# Section 2
# Hydrology and Hydraulics






# Identified areas to address in this update

- Consider both ***Hydrology*** (amount of water) and ***hydraulics*** (motion of water):
  - Importance for performance of the hydropower project (especially for Run-of-the-River projects)
  - It is often the carrier of impacts to other themes (flood safety, fish habitats, etc.), and therefore strongly interlinked.
- Relevance of addressing the **risks and mitigation** of **short-term water level fluctuations**
- Guidance to the proper **use of methods and tools** forms the core of this section (data, monitoring, modelling)



# PDG 2009 versus PDG 2018

- The **original PDG** did not include a section on **hydrology, hydraulics, or managing flows**
- Some PDG2009-clauses provide guidance on dealing with hydrology and hydraulics: mostly related to ‘environmental flow releases’, fish ways or mitigation of downstream impacts on ecology and sediment
- PNPCA process requires the PDG to guide much more on assessing the flows (monitoring and modelling), quantifying transboundary risks upstream and downstream, and mitigation of impacts

# 2.1 OBJECTIVES

# Section 2.1 Objectives

**Clause 34:**

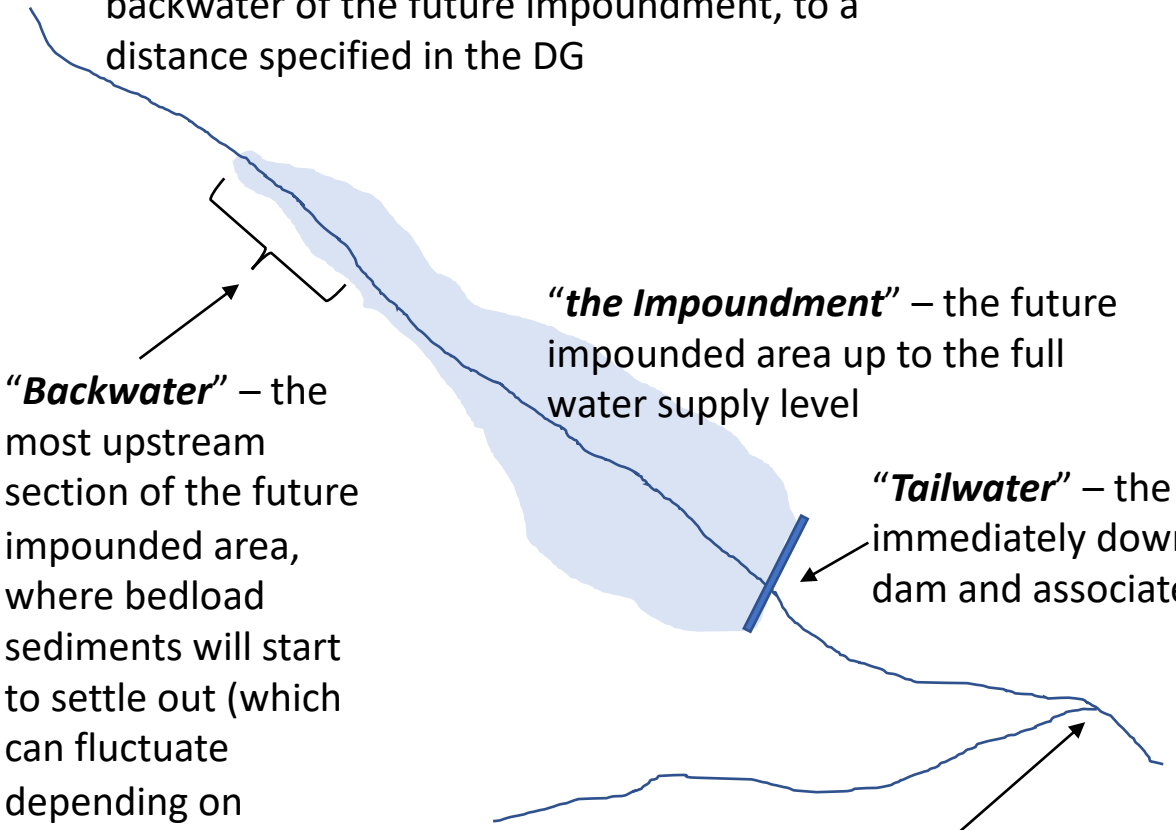
1) Detailed understanding on hydrological resource availability and reliability, and including the current and future trends (climate, upstream development)
2) Impact mitigation is underpinned by sound modelling and monitoring
3) Meet the objectives of the Procedures for Maintenance of Flows on the Mainstream (PMFM) and the Procedures for Water Use Monitoring (PWUM) within the Mekong Agreement framework: maintain minimum flow and minimize rapid changes

**Notes:**

- Flow alterations affect many of the other themes: strong interlinkages
- Also consider the cumulative impacts of cascades, not only the individual project

# Clause 35. Relevant terminology

"***Upstream***" – the Mekong River upstream of the backwater of the future impoundment, to a distance specified in the DG



"***the Impoundment***" – the future impounded area up to the full water supply level

"***Backwater***" – the most upstream section of the future impounded area, where bedload sediments will start to settle out (which can fluctuate depending on impoundment water levels)

"***Tailwater***" – the section of river immediately downstream of the future dam and associated structures

"***Downstream***" – the Mekong River downstream of the future dam, to the distance specified in the DG (which can fluctuate depending on dam discharges)

"***Tributary confluence***" – where a tributary river meets the mainstream Mekong River

- Impoundment vs. reservoir?
- Individual dam or cascade?

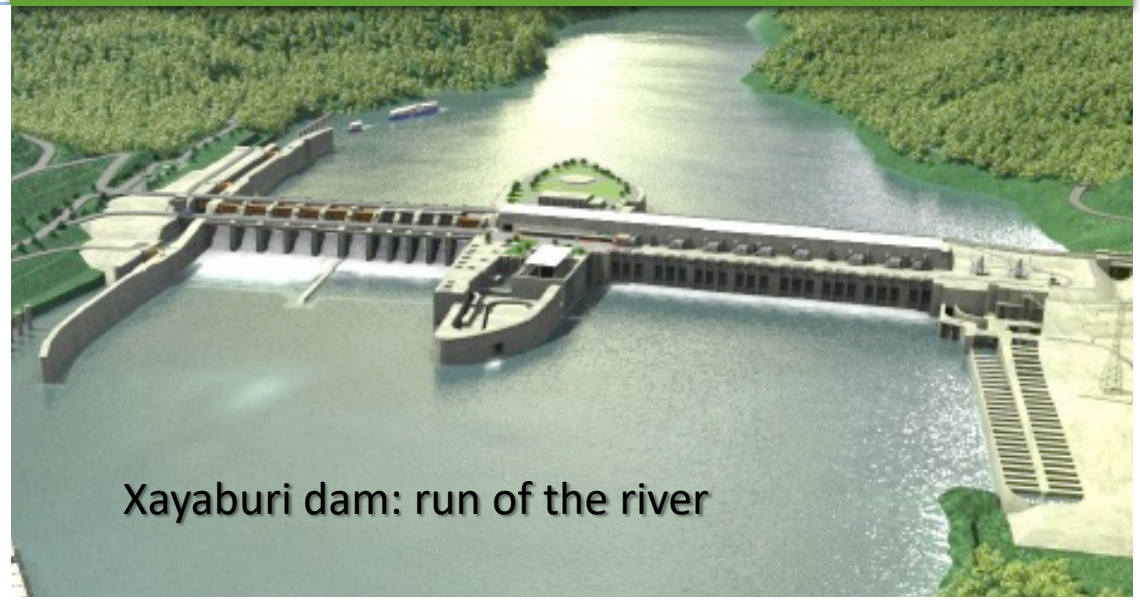
# ‘storage’ versus ‘run-of-the-river’

- Storage reservoirs (often high dams) are used to capture the fluctuations in the inflow discharge: downstream of such dams the flow is more constant (reduced high flow, increased low flow): large impact downstream.
- Large reservoir, large active storage



Nuozhadu dam, Lancang: storage

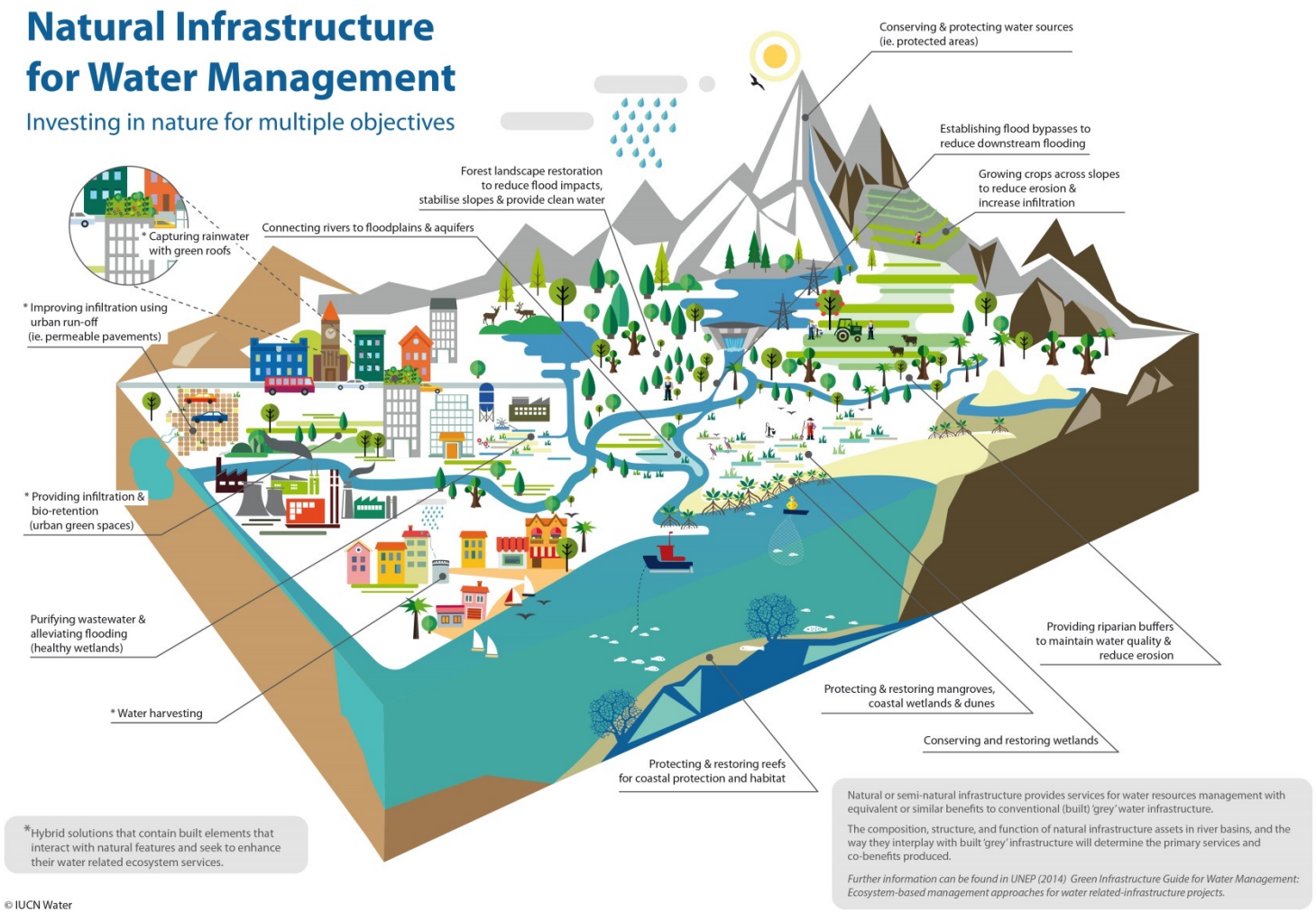
- Run-of-the River reservoirs (often low dams) operate with a more-or-less constant water level: all incoming discharge is going through the turbines and spillways. Downstream smaller impacts.
- Still impoundment often included to create head (not entirely based on kinetic energy)



Xayaburi dam: run of the river

# 2.2 RISKS

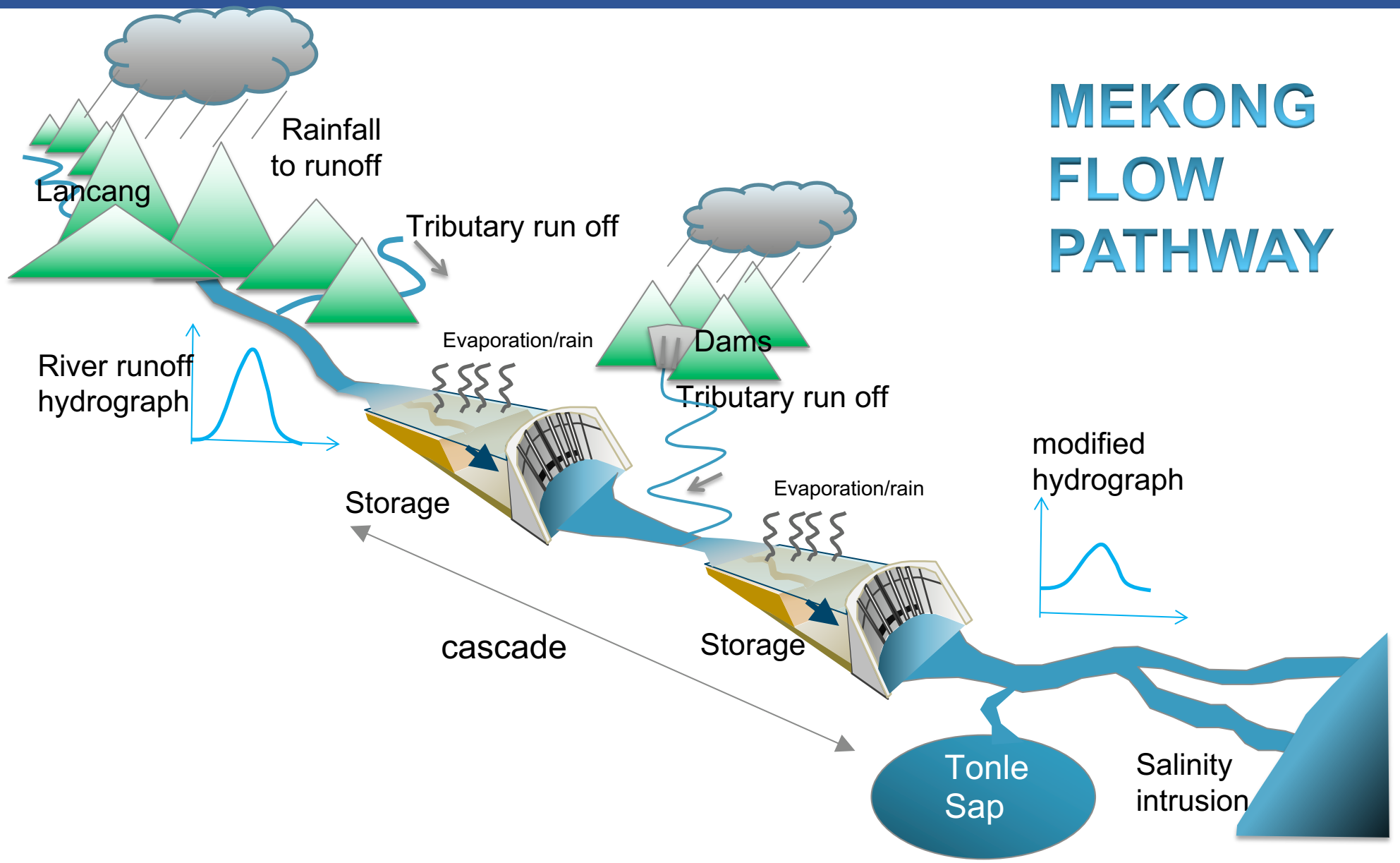
# Section 2.2 Impacts and risks




- A HPP scheme is just an element of the system or basin: impacts extend basin wide
- It affects many functions

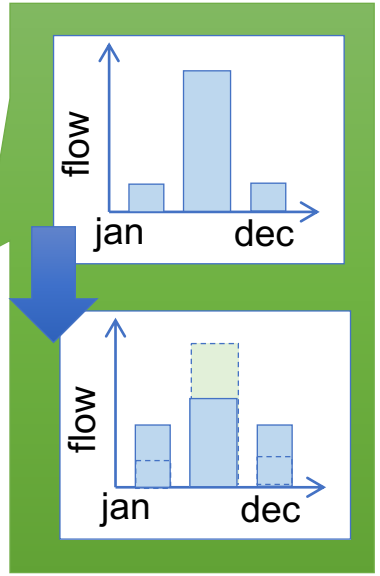
http://cmsdata.iucn.org

# Section 2.2 Impacts and risks



# Downstream flow impacts/risks/vulnerabilities

| Annual / inter-annual changes to flow | |
|---|---|
| Changes in seasonality & continuous uniform release | Change of timing & duration of floods and low flows, changes in flows Tonle Sap and changes in salt intrusion in the delta |
| Modification of flood intervals: Reduction in occurrence of minor floods & no change in large events | Peaks in flood and low flow change, smoother hydrograph |



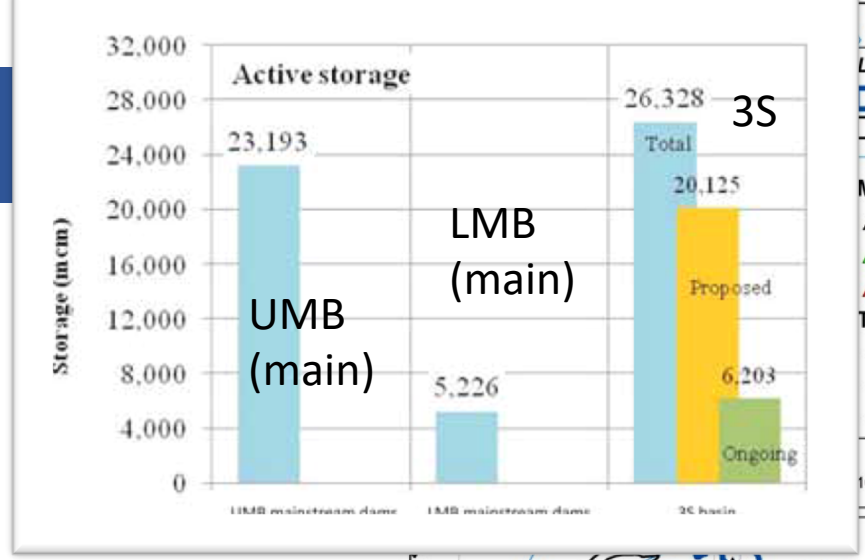

| Daily / short-time period changes in flow | |
|---|---|
| Hydro-peaking | Safety and navigation related changes caused by sudden rise or drop of water levels |
| Pulses by operations | idem |

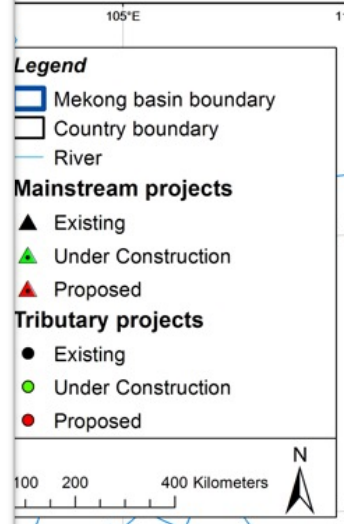
**Secondary (indirect) risks through impacts on sediment movement, fish, navigation, water quality**

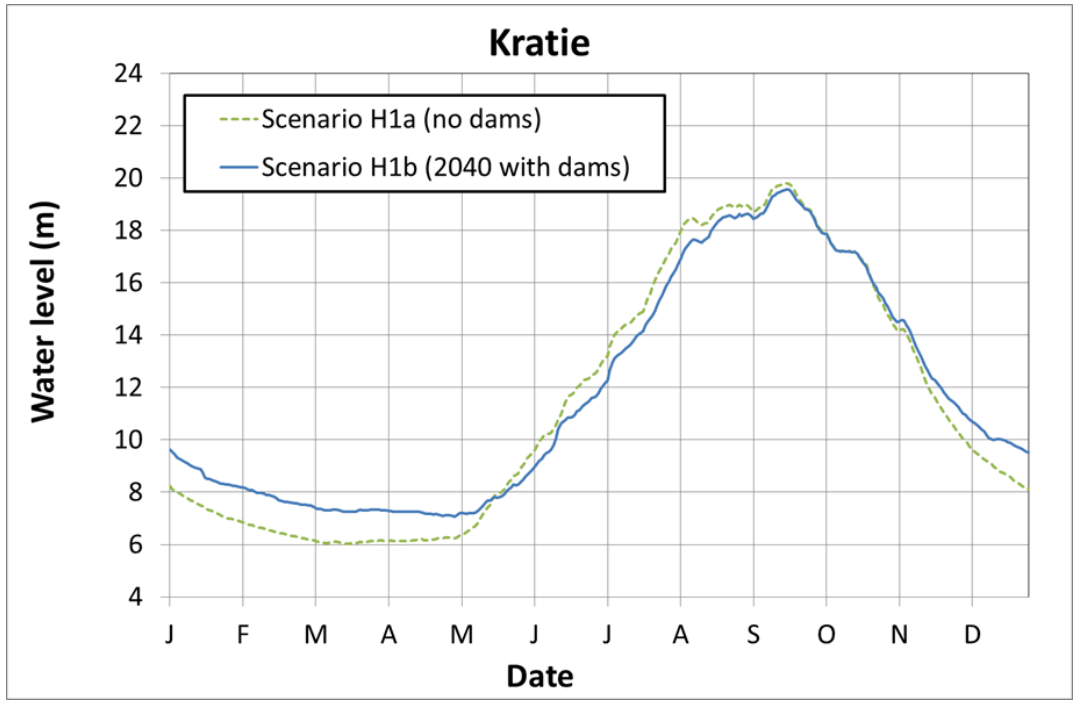
# Annual/seasonal impacts

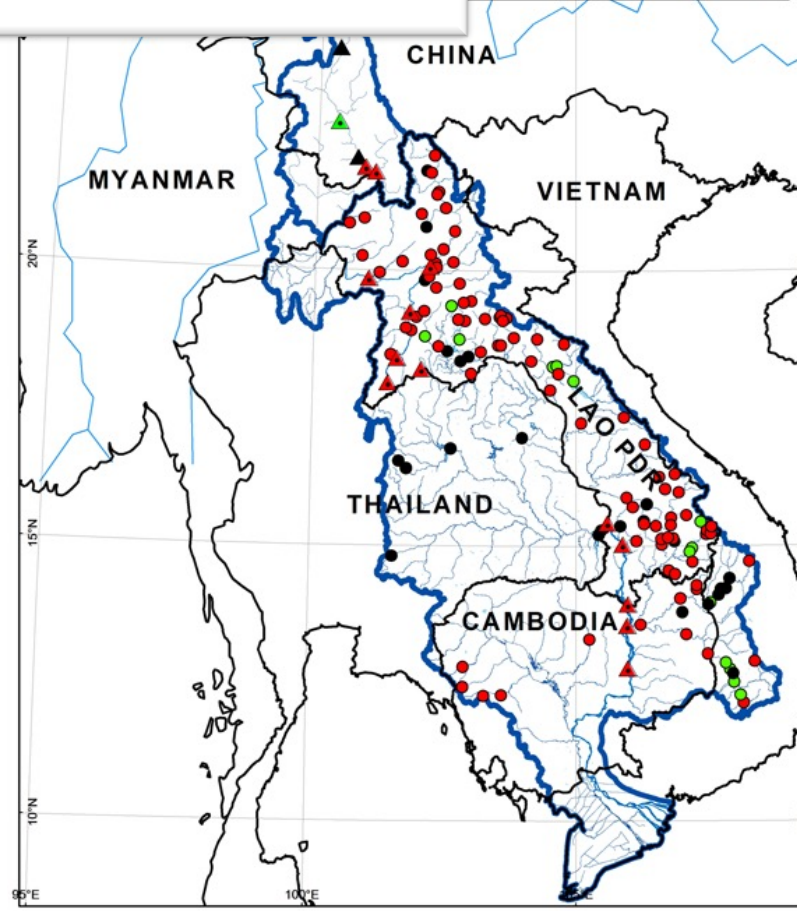
Lower reaches of the Mekong River will:

- have higher flow in dry season
- have later start of wet season
- have lower high flows in start of wet season



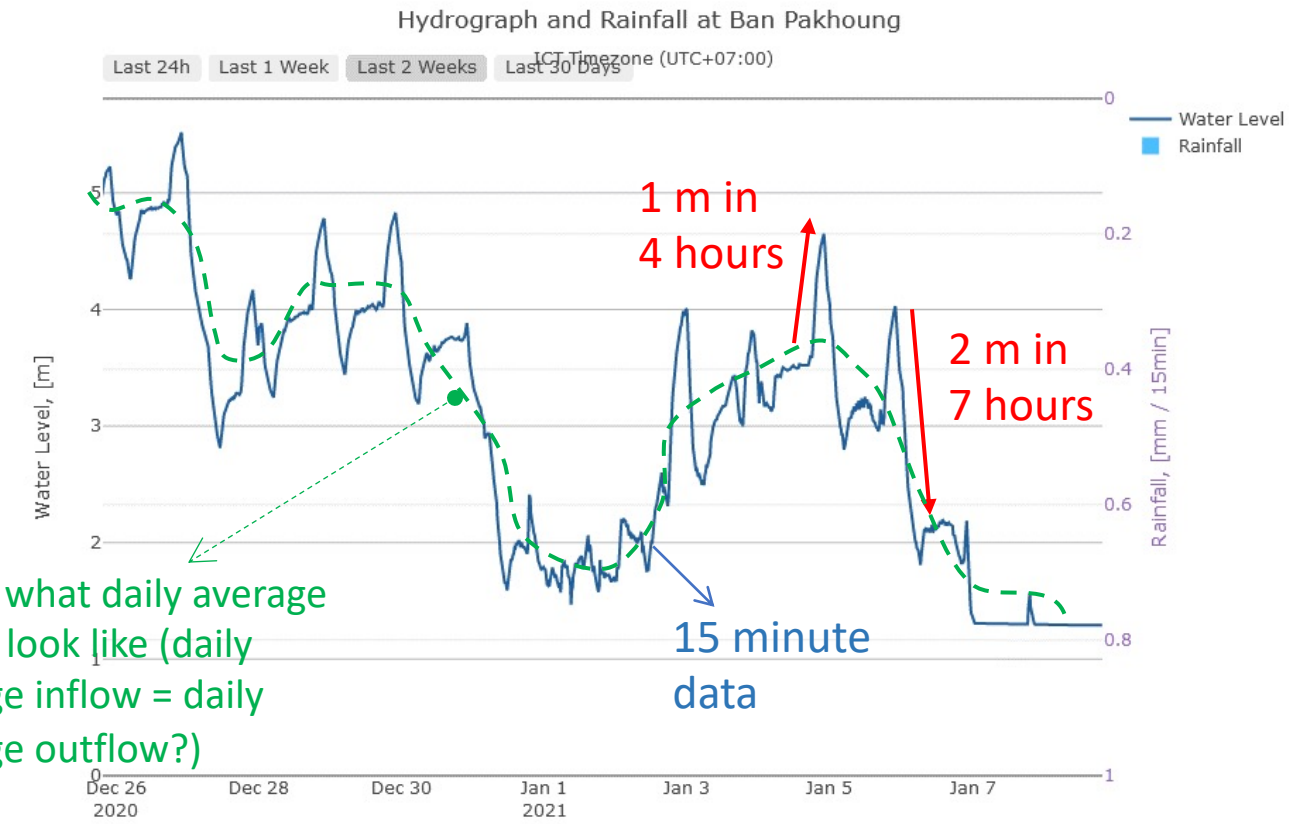






# Hydropeaking: concerns and risks

- What can be expected from a Run-of-river (Ror) operation? Example of peaking flows downstream of Xayaburi Ror scheme:




This is what daily average would look like (daily average inflow = daily average outflow?)

# Experience: sub-daily fluctuations due to power peaking

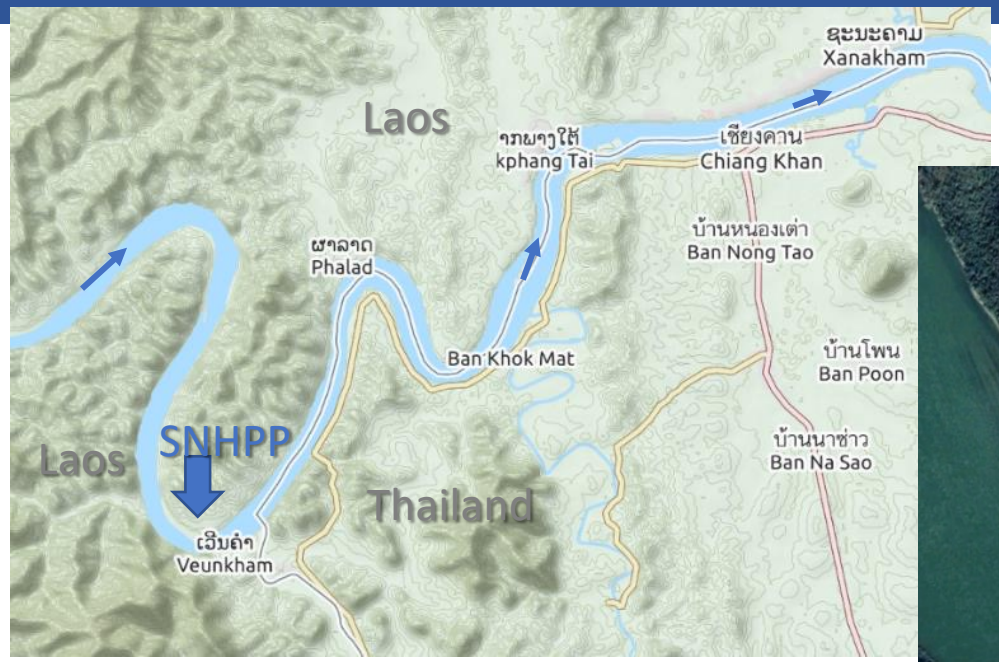
- Xayaburi: Peak hours between 6AM – 8PM when high discharges are turbined
- Apply ramping (rate in m/hours at which water levels may change):
  - Relevant for ecology (fish stranding), navigation, safety, etc.
  - Consider natural rates of water-level variation (for instance 0.05 m/hour)



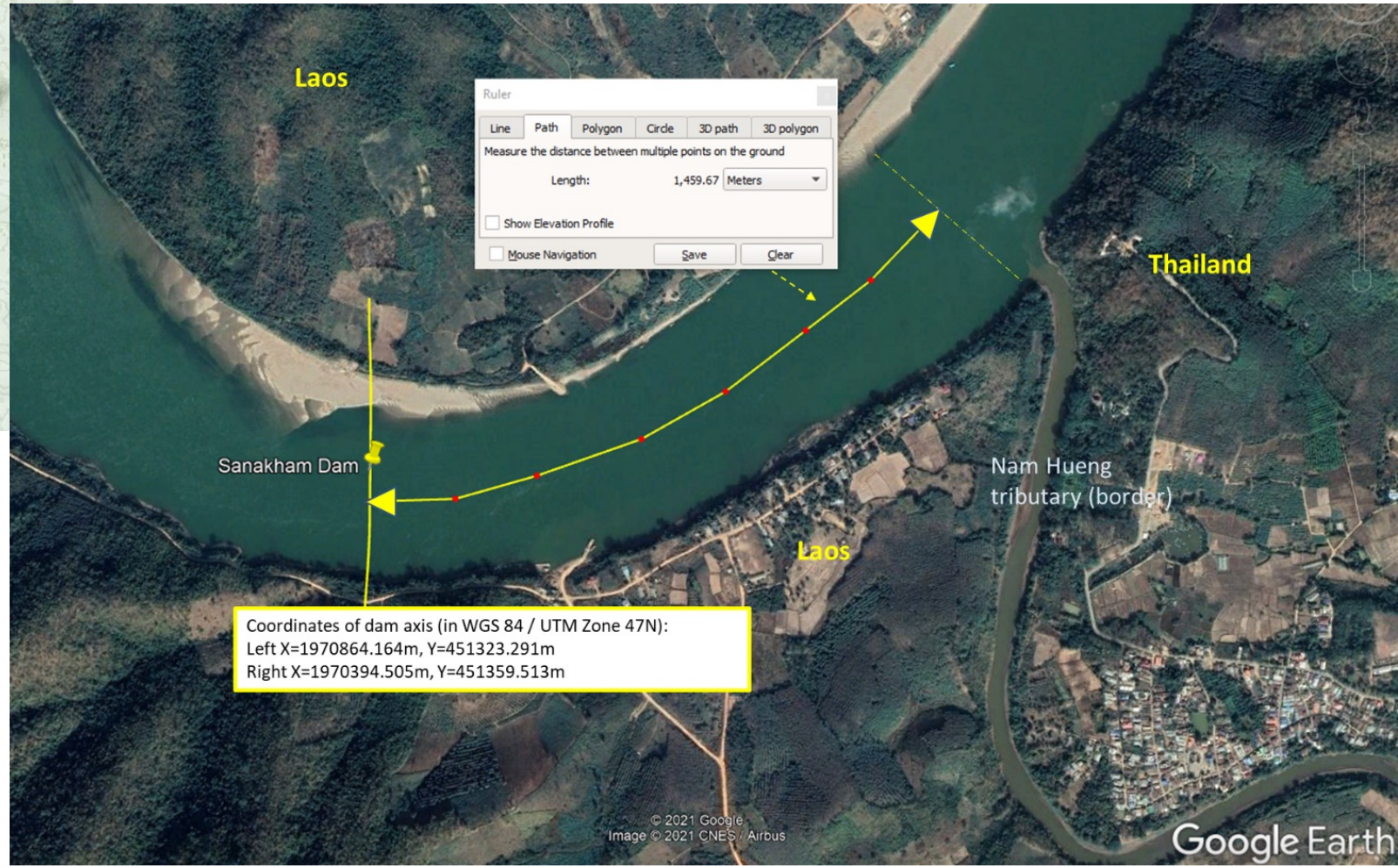




# Experience from PNPCA: Rapid Assessment for Sanakham



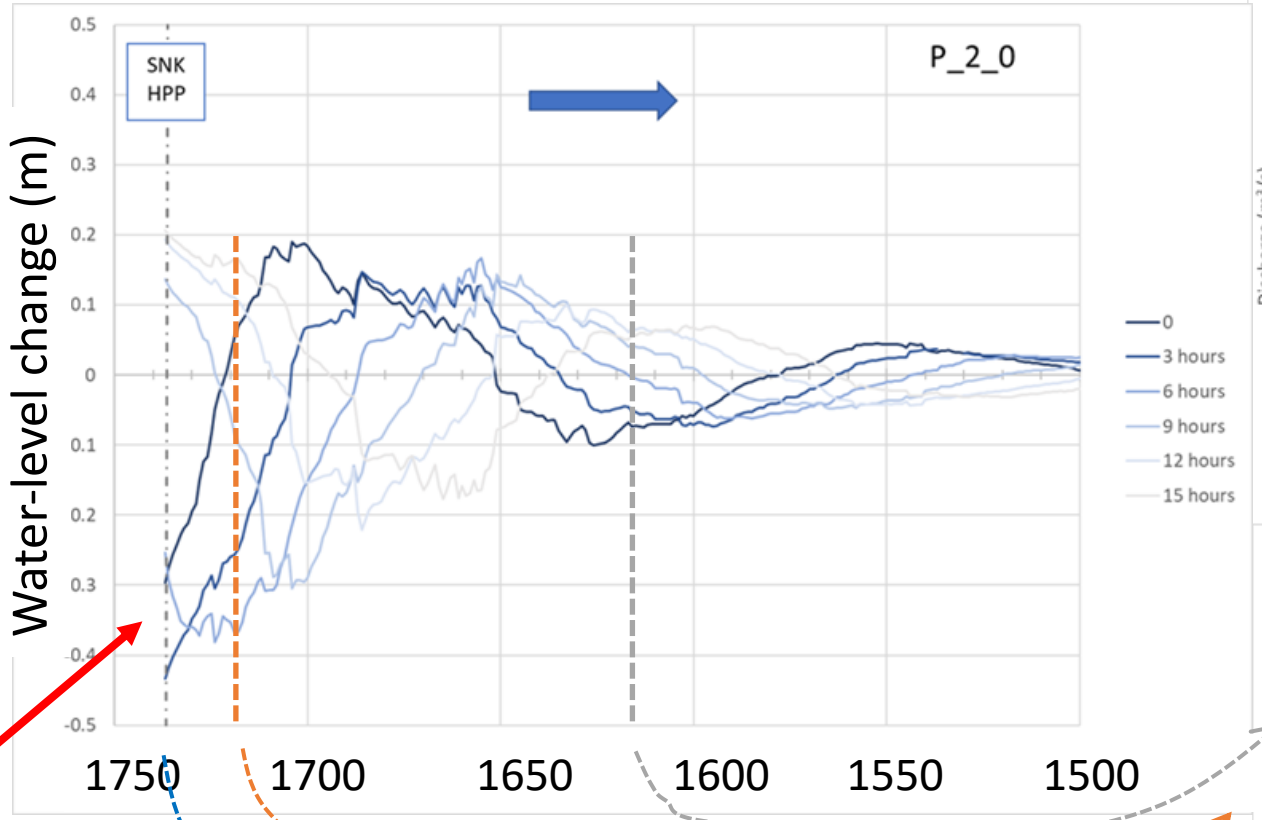

Sanakham HPP is sited directly upstream of border with Thailand: **how does SNHPP influences discharges and water levels downstream?**




- **Did the developer use proper methods to quantify the physical behavior of the river, and its variability along the border reach?**
- **How about the role of SNHPP in the Lao dam cascade, and its contribution to the impacts of the cascade downstream?**

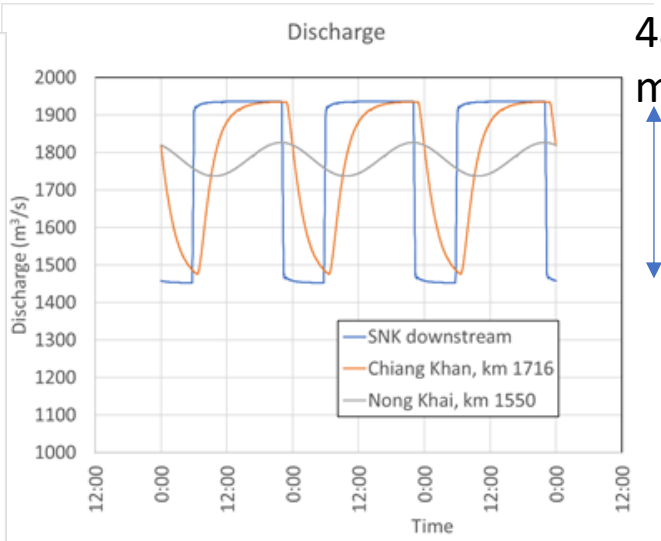
# Experience from PNPCA: Rapid Assessment for Sanakham

In the downstream river, the flow fluctuations propagate down as damped waves over long distances

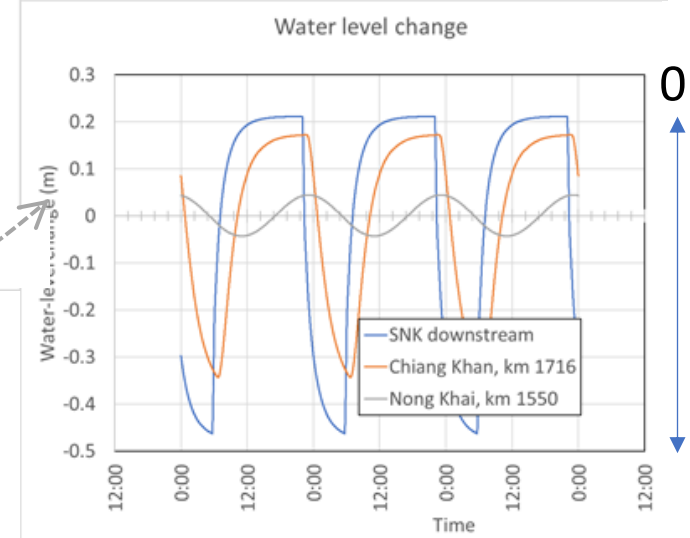



Sanakham HPP

Calculated time series at 3 stations (mild peaking scenario):




484 m³/s



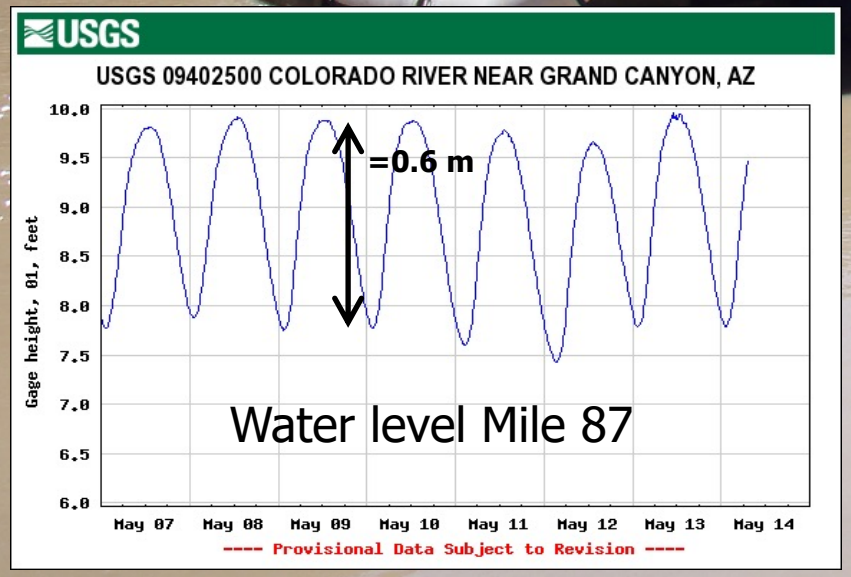

0.7 m

# Example: daily impacts of storage scheme (hydropeaking) in the Colorado River USA

Daily fluctuation related to power peaking:

- Causes erosion of sand bars (bank erosion)

11 September 2026




range of water-level variation

# Upstream flow impacts/risks/vulnerabilities

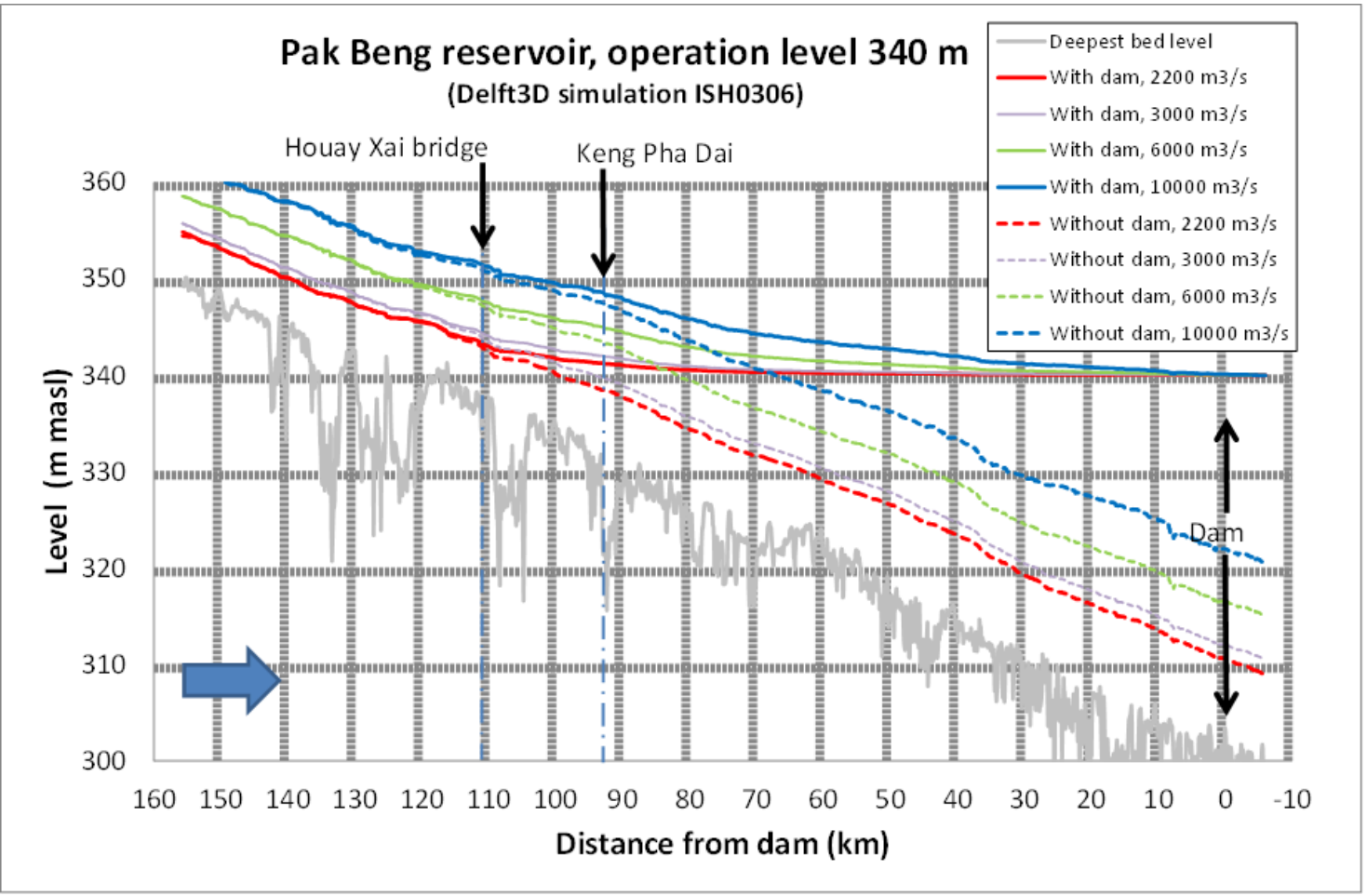
| Impoundment | |
|---|---|
| Rise and fluctuation of water level | Inundation (loss of land) and habitats, land slides, bridge clearance, resettlement, ships hitting submerged rocks, etc |
| Reduced flow velocities | Sedimentation, water quality, larvae drift, fish habitats, shipping, etc. |

| Backwater | |
|---|---|
| Increased water level upstream | Safety and navigation |
| Reduced flow velocities upstream | idem |

**Secondary (indirect) risks through impacts on sediment movement, fish, navigation, water quality**

# Experience from PNPCA: backwater upstream of Pak Beng reservoir

## Pak Beng dam: transboundary issue.



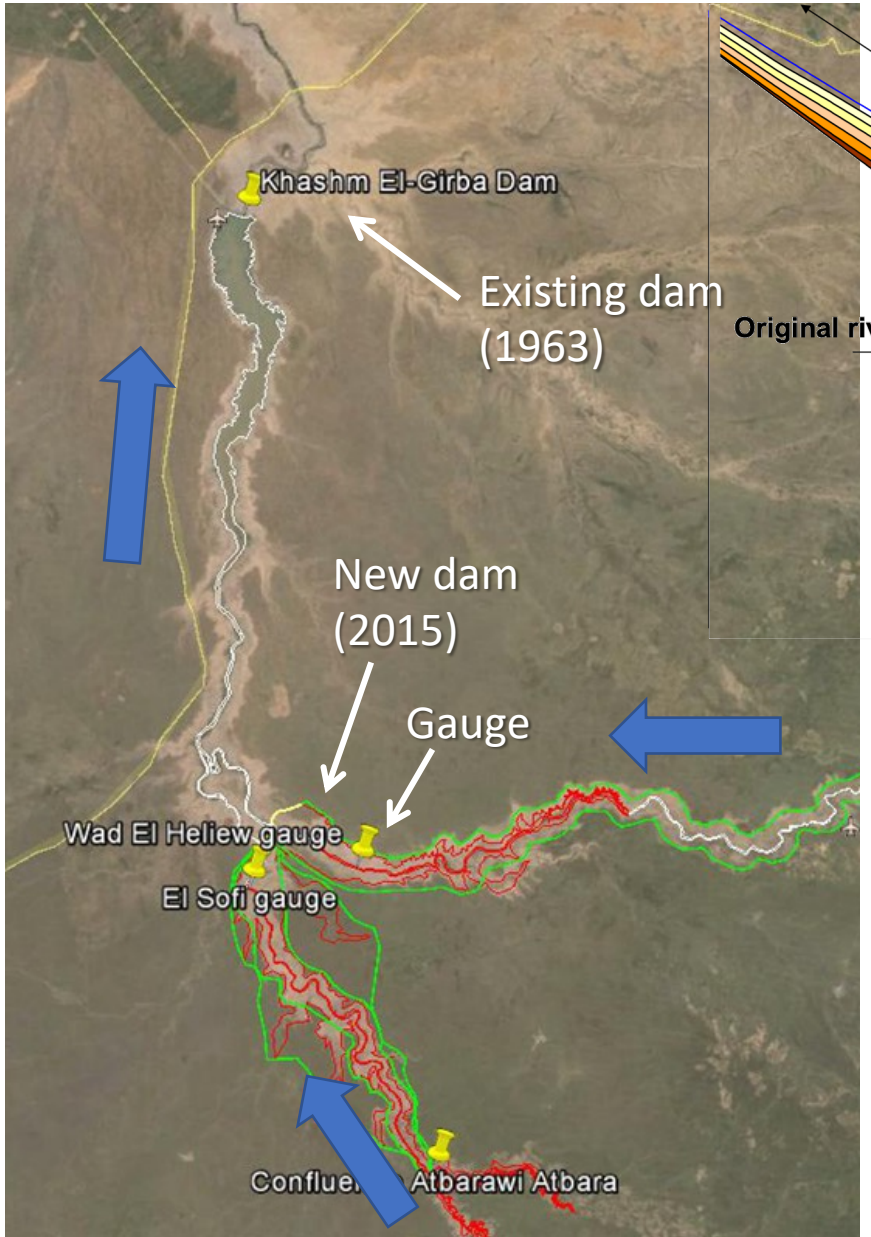

Impact:
During dry season Keng Pha Day reefs should be emerged.
Due to backwater of dam the reefs get submerged.

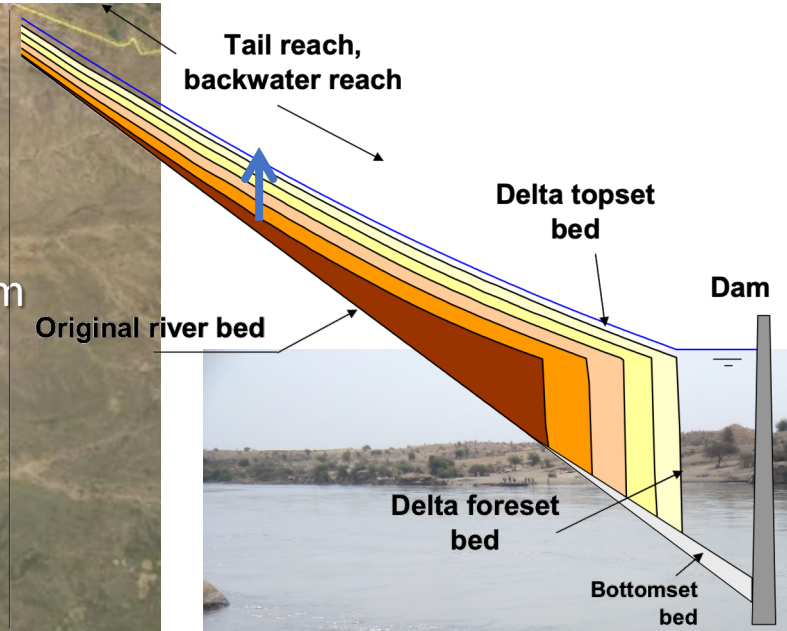


Mitigation: Model results show that water level can be reduced at low discharge by applying a 5 m lower operation level during dry season

# Example backwater deposition, Sudan

Rise of water levels in time









# Impacts and risks for other themes

- Clause 38: table with impacts mainly for Run-of-River

Theme

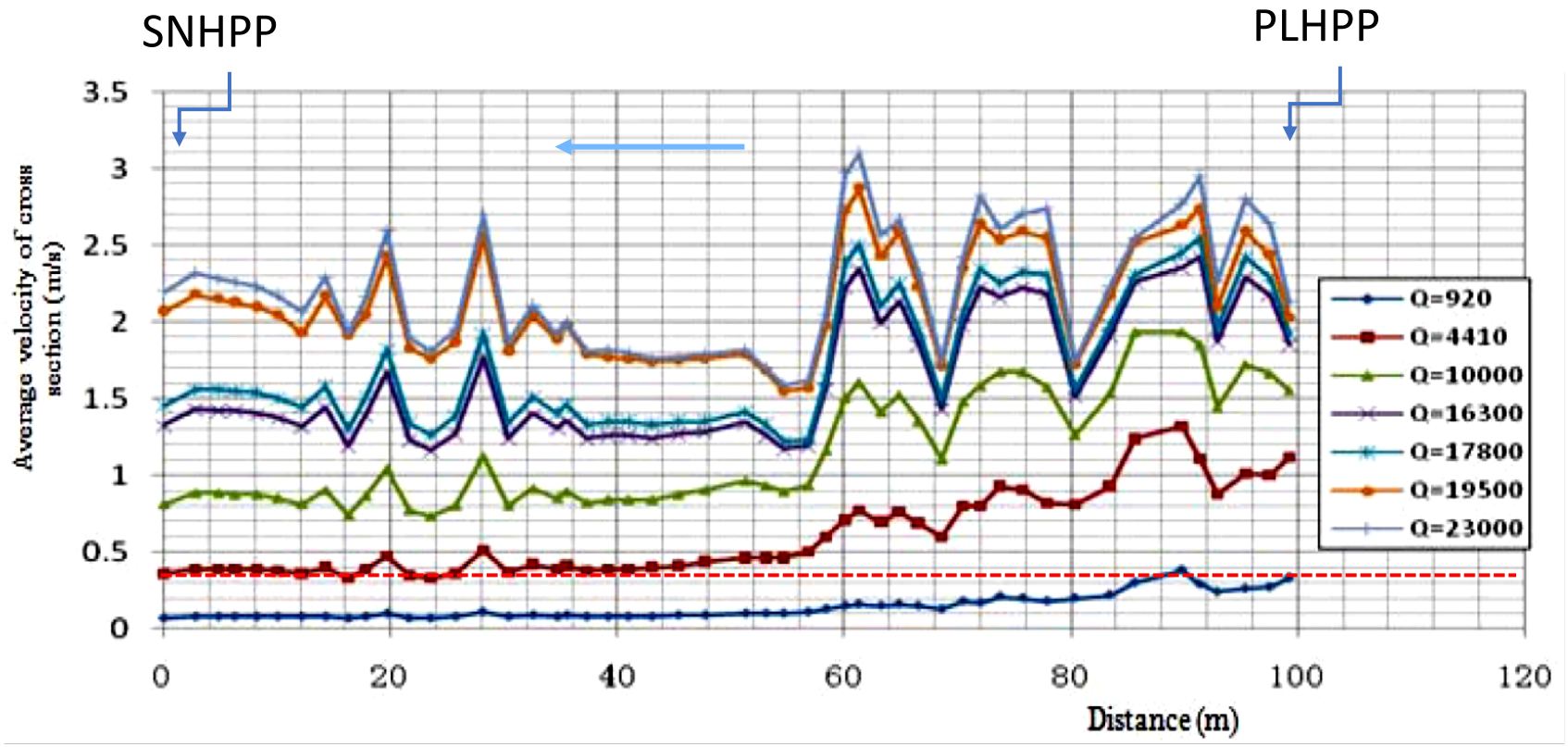
Downstream

Upstream (impound-ment)

| Risks | Focal area of impact |
|---|---|
| **Risks arising due to daily or short-term changes in downstream flows** | |
| Riverbank erosion, sediment grain-size changes | Sediments and Geomorphology (see Section 3) |
| Fluctuating water quality, with variable temperature and nutrients; altered concentration of downstream discharges | Water Quality (see Section 4) |
| Flow velocity changes causing drift or stranding; habitat impacts and loss; temperature changes causing stress and offset of migration triggers | Aquatic Ecology (see Section 5) and Fish (see Section 6) |
| Fluctuating water flows and water levels, transient impacts on infrastructure, such as in the tailrace due to load rejection, spillway gate operation, and dam safety risks due to extreme floods or maximum hydraulic loads | Project Infrastructure and Dam Safety (see Section 7) |
| Public safety and navigation-related risks with water levels in the tailrace and downstream river; flood risk in the downstream river due to sudden releases from the dam during floods (e.g. lowering operation level for flood protection, or for flushing) | Socio-Economics including Navigation (see Section 8) and Public Safety |
| **Risks arising due to river impoundment** | |
| Deposition of sediments in the impoundment; bank instability | Sediments and Geomorphology (see Section 3) |
| Stratification; temperature changes; nutrient trapping. | Water Quality (see Section 4) |
| Drowning and sedimentation of deep pools; habitat loss due to inundation; deposition of drifting eggs/larvae due to low flow velocities | Aquatic Ecology (see Section 5) and Fish (see Section 6) |
| Backwater impacts due to inundation or backwater fluctuations near areas of social importance; increasing flood levels in time upstream; navigation risks due to submerged rocks | Socio-Economics including Navigation (see Section 8) and Public Safety |

# Experience from PNPCA: fish in impoundment

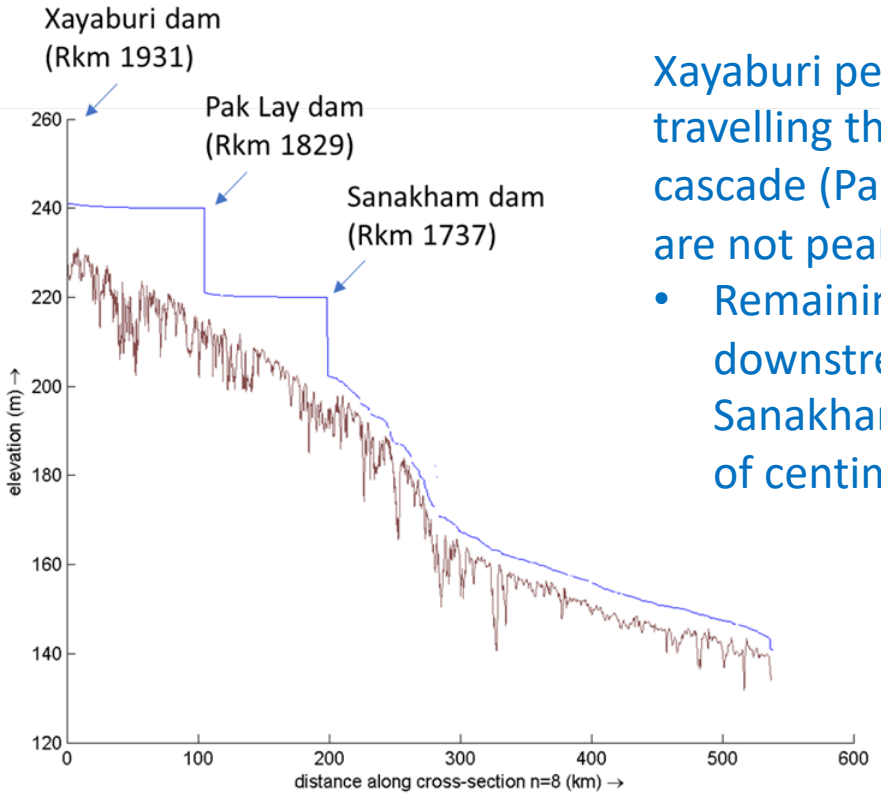
- Decreased velocities in impoundment will impact fish larval drift (V<0.3 m/s, about 65% of time): needs to be addressed




Flow velocities calculated for Sanakham impoundment

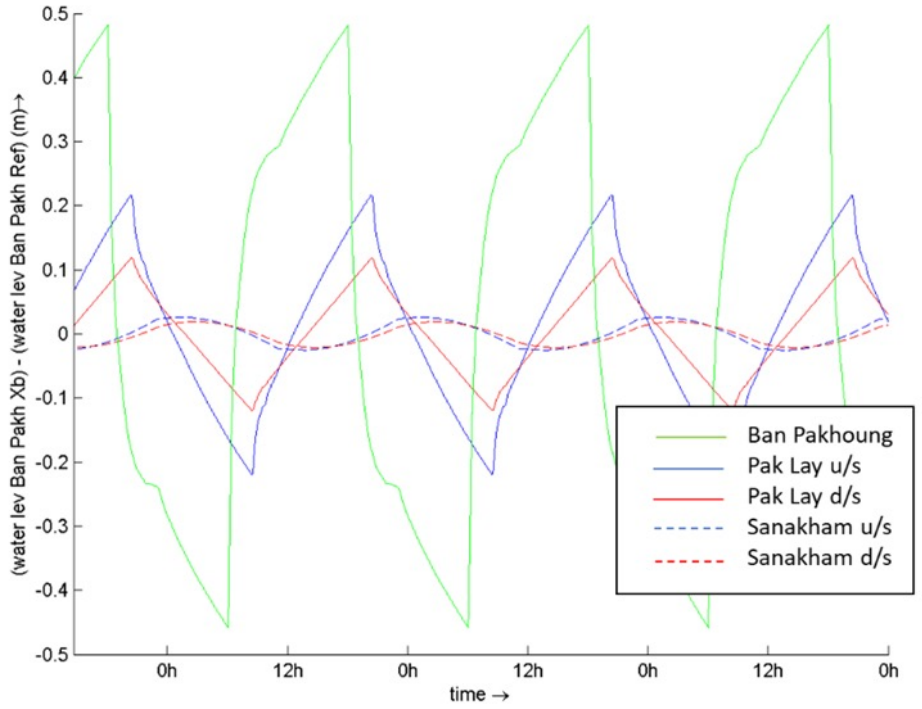
# Clause 39: Cumulative hydrological impacts

- Consider the impacts of other developments as well
- Position in cascade / upstream dams:
  - Safety: high releases from one dam can amplify flood in the next dam
  - Fluctuations: can be passed through or damped by downstream dams




Xayaburi peaking waves travelling through the cascade (Pak Lay and SNK are not peaking):

- Remaining fluctuation downstream of Sanakham in the order of centimeters



# Experience from PNPCA: checks needed

- Are all (transboundary) risks/impacts addressed?:
  - Look upstream (backwater) and downstream (rapid fluctuations, hydropeaking)
  - Look at short term (during construction and first-time operation) and long-term (full life cycle)
  - Indirect risks (fish stranding, larvae drift, backwater deposition, decreased safety of navigation, etc.) should be carefully considered
  - Cumulative impacts, considering risks from upstream and downstream developments, and the position of the project in the river system
- Are mitigation measures defined?:
  - Is ISH0306 mitigation guideline considered?
  - Is there sufficient prove that proposed mitigation is effective?

For run-of-river main-stream dam there will not be a seasonal large-scale impact: system scale hydrograph changes do not have to be addressed (e.g. impact Tonle Sap and Mekong Delta)

# Takeaway message: risks and impacts in PNPCA

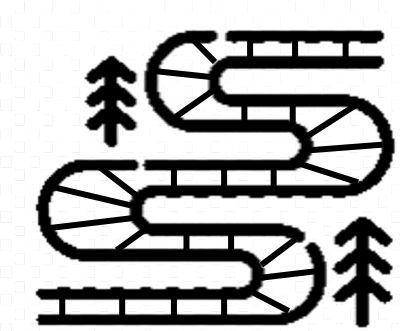
- Because the main-stream dams in the LMB will be operated in run-of-river mode, the key risks for environmental and socio-economic receptors of impact, mainly arise due to daily and short-term flow changes to the downstream river with hydropower operations, and from the impoundment of water behind the dam.
- The focus of the PNPCA review is on the large-scale and transboundary impacts. However, specific details of the design that require more detailed explanation or motivation are also addressed.

# 2.3 PRE-PROJECT MONITORING AND ANALYSES

# Section 2.3 : Pre-Project Monitoring and Assessments



**Clause 41-60 : Quantification of *pre-project conditions*, and of *potential changes* associated with the project:**



- **Monitoring**: the PDG provides guidance where monitoring is needed (upstream, downstream), when to monitor (long ahead), what to monitor (for flow minimal: water levels, discharges)
- **Hydrological modelling**: needed to determine conditions between monitoring stations (or missing stations), and forecast future discharges
- **Hydraulic numerical modelling**: quantify the water level fluctuations and flow velocities with unsteady flow models. Also physical scale models are mentioned for local 3D assessments.

# Pre-project monitoring

"Design should be based on a good understanding of the hydrological **resource availability** and **variability** in the **short and long term**, as well as the **hydraulic characteristics** in the river near the dam infrastructure"

- Monitoring rainfall and discharge (upstream basin)
- Hydrological model
- Etc.

- Survey flow patterns, water-level variations
- 2D/3D modelling
- Etc.

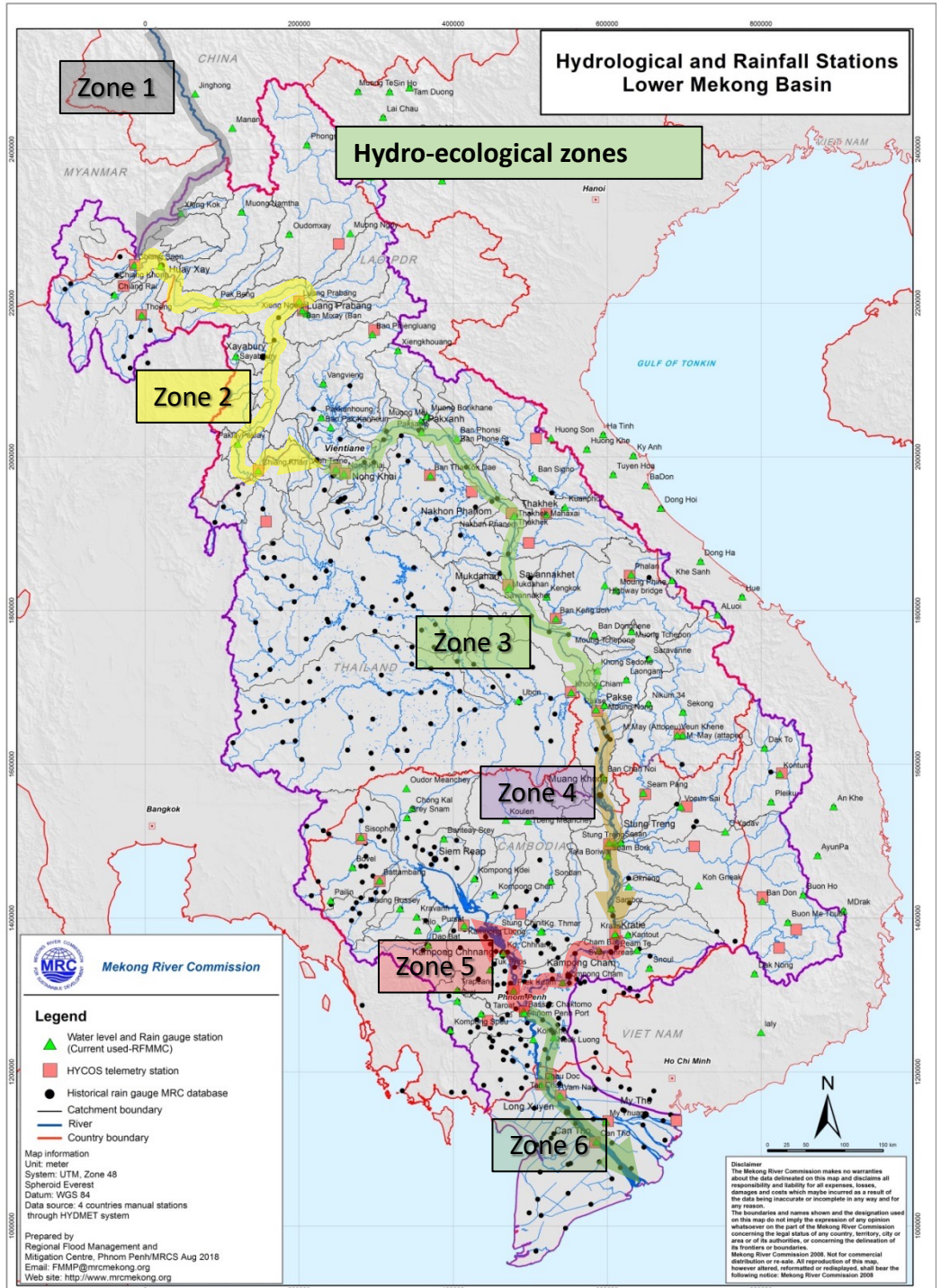
- Install new stations
- High frequency
- Etc.

- MRC stations
- Satellite data
- Etc.

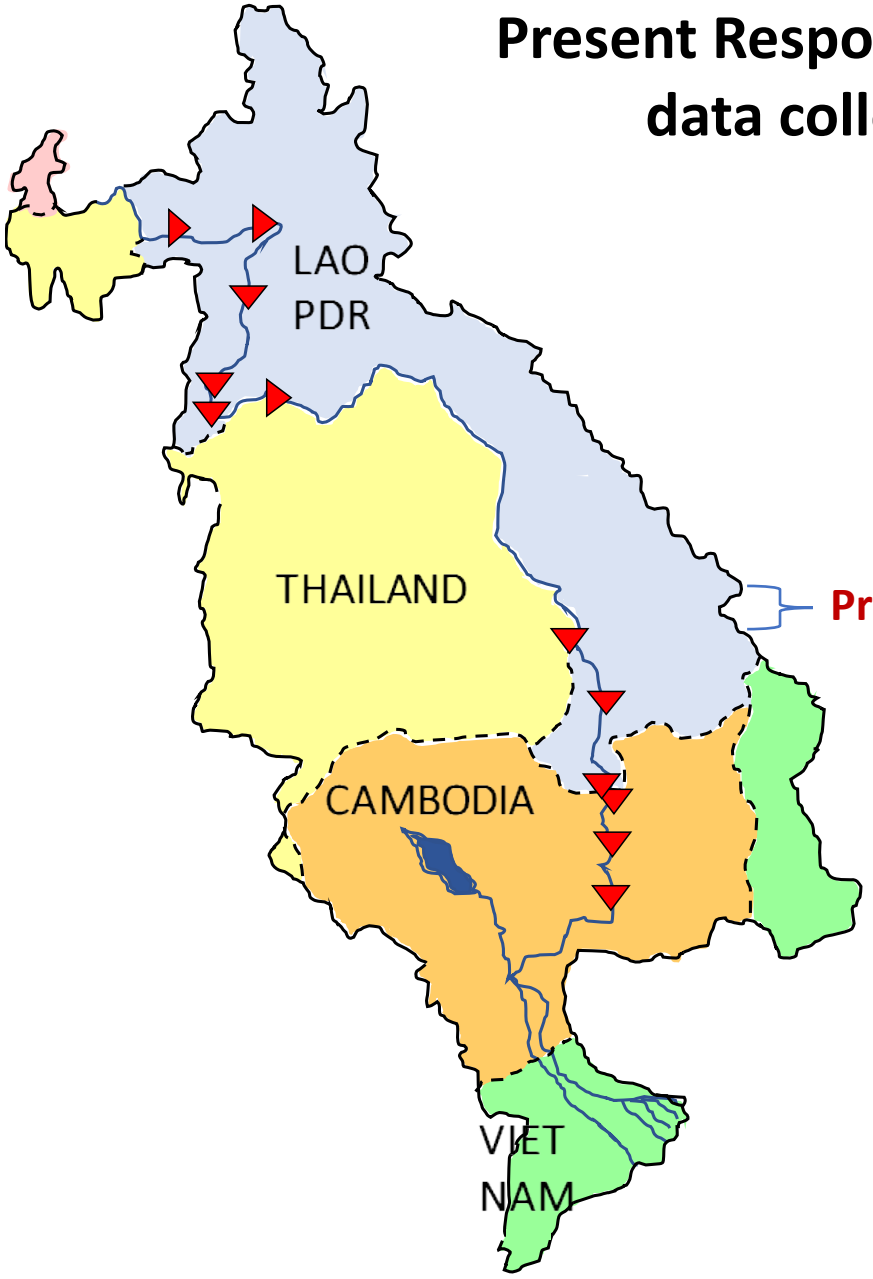
# Existing monitoring

- 138 near real-time hydrometric stations (water level and rainfall)
- Another 114 stations from Global Telecommunication System (GTS) of WMO
- Mekong-HYCOS* system: 45 stations
- Water-level, rainfall, temperature, etc.





# Present Responsibilities & data collection




**Project**

**Country:**

Line agencies:

**Cambodia:**
Department of Hydrology and River Works (DHRW) and the Department of Meteorology (DOM)

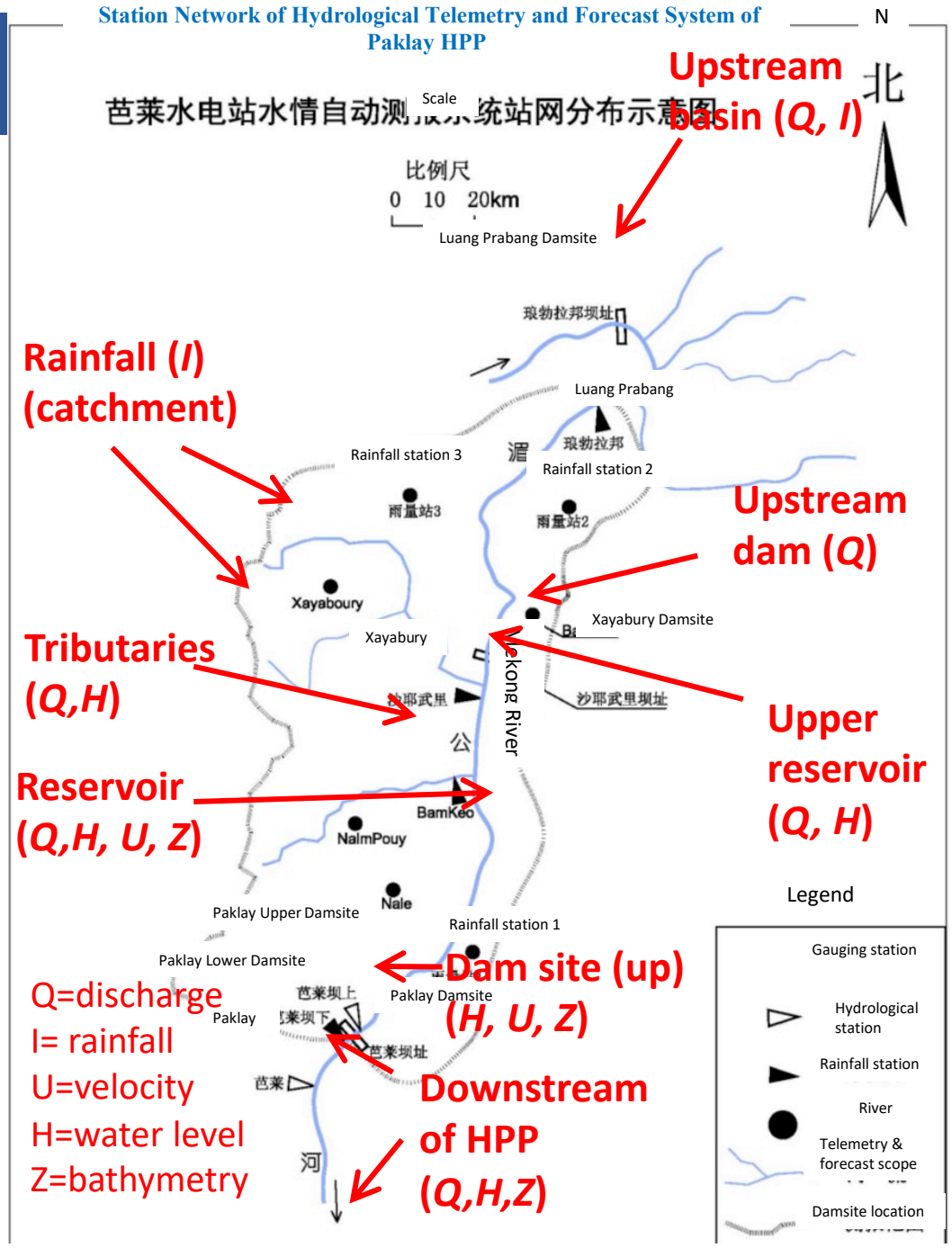
**Vietnam:**
Southern Regional Hydro-meteorological Center (SRHMC) and National Hydro-Meteorological Service (HMS)

**Lao PDR:**
Department of Meteorology and Hydrology (DMH) and Waterway Administration Division (WAD)

**Thailand:**
Department of Water Resources (DWR)and Thai Meteorological Department (TMD)

**Basin**:
MRC

(Hycos + historic data-base)




# Project monitoring network

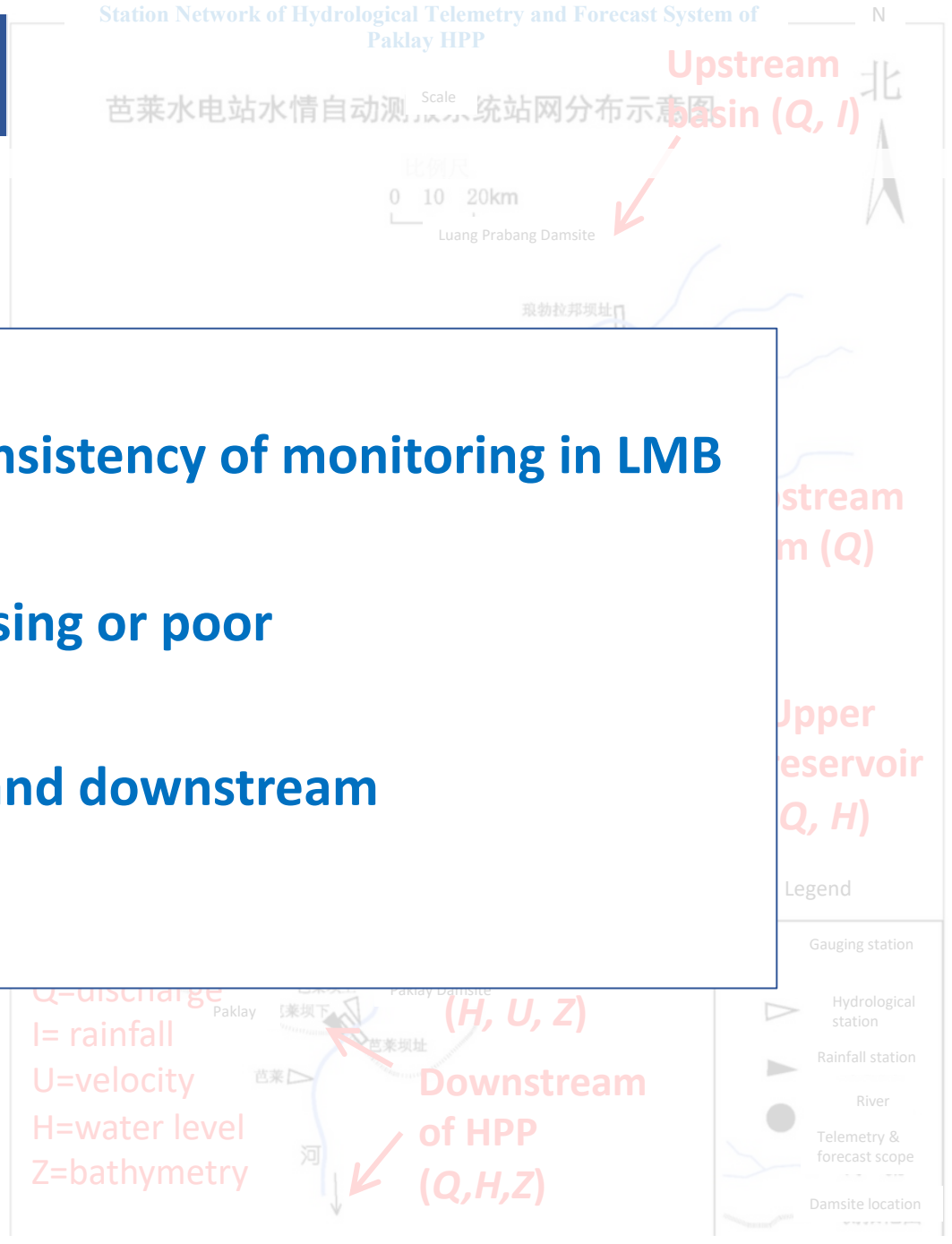
- Should be part of topic-specific monitoring framework (combined with water-quality, sediment, etc.)
- Network of stations carefully selected, and integrate national and MRC stations
- Frequency and parameters depending on purpose of the data

# Project monitoring network

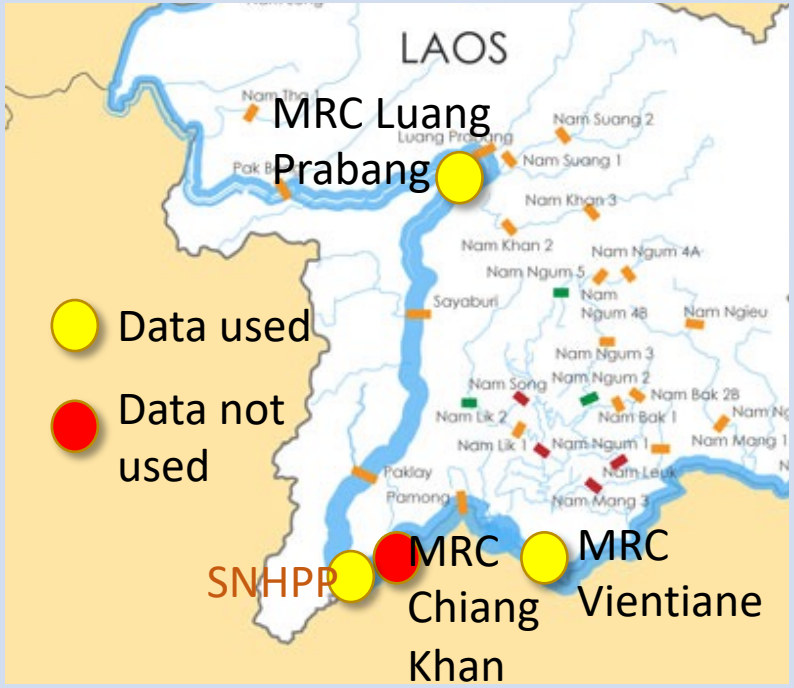
- Should be part of topic-specific monitoring framework (combined with water quality, sediment, etc.)

**PNPCA experience:**

- **Not follow MRC and WMO guidelines for consistency of monitoring in LMB**
- **QA/QC processes often unclear**
- **Monitoring for environmental purposes missing or poor**
- **Not prepared for full life cycle of project**
- **Not accounting for operations of upstream and downstream developments/dams**



# Experience from PNPCA: Pre-project monitoring & analysis - Sanakham

| Data | Long-term data daily discharge at dam site (interpolation) | Discharge directly measured at dam site |
|---|---|---|
| |  |  |
| Issues | • Chiang Khan data not used for computing/comparing DAILY discharge<br>• Only data until 2012 used: excludes impacts of upstream dams (present hydrology, influence Lancang and tributary dams)<br>• Influence of climate change not considered | • Accuracy of data cannot be judged (no information on QA/QC or comparison with Chiang Khan) |

# Experience from PNPCA: tailwater

- Tailwater is calculated from measured water levels and discharges at the dam site, and modelling for higher discharges (Q-h curve)
- Should include downstream erosion, downstream dams, uncertainties

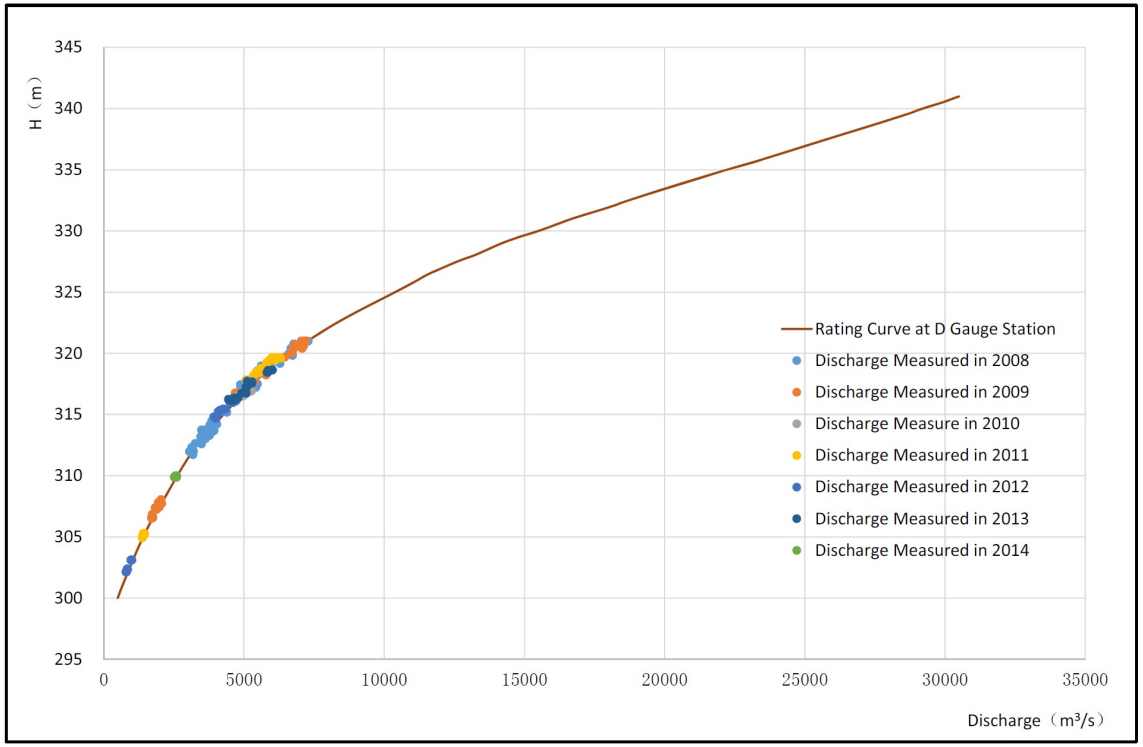
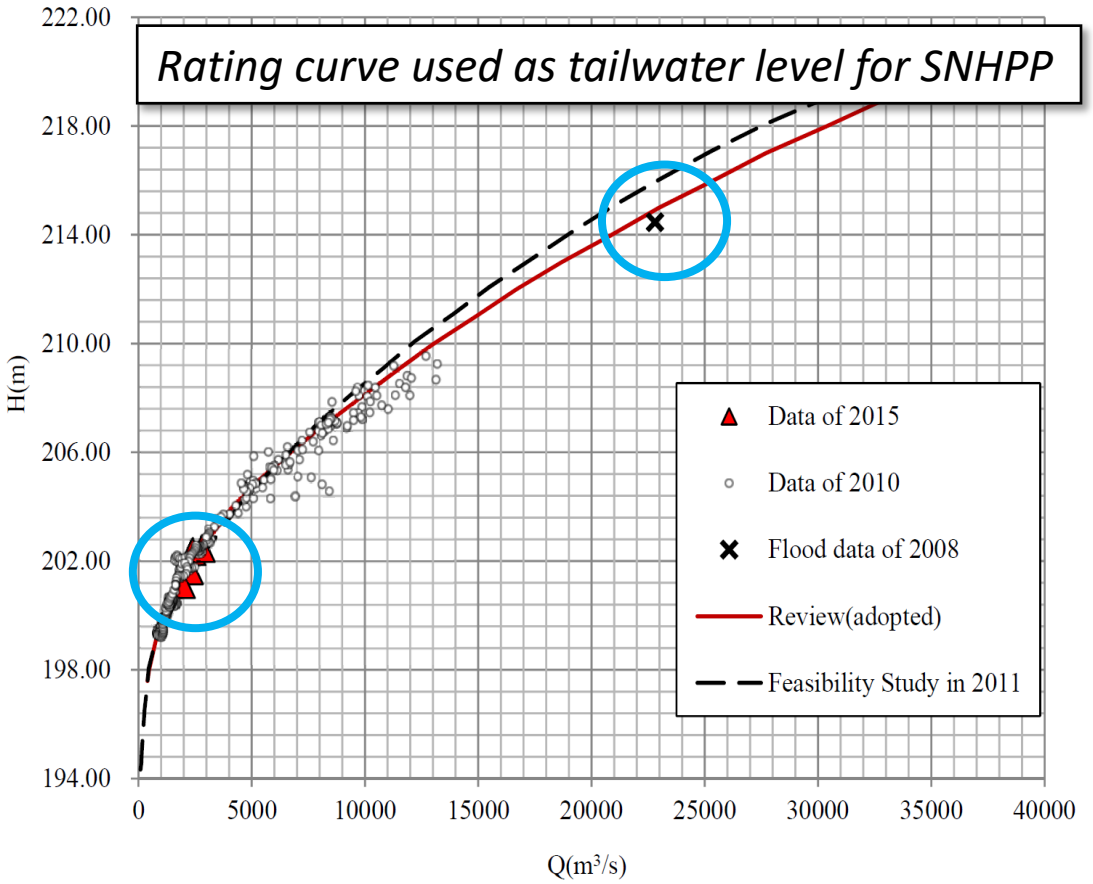
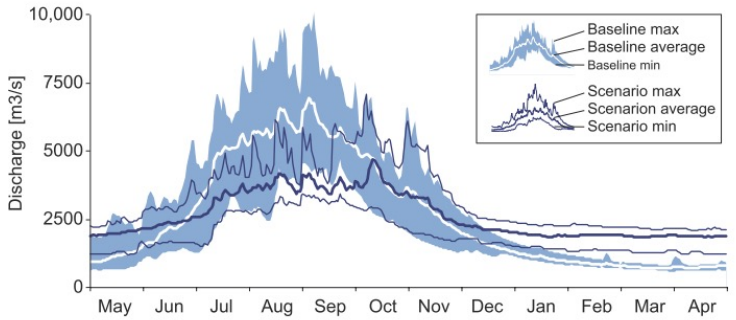



**Fig. 4.6-1 Rating Curve at Pak Beng HS**



# Experience from PNPCA: future hydrology

- Flood frequency not consistent among the different dams
  - Flood frequency and design flood based on log-Pearson Type III method, but more methods should be considered (like Generalised Extreme Value, GEV, as used by MRC)
  - all dams in cascade should be consistent
- Impacts of future upstream dams and climate change not well considered



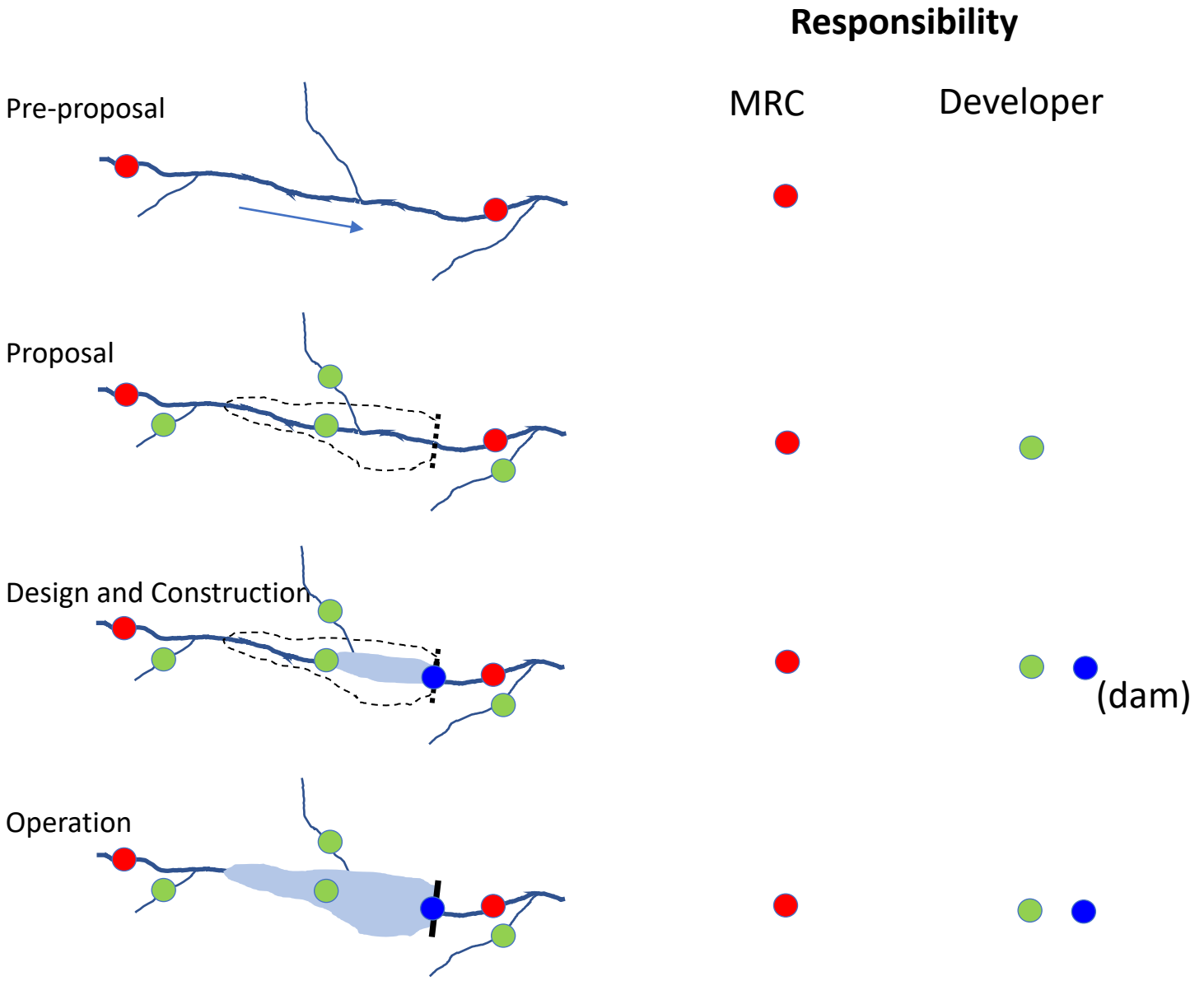

*Comparison of changes to the magnitude of extreme events for the same return period over an estimated project life of 100 years (source: ICEM, 2010)*

| | EXTREME VALUE DISTRIBUTION | | | | EXTREME VALUE DISTRIBUTION | | | |
|---|---|---|---|---|---|---|---|---|
| | Historic Return period flow (EV dist) | | | | Project 2030 Return period flow (EV dist) with CC | | | |
| Station | *10yr* | *100yr* | *1,000* | ***10,000*** | *10yr* | *100yr* | ***1,000yr*** | *10,000* |
| Chiang Saen | 12,252 | 14,551 | 16,808 | 19,061 | 13,209 | 15,769 | 18,282 | 20,790 |
| Luang Prabang | 17,137 | 19,912 | 22,637 | 25,357 | 18,783 | 22,362 | 25,876 | 29,384 |
| Vientiane | 18,670 | 21,285 | 23,852 | 26,414 | 19,692 | 22,745 | 25,742 | 28,734 |
| Pakse | 40,842 | 45,344 | 49,765 | 54,177 | 43,459 | 49,149 | 54,734 | 60,311 |
| Kratie | 56,254 | 62,934 | 69,493 | 76,040 | 59,000 | 66,886 | 74,629 | 82,358 |

**The past 1/10,000 yr flood is about 26,000 $m^3/s$**

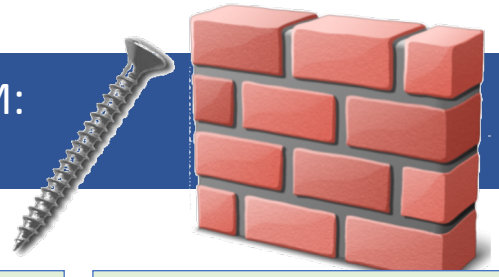
**In 2100 it will be the 1/1,000 yr flood**

# Example: proposed JEM Strategy



# Modelling

PROBLEM:

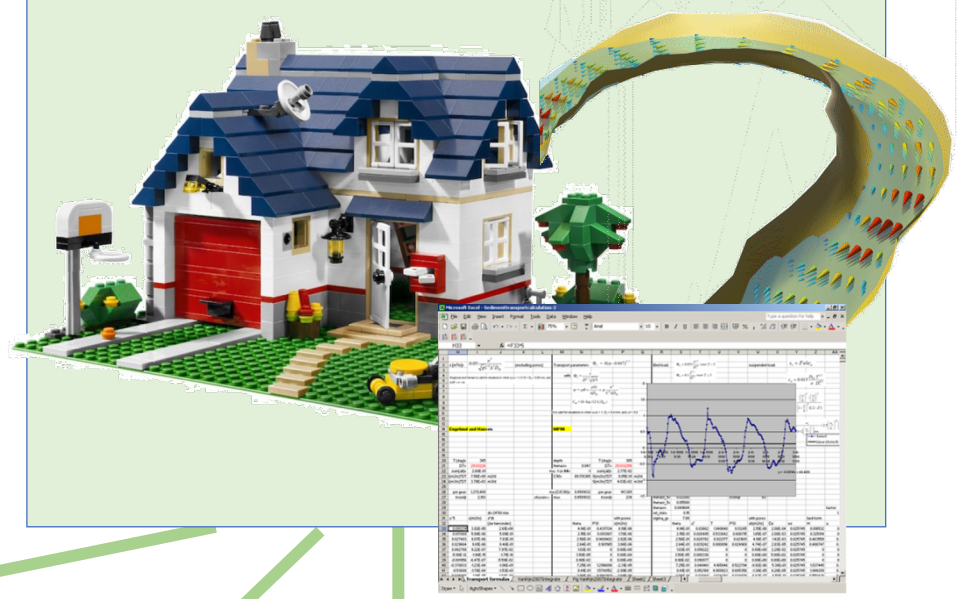


## Physical models (laboratory scale models)





## Computational models (numerical models)



Simple models: empirical, equilibrium states, spreadsheet

ANALOG:



Advanced models: 1-dimensional models, catchment models

ANALOG:



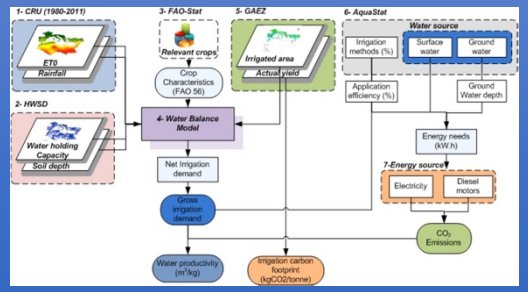
Advanced models: high-resolution 2 and 3-dimensional models

ANALOG:



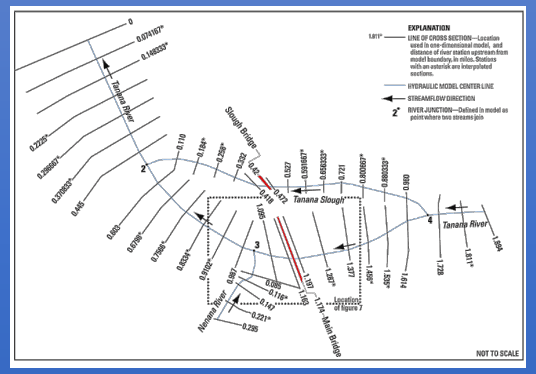
# Numerical models: dimensions

## 0-dimensional (0D)



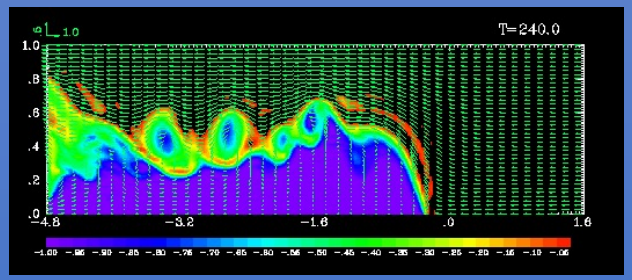

0D basin model (catchment models, water-balance models)

## 1-dimensional (1D)

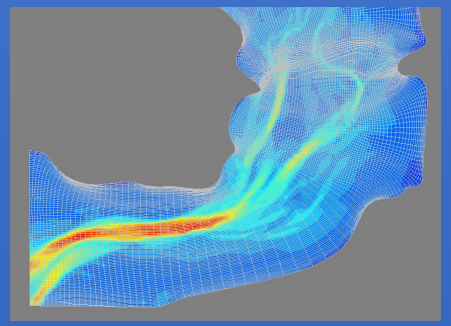



1D cross-section average:
Variations in time (unsteady)
Spatial varying in 1 dimension

## 2-dimensional (2D)

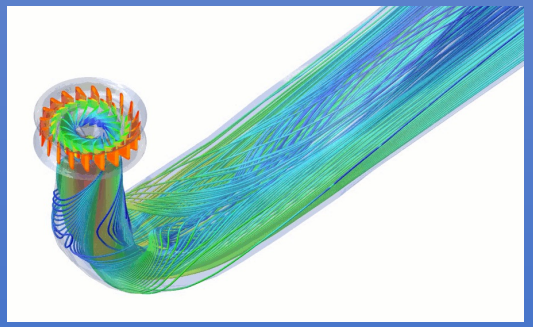



2DV (width average):
Variations in time (unsteady)
Spatial varying in 2 dimensions

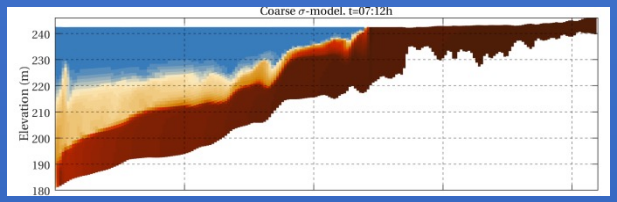


2DH (depth average):
Variations in time (unsteady)
Spatial varying in 2 dimensions
3D processes parametrized

## 3-dimensional (3D)



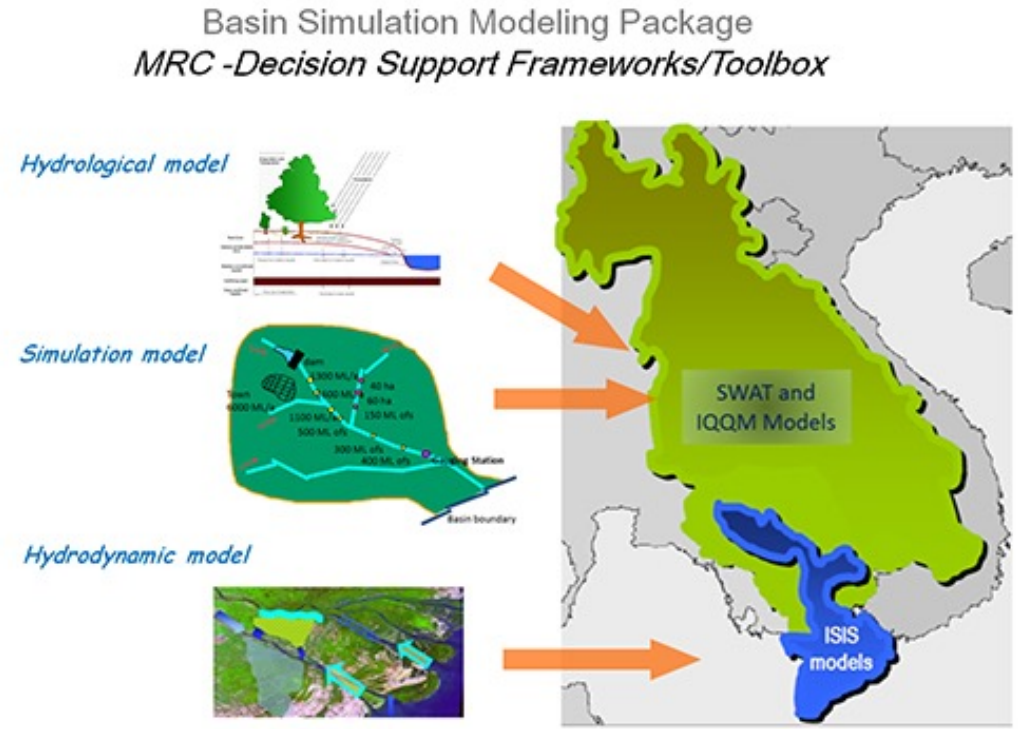
Full 3D DNS (CFD):
Variations in time (unsteady)
Spatial varying in 3 dimensions
Details turbulence




**Delft3D**

Reynolds average 3D:
Variations in time (unsteady)
Spatial varying in 3 dimensions
Averaged turbulence models (LES, eddy viscosity, k-epsilon)

# Hydrology models versus hydrodynamic models




Similar for erosion models versus morphodynamics models

## Hydrology models

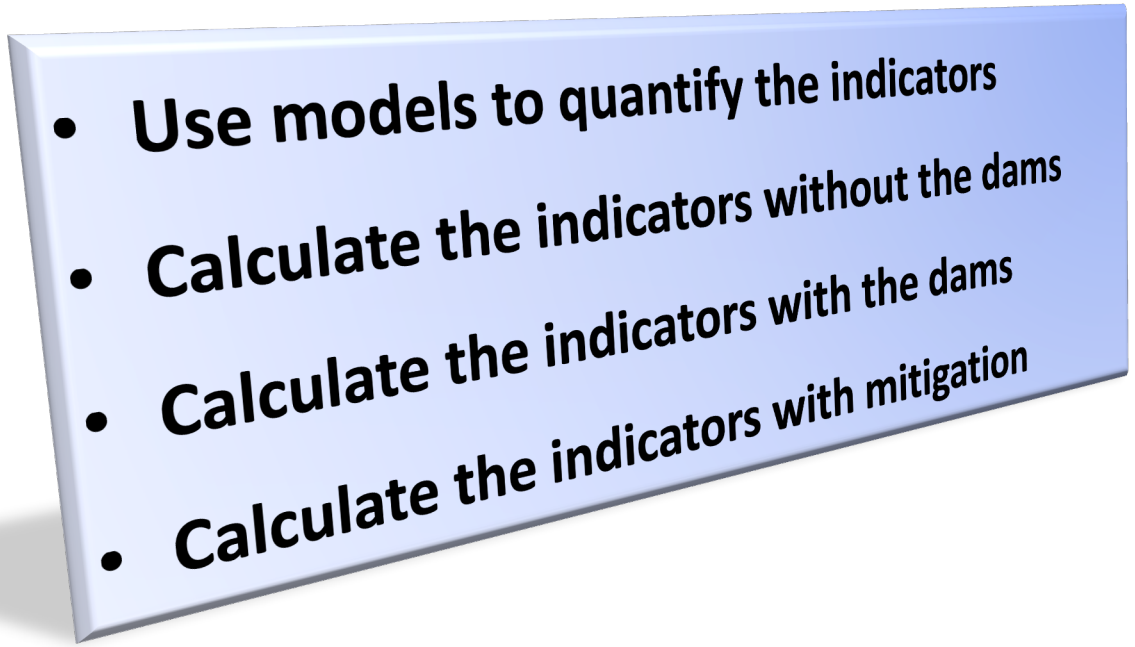
- Used to calculate rainfall to runoff
- Usually catchment models and simple flow routing (0-D)
- Time steps in the order of weeks to months (output monthly average discharge, etc)
- Does not include a detailed physical description of fluids

## Hydrodynamic models

- Used to calculate physics of flow processes (velocities, water levels,…)
- 1-D to 3-D models
- Time steps in the order of minutes to hours
- Also includes modules for sediment, geomorphology and water quality

# Models and indicators

- Indicators depend on purpose:
  - Ecology: e.g., flow velocity along reservoir as function of time for larvae drift, water depth in deep pools, rapid fluctuations downstream for fish stranding
  - Sediment: e.g., flow velocities along reservoir for deposition patterns, water level fluctuation for bank erosion
  - Navigation: e.g., water levels to assess submergence of rocks, flow velocities near locks, water levels at bridges for clearance

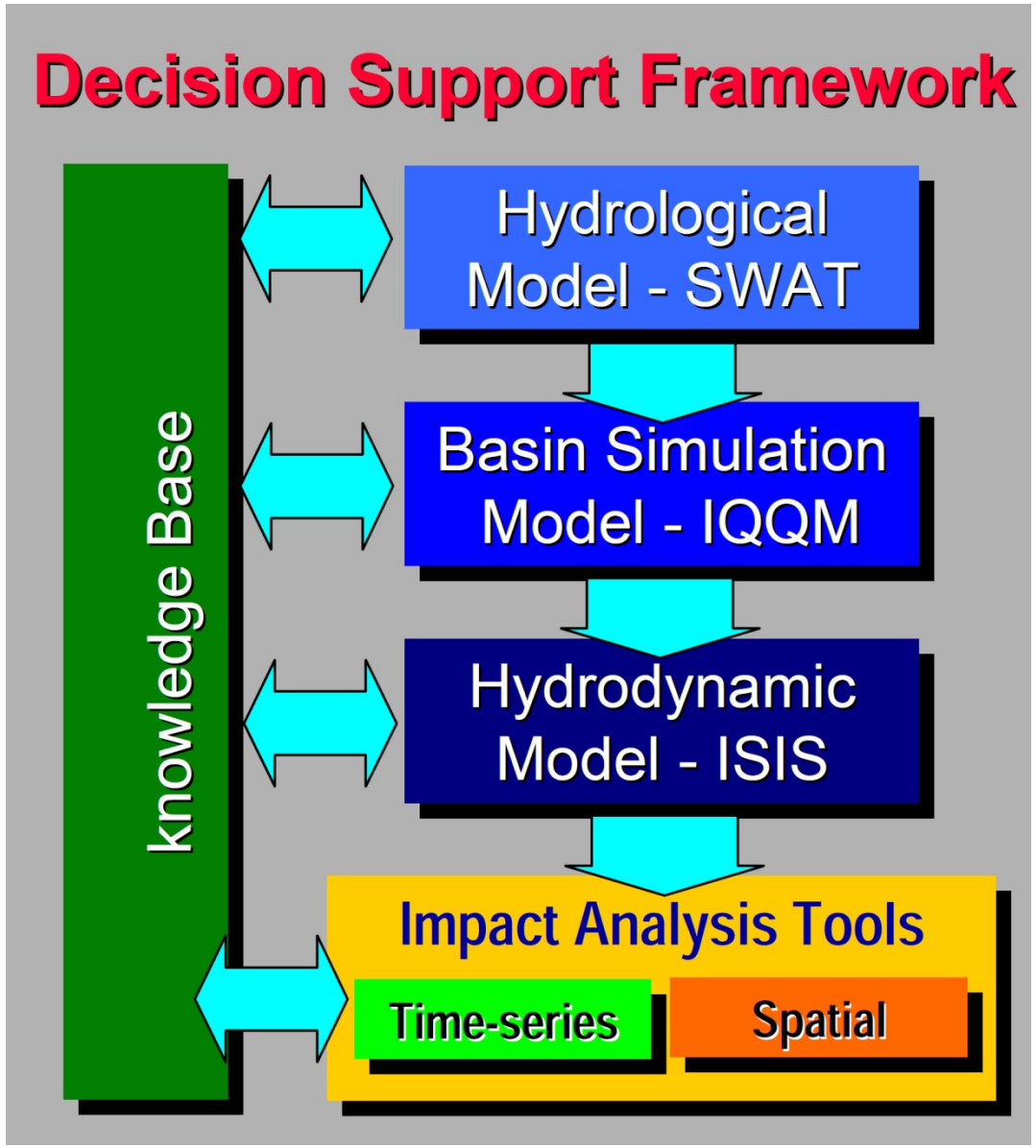


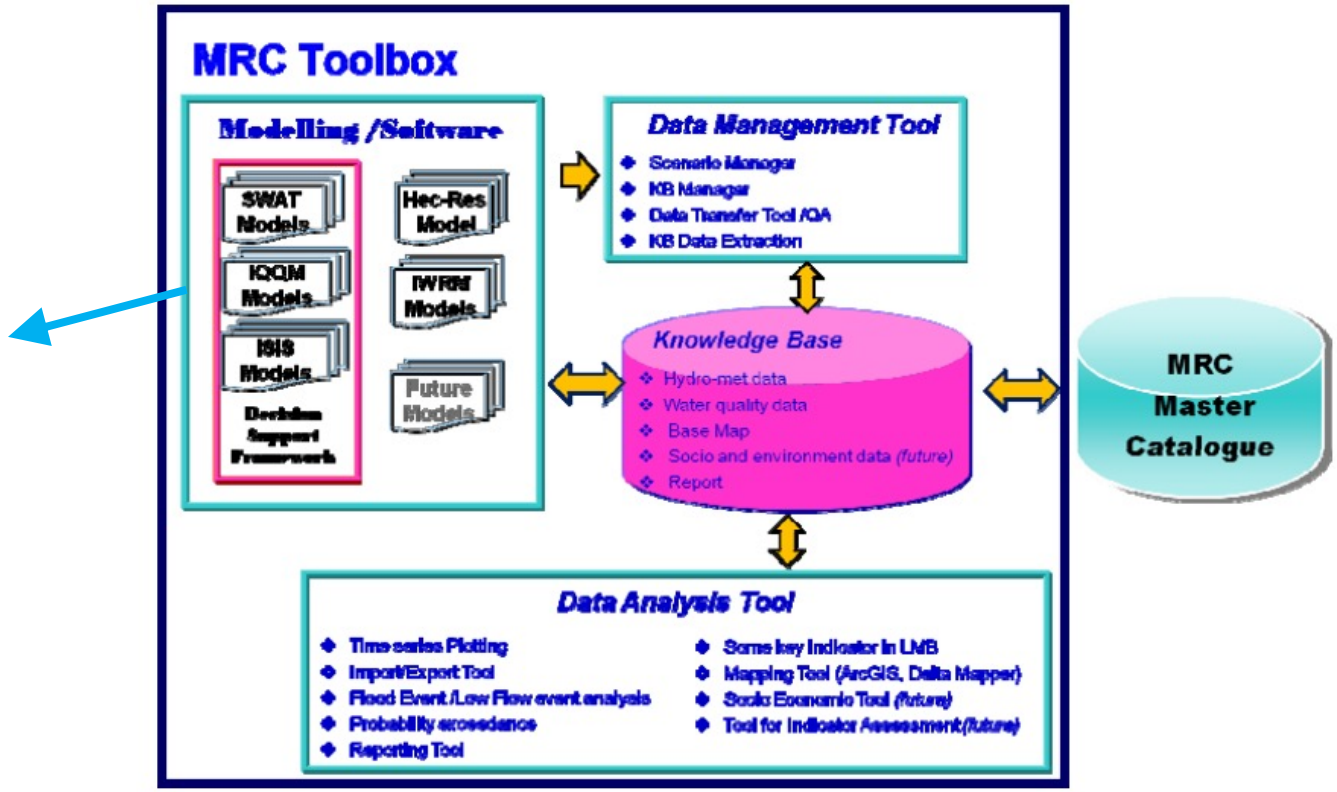
# Modelling

# Fit for purpose

- Assessment of extreme floods (flood safety):
  - Often based on extreme-value analysis of recorded floods: only for past conditions
  - Calculation with Possible Maximum Rainfall and hydrological model (rainfall-runoff, water balance, etc): can include future changes (dams, climate)
- Assessment of water levels and flow velocities **upstream**:
  - Hydraulic and morphological modelling 1D or 2D for large scale: backwater, variation in velocities along impoundment, morphology to include development of backwater deposits and rise of water level
  - Detailed hydraulic modelling 2D and 3D for flows near dam: approach flows for locks and power station, sediment deposits
- Assessment of water levels and flow velocities **downstream**:
  - Hydraulic and morphological model: tailwater prediction, fluctuations related to outflows (e.g., draw down for flood protection, flushing, peaking)
  - Serves environmental purposes and impact mitigation measures

# Example modelling framework MRC: DSF

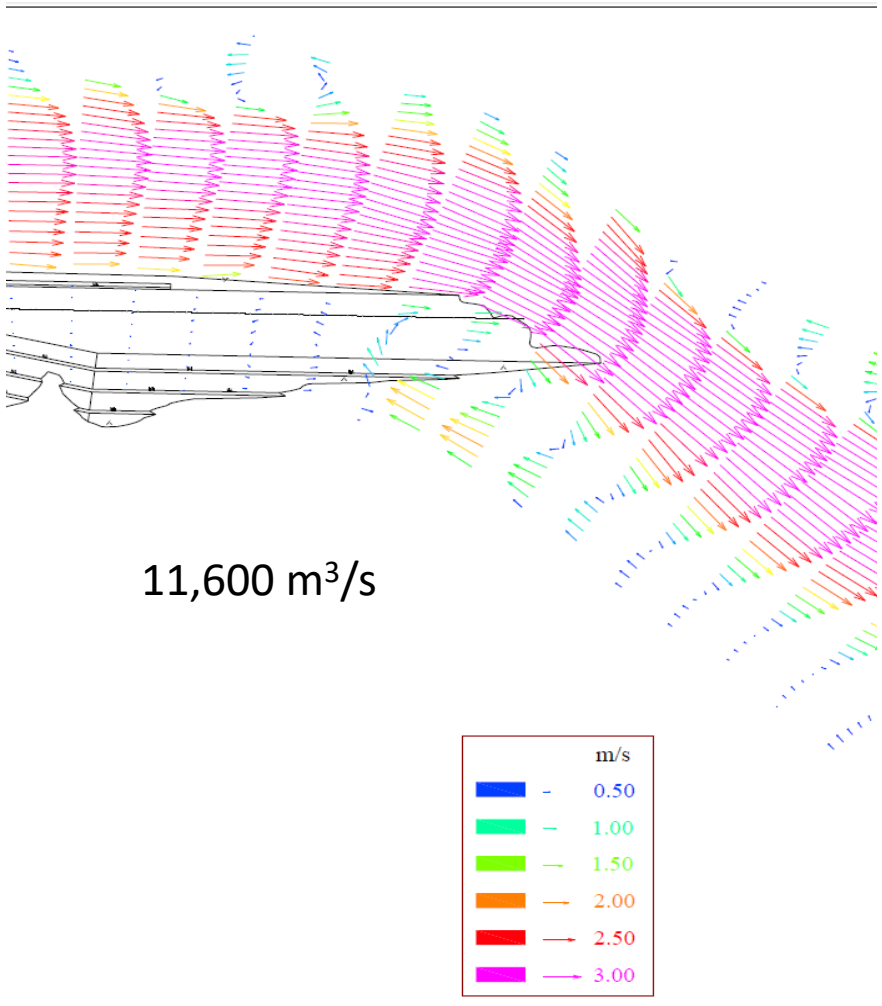


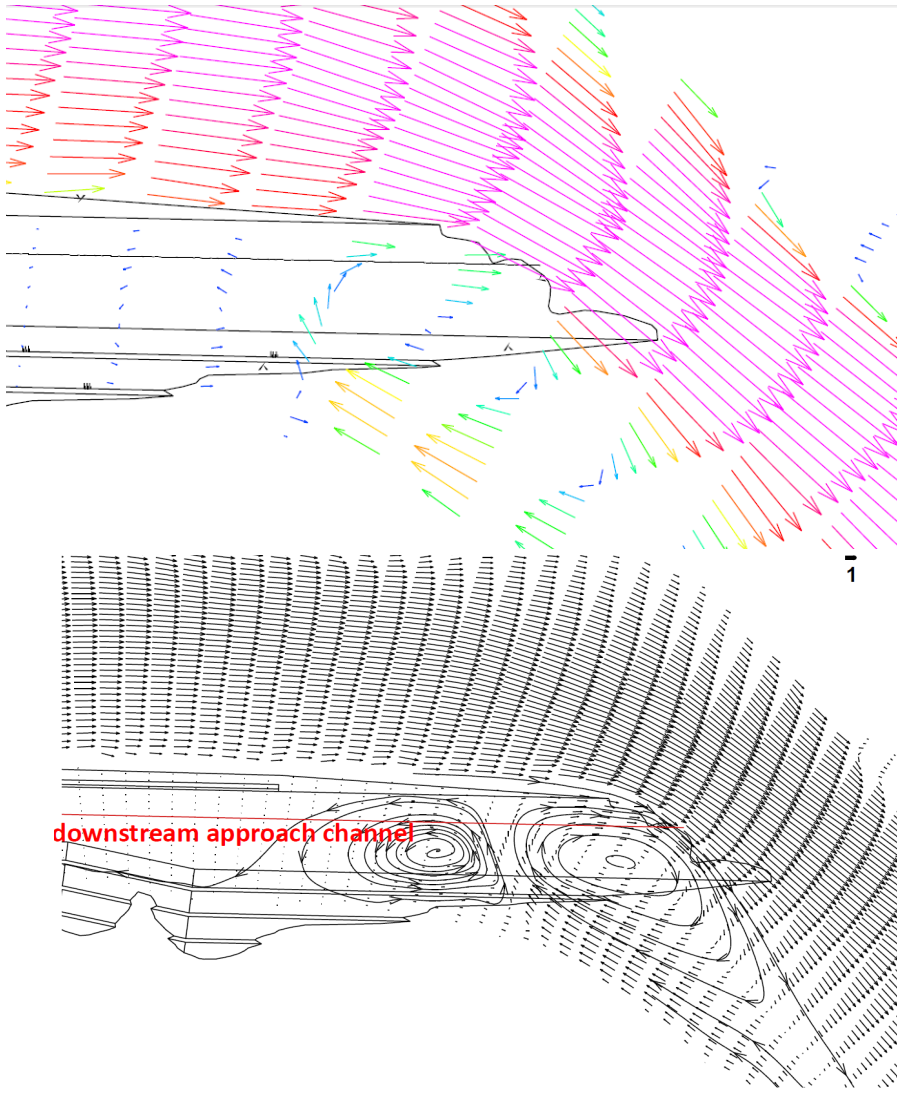

PNPCA: developers do not use this toolbox

# Experience from PNPCA: Flow near approach channel

**2D model**




11,600 $m^3/s$

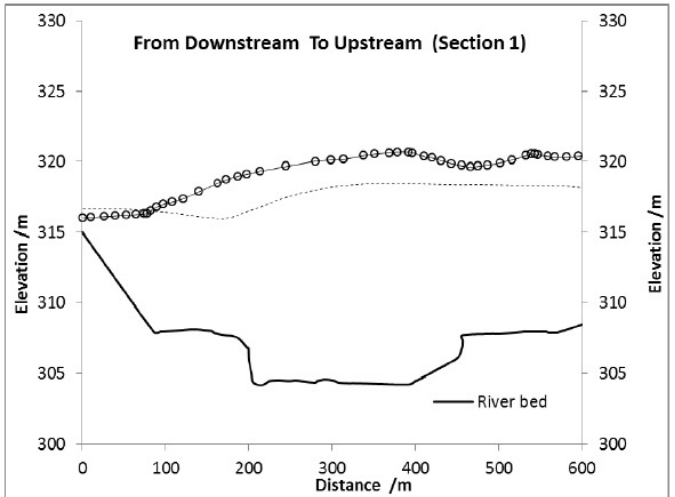


# Use of physical scale models

- Useful for local complex 3D flows (near the dam and turbines)
- Much work and time consuming, and still just a model
- Most problematic to do the right scaling:
  - Use Geometrical scaling: $\lambda = L_F / L_M$ ((keep the same)
  - For flow use Froude scaling (ratio inertia/gravity): $\frac{U_M^2}{gL_M} = \frac{U_F^2}{gL_F}$
  - For flow use Reynold scaling (ratio inertia/viscous): $\frac{UL}{\nu} = Re$
  - For sediment use Shields scaling: $\theta_f = \frac{\tau}{(\rho_p - \rho_f) gD}$

  Impossible to satisfy all scaling rules






Pak Beng hydropower project - Overall Hydraulic Physical Model Investigation of Pak Beng HPP

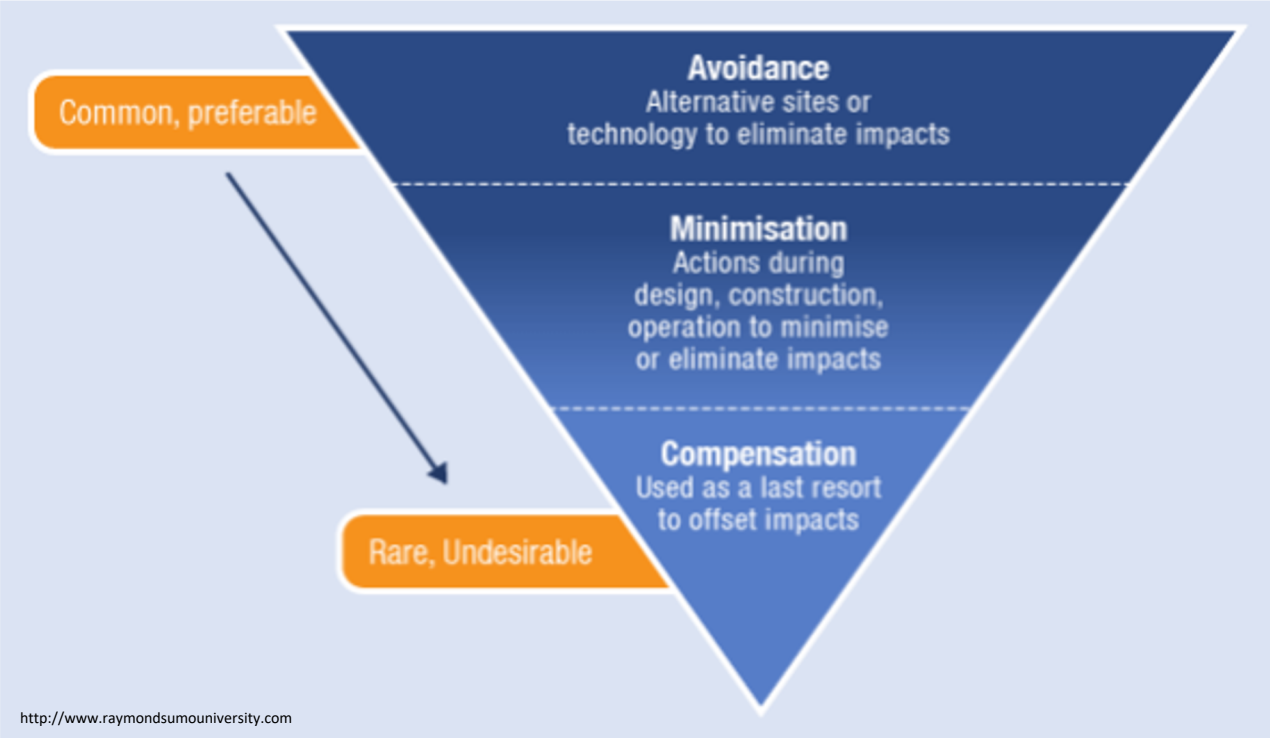
# Experience from PNPCA: hydraulic models

- Require calibration on basis of detailed data: calibration approach should be shared, and additional verification is required (split data sets in 2 parts)
- Highly dependent on the geometry: accurate and recent data should be used, and these should be well described in documents
- Extrapolation to extreme (not measured) conditions possible, but sensitivity or accuracy of results should be addressed
- Reports on details of hydraulic models are often not provided
- Hydraulic modelling software used should be validated and well described: references have to be added

# 2.4 DESIGN AND OPERATIONAL GUIDANCE

# Clause 61: Avoidance – Mitigation - Compensation

- The risks, impact and vulnerabilities (section 2.2) is the basis for the detailed mitigation options
- Using the full mitigation hierarchy (avoidance, minimization, compensation) should be the New Frontier for the LMB countries
- ISH0306 mitigation guidelines provide guidance



# Section 2.4 : Specific Design and Operational Guidance

**Clause 62** : Table 2-2 Mitigation options to address hydrological and hydraulic changes

| Hydrological or Hydraulic Changes | Mitigation Options |
|---|---|
| **Daily or short-term alterations in the downstream flows** | • Siting of the project so that downstream impacts are reduced due to the river configuration or by entering tributaries<br>• Cascade Joint Operating Rules to ensure harmonised operations<br>• Project-Specific Operating Rules to minimise flow fluctuations downstream of the dam (note the most downstream dam in a cascade can be operated as a re-regulation dam if required during specific operational activities of the cascade)<br>• Notification and warning systems for spill events or rapid water level changes |
| **River impoundment** | • Siting and design to minimise the inundation area<br>• Siting and design to minimise the water residence time<br>• Filling rules to address any flow interruptions following dam closure<br>• Operating rules for the impoundment to minimise water level fluctuations, and prevent upstream flood damage. |

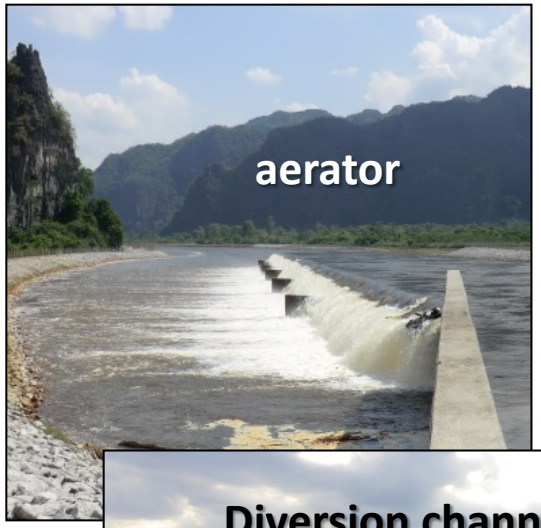
# Section 2.4 : Specific Design and Operational Guidance (continued)

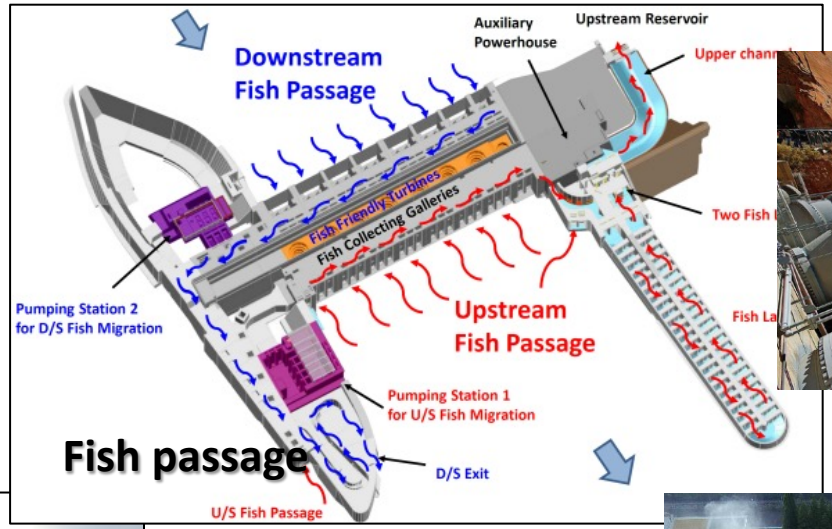
**Stage-specific guidance:**

- Planning and design stage (#63-67): Consider siting, establish project-specific operation rules, consider future additional dams, environmental flows
- Construction and filling stage (#68): Demonstrate that issues have been addressed
- Operation stage (#69-72): Consider cascade joint operation rules, and assess risks related to water-level ramping



# Mitigation measures (some examples)



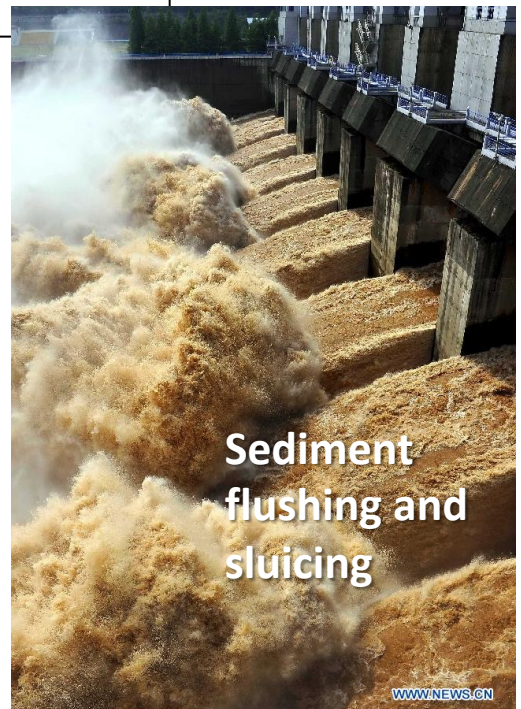






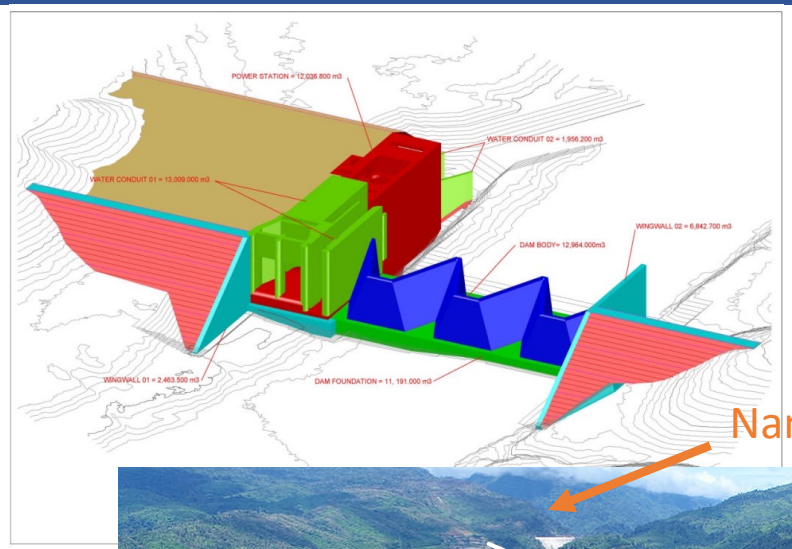




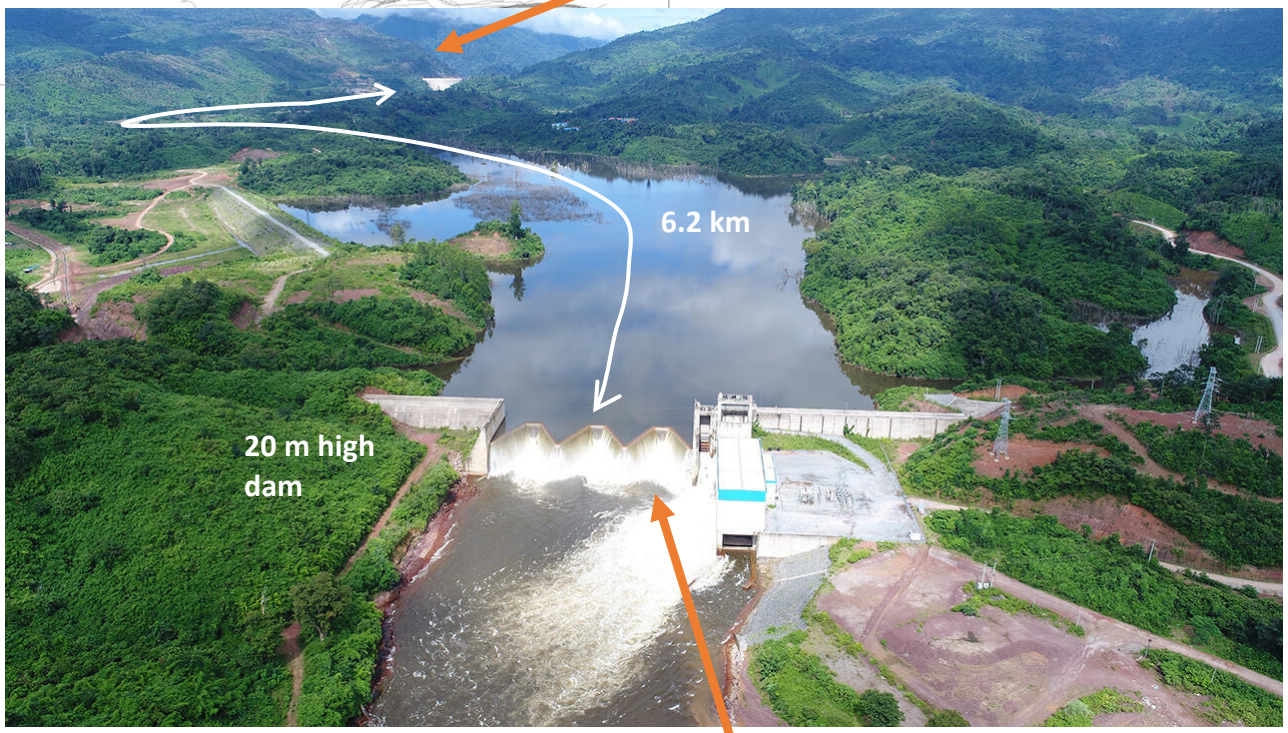




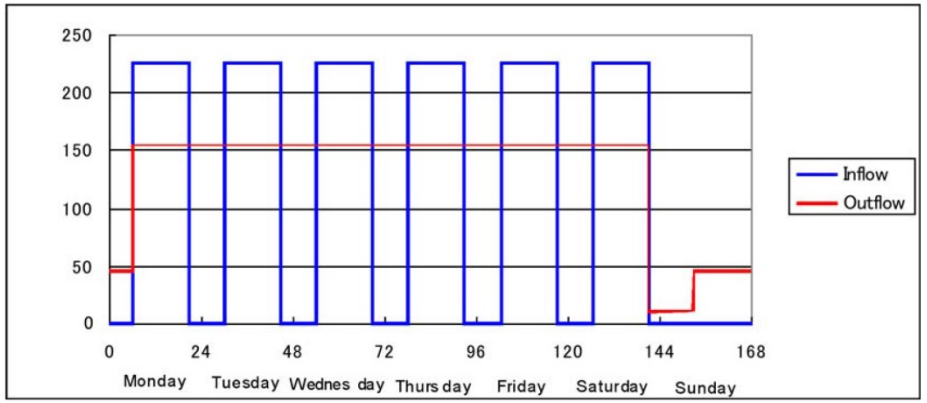

# Example: Regulation weir at Nam Ngiep 1




Nam Ngiep 1 dam (Laos)




Nam Ngiep 1 re regulation dam

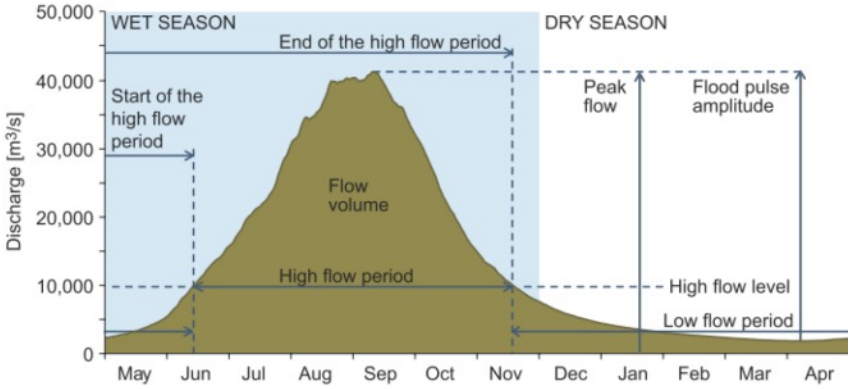



- The re-regulation reservoir is to store water discharged from the main dam for 16-hour peak power generation, re-use it for power generation and release it downstream evenly on a 24-hour basis on weekdays and Saturday
- Operation level between EL 174.0 and EL 179.0 (eff. Storage 4.6Mm$^3$)

# Example planning: avoidance (flows and sediment)

## Nam Ou Cascade, Northern Laos

1995 Pre-Feasibility Study – proposed 140 m high dam (900 MW) at Nam Ou 2 site




*Some risks/Impacts:*

- Inter-annual changes due to large storage
- Elimination of large sediment contribution to Mekong (>8 Mton/yr)
- Etc

2007 Feasibility Study – proposed barrage impounding ~15 m gross head (120 MW) in a cascade of seven projects (adopted)



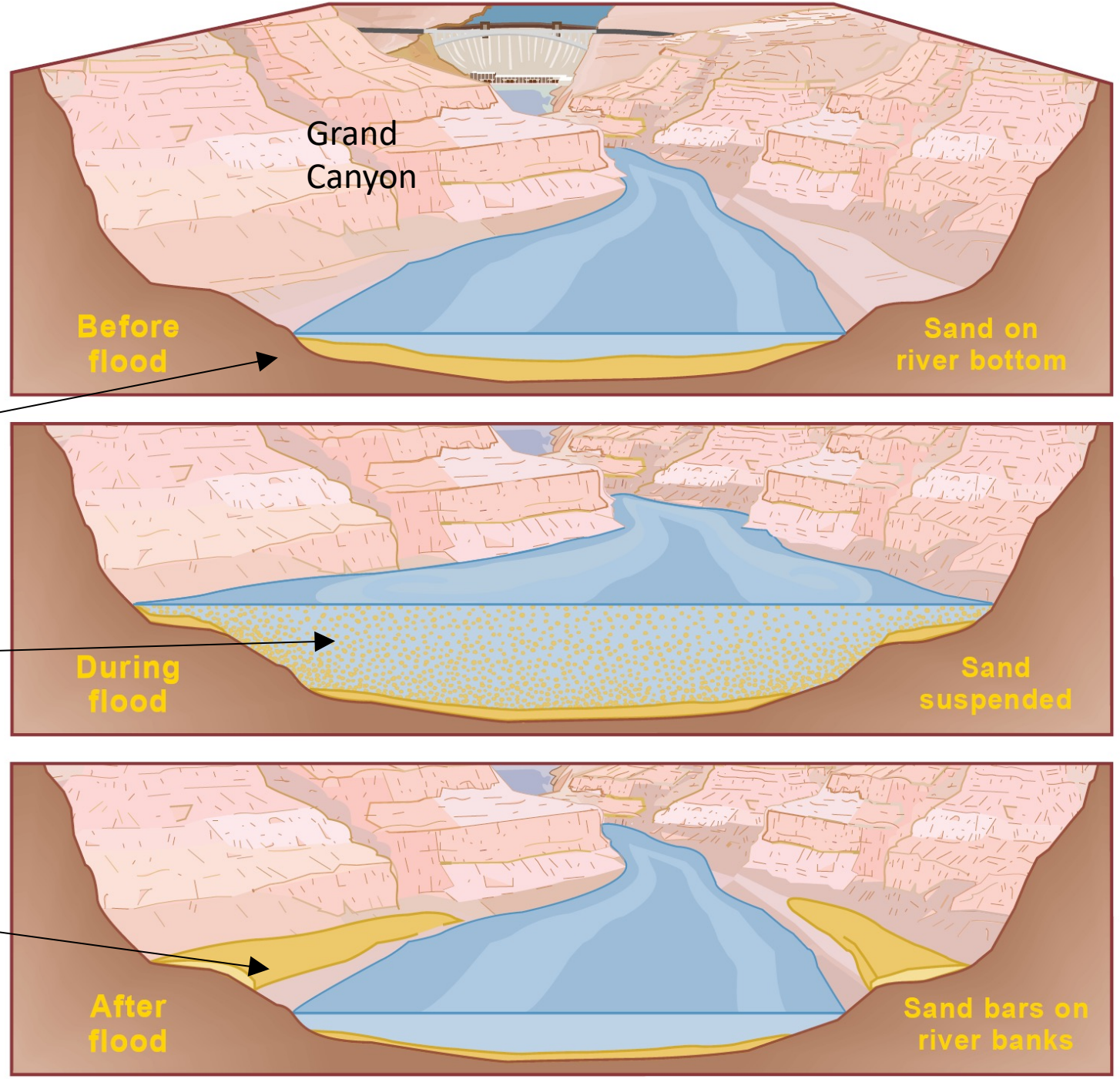
Nam Ou 2 – Lao PDR
Gated bulb turbine barrage

# Environmental flows

- Often incorrectly referred to as ‘minimal discharge’
- International practice: all flow releases that are needed to sustain or enhance the ecological integrity and functionality of a river or downstream ecosystem. It involves allocating and managing water resources to meet the environmental requirements of the affected river system.
- The fundamental principles involve simulating or approximating the natural flow patterns and characteristics that existed before the dam's construction
- Example: artificial high-flow releases in the Colorado River to sustain sand bars in the Grand Canyon

# Releasing high flows periodically






coarse “fixed” bed, covered with fine sand

fines picked up during flood (roughly 0.06-0.5 mm)

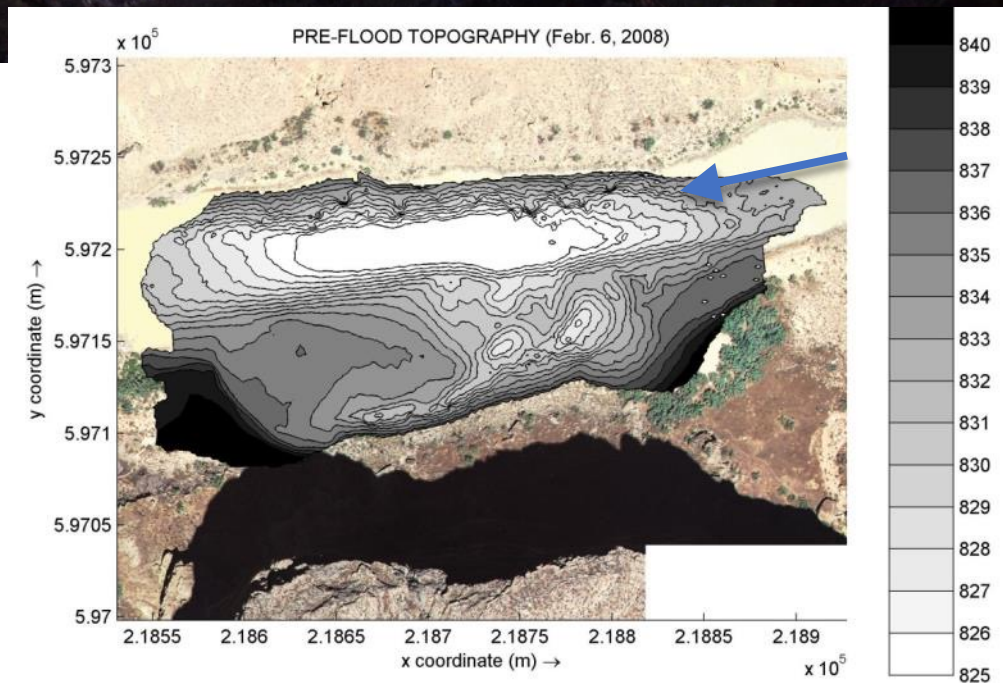
deposits remaining at high elevations

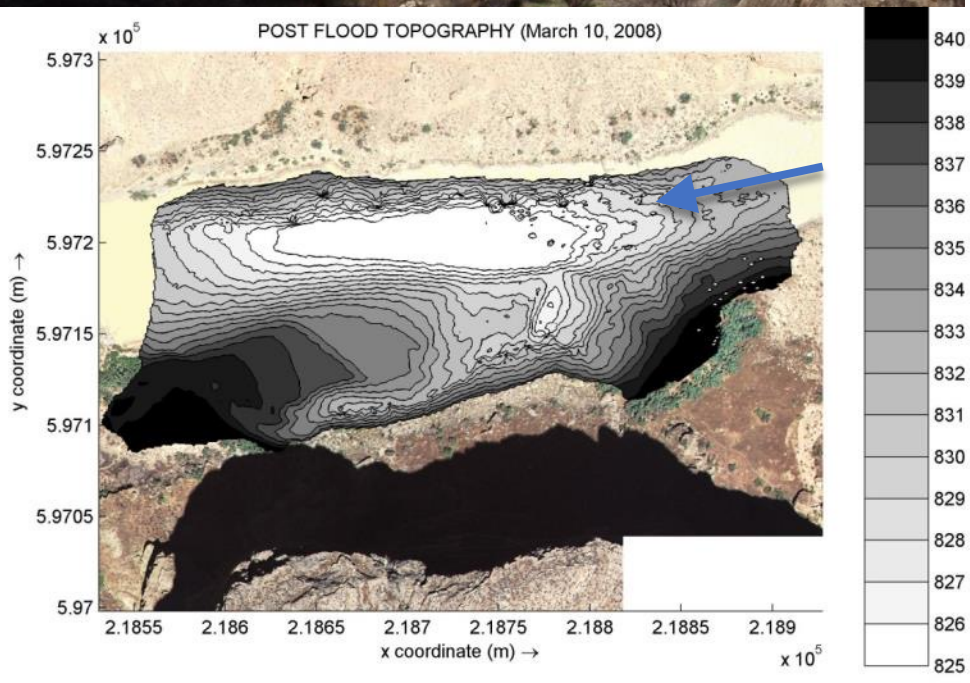
# Bed topography changes









# 2.5 PROJECT MONITORING AND ADAPTIVE MANAGEMENT

# Section 2.5 : Construction and Operation Monitoring and Assessments

- Flows are highly stochastic and changing: **comprehensive monitoring** should continue throughout **design, construction and operation** (73)
- Monitoring results can be compared to predefined targets and used to identify needs for **adaptive management of discharges and water levels** at key locations up- and downstream of the project (74, 75)



# TAKEAWAYS

# Takeaways

- Dam projects always generate flow alterations, both positive and negative, both upstream and downstream the dam
- Run-of-river dams have less impact on flows, but still can cause large sub-daily (hourly) flow fluctuations
- For assessing and mitigating dam impacts it is necessary to consider the full river system (all pathways of water, pulses, joint operation, etc.)
- Lack of mitigation of risks can have many reasons: economic considerations, lack of understanding, political pressure, limited stakeholder engagement, technological optimism, compromises, etc.

# Thank you

