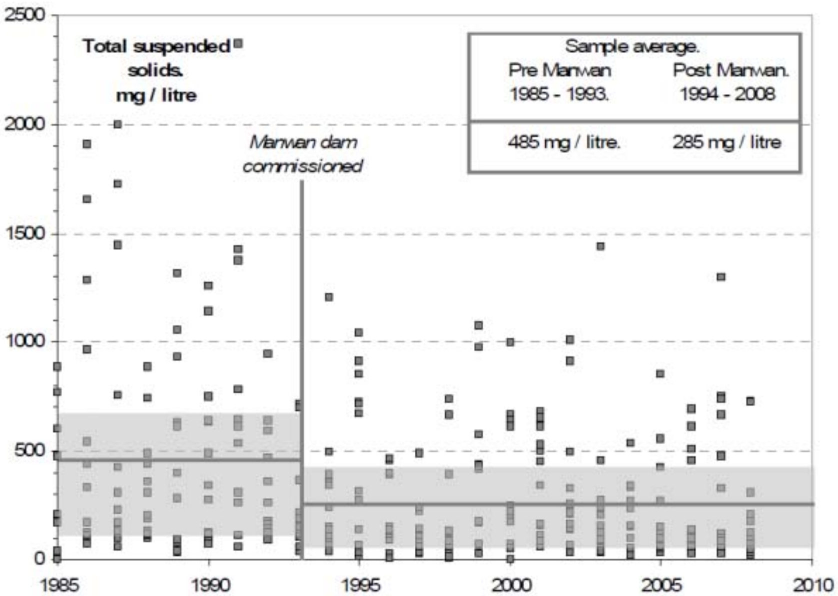


- Basin formed by different tectonic shifts millions of years apart => differing sediment yields for different areas of the basin
- Ailao-Shan shear zone and the Central Highlands dominate sediment production
- Small sediment contribution from northern Lao tributaries
- Hydropower development to 2020 is focussed in the high sediment yield zones of the basin: Yunnan province & the Central Highlands

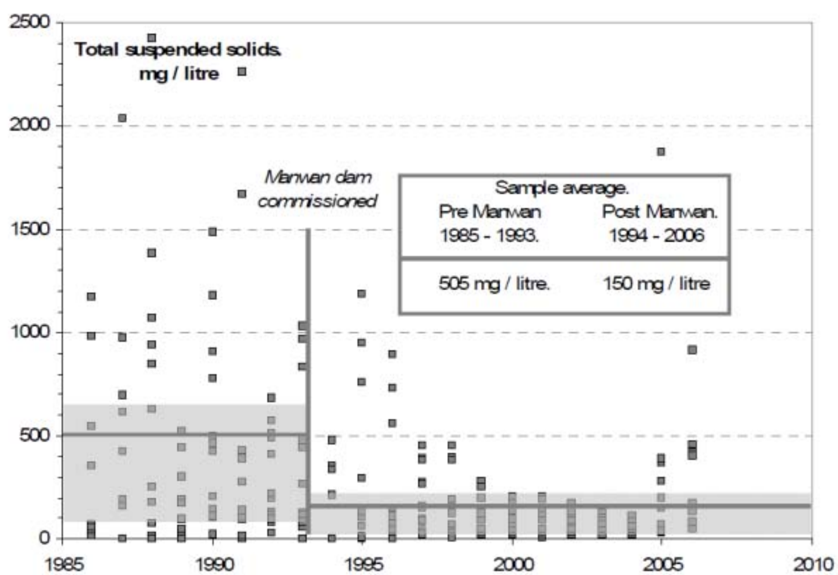


Source: Conlan, 2009

Observed sediment impacts from Manwan

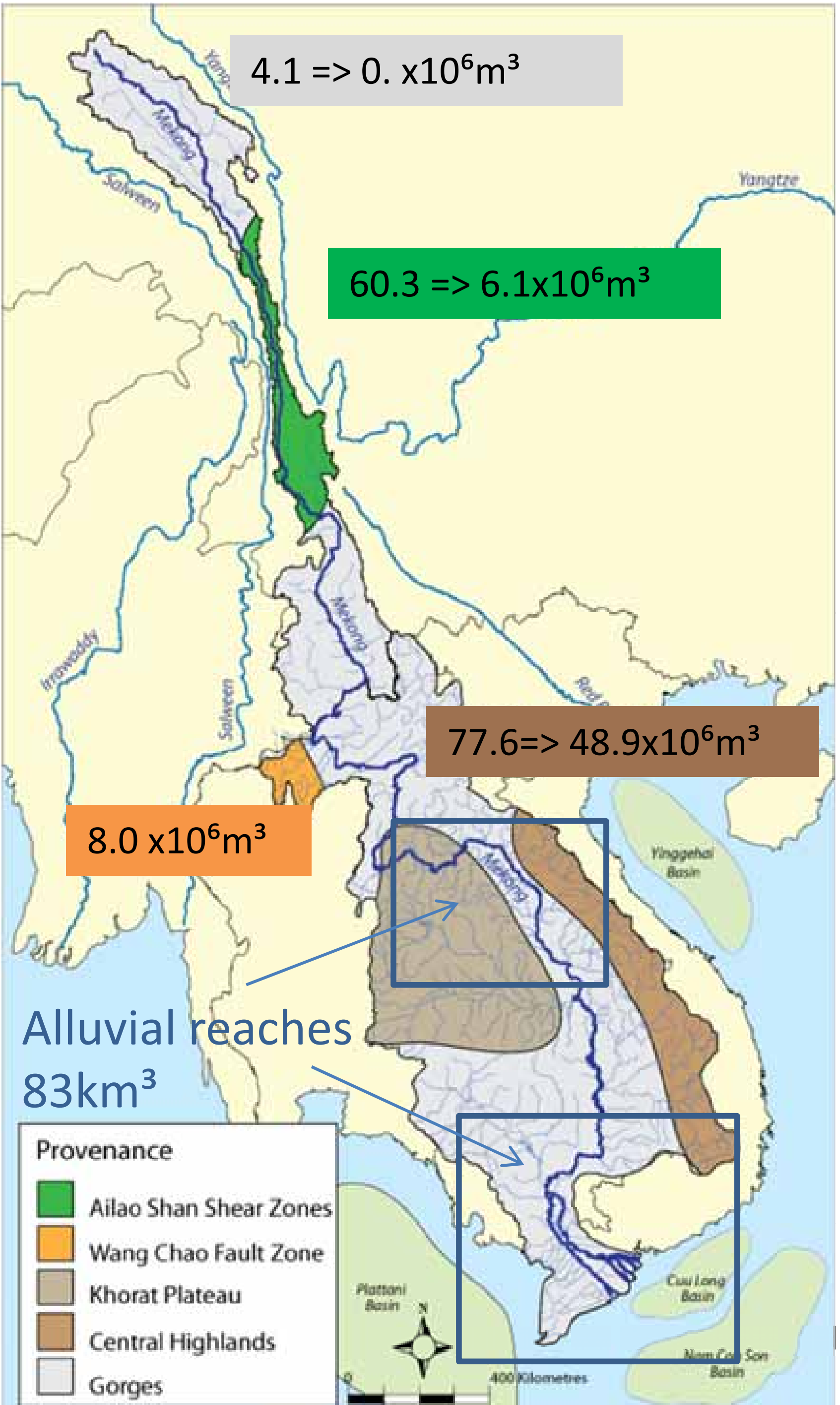


Chiang Saen



Luang Prabang

- Manwan has reduced mainstream sediment concentrations
- Reduction ranges from 25-65%
- Poor sediment data sets mean that it is difficult to put an exact value



Quick future sediment balance

- Current sediment load: ~150 x10^6m^3/yr
- *Future sediment production: 67* x10^6m^3*/yr*
- 67% reduction in sediment entering the mainstream due to Yunnan & central highlands development

- If transport capacity doesn't change but headwater production is reduced => river will try to compensate

- Significant proportion of LMB south of Vientiane is alluvial
- make up 83x10^6m^{3}deficit in sediment load by in-channel erosion
- Complex process of scour and deposition determined by the channel geology.

Sediment load future trends to 2020

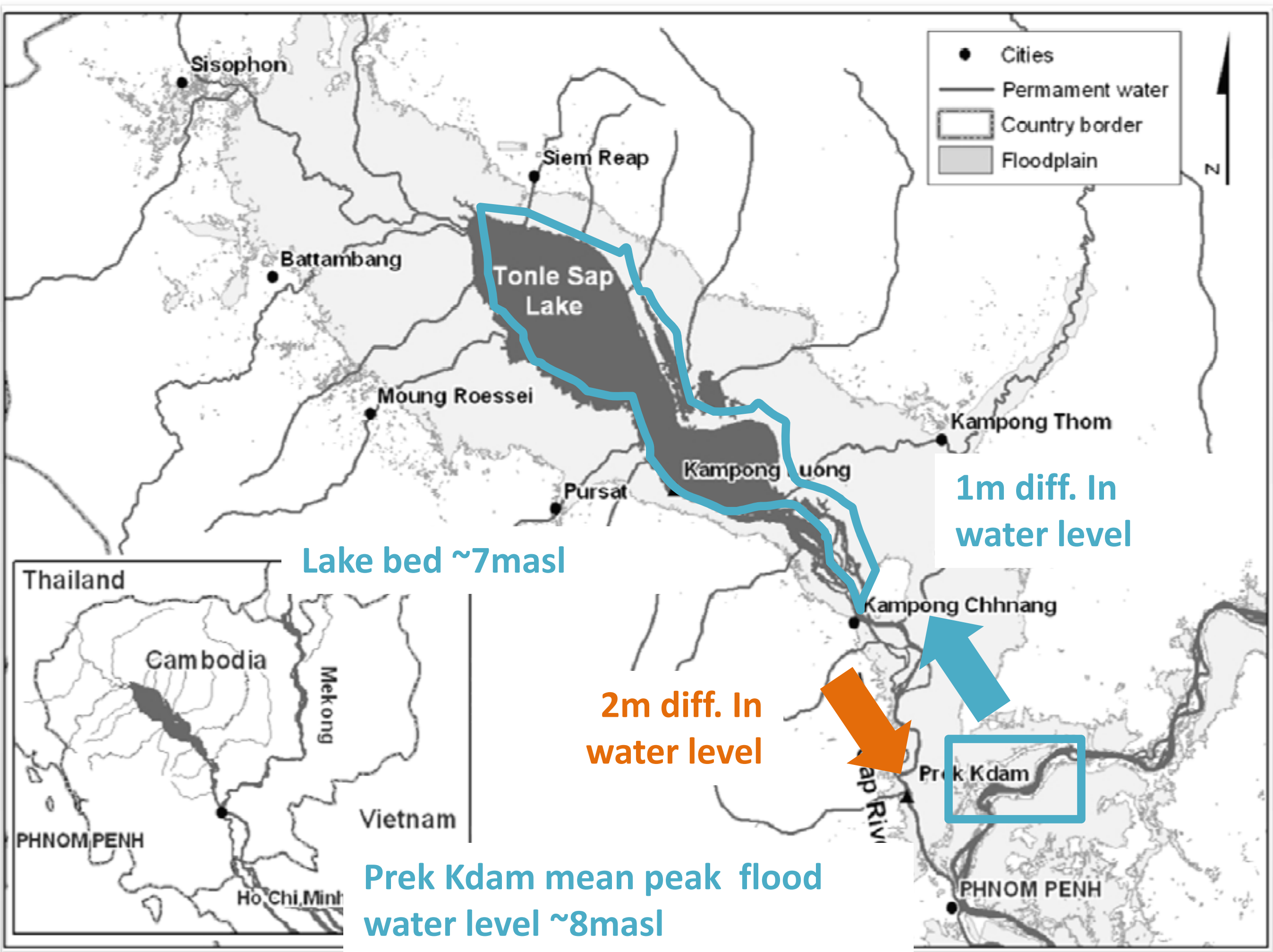
- 80-90% of Yunnan sediment will be trapped by the cascade
- 37% of central highlands load will be trapped by hydropower
- In 10yrs there will be noticeable, localised effects from erosion on alluvial channels
- In 20years there will be significant regional effects from erosion

Hydrological seasons

- 4 seasons:
  – dry – transition 1 – wet – transition 2 -
- Consistent over monitoring record
- Flood peak occurs with less than 2 weeks variability in start date
- Yunnan projects will shift the length & timing of seasons

Tonle Sap

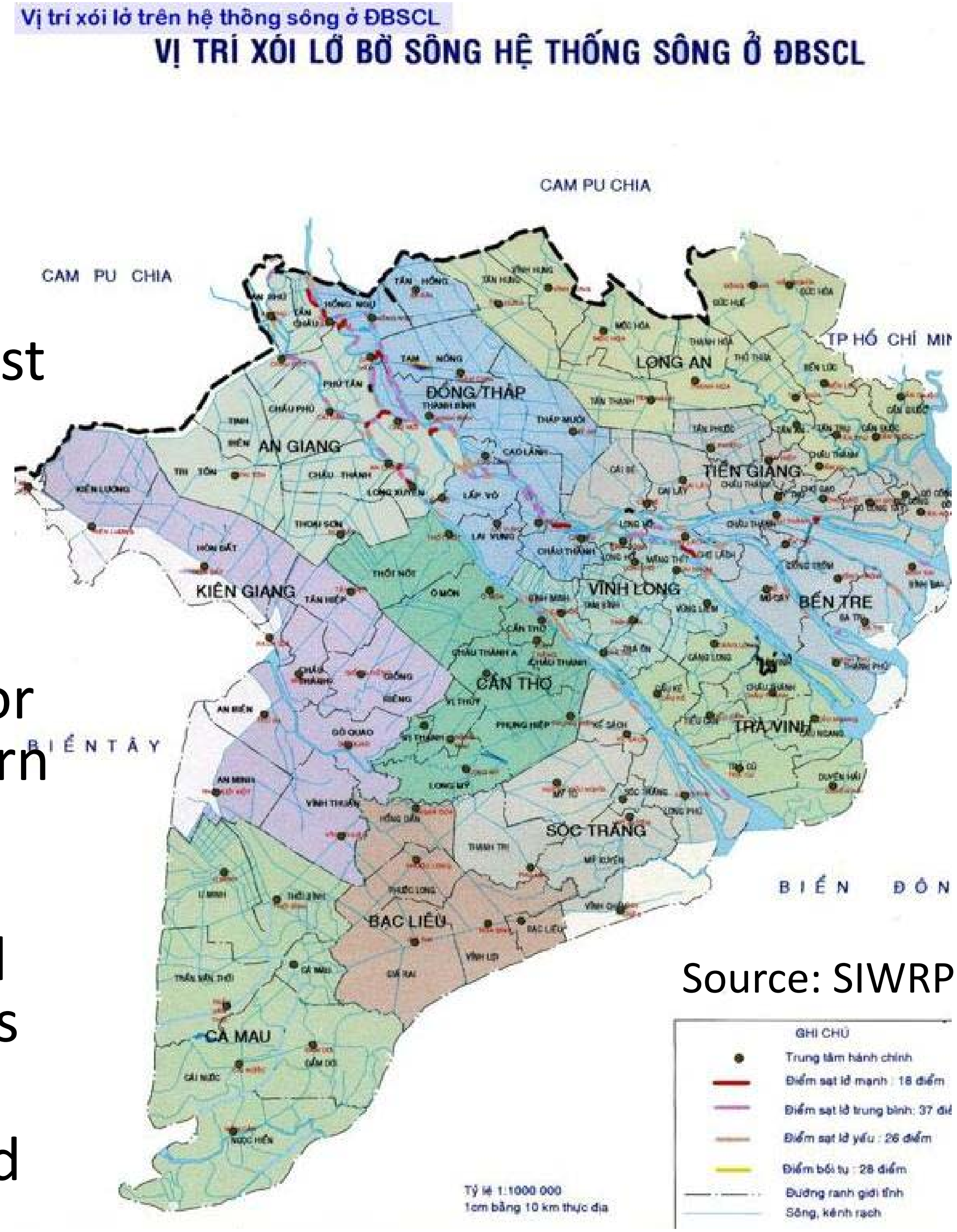
- Tonle flow reversal is the result of seasonal differences in lake and Mekong water levels (typically 1-2m)
- Yunnan cascade will reduce peak wet season flows by 2-2.5m
- This is the same order of magnitude as the key driver of Mekong – Tonle sap flow
- Needs detailed study



Direction	Mean annual Flow [km³/yr]	Sediment [ton]
Mekong – Tonle Sap (wet)	79 (57% of inflow to tonle sap)	4.5 x10^6
Tonle sap – Mekong (dry)	78.6 (88% of outflow)	3 – 6.7 x10^6

Delta sediment dynamics

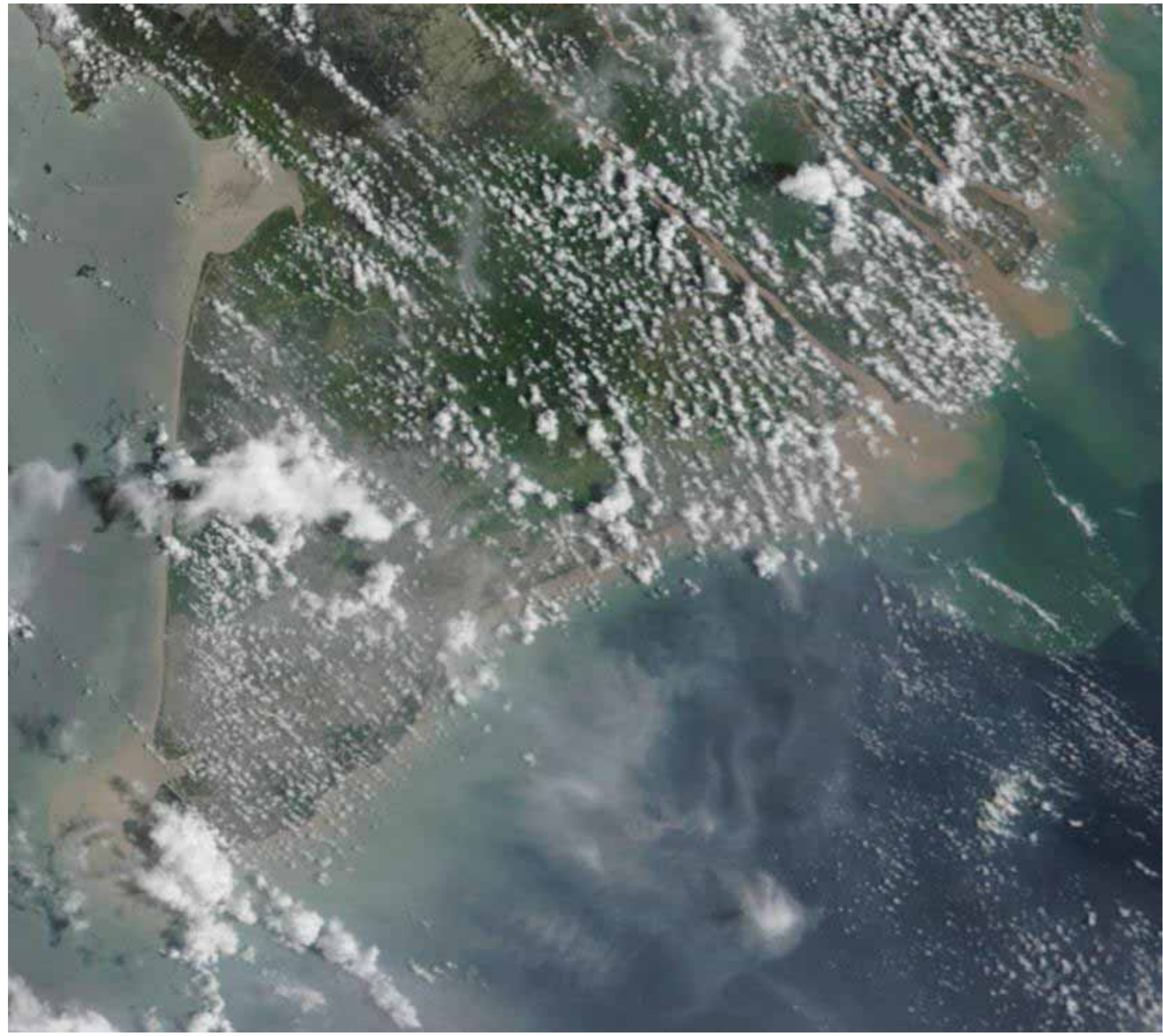
- Saline intrusion affects almost half of the delta
- Increased dry season flows may reduce the extent and duration of saline intrusion
- Modelling suggest only minor changes to delta flood pattern
- The Vietnamese delta has highest erosion rates in the basin (can be >10m) and will likely face the greatest losses of land
- Detailed modelling is needed



Source: SIWRP

Marine sediment plume

- Sediment plume is swept southeast along the delta coastline
- Rebuilds the Ca Mau peninsula
- Sediment plume transports nutrients into the marine environment => critical for coastal fisheries



Thank you!