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# Xayaburi Hydro Power Project

# Follow-up of recommendations made by CNR during the Peer Review regarding navigation and sediments issues

***Vientiane (Laos), 15th July 2015***

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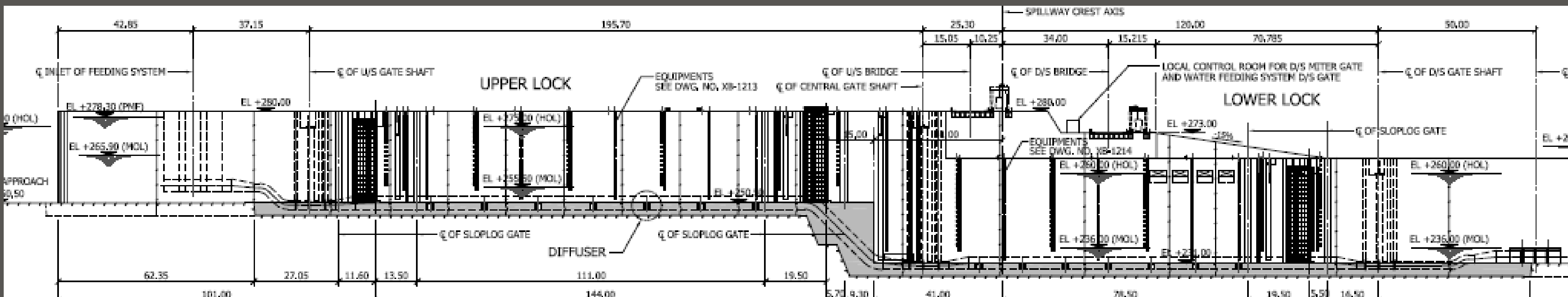
# Navigation Issues

1. Main features of Xayaburi lock complex
2. Highlights from the Peer Review for the lock design
3. Complementary study methodology
4. Main improvement brought to initial layout
5. Summary of changes brought to initial layout
6. Comparison between initial & retained F/E system hydraulic performances

# Main features of Xayaburi lock complex




- Two steps locks
- Maximum head :
  - 19.5 m between upper pond and upper lock,
  - 39.0 m between upper lock and lower lock,
  - 19.5 m between lower lock and lower pond.

# Highlights from the Peer Review for the lock design

- Very unbalanced flow distribution along the bottom F/E system generating unsafe water movements in the lock chamber during F/E operations;

- Sudden changes of hydraulic sections (valves, connection lateral culvert/diffuser) creating over speed and high head losses;

- Too high velocity in valve section;

- Unbalanced flow distribution between water intakes increasing the risk of vortices occurrence;

- No redundancy of the culvert valves, any outage of one valve leading to the entire outage of the lock system.

# Complementary study methodology

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## ➢ Step 1 – Preliminary hydraulic analysis

Diagnosis of the problems, validation by the lock designer of the possible improvements of the F/E system and recovering of the data required to build the 3D numerical model.

## ➢ Step 2 – 3D numerical modeling of the F-E system

- Phase 1 - Modeling of the entire F-E system in order to assess its hydraulic performance;
- Phase 2: Modeling of specific elements of the system (local models) in order to study into details the proposed improvements and update their design if necessary;
- Phase 3: Modeling of the final design of the F-E system.

## ➢ Step 3 – 1D numerical modeling of the F-E system

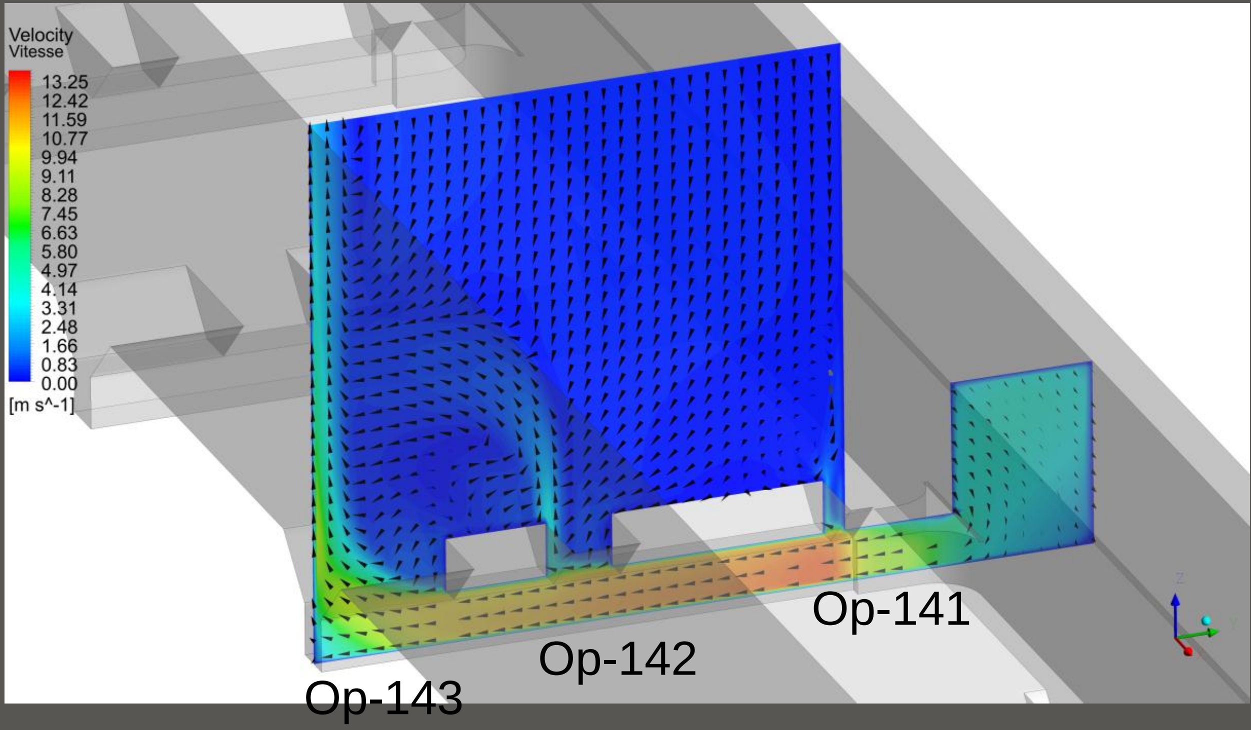
Calculation of F/E hydraulic performances & definition of best valves opening/closing schedules

# Main improvement brought to initial layout

- Modification of diffuser geometry – Initial design

Three openings – Flow distribution very unbalanced

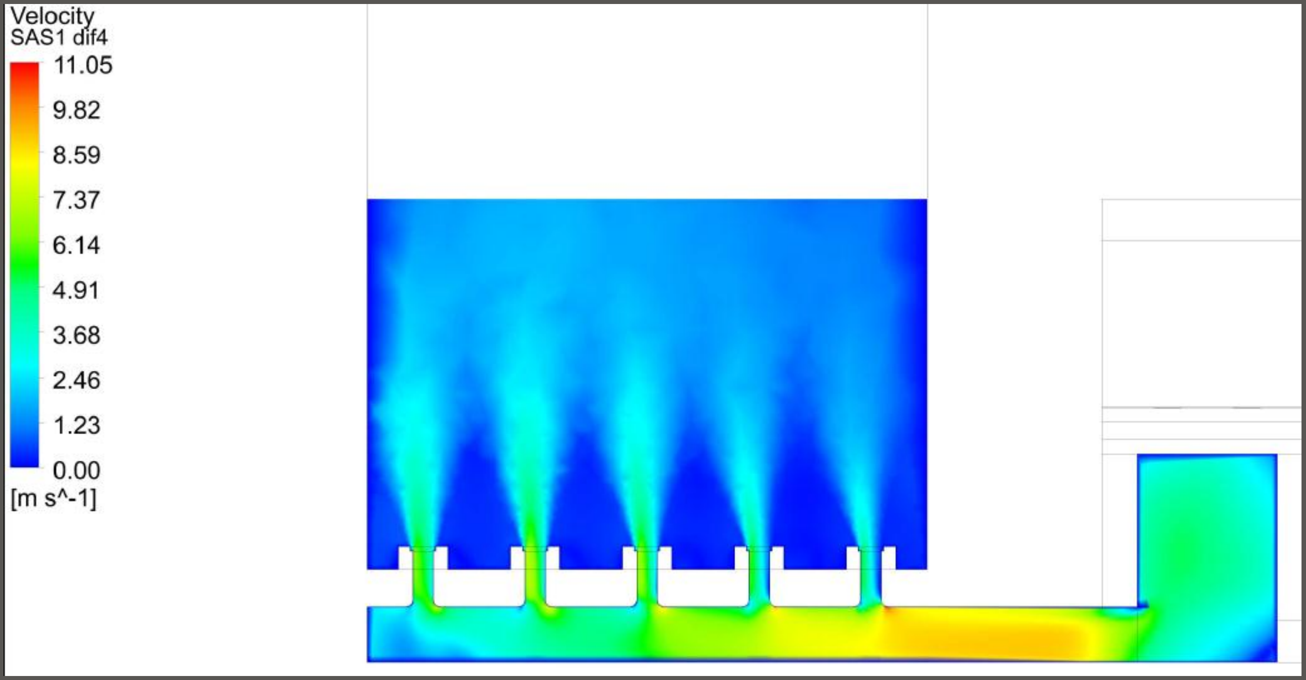
| | Mass flow rate (kg/s) | Distribution |
|---|---|---|
| **Op-141** | 102 | 1% |
| **Op-142** | 752 | 6% |
| **Op-143** | 11 927 | 93% |
| **TOTAL** | **12 781** | **100%** |



# Main improvement brought to initial layout

➢ Modification of diffuser geometry – Final design

Five openings – Balanced flow distribution




| Mass flow rate (kg/s) | Distribution | Distribution (rounded openings) | Opening 1 | Opening 2 | Opening 3 | Opening 4 | Opening 5 |
|---|---|---|---|---|---|---|---|
| 12 477 | 12.5% | 13.4% | 12.5% | 12.5% | 12.5% | 12.5% | 12.5% |

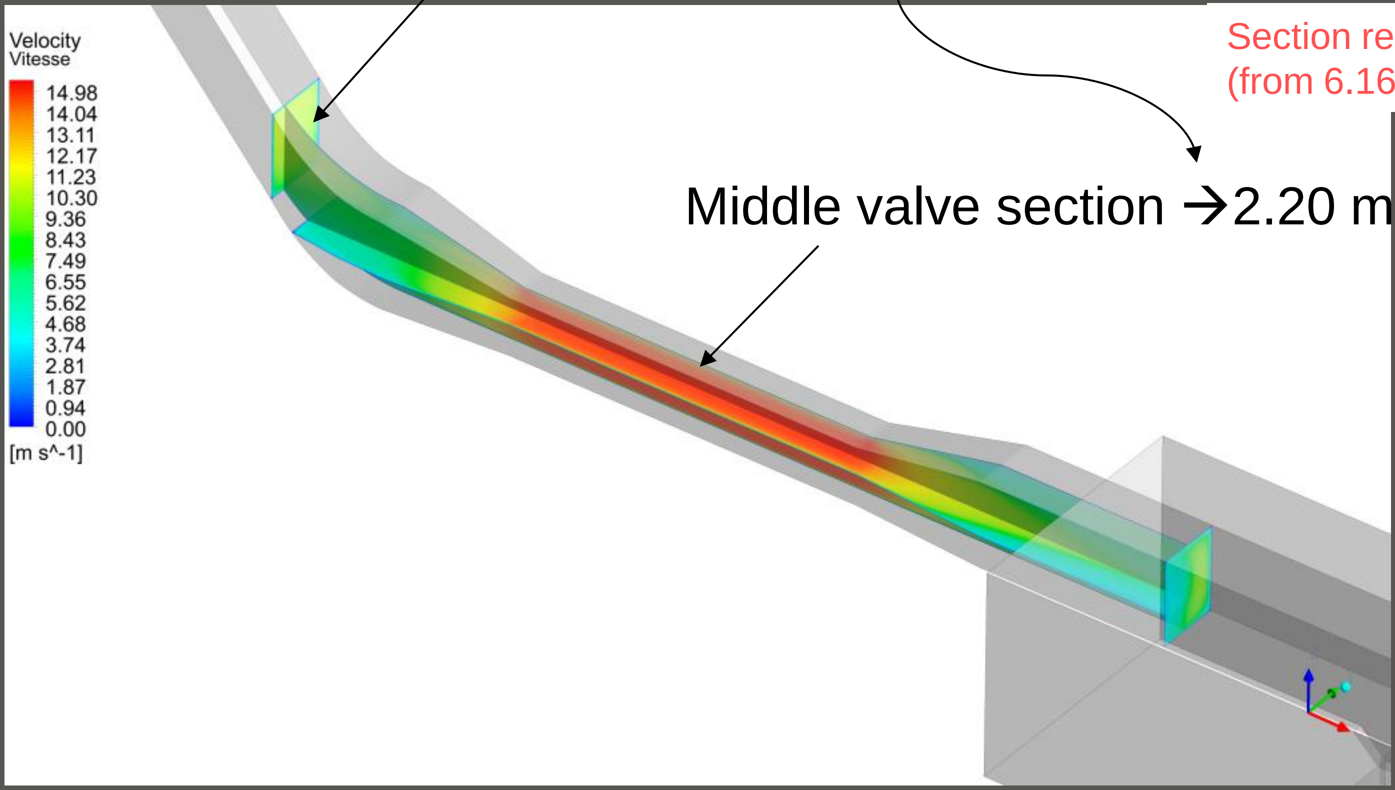
# Main improvement brought to initial layout

- Modification of the culvert valve section – Initial design

Main culvert section →3.20 m x 4.20 m

Section reduced by 55% (from 6.16 m² to 13.44 m²)

Middle valve section →2.20 m x 2.80 m



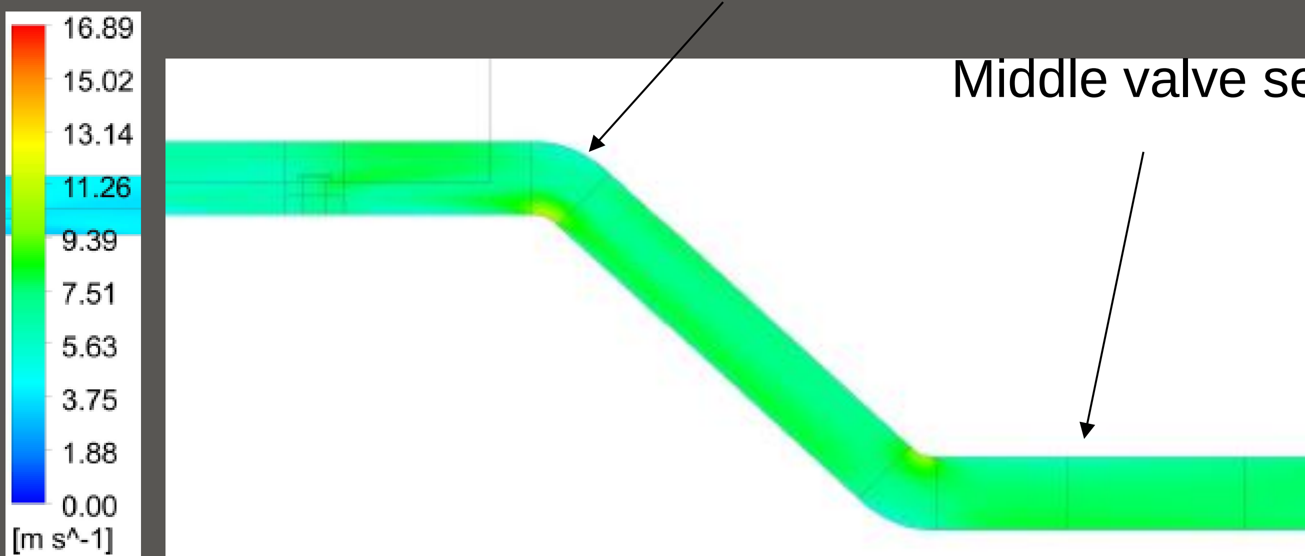

Maximum velocity in valve section ~ 15 m/s

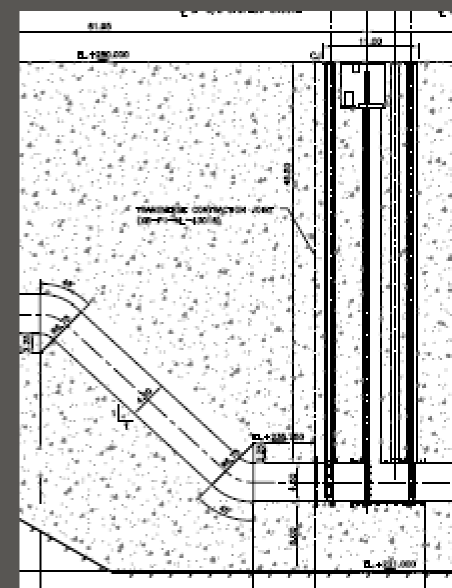
# Main improvement brought to initial layout

- Modification of the culvert valve section – Final design

Main culvert section → 3.00 m x 4.50 m

Middle valve section →3.00 m x 4.50 m



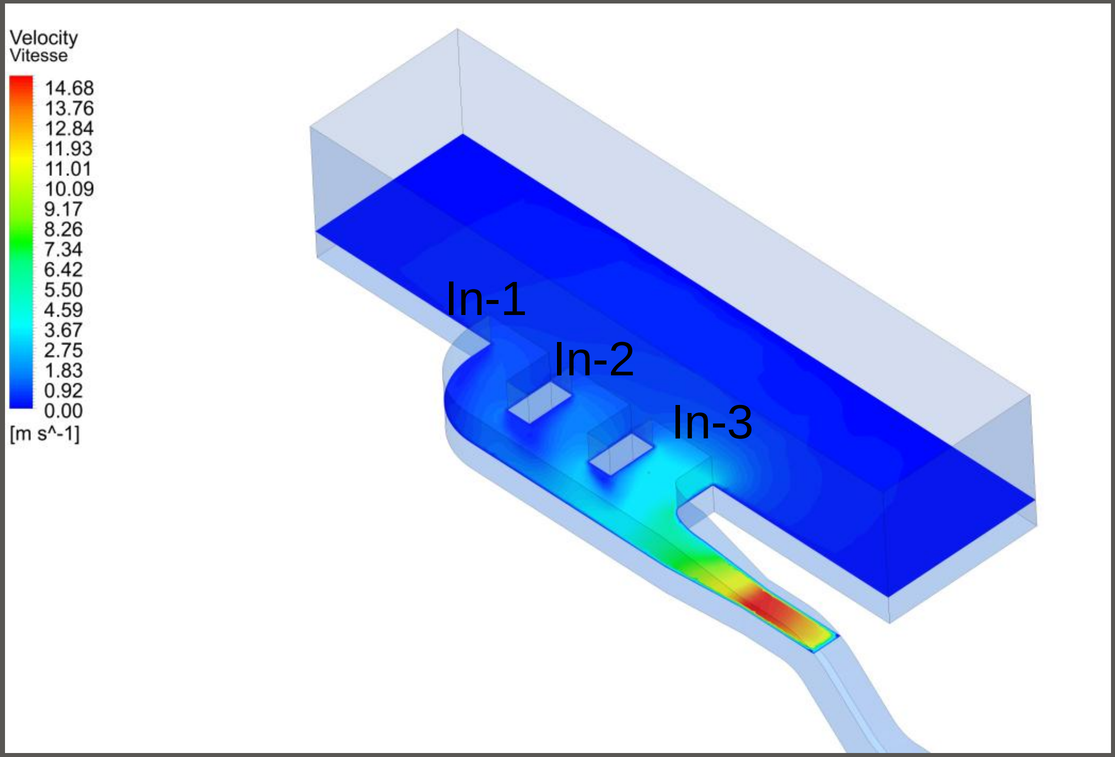



Maximum velocity in valve section ~ 7.5 m/s

Maximum velocity in culvert section ~ 12 m/s (bends intrados)

# Main improvement brought to initial layout

- Modification of the water intake layout – Initial design



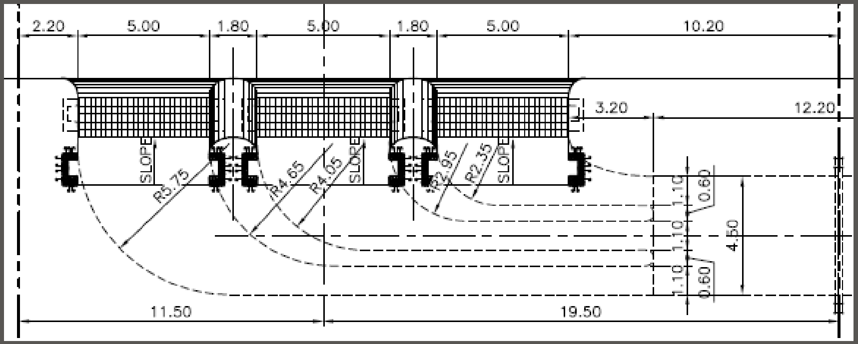

| | Mass flow rate (kg/s) | Distribution | Average velocity (m/s) |
|---|---|---|---|
| **In-1** | 9 371 | 10% | 0.45 |
| **In-2** | 18 754 | 21% | 0.90 |
| **In-3** | 61 695 | 69% | 2.94 |
| **TOTAL** | **89 820** | **100%** | |

Unbalanced flow distribution

Vmax (In-3) ~ 4 m/s

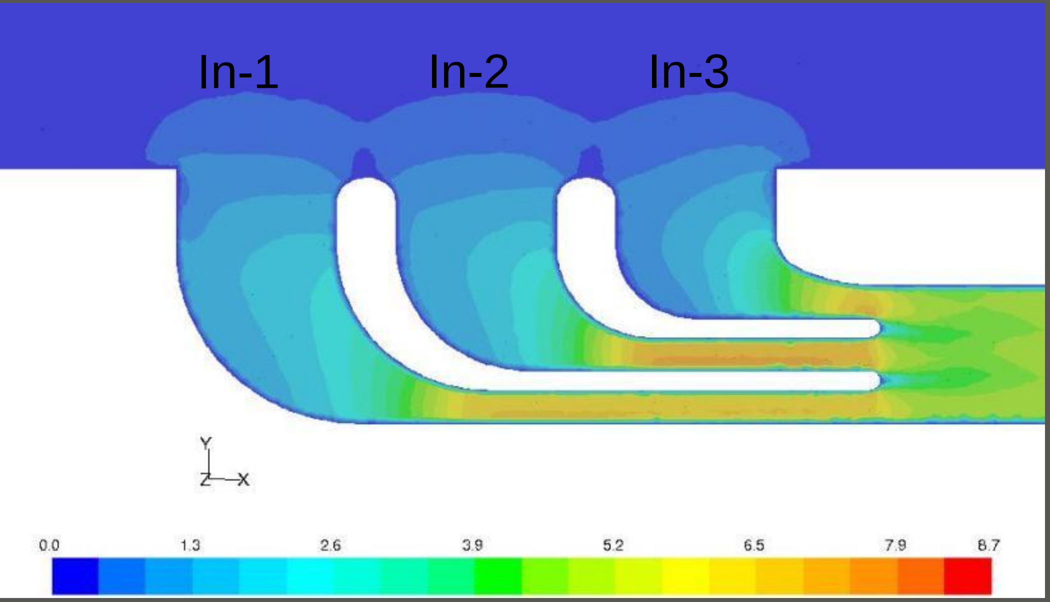
# Main improvement brought to initial layout

➢ Modification of the water intake layout – Final design




**Three intakes**

**5.00 m (W) x 4.50 m (H)**




| | Mass flow rate (kg/s) | Distribution | Average velocity (m/s) |
|---|---|---|---|
| **In-1** | 33 523 | 33.6% | 1.49 |
| **In-2** | 33 581 | 33.6% | 1.49 |
| **In-3** | 32 721 | 32.8% | 1.45 |
| **TOTAL** | **99 825** | **100%** | |

Balanced flow distribution and velocity < 2 m/s.

# Summary of changes brought to initial layout

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1- Intake: to be modified including culvert height of 4.5 m and dividing walls;

2- Lateral culvert: new dimension all along 3.0 x 4.5 m (w x h);

3- Gate number and size: one gate per section (upper, middle and lower) 3.0 x 4.5 m (w x h);

4- Steel liner remain 4.0 m d/s the gate plus 20.0 m of silica fume concrete;

5- Maintenance access shaft to be moved u/s the gate section (to be confirmed);

6- Diffusers/openings: seven (7) diffusers per lock 1.5 x 1.2 m (w x h)/ five (5) opening per diffuser 1.5 x 0.45 m (l x w);

7- Outlet: to be modified as the intake (guiding walls and culvert height );

8- No change in elevation of the culvert different sections.

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# Comparison between initial & retained F/E system hydraulic performances

| | Initial design | Final (proposed) design |
|---|---|---|
| **F-E times** | Exceeded for maximum initial head | Complied with for maximum initial head |
| **Water intakes** | Unbalanced flow condition between the 3 intakes (10 % - 21% - 69%) | Balanced flow condition between the 3 intakes (34% - 33% - 33%) |
| | Average velocity ~ 3 m/s | Maximum average velocity < 1.5 m/s |
| **Flow distribution between openings** | Very unbalanced for lock filling operations (distribution with repsect tot total discharge max 13.5% - min 0.1%) | Balanced for lock filling operations (distribution with repsect tot total discharge max 4.0% - min 1.8%) |
| | Very unbalanced for lock emptying operations (distribution with repsect tot total discharge max 7.4% - min 2.2%) | Balanced for lock emptying operations (distribution with repsect tot total discharge max 5.1% - min 1.7%) |
| **Lateral culvert section** | 3.20 m (W) x 4.20 m (H) upstream lower valve - Maximum local velocity up to 18 m/s --> too high | 3.00 m (W) x 4.50 m (H) all along<br>Average velocity < 8m/s<br>Maximum local velocity up to 12 m/s --> OK |
| | 2.20 m (W) x 2.80 m (H) downstream lower valve which leads to average velocity of 14 m/s >> 8 m/s | |
| **Valves** | Section reduced too much (by 55%) compared to the lateral culvert section | Section set at the same dimension than the lateral culvert 3.00 m (W) x 4.50 m (H) |
| | Average velocity in the valve section ~ 14 m/s >> 10 m/s | Average velocity in the valve section ~ 7.5 m/s < 10 m/s |
| | High risk of cavitation and air entrainment downstream to the valve section | Low risk of cavitation and air entrainment downstream to the valve section - Could be minimized by suitable valve operating schedule |
| **Water outlets** | Unbalanced flow condition between the 4 outlets (-3 % - 8% - 28% - 67%) | Balanced flow condition between the 3 outlets (33% - 36% - 31%) |
| | Maximum velocity of the transversal current ~ 8 m/s | Maximum velocity of the transversal current ~ 3 m/s |

# SEDIMENT ISSUES

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3. Highlights from the Peer Review for sediment issues
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7. Situation downstream Xayaburi dam
8. Strategy recommended for managing sediment fluxes

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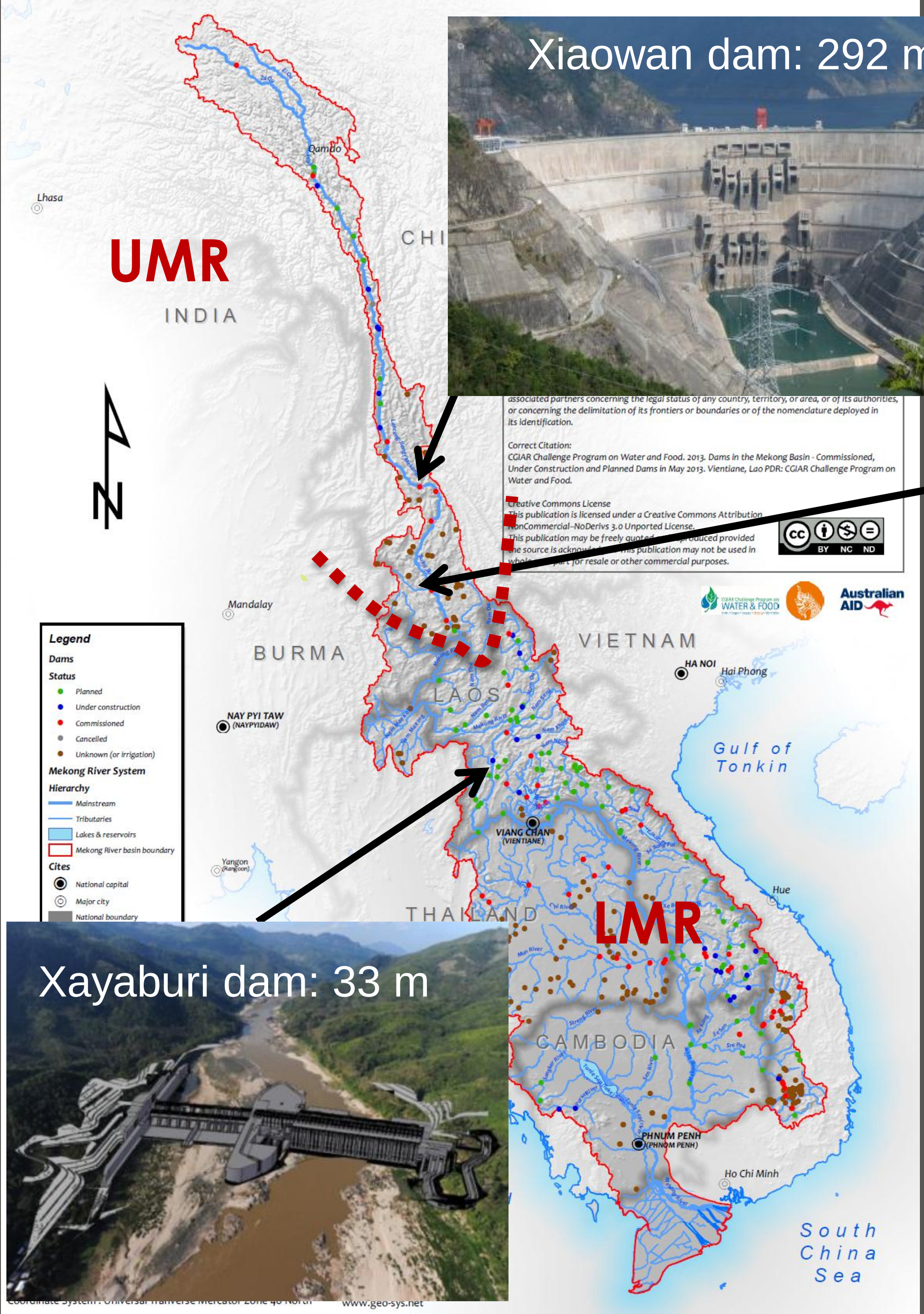


# Mekong River Basin overview


- Basin area:
  - At basin outlet: 795,000 km²
  - At Xayaburi dam: 272,000 km²
- Total length: 4910 km
- 6/8 dams already built across UMR (total stor. cap. > 20 Bm³)
- 1 under construction across LMR: Xayaburi dam
  - 33 m high and 820 m wide
  - Storage capacity: 726 Mm³
  - Max. capacity: 1285 MW

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# River morphology and transported sediments

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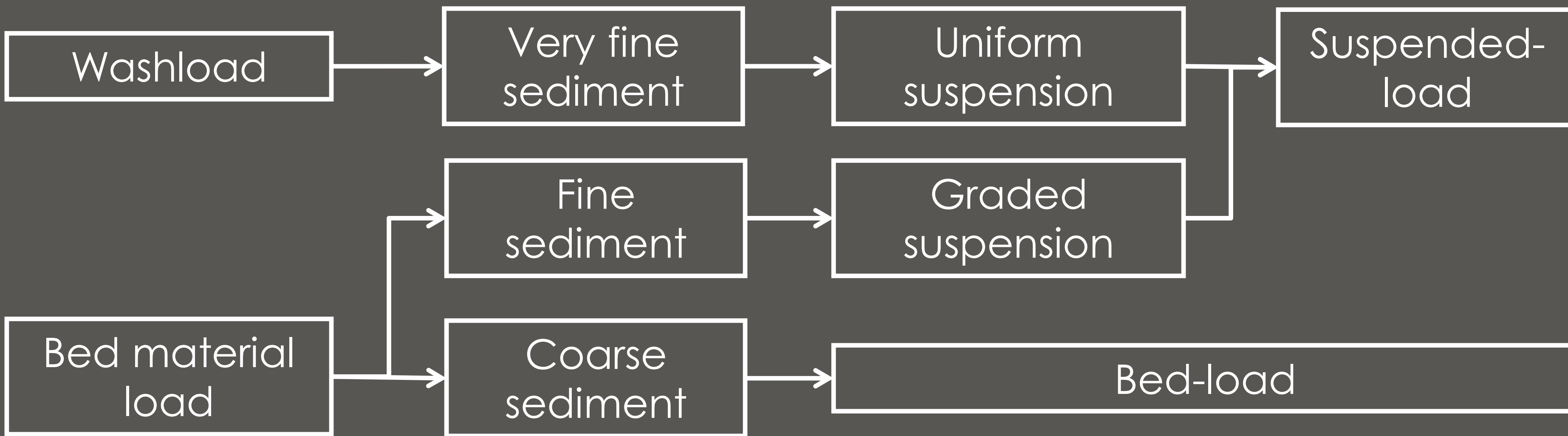
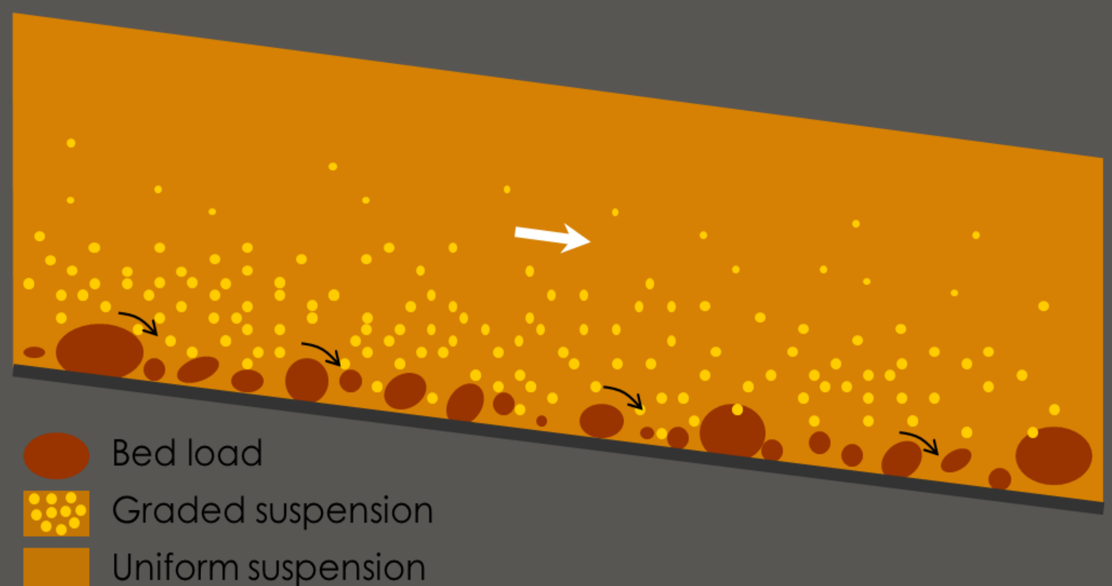
# Sediment transportation processes



# Sediment continuity and diversity

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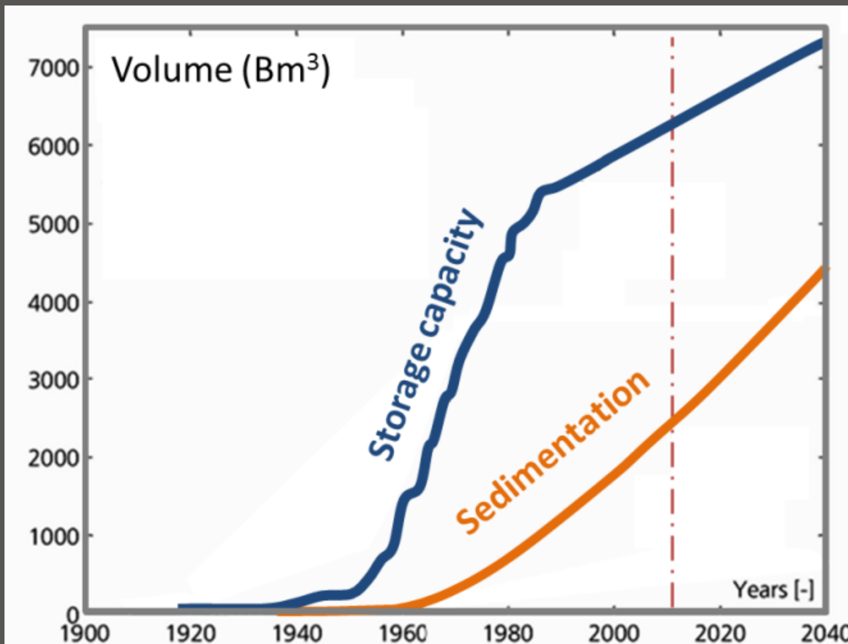



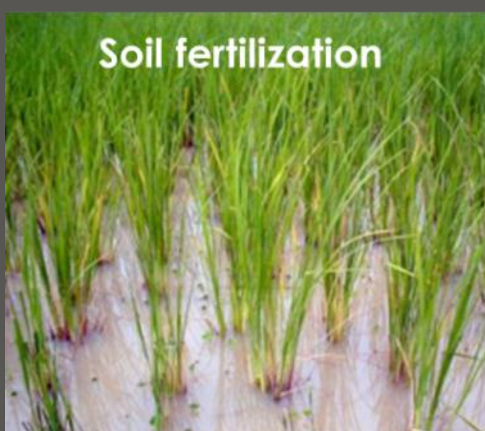



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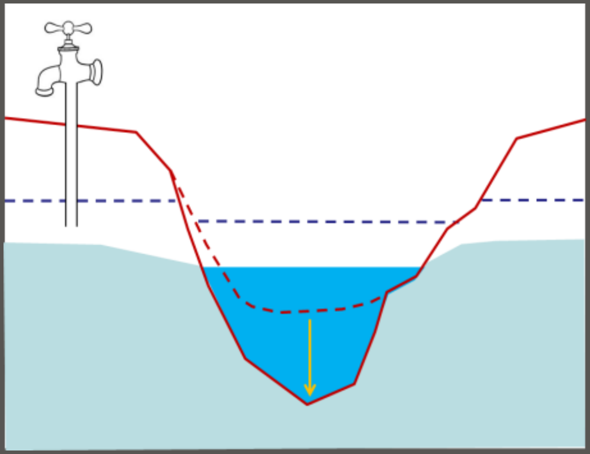
# Factors leading to sediment continuity disruption

- Two main infrastructures or engineering activities are likely to disrupt sediment continuity in a river:
  - Construction of a reservoir dam
    - Run of river dam: only coarsest fractions are generally trapped
    - Large dam: all fractions can be trapped
  - Overharvesting of in-channel sediments (sand and gravel), i.e. as soon as a few % of the mean annual load is affected

# Consequences of sediment continuity disruption

Over flooding and storage capacity reduction

Fertilization reduction



Threat on water supply

Nutrient decreasing

Banks failure

Infrastructures collapse

Shoreline erosion

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# Highlights from the Peer Review for sediment issues

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- The Peer Review conducted by CNR for the GoL-MEM from 12/2011 to 04/2012 has pointed out that solid material must pass the Xayaburi dam ; for that some improvement of the project and appropriate operation rules are needed.
- Main points to improve concerned:
  - The baseline knowledge about sediment features and solid fluxes likely to arrived at reservoir inlet to date and in a +/_ close future
  - The dam gates design and in particular the efficiency of the hydraulic facilities designed to pass sediments fluxes through the dam (bottom and low level outlets)
  - The dam impact assessment regarding all possible solid fluxes flowing usually in the river channel
  - The sediment management scheme likely to be implemented to facilitate sediment routing through the reservoir and reduce residual dam impacts on solid fluxes

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# Complementary works executed regarding sediment issues

- Following the recommendations of the Peer Review the GoL-MEM hired CNR for complementary investigations. The requirements satisfied were as follows:

**Field survey**

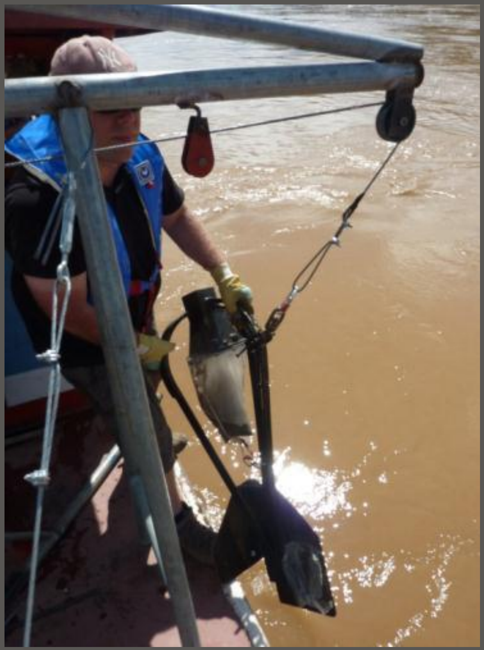
1. Characterization of sediment deposits and solid fluxes through an extensive and unparalleled sampling survey conducted in the field at 3 distinct times

**Modelling study**

2. Preliminary analysis of flow conditions in the proposed reservoir using a 1D hydraulic model
3. Comprehensive study of sediment dynamics at natural state and after dam completion using 2 specific 1D models to address separately the case of:
   - Suspended load
     - ❖ Clay and silt (washload)
     - ❖ Medium and fine sand in suspension (fine bed-materials)
   - Bed-load:  coarse sand and gravel (coarse bed materials)

# Field surveys

- Purposes of the 3 campaigns performed in the field:
  - Improve significantly the knowledge about river deposit features observed before and after the monsoon season (grain size, armoring degree, clay content, shear strength…)
  - Evaluate the relative importance of each solid flux thanks to a series of field measurements performed for the first time simultaneously during the monsoon season (washload, sand in suspension and bed-load)



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# Field surveys


- Key figures:
  - 1000 km of river explored by boat
  - 35 sampling sites surveyed
  - 230 samples collected
  - 2 tons of sediment sampled
  - 100 stream gauging operations performed
- Team composition and responsibilities:
  - **CNR**: technical supervisor and operator
  - **IRSTEA**: scientific partner and advisor
  - **MRCS**: independent observer mandated by the Lao National Mekong Committee (LNMC)
  - **XPCL** for logistical issues

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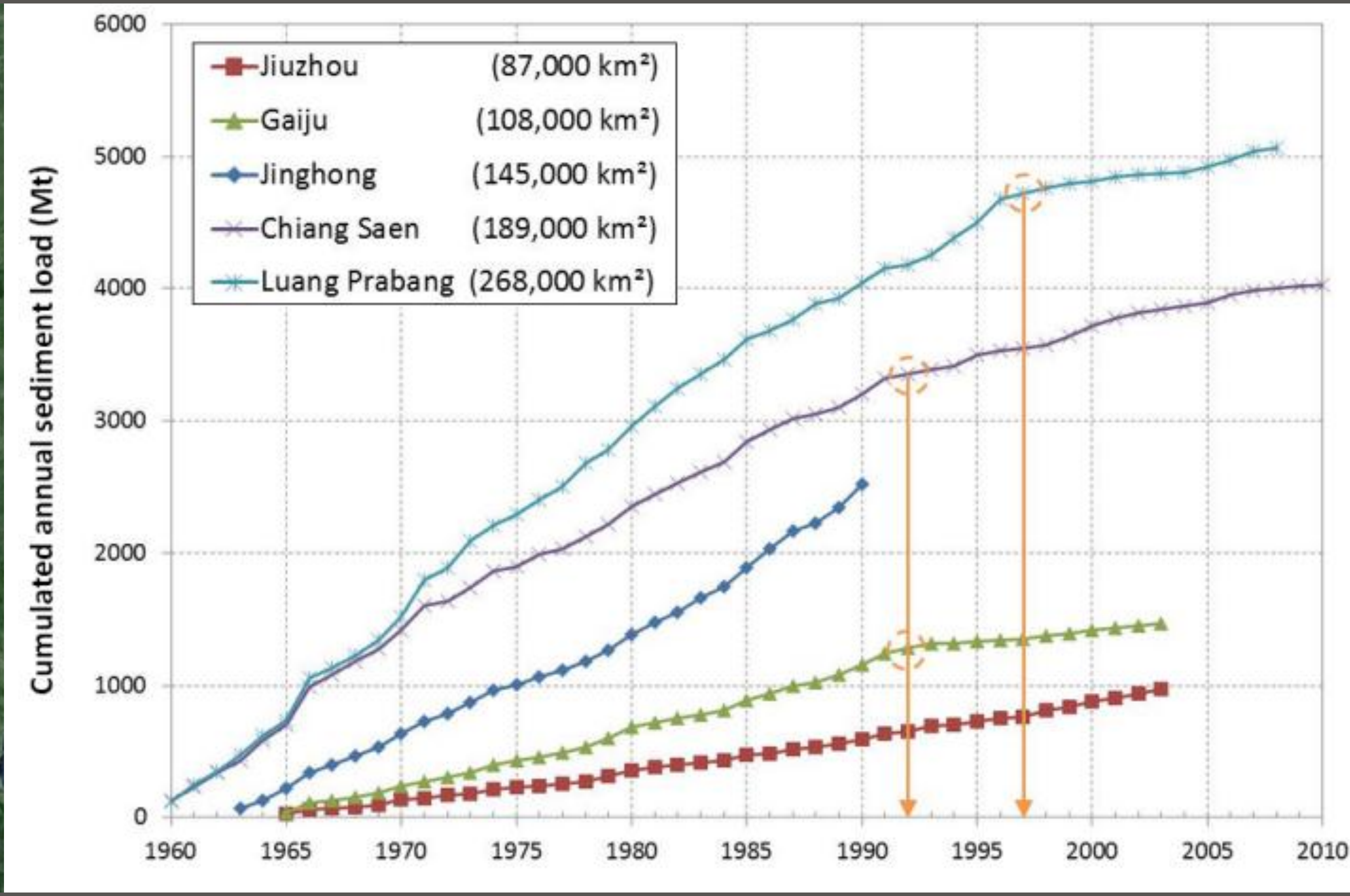
# Sediment inflow at Xayaburi reservoir inlet

- A significant reduction of the annual sediment load has been highlighted since 1993, which corresponds to Manwan dam completion

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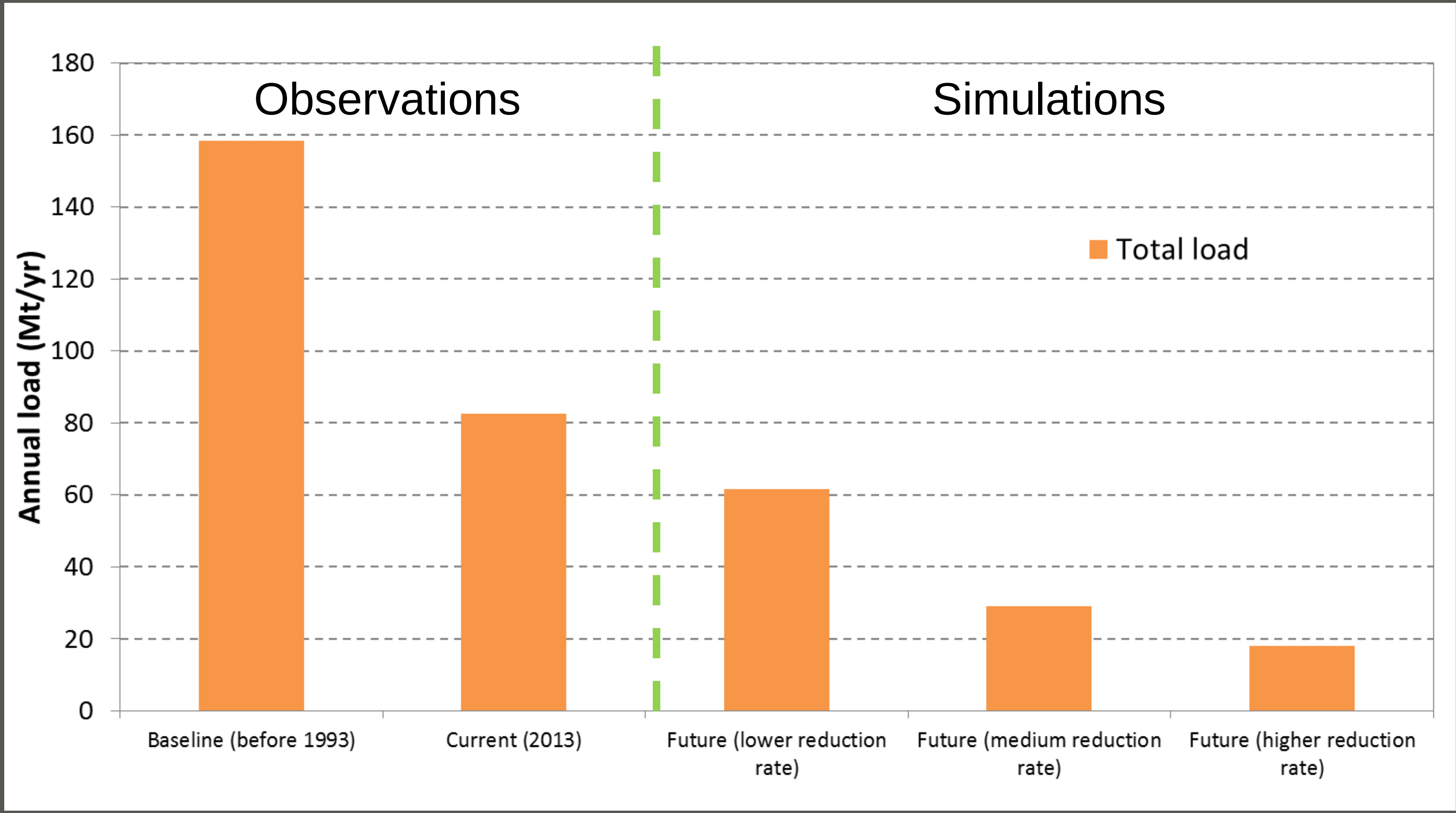
# Current sediment inflow at Xayaburi reservoir inlet

- Different periods need to be distinguished to account for past and current situations
- Data analysis performed show that:
  - **Washload** corresponds to the dominant sediment load (80% to 65%) and it has already experienced a -58% reduction due to Yunnan dam cascade impact
  - **Sand in suspension** is also a significant part of the total load (18% to 34%)
  - **Bed-load** represents a very tiny part of the total load (less than 1%)

| Sediment supply | Annual load (Mt/year) | | | |
|---|---|---|---|---|
| | Washload | Sand in suspension | Bed-load | Total |
| Baseline (before 1993) | 130 | 28 | 0.5 | 158.5 |
| Current (2013) | 54 | 28 | 0.5 | 82.5 |

# Sediment fluxes reduction due to Yunnan dam cascade

- Future expected changes have been evaluated theoretically but results obtained are very consistent with the very first trends observed to date



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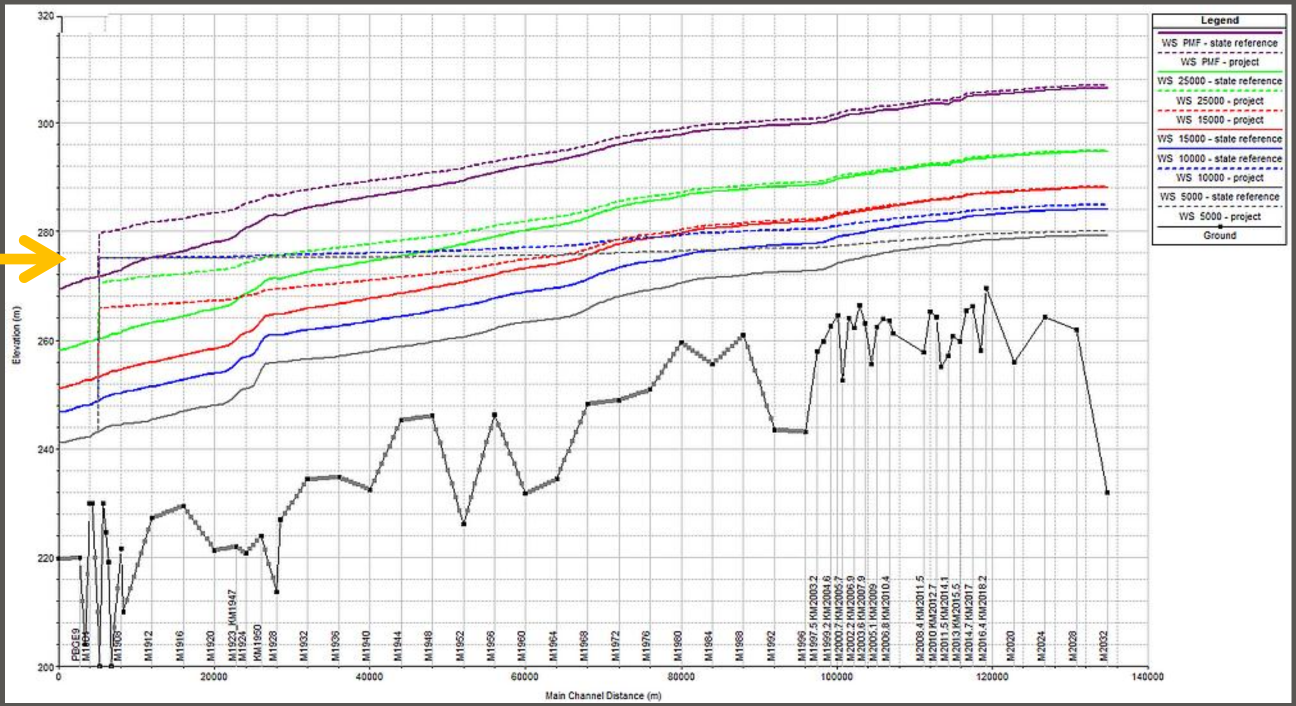
# Expertise of Xayaburi dam design regarding sediment routing

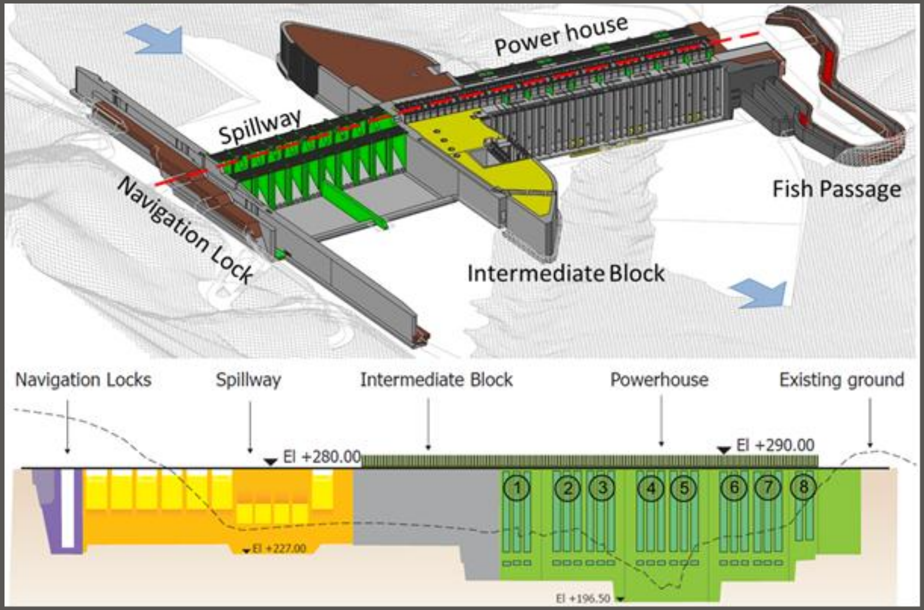
- Xayaburi dam is a run-of-river development, meaning a reservoir management concept as follows:
  - Storage capacity of the impoundment negligible compared to river flow volumes, especially for flood conditions ⇨ no flood mitigation
  - As the river flow increases, gates are opened so as to obtain a drawdown of the reservoir water level and a tilt of the flow slope ⇨ natural conditions almost recovered for the design discharge

**Normal operating level**



# Expertise of Xayaburi dam design regarding sediment routing

- Sediment-laden flows are likely to pass the dam through regularly distributed openings, ranging from elevation 220 m up to elevation 275 m.
- This situation is very favorable for sediment routing, and in particular for the transportation of bed-materials still mobilized by suspension after dam completion.

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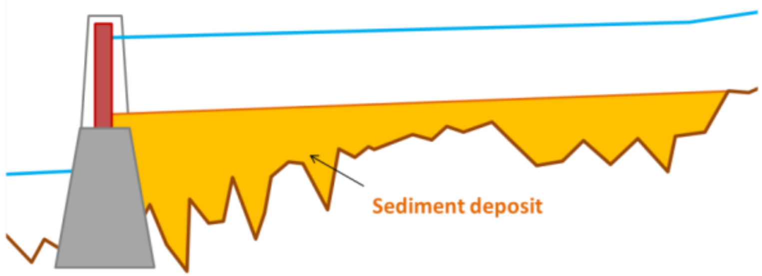
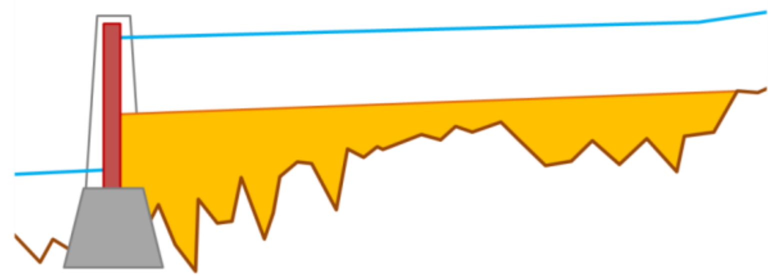
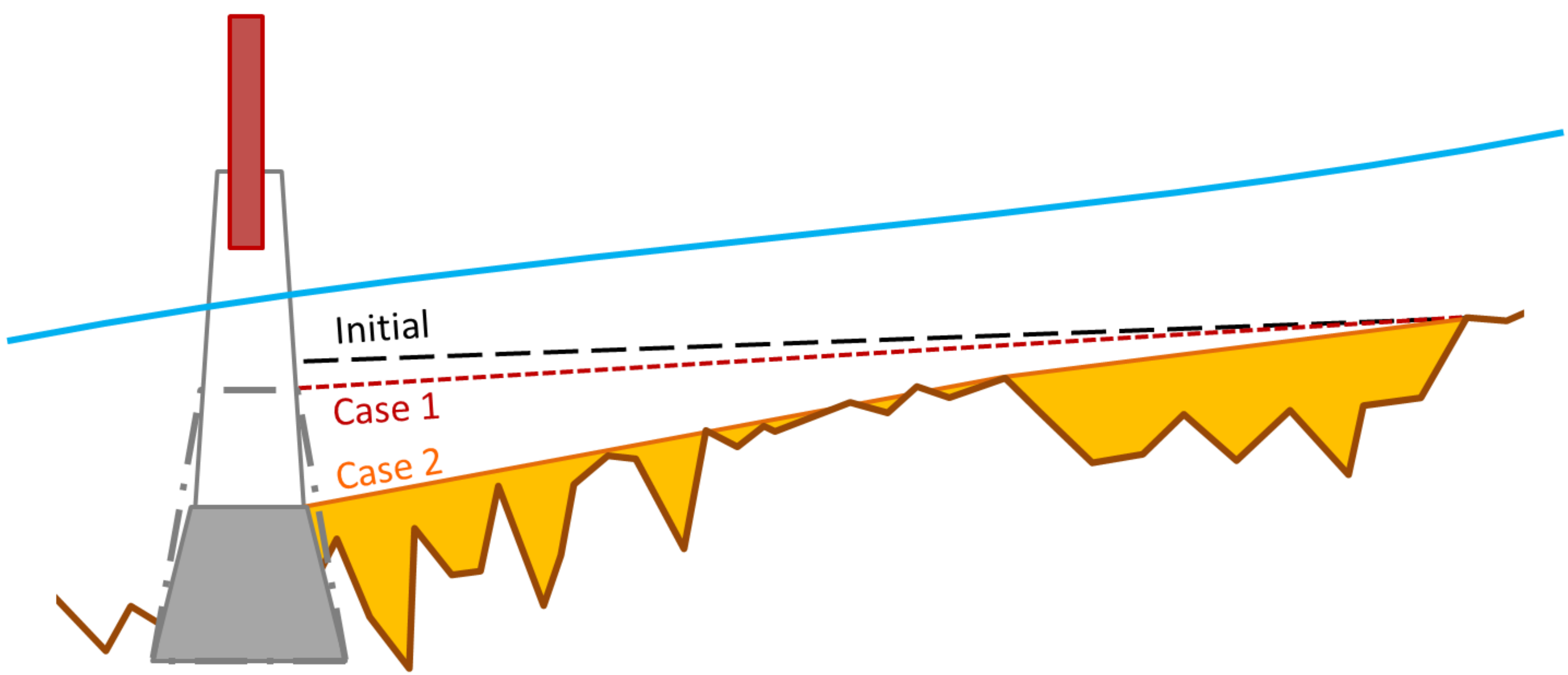
# Importance of lowering the sill elevation of gates for upward erosion

Case 1: high sill elevation




Case 2: low sill elevation





# Importance of Sediment Passing Facilities position

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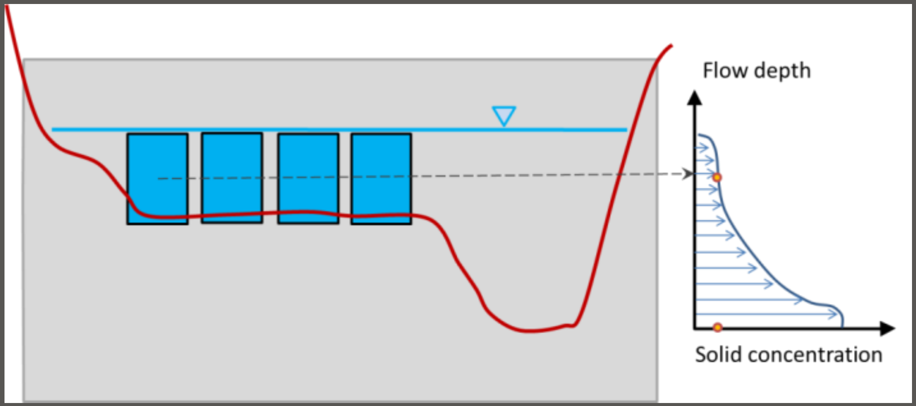
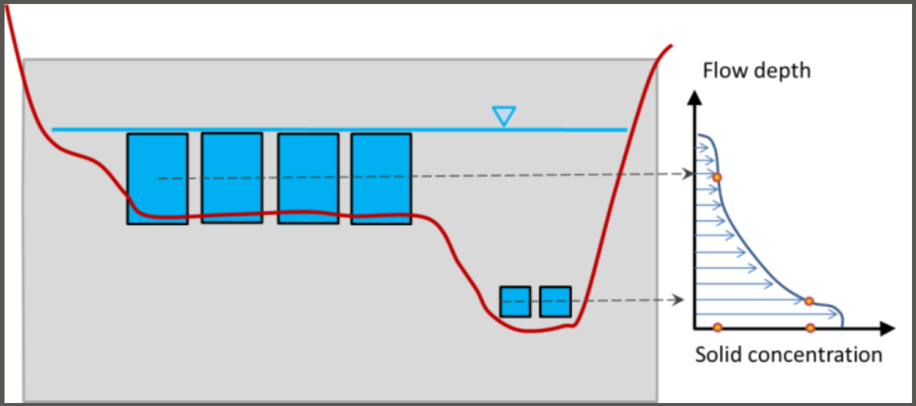
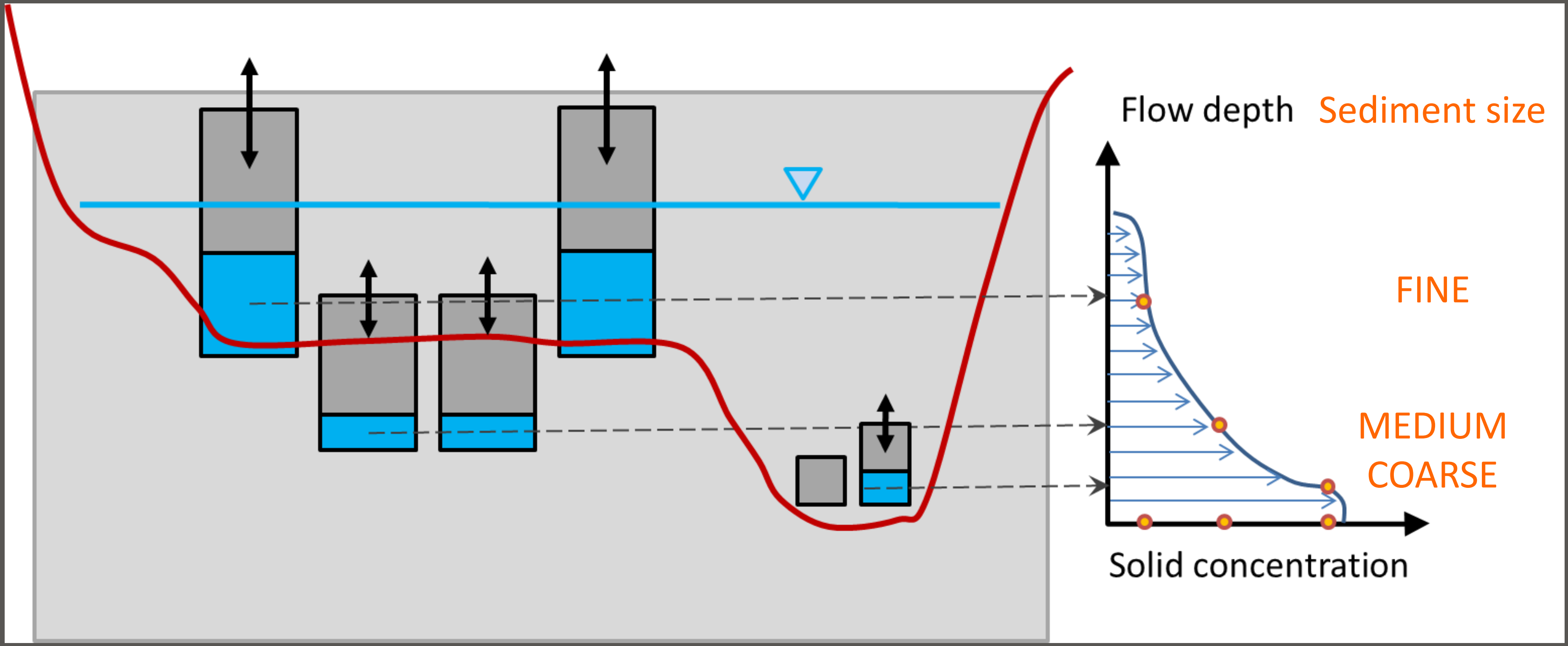
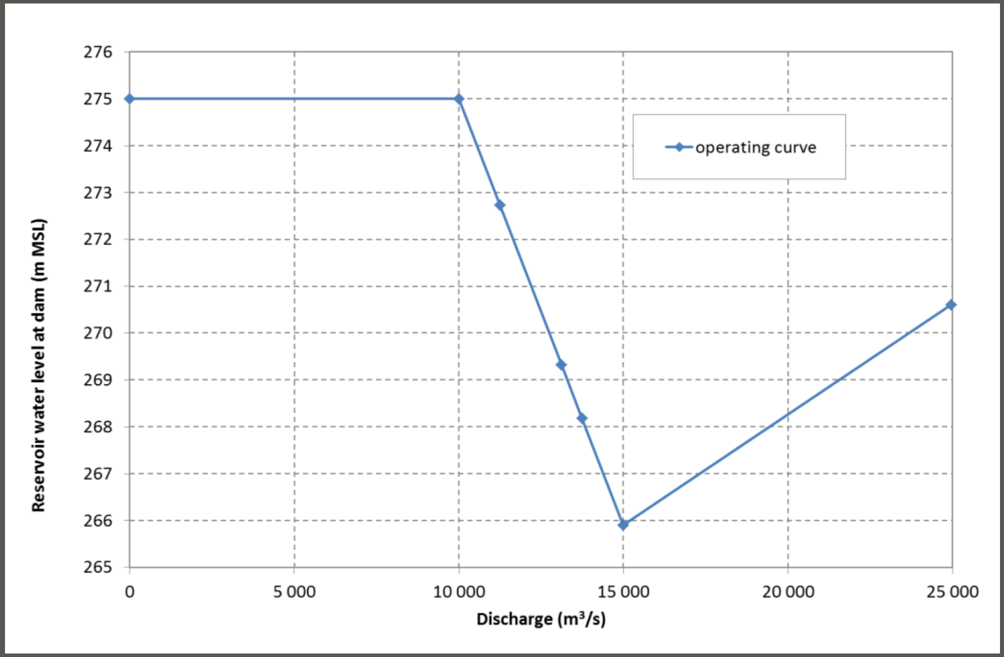


# Management concept improvement provided by CNR

- A provisional operating curve has been also designed by CNR in the framework of this study so as to:
  - Prevent extra inundation hazard at Luang Prabang for flood conditions by lowering the reservoir water level
  - Facilitate as much as possible sediment routing during high flows by recovering velocities such as solid particles settling is almost avoided
  - Respect the EPC contract with CHK



# Expected Xayaburi dam impact on sediment fluxes

- Modelling results regarding Xayaburi dam impact for current sediment supply provide the following estimations:

| Sediment flux | Sediment source | Mode of transport | Sediment mass for current supply (Mt/year) | | | |
|---|---|---|---|---|---|---|
| | | | Inflow | Outflow | Deposit | |
| Bed-load | River channel | Bed-load | 0.5 | 0.1 | 0.4 | |
| Sand in suspension | | Suspended -load | 28.0 | 25.8 | 2.2 | |
| Washload | Hillslope | | 54.0 | 53.9 | 0.1 | |
| | | Total | 82.5 | 79.8 | 2.7 | **3.3%** |

- The sedimentation rate is around 3% (transparency rate of 97%) mainly made-up of sand and bed-load materials
- Impact of Xayaburi dam on very fine suspended sediments (washload) is extremely limited, meaning that nutrients reduction further downstream is unlikely

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# Comparison with other impactful factors

- Sedimentation in Xayaburi res. is negligible compared to :
  - Sediment reduction due to the Yunnan dam cascade (-76 Mt/yr)
  - Total sediment extractions performed in the LMR channel (-55 MT/yr)

- But sedimentation in Xayaburi reservoir:
  - Exceeds total sediment extractions performed in Lao PDR (-2.2 Mt/yr)
  - Could affect sediment fractions likely to be useful for the channel stability in Vientiane and further downstream in the long term

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# Sediment management strategy recommended for Xayaburi project

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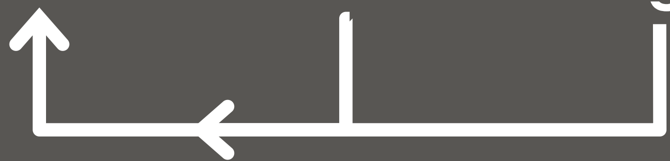
- Physical processes regarding solid transportation are complex and modelling uncertainties still important to date
- To deal with those concerns, a **“3M” iterative** strategy fully based on field data collection has been developed and applied successfully on the Rhône by CNR for decades.

**Monitor → Model → Mitigate**



- Steps to implement in the Xayaburi dam case consists in:
  - Monitoring sedimentation rate and deposit location in reservoir
  - Modelling flow conditions with updated bathymetric state for identifying possible adverse impacts due to reservoir sedimentation
  - Defining and implementing alternative operation rules and mitigation measures, if required

# Sediment management strategy recommended for Xayaburi project

- As a result, a comprehensive sediment monitoring should be engaged as soon as possible to:
  - Define a more relevant baseline situation regarding solid transportation and river morphology
  - Improve current knowledge and highlight future changes due to upstream dams
- After Xayaburi dam completion, sediment monitoring should be continued to check the real efficiency of implemented measures. Data collection may concern in particular:
  - Sediment inflow and outflow
  - Bathymetric evolutions
  - Deposits characteristics: grain size, mud contents, cohesion, plasticity, critical shear stress for erosion…
- Xayaburi dam management should be also consistent with other existing or expected developments, which requires a close cooperation between the different operators involved

# Key points

- Sediments play a crucial role for the river eco-system ;
- Yunnan dam cascade has already a huge impact on sediment supply to the Lower Mekong River (-58% compared to natural state) ;
- Xayaburi dam has been designed to ensure as much as possible sediment continuity in the long run ;
- Such goal has been achieved thanks to the improvement of the spillway arrangement and to the operation curve proposed:
  - Quasi-free flow state recovered frequently and for a large range of discharges ;
  - Vertical distribution of gates positioned so as to pass a large range of sediment through the dam (coarse + fine) ;
  - Wide variety of techniques possibly applicable for sediment transfer (drawdown routing, eco-friendly flushing…).

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# Key points

- The overall sedimentation rate expected by considering  current sediment supply is around 3% ;
- The coarsest particles transported as bed-load (1% of total sediment load)are impacted by the reservoir operation ;
- Sand in suspension transfer reaches around 92% ;
- Nutrients attached to very fine suspended sediments are barely affected by the project ;
- Sediment monitoring should start ASAP and continue after dam completion so as to:
  - Define a relevant baseline situation ;
  - Check the effective impact of the project after its completion ;
  - Adapt operation rules and implement mitigation measures if necessary ;

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# ຂອບໃຈສຳລັບຄວາມສົນໃຈຂອງທ່ານ

# Merci pour votre attention

# Thank you for your kind attention