JOINT ENVIRONMENTAL MONITORING PROGRAMME

AT TWO MEKONG MAINSTREAM DAMS: THE DON SAHONG AND XAYABURI HYDROPOWER PROJECTS

Environment Fisheries Hydropower Irrigation Navigation People

AUGUST 2022

Mekong River Commission

Joint Environmental Monitoring Programme at Two Mekong Mainstream Dams: The Don Sahong and Xayaburi Hydropower Projects

August 2022

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ABBREVIATIONS AND ACRONYMS

ADCP	Acoustic Doppler Current Profiler
ATSPT	Average Tolerance Score Per Taxon
CK	Chiang Khan
COD	Chemical oxygen demand
CPUE	Catch per unit effort
CRMN	Core River Monitoring Network
CSU	Charles Sturt University
DHRW	Department of Hydrology and River Works, Cambodia
DO	Dissolved oxygen
DMH	Department of Meteorology and Hydrology (Lao PDR)
DSH	Don Sahong
DSHPP	Don Sahong Hydropower Project
DSM	Discharge and sediment monitoring
DWR	Department of Water Resources
EH	Ecological health
EHI	Ecological Health Index
EGEM	Expert Group on Environmental Management
EHM	Ecological health monitoring
EIA	Environmental Impact Assessment
ESIA	Environmental and Social Impact Assessment
FADM	Fish abundance and diversity monitoring
FC	Faecal coliforms
FLDM	Fish larvae drift monitoring
IFReDI	Inland Fisheries Research and Development Institute
GIS	Geographical Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GPS	Global positioning system
HPP	Hydropower project
HYCOS station	Hydrological Cycle Observing System – Automatic hydrological monitoring station
ICEM	International Centre for Environmental Management
JEM	Joint Environmental Monitoring
Lao PDR	Lao People's Democratic Republic
LMB	Lower Mekong River Basin
MC	Member Country
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
Mt	Million tonnes
Pak	Pakse
PNPCA	Procedures for Notification, Prior Consultation and Agreement
QA/QC	Quality Assurance and Quality Control
SSC	Suspended sediment concentration
ST	Stung Treng

TOTs	Training of Trainers
TSS	Total suspended solids
USD	US dollar
WQ	Water quality
WQMN	Water Quality Monitoring Network

EXECUTIVE SUMMARY

This Final Report provides an overview of activities conducted and resulting recommendations from *Piloting the Joint Environmental Monitoring (JEM) Programme on two Mekong mainstream dams: the Don Sahong Hydropower Project and the Xayaburi Hydropower Project*. It summarizes the pilot monitoring results from the first pilot site report for each hydropower Project (HPP) and the Combined Annual Report in a way that illustrates how findings in all four disciplines can be interpreted together. The report then provides some initial suggestions for mitigation and adaptive management of construction and operation of HPPs based upon this first year of monitoring. The report concludes with recommendations for revisions to the guidelines and monitoring protocols that can then be incorporated into the JEM Programme document, to be finalized by the Mekong River Commission Secretariat (MRCS) in 2022.

The JEM Pilots comprised three packages of work covering the two pilot sites:

- **Work package 1: Equipment procurement.** The procurement and installation of monitoring equipment;
- **Work package 2: Technical support and expertise.** Data collection, analysis and communication;
- **Work package 3: Capacity building.** Training and awareness-raising with communications materials.

Supporting activities

Under work package 1, equipment was procured both through a contract with OTT Hydromet and through competitive open Request for Quotation processes to supply to monitoring teams in Cambodia, Lao PDR and Thailand. This included supply and installation of new monitoring stations – a HYCOS (water level and rainfall) station at Ban Pakhoung (Lao PDR) downstream of Xayaburi, a manual water level gauging site upstream of Luang Prabang at Ban Xanghai, a HYCOS station at Koh Key upstream of Stung Treng and a HYCOS station and water quality (WQ) monitoring station downstream of the Don Sahong Power Station. In addition, a major package of equipment was procured to enable training and implementation of fish tagging activities at Khone Falls. The provision of Acoustic Doppler Current Profilers (ADCPs) to Lao PDR and Thailand allowed to upgrade the discharge monitoring equipment at several long-term discharge and sediment monitoring (DSM) sites and the JEM sites.

Capacity building has been a major component of the JEM Pilots to support the teams in implementing the JEM monitoring protocols and conducting associated analysis, which has undergone a number of adaptations due to the COVID-19 travel restrictions and lockdowns. Across the two-year implementation period, the JEM Pilots delivered or supported 72 days of training events and capacity building workshops both online and in person, as well as a further 26 days of in-field survey and documentation at the Khone Falls area specifically. A description of key training events under each discipline is provided, together with a description of the regional workshops conducted to guide share knowledge and guide the JEM data analysis.

The initiation of monitoring activities for the JEM Pilots experienced some delays due both to the COVID-19 global pandemic and some internal coordination issues in Lao PDR and Thailand to prepare the Working Agreements between MRCS and implementation/line agencies. Monitoring therefore commenced in Cambodia in June 2020, while Lao PDR and Thailand started in September 2020. The monitoring data collected during the JEM Pilots has been integrated within a custom-built database system covering all six disciplines. All monitoring data provided by the national monitoring teams has been integrated to this database, even if it has not all been analysed to the same extent due to the reporting timeframes of this project.

Development and data entry within this JEM database is now complete and is accompanied by the JEM Database User Manual. These databases have been designed to enable good practice data storage, management and ease of visualization for the monitoring data of the JEM and MRC as collected historically and within the JEM Pilots specifically. The structure, list of integrated records, and query functionality are provided for each discipline. These databases will be handed over to the MRC for integration within the MRC Master Database in December 2021. Access will then be arranged for MCs by the MRCS.

The JEM pilot programme is a regional cooperation programme between the four MCs as facilitated by the MRC, and has involved four regional meetings or workshops across the two-year period. Implementation and adjustment to the JEM Pilots are overseen by the Expert Group on Environmental Management (EGEM). The EGEM met three times to date; the most recent consultation on the JEM Pilots took place in November 2021. A brief description of each EGEM and key outcomes is provided.

Key findings

Hydrology and hydraulics: Flows in river are impacted by hydropower developments in China and tributaries. Water level at Luang Prabang reflects backwater of Xayaburi impoundment, and shows small daily fluctuations associated with HPP operations. Large, rapid and frequent water level commonly occur during low and moderate flows downstream of Xayaburi dam at Ban Pakhoung station. Flow levels at Pakse show small scale water level fluctuations most likely related to the operation of HPPs in the tributaries. Water level fluctuations observed at Pakse are not present at Don Sahong. The water level monitoring results from the Koh Key HYCOS site (below Don Sahong) do not show any water level fluctuations related to hydropower operations at Don Sahong, and show strong similarities to the general pattern at Pakse (without the small fluctuations).

Sediment: Upstream sediment loads are reduced compared to historic (pre-2008) results due to trapping in Upper Mekong impoundments and Lower Mekong tributaries. Sediment concentrations and loads downstream Xayaburi dam at Chiang Khan and Nong Khai have decreased substantially since 2018, which may reflect increased trapping in tributary HPPs and in Xayaburi.

Water quality: Generally good quality water lying within the water quality (WQ)water quality with concentrations of the measured parameters lying within the thresholds of the MRC's Water Quality Guidelines for Protection of Aquatic Life and for the Protection of Human

Health. Normal levels of total suspended solids (TSS) for the river tend to decrease in recent years. No evidence of stratification was found in the impoundment.

Ecological Health Indices (EHIs): EHIs at the upstream of both Xayaburi and Don Sahong HPPs show good condition, similar to long established routine ecological health monitoring (EHM) stations results where have been located nearest to the JEM EHM sampling stations. At the impoundment area and the downstream of both HPPs, the EHIs show a 'moderate' condition, resulting from changes from riverine to lacustrine habitat and sedimentation in the impoundment, as well as changing substrate conditions and fluctuating water levels and flows downstream. Then, EHIs show recovery evidence with passage downstream by 10 km from the dam sites.

Fisheries: For Xayaburi, data consistently show a sharp reduction of biodiversity, by 40 to 60%, in almost all sites. This does not indicate that species have disappeared yet, but they are too rare to appear and be recorded in catches. This pattern was somewhat expected as a result of the HPP development and overall human pressures on the river; however, the extent and speed of change seem extremely high. In relation to Don Sahong, data of average monthly catch per fisher over the years provide contradictory patterns, with a sharp catch decline in northern Cambodia over the years but a progression (increase) in the nearby downstream Lao site, and a significant increase in catches upstream of the dam. These increasing catches recorded in Lao PDR are contradicted by interviews of fishers detailed as in the report, "Recent fish migrations in Khone Falls (Lao PDR) according to local ecological knowledge", prepared within this JEM Pilot.

Preliminary conclusions

While the monitoring data collected for five disciplines may have been relatively limited to the dry season with incomplete wet season results, it has been possible to highlight: (i) changes in the flow and sediment conditions at the different sites; (ii) water quality and ecological health changes both downstream of dams and within the impoundments; and (iii) changes in the fish monitoring results. **It is not always possible with this limited data to attribute impacts related to the dams and differentiate from other changes in conditions in the river.** However, the experience of the JEM Pilots has provided a valuable testing of the JEM Programme principles, methods and protocols so that recommendations can be incorporated into future monitoring of mainstream hydropower and other development projects in the new Core River Monitoring Network (CRMN). The JEM pilots have shown the need and usefulness of continued multi-disciplinary monitoring of the river – not only around HPPs, but also generally throughout the basin, in order to understand the large-scale changes that are occurring and to provide a context for JEM monitoring results.

Recommendations for the JEM programme

With respect to recommendations, there is consensus across the disciplines that JEM monitoring should be continued for at least another 12 months, using the same monitoring schedule (sites, parameters, monitoring frequency) so that a complete wet and dry season can be captured by the monitoring. A longer time-series would improve the understanding of potential hydropower impacts and result in an increase on the return on the investment in the JEM monitoring.

Water level monitoring at HYCOS sites was sufficient to capture short-term changes to water level associated with both mainstream and tributary hydropower operations, and clearly demonstrated that the operation of run-of-river mainstream HPPs can impact frequent, large scale (up to 1 m/day) water level fluctuations downstream, which persist for several kilometres, but not hundreds of kilometres. The JEM discharge and sediment monitoring protocols are appropriate to capture changes associated with hydropower; however, the short duration of data collection, and lack of wet season results limited the ability to establish sediment trapping rates in impoundments.

For discharge and sediment monitoring there are JEM specific recommendations that relate to the sites and parameters included in the JEM monitoring but not included in the ongoing DSM monitoring, and there are additional general recommendations that are applicable to JEM monitoring, to the ongoing DSM monitoring and to the development of the Core River Monitoring Network. Examples of JEM specific recommendations include the establishment of the Ban Xang Hai site as a HYCOS site and active collaboration with hydropower operators, and general recommendations include a review of all mainstream rating curves and updating of the reporting systems for monitoring results.

Generally, the water quality protocol was found to be appropriate. Because the monthly samples are spot samples, which do not adequately capture the daily variation in different parameters, it is recommended that continuous monitoring equipment be established at both sites as close downstream to the dam as possible to obtain a representative sample of the water. Wherever available, the results of water quality monitoring taken by the hydropower companies should be compared with the JEM results and both should be related to operation details provided by the companies.

The JEM results show up some differences between the routine measurements and those undertaken by the WQMN teams. This underlines the need for calibration and intercomparison of equipment and sampling methods undertaken by all national WQ teams, to reduce the risks of sampling error, coupled with regular training in standard sampling methods.

For EHM, the experience of the JEM has shown that method it is sensitive to the changes likely to occur in the localised habitats around hydropower. However, pre-selection of the exact sampling locations is not always appropriate and should wait for the EHM teams to find the best range of sites to sample depending upon ease of access, safety and the suitability of the substrate conditions. These may change from year to year and so only the approximate location should be specified, with room to sample within a radius of say 1 km. It is recommended that a quicker method of assessing the aquatic health be developed to be used more frequently and in additional locations, in order to complement the annual or biennial monitoring campaigns. Since the EHM biota for inundation and reservoir areas are likely to be very different from riverine areas with different tolerances, it will be important in the long-term to build up a series of reference sites within reservoirs of both mainstream and tributaries, so that quality changes in the reservoirs can be compared.

For Fish Abundance and Diversity Monitoring (FADM), the procedure follows instructions in the standard sampling guidelines for FADM section 6.2 and JEM documents v.3 Annex 19. which does not pose any major problems. Improvements are suggested to strengthen the consistency and quality of monitoring data including update of supporting resources such as photo flipcharts, and review of equivalence between local names and the latest scientific names. Given the significant difference between results according to country, despite the similar conditions on either side of the border, a further recommendation is to strengthen and harmonize the national teams by organizing a field-based session during which the most experienced riparian scientists will mentor and assist colleagues from other countries. For fisheries gillnet monitoring, a number of recommendations are made based on the testing of different configurations during the JEM Pilots. For fisheries FLDM, the pilot monitoring confirms the most useful months for sampling and confirm the latest JEM sampling protocol including two sampling locations on two banks and one in the mainstream. Instead of midnight sampling, the timing should evolve to occur at 21:00. The Lao team being new to larvae identification, continued training is required to strengthen capacity.

Integration of results between disciplines

Moving from physical parameters (hydrology, sediment) to chemical parameters (water quality), and then to 'lower', short-lived biological components (plankton, benthos) and finally to 'upper' biological components (fish resources, fisheries), the interaction between environmental system components becomes increasingly complex. Within this report, and in recognition of the short record of data collected during the JEM Pilots period, an attempt has been made to qualitatively link the results of the different disciplines according to clusters of monitoring sites above, within and below each of the HPP impoundments. An overview of quantitative integration approach is also provided as guidance for future once more comprehensive datasets are available.

Opportunities for mitigation and adaptive management of hydropower operation

Some initial suggestions have been made for mitigation and adaptation of the operation of the two HPPs based on trends identified by the pilot monitoring results.

From the perspective of hydrology and sediments, recommended mitigation approaches include:

- the introduction of targets or limits on the rate of water level change in the mainstream;
- the implementation of a central communication/notification system to alert downstream communities and countries of impending flow releases, or other changes to operations that could affect downstream communities (e.g. sudden low flows or high flows);
- the maintenance of environmental flows as per commitments in Procedures for Notification, Prior Consultation and Agreement (PNPCA) documentation and/or power purchase agreements;

- joint work between the MRC and the MCs and hydropower operators to provide a reporting mechanism for the operation of low-level gates at HPPs that will affect sediment transport in the river.

From the WQ and EHM perspective, mitigation approaches should emphasize:

- the importance of systematic water monitoring during all phases of hydropower construction and operation so that appropriate action can be taken if poor water quality conditions emerge;
- the appropriate selection of monitoring locations associated with HPPs with at least one upstream location, one location within the impoundment, and two downstream;
- monitoring of bed and banks erosion downstream, and careful trialling and management of sediment flushing of the dam so that poor water quality is not passed to further downstream;
- the importance for the developer to monitor for pollution and poor water quality within the impoundment and take appropriate measures to treat if detected;
- attention paid to ensuring both that water intakes are above the level of the hypolimnion, and to ensure mixing of water between levels through various measures;
- greater attention paid to setting site-specific ramping rate limits and working within them, so that the biota experience more gradual changes in water level and flow rate.

From the fisheries perspective, for Xayaburi HPP:

- Possible sources of fish replenishment in this part of the river (Nam Soung, Nam Khan) deserve specific attention and protection so that remaining fish exchange between upstream sub-catchments and the upstream part of the Xayaburi reservoir are not interrupted. Management of the Nam Theun 2 upstream tributaries flowing into the impoundment provide an example and framework for such an initiative;
- Some areas of the Xayaburi impoundment should be considered for implementing constructed wetlands, as proposed for Nam Gnouang Reservoir.

For Don Sahong, adaptive management from fisheries perspective would include:

- deepening the entrance of the fish passages formerly operational in the dry season such as Don Sadam and/or improved by Don Sahong Power Company Ltd. to facilitate fish migrations (Hoo Som Yai, Hoo Sadam, Nyoi Koong, Koum Tao Hang) to increase the likelihood of adequate flow for fish passage during the dry season, even if flows in the eastern channel continue to be <800 m^3/s;
- Given the importance of Khone Phapheng waterfall as a fish attractor during migrations (although Hoo Sadam, Hoo Som Yai and Hoo Som Pordan are not operational due to low flow or dryness) the recommendation is to return to sufficient flow for fish attraction in Hoo Sadam and for fish attraction and passage in Hoo Som Yai;

- Two other channels, Hoo Wai, and Hoo Don Lai, can be substantially improved with minimal work to better accommodate fish migrations, in particular in the dry season;
- Consideration of two channels for improved passage in the dry season if levelling and deepening are undertaken: Hoo Khone Souang and Hoo Pataep.

1 INTRODUCTION

1.1 Scope of the report

This final report provides an overview of activities conducted, key findings and resulting recommendations from the “Piloting the Joint Environmental Monitoring (JEM) Programme on two Mekong mainstream dams: the Don Sahong Hydropower Project (DSHPP) and the Xayaburi Hydropower Project”. The MRC finalized the design of the JEM Programme for Mekong Mainstream Hydropower Projects in May 2019 with the aim to provide a common basis for constructive discussions by communities and MCs on the implications of hydropower development. With the support of Germany, the MRC then developed two-year pilot projects around the Xayaburi HPP and the DSHPP in order to trial and refine the JEM approach, monitoring, and reporting protocols. The pilots cover five disciplines:

- Hydrological monitoring
- Sediment monitoring
- Water quality monitoring
- EHM
- Fisheries (fish abundance, fish larvae and fish passage monitoring).

The main purpose for the JEM Pilots Project has been to trial and suggest improvements to the JEM Programme and Protocols. During these pilots, monitoring activities in the five disciplines were conducted at stations around Xayaburi and Don Sahong dams and impoundments for a limited period, and this field experience was used to inform the findings and recommendations for improving the JEM Programme. These may be extended to the MRC’s routine monitoring programme on which the JEM programme was based, and suggesting the Core River Monitoring Network (CRMN) for the Mekong currently under development.

At the time of initiating the two-year pilot projects it had been anticipated that at least a full year of sampling and data collection would have been possible. Limitations on movement due to COVID-19 travel restrictions and associated delays in equipment procurement instead meant that the field monitoring was limited to at best 8 months and mainly during the dry season of 2020-2021. Interpretation of these results to assess impacts related to the hydropower dams and impoundments is therefore necessarily limited and should be primarily seen as indicative of how the monitoring data can be used. Nevertheless, where the monitoring results around these dams have indicated changes been indicated, impacts have been interpreted to provide generalized suggestions for potential mitigation and adaptation of mainstream HPPs.

In Section 2, this report first describes the key supporting activities that were conducted to establish the JEM Pilots with procurement of equipment, development of a d6atabase, extensive training and consultation with the MCs. Section 3 gives a summary of the actual pilot monitoring activities conducted by the national teams in order to test the JEM Programme protocols. The data resulting from the pilot activities was then analyzed, where possible, in light of the longer-term MRC routine monitoring results to test its suitability to identify impacts of interest. Assessment of the data quality, monitoring practice, and analysis of indicative trends resulted in the overall conclusions and findings for each discipline as described in Section 4. Following from these in Section 5 are resulting recommendations for strengthening the monitoring protocols both of the JEM Programme, to be finalized by the MRCS in 2022, and other MRCS-supported monitoring initiatives. Section 6 then considers how the five disciplines monitored by the JEM Pilots may be linked. This describes how hydropower-linked changes in flow, water level and sediment might affect processes at different trophic levels, given the high complexity of the riverine environment. Based on the preliminary trends indicated by the JEM Pilots, adaptive management and mitigation measures for hydropower are then suggested in Section 7.

This is the final report for the JEM Pilot projects, completing and summarizing the full set of reports:

1. Inception report (March 2020)
2. Report on three fisheries training events (February – March 2020)
3. Report on online Discharge and Sediment Monitoring Training (22–26 June 2020)
4. Report on online Water Quality Monitoring Training (16–19 June 2020)
5. Report on online EHM Training (9–13 July 2020)
6. First Pilot Site Report on Xayaburi (March 2021)
7. First Pilot Site Report on Don Sahong (March 2021)
8. Fish tagging options for the study of river fish migrations – a review with particular focus on the Mekong (March 2021)
9. Recent fish migrations in Khone Falls (Lao PDR) according to local ecological knowledge (May 2021)
10. Roadmap to a fish tagging methodology for the Khone Falls, Lao PDR (December 2021)
11. Annual Combined Report: Second Pilot Site Reports and Basin-wide perspective (September 2021).

1.2 Background of the JEM Programme

The need for joint environmental monitoring of hydropower developments has become apparent to the Lower Mekong countries through their collaboration on the Procedures for Notification, Prior Consultation and Agreement (PNPCA) processes of the HPPs being developed on the Mekong mainstream. This has particularly been highlighted by the processes for Xayaburi, Don Sahong, Pak Beng and Pak Lay HPPs and the ongoing process for Luang Prabang HPP, which identify the potential changes in water resources and quality, river health and fisheries as key impacts of hydropower development. The MRC's Initiative on Sustainable Hydropower undertook a series of studies addressing the question of information needs for sustainable hydropower development and operations through the ISH11 project, *Improved Environmental & Socio-economic Baseline Information for Hydropower Planning*, and the ISH0306 project, *Development of guidelines for hydropower environmental impact mitigation and risk management in the lower Mekong mainstream and tributaries*. These have been incorporated into the MRC's updated *Preliminary Design Guidance for Hydropower Projects.*

The JEM programme was designed meets this need by aiming to generate information about the availability and condition of the water resources, their linkages with environmental conditions in the basin, and how these are changing under present and future hydropower developments. The purpose of the JEM Programme is to ensure capture of the more localized impacts related to specific developments. These cover five key discipline areas – hydrology and hydraulics, sediment and geomorphology, water quality (WQ), aquatic ecology, and fisheries – through a monitoring network of sampling sites/stations monitored regularly by national teams.

The JEM Programme design builds directly on MRC's longstanding routine monitoring of the river's resources and condition with additional sampling sites/stations and new measurement parameters in order to assess particular changes that may result from hydropower development, construction and operation. The linkage between the JEM monitoring and the historic and regular monitoring undertaken by the MCs is important because regular monitoring provides the baseline and control information against which results from the specific hydropower sampling sites/stations can be compared.

Three key documents were developed by the MRC and MCs between 2018 and 2019. The first "Joint Environment Monitoring of Mekong Mainstream Hydropower Projects" (version 4.0) provided the basis for the design of the monitoring system as well as for piloting of the programme. This design document guides the specification of a methodology for where, how, and what environmental parameters should be collected to capture the impacts of these specific projects as a complement to the current regional environmental monitoring system conducted by the MRC on the whole Mekong Basin.

The other two documents developed are the project proposals to pilot the JEM Programme at the DSHPP and Xayaburi HPP sites ("JEM pilot project proposal – Don Sahong" and "JEM pilot project proposal – Xayaburi"). The pilot projects are intended to trial and finalize the JEM Programme for future application on upcoming mainstream dams and to show how the results may be used to develop potential mitigation and management measures for the impacts that are identified and to complement the advice of the updated Preliminary Design Guidance. The results will also be used to illustrate how monitoring can inform adaptive management of hydropower operations. Recommendations for updating the JEM Programme guidelines based upon the experience gained are a key output from these pilots.

These three key documents have been prepared by taking into consideration: the necessary questions on environmental impacts, the environmental monitoring systems already in place at the national and regional levels, the existing capacity, knowledge and facilities available in MCs, and the reasonably available budget resources. The documents have been presented, discussed and accepted by the MRC MCs through an iterative consultation process at regional and national levels conducted in 2018 and 2019.

The JEM Programme recognizes that hydropower developers also carry out regular monitoring, particularly of hydrology, sediments, WQ and fish passage. The JEM monitoring programme uses a system independent of that used by the HPP developers. It is expected that future HPPs will carry out their own monitoring programmes as part of their compliance with ESIA licences. It is also expected that in the future relevant government agencies will share developers' monitoring information with the MRC, and that this will complement the JEM results. This joint nature of the monitoring is enshrined in the two Joint Action Plans for the Implementation of the Statement on the Prior Consultation Process for the Pak Beng and Pak Lay HPPs, which specifies the two-way sharing of monitoring information.

Together, monitoring information from the JEM Programme, from regular MRC monitoring programmes, and from monitoring conducted by developers is expected to be used to increase understandings about the changes and impacts that HPPs have on the river and its natural resources, as well as for developing mitigation and management measures to improve the environmental performance of existing and future HPPs.

1.3 Purpose of the JEM Pilots

As part of its support to the MRC, Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) has formulated several programme outputs of which the objective of Output 2 is: A joint monitoring of the environmental impacts of the Xayaburi and Don Sahong HPPs has been established.

- The Xayaburi Dam is a run-of-river dam built across the mainstream of the Mekong River approximately 100 km downstream of Luang Prabang and 200 Km upstream of where the Mekong becomes the border between Thailand and Lao PDR;
- The Don Sahong Dam is located on a river channel of the Mekong River mainstream in the border area between Lao PDR upstream and Cambodia downstream, adjacent to the Khone-Phapheng Falls.

The International Centre for Environmental Management (ICEM Asia) was then commissioned by GIZ and the MRC in November 2019 to support the implementation of the two-year Environmental Monitoring Pilots project for the Joint Environmental Monitoring (JEM) Programme until December 2021. The Team members from MRCS, GIZ, and ICEM are provided in Annex 1.

The purpose of the JEM Pilots is to establish and test the joint monitoring protocols as set out in the JEM Programme document and according to the project approach set out in the JEM Pilots Inception Report that was agreed to by the MCs in February 2020. The JEM Pilots tested standardized protocols to collect data for impact assessment so that the final design of the JEM Programme could be fine-tuned based on field experience. Given the short duration of the JEM Pilots, the project objective is not to do an impact assessment of the two dams. The monitoring data collected is analysed to identify trends, where possible, primarily as a means to check that the data collected is indeed suitable to detect the impacts of interest.

The high complexity of the expected JEM Pilots tagging activities for fish passage monitoring, as a new endeavour, was identified during the Inception Phase. ICEM therefore supported the MRC in establishing a formal collaboration between the MRC Secretariat and the Charles Sturt University team already conducting tagging at the Xayaburi site. Additional funding from the Australian Water Partnership (AWP)/Department of Foreign Affairs and Trade (DFAT) was provided to enable this expansion of the fish tagging component from December 2020 to December 2022, with the required equipment to be procured by the ICEM team in support.

The JEM Pilots forms part of a broader, longer-term review and rationalization of environmental monitoring within the LMB. During implementation of the JEM Pilots, the MRCS engaged the French group Compagnie Nationale du Rhône in a project for the assessment and re-design of the routine monitoring as the new MRC CRMN from the third quarter of 2021 until the fourth quarter of 2022. The objectives are for rational, optimal and sustainable expansion of the MRC river monitoring network in the same five disciplines – hydrology, sediment/river morphology, WQ, aquatic ecology, and fisheries. The CRMN project has been funded by the Agence Française de Développement (AFD) and consists of five components, of which the following two components are directly related to the JEM programme:

- Component 1: Review, analysis, and re-design of a core river monitoring network;
- Component 3: Improving data use and statistics based on information technology (IT) tools for hydro-meteorological data analyses developed under Mekong-HYCOS Phase II.

The JEM Programme is proposed to be incorporated into the design of the CRMN, and the recommendations from the JEM Pilots (as provided by this report) on improvements to monitoring protocol are to be fed into this process.

2 OVERVIEW OF SUPPORTING ACTIVITIES

The JEM Pilots comprised three packages of work covering the two pilot sites:

1. **Work package 1: Equipment procurement.** The procurement and installation of monitoring equipment;
2. **Work package 2: Technical support and expertise.** Data collection, analysis and communication;
3. **Work package 3: Capacity building.** Training and awareness-raising with communications materials.

This Section 2 provides a summary of activities and outputs under work package 1 and work package 3, as well as the data collection and data storage within the JEM database under work package 2. These supporting activities established the systems and capabilities to conduct the pilot monitoring activities as reported in Section 3.

2.1 Procurement and installation of equipment

The JEM pilots have involved a significant procurement component to delivery equipment needed both for establishment of new monitoring stations and for the upgrade of field monitoring capability generally (but not always) targeting the two pilot sites. Equipment was supplied to monitoring teams in Cambodia, Lao PDR and Thailand. A major package of equipment was also procured to enable training and implementation of fish tagging activities at Khone Falls. Equipment was procured both through a contract with OTT Hydromet and through competitive open Request for Quotation processes.

Supported by the JEM Pilots implementation partner and specialist monitoring equipment supplier OTT Hydromet, new monitoring stations have been supplied and installed at:

- New HYCOS station at Ban Pakhoung (Lao PDR) downstream of Xayaburi, as well as extension of the water level probe in January 2021 to increase the range over which water levels at the site are able to be recorded;
- A manual water level gauging site was installed upstream of Luang Prabang at Ban Xanghai. This site was required since the existing Luang Prabang water level site is now affected by backwater from the Xayaburi dam;
- New HYCOS station water level recorder at Koh Key upstream of Stung Treng was installed in early 2021;
- New HYCOS station was installed downstream of the Don Sahong Power Station in July 2021. A WQ station is in the process of being installed at the same location.

Numerous items have been added and adjusted to the procurement list for the JEM Pilots. Delays, project timeframes and global supply chain issues associated with COVID-19 have meant the procurement of some items has been cancelled, including a D96 depth-integrated suspended sediment sampler for Chiang Khan that was affected by sale and new ownership of the equipment manufacturing company, Ricklys. The following sections provide a summary of equipment procured to support monitoring activities under each discipline.

2.1.1 Hydrology and sediment transport

For hydrology and sediment transport monitoring, equipment procured benefited the JEM monitoring and also ongoing DSM since the equipment was used at existing, as well as new monitoring sites. For example, provision of ADCPs to Lao PDR and Thailand allowed upgrading of discharge monitoring equipment at several long-term DSM sites and the JEM sites.

The procured equipment and its delivery status are detailed in Tables 2.1 and 2.2 for the teams at the Xayaburi and Don Sahong JEM Pilot sites, respectively. Most of the equipment was delivered, only the equipment did not deliver is the sediment monitoring equipment, D-96, due to global supply shortage.

Table 2.1. Summary of equipment procured, delivered and installed associated with the Xayaburi JEM pilot

Country	Equipment Delivered	Status
Lao PDR	1 new HYCOS station, with water level recorded, rain gauge, telemetry and solar panels installed at Ban Pakhoung	Delivered
	2 Pipe dredge for the collection of bed material samples, one for Luang Prabang and one for the Pakse team	Delivered
	1 all-weather digital GPS camera for the collection of repeat photos at monitoring sites	Delivered
	1 85 HP Yamaha engine, fuel tanks and controller switch	Delivered
	1 trailer for transporting the boat based at Luang Prabang downstream to measure the downstream of Xayaburi site	Delivered
	1 Nissan Pick Up tow bar for the Luang Prabang DSM team, Vigo Pick Up tow bar for the Pakse team.	Delivered
	2 Electric Scales, one for DMH and one for Luang Prabang	PO signed
	2 field laptops, one for Luang Prabang andone for the Pakse team	Delivered to Vientiane
	1 handheld GPS for the Pakse team	PO signed
	2 sets of spare boat propellers, one for Luang Prabang and one for the Pakse team	PO signed
	1 spare winch rope for the Pakse team's winch earlier procured under this project	PO signed
	1 camera with GPS attached for the collection of repeat photos at monitoring sites by the Pakse team	PO signed
Thailand	1 Teledyne RiverRay ADCP	Delivered
	1 newly developed winch system to use with D96 depth-integrated suspended sediment sampler	Delivered
	1 Pipe dredge for the collection of bed material samples	Delivered
	1 all-weather digital GPS camera for the collection of repeat photos at monitoring sites	Delivered

Table 2.2. Summary of equipment procured, delivered and installed associated with the Don Sahong JEM pilot

Country	Equipment Delivered	Status
Lao PDR	1 Teledyne RiverRay ADCP for use at Pakse	Delivered
	1 boat suitable for field monitoring	Delivered
	1 85 HP Yamaha engine, fuel tanks and controller switch	Delivered
	1 Pipe dredge for the collection of bed material samples	Delivered
	1 newly developed winch system to use with D96 depth-integrated suspended sediment sampler	Delivered
	1 new HYCOS station, with water level recorded, rain gauge, telemetry and solar panels installed downstream of the Don Sahong Power Station, July 2021	Delivered
	1 electric scale for weighing of sediment samples for Pakse team	PO signed
Cambodia	1 new HYCOS station, with water level recorded, rain gauge, telemetry and solar panels installed at Koh Key upstream of Stung Treng	Delivered
	1 Pipe dredge for the collection of bed material samples	Delivered
	1 all-weather digital GPS camera for the collection of repeat photos at monitoring sites	Delivered
	Replacement cable for Rio Grande ADCP	Delivered
	1 Dell Latitude Field Computer to use with the ADCP	Delivered
	1 outboard engine to replace old worn engine on the monitoring boat	Quotes under evaluation.

2.1.2 Water quality and ecological health monitoring

Equipment was procured to support WQ monitoring and analysis – as well as for training activities hosted by the MRC Secretariat in Vientiane as listed for EHM in Table 2.3 and WQ monitoring in Table 2.4. The procurement of the AlgaeTorch, for example, now allows for the measurement of new WQ parameters of turbidity, chlorophyll-a and cyanobacteria. New WQ probes have also been supplied. chlorophyll-a training supplies were recently delivered in time for training in September 2021.

Table 2.3. List and status of equipment procured and delivered for the EMH monitoring teams

Country	Equipment for EHM monitoring teams	Status
Lao PDR	Vertical Water sampler for the EHM team	PO signed
	Ekman Grab Sediment Sampler for the EHM team	PO signed
	Microscope with Camera for the EHM team	PO signed
	Zooplankton counting Chamber for the EHM team	PO signed

Table 2.4. List and status of equipment procured and delivered for the WQ monitoring teams

Country	Equipment for the water quality monitoring teams	Status
Cambodia	One multi-parameter water quality portable meter	PO signed
	One turbidity meter	PO signed
Lao PDR	One AlgaeTorch	Delivered
	Two packs of spare Dissolved Oxygen screw cap membranes	Delivered
	One bottle quick calibration solution	Delivered
	Two bottles Dissolved Oxygen, electrolyte fill Solution	Delivered
	Chlorophyll sample bottles (high-density polyethylene (HDPE)	Delivered
	Standard Method for the Examination of Water and Wastewater, 23rd Edition, APHA/AWWA/WEF	PO signed
	Lab equipment and supplies for chlorophyll-a training (centrifuge, ultrafilter membrane discs, disposable tissue grinder pestle, buffer solution)	Delivered
	1 new water quality station (OTT Hydrolab Sonde) supplied of the downstream of the Don Sahong Power Station site	Delivered
	Buffer solutions for calibration of the new Hi frequency WQ station at Don Sahong downstream	Delivered
Thailand	Two sets of multi-parameter water quality sonde, sensors and handheld meter	PO signed

2.1.3 Fisheries monitoring

A major procurement process was conducted to source the required specialist equipment required for the fish tagging training and upcoming pilot activities by the Charles Sturt University (CSU) team for Khone Falls in Lao PDR. Since the team is seeking to share a database with existing monitoring stations already deployed at the Xayaburi Dam in Lao PDR, the items procured under the JEM Pilots were sourced to match the functionality of that existing system in all aspects.

This equipment comprised 10 packages. All items for the fish tagging activities were delivered to Vientiane by mid-October 2021 with the exception of the locally supplied hardware items (No 9 in Table 2.5) currently under quotation. This equipment was used for a training event in September 2021 and will be deployed for pilot activities in 2022.

Table 2.5. Fish tagging equipment packages and status

No.	Equipment packages	Status
1	PIT tag equipment package	Delivered to Lao PDR
2	Acoustic tag equipment package	Delivered to Lao PDR
3	Flotation buoys	Delivered to Lao PDR
4	Veterinary surgery equipment package	Delivered to Lao PDR
5	Spaghetti tag equipment package	Ordered for Lao PDR
6	Box closure (accessory for PIT tag equipment)	Delivered to Lao PDR
7	Solar array (accessory for PIT tag equipment)	Delivered to Lao PDR
8	Tadiran Lithium batteries for Lao PDR	Delivered to Lao PDR
9	Hardware and equipment for fish tagging	Quotes under evaluation.
10	Storage lockers	Delivered to Lao PDR

Equipment procured to support the FADM/FLDM activities included both items for sampling, such as custom-made gillnets for implementation and testing of adapted protocols, and for laboratory analysis. A full list of these items for the teams in Cambodia and Lao PDR is provided in Table 2.6.

Table 2.6. Summary of equipment procured, delivered and installed associated with the Don Sahong JEM pilot

Country	Equipment for fisheries teams	Status
Cambodia	2 mechanical flow meters	PO signed
	1 water depth meter	PO signed
	2 digital flow meters	PO signed
	1 camera to support panel gillnet monitoring team	Delivered
	1 printer	PO signed
	2 computer laptops to support panel gillnet monitoring team	PO signed
Lao PDR	3 bongo nets	Quotes evaluated
	10 standard flowmeters	PO signed for 3 additional. 7 already delivered.
	20 sets of featherweight entomology forceps	PO signed
	3 sets of digital Caliper	Quotes evaluated
	3 sets of glass petri dish	Quotes evaluated
	2 field laptops	Delivered
	Gillnets (gillnet ID1 42m long, gillnet ID2 70m, and gillnet ID3 112m long)	Delivered
	Microscope and C Mount microscope camera	Delivered

2.2 Training

Capacity building has been a major component of the JEM Pilots to support the teams in implementing the JEM monitoring protocols and conducting associated analysis. Travel restrictions due to COVID-19 required adaptation of format and timing for numerous training events, meetings and workshops. This included a shift in approach towards peer-to-peer training and hybrid formats with a mix of online theoretical training and practical training for only some national teams as possible. Other adaptations have been made in response to requests from the Member Country (MC) teams. Implementation of these capacity building events involved significant support from the experts of the MRC ED team and GIZ as well as partnership with the MC experts.

Across the two-year implementation period the JEM Pilots delivered or supported 72 days of training events and capacity building workshops both online and in person, as well as a further 26 days of in-field survey and documentation at the Khone Falls area specifically. A full list of these events and training days (planned and actual supported) is provided in Annex 2. The following sections describe key training events by discipline.

The JEM Programme has generated an impressive set of training materials covering all five disciplines. In the final months, this will be summarized in a set of key materials that can be used by the MRC and MCs to facilitate training refreshers or guide the onboarding of new monitoring staff. These materials will be translated into the four languages of the MCs.

2.2.1 Hydrology and sediments

Training for hydrology and sediments was combined because the two disciplines are required to be monitored by the same teams on the same day. The completed training is described below.

2.2.1.1 On-line discharges and sediment monitoring

An online course was delivered by Dr Lois Koehnken on 22, 23, 24, and 26 June 2020, 8:30 – 12:30, with participants from 15 different locations. The training used PowerPoint presentations with English subtitles and some simultaneous translation into Lao. Topics included:

- theories of water level, discharge, and suspended and bedload sediment monitoring;
- the operation and use of field equipment using videos and live demonstrations of software;
- the order of field monitoring to be completed, and reporting of results;
- detailed demonstrations of the processing of Acoustic Doppler Current Profiler (ADCP) data to extract reliable discharge measurements and estimates of bedload transport;
- answer and question sessions for each topic covered and in the final session.

2.2.1.2 *Peer training for hydrographic teams*

This onsite training consisted of the national teams that was capable of operating ADCPs and D96 sediment sampler to train the less experienced team from the same country. The Lao PDR peer training sessions consisted of the Luang Prabang team training the Pakse team (Figure 2.1). In Thailand, the Nong Khai team assisted the Chiang Khan team. Two peer training sessions were completed for each pair of teams, and activities included practice in setting up and calibrating instruments and collecting field measurements. GIZ and MRC experts facilitated these training sessions.

Figure 2.1. Peer training in Xayaburi, with the RiverRay ADCP, included in the photo

2.2.1.3 Other training support

In addition, the following was provided to support the DSM:

- training in the loading and unloading of the boat on Xayaburi's boat trailer for transport through the Xayaburi dam site;
- training in the use of the new boat procured for Pakse, and a new winch system developed by VGS for the JEM pilot programme;
- ad hoc support in Lao PDR to train new staff in completing suspended sediment concentration (SSC) measurements and the grain-size analysis of bed materials.

2.2.2 Water quality

2.2.2.1 On-line water quality training

An on-line WQ training course consisting of three half-days was provided for the WQ teams in each of the Mekong countries (Cambodia, Lao PDR, Thailand and Viet Nam); technical staff from the MRCS, and from the Don Sahong HPP (DSHPP) also participated.

The JEM monitoring extends and complements the existing ongoing monthly MRC WQ monitoring, and the workshop provided a good opportunity to highlight the new monitoring stations and to introduce some new parameters and techniques to be trialled under the JEM project.

Initially, the basic training had been planned to be conducted in Vientiane in March 2020, but due to travel restrictions associated with the COVID-19 pandemic, it was conducted via the web, with participants in the MRC offices in Vientiane and the offices of the National Mekong Committees in the other countries. Originally, the planned training included field visits to take samples in the Xayaburi impoundment in order to put theory into practice. However, the practical application of the protocols must rely on feedback from actual monthly sampling visits.

Training modules included: Module 4: Rationale for JEM Water Quality monitoring – looking for impacts of hydropower; Module 5: New aspects of Water Quality monitoring introduced for JEM; Module 6: Preparation for JEM Water Quality field sampling; and Module 7: Water Quality Data entry and management.

Training was conducted using PowerPoint presentations on the Cisco Systems, Inc. WebEx platform in three half-day sessions on 16–19 June 2020. Each module was followed by a question and answer/discussion period during which each country was called on to ask questions or provide comments. The final session was an interactive discussion based on questions and comments submitted by each of the countries.

In addition to the presentations used for the training, each session was video recorded, and the recordings made available to the participants each day. Supplementary training materials were provided to each of the countries as a source of additional guidance for field monitoring.

2.2.2.2 Laboratory-based chlorophyll-a analysis training

The chlorophyll-a training was divided into two parts. The first part focused on the theory, organized regionally on 15 September 2021 via teleconference, and the second part focused on the lab and field-based training. Due to the COVID-19 pandemic, international and regional travel were not allowed; the later part of the training was conducted for only Lao WQ monitoring team on 16–17 September 2021, at the Laos WQ monitoring networks labs and at the WQ monitoring station in Vientiane. Videos were taken during the field and lab-based training in Lao PDR. The MRC will share the video clips with Cambodian, Thai, and Vietnamese teams after editing. The three-member countries teams then can explore and familiarize themselves with the procedures before the regional physical training is possible.

The training objectives were to:

- introduce the national laboratory of the MRC WQMN teams to the theoretical principle for the monitoring of chlorophyll-a in surface water, including the available methods, MRC's recommended method, and the MRC Standard Operating Procedures for Spectrophotometric Determination of Chlorophyll a in the Presence of Pheophytin (SDCP);
- provide training in step-by-step procedures that includes field sampling preparation, laboratory analysis, and reading and reporting of water quality concentrations.

A comparison was made between the in-situ AlgaeTorch monitoring method and SM10200 – spectrophotometric determination method. The results of this comparison indicated that at a monitoring location with flowing water, the spectrophotometric determination method (laboratory method) is the more appropriate one, and should be the recommended method if chlorophyll-is to be integrated into the routine WQMN. It should be osd that field measurements in a bucket as recommended was not compared. The two methods were not compared for impoundment type of stations.

There has not been a direct comparison of the advantages and disadvantages of the laboratory analysis of chlorophyll-a and the use of the AlgaeTorch. A preliminary comparison is provided in Table 2.7.

Table 2.7. Initial comparison of advantages and disadvantages of laboratory analysis of chlorophyll-a and the AlgaeTorch

Criteria for comparison	Laboratory analysis, SM10200	Algae Torch
Running water sampling method	Simple water sampling	Difficulties of sampling in running water can be overcome by taking sample and using Algae Torch in a bucket
Impoundment sampling	Multiple samples to be taken at depths, increasing complexity of sample preparation and transport	Probe lowered to different depths to give instantaneous readings
Transport of samples	Requires sample preparation and storage on ice and timely delivery	Samples analysed immediately on site
Analysis	Chlorophyll-a only	Chlorophyll-a, Cyanobacteria and Turbidity
Detection limits	5 µg chl-a/l	0.15 µg chl-a/l
Costs	Ongoing costs per sample for transport and laboratory analysis	One-off capital cost for Algae Torch equipment

2.2.2.3 Follow-up water quality meetings

A follow-up meeting was held with the Lao national water quality monitoring team to discuss the initial results from October 2020 to January 2021 on 2 February. This meeting provided an opportunity to emphasize the protocols and analysis. The team discussed issues with sampling, especially the use of the AlgaeTorch in fast running waters, and interpretation of the results.

2.2.3 Ecological health monitoring

An on-line EHM training course consisting of three half-days was provided for the EHM teams in each of four Mekong countries (Cambodia, Lao PDR, Thailand, and Viet Nam). Technical staff from the MRC Secretariat, and from DSHPP also participated.

The JEM monitoring extends and complements the MRC's ongoing biennial EHM. The online training provided a good opportunity to highlight the new monitoring stations and to introduce some new parameters and techniques applied under the JEM project.

Initially, the training had been planned to be conducted in Vientiane, in March 2020, but due to travel restrictions associated with the COVID-19 pandemic, face-to-face training was not possible. In place of the planned training, the basic training reported on here was conducted in an on-line format, with participants located in the MRC offices in Vientiane and the offices of the National Mekong Committees in the other countries. The original planned training had included field visits to take samples in the Xayaburi impoundment in order to put theory into practice; however, the practical application of the protocols relied upon feedback and site reports from the actual annual sampling visits.

Training modules included: Module 4: Rationale for JEM EHM – looking for impacts of hydropower; Module 5: New aspects of Ecological Health Monitoring introduced for JEM; Module 6: Preparation for JEM Ecological Health field sampling; and Module 7: Ecological Health Monitoring Data entry and management.

Training was conducted using power point presentations on the Cisco Systems, Inc. WebEx platform in three half-day sessions on 9–13 July 2020. Each module was followed by a question and answer/discussion period during which each country was called upon to ask questions or provide comments. The final session was an interactive discussion held following a two day break, and was based on questions and comments submitted ahead of time by each of the countries.

In addition to the presentations used for the training, each session was video recorded, with the recordings made available to the participants at the end of each day. Supplementary training materials were provided to each of the countries as a source of additional guidance for field monitoring.

2.2.4 Fisheries

In fisheries, three main training sessions were provided to national teams:

- Training 1: Fisheries monitoring field training, Luang Prabang, 24–27 February 2020;
- Training 2: Fish larvae identification, 24–27 February 2020 in Luang Prabang, and 2–6 March 2020 in Phnom Penh;
- Training 3: Data management and analysis training, 9–11 March 2020.

This training was documented by the ICEM team in a 127-page training manual including 158 slides of training material and discussions (MRC, 2020).

These 2020 formal training sessions in fishery science were further complemented in September 2021 during the series of four national workshops on JEM integrated data analysis, reporting, and sharing (see Section 2.5), during which JEM pilot data, case study data on multi-year, multi-site analysis, and a 20-page data analysis manual were shared with participants.

Finally, capacity was built by sharing information with national partners on gillnet testing and larvae sampling.

2.2.4.1 Training 1 – Fisher catch and gillnet monitoring training

The training objectives were to: (i) strengthen the capacity of trainees in mastering the various field techniques described in the JEM guidelines; and (ii) enable trainees to be able to instruct and supervise local fishermen to collect samples regularly. Fifteen participants from four countries attended the training. Trainees were shown how to: check equipment provided to fishers; measure mesh size; collect nets (work carried out by fishers); handle the catch for identification; identify fish (comparative use of three different identification books and flipcharts), and use scales to weigh individual fish. The training was also an opportunity to discuss the protocol and to collectively make some decisions, in particular about:

- adapting dimensions and mesh sizes, while noting that the adapted protocol would need to be tested;
- simplifying the sub-sampling part of the protocol and the proposed "length frequency distribution" form;
- postponing the implementation of frame surveys, thus making it possible to infer from monitoring results the situation basin-wide while having identified the key socioeconomic and biological parameters to be considered when frame surveys are undertaken.

As a result of the training, the Lao team strengthened its capacity in identifying fish taxonomy. A recommendation was made to introduce a mentoring programme by national or regional colleagues experienced in identify fish taxonomy. It was also proposed to train fishers to enable them to better understand the standards and requirements of the protocol.

2.2.4.2 Training 2 and 3 – Fish larvae sampling then fish larvae identification

The training objective was to enable national teams to better train local fishers on how to deploy larvae sampling using bongo nets; 14 participants from four countries attended the training. Trainees were shown: (i) how to choose sampling stations in different areas; (ii) the tools, gears and methods used for sampling, preservation, and sample identification techniques; and (iv) sample identification (how to identify larvae and juveniles in 37 families). The conclusions of the training underlined two particular needs: in the field, fishers should be trained since they are key to the new protocol; and in the lab, the Lao team should be trained to strengthen their skills since they are new to larvae taxonomy. The taxonomic challenge in particular resulted in a time constraint for the Lao team in relation to the number of samples generated. In addition, reference fish samples should be created or strengthened in each county so that teams can compare any given sample from the field with a reference fish to secure identification.

A follow-up to Training 2 was conducted in July 2021 as a five-day refresher training on fish larvae identification at the Ban Na Hatchery Centre in Lao PDR. The first three days reviewed basin theory with hybrid attendance of participants both online and in-person due to COVID-19 restrictions. The participants in Lao PDR continued with a further two days of practical training.

2.2.4.3 Training 4 – Data management and analysis

The training objectives were to strengthen the capacity of trainees to manage data, to perform quality assurance and quality control, to analyse data according to a set of predetermined questions, and to present results using the reporting standards defined by JEM guidelines; 22 participants from four countries attended the training. Trainees were introduced to the principles of formulating research questions and of data management using Microsoft (MS) Access, as well to data cleaning and data analysis using Excel. They were also introduced to using and ultimately analysing data, and visualizing results and then drafting a report by scientific standards.

Conclusions of the training underlined the need for: (i) additional training sessions (e.g. hands-on training in analysing actual data gathered during the project); (ii) mentoring on species identification (collaboration between countries, possibly online); and (iii) ensuring that trainees frequently and regularly put the learning into practice.

2.3 Database design and application

The monitoring data collected during the JEM Pilots were integrated within a custom-built database system covering all five disciplines, as shown in Figure 2.2. Development and data entry within this JEM database is now complete and is accompanied by the JEM Database User Manual. These databases have been designed to enable good practice data storage, management, and ease of visualization for the monitoring data of the JEM and MRC as collected historically and within the JEM Pilots specifically. These databases were handed over to the MRC for integration within the MRC Master Database in early December 2021. Access will then be arranged for MCs by the MRCS upon official request.

Preparation of these integrated databases required substantial effort to adapt and integrate relevant information, hard copy records and digital office record tools of historical monitoring datasets from the national teams and MRC. A key effort has been to align the monitoring station codes used within these existing datasets to match the MRC's standardized database coding system. Although this standardized system was established some time ago, it has not yet been fully adopted by the national teams and line agencies. Stronger uptake of this system will enable future data collected by the JEM programme to be integrated and linked within the MRC Master Database system.

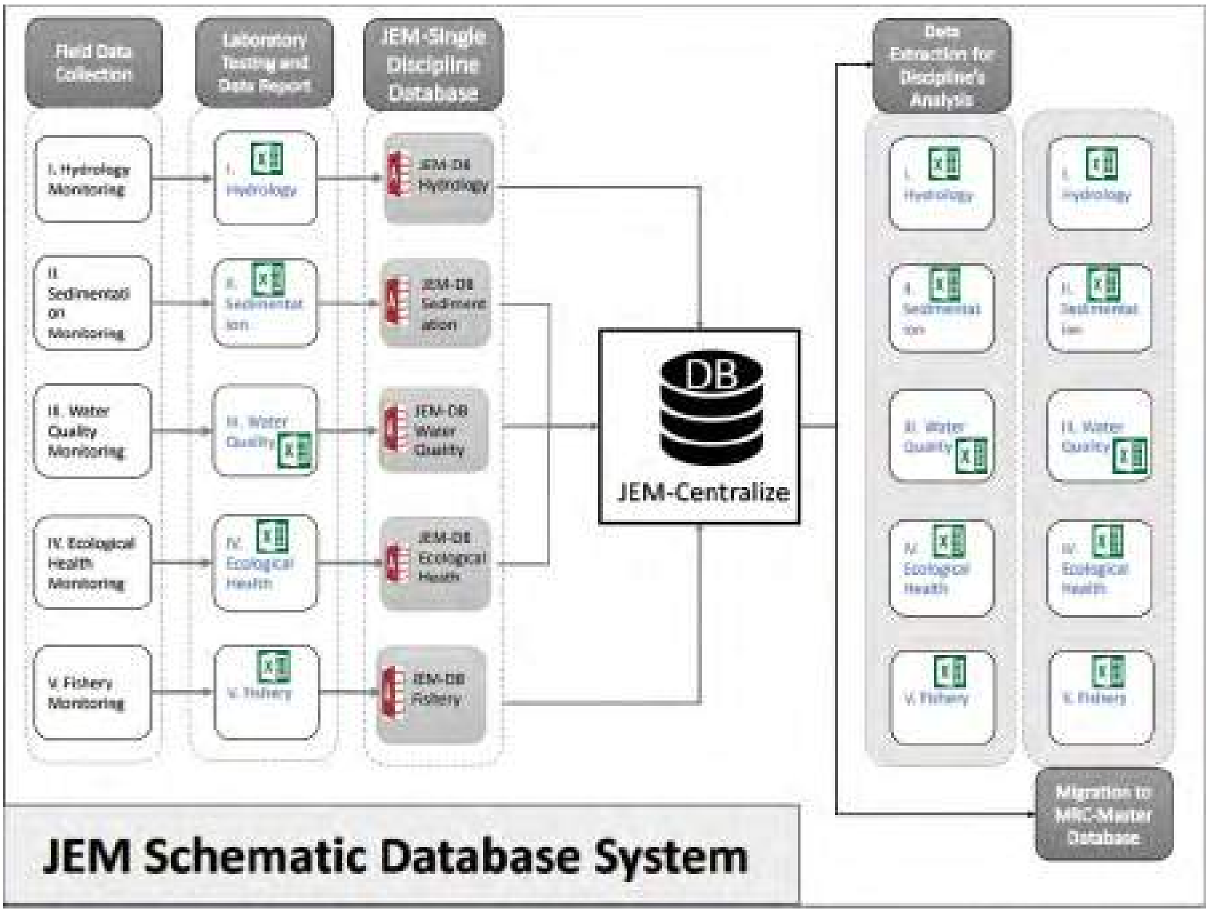


Figure 2.2. The JEM Schematic Database System

2.3.1 Hydrology, sediment, water quality and ecological health monitoring databases

The hydrology and sediments, WQ and ecological health databases are relational database in which the key relationship is between the principal monitoring parameters and location specific information (monitoring site). The databases have been populated with both historical data and JEM monitoring data. User-friendly data visualization functions have also been developed to produce autogenerated graphs according to station. Table 2.8 provides a summary overview of the structure, integrated records and query functionality that has been developed within these databases. Further detail on the parameters contained within the database structures can be found in Annex 2.

Table 2.8. Key features and data of the hydrology, sediment, water quality and ecological health monitoring databases

Database	Structure	Integrated records	Query functionality
Hydrology and sediment	1. hydrology-sedimentation monitoring, 2. sediment grain size monitoring 3. hydro-timeseries monitoring	Historical data: • 1,726 data records for hydrology-sedimentation • 980,217 data records for hydro-timeseries monitoring.	**Data extraction** by a) monitoring station and b) time period of interest. **Summary of data** for analysis and visualization by a) month or b) year.

Database	Structure	Integrated records	Query functionality
Water quality	1. WQ monthly monitoring 2. water quality profile monitoring	Historical monthly data have been stored in the system for all the routine WQMN sites on the Mekong mainstream from 2010 onwards: • 1,398 data records for water quality monthly monitoring • 372 data records for impoundment profile monitoring	**Data extraction** by a) monitoring station and b) time period of interest. **Summary of data** for analysis and visualization by a) month or b) year.
Ecological health	1. EHM-level1: Every single species recorded at each site with total number of individuals, total number of samples with species present. 2. EHM-Level2 records at biota level	(i) Historical EHM data for all the mainstream sites from 2011, 2013, 2015, 2017, 2019. (ii) JEM sites in 2021. For the period year 2011 to 2021: • 134,959 data records for EHM-level 1 • 55 data records for EHM-level2	**Auto-calculation** for all ecological health monitoring index. Auto-conditional calculation for **EHM classification**. **Data extraction** by a) monitoring station and b) time period of interest. **Summary of data** for analysis and visualization by a) month or b) year.

Key components of the interface are the data entry forms for WQ monthly monitoring and WQ profile monitoring. Key components of the interface are the data entry forms for hydrology-sedimentation monitoring, sediment grain size monitoring, and hydro-timeseries monitoring.

The EHM database design and construction reflect the monitoring activities of JEM and the MRC's biennial routine EHM, with data entry forms provided for:

- EHM Parameter 1. Zooplankton;
- EHM Parameter 2. Benthic diatoms;
- EHM Parameter 3. Macroinvertebrates – littoral;
- EHM Parameter 4. Macroinvertebrates – benthic.

Note that for the WQ monitoring database and EHM database, all the JEM sampling stations were incorporated into MRC universal standard code, which provides the focus for future data relations.

2.3.2 Fishery monitoring database

The FADM fisheries database was developed according to the structure of the existing MRC Master Database, with data disaggregated by country and year. The preparation of this database required the integration of distinct databases, as shown in Figure 2.3, covering the 2007–2021 period. Each country provided data in slightly different table structures that were adapted to facilitate their merging.

Name	Type
5_6159105405952721803.accdb	Microsoft Access Database
Daily_Catch_Monitoring_Cam_2017_2021_laste...	Microsoft Access Database
Data FADM From Jan to Dec-2020_Jun 2021.m...	Microsoft Access Database
Database-TSA-Jan-2017 to-Dec2018.mdb	Microsoft Access Database
Database-TSA-Jan-Dec-2019 9-2-2020.mdb	Microsoft Access Database
FADM THAI UPDATE December 2017 to 19.acc...	Microsoft Access Database
FADM THAI UPDATE to 2020-May 2021_edit.a...	Microsoft Access Database
FADM Total Daily Fisher Logbook Database_V...	Microsoft Access Database
Fisher Catch Monitoring Database_27Dec18.m...	Microsoft Access Database
JEM_Larvae in Sep_2021-Jul_2021.accdb	Microsoft Access Database
JEM_Stadard gillnet in Sep_2020-Jul_2021.acc...	Microsoft Access Database
Lao_FADM_2018.accdb	Microsoft Access Database
Lao_FADM_Jan-Dec 2019_Checking on May 20...	Microsoft Access Database
Lao_FADM_North_31072018.accdb	Microsoft Access Database
Lao_FADM_South_31072018.accdb	Microsoft Access Database
MRC_FADM_Jan-Dec_2020.accdb	Microsoft Access Database
MRC_FADM_Jan-Jul_2021.accdb	Microsoft Access Database
Panel_gillnet monitoring database.accdb	Microsoft Access Database
TSA2012_15.accdb	Microsoft Access Database

Figure 2.3. Original fisheries database as of 1 September 2021

These databases of historical data were complemented by development of two databases for gillnet monitoring as initiated within the JEM Pilots, and two databases for Fish Larval Drift Monitoring covering the 2020–2021 period only.

2.4 Regional meetings and data sharing workshops

The JEM Programme's Pilot Projects is a regional cooperation project between the four MCs facilitated by the MRC, which has involved four regional meetings or workshops over the two-year period. Implementation and adjustment to the JEM Pilots are overseen by the Expert Group on Environmental Management (EGEM). The EGEM has met twice to date and conducted the third and final consultation meeting on the JEM Pilots in November 2021. A Regional Data Sharing and Analysis Workshop was also conducted with the national monitoring teams in October 2021. A summary overview of outcomes from each meeting is provided below.

2.4.1 Meeting of the Expert Group for Environmental Monitoring

The EGEM Meeting held on 21–22 February 2020 in Nong Khai, Thailand reviewed the inception report prepared for the JEM Pilots and agreed to the proposed implementation approach and monitoring of the five key environment disciplines. Feedback from the EGEM was incorporated into the final design of the JEM Pilot activities as detailed in the inception report. This meeting signified the start of the JEM Pilots implementation phase.

2.4.2 The 27th Meeting of the Expert Group for Environmental Monitoring

The EGEM met in May 2021 to present and discuss the first monitoring results from the JEM Pilots, the preliminary interpretation of findings and the initial recommendations for revisions to the monitoring protocols. Also presented and discussed were fish pass monitoring methodology and the approach to be tested at Don Sahong Dam, as well as the concept for the assessment and redesign of the MRC CRMN in the LMB. This meeting reiterated that the JEM Pilot recommendations will be further incorporated in the CRMN currently being initiated.

Representatives from the Chiang Khan (CK) Power Public Company Limited and the DS HPP attended this meeting and also provided feedback on the preliminary interpretation of monitoring data, according to their knowledge of hydropower operations over that period.

Feedback and points raised by the MCs were incorporated into the revised First Pilot Site Reports for DS HPP and Xayaburi HPP sites, and noted to inform preparation of the Combined Annual Report following further monitoring.

2.4.3 National and Regional Data Sharing and Analysis Workshops

A Regional Data Sharing and Analysis Workshop was held in October 2021 to provide an opportunity for teams from each of the MCs to review and familiarize themselves with the data that they collected during the period from October 2020 to June 2021 and their scientific implications. The objectives were to introduce the national teams to the JEM database, interpret findings across the disciplines regarding implications for hydropower operation, and make suggestions for further analysis of results across various parameters. Also considered were opportunities for cross-analysis of data collected under the various disciplines.

This workshop was originally intended as a three-day in-person regional workshop. However, given travel restrictions, this was conducted as a series of workshops. First, a one-day national workshop was conducted via videoconference with the national teams from each of the four MCs, with simultaneous interpretation. This was held on:

- 22 September for Cambodia;
- 27 September for Thailand;
- 5 October for Viet Nam;
- 7 October for Lao PDR.

At each workshop, monitoring data and extracts from the database were presented for each of the disciplines together with further guidance on replicable analysis and interpretation. These presentations were conducted both in-person and pre-recorded in order to be viewed as desired to guide future data analysis. In the afternoon, participants worked together to review, discuss and interpret the data to prepare a presentation to the broader regional workshop. Each national workshop provided an important opportunity for detailed discussion with the monitoring teams conducting the monitoring and for a review of the overall implementation of the JEM Pilots prior to the preparation of the final recommendations.

The final Regional Workshop was then conducted on 8 October to bring all national teams together with developers to present and reflect on the data collected across the five disciplines, consider how their analysis can lead to new insight on the pilot projects, and discuss opportunities for data sharing. Representatives from the DS HPP presented on their own monitoring activities, and commitment to transfer datasets to the MRC team while the CK Power Public Company Limited could not join but indicated that they would share their monitoring data with the MRC.

An outcome of this Regional Workshop was the lesson learned that the JEM Pilots can only provide preliminary indications of the actual impact of the HPPs, with the primary objective being to test and refine the monitoring protocols. The full value of the JEM Programme will be seen in the long-term monitoring effort by the MCs, and data sharing between MCs, the MRC and developers, which will allow for assessment of hydropower impacts. All four countries reiterated the importance of the joint monitoring of the JEM Pilots and future JEM Programme implementation for the regional community and for understanding the basin. The value of the new protocols was noted and suggested for incorporation with the routine monitoring.

2.4.4 The 31st Meeting of the Expert Group for Environmental Monitoring

A second and final EGEM meeting was planned for November 2021, where the final results of the JEM Pilots were reported for feedback from the perspective of each MC. The recommendations for revision to the JEM Guidelines were discussed for agreement on the way forward to finalize the overall JEM Programme. The roadmap for its implementation and integration into the CRMN Project was also discussed, together with the inception report for the CRMN project. Key reports presented and discussed at this meeting were the JEM Pilots Combined Annual Report and this Final Report. Comments and suggestions from the MRC and MCs have been incorporated in the final versions of these reports.

3 PILOT MONITORING ACTIVITIES

This section summarizes all sampling missions conducted under the JEM Pilots with a report, by discipline, on the frequency, timing, and parameters collected. It also describes the review and data collection activities conducted during the JEM Pilots in 2020–2021 as input to the design of the fish tagging methodology to be implemented in 2022. Descriptions of monitoring and a more in-depth discussion of all monitoring results are contained in the first pilot site report and the Combined Annual Report.

The start of monitoring activities in both locations experienced some delays for two reasons: the COVID-10 global pandemic, and some internal coordination issues in Lao PDR and Thailand regarding the preparation of the working agreements between MRCS and implementation/line agencies. Monitoring therefore commenced in Cambodia in June 2020, while Lao PDR and Thailand, it started in September 2020. Together with the historic routine monitoring data, these activities generated the data giving rise to the key findings set out in Section 4.

The JEM pilot sites build on routine monitoring sites. Monitoring activities focused on the two pilot sites of Xayaburi region in northern Lao PDR, and the Don Sahong area in southern Lao PDR. Both routine monitoring and JEM pilot monitoring sites around Xayaburi are illustrated in Figure 3.1, and around Don Sahong illustrated in Figure 3.2.

Figure 3.1. Existing monitoring and JEM sites upstream and downstream of Xayaburi

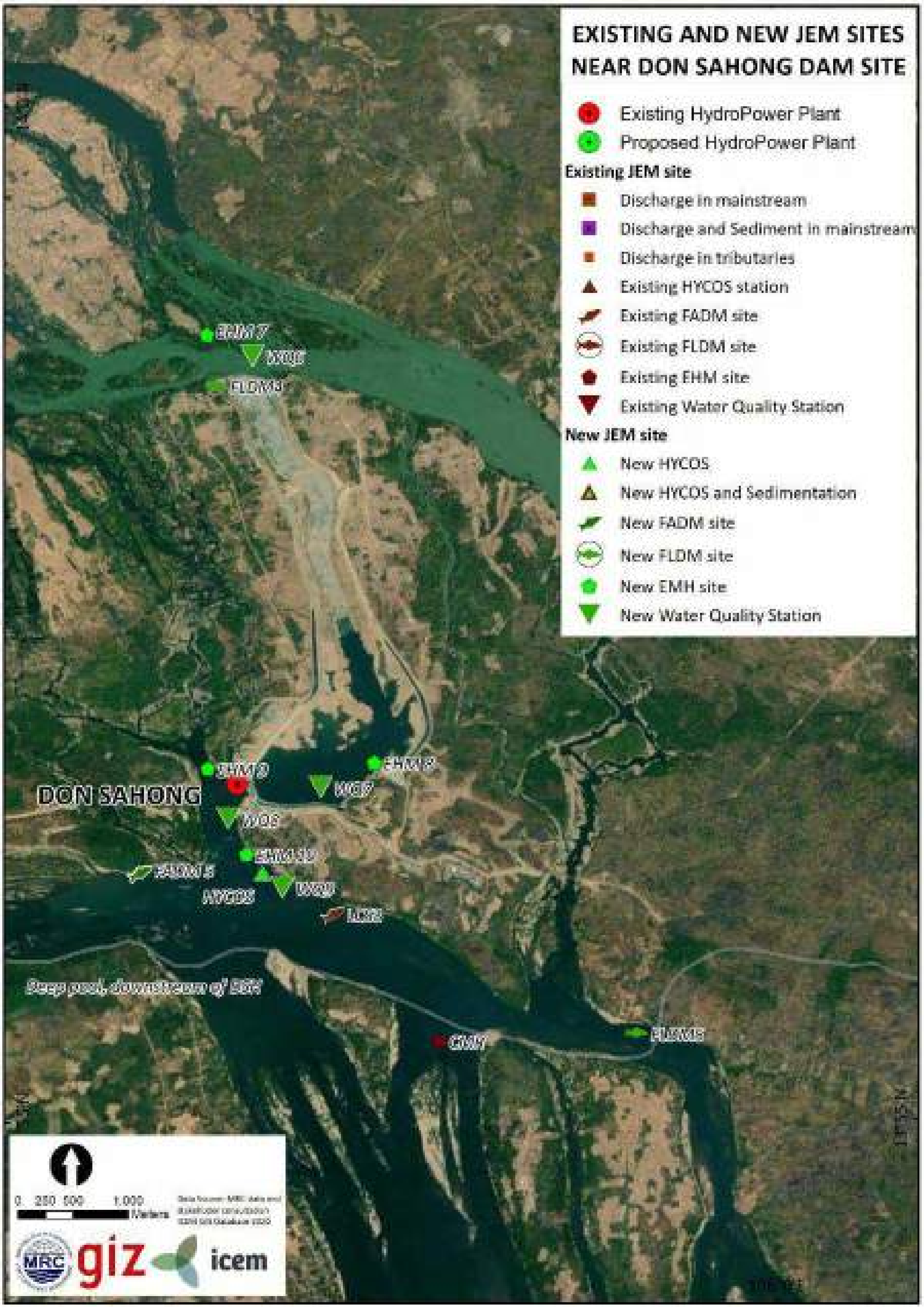


Figure 3.2. Existing monitoring and JEM sites upstream and downstream of Don Sahong

At Xayaburi, the JEM Pilot site at Ban Xanghai for HYCOS and sediment sampling, WQ and EHM Note replaces the routine sites nearer to Luang Prabang due to the probability that they are now influenced by the Xayaburi impoundment.

The choice of JEM sampling stations around Don Sahong has been constrained by the complexity of the multiple channels and the need to identify locations that show the direct impacts of the dam operations. Since routine monitoring has never been carried out near both the Don Sahong and Xayabori Hydropower Projects, comparative results (e.g. at Pakse and Stung Treng) are necessarily distant from the new sites sampled by the JEM Pilots. Note that the discharge and sediment monitoring sites for Don Sahong are not shown in these maps because they are distant both upstream in Pakse and downstream near Stung Treng. This is due to the specific requirement for monitoring sites for these disciplines to be located where the river occupies a single channel. To capture local water level changes, new, continuous water level equipment (HYCOS site) was installed near the Don Sahong tailrace (see Figure 3.2).

3.1 Hydrology and sediments

Sampling missions for hydrology and sediments were completed and reported at each of the indicated JEM stations between April 2020 and September 2021, as shown in Table 3.1 and 3.2.

Table 3.1. Discharge and SSC monitoring locations and monthly sampling frequency, July 2020 – September 2021 completed associated with the Xayaburi

	Jul20	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
PXH				3	1	1	1	1	1		2	4*
BPH				2	1	1	2	1	1		1	3*
CK	4	4	2	1	2	2			1	1	1	4
NK	5	4	3	4	3	2						
	Jul21	Aug	Sep									
PXH	4*	4*	4*									
BPH	3*	4*	4*									

Note: *Indicates discharge results only

Table 3.2. Discharge and SSC monitoring locations and monthly sampling frequency, April 2020 to September 2021**,** associated with the Don Sahong pilot

	Apr20	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar		Apr	May	Jun
Pakse								1	1			1		1	1	
ST-UP	1	2	4	4	4	4	3	1	1						2	1
ST	1	2	4	4	4	4	3	1	1						2	1
SKB	1	2	4	4	4	4	3	1	1						2	1
	Jul21	Aug	Sep													
Pakse	4*	4*	3*													

Note: *Indicates discharge results only

The total set of parameters monitored at the sites, shown in Table 3.2, includes: discharge (Q), depth- integrated suspended sediment (SSC), bed material grain size analysis (BGSA), and SSC-grain size distribution (SSC-GSA). In addition, manual water level results for the gauges at Ban Xang Hai, Ban Pakhoung, and Chiang Khan were also received.

A review of the distribution of monitoring between sites and throughout the year highlights that there are only limited months where results were collected at all sites, and that most of the monitoring was completed during the dry season. These factors have limited the ability to analyse the JEM results with respect to any changes occurring between upstream and downstream sites.

3.2 Water quality

The Lao WQ monitoring team, provided by the Natural Resources and Environment Statistics and Research Institute (NRESRI), Ministry of Natural Resources and Environment and the Department of Natural Resources and Environment of Luang Prabang and Champasak, visited the Xayaburi and Don Sahong sampling stations on the following occasions shown in Table 3.3.

Table 3.3. Dates of sampling visits to Xayaburi pilot sampling stations

Sampling stations	2020			2021								
Month	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Xayaburi												
WQ1	1.11	15.11	11.12	13.1	15.2	13.3	6.4	N/A	21.6	12.7	11.8	8.9
WQ2	2.11	16.11	11.12	13.1	14.2	14.3	7.4	N/A	22.6	13.7	12.8	9.9
WQ3	2.11	16.11	11.12	13.1	14.2	14.3	7.4	N/A	22.6	13.7	12.8	9.9
WQ4	2.11	16.11	11.12	13.1	14.2	14.3	7.4	N/A	22.6	13.7	12.8	9.9
WQ5	2.11	16.11	11.12	13.1	14.2	14.3	7.4	N/A	22.6	13.7	12.8	9.9
Don Sahong												
WQ6	27.10	13.11	14.12	15.1	17.2	15.3	9.4	N/A	24.6	15.7	14.8	12.9
WQ7	27.10	13.11	14.12	15.1	17.2	15.3	9.4	N/A	24.6	15.7	14.8	12.9
WQ8	27.10	13.11	14.12	15.1	17.2	15.3	9.4	N/A	24.6	15.7	14.8	12.9
WQ9	27.10	13.11	14.12	15.1	17.2	15.3	9.4	N/A	24.6	15.7	14.8	12.9

It was not possible to visit either pilot sites or monitoring stations during May 2021 due to COVID-19 travel restrictions in Lao PDR. The eight monthly results between October 2020 and June 2021 were analysed and reported in the Combined Annual Report prepared in

September 2021. The results from the sampling visits in July, August, and September 2021 were received during the preparation of this Final Report and have not been analysed to the same extent to date, although they have been entered into the WQ database.

3.3 Ecological health monitoring

The first annual bio-assessment monitoring was planned for April 2020, but had to be cancelled due to the COVID-19 restrictions on travel within Lao PDR. It was not possible to carry out the 2020 field mission later in the year because bio-monitoring has to be carried out when river levels are low, and the indicator groups will not have been dispersed by rising water levels and flash flows at the beginning of the wet season. The 2021 campaign originally planned for April 2021, was brought forward to February–March 2021 to allow for the identification and reporting process to be conducted in a timely manner. Bio-monitoring at the two pilot sites was carried out by the Lao EHM team between 24 February and 7 March 2021, as shown in Table 3.4.

Table 3.4. Dates of EHM sampling missions

Site No.	Name of site	Date sampled
Xayaburi		
EHM1	Right upstream of Xayaburi Impoundment	5 March 2021
EHM 2	Within the impoundment	4 March 2021
EHM 3	Xayaburi downstream around 2 km	3 March 2021
EHM 4	Xayaburi downstream around 5 km	3 March 2021
EHM 5	Xayaburi downstream around 8 km	2 March 2021
EHM 6	Xayaburi downstream around 12 km	2 March 2021
Don Sahong		
EHM 7	Don Sahong upstream at inlet of impoundment	26 February 2021
EHM 8	Don Sahong impoundment	26 February 2021
EHM 9	Downstream Don Sahong at round 2 km	25 February 2021
EHM 10	Downstream Don Sahong at around 4 km	25 February 2021

3.4 Fisheries

Fisheries monitoring started in the first half of 2020 and comprised the following:

- Fish Abundance and Diversity Monitoring (FADM): three fishers in each site using their gears, catch is recorded daily;
- Standardized multiple panel gillnet sampling: three fishers in each site, using a set of 14 panel gillnets provided by the project. The gillnets are set in the evening and retrieved the next morning. Catches are recorded once a week;
- Fish Larval Drift Monitoring (FLDM): sampling operated by local fishers using bongo nets (1-m diameter, 5-m length, 1-mm mesh size), in three locations at each site in Cambodia (two banks and in the middle of the river) but only two locations in Lao PDR (two banks), 2 m below the surface, during 30 minutes each time, four times a day (at 06.00, 12:00, 18:00 and 21:00), one day per week from August to April, and two days per week from May to July.

The fish sampling was carried out in the sites listed in Table 3.5, several of which set by the MRC routine monitoring programmes before the JEM Pilot Project. However, this report picked up data from the 2017–2021 period for the integrated temporal trends assessment.

Table 3.5. Sites sampled as part of the JEM Pilot projects

Site	Station ID	Station code	FADM JEM	FLDM JEM	FADM MRC	FLDM MRC	Gillnets JEM	Location name
Xayaburi	LA_010702	LPB, LJXU	X	X	x	x	X	Pha O
	LA_011302/4	XLB, LJXI	X		x		X	Ban Thadeua
	LA_011506	LJXD	X	X		x	X	Ban Pakhoung
Don Sahong	LA013305/6	LJDU	X	X		x	X	Hoo Sahong
	-	LJDU	X					Muang Saen Nua
	-	LCS	X				X	Ban Hat
	LA_013309	LSD, LJDD	X	X	x	x	X	Hang Khone/Sadam
	-	CJDD		X				Preah Romkel
	KH_014002	CST			X		X	Ou Run

Note: MRC sites listed are part of the regular MRC sampling (x) and their data were also used for impact analysis

Data gathered on standard forms was entered to produce seven distinct databases, with months of data collection indicated:

1. FADM by FIA in Cambodia (May 2017 to May 2021)
2. FADM in Lao PDR 2020 (January 2020 to December 2020)
3. FADM in Lao PDR 2021 (January 2021 to July 2021)
4. Gillnets in Cambodia (June 2020 to May 2021)
5. Gillnets in Lao PDR (September 2020 to July 2021)
6. FLDM in Cambodia (8 July 2020 to 28 June 2021)
7. FLDM in Lao PDR (September 2020 to July 2021).

It should be noted that the gillnet monitoring did not produce standardized data to allow for detection of dam impacts as a result of the JEM Pilot; instead, the gillnet monitoring activities focused on testing and refining the monitoring protocol. This process began in February 2020 when the protocol initially planned in the JEM Programme document was modified to include only those mesh sizes that are commercially available and permitted by all MCs. In May 2020, a further decision was taken to test a different distribution of panels in response to the initial, inconclusive fishing sessions where extremely low catches were harvested as well as to recommendations from fishers. The testing was subsequently carried out from June 2020 to May 2021 and included three different net configurations to identify the best net configuration and fishing practice (see the First Pilot Site Reports and Combined Annual Report for details). This necessary process of trialling and improvement to the protocols was suggested by the national monitoring teams in August 2021.

3.5 Fish passage

In 2020, the fish tagging component of the JEM Pilots was reviewed and expanded by the MRC with the development of a full fish tagging project with USD 0.4 million funding from the Australian Water Partnership to be coordinated with the JEM Pilots approach implemented by the ICEM team. This established a partnership with the team at the Charles Sturt University (CSU) in Australia, which is already involved in fish tagging at Xayaburi Dam site. The partnership ensures that the MRC's approach is compatible and can be integrated with other fish tagging activities in the region. The dovetailing of teams further ensures that: regional lessons learned are integrated into the JEM Programme; detailed training in tagging can be provided to national teams; procurement focuses on tag and database systems that are compatible across partner projects; and the strategy ultimately recommended by JEM Pilots has the necessary support and resourcing for implementation beyond the life of the project.

The activities of the JEM Pilots related to fish passage, which were carried out by the ICEM team, were revised to support this expansion, with a review and the collection of information as the basis for developing the detailed fish tagging methodology. These activities included:

- mapping of Khone Falls with detailed toponymy of islands, waterfalls and channels (inception report);
- an initial exploration of existing tagging methods with regard to fish tagging methods, the local environment and constraints (inception report and Don Sahong Year 1 report);
- a systematic survey of local ecological knowledge in Khone Falls to identify 10 target species and document recent fish migration patterns, the characteristics of migration channels, and the latest trends in fisheries;
- the development of a manual for selecting fish tagging tools and methodologies in line with expectations, local constraints and study duration;
- the preparation of a roadmap for fish passage monitoring and methodological design of both electronic and spaghetti tagging approaches at Khone Falls.

Travel restrictions due to COVID-19 cause significant delays in the implementation of the fish tagging components, since none of the international specialists could fly to Lao PDR to guide field-based activities as expected. During 2021, the CSU team focused on the development an online training course in fish tagging in several riparian languages ("Tagging fish from afar" YouTube channel), with first trials of Passive Integrated Transponder (PIT) tagging of fish occurring in late 2021.

4 KEY FINDINGS FROM JEM PILOTS

The primary purpose of the JEM Pilots is to test protocols for identifying changes to the river associated with hydropower operations. This section summarizes the analysis of the data collected by the pilot monitoring activities in order to detect changes in each environmental discipline using the JEM Programme methodology. Since the JEM Pilots monitoring was initiated after the construction of the dams, the inclusion and analysis of data from longer-term MRC routine monitoring at established sites is required to provide context against which to identify changes. The trends identified in this analysis therefore indicate the possible impacts arising from hydropower operations. As previously noted, the JEM Pilots' monitoring results cover less than a full year of data, and in general, the identified changes should be considered preliminary in light of this short monitoring record.

The historic results from the MRC's monitoring programme (HYCOS, DSM, WQMN, EHM, FADM, FLDM) have been used from as far back as 2010 as reference and controls for comparison with the results from the JEM Pilots sites. In some cases, the JEM pilots have carried out samplings at new monitoring stations. Some JEM suggested sites overlap with the MRC routine monitoring, so there is potential for direct comparison and observation of longer-term changes in the river. It is noted that locating the Pilot monitoring sites around DSHPP is constrained by the complexity of the multiple channels, and that comparative, longer-term monitoring sites are located at a significant distance both upstream and downstream.

For disciplines and sites where it has been possible (flows, sediment and WQ), the routine monitoring data have been selected in the same months and years as the JEM Pilots data to enable direct comparisons. For disciplines where the limited sampling time period of the JEM Pilots does not allow for the required aggregation on a yearly basis (e.g. fish species diversity), the results are considered indicative only. Statistical analysis of WQ and EHM is also limited since the existing records for WQ and EHM do not include baseline data from before the dam was constructed for comparison with the JEM Pilots data.

4.1 HYDROLOGY AND SEDIMENT

This summary is limited to changes that have been identified by the monitoring that are directly related to hydropower operations. Additional information in the Combined Annual Report includes characteristics of the monitoring sites, results of bed material monitoring, estimates of bedload transport, and changes in channel cross-sections. This summary of results is presented for each of the regions, with identified impacts presented from an upstream to downstream direction.

This analysis builds upon the long-term DSM data set, which provides a large-scale, longer-term understanding of hydrology and sediment transport in the Mekong. Where possible, the JEM results are interpreted within this larger context.

4.1.1 Xayaburi Hydropower Project

The monitoring locations relevant to understanding impacts from Xayaburi are shown in Figure 4.1 and include the new JEM sites of Ban Xanghai and Ban Pakhoung, as well as the existing sites of Chiang Saen, Luang Prabang, Chiang Khan, and Nong Khai.

Hydrologic changes associated with hydropower are evident through a comparison of water levels at different locations. Water level is used rather than discharge because there are insufficient monitoring results to derive rating curves for the new monitoring sites of Ban Xanghai and Ban Pakhoung, and the existing rating curve for Luang Prabang is no longer applicable due to backwater effects at the station. In the following sections, the time periods for the data on water levels shown on Figures 4.2–4.4 varies depending on the availability of monitoring results at the sites and overlaps between sites.

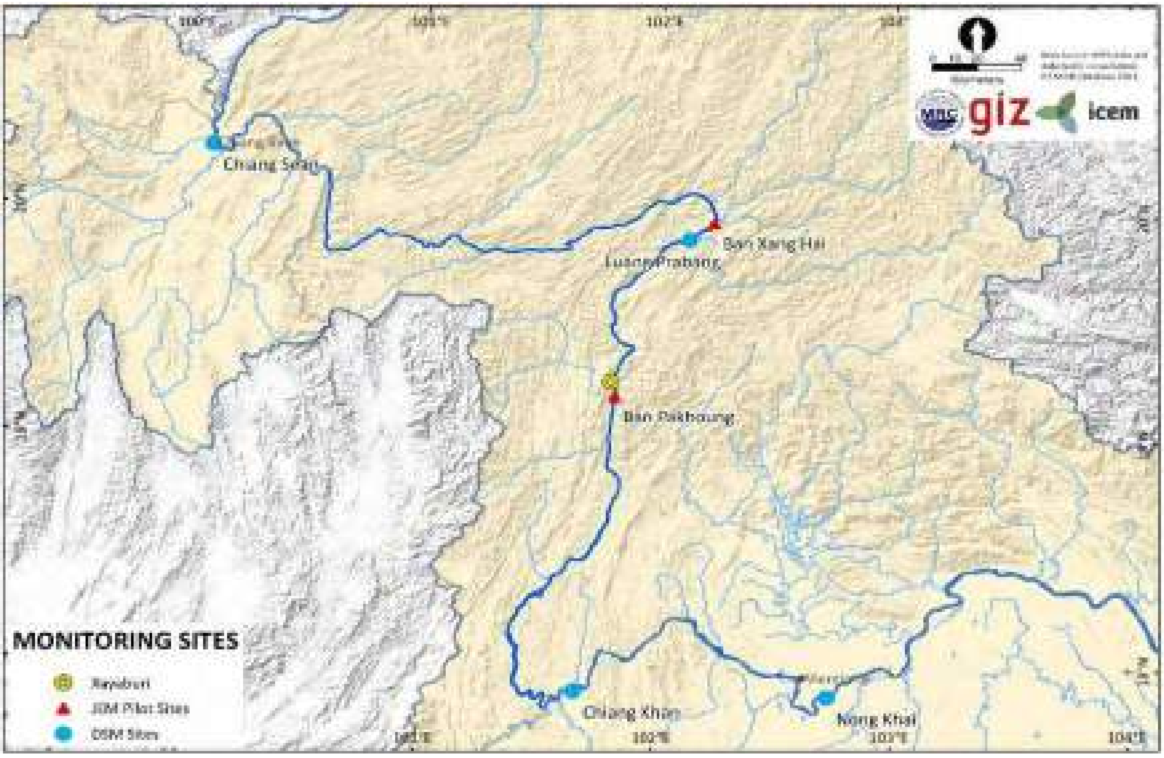


Figure 4.1. Monitoring locations relevant to Xayaburi JEM monitoring.

Note: River flows from north to south

4.1.1.1 Water level upstream of Xayaburi

Upstream of Xayaburi at Ban Xanghai, water level closely parallels levels recorded at Chiang Saen, indicating that most of the flow at the site is governed by inflows from upstream of Chiang Saen. There are several peaks in the Xanghai time-series that are not present at Chiang Saen, showing that either localized rainfall events or releases from tributary HPPs between the two sites can be substantial contributors to flow in the river (Figure 4.2). The water level and discharge results from Ban Xanghai during low flows suggest that backwater effects from Xayaburi do not extend to the station, and the site may be suitable for a long-term HYCOS site. It would be desirable to establish a site in this area since it is projected to remain in a free-flowing reach of the river downstream of the Luang Prabang HPP and Xayaburi impoundment.

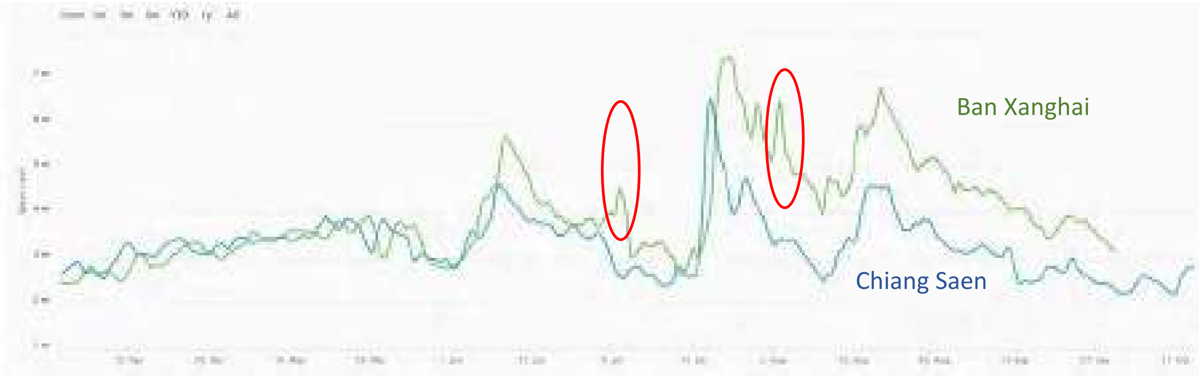


Figure 4.2. Water level at Chiang Saen (blue) and Ban Xanghai (green). Chiang Saen based on 15-minute HYCOS results and Ban Xanghai from daily manual results.

Note: Red circles show water level peaks at Ban Xanghai not present at Chiang Saen

At Luang Prabang, the backwater of the Xayaburi impoundment extends past the long-term HYCOS site, resulting in the probe recording the level of the impoundment rather than a level indicative of river flow (Figure 4.3). The data show that water level during the JEM monitoring generally fluctuated between 8 m and 10 m. The gauge records small fluctuations (up to 5 cm) on a daily basis at the HYCOS site, reflecting the net change between inflows and outflows due to operations (Figure 4.3). There are no water level gauges further downstream in the impoundment, so the maximum range of water level fluctuations near the dam is not available.

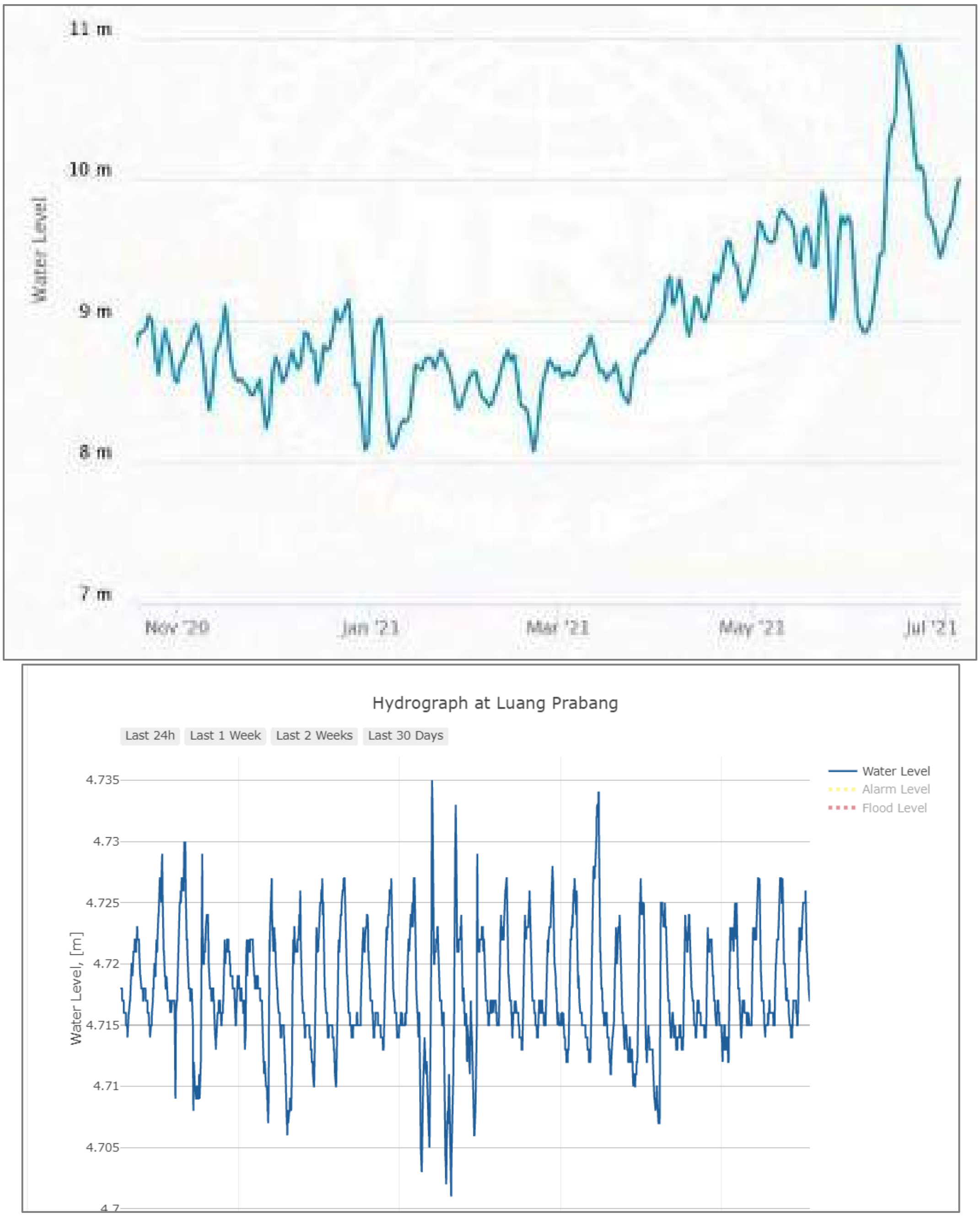


Figure 4.3. (Top) Water level at Luang Prabang during JEM monitoring period. (Bottom) Water level fluctuations at Luang Prabang HYCOS site, September to October 2021

4.1.1.2 Water levels downstream of Xayaburi

Approximately 4 km downstream of the Xayaburi power station, the Ban Pakhoung HYCOS site records frequent water levels, reflecting the generation of hydropower at the station. The site has recorded frequent and rapid and water level fluctuations, that often exceed the MRC Hydropower Mitigation Guideline value of 0.05 m/hr (Figure 4.4). Fluctuations commonly occur on a daily basis during periods of low and moderate flow. The shape and timing of the water level changes are consistent with Xayaburi increasing generation during peak power demand periods.

These water level changes demonstrate that HPPs with small storage capacity and operating as a run-of-river schemes over a period of hours or a few days have the capacity to substantially alter flow conditions in the downstream river.

At Chiang Khan, located approximately 200 river km downstream of Xayaburi, the water level fluctuations have dissipated due to the attenuation of the peaks and additional inflows to the mainstream.

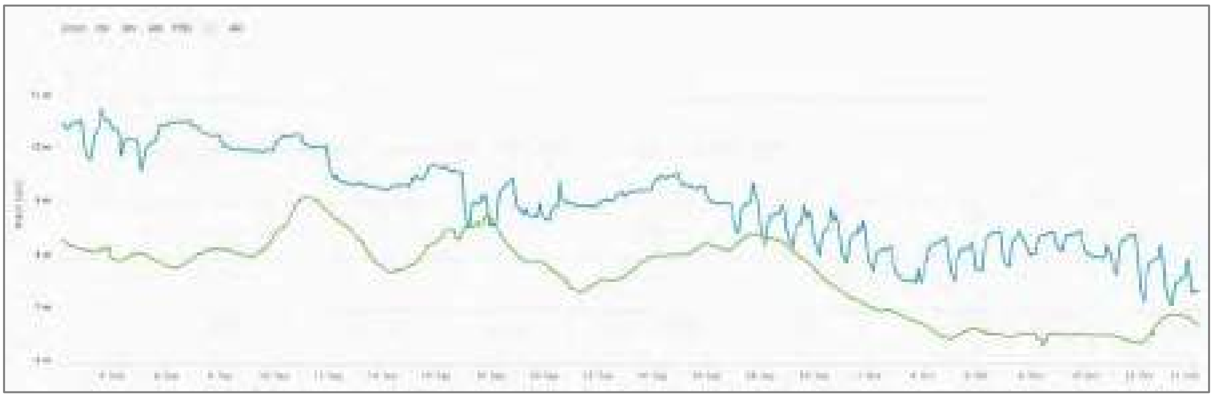


Figure 4.4. Water level at Ban Pakhoung (blue) and Ban Xanghai (green)

Note: Both sites based on 15-minute HYCOS results

4.1.1.3 Sediment upstream of Xayaburi

The MRC-coordinated long-term discharge and sediment monitoring has provided insights into changes to sediment transport associated with the development of the hydropower cascade in the Upper Mekong Basin.

Figure 4.5 compares historic suspended sediment monitoring results with DSM results collected in 2009–2013, and shows a marked decrease in the concentrations, resulting in a decrease in sediment loads.

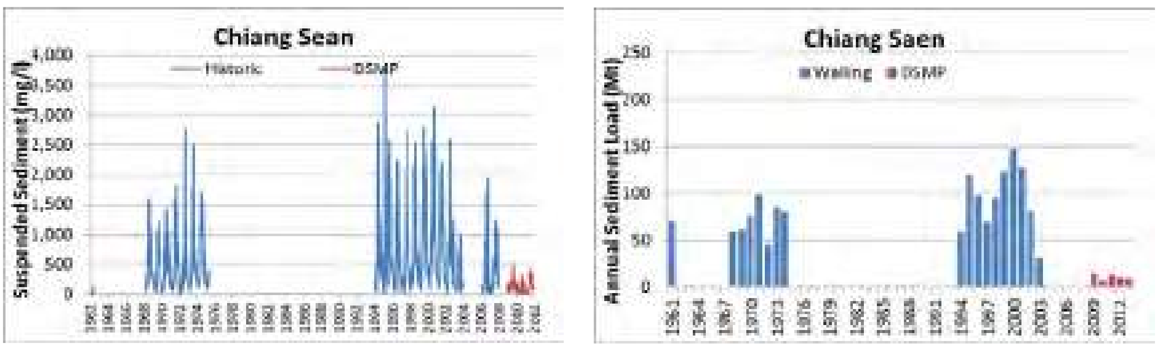


Figure 4.5. Suspended sediment concentration and calculated annual suspended sediment load at Chiang Saen, 1968–2012

Source: Koehnken (2015)

Prior to dams being constructed on the mainstream Mekong in China, annual SSC loads were estimated at around 60–100 Mt/yr. Following 2008, these loads decreased to around 10–20 Mt/yr.

This large decrease in sediment supply from the upper basin provides a context for the JEM monitoring results.

4.1.1.4 Sediment downstream of Xayaburi Hydropower Project

SSC sediment monitoring at Ban Xanghai and Ban Pakhoung was limited during JEM monitoring due to COVID-19 restrictions, with only results collected between October 2020 and May 2021 reported. This period coincided with the dry season, and the ranges of the SSC at the two sites were low, ranging from <10 mg/L to 90 mg/L (Figure 4.6). **The short time-series and the low flow sampling results are insufficient to provide insights on the degree of sediment trapping occurring within Xayaburi**. SSC monitoring at Chiang Khan and Nong Khai over the JEM period also shows low SSC results, with concentrations during the wet season generally ranging between 90 mg/L and 200 mg/L.

Figure 4.6. SSC concentration at the JEM monitoring sites in the upper LMB, June 2020 to May 2021

Note: SSC is in log scale

Source: Data collected by Thai and Lao PDR DSM teams

Long-term discharge and sediment monitoring at Chiang Khan shows that 2020 and 2021 were dry years with very low SSC concentrations, yielding low SSC loads relative to previous years (Figure 4.7*)*. Some of the decrease in SSC is likely attributable to drought conditions; however, in order to investigate whether sediment concentrations have decreased relative to flow rates since the construction of Xayaburi, the relationship between flow and SSC concentrations was statistically compared for the periods 200–2018 and 2019–2020 using an analysis of covariance (ANCOVA). The analysis was restricted to data collected when the flow was in the range of 1,700 m^3/s to 8,000 m^3/s, equivalent to the flow range captured in the 2019 to 2020 data set.

The analysis found that the relationship between flow and sediment in the 2019-2020 results is statistically different from the historic results ($p<0.01$), suggesting a reduction in sediment transport relative to flow since the end of 2018. This reduction may be due to the length of the drought relative to previous flow patterns, or to increased sediment trapping in tributary or mainstream impoundments. Since 2018, several tributary HPPs have been commissioned, including several in the large Nam Ou catchment, and Xayaburi commenced operations. Longer time series of SSC and flow at the JEM sites and the long-term DSM sites are required to further understand these changes.

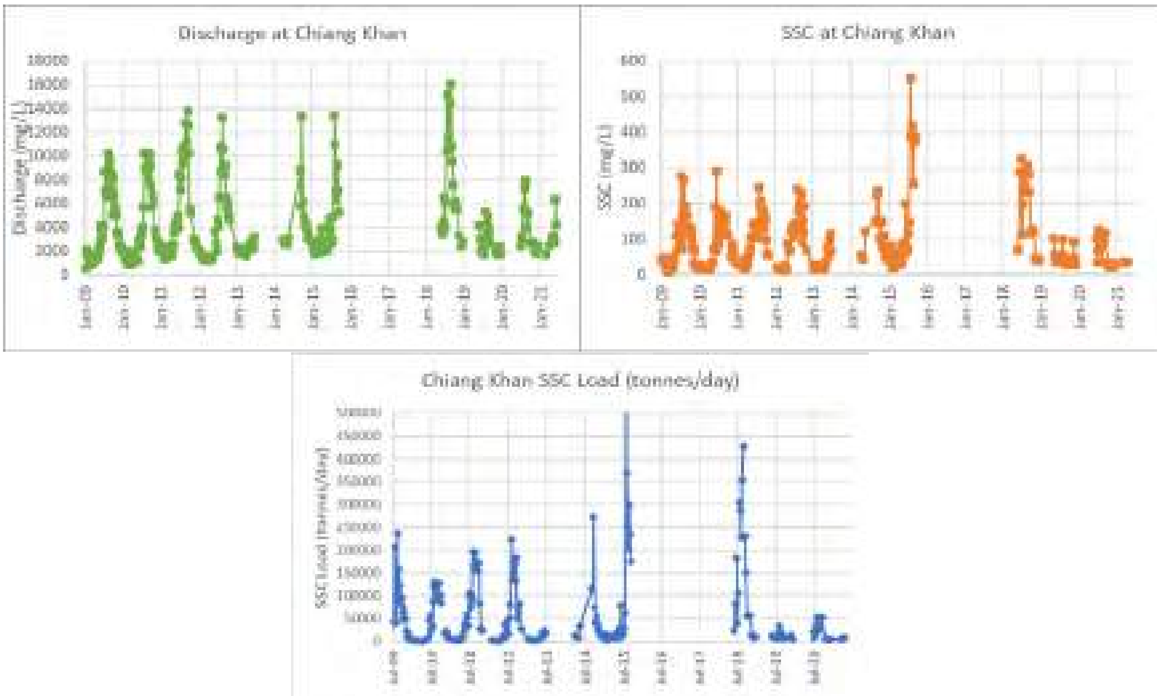


Figure 4.7. Long term discharge measurements, SSC results, and the calculated SSC loads on monitoring days from Chiang Khan

Source: Based on DSM monitoring results. Results collected by DWR Thailand

The long-term DSM monitoring results from Chiang Saen and Nong Khai also show that 2019 and 2020 had low SSC loads (Figure 4.8). The input at Chiang Saen was calculated at <5Mt/yr. This can account for some of the reduction observed at Chiang Khan; however, in all previous years, the SSC load at Chiang Khan was greater than at Chiang Saen, which was not the case in 2019. This is consistent with a decrease in sediment input occurring since 2018, in addition to reductions associated with the drought. The SSC loads for Chiang Saen for 2020 are not available due to equipment problems.

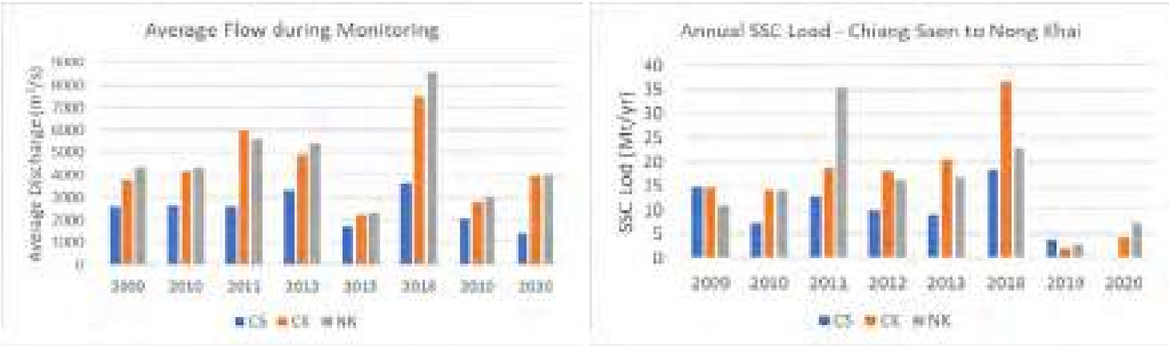


Figure 4.8. (left) Average flow on monitoring dates for Chiang Saen (CS), Chiang Khan (CK), and Nong Khai (NK). (right) Long-term SSC loads the same sites

4.1.1.5 Summary of hydropower-related impacts in northern Lao PDR

Table 4.1 summarizes the likely hydropower-related impacts that were identified through JEM and long-term DSM monitoring. Because of the high natural variability of sediment transport in rivers and the short duration of JEM monitoring, the identified trends should be further investigated and confirmed through future monitoring at the DSM and JEM sites.

Table 4.1. Summary of hydrology and sediment impacted related to hydropower operations in northern Lao PDR

Region	Hydrology Impacts from HPP	Sediment Impacts from HPPs
Upstream of Xayaburi	• Flow in river controlled / impacted by hydropower developments in China and tributaries • Water level at Luang Prabang reflects backwater of Xayaburi impoundment, and shows small daily fluctuations associated with HPP operations	• Upstream sediment loads are reduced compared to historic (pre-2008) results due to trapping in Chinese impoundments • The JEM SSC time-series at Ban Xanghai and Ban Pakhoung are insufficient to calculate SSC inputs to Xayaburi or sediment trapping in the impoundment •
Downstream of Xayaburi	• Large, rapid and frequent water level commonly occur during low and moderate flows at Ban Pakhoung • Water level fluctuations do not persist at Chiang Khan	• Sediment concentrations and loads at Chiang Khan and Nong Khai have decreased substantially since 2018, which may reflect increased trapping in tributary HPPs and in Xayaburi but a longer record of results is required to confirm this observation • Statistical analysis indicates the SSC decrease is larger than can be attributed to the flow conditions alone • A decrease in sediment inputs at Chiang Saen can account for some of the decrease, with sediment trapping in tributary HPPs and Xayaburi also likely contributors

4.1.2 Don Sahong

Monitoring sites associated with the DSHPP include a new HYCOS station near the tailraces of the project. An additional new HYCOS site was also established upstream of the 3S confluence at Koh Key, a discharge and sediment monitoring site at Stung Treng-Up, and the long-term DSM sites of Pakse, Stung Treng and Sekong Bridge at the mouth of the Sekong River (Figure 4.9).

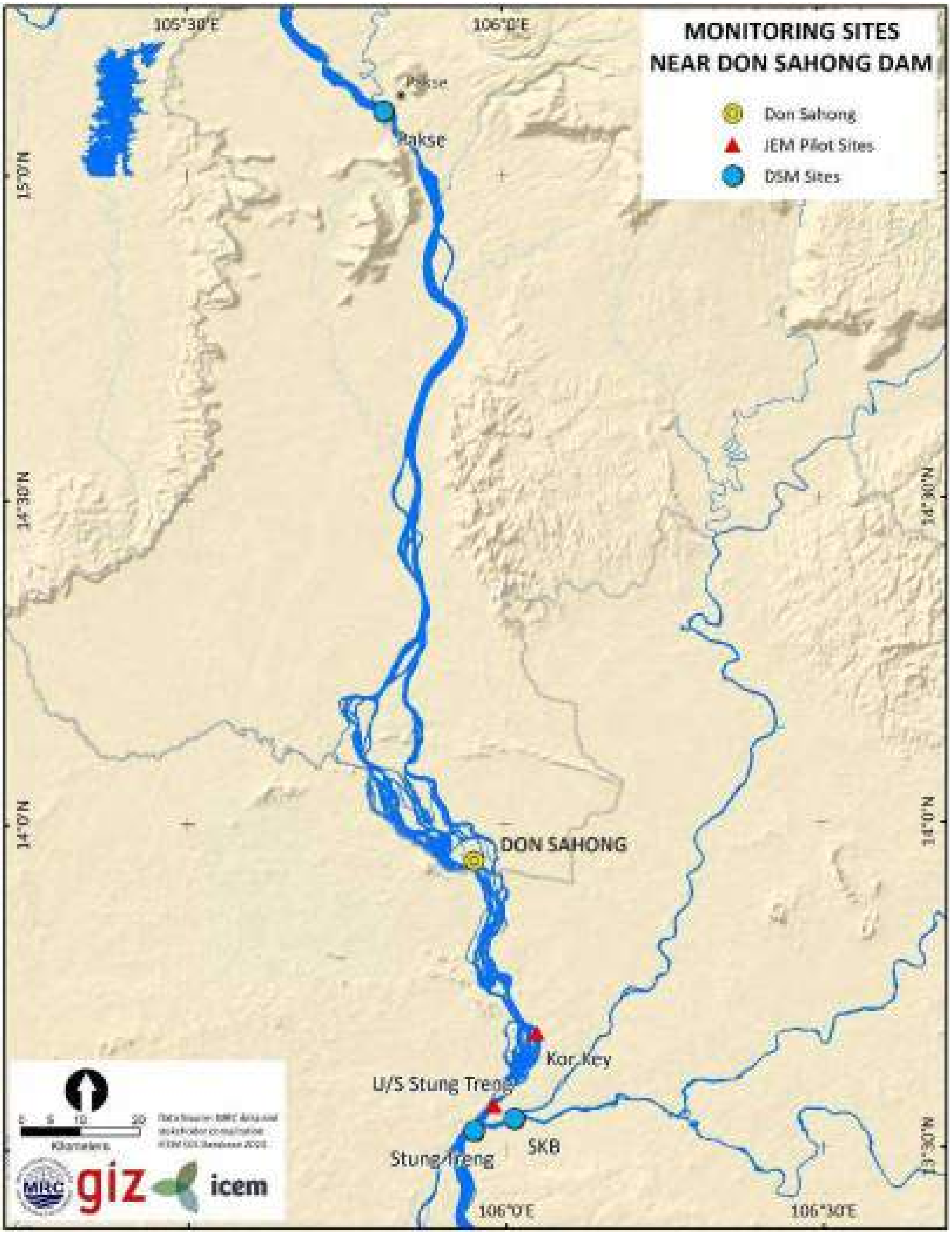


Figure 4.9. JEM-related monitoring locations near Don Sahong

4.1.2.1 Water level across Don Sahong

Continuous water level results for Pakse, Don Sahong and Koh Key are shown in Figure 4.10. The period of monitoring overlap between the sites is limited to August to October 2021, which is outside of the JEM monitoring period, due to the installation of the Don Sahong site in August. The time-series show the following characteristics:

- Small water level fluctuations are present in the Pakse water level record that are absent in the Don Sahong and Koh Key results. This suggests that the operation of tributary HPPs is having a small impact on water levels at Pakse. Comparing the water level traces demonstrates that the fluctuations do not persist through the complex Si Phan Don reach of the Mekong;
- The Don Sahong water level trace shows small perturbations, but no large water level fluctuations. The record is limited to some extent due to the base level of the probe being higher than the minimum water level occurring at the site;
- The water level record at Koh Key does not show rapid water level changes, which suggests that discharge from the DSHPP is not affecting water patterns at the site.

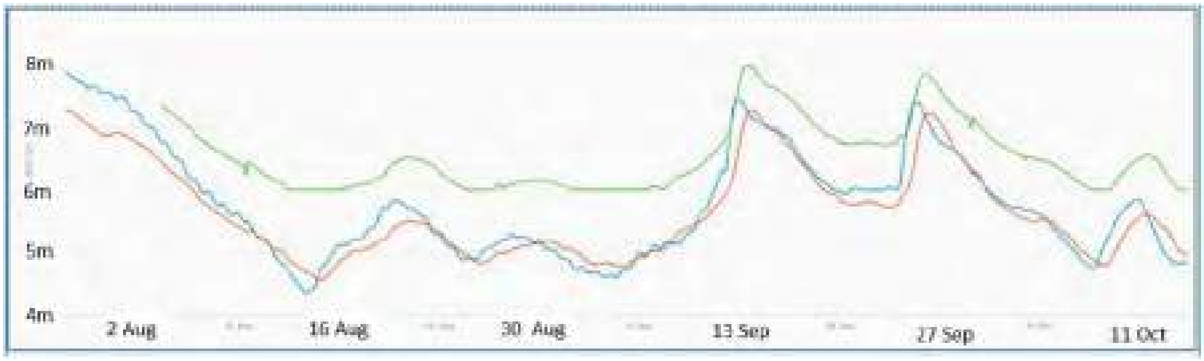


Figure 4.10. Water level at the HYCOS sites of Pakse (blue), Don Sahong (green), and Koh Key (red) for the period of overlap between the sites (August to October 2021)

Note: Water level is recorded at 15-minute intervals

Source: Data from MRC Data Portal: https://portal.mrcmekong.org/home

The operator of Don Sahong provided time series of energy production and water level in the tailrace. Periods showing wet season and dry season operations are presented in Figure 4.11 and show the following characteristics:

- During the wet season, when water level is >52 m, there is no similarity between water level in the tailrace and energy generation at Don Sahong. This suggests that water level at the tailrace is affected by the ambient level of the river as well as the discharge from the power station;

- During the dry season, when water level in the tailrace is <52 m, there is a strong similarity in the pattern of energy generation and water level in the tailrace. This demonstrates that water levels are locally affected by power station operations during periods of low water level.

A longer water level record at the MRC Don Sahong HYCOS site is required to further evaluate water level changes in the area.

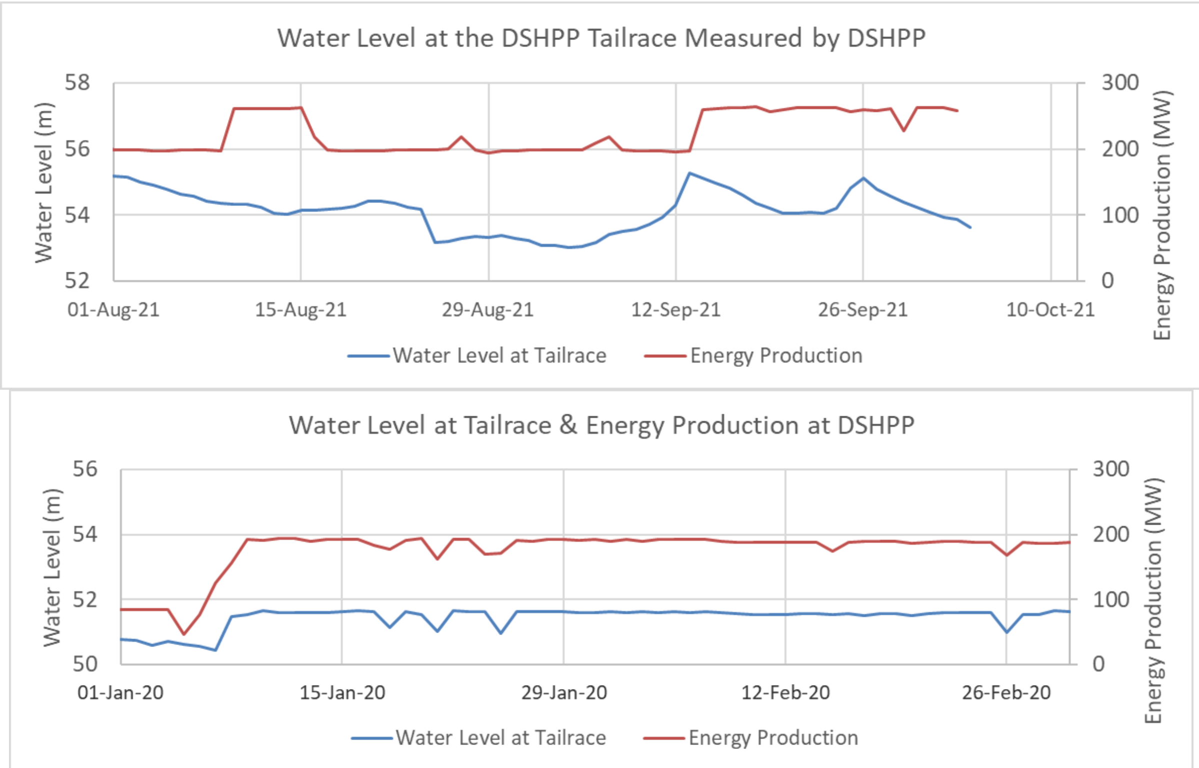


Figure 4.11. Water level at the Don Sahong tailrace and energy production as recorded by the DSHPP operators during the (top) wet season and (bottom) dry season

4.1.2.2 Water level downstream of Don Sahong

Based on the limited water level record, the operation of Don Sahong does not appear to be affecting water levels at Koh Key, but water levels at the next site downstream of Koh Key, Stung Treng shows frequent water level changes of a few centimeters (Figure 4.12).

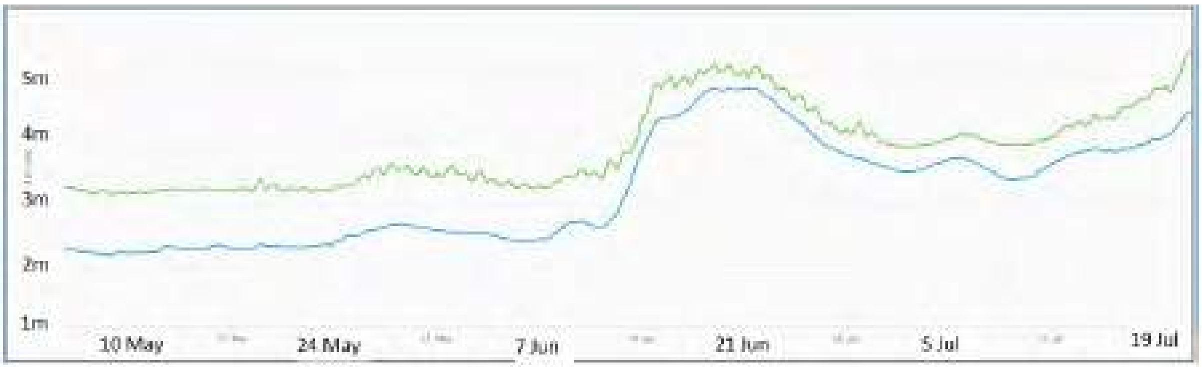


Figure 4.12. HYCOS water level at Koh Key (blue) and Stung Treng (green), May 2021 – July 2021

Source: Data from MRC data portal: https://portal.mrcmekong.org/home

The water level fluctuations must be originating in the 3S catchment, and could be associated with the operation of the Lower Sesan 2 HPP, which is located approximately 35 river km upstream of the confluence. It is expected that this magnitude of water level change poses a low risk to the Mekong mainstream because it tends to fluctuate 10 cm to 15 cm over a period of 10 or more hours. It is likely that the fluctuations are higher in the Sesan and Lower Sekong Rivers.

4.1.2.3 Suspended sediment at Don Sahong

Changes to the SSC upstream and downstream of Don Sahong cannot be investigated based on the JEM results because there are insufficient SSC results available from Pakse to compare with results from the Stung Treng – UP site.

Insights into sediment trapping at Don Sahong were provided during a presentation by the DSHPP operator to the MRC, which showed that turbidity levels were generally similar upstream and downstream of the impoundment, except at the onset of the wet season when turbidity in the impoundment is lower than in the upstream and downstream (see 3.3.2 *Water quality section*).

4.1.2.4 Suspended sediment at the 3S confluence

The JEM monitoring has provided an opportunity to better understand the distribution of sediment between the Mekong River and the 3S basin by comparing results at the new JEM site at Stung Treng-UP with the existing Stung Treng and Sekong Bridge DSM sites. This allows a better understanding of how hydropower and other water resource developments have affected sediment transport in the basin at a large scale. Similar to the results from northern Lao PDR, the DSM long-term monitoring shows a decrease in SSC concentrations and loads at the mainstream sites over time (Figure 4.13).

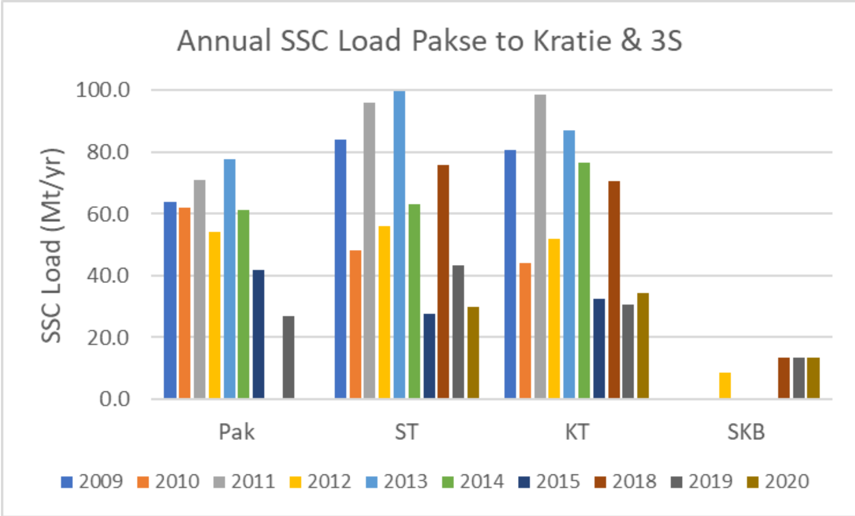


Figure 4.13. SSC loads at sites in southern Lao PDR and northern Cambodia

Notes: Pak = Pakse, ST = Stung Treng, KT = Kratie and SKB = Sekong Bridge. Annual loads are based on rating curves or interpolation of results between monitoring dates

Within this context, the JEM results provide more detail about the source and timing of sediment input to the lower river and delta.

Flow and sediment balances across the 3S confluence (Mekong at Stung Treng-UP plus 3S inflow gives total flow at Stung Treng, Figure 4.14) show that most of the flow is derived from the Mekong, with maximum flow input from the 3S occurring late in the wet season.

Figure 4.14. Flow and sediment balance across the 3S catchment for each monitoring period from April to December 2020

Source: Results collected by Cambodia DHRW

The sediment load balance also shows that the Mekong contributing most of the sediment during most of the monitoring runs; however, during October, a very large sediment pulse was recorded at the Sekong Bridge site. This magnitude of sediment input likely reflects large-scale landslips in the catchment, or possibly the release of sediment from one or more HPPs. The SSC results suggest that almost half of the SSC load was derived from the 3S compared to only 25% of the flow, as measured at Stung Treng. Understanding the sources of flow and sediment is important for tracking trends for basin management.

4.1.2.5 Summary of hydropower related impacts in southern Lao PDR

Table 4.2 summarizes the likely hydropower-related impacts that have been identified through JEM and long-term DSM monitoring. Due to the high natural variability of sediment transport in rivers and the short duration of JEM monitoring, the identified trends should be further investigated and confirmed through future monitoring at the DSM and JEM sites.

Table 4.2. Summary of hydropower-related impacts identified through JEM monitoring

Region	Hydrology Impacts from HPP	Sediment Impacts from HPPs
Upstream and at Don Sahong (Pakse, Don Sahong)	• Flow levels at Pakse show small scale water level fluctuations related to the operation of HPPs in the tributaries • Water level fluctuations observed at Pakse are not present at Don Sahong. • Water level at the Don Sahong tailrace is affected by the river flow as well as discharge from the HPP.	• There are insufficient SSC monitoring results available at Pakse to compare SSC concentrations or loads upstream and downstream of the DSHPP. • The operator of the DSHPP presented monitoring results showing some reduction in turbidity at the start of the wet season reflecting sediment trapping in the impoundment.
Downstream of Don Sahong (Don Sahong, Koh Key, Stung Treng UP)	• The water level monitoring results from the Koh Key HYCOS site do not show any water level fluctuations related to hydropower operations, with the water level records showing strong similarities to Pakse. • Water level fluctuations are present at the Stung Treng HYCOS site, and reflect hydropower operations in the 3S basin.	• Sediment loads in the Mekong mainstream have shown a decrease over time attributable to trapping in impoundments in China and tributaries • A very large influx of sediment from the 3S basin to the Mekong occurred in October 2020, which may reflect sediment flushing or large scale slope failure

4.2 WATER QUALITY

WQ at both pilot sites was monitored monthly between October 2020 and June 2021, except for May 2021, when sampling could not take place because of COVID-19 travel restrictions. Measurements were taken by probe for temperature, pH, conductivity, dissolved oxygen (DO), and turbidity, chlorophyll-a and cyanobacteria content, and samples taken for laboratory analysis were total suspended solids (TSS), nutrients, chemical oxygen demand (COD) and faecal coliforms (FC). Within the impoundment, WQ profiles were taken in the water column at 1-m intervals down to 20 m depth.

Data at the JEM pilot monitoring stations were compared with the WQMN routine monitoring as reference with results presented as box and whisker charts showing median, maximum and minimum for the period October 2020 to June 2021. The reference WQMN routine monitoring sites used were above and below the Xayaburi dam at Luang Prabang and

Vientiane, and above and below the Don Sahong dam at Pakse and Stung Treng. Results are analysed in three different groupings:

- General WQ parameters;
- Nutrients and phytoplankton;
- Indicators of poor WQ.

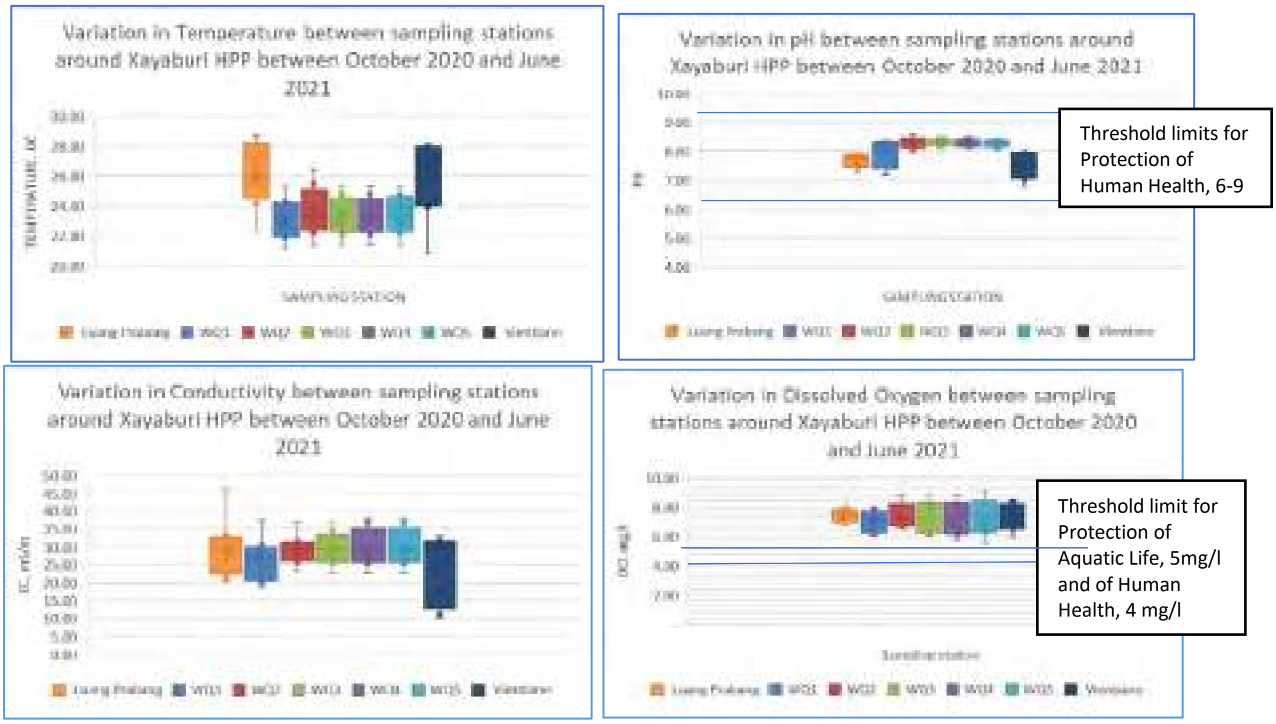
Where appropriate, the threshold limits from the MRC Guidelines for Protection of Human Health and for Protection of Aquatic Life are indicated to highlight readings that are either above or below these thresholds.

4.2.1 Xayaburi

The results of the analyses of the surface water samples at the Xayaburi JEM sites (WQ1 to WQ5) with reference to the Luang Prabang and Vientiane reference sites are presented in Figure 4.15 to Figure 4.17.

4.2.1.1 Surface water results

Water quality results with passage through the impoundment and downstream of the dam (Figure 4.15) do not show any obvious patterns of changes in the general WQ parameters of temperature, pH, conductivity and DO. The readings from the impoundment are more frequently statistically (p-value <0.05) higher for temperature, pH, DO, and conductivity than from above the impoundment, and for temperature, pH, and DO compared to the downstream sites, which show less variability.



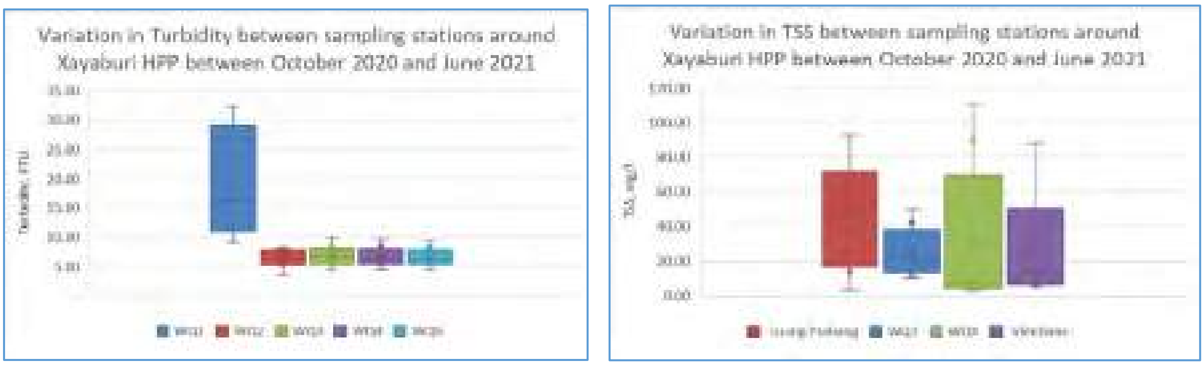


Figure 4.15. Box and whisker charts for water quality parameters, temperature, pH, conductivity, DO, turbidity, and TSS at Xayaburi JEM sites, October 2020 – June 2021

Note: “x” indicates the mean value, the line indicates median values, and the boxes are the upper and lower quartiles range, with outliers indicated above or below.

Although the WQ conditions in the impoundment are different from the riverine sites, none of the parameters in the impoundment exceed the MRC’s thresholds of water quality guidelines for the Protection of Human Health. This would indicate that the operation of the Xayaburi HPP has not affected these parameters substantially to reduce the overall WQ conditions, at least at the time of visits for the eight monthly samples. It must be noted that these parameters, especially DO and pH, may vary over a 24-hour period, and the sampling time is usually during the middle of the day when oxygen levels would be expected to be higher. During the night, phytoplankton are not photosynthesizing and are consuming oxygen, so DO levels decrease, CO_2 levels increase with slight acidification, which reduces pH concentration in the water. To capture diurnal changes in WQ, it would be necessary to install high frequency WQ monitoring equipment.

The main differences between upstream and downstream occur in the results of TSS and turbidity, with the impoundment and downstream results generally much lower than upstream, with median values falling by up to 60%. Turbidity is more frequently significantly higher above the impoundment than in the impoundment or downstream. This indicates a major role in trapping of sediments in the impoundment, which are thus removed from the sediment load transported downstream. There is one higher value of TSS in WQ4 downstream site, which might be caused by a minor flushing event by the hydropower operation or downstream bank erosion caused by water fluctuations in November 2020; however, without information on the operation at the time, it is impossible to make this correlation.

The median, maximum and minimum results of nutrients – NO32 and total phosphorus – and phytoplankton – chlorophyll-a and cyanobacteria – for October 2020 to June 2021 are shown in Figure 4.16, together with appropriate threshold values.

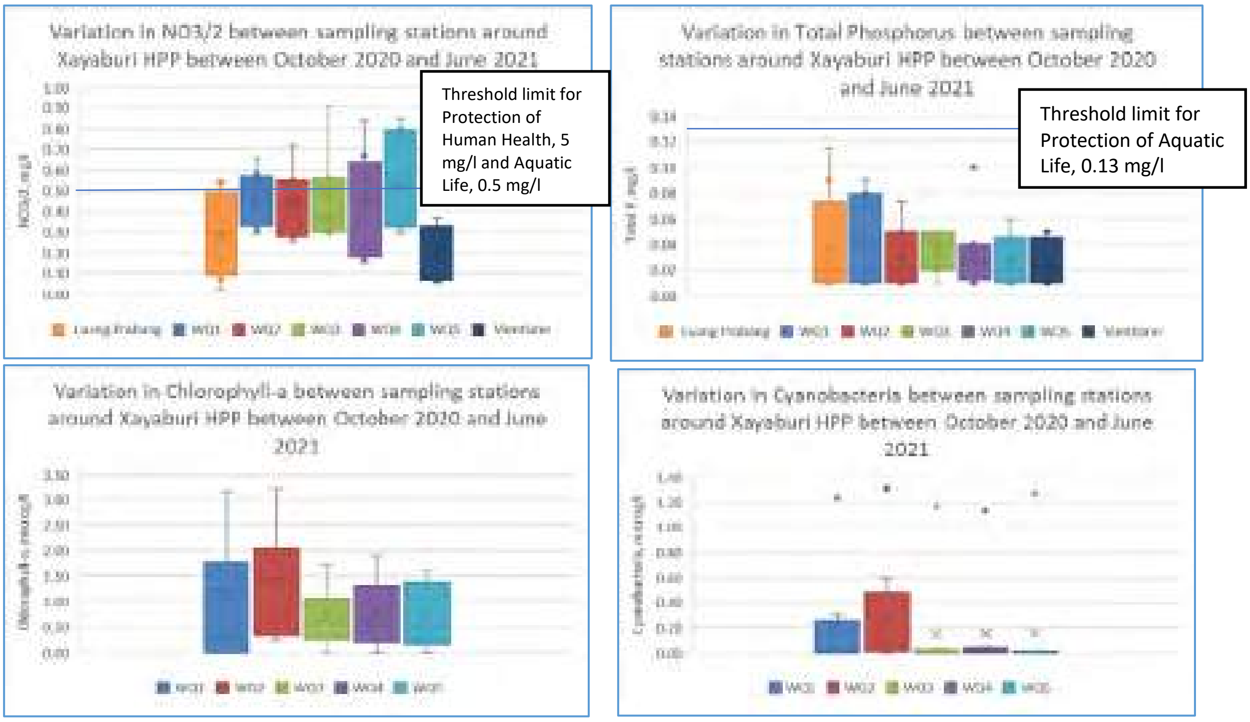


Figure 4.16. Box and whisker charts for nutrients, NO32 and total phosphorus, chlorophyll-a and cyanobacteria at Xayaburi JEM sites, October 2020 – June 2021

Note: "x" indicates the mean value, the line indicates median values, and the boxes are the upper and lower quartiles range, with outliers indicated above or below.

The parameters for nutrients and phytoplankton are more variable each month, but generally reflect incoming nutrient levels. NO32 values are generally lower than the threshold values for the Protection of Aquatic Life (0.5 mg/l), but with some higher values well below the threshold for the Protection of Human Health (5 mg/l). Generally, TOTP levels were below the threshold levels of 0.13 mg/l, but on one month, December 2020, very high TOTP levels were recorded, four times higher than ever recorded in the WQMN monitoring at any site on the Mekong. These have been considered to be due to sampling error, but regular monitoring needs to be aware of future events when high levels of TOTP are recorded, because there is a recognized relationship between raised TOTP and cyanobacteria blooms.

The median levels for chlorophyll-a in the impoundment are generally higher than downstream. This indicates that phytoplankton, especially cyanobacteria, are concentrated in the impoundment, but the concentrations recorded are well below levels of 50 micrograms/litre recognized as a moderate health alert according to World Health Organization (WHO) threshold levels of cyanobacteria in freshwater for recreational waters. There is one month, January 2021, when the proportion of cyanobacteria in the river is generally very high, up to 80% of the chlorophyll-a in the impoundment, indicating a growth spurt of blue-green algae, although the concentrations are still very low.

The median, maximum, and minimum results of indicators of pollution – COD, ammonium and FC – are shown in Figure 4.17.

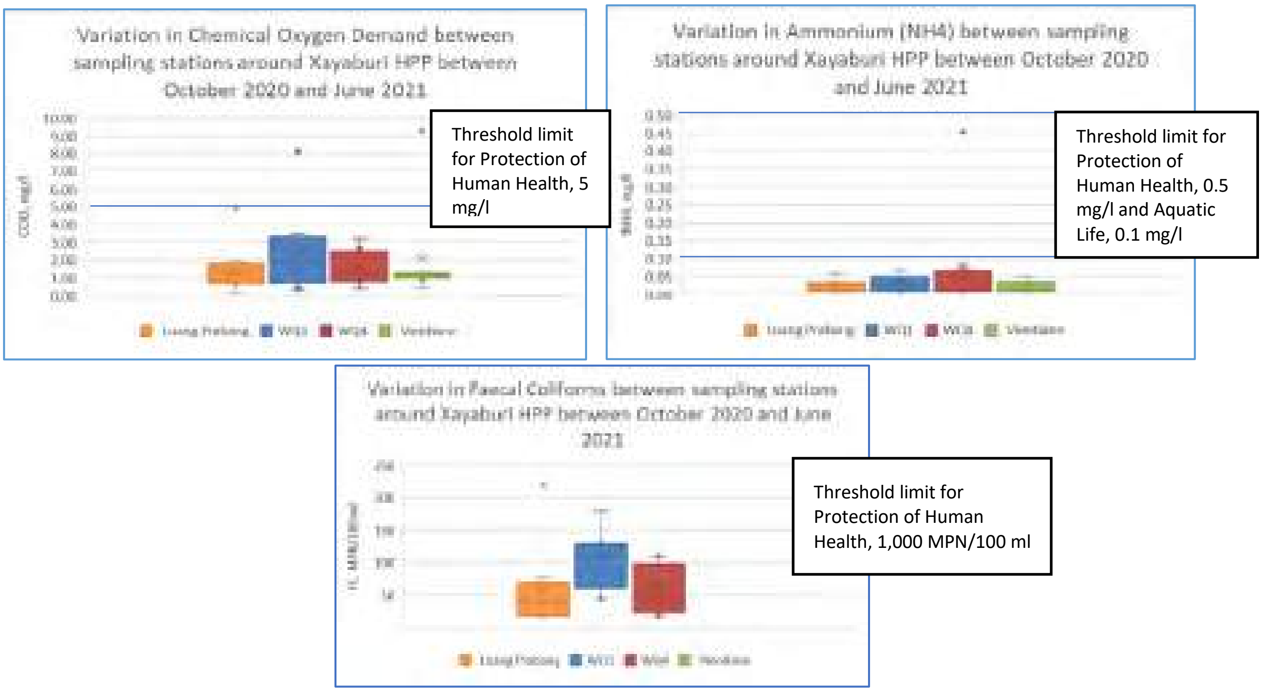


Figure 4.17. Box and whisker charts for indicators of poor water quality COD, ammonium and faecal coliforms at Xayaburi JEM sites, October 2020 – June 2021

Note: "x" indicates the mean value, the line indicates median values, and the boxes are the upper and lower quartiles range, with outliers indicated above or below

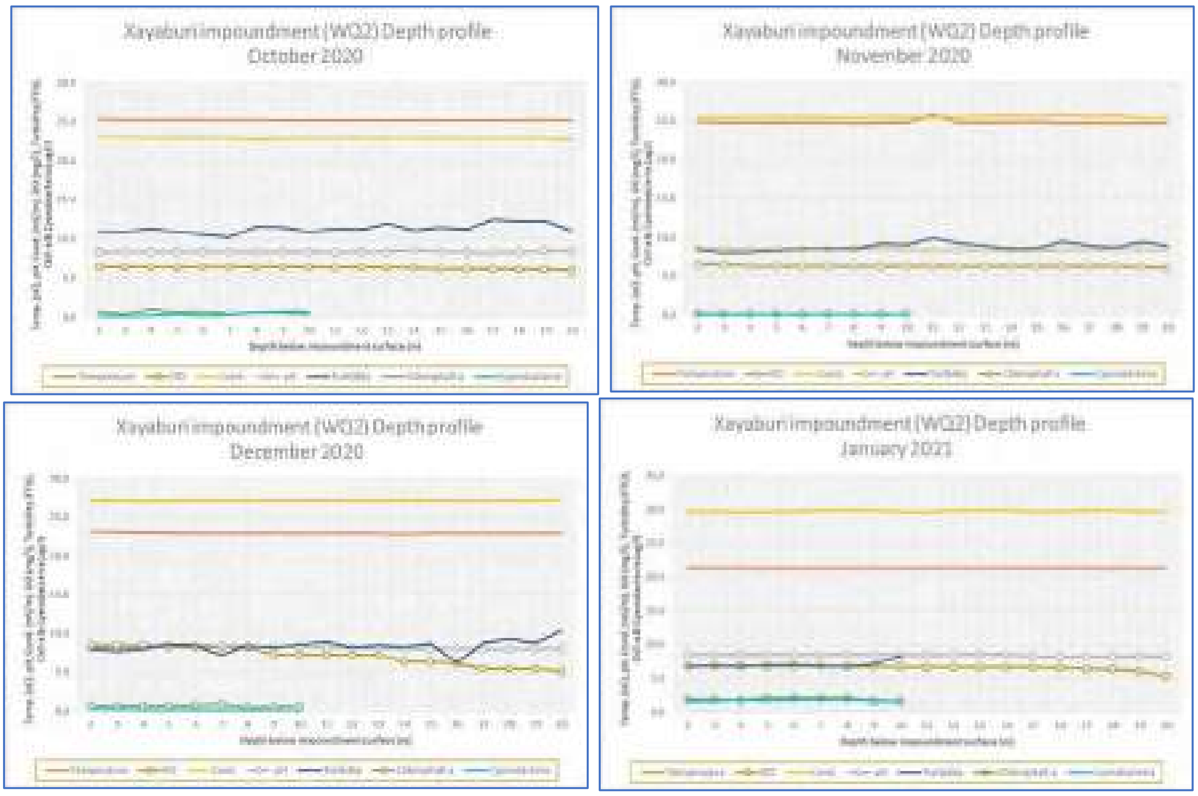
Generally, there was little or no change with passage downstream through the impoundment and below the dam, and generally. the readings were below the threshold values for the Protection of Human Health and Protection of Aquatic Life. There were three occasions when COD levels were at or above the threshold at Luang Prabang, WQ1, and in Vientiane, but these were not connected with the Xayaburi HPP.

4.2.1.2 Impoundment water quality depth profiles

The other set of parameters that are important for the operation of the Xayaburi HPP are the impoundment depth profiles to determine whether stratification is occurring. Stratification can occur in impoundments and reservoirs if the upper and lower layers of water are not mixed and become separated by temperature differences, so that upper layers are more equilibrated with ambient air temperatures, and lower layers become progressively colder with depth. If the layers are not mixed, lower layers will become depleted in DO, and may even become anaerobic near the bottom. pH will tend to become more acidic under these conditions, and there may also be changes in conductivity. Because of poor WQ in the bottom layers of a stratified reservoir, the benthic fauna will favour more tolerant species and will deter most fish species.

If stratification is present and the dam offtake is located at depths below the levels where temperature, pH, and DO are reduced, this may be one of the causes of poor WQ passing downstream. Also, at certain times of the year, a stratified reservoir may become mixed, e.g. under the influence of wind or inflow of warmer water into the bottom layers, with the result that poor quality water can be brought to the surface, leading to mortality of fish and other aquatic biota.

Monthly depth profiles at 1-m intervals down to 20 m below the surface for the sampling period from October 2020 to June 2021 are shown in



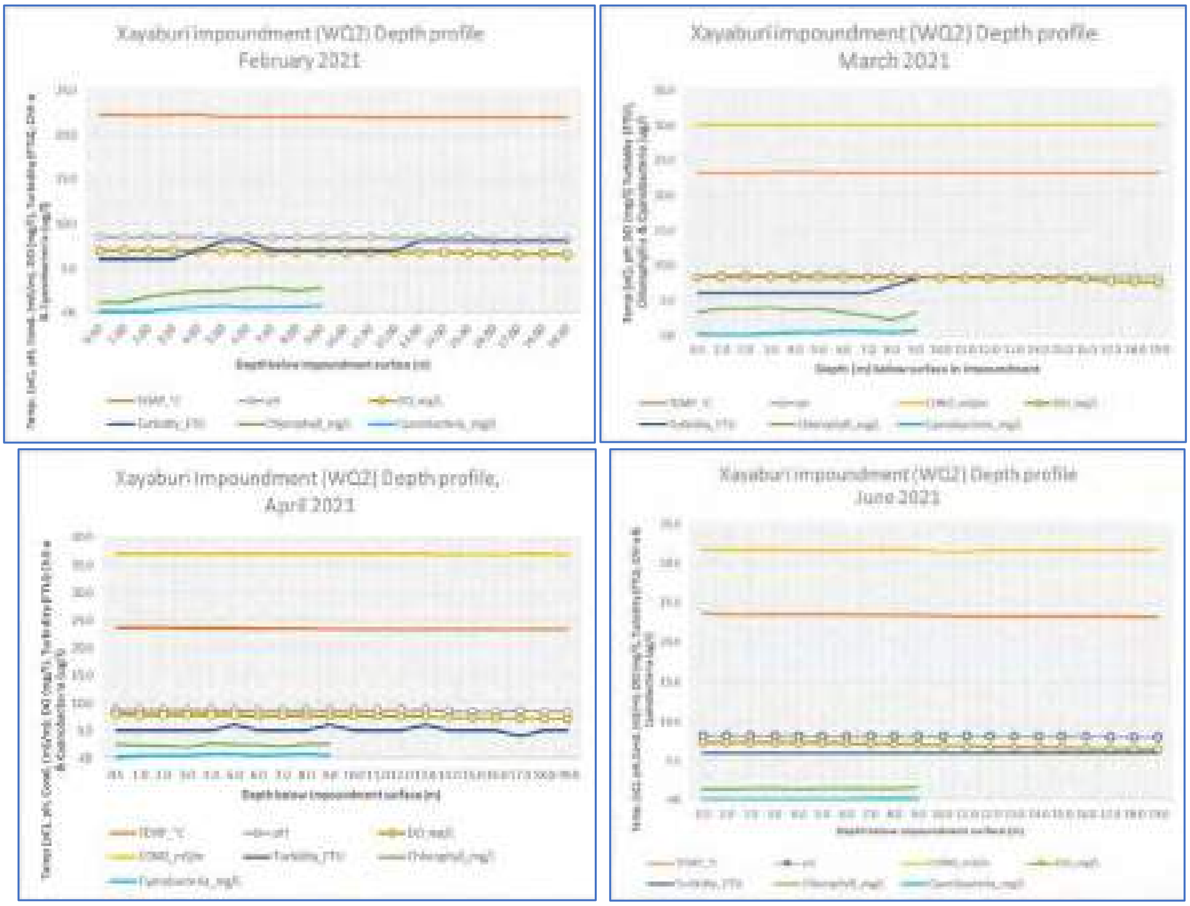


Figure 4.18. Xayaburi impoundment profiles, October 2020 – June 2021

Most of the parameters showed that there was no difference in the measurements made at different depths down to 20 m, indicating that stratification was not occurring, except in December 2020, when DO fell progressively with depth from about 8.0 mg/l, to about 5.0 mg/l, and it could have fallen to levels lower than the 5 mg/l DO threshold for Protection of Aquatic Life at depths below 20 m. The same pattern occurred to a more limited extent in January 2021.

Phytoplankton levels measured by chlorophyll-a and cyanobacteria are variable with depth, but without showing any regular depth patterns. Generally, the chlorophyll-a has a much higher value than the cyanobacteria, except in January 2021, when the same high proportions of blue-green algae are found in the water column as at the surface. In other months, there may be a slight increase in cyanobacteria with depth, but these appear to be marginal increases. There may be a tendency for the cyanobacteria to reduce at the beginning of the rainy season in June 2021, but this would have to be confirmed with analysis of wet season sampling.

4.2.1.3 Summary of water quality findings around Xayaburi

In summary, the WQ results around Xayaburi indicate the following:

- It appears that the presence of the Xayaburi dam and impoundment does not affect most parameters of WQ measured during the dry season months between October 2020 and June 2021;
- The main parameters that show changes with passage through the impoundment and below the dam are turbidity and TSS, indicating sedimentation processes in the impoundment removing suspended solids. Median turbidity and TSS values drop by up to 60–70% in the impoundment and downstream compared to upstream;
- Nutrient levels appear to be slightly increased in the impoundment, but not passed on downstream below the dam, although abnormally high levels of total phosphorus, as recorded in December 2020, need to be watched in conjunction with phytoplankton blooms;
- There may be a slight indication of higher phytoplankton levels in the impoundment compared to downstream and a probable growth spurt of cyanobacteria in January 2021;
- Impoundment profiles do not show thermal or chemical stratification, although there may be evidence of declining DO with depth during the colder months of January and February 2021.

4.2.2 Don Sahong

The results of the analyses of the surface water samples at the Don Sahong JEM sites (WQ6 to WQ9) with reference to the Pakse and Stung Treng long-term sites are presented in Figure 4.19 to Figure 4.21.

4.2.2.1 Surface water results

The WQ results with passage through the impoundment and downstream of the Don Sahong dam (Figure 4.19) do not show any obvious patterns of changes, either in the general WQ parameters of temperature, pH, conductivity and DO. DO levels were always above the thresholds for the Protection of Aquatic Life and for the Protection of Human Health. This would indicate that the operation of the DSHPP has not affected these parameters, at least at the time of visits for the eight monthly samples. It must be noted that these parameters, especially DO and pH, may vary over a 24-hour period, and the sampling time is usually during the middle of the day, when oxygen levels would be expected to be higher.

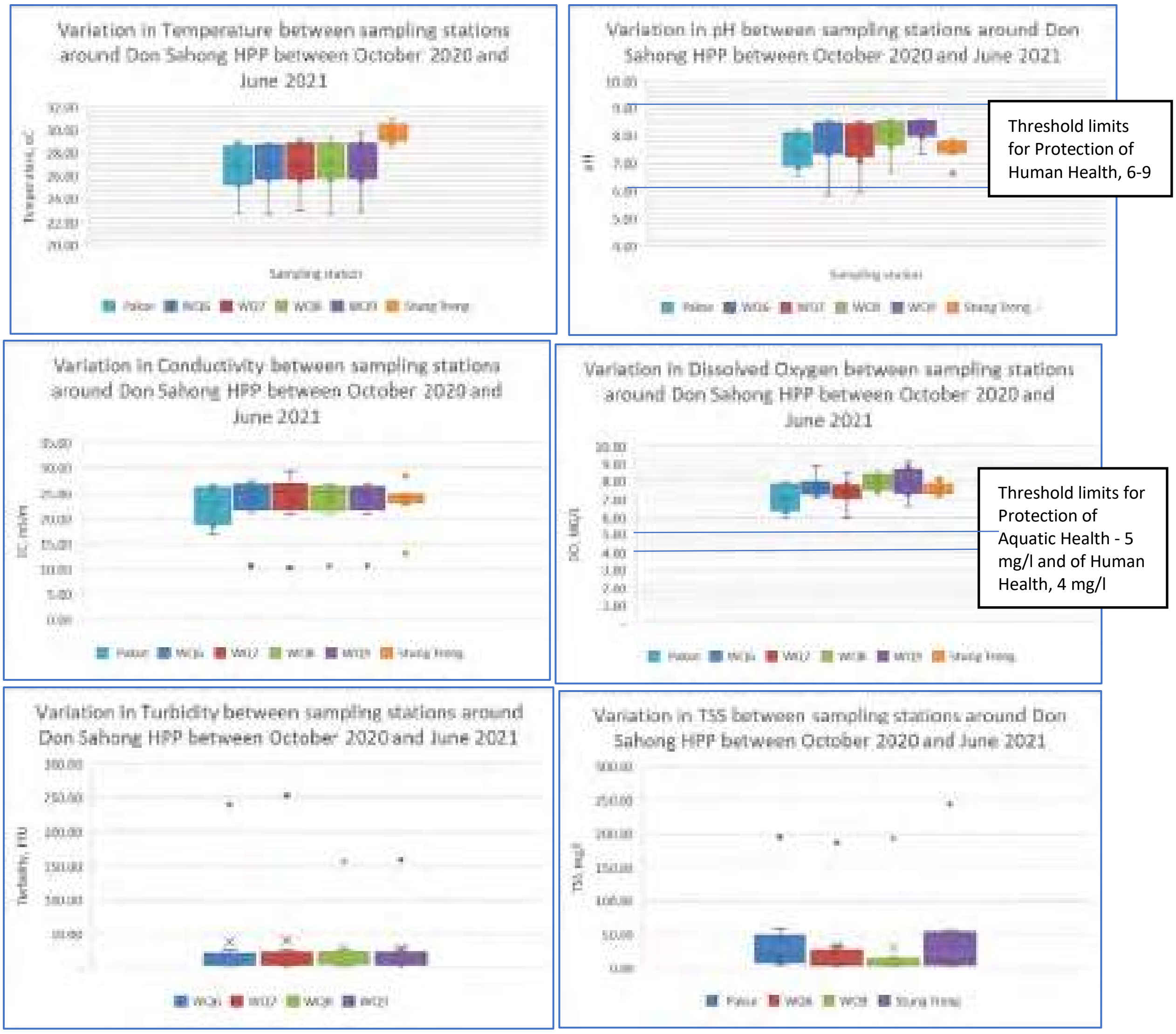


Figure 4.19. Box and whisker charts for water quality parameters, temperature, pH, conductivity, DO, turbidity and TSS at Don Sahong JEM sites, October 2020 – June 2021

Note: "x" indicates the mean value, the line indicates median values, and the boxes are the upper and lower quartiles range, with outliers indicated above or below.

Unlike in Xayaburi, there are no marked differences between upstream and downstream in the results of TSS and turbidity; the impoundment and downstream results generally have similar values to those at WQ6 upstream. The high outliers shown in these charts relate to the October 2020 monitoring visit when flows in the river were higher. This would indicate that smaller impoundment at Don Sahong, with a much lower residence time, is not trapping sediments to the same extent.

The median, maximum and minimum results of nutrients – NO32 and total phosphorus – and phytoplankton – chlorophyll-a and cyanobacteria – for October 2020 to June 2021 are shown in Figure 4.20, together with appropriate threshold values.

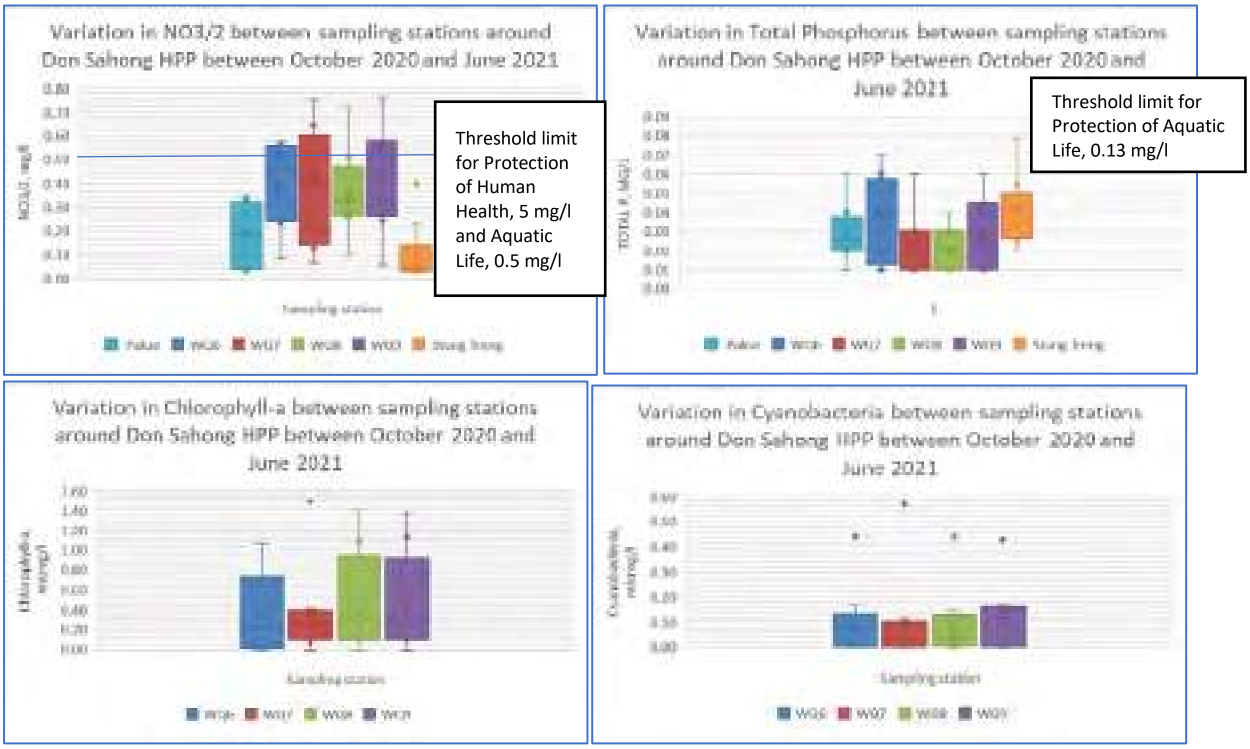


Figure 4.20. Box and whisker charts for nutrients – NO32 and total phosphorus, and for phytoplankton – chlorophyll-a and cyanobacteria, at Don Sahong JEM sites, October 2020 – June 2021

Note: "x" indicates the mean value, the line indicates median values and the boxes are the upper and lower quartiles range, with outliers indicated above or below.

The parameters for nutrients and phytoplankton are more variable each month, but generally reflect incoming nutrient levels. The median nitrate/nitrite levels around Don Sahong tend to be higher than at Pakse and at Stung Treng, but since WQ6 has similar levels to the levels at WQ7 to 9, these probably reflect local inputs of nutrients rather than changes due to plant operation. NO32 levels are generally below the thresholds of the MRC's Water Quality Guidelines for the Protection of Aquatic Life (0.5 mg/l), occasionally increasing but well below the thresholds for Protection of Human Health (5 mg/l). Total phosphorus concentrations tend to be lower within the impoundment and immediately downstream compared to upstream, which may reflect some trapping of phosphorus in the impoundment, but all were lower than the threshold of the MRC's Water Quality Guidelines for the Protection of Aquatic Life (0.13 mg/l). However, unlike in Xayaburi JEM sites, the median levels for chlorophyll-a are generally very similar upstream and downstream. This is similar to cyanobacteria, although there are some higher outlier values, for example, in February 2021 when the proportion of cyanobacteria in the river is generally higher – up to 40% of the chlorophyll-a in the river – indicating a growth spurt of blue-green algae. Nevertheless, the concentrations are still very low, and well below the levels of 50 micrograms/litre recognized as a moderate health alert recommended by WHO threshold levels of cyanobacteria in freshwater for recreational waters.

The median, maximum, and minimum results of indicators of pollution – COD, ammonium and FC – are shown in Figure 4.21. Generally, there was little or no change with passage downstream through the impoundment and below the dam, and the readings were usually below the threshold values for the Protection of Human Health and Protection of Aquatic Life. There was one occasion when COD was above the threshold at Pakse and when ammonium concentrations were above the threshold at Stung Treng, but these were not connected with the DSHPP. These are occasional instances when pollution indicators are raised, and reflect relatively small pollution events, rather than being caused by the impoundment or dam.

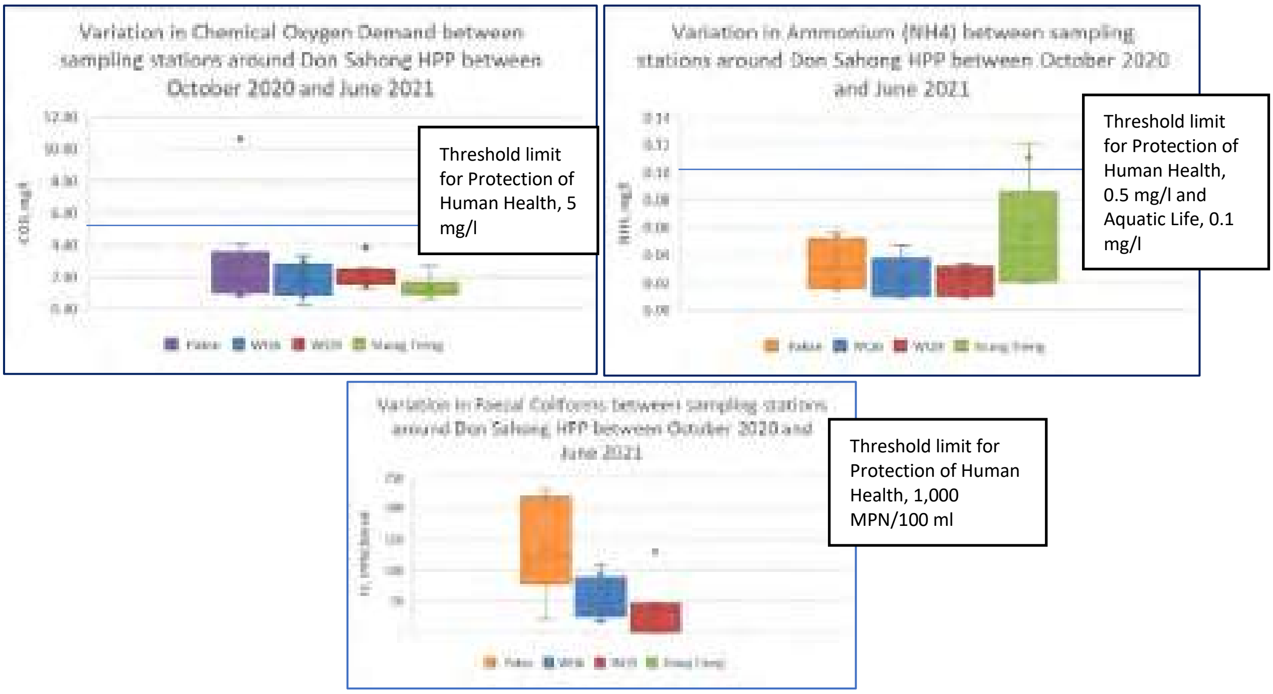


Figure 4.21. Box and whisker charts for indicators of poor water quality COD, ammonium and faecal coliforms at Don Sahong JEM sites, October 2020 – June 2021

Note: "x" indicates the mean value, the line indicates median values, and the boxes are the upper and lower quartiles range, with outliers indicated above or below.

4.2.2.2 Impoundment water quality depth profiles

The other set of parameters that are important for the operation of the DS HPP are the impoundment profiles to see whether stratification is occurring. If stratification is present and the dam offtake is located at depths below the levels where temperature, pH and DO are reduced, this can be one of the causes of poor WQ passing downstream. Figure 4.22 shows that during the sampling period from October 2020 to June 2021, there was little difference in most of the parameters at 1-m intervals down to 20 m, indicating that stratification was not occurring, except in January 2021, when DO fell progressively with depth from about 8.0 mg/l, to slightly greater than 5.0 mg/l. This also mirrors the pattern experienced in Xayaburi, but a month later.

The turbidity measurements appear to be slightly more variable with depth, especially in November 2020, and the phytoplankton measurements down to 10 m generally show similar levels throughout the water column, with chlorophyll-a being a much higher value than the cyanobacteria, except in January 2021, when the same high proportions of blue-green algae are found in the water column as at the surface.

The turbidity measurements are more variable with depth, and the phytoplankton measurements down to 10 m show variable levels throughout the water column, though in January, March and June 2021, there appears to be tendency for chlorophyll-a to increase with depth. Chlorophyll-a has a much higher value than the cyanobacteria, except in November and December 2020, and April 2021, when the cyanobacteria concentration increases at depth and sometimes matching the chlorophyll-a readings. This would indicate that in some months, the cyanobacteria may concentrate at depths.

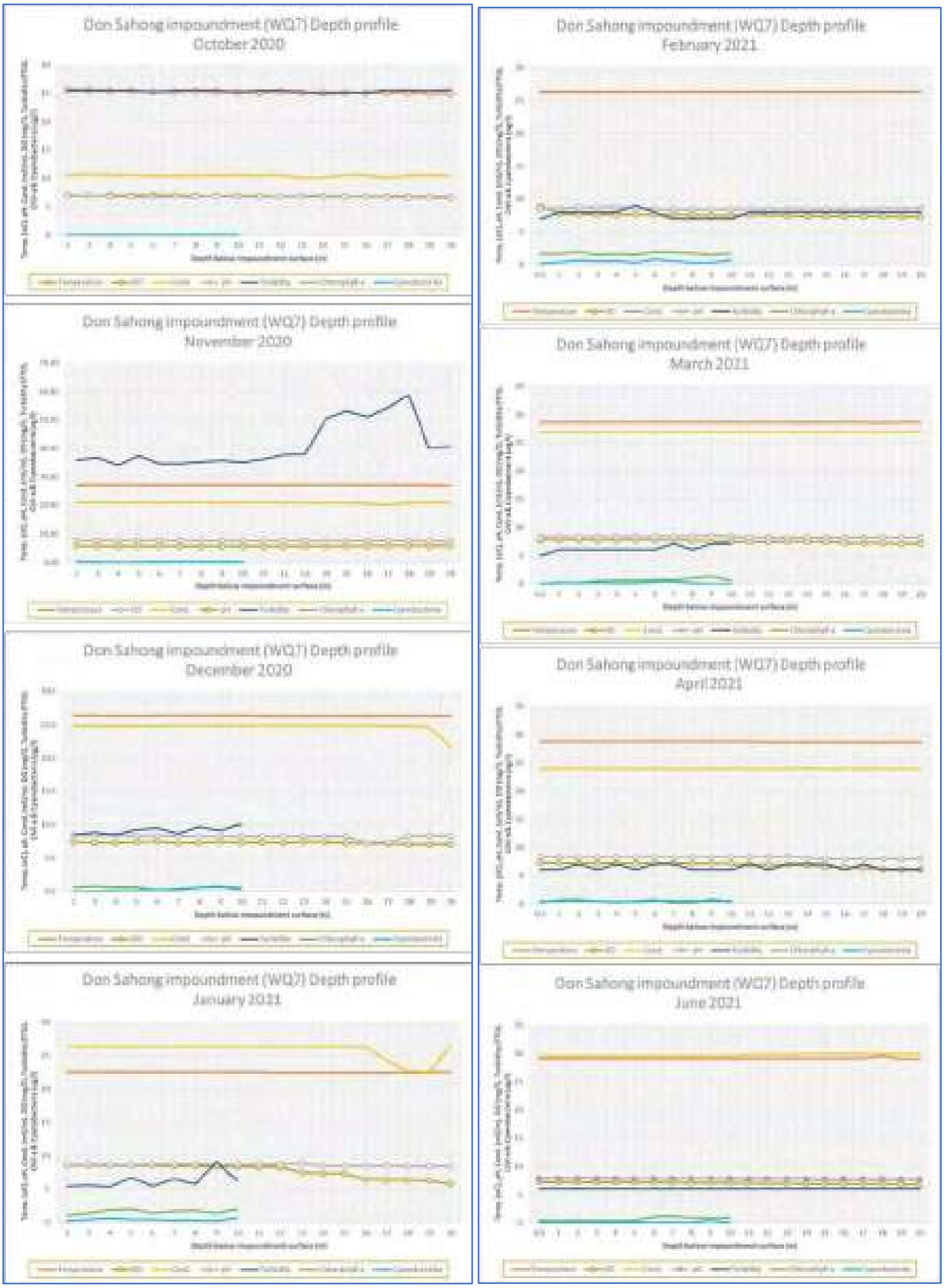


Figure 4.22. Don Sahong impoundment (WQ7) profiles, October 2020 – June 2021

4.2.2.3 Summary of water quality findings around Don Sahong

In summary, the WQ results around DS HPP indicate the following:

- The presence of the Don Sahong dam and impoundment does not appear to be affecting most parameters of WQ measured during the dry season months between October 2020 and June 2021;
- Unlike the Xayaburi pilot site, the turbidity and TSS do not show clear patterns of changes with passage through the impoundment and below the dam, perhaps indicating that the low residence time in the small Don Sahong impoundment does not allow sediment to settle out;
- NO32 levels appear to be slightly higher in the sampling stations around Don Sahong than Pakse and Stung Treng, probably due to increasing agricultural run-off with progress downstream, but these nutrient levels are not affected by the dam. TOTP levels are lower in the impoundment and downstream of the dam than in upstream stations, which may indicate trapping of Phosphorus;
- There is a slight indication of higher phytoplankton levels in the impoundment compared to downstream and a probable minor growth spurt of cyanobacteria in February 2021;
- Impoundment profiles do not show thermal or chemical stratification, although there may be evidence of declining DO with depth during the colder month of January 2021.

4.2.3 Basin-wide water quality comparisons

The JEM results have been compared to the WQMN sites along the Mekong mainstream by calculating the WQ Indices for the Protection of Aquatic Life and the Protection of Human Health. The calculations have been made for the two years previous to the JEM pilots, i.e. 2019 and 2020, with 11 or 12 monthly samples taken. By comparison, the eight samples taken from the JEM pilot sites from October 2020 to June 2021 have been aggregated as the 2021 figures, noting that these do not include any substantive wet season figures. The results of both WQ Indices are shown in Table 4.3, together with the parameters that have failed by exceeding the target values.

The results show that most stations, including all the JEM stations, can be classified as having 'high' or 'excellent' quality for the WQ Index for the Protection of Aquatic Life and the WQ Index for the Protection of Human Health. However, Stung Treng and Kratie recorded a slightly reduced classification to 'good quality' in 2019 and 2020, failing to meet the Aquatic Health thresholds on one or two occasions for ammonium and total phosphorus. Pakse and Stung Treng were classified as lower to 'good quality' according to the WQ Index for the Protection of Human Health in 2020, failing to meet the COD thresholds on one or two occasions.

Although the JEM pilot sites are classified as being 'excellent' or 'high' quality according to the WQ Index, the results also show several instances when the thresholds are exceeded at all sites. Principally, the failing parameters at the Xayaburi JEM sites are NO32 and TOTP for

WQ Index of Aquatic Health and COD at WQ1 for WQ Index for Human Health. At the Don Sahong impoundment, the failing parameters are pH, NO32, and TOTP.

Table 4.3. WQ Indices for all mainstream WQ stations and JEM stations for 2019, 2020, and 2021

		WQ Index Aquatic Health				WQ Index Human Health			
WQ sampling station	**ID**	**2019**	**2020**	**2021**	**Failing parameter**	**2019**	**2020**	**2021**	**Failing parameter**
Houa Khong	H010500	**9.92**	10	10	NO32	100	100	100	
Chiang Saen	H010501	10	**9.64**	10	NH4, NO32, TotP	100	100	100	
Luang Prabang	H011200	**9.92**	10	10	NO32	100	100	100	
Xayaburi	WQ1			**9.88**	TotP			**95.83**	COD
	WQ2			**9.63**	NO32, TotP			100	
	WQ3			**9.63**	NO32, TotP			100	
	WQ4			**9.63**	NH4, TotP			100	
	WQ5			**9.25**	NO32, TotP			100	
Vientiane	H011901	**9.75**	**9.82**	10	Cond, NO32, TotP	100	**95.8**	100	COD
Nakhon Phanom	H013101	**9.75**	10	**9.67**	NH4, TotP	**99.09**	100	100	COD
Savannakhet	H013401	**9.92**	**9.73**	**9.60**	DO, NO32	100	100	**99.85**	DO
Khong Chiam	H013801	10	**9.73**	10	NH4, NO32	100	**96.53**	100	COD
Pakse	H013900	10	**9.91**	10	TotP	100	94.66	100	COD
Don Sahong	WQ6			**9.75**	pH			**99.80**	pH
	WQ7			**9.5**	pH, NO32, TotP			**97.08**	pH
	WQ8			**9.75**	NO32, TotP			100	
	WQ9			**9.625**	NO32, TotP			100	
Stung Treng	H014501	**9.33**	**8.82**		NH4, TotP	100	94.98		COD
Kratie	H014901	**8.92**	**9.55**		NH4, TotP	100	100		
Kampong Cham	H019802		**9.36**		NH4, TotP		100		

Although the JEM pilot sites are classified as being 'excellent' or 'high' quality according to the WQ Index, the results also show several instances when the thresholds are exceeded at all sites. Principally, the failing parameters at the Xayaburi JEM sites are NO32 and TOTP for WQ Index of Aquatic Health and COD at WQ1 for WQ Index for Human Health. At the Don Sahong impoundment, the failing parameters are pH, NO32, and TOTP.

The WQ indices do not take into account any changes in TSS, but this is the one parameter that is showing significant changes within all WQMN sites from Houa Khong to Pakse over the 2010–2020 period. There is a marked variability between the years, reflecting the different rainfall contributions to the flows each year, and hence the different TSS concentrations in wet and dry years. Nevertheless, there is a downward trend in TSS in all mainstream sites above Stung Treng over the decade.

The TSS levels also show similar trends as the changes in SSC described in section 4.2. The annual median time series at all sites above Stung Treng show downward trends in the suspended solids concentrations over the past decade; it is assumed that this has been partially due to the trapping of sediments in the hydropower dams in the mainstream and tributaries.

This downward trend in annual median values of TSS at all stations is reversed at Stung Treng and Kampong Cham where there is a generally upward trend. These trends have been observed since measurements of sediments began, and reflect the general dilution of sediments coming from the upper parts of the basin, i.e. from China, where water from the tributaries has a lower sediment load in the LMB, until Stung Treng, where the sediment load from the 3S rivers creates the upward trend noted.

4.3 ECOLOGICAL HEALTH MONITORING

EHM consists in collecting and counting the numbers of individuals of aquatic biota in four groups – benthic diatoms, zooplankton, littoral macroinvertebrates and benthic macroinvertebrates. When these species have been identified and counted in the laboratory, the numbers are analysed according to three criteria – average abundance, species richness, and Average Tolerance Score Per Taxon (ATSPT). These three criteria for each group can then be assessed against threshold limits to generate an Ecological Health Index (EHI). In addition, variation in the presence/absence of certain indicator species can be assessed to understand why there are differences between the sites, such as changes in substrate and habitat, changes in flow regimes, changes in WQ, and pollution events.

EHM sampling stations were established above both of the impoundments, within the impoundment and several sites downstream of both Xayaburi and Don Sahong dams. Since samples can only be collected at times of low flow, i.e. during the dry season, and the identification of species requires significant laboratory time and expertise, it is only practical to carry out EHM monitoring once a year. It had been planned to carry out two EHM campaigns in 2020 and 2021, but because of the COVID-19 travel restrictions, only the 2021 campaign was possible in February–March 2021.

The routine EHM monitoring on the Mekong mainstream has been carried out every two years since 2011, and the results have been compared with the JEM EHM results.

4.3.1 Xayaburi

The calculations of the EHI for the Xayaburi JEM sites (EHM 1 – above the impoundment, EHM 2 – within the impoundment, EHM 3, 4, 5, and 6 downstream of the impoundment) are shown in Table 4.4.

The changes in the EHI and individual biota parameters within the Xayaburi impoundment, and three downstream sites closest to the dam compared to the upstream reference site indicate that the ecological health quality is being impacted by the dam. Statistical analysis of the presence/absence of species shows that for diatoms, EHM 1 and EHM 2 are the least similar, while EHM 3, 4, and 5 form a similarity cluster, and EHM 6 is more similar to EHM 1. Zooplankton are most variable with no obvious similarities. For littoral macroinvertebrates, the most similar sites are EHM 1, 2, and 5, while EHM 3, 4, and 6 are different. For benthic macroinvertebrates EHM 1 and 3, above the impoundment and immediately below the dam appear to be similar to each other, while the other sites have different assemblages of species present. The similarities and differences are considered to reflect differences or changes in substrate conditions.

Table 4.4. Ecological Health Index classifications for the EHM sites around Xayaburi

Site					EHM1	EHM2	EHM3	EHM4	EHM5	EHM6
Year					**2021**	**2021**	**2021**	**2021**	**2021**	**2021**
Site Disturbance Score SDS					1.46	1.41	2	1.92	1.5	1.46
Average Abundance										
	Benthic diatoms	BD			667.5	1954.0	1026.6	982.6	1283.8	1479.2
	Zooplankton	ZPT			25.33	39.6	32.00	26.33	15.00	12.60
	Littoral macroinvertebrates	LM			160.8	9.1	4.2	7.7	148.9	39
	Benthic macroinvertebrates	BM			2.75	3.08	2.25	1.25	2.58	3.16
Richness	Benthic diatoms	BD			13.6	2.7	26.6	26.6	28	30.5
	Zooplankton	ZPT			8.66	5.66	10.33	7.33	7.00	5.66
	Littoral macroinvertebrates	LM			6.3	1.4	1.5	2	5.2	6.7
	Benthic macroinvertebrates	BM			1.66	1.58	1.16	1.00	1.58	1.25
ATPST	Benthic diatoms	BD			39	39	42	40	39	38
	Zooplankton	ZPT			33	30	42	37	32	31
	Littoral macroinvertebrates	LM			31	31	32	28	30	33
	Benthic macroinvertebrates	BM			34.5	31.8	33.7	28.1	29.4	21.3
Ecosystem Health index Calculations										
		10th percentile	**90th percentile**	**Guideline**						
Abundance	Benthic diatoms	136.22	376.34	>136.22	1	1	1	1	1	1
	Zooplankton	22.33	174.07	>22.33	1	1	1	1	FALSE	FALSE
	Littoral macroinvertebrates	46.68	328.56	>46.48	1	FALSE	FALSE	FALSE	1	FALSE
	Benthic macroinvertebrates	5.37	56.34	>5.37	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Richness	Benthic diatoms	6.54	11.78	>6.54	1	FALSE	1	1	1	1
	Zooplankton	9.8	20.2	>9.8	FALSE	FALSE	1	FALSE	FALSE	FALSE
	Littoral macroinvertebrates	5.37	18.48	>5.37	1	FALSE	FALSE	FALSE	FALSE	1
	Benthic macroinvertebrates	1.87	7.88	>1.87	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
ATPST	Benthic diatoms	30.85	38.38	<38.38	FALSE	FALSE	FALSE	FALSE	FALSE	1
	Zooplankton	34.83	41.8	<41.8	1	1	FALSE	1	1	1
	Littoral macroinvertebrates	27.8	33.58	<33.58	1	1	1	1	1	1
	Benthic macroinvertebrates	31.57	37.74	<37.74	1	1	1	1	1	1
	Total number of parameters meeting threshold				8	5	6	6	6	7
Quality	**Classification**	**Score**			**B**	**C**	**C**	**C**	**C**	**B**
Excellent	A	>10								
Good	B	>7			8					7
Moderate	C	>4				5	6	6	6	
Poor	D	<4								

Considering the JEM sampling sites for Xayaburi in Table 4.4, it is clear that benthic diatoms meet the abundance thresholds for all sites but only fail the species richness thresholds in EHM 2 in the impoundment, but fail the ATSPT threshold for all sites except EHM 6, i.e. the species represented are generally more tolerant species. For zooplankton, generally, abundance scores are higher than the threshold, except for EHM 5 and EHM 6; the species richness generally fails at all sites except EHM 3 immediately below the dam; and the ATSPT scores meet the threshold in all sites except EHM 3, where the only more tolerant species are found.

For the littoral macroinvertebrates, the abundance is above the threshold in EHM 1, but falls below the threshold in the impoundment and for two stations below the dam. Abundance recovers at EHM 5, but falls again at EHM 6. Species richness is above the threshold at EHM 1 but falls below the threshold for the impoundment and the three stations below the dam, recovering by EHM 6. The ATSPT scores for littoral macroinvertebrates show that the abundance meets the threshold for all sites. For benthic macroinvertebrates, the abundance and species richness fails to meet the threshold in all sites but meets the threshold for ATSPT.

Correlation with the absence of patterns in the WQ parameters with passage downstream suggests that the changes in EHM are not related to changes in WQ, but rather to changes in the flow and water level regime and reduction in sediment transport. Within the impoundment, the raised but relatively steady water levels have changed the riverine habitat to a lacustrine habitat, thus changing the species composition and population number of the biota, as well as their tolerance characteristics. The trapping of sediment within the impoundment will also tend to cover substrates that might have been more attractive to riverine biota.

Downstream of the dam, the peaking operation, which raises and lowers the water levels by at least one metre during the day, has had an impact on the biota, tending to encourage the benthic diatoms that can withstand short periods of exposure to the air while significantly reducing the species and populations of littoral macroinvertebrates immediately downstream of the dam. This impact is combined with the reduction in sediments being transported downstream of Xayaburi so that the bed and bank habitats will tend to be eroded and degraded for littoral and benthic macroinvertebrates. The EHM results at Xayaburi indicate that there is progressive recovery downstream of the dam, so that by 10 km downstream (EHM 6), the aquatic biota appears to be comparable to the upstream site, above the impoundment.

In summary:

- The EHM results around Xayaburi show clear changes in the species diversity and numbers of biota present within the impoundment and downstream compared to the upstream reference site;
- The EHI in the impoundment and downstream are all classified as being in 'moderate' health, with indications of recovery with passage downstream, compared to the upstream reference site, which is classified as being in 'good' health;
- The changes in the impoundment and downstream are likely to be caused by changes in the flow rates and water levels at the sites with resultant changes in the substrate and habitat conditions, rather than by changes in WQ;
- The responses of the different biota types provide greater insight into the changes of substrate and habitat, considering the average abundance, species diversity and ATSPT for each biota type, compared to the simple EHI;
- The littoral macroinvertebrates show the clearest changes in species diversity and abundance with passage downstream after the dam, but the responses of benthic diatoms, zooplankton and benthic macroinvertebrates in the impoundment and downstream are all useful indicators.

4.3.2 Don Sahong

The calculations of the EHI for the Xayaburi JEM sites (EHM 7 – above the impoundment, EHM 8 – within the impoundment, EHM 9 and 10 downstream of the impoundment) are shown in Table 4.5.

Table 4.5. Ecological Health Index classifications for the EHM sites around Don Sahong

Site					EHM7	EHM8	EHM9	EHM10
Year					2021	2021	2021	2021
Site Disturbance Score SDS					1.33	2.1	2.25	2.13
Average Abundance								
	Benthic diatoms	BD			1162	6238.4	1264.5	3653.4
	Zooplankton	ZPT			14.00	22.66	16.00	17.00
	Littoral macroinvertebrates	LM			77.3	134.2	96.3	66.0
	Benthic macroinvertebrates	BM			5.16	7	12.25	10.58
Richness	Benthic diatoms	BD			15	4.1	25	36.2
	Zooplankton	ZPT			6.33	5	6.00	5.66
	Littoral macroinvertebrates	LM			17.5	3	9.3	12.6
	Benthic macroinvertebrates	BM			2.41	1.91	3.90	5.16
ATPST	Benthic diatoms	BD			37	47	46	47
	Zooplankton	ZPT			28	47	47	47
	Littoral macroinvertebrates	LM			29	42	45	42
	Benthic macroinvertebrates	BM			36.6	48.7	47.8	49.9
Ecosystem Health index Calculations								
		10th percentile	90th percentile	Guideline				
Abundance	Benthic diatoms	136.22	376.34	>136.22	1	1	1	1
	Zooplankton	22.33	174.07	>22.33	FALSE	1	FALSE	FALSE
	Littoral macroinvertebrates	46.68	328.56	>46.48	1	1	1	1
	Benthic macroinvertebrates	5.37	56.34	>5.37	FALSE	1	1	1
Richness	Benthic diatoms	6.54	11.78	>6.54	1	FALSE	1	1
	Zooplankton	9.8	20.2	>9.8	FALSE	FALSE	FALSE	FALSE
	Littoral macroinvertebrates	5.37	18.48	>5.37	1	FALSE	1	1
	Benthic macroinvertebrates	1.87	7.88	>1.87	1	1	1	1
ATPST	Benthic diatoms	30.85	38.38	<38.38	1	FALSE	FALSE	FALSE
	Zooplankton	34.83	41.8	<41.8	1	FALSE	FALSE	FALSE
	Littoral macroinvertebrates	27.8	33.58	<33.58	1	FALSE	FALSE	FALSE
	Benthic macroinvertebrates	31.57	37.74	<37.74	1	FALSE	FALSE	FALSE
	Total number of parameters meeting threshold				9	5	6	6
Quality	Classification	Score			B	C	C	C
Excellent	A	>10						
Good	B	>7			9			
Moderate	C	>4				5	6	6
Poor	D	<4						

As with Xayaburi, the Don Sahong EHM sites indicate a marked reduction in the quality of the biota within the impoundment and downstream of the dam, with potential indications of improvement in the further downstream site. The situation is marked because the upstream site has a much higher scoring for all parameters, i.e. it is very rich, and close to the top of the impoundment. Within the impoundment not only has there been an increase in water level, but also extensive disturbance during construction which will have reduced the habitat and substrate quality. Because of its size, the flow rate through the impoundment is much faster than through the Xayaburi impoundment, which tends to reduce the sedimentation process.

Downstream of the dam, the aquatic biota is exposed to similar changes in water level and flow rates, which will tend to depress the populations and affect the species richness. Since the water from the Don Sahong dam mixes with water from other channels downstream of Khone Phapheng Falls, the recovery of the habitats and aquatic biota would be expected to be quicker than at Xayaburi where the entire flow of the river passes through the dam.

The statistical analysis ($p < 0.05$) of the EHM results of the Don Sahong sampling sites shows that the biota assemblages at the Don Sahong sites are significantly different from the Xayaburi sites, and that for diatoms and zooplankton, all of the EHM sites 7 to 10 have different species present, but that for littoral and benthic macroinvertebrates sites EHM 9 and EHM 10 have similar species present, while above the impoundment and in the impoundment, the species are different.

The calculation of the EHI for each of the sites in Table 4.5 shows that EHM 7 is classified as being in 'good' condition, with a high score of nine threshold levels achieved, while in the impoundment, the EHI score is only five threshold levels, and the two sites immediately downstream of the dam (six threshold levels achieved) are all classified as being in 'moderate' condition. There is a clear change occurring within the impoundment and below, showing the impact of the dam on the populations of aquatic biota.

Close analysis highlights the differences in responses of the four biota types. For benthic diatoms, Abundance meets the threshold in all sites, species richness fails in the impoundment (EHM 8), and fails in ATSPT in all sites except the control site above the impoundment (EHM 7). For zooplankton, abundance thresholds are only met in the impoundment (EHM 8), but fail in other sites; species richness thresholds fail in all sites; and for ATSPT, all sites fail except at EHM 7 above the impoundment.

For littoral macroinvertebrates, abundance thresholds are met in all sites, as are species richness thresholds, except within the impoundment, and ATSPT thresholds are only met in EHM 7. For benthic macroinvertebrates, EHM 7 fails to meet the abundance threshold, but all the other sites meet it. The species richness thresholds are met in all sites, but the ATSPT threshold is only met in EHM 7.

In summary:

- The EHM results around Don Sahong show clear changes in the species diversity and numbers of biota present within the impoundment and downstream compared to the upstream reference site;
- The EHI in the impoundment and downstream are all classified as in Moderate health, with indications of recovery with passage downstream, compared to the upstream reference site, which is classified as in 'good' health;
- The changes in the impoundment and downstream are likely to be caused by changes in the flow rates and water levels at the sites with resultant changes in the substrate and habitat conditions, rather than by changes in WQ;
- The responses of the different biota types provide greater insights into the changes of substrate and habitat, considering the average abundance, species diversity and ATSPT for each biota type, compared to the simple EHI;
- The littoral macroinvertebrates show the clearest changes in species diversity and abundance with passage downstream after the dam, but the responses of benthic diatoms, zooplankton and benthic macroinvertebrates in the impoundment and downstream are all useful indicators.

4.3.3 Basin-wide EHM comparisons

The EHIs and classification for all the mainstream sites from 2011 to 2019 are shown in Table 4.6. These are then combined into an average for the decade of five biennial monitoring occasions, which are then compared to the JEM pilot sites monitored in 2021. This comparison clearly indicates that the two sites upstream of Luang Prabang at Ban Xieng Kok (LMX) and Chiang Saen (TCS) are of 'moderate' and 'poor' EH condition, respectively, and that the mainstream sites at Luang Prabang (LPB) and EHM 1 are in 'good' condition. The Xayaburi impoundment and three downstream sites show a decline into 'moderate' condition, which recovers by EHM 6.

Table 4.6. Comparing decadal average of Ecological Health Index scores for mainstream sites from the Ban Xieng Kok to Kratie with the 2021 JEM sites above and below Xayaburi and Don Sahong HPPs

EHM Site	Site Name	2011	2013	2015	2017	2019		Decadal Average/ 2021
LMX	Ban Xieng Kok	4	5	4	6	6		5
TCS	Chiang Saen	6	4	3	2	3		3.6
LPB	Luang Prabang	11	5	8	8	7		7.8
EHM1	Xayaburi							8
EHM2								5
EHM3								6
EHM4								6
EHM5								6
EHM6								7
LVT	Vientiane	8	2	7	6	8		6.2
TNP	Nakhon Phanom	5	7	6	5	6		5.8
TKC		8	5	3	3	4		4.6
LDN	Don Ngew	11	5	7	6	8		7.4
EHM7	Don Sahong							9
EHM8								5
EHM9								6
EHM10								6
CKM	Kbal Koh	N/D	7	8	10	8		8.25
CKT	Stung Treng	N/D	8	10	9	8		8.75
CMR	Kratie	N/D	6	11	9	7		8.25

EH Condition	Classification	Score
Excellent	A	10 - 12
Good	B	7 - 10
Moderate	C	4 - 7
Poor	D	1 - 4

The three sites downstream of Vientiane to Siphandone have varying EH scores over the decade, averaging Moderate conditions, but in Siphandone at Don Ngiew (LDN), the condition is restored to Moderate. This is confirmed by the high "Good" condition score at EHM 7 and at Kbal Koh (CKM) on the border between Cambodia and Lao PDR. However, the scores for the Don Sahong impoundment (EHM 8) and the two downstream sites (EHM 9 and EHM 10) fall into the Moderate condition class. Further downstream at Stung Treng (CKT) and Kratie (CMR), the average EHI scores fall into the "Good" condition class.

This analysis illustrates the localized changes taking place in the ecological health of the river within the impoundment and immediately downstream of the dams. It is recognized that there was no baseline condition measured at these JEM pilot sites with which to compare the changes, and that the dams have only recently started operating (2019), so conditions within the impoundment and downstream may still be stabilizing and recovering from the disturbance caused by dam construction.

4.4 FISHERIES

Key findings from fisheries are presented for FADM and FLDM monitoring, supplemented by information from the local ecological knowledge survey at Khone Falls, and for the design of a fish tagging methodology. Findings from the gillnet protocol are not presented here, but rather in Section 5, since the duration of the JEM Pilots was used for iterative testing of a revised protocol and therefore has not yet yielded standardized data for analysis of trends.

The key findings for FADM reflect the most comprehensive dataset currently available, i.e. the monitoring of fishers' catch between 2017 and 2021 at those sites coordinated with those of the other JEM Pilot disciplines. The data analysis focused on the following *monitoring* questions:

- **What is the evolution of monthly catch per fisher in each site over the years?**
- **What is the trend in number of species caught each year in each site?**
- **What is the trend in average CPUE?** (i.e. fish biomass caught by square metre of net by hour fishing, in gillnets used by fishers).

As described in Section 3.4, the interpretation of fisheries results should reflect the fact that two of these years have only partial data: in 2017, only eight months of data were gathered, and in 2021, only seven months of data had been gathered so far. This to some extent influences both the CPUE calculation, since the average catch per square metre of net can be influenced by missing months during which CUPE is higher or lower than in other months, and the catch per fisher per month, since similarly, the annual averaging of monthly catch can be influenced by missing months with a particularly high or low catch. It also substantially influences the assessment of species diversity since fewer species can be recorded when the sampling is smaller and over a shorter period of time. For these reasons, Figures 4.27 and 4.28 present annual figures for 2018, 2019 and 2020, but half-annual symbols, and no connections with the other years, for 2017 and 2021.

4.4.1 Xayaburi

4.4.1.1 Changes in monthly catch per fisher

Over the 2017–2021 period, the monthly catch per fisher (Figure 4.23) was stable at around 20 kg/fisher/month and shows no apparent sign of decline at Pha-O upstream of Xayaburi reservoir. In the site at Thadeua, this became part of the impoundment the catch evolved from 48 kg/fisher/month on average in 2017 to around 27 kg/fisher/month between 2018 and 2020. Downstream of the dam the sampling site at Pak Houng features only one annual data point (currently 34 kg/fisher/month, based on seven months of sampling). Thus, recent data just downstream of Xayaburi dam do not yet allow conclusions about the possible impact of the dam.

At the upstream tip of the reservoir, the catch seems to be stable. in addition, in the impoundment, the identification of a clear trend will require a few more years of data as does the downstream of the dam where monitoring started in the second half of 2020.

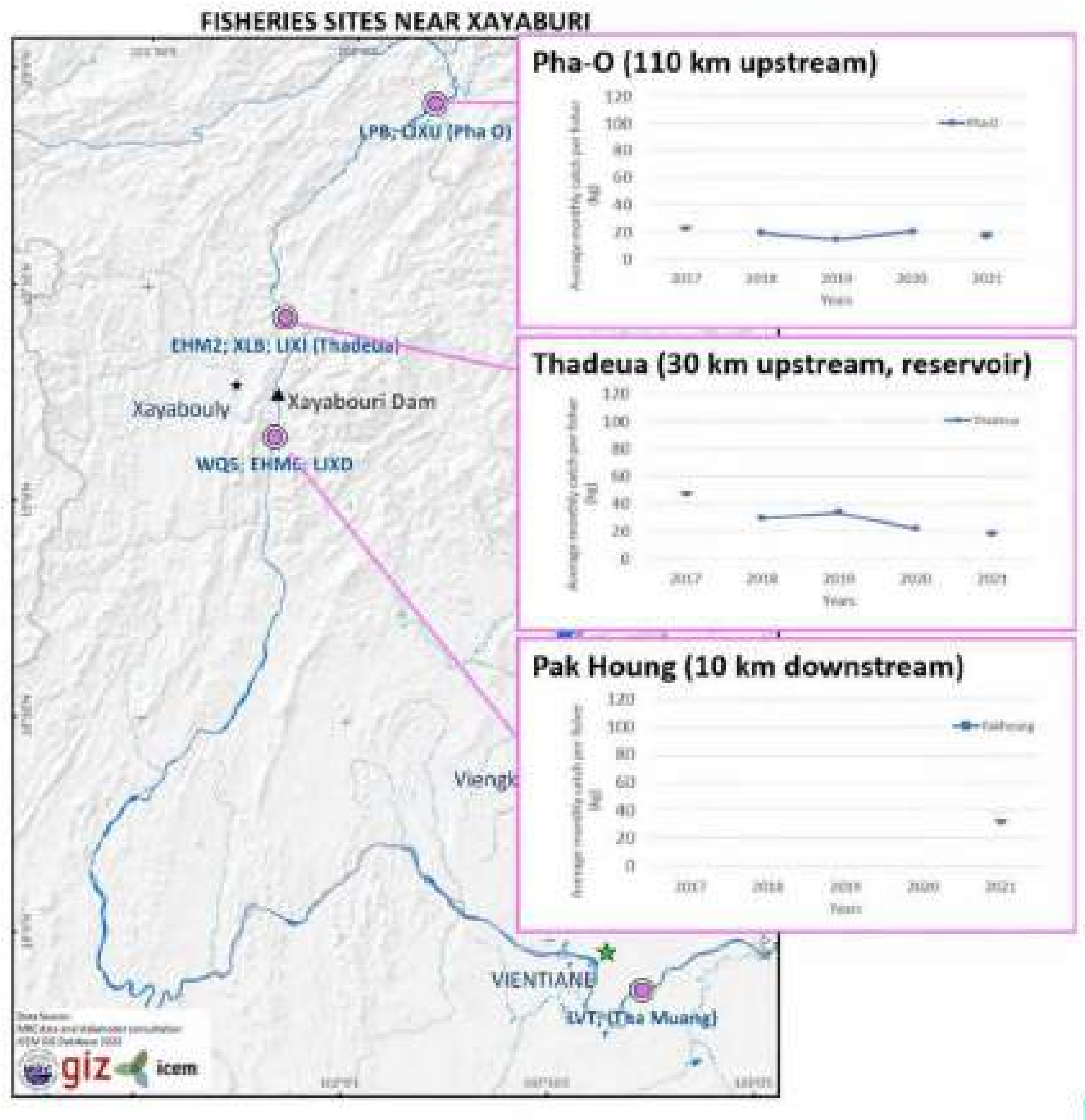


Figure 4.23. Monthly catch per fisher in fish monitoring stations upstream and downstream of Xayaburi Dam

4.4.1.2 Changes in fish biodiversity

Over the 2017–2021 period, the biodiversity in the catch of fishers (Figure 4.24) upstream of the impoundment at Pha-O indicates some stability at around 50–60 species in 2017–2019, but features 32 species only in 2020 based on one full year of sampling. In the impoundment, at Thadeua, the biodiversity amounted to 88 and 75 species in 2017 and 2018, respectively, and to 32–36 species in 2019–2020. Downstream of the dam at Pak Houng, with seven months of sampling so far, it reached 84 species.

A perspective based on the Shannon-Weaver diversity index indicates a structural change from a limited diversity with medium evenness upstream to a similar diversity but low evenness among species in the impoundment. Both biodiversity and evenness then increase again downstream, indicating a more mature community.

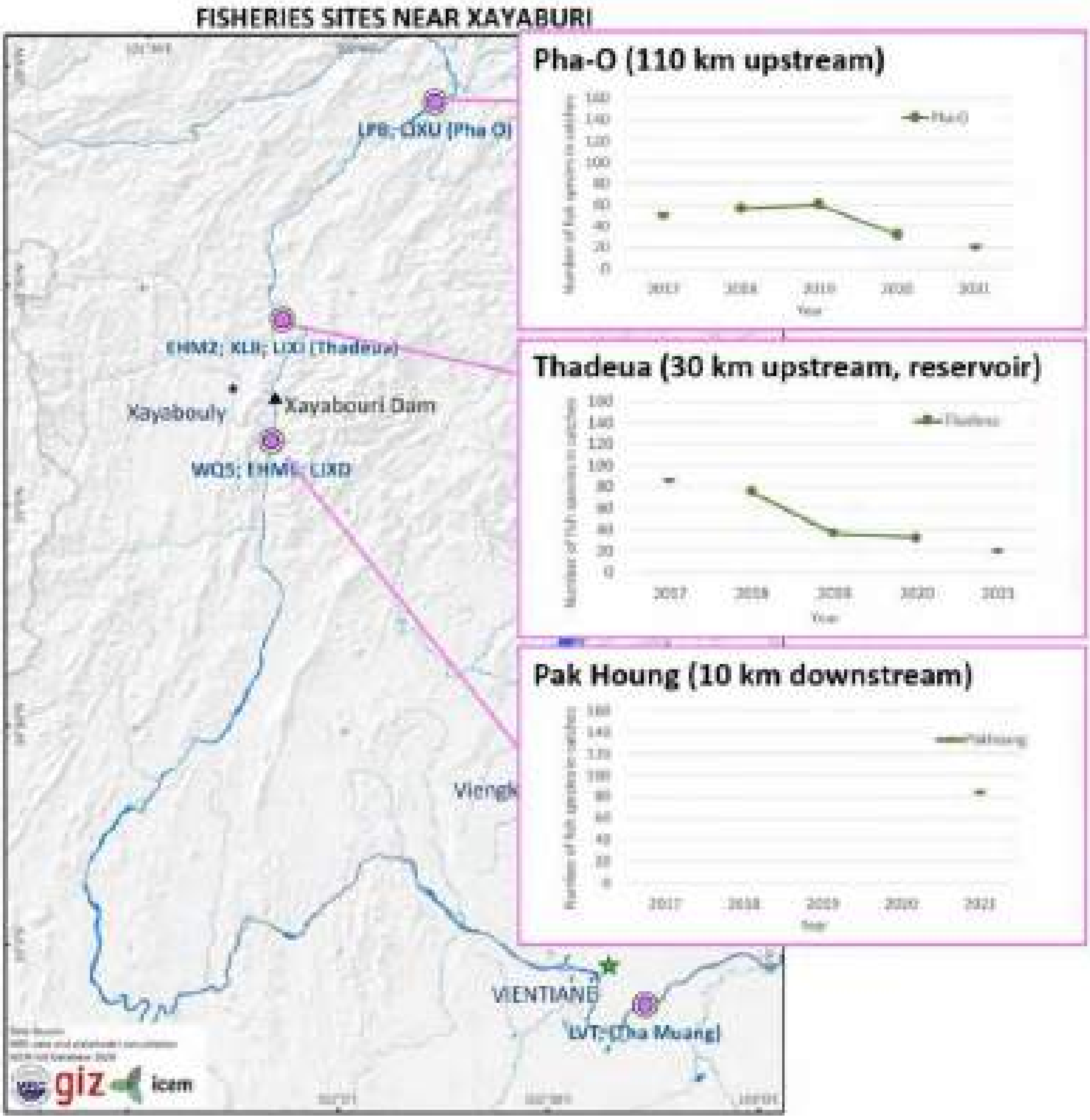


Figure 4.24. Number of fish species caught in fish monitoring stations upstream and downstream of Xayaburi Dam

4.4.1.3 Changes in catch per unit effort

Over the 2017–2021 period, the gillnet CPUE (grams of fish per square metre of net per hour fishing, Figure 4.25) shows a strong variation upstream of the impoundment at Pha-O. A very high value is observed in 2017, with values ranging between 4.9 and 0.7 grams/m^2/hour between 2018 and 2020, and another high value indicated in 2021, although the annual time series for that year is still incomplete. Within the impoundment at Thadeua, CPUE values varied between 0.7 and 2 g/m^2/h over the year 2017-2021 period while 1.1 g/m^2/h is indicated downstream of the dam (based on seven months of data only).

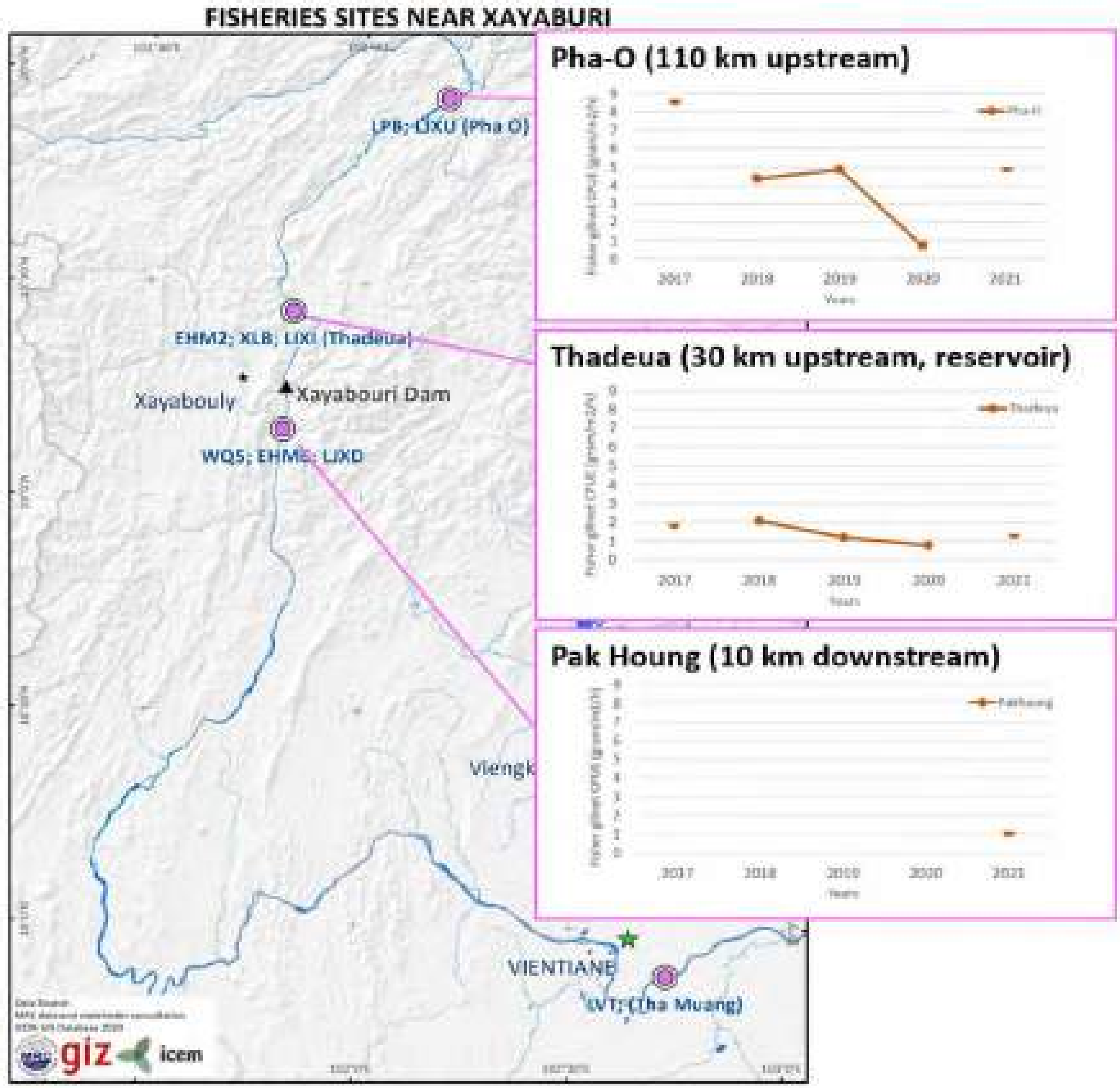


Figure 4.25. Catch per unit effort (in fish monitoring stations upstream and downstream of Xayaburi Dam

Note: Catch per unit effort = grams per m^2 of gillnet per hour fishing

Thus, values of monthly catch per fisher and CPUE vary according to sites and will require a few more years of monitoring to show clear trends over the years. For biodiversity, data upstream of the reservoir indicate a certain stability until 2019 and then a much lower diversity in 2020 – this possible evolution is to be further monitored. In the reservoir data indicate about 40% less species in 2019-2020 compared to 2017–2018. Downstream of the reservoir, the diversity appears to remain high, as observed over the seven months of data collected in 2021 to date.

4.4.1.4 *Fish larval monitoring*

JEM Pilots data gathered and analysed by the Lao team indicate for upstream Pha O site 30 genera and a larval abundance reaching 71 individuals per day (density: 119 individuals/1,000 m^3). At Thadeua in the impoundment the larval diversity was similar (30 genera), with abundance peaking at 36 individuals per day (114 individuals/1 000 m^3). In Pak Houng downstream of Xayabouri Dam, 35 genera were recorded, with abundance and density reaching 46 individuals per day and 57 individuals/1,000 m^3. Overall, the most abundant genera in Xayaburi (all sites) were *Pangasius* (pangasiid catfish), *Opsarius* (Danionidae) and *Mystacoleucus* (Cyprinidae). Additional years of sampling will allow for observation of trends once the fish community structure has stabilized under the new environmental conditions.

4.4.2 Don Sahong

4.4.2.1 *Changes in monthly catch per fisher*

Over the 2017–2021 period, the trend in monthly catch per fisher (Figure 4.26) seemingly increased upstream of Don Sahong Dam according to the monitoring results, from 14 kg to 46 kg per fisher and per month. This finding is contradicted by interviews of local fishers during the 2021 Local Ecological Knowledge survey. Fishers described a sharp decline in yield at most locations in the falls, in particular in upstream villages, with a rapid decrease in catch abundance and diversity following a reduction in water levels and a strong current towards the dam inlet. The Local Ecological Knowledge survey indicated that upstream of the dam, fishing had shifted towards the west bank and fishers started diversifying activities to keep making a living.

Just downstream of the dam, fish abundance in catches fluctuated between 2018 and 2020, with a few more years of monitoring required to identify a clear trend. Increasing catches in Khone Falls according to Lao FADM data are not reflected in the data from the nearby Ou Run site located 8 km downstream in Cambodia, where abundance declined from 114 kg/fisher/month to 83 kg/fisher/month between 2018 and 2020, a trend also confirmed by the additional year of partial data gathering in 2021.

Viewed together, the data from Lao PDR versus Cambodia, and from FADM versus Local Ecological Knowledge surveys give contradictory results, with FADM catch decline observed in northern Cambodia and in Khone Falls according to fishers, but catch increase monitored upstream of the dam according to Lao FADM data.

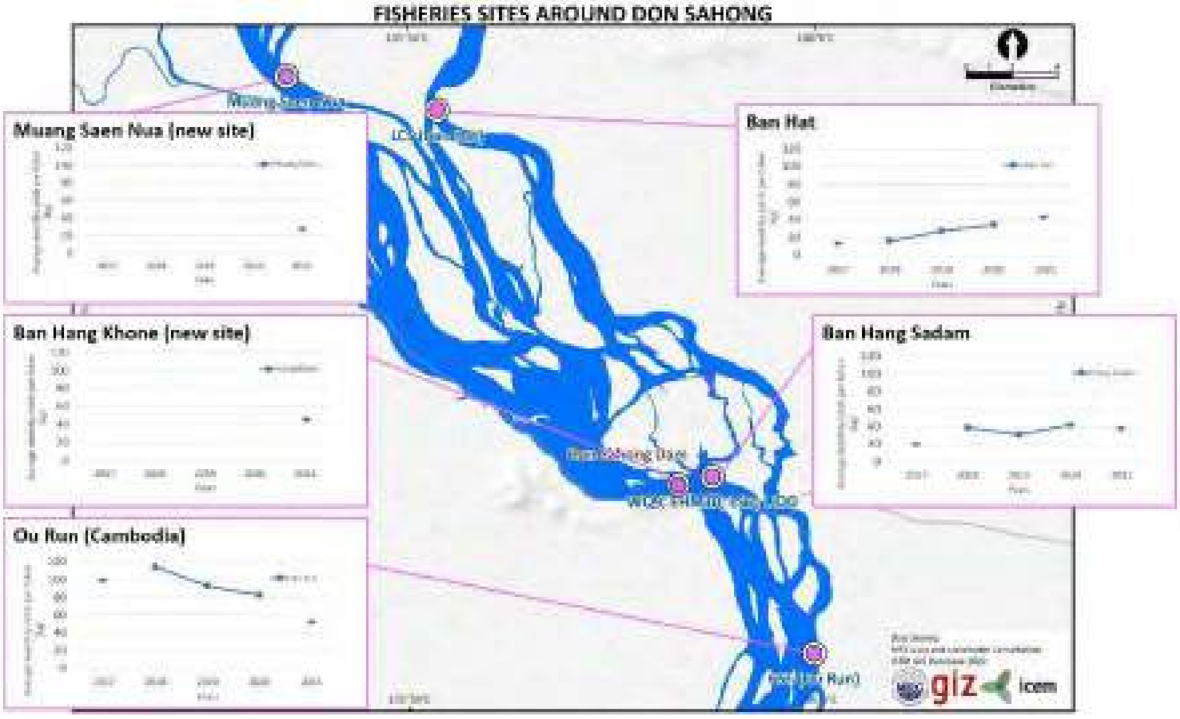


Figure 4.26. Monthly catch per fisher in fish monitoring stations upstream and downstream of Don Sahong Dam

4.4.2.2 Changes in fish biodiversity

Over the 2017–2021 period, the biodiversity in the catch of fishers (Figure 4.27) varied between 38 and 60 species per year upstream of Don Sahong Dam, without any discernible trend. Biodiversity varied between 107 and 160 species just downstream of the dam in Lao PDR, with no discernible trend. However, FADM data from Cambodia indicate that biodiversity decreased from 90 species in 2018 to 50 species in 2020 at the Ou Run site 8 km downstream of the dam.

As with total monthly catch per fisher monitoring, biodiversity results are very heterogeneous from site to site, with very different figures over a seven-month period of sampling and in a similar environment, ranging from as high as 160 species observed at Ban Hang Khone to as low as 40 species only 8 km away at Ou Run. Although some difference in species diversity is expected between downstream sites (with expected higher diversity) and upstream sites (with expected lower diversity, in particular due to the obstacle of the falls), it is not expected between such close downstream sites, and does require additional analysis (e.g. assessing the influence of fish identification occurring in two different local languages, Khmer and Lao PDR).

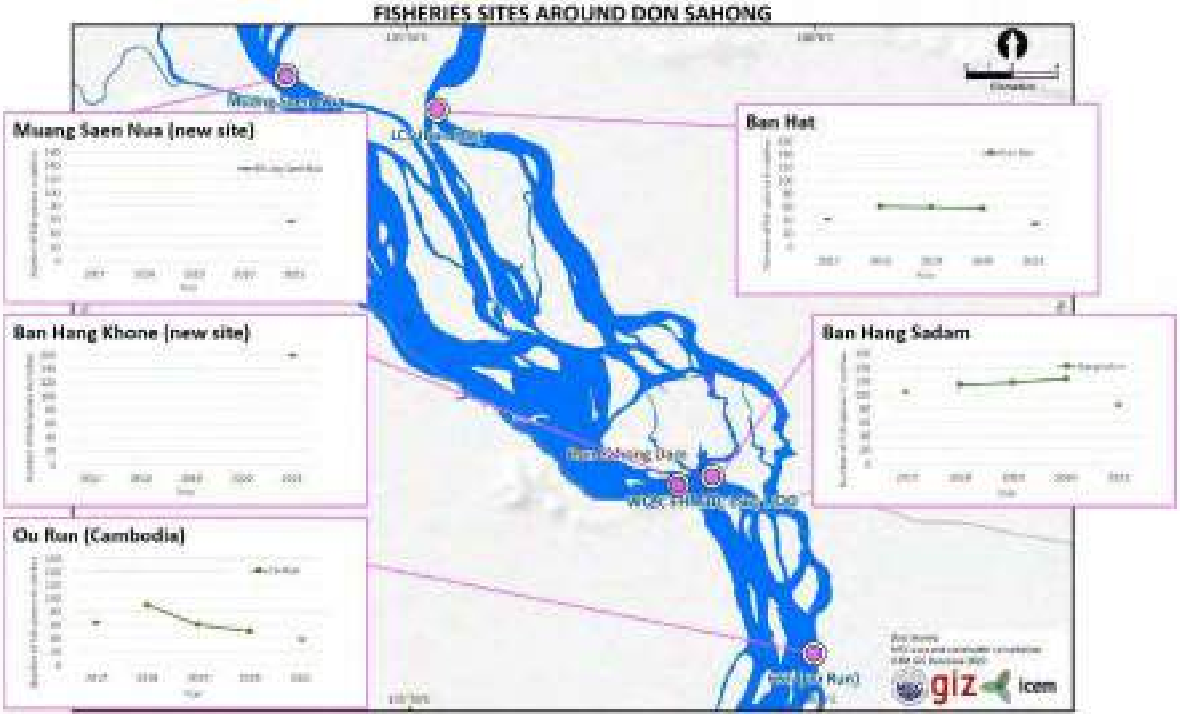


Figure 4.27. Number of fish species caught in fish monitoring stations upstream and downstream of Don Sahong Dam

4.4.2.3 Changes in catch per unit effort

Over the 2018–2020 period, the gillnet CPUE (Figure 4.28) does not show a clear pattern upstream of Don Sahong Dam, and varied between 1.72 and 2.2 grams of fish per m^2 of gillnet per hour fishing. It should be noted that if the two years calculated with only partial data (2017 and 2021) are included, then a downward trend may be indicated, which is to be confirmed. CPUE seems to have declined downstream of the dam in Ban Hang Sadam, from 5.9 $g/m^2/h$ in 2018 to 4 $g/m^2/h$ in 2020 (a trend also suggested by the partial data years of 2017 and 2021). Conversely, the CPUE has been almost constant at about 0.3 $g/m^2/h$ over the years at Ou Run in Cambodia (i.e. a value less than one third of that calculated for nearby Lao sampling sites).

Here again, these results indicate a large discrepancy in CPUE value between Ou Run, Ban Hang Khone, and Ban Hang Sadam sites, despite all having a similar environment and located close to each other.

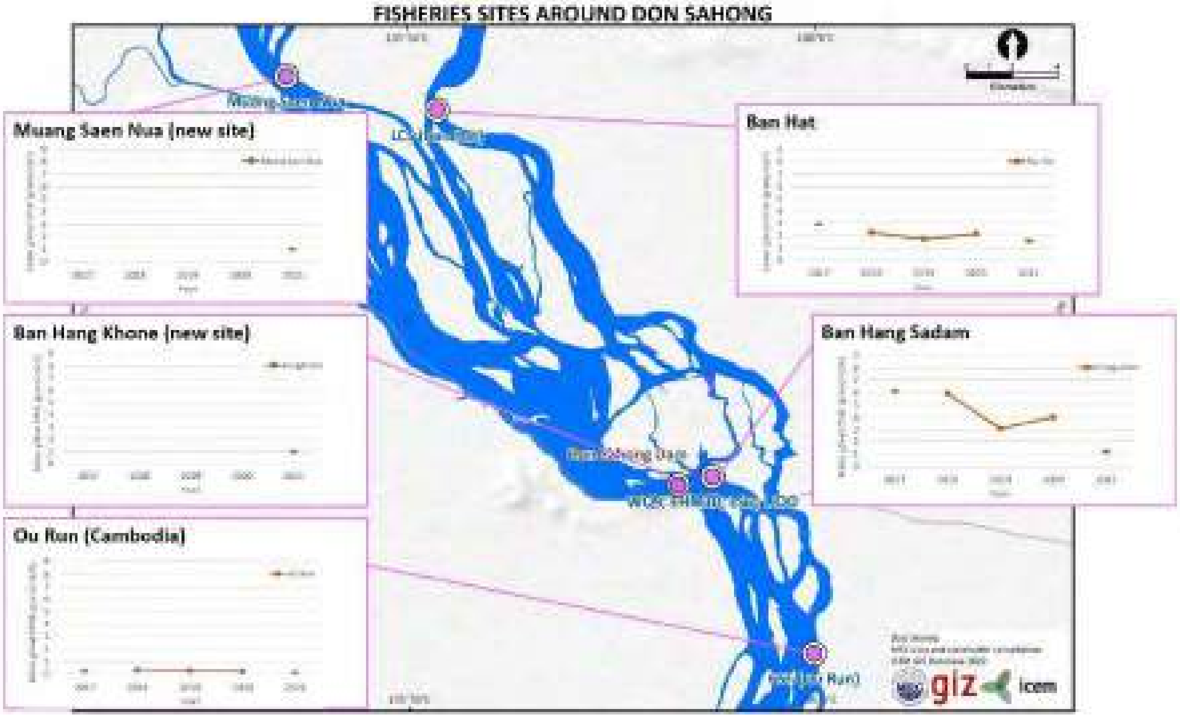


Figure 4.28. Catch per unit effort (grams per m^2 of gillnet per hour fishing) in fish monitoring stations upstream and downstream of Don Sahong Xayaburi Dam

4.4.2.4 Fish larvae monitoring

Sampling and data analysis by the Lao team indicate that the site upstream of Don Sahong Dam (LJUD, fiatures 32 genera with a larval density of 219 individuals per 1,000 m^3 (63 individuals/day). The site downstream of the dam (LJDD) is characterized by 39 genera and 98 individuals/1,000 m^3 (40 individuals/day). The genera most abundant in both sites are *Pangasius* (pangasiid catfish), *Mystacoleucus* (Cyprinidae) and *Laides* (Ailiidae catfishes).

In Cambodia, FLDM analyses reveal 91 species belonging to 20 families: Cyprinidae (57%), followed by 9%, 6% or 5% of Pangasiidae, Bagridae and Clupeidae, respectively). However, the sampling in three locations per site (left bank, right bank, middle of the river) shows that larval diversity varies from bank to bank by as much as 30%. A Shannon-Weaver diversity index combining species counts and abundance of each species also points to a difference in evenness between sampling locations (i.e. the species vary as does the abundance by species between close sampling locations at the same site).

In terms of time series, data from Cambodia show abundance peaks in July in all sites (Figure 4.29). Varying peaks in April, May, June, and October are shown, depending on the sampling location. Densities range between 510 and 968 individuals/1,000 m^3

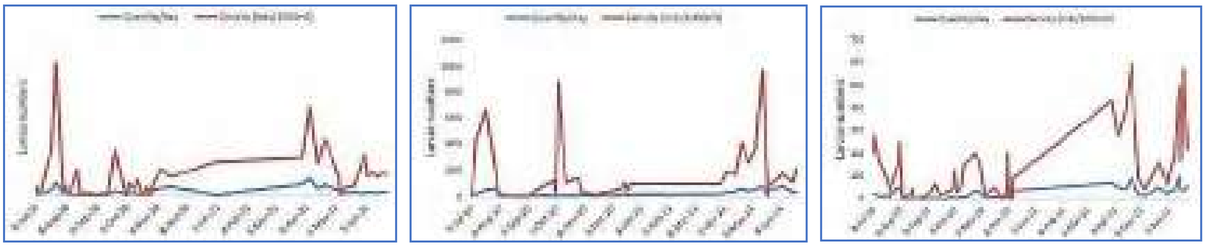


Figure 4.29. Fish larvae densities over time in western, middle and eastern sampling sites in Preah Romkel site in Cambodia

Length analyses performed on *Pangasius macronema* and *Cyclocheilichthys repasson* show that the individuals surveyed in Preah Romkel site in Cambodia just below the Lao border were around 25 days old. This indicates the presence of breeding sites upstream in the Mekong, largely upstream of Khone Falls, for these two species.

Overall, FLDM results from the JEM Pilot at Don Sahong indicate the following:

- Larval abundance shows some irregular peaks in April, May and June corresponding to early rains; July is clearly a month of maximal larval abundance; and smaller abundance peaks corresponding to the end of the rainy season can also be observed in October;
- Clear differences observed between sampling locations situated a few hundred metres apart, within the same station confirm the suitability of the latest JEM sampling protocol with two sampling locations on two banks and one in the mainstream.

4.4.2.5 Changes in migration patterns and dominant species

The Local Ecological Knowledge survey in Khone Falls (MRC, 2021) identified 10 species relevant to the monitoring of fish passage at Khone Falls; findings are summarized in Table 4.7. These species belong to different size groups (a parameter relevant to swimming ability, and to tag selection), migrate at different times of the year in different water levels, and reflect ecological groups previously identified.

Table 4.7. Recent patterns for six groups of migratory fishes at Khone Falls

Migration pulses	Representative species	Recent patterns
End of rainy season large- and medium-size cyprinids	*Hypsibarbus malcolmi*	Upstream migration now mainly in January – February, later than reported 15-20 years ago. Not caught in Hoo Sadam anymore. Downstream migration in June-August via Khone Fang area.
Early dry season small cyprinids	*Gymnostomus. siamensis* and *G. lobatus*	Quasi-disappearance of these species that used to be the most abundant ones. Upstream migrations now limited to a few days a year (cf. reduced water levels in former key passages such as Khone Pa Soi).
Early dry season medium-sized cyprinids	*Scaphognathops bandanensis*	Upstream migrations in January-February and downstream in July-August but now in some sites only. Unclear patterns suggesting a new permanent residence in some sites, in particular upstream of Khone Falls (e.g. Don Tholathi).
Dry- to early wet season large cyprinids	*Cirrhinus microlepis* and *Cyclocheilos enoplos*	Vanishing from catches in the falls and upstream of them; the remaining individuals caught are not sufficient to characterize migrations any more
Early wet season small Pangasiids	*Helicophagus leptorhynchus* and *Pangasius macronema*	Progressive disappearance; the remaining individuals are not enough to characterize migrations any more.
Early wet season large Pangasiids	*Pangasius krempfi*, *P. conchophilus*	Migration now in June-August (much delayed). 50 to 100% loss of abundance. Some permanent presence in very low abundance without migration pattern in several sites. Downstream migration never reported.

These findings show the following:

- a drastic reduction in fishers' yield;
- the quasi-disappearance in catches of species formerly abundant such as mud carps (*Gymnostomus. siamensis* and *G. lobatus)* and large cyprinids (*Cirrhinus microlepis, Cyclocheilos enoplo*s);
- the drastic reduction of large and even small Pangasiids (*Pangasius krempfi, P. conchophilus. P. macronema, Helicophagus leptorhynchus).*

In Cambodia, a recent study (Fisheries Administration, 2021) based on a protocol that is very similar to the JEM Pilots FADM protocol identifies both the 2017–2020 emergence of *Labeo chrysophekadion,* a large cyprinid, as a new dominant species, and a shift in species composition and community structure (a decline of *Hypsibarbus malcolmi*, *Pangasius macronema*, *Puntioplites proctozysron, Puntioplites falcifer, Hemibagrus wyckioides*, and conversely, an increase of *Cosmochilus harmandi* and *Cyclocheilichthys enoplos*).

4.4.2.6 Hydrological changes in migration channels

The JEM Pilot Local Ecological Knowledge survey in Khone Falls documented in detail 10 main fish migration channels and key passages through the falls (Figure 4.30), and their characteristics in particular in the dry season (Table 4.8). Dry season characteristics are important to ensure permanent fish passage through the fall despite water abstraction by the dam.

Figure 4.30. Main islands (yellow), waterfalls (blue) and migration channels (orange) in Khone Falls

Table 4.8. Key characteristics of the ten main fish migration channels and key passages through Khone Falls

	1. Hoo Som Yai	2. Hoo Som Pordan	3. Hoo Sadam	4. Hoo Sang Peuak Yai	5. Hoo Sang Peuak Noy	6. Nyoi Koong	7.Koum Tao Hang	8. Hoo Wai	9.Luong Pi Teng	10.Hoo Don Lai
Max. depth (m) in wet season	2	1.8	3	4-5	2	2.5	4	10	2	1-2
Min. depth (m) in dry season	Dry	Dry	0.3-0.5 but no flow	1.3	0.2	Dry	Dry	0.5	Dry	0.4-1
Dry months 10 years ago	No dry month	Apr to May	No dry month	No dry month	No dry month	No dry month	No dry month	No dry month	Mar-Apr	Mar- Jun
Current dry months	Nov. to Jun	Dec. to Jun	Dec. to Jun	No dry month	No dry month	Dec to Jun	Mar - May	No dry month	Mar - Jun	Impas-sable

Among the 10 main channels allowing fish passage at Khone Falls, including the 9 that were improved accordingly in recent years by Don Sahong Power Company, these results show that **7 are currently dry or do not have attractive flows to trigger upstream fish migration in the dry season** (in red in Table 3.8). This is a change from a decade ago when 4 of these 7 channels were not dry in the dry season.

The survey indicates that fish from the downstream arrive to the falls through the deep eastern Mekong channel (between Koh Chheu Teal Thom and the east bank) and then move upstream by following the line of deepest waters either towards Hoo Phapheng, the central zone (Hoo Nok Gasoom, Hoo Dtat Wai), or eastwards towards Khone Fang area.

In recent years, Hoo Phapheng kept attracting fish despite the reduced discharge resulting from the Don Sahong Dam flow diversion. Fish then stay in Hoo Phapheng downstream of the falls, without attempting the migration through Hoo Sadam, as a result of lower water levels and the loss of current-related migration cues. Furthermore, for the same reason, passage is impossible at Khone Phapheng, and the lateral channels (Hoo Som Yai and Hoo Som Pordan) are now dry most of the year. Due to high discharge at Don Sahong Dam site, which creates attractive noise and oxygen levels, fish tend to stay in the outflow, and many do not attempt to go further upstream towards Hoo Xang Pheuak or Khone Lan like they did a few years ago. Overall, fish passage these recent years is also compromised by the high number of gears set to compensate for a drastically decreasing CPUE.

Thus, for these past two years, the following is concluded regarding dry season fish passage:

- It has been impossible at Hoo Som Yai and Hoo Som Pordan around Khone Phapheng;
- It does not happen in Hoo Sadam;
- It is limited through the central zone (less intense at Hoo Sang Peuak);
- It is impossible at Nyoi Koong, Koum Tao Hang and Luong Pi Teng).

5 RECOMMENDED REVISIONS TO MONITORING PROTOCOLS

This chapter addresses the main objective of the JEM Pilots project, which is to provide recommendations for the improvement of the JEM Programme and the monitoring protocols, based on the experience of the pilot monitoring activities and data analysis. The recommendations cover the protocol components, the parameters measured, the frequency and timing of measurement, and the choice of sampling locations. This chapter also provides recommendations that are applicable to the MRC's routine monitoring and its extension into the CRMN.

5.1 HYDROLOGY AND SEDIMENT

Recommendations for the discharge and sediment monitoring are presented in two parts. The first part outlines JEM-specific recommendations that relate to the sites and parameters included in the JEM monitoring but not included in the ongoing DSM monitoring. The second part outlines recommendations for discharge and sediment monitoring in general, and are applicable to JEM monitoring, to the ongoing DSM monitoring, and to the development of the CRMN.

5.1.1 JEM specific recommendations

5.1.1.1 Sites, parameters and frequency of monitoring

Overall, the monitoring sites, parameters and monitoring frequency included in the JEM Programme have been suitable for identifying changes to water level, flow, and sediment transport associated with hydropower operations when the JEM monitoring data are integrated with data from the ongoing DSM and HYCOS monitoring. The following provide generic guidance on monitoring sites, parameters and monitoring frequency related to any future JEM monitoring:

- **Monitoring locations** for discharge and sediment measurements (SSC, bedload, grain-size distribution) should include sites upstream of the impoundment and downstream of the power station, noting that:
    - the upstream site should be beyond the backwater influence of the hydropower impoundment; and
    - the downstream station should be located based on the potential for impacts.
- The selection of new monitoring locations should take into consideration the location of long-term DSM monitoring sites, so that the JEM results can be interpreted within the wider catchment context. Where possible, new discharge and sediment monitoring locations should coincide with WQ monitoring sites so that the data can be readily integrated. JEM monitoring locations should also be coordinated with the developer/operator of the HPP to optimize available resources.

- Locations for the establishment of continuous recording water level gauges (HYCOS sites) should be selected based on the potential for downstream impacts associated with water level changes, proximity of international boundaries, and existing HYCOS sites.
- Cross-sectional repeat survey locations should be sited in alluvial sections, which are the most prone to changes in sedimentation and deposition.
- **Monitoring parameters** should include the ones included in the Xayaburi and Don Sahong pilots (water level, discharge, SSC, bedload estimation, grain-size distribution, channel cross-sections). Future JEM monitoring should endeavour to include repeat photo monitoring of river banks that was recommended for inclusion in the pilots, but not implemented.
- **Monitoring frequency** for future JEM monitoring should be consistent with the DSM monitoring schedule to allow integration of the data sets. The DSM monitoring strategy includes a higher monitoring frequency (e.g. weekly) during the wet season when the flow is highest and most sediment moves through the river, and a reduced monitoring frequency during the transition seasons (fort-nightly monitoring) and dry season (monthly). It is recommended that monitoring be completed every season in the dry season as larger volumes of water are now discharged during this season due to the cumulative flow regulation in the catchment.

The following recommendations are made for improving the JEM monitoring programme relating to Xayaburi HPP and DSHPPs, specifically:

- **Continue monitoring:** JEM monitoring should be continued for at least another 12 months using the same monitoring schedule (sites, parameters, monitoring frequency) so that a complete wet and dry season can be captured. COVID-19-related delays to the delivery of equipment and restrictions on field monitoring resulted in a limited data set at many of the JEM monitoring sites, with most monitoring occurring in the dry season. Since most of the flow and sediment are transported during the wet season, a longer data set is required to investigate and quantify changes related to power station operations. An example of this is the inability of the existing JEM data set to quantify to what extent sediment trapping is occurring within the Xayaburi impoundment. Ideally, all JEM sites will be monitored at the same frequency over a wet season to provide a data set showing changes in the upper and lower LMB under the same flow conditions;
- **Co-locate DSM and WQ monitoring sites and coordinate monitoring frequency to allow greater integration of the results.** Water quality and sediment transport are closely related, and additional information could be gained if monitoring between the disciplines were coordinated. The monthly WQ monitoring should coincide with DSM monitoring so that the SSC and flow conditions on the day can be integrated with the WQ results. Consideration should be given to collecting depth integrated water samples for the determination of WQ parameters;
- **Implement photo monitoring at the JEM sites as proposed in the JEM Guidelines.** Due to the delays and difficulties with field monitoring, the monitoring teams did not implement this component of the project. A field-based

demonstration of this monitoring approach should be incorporated into future JEM capacity-building activities;

- **Implement the transboundary (Thai – Lao) surveying of cross-sections in the alluvial reach upstream of Vientiane**. Due to border closures associated with COVID-19, this component of the JEM monitoring schedule could not be completed;
- **Continue the repeat surveys at the Dolphin Pools in Cambodia near the PDR border to track changes.** It is recommended that the surveying be completed at a much higher resolution than presently reported to allow the detection of changes;
- **Derive preliminary rating curves for the new HYCOS sites at Ban Pakhoung and Koh Key and the manual site at Ban Xanghai.** Rating curves would allow flow rates to be calculated for the sites based on water level results. At Ban Xanghai, the curve can be used to evaluate whether the site is suitable as a long-term water monitoring site, or is affected by the backwater of the Xayaburi impoundment. At Ban Pakhoung, a rating curve would allow determination of the flow changes associated with the water level changes;
- **Measure the discharge in individual channels near Don Sahong.** Understanding the distribution of flow between the different channels under a range of flow conditions would be useful for the fish migration investigation and assist the operator of Don Sahong in refining level/discharge relationships. This work should be coordinated with fish tag monitoring teams and the operator of the DSHPP;
- **Future JEM monitoring should consider inclusion of additional sites to record pre-hydropower conditions near HPP project sites that have been through the PNPCA process, but have not yet begun construction.** Initiating monitoring prior to the development of a project would provide a reliable baseline against which future monitoring results could be compared to identify changes related to construction or operations. Consideration should also be given to the establishment of monitoring sites that will not be affected by future hydropower developments so that long-term monitoring would show changes to the system over the long term (e.g. Ban Xanghai);
- **Include sufficient lead up time for establishing future JEM monitoring.** Future JEM monitoring should include sufficient time prior to the commencement of field monitoring to allow for the procurement and delivery of equipment, installation of new HYCOS sites, and training of field staff (if new methodologies are being used). This will ensure that a full year of complete monitoring results can be collected for all parameters at all sites.

5.1.2 Recommendations applicable to the JEM, DSM, and CRMN

The standard operating procedures of the DSM ongoing monitoring served as the basis for the JEM monitoring protocol. The combined JEM and DSM results and field monitoring experience have shown that there are aspects of the discharge and sediment monitoring regimes that could be improved. The following recommendations are relevant to future JEM monitoring, the ongoing DSM monitoring, and the CRMN:

- **Build capacity in the measurement of discharge using ADCP technology.** Monitoring results reported by the field teams are frequently not as accurate as they could be due to a lack of compass calibration and of applying moving bed corrections, or due to instruments not being correctly set up in the field. Field and classroom-based capacity building should be developed in the set-up, deployment, and post-processing of the data files;
- **Consider conversion to in-situ laser-based technology for DSM:** The DSM Standard Operating Procedure includes the collection of depth-integrated suspended sediment samples using a D96 water sampler. This equipment could not be procured during COVID-19, and it is unclear when or if the supply will resume in the future. In-situ laser-based technology should be investigated and trialled at some of the DSM sites, with the results compared to the D96 results. If the laser equipment provides meaningful results, then a long-term plan should be implemented to convert all sites to this technology over the coming years;
- **Review lab facilities and capacity building-related laboratory analyses of sediment samples for grain-size distribution and SSC.** Several countries have struggled with completing the required laboratory analyses due to a lack of experienced personnel, and/or of suitable equipment. A review of laboratory procedures as well as an audit of the sediment analysis capability of each country should be completed. Resources should be sought to upgrade laboratories where required, especially with respect to equipment for determining the grain-size distribution of SSC samples (see below);
- **Investigate options for use of automatic particle size analyser for determining grain-size results:** The laboratory determination of SSC grain size is not being completed by several countries due to a lack of equipment and training. Automatic particle size analysers should be used to determine the grain-size results. These instruments would complement the collection of SSC using the D96 sampler. Where an in-situ laser instrument is used for field monitoring, the grain-size distribution will be recorded by the instrument and a separate grain-size analyser is not required. At sites continuing to use D96 samplers, these units would provide rapid grain-size information and could be field- or laboratory-based. It is recommended that during the development of the CRMN the available options be investigated;
- A **web-based reporting system with in-built Quality Assurance and Quality Control (QA/QC) QA/QC procedures should be developed and implemented with the hydrologic and sediment data directly uploaded to Aquarius.** The reporting system for the DSM results requires major revision. The reporting system is based on multiple excel spreadsheets that require subsequent QA/QC and integration. Adopting a web-based reporting system with in-built QA/QC would provide more accurate and timely use of the results. Under the present system, results are not reported until months after collection, and then require additional QA/QC before use;
- **The rating curves developed in 2012 for the DSM monitoring sites should be reviewed and updated.** Rating curves can change over time due to changes in the channel cross-section, so the rating curve review should include a review of the long-term, cross-section survey results from the DSM sites.

5.2 WATER QUALITY

Recommendations for the WQ monitoring are presented in two parts. The first part outlines JEM specific recommendations according to parameters measured, frequency and timing of measurements, choice of sampling locations and interpretation of results. The second partoutlines recommendations for WQ monitoring more generally as relevant to the ongoing MRC routine monitoring and to the development of the CRMN.

5.2.1 JEM-specific recommendations

The WQ monitoring has shown some interesting results in both Xayaburi and Don Sahong, even if these do not show clear impacts with passage through the impoundments and downstream, and with very little evidence of stratification of the impoundments. These JEM Pilots have only been able to work with eight monthly samples and have not included a full set of wet season results. It is noted that the water levels and flows in the 2021 wet season were low; therefore, the water level data used in this report may not be typical of wet seasons with greater rainfall.

5.2.1.1 Parameters measured

In general, the WQ parameters measured by this project are appropriate to understand the change of water quality due to the operation of hydropower projects. It is important to continue the long-time sequence of measurements that already collected under the routine WQMN monitoring. Recommendations relating to JEM Programme monitoring parameters are identified as follows:

- The most important parameters to be measured under the JEM Programme are the general WQ parameters of temperature, pH, DO, conductivity, TSS and turbidity, the nutrients and phytoplankton measurements (NO32, ToTN and TOTP and chlorophyll-a and cyanobacteria), and the indicators of pollution (COD, NH4, FC). Alkalinity and acidity measurements may be useful if there are marked changes in pH and DO for water that passes through the hydropower dams and their impoundments;
- The measurement of TSS and nutrients, COD and FC was limited to certain sampling locations due to cost restrictions. It would have been better to have included the full set of measurements in all sampling stations;
- The cations and anions measured during the wet season have not been analysed because of the incomplete wet season sampling. The usefulness of these parameters in the context of hydropower in comparison with overall river WQ remains to be demonstrated. If it is necessary to restrict continued sampling on cost grounds, **the laboratory analyses of these parameters could be dropped;**
- When WQ teams are in the field and spot results that are out of the ordinary from the probe readings and impoundment profiles, they should **carry out additional readings to confirm them, or recalibrate the probes**. This should be the start of the QA/QC process;
- When samples are being analysed in the laboratory and the results are out of the ordinary, especially regarding nutrients, **duplicate analyses should be performed**;

- For the depth profiles within the impoundments, the demonstration of stratification at deeper depths has been limited by the length of the cables at 10 m for the AlgaeTorch and 20 m for the routine parameters. **Future depth profile monitoring should invest in longer cables** at least down to the depth of the water intakes on the dams and preferably to the bottom of the impoundment at the monitoring station;
- **Continue use of the AlgaeTorch:** The AlgaeTorch has been demonstrated as a very useful monitoring tool, providing instantaneous results for the phytoplankton at both surface and in-depth profiles. The advantage of the AlgaeTorch is that it combines measures of turbidity and cyanobacteria as well as chlorophyll-a, and the results are immediately available. Whilst relatively low levels of phytoplankton have been measured, its use in the future JEM and in routine WQMN will provide ongoing information on the development of algae in the river, especially when more of the river becomes impounded;
- **Check results using the AlgaeTorch:** The method required for using the AlgaeTorch in fast running water, where the measurements have been unreliable, should be clarified. To do this, results obtained via the method of collecting a sample of the fast-running water in a bucket in which the AlgaeTorch is dipped to measure chlorophyll-a should then be confirmed by comparing with results from a laboratory analysis of chlorophyll-a.

5.2.1.2 Frequency and timing of measurement

The routine WQMN measurements are carried out monthly, and the JEM Programme follows this frequency of measurement. This is appropriate for direct comparison with the WQMN results. However, the monthly measurements are spot samples, which do not adequately capture the daily variation in parameters such as DO and pH. Matching the frequency of measurements of parameters such as temperature, DO, pH, conductivity, and turbidity with flows and water levels, will also facilitate linkages between disciplines and help to demonstrate how WQ parameters can be related to dam operation much more clearly.

It is therefore recommended that:

- **High-frequency WQ monitoring equipment be established at JEM sites as close downstream to the dam as possible to obtain a representative sample of the water, and if possible co-located with automatic water level and flow monitoring stations.**

It is noted that a high-frequency WQ monitoring probe measuring these parameters is being constructed under the JEM programme at Don Sahong.

5.2.1.3 Choice of sampling locations.

The choice of locations for the WQ sampling has been appropriate for assessing the impacts of hydropower dams and impoundments. The following recommendations are made for the JEM Programme:

- The basic pattern should be one site above the impoundment, one site within the impoundment, and several sites downstream to show recovery of WQ after the dam;
- When considering future hydropower dams on the Mekong mainstream, it will be important to follow the same choice of locations and start monitoring at least one year before construction starts in order to establish a baseline;
- The actual sampling locations will depend upon issues of ease of access, safety, and representativeness of the samples being collected.

5.2.1.4 Analysis and interpretation of results

Statistical analysis of the multiple probe results taken at the same location on the same day were used to compare between different sites, e.g. above and within the impoundment or below the dam. While the results show that the impoundment is statistically significantly different compared with above the impoundment and downstream of the dam, the changes are not necessarily ecologically significant. The follow recommendations for the JEM Programme are therefore made:

- **Water quality measurements around these pilots should be continued for another year** in order to develop a more statistically comprehensive set of results that can be available for analysis;
- Analysis of results should **differentiate between statistical and ecological significance**;
- Wherever available, the **results of WQ monitoring taken by the hydropower companies should be compared with the JEM results,** and both should be related to operation details provided by the companies. The correlation of high-frequency WQ measurements with hydropower operation and flow variation should be analysed for better understanding of impacts;
- The guideline thresholds of 50 micrograms/l used for chlorophyll-a are based on WHO recommended guidelines for human safety contact recommendations for safety for human water contact. A **Mekong-specific threshold value for cholorophyll-a guidelines should be established to address riverine eutrophication concerns developed for chlorophyll-a geared towards eutrophication** concerns, and links with increasing nutrient concentrations The established threshold value can also be used to monitor may also be linked to the change in water colour of the Mekong River during low flows experienced during the dry season JEM sampling;
- Nutrient concentrations should be an important set of parameters being measured regularly throughout the year. **The proportions of dissolved and sediment-bound nutrients in the total nitrogen and total phosphorus should also be investigated** to understand how much nutrients are being trapped with sediments in the impoundments;
- Turbidity provides an immediate measure of the transparency and suspended sediment in the water. The relationship between turbidity and TSS should be investigated to **establish an equivalence curve suitable for Mekong waters**. For each location, the correlation of TSS with SSC measurements would also indicate the representativeness of TSS as a measure of sediment loads. This could also be

extended to the relationship between turbidity and Secchi disc measurements used by the EHM teams.

5.2.2 Recommendations applicable to the WQMN and the CRMN

The JEM WQ monitoring was designed to complement the routine WQMN by measuring the same parameters at monthly intervals at the additional JEM WQ stations. This principle remains valid, so that the JEM results can be compared with the ongoing routine WQMN results in the wider basin. The JEM results reveal some differences between the routine measurements and those undertaken by the WQMN teams, both in time and in different countries, for example, in pH and conductivity. While this is not necessarily critical to interpretation of the results, it does lead to the following recommendations:

- **Standardization of equipment and sampling methods should be undertaken by all the teams, so as to reduce the risks of sampling error**;
- **Continued training on standard sampling methods and calibration of equipment** for all the national WQ teams.

For the CRMN, it is clear that the choice of sampling stations to be continued or established for the will require rationalization of sampling stations from both JEM and the routine monitoring in light of existing and future developments on the Mekong and its tributaries. It is also apparent that the WQ monitoring of the hydropower companies (as shown by Don Sahong) is very similar to the JEM, and often more frequent. With these points in mind, recommendations for the CRMN work are that:

- The **JEM principles of the siting for WQ sampling above impoundment, within impoundments and downstream of dams should be respected**, for both existing and planned mainstream dams, so that changes due to construction and operation of the cascade of dams can be monitored;
- The comments made above on the WQ parameters for the JEM are valid for the WQMN and CRMN;
- The **opportunities for integration of the WQ monitoring stations and data sharing into the CRMN need to be actively explored**, so that the CRMN becomes a real joint monitoring exercise with the hydropower companies closely involved.

5.3 ECOLOGICAL HEALTH MONITORING

Recommendations for the EHM are presented in two parts. The first part outlines JEM specific recommendations according to parameters measured, frequency and timing of measurements, choice of sampling locations and interpretation of results. The second part outlines recommendations more generally as relevant to the ongoing MRC routine monitoring and to the development of the CRMN.

5.3.1 JEM-specific recommendations

The EHM around the JEM pilot sites showed some clear indications of changes in the aquatic biota both within the impoundments and downstream of the dams. There are also signs of recovery to more normal riverine conditions with distance downstream of the dams. The EHM method has shown that it is sensitive to the changes likely to occur in the localized habitats around hydropower and that it is an important monitoring discipline that complements the other disciplines.

5.3.1.1 Parameters measured

There are three sets of field measurements that are undertaken at the time of sampling – Site Disturbance Score, Substrate Suitability Score, and environmental parameters. All three are important to capture the site conditions, noting the following recommendations:

- The Site Disturbance Score **should have a scoring question related to impoundments**, since this is the most obvious change in sampling sites caused by HPPs;
- The Substrate Suitability Score provides an important assessment of the suitability of the sampling site for finding a range of aquatic biota. The JEM analysis indicates that downstream of the dam, the substrate suitability is reduced, possibly by a combination of the rapid changes in water level, flow rates, and reduced sediment transport. **The Substrate Suitability Score should be included in the analysis** to correlate with changes in the EHM Index;
- The environmental parameters measured are very similar to the WQ parameters, but represent only one spot sample in the year. When analysing and interpreting the EHM results, the environmental parameters measured should be compared with the monthly WQ results, and the EHM index should be correlated with the annual median, maximum, and minimum for the nearest WQ monitoring station, rather than the field measurement made by the EHM team.

The methods of the JEM Programme for collecting the samples of benthic diatoms, zooplankton and littoral and benthic macroinvertebrates are well established, although some adaptations in the sampling methods have to be made for sampling in the deeper areas of the impoundments, especially for zooplankton and benthic macroinvertebrates, (e.g. the use of a vertical tow of the zooplankton net and choice of sampling locations in the impoundment for benthic macroinvertebrates as suggested in the protocols). There are three parameters for each of the four biotic groups:

- the abundance or number of individuals of distinct species counted in each set of sub-samples;
- the species richness or numbers of species represented in each set of sub-samples;
- the Average Tolerance Score per Taxon (ATSPT).

These scores are assessed against pre-determined threshold values in order to calculate the EHI. These three parameters are well established and do not need to be changed.

However, this system was developed to assess <u>changes in WQ</u>, rather than the <u>changes from lotic to lentic water bodies</u>. The reduction in the EHI within the impoundments that the JEM Pilots results are showing is likely to be caused by the lotic to lentic changes, rather than WQ. The EHM biota for inundation and reservoir areas are likely to be very different from riverine areas with different tolerances (ATSPT scores). In the future, it is recommended to **build up a series of reference sites within reservoirs of both mainstream and tributaries** in the long term so that WQ changes in the reservoirs can also be compared.

The JEM database of the species in all four groups incorporates all the species that have been recorded in the Lower Mekong Basin over the past decade. It is clear from the JEM data that the two pilot sites have different assemblages of species, which is to be expected with widely separated river reaches. it is therefore all the more important to **establish baseline conditions at each site so that changes over time in the same site assemblages can be compared**.

The database now facilitates the separation of particular taxonomic groups that can be used as specific indicators. The JEM has explored the potential of identifying changes *in Ephemeroptera, Plectoptera and Trichoptera* (EPT) and filter-feeding species (*hydropsychidae* and *simuliidae*), which can complement the basic EHI. **It is recommended that indicator species or taxonomic groups from each of the four biota be identified for future analysis and interpretation of the changes observed.**

5.3.1.2 Frequency and timing of sampling

Monitoring of the aquatic biota requires time, effort and specialized expertise, especially in identification of the species, hence it can only be realistically carried out once a year at times of low flow. The following is therefore recommended:

- Develop **a quicker method of assessing the aquatic health** that an be used more frequently in order to complement the annual or biennial monitoring campaigns. The results from the JEM pilots indicate that the littoral macroinvertebrates are the most sensitive of the biota to the changes in the river typical of hydropower. However, zooplankton could be sampled at all times of year, not just in the dry season;
- **Add additional sites downstream of dams to be assessed with this quicker method in order to increase understanding of the length of the recovery zone downstream**. This may be up to 30 km downstream or until the peaking flows become more balanced by tributaries entering the river.

5.3.1.3 Choice of sampling locations.

The locations chosen for the JEM monitoring of ecological health are broadly the same as for WQ – above the impoundment, in the impoundment, and then several with distance downstream of the dams. This provides a good opportunity to compare changes in WQ over the year with the annual changes in the ecological health parameters. However, the experience of the JEM Pilots has shown that pre-selection of the exact sampling locations is not always appropriate due to issues of access, safety, and the suitability of the substrate conditions, which may change from year to year according to conditions. The following is therefore recommended:

- **EHM teams find the best range of sites to sample, at the time of the visit, according to the identified factors**;
- **only the approximate location should be specified,** with a sampling radius of approximately 1 km, so that the EHM teams can select the most suitable site.

5.3.1.4 Analysis and interpretation of results

The statistical analysis of the JEM EHM results was limited because only one year's sampling was available, and it was only possible compare the presence/absence of species found at each site. For a more comprehensive statistical analysis and to show differences between the sites, a larger number of yearly results, including baseline conditions for all sites, should be included for monitoring of future dams. These following recommendations emerged from the comprehensive analysis:

- The abundance of species should be assessed as well as their presence/absence;
- In order to interpret the impacts of hydropower, aquatic biota were correlated to results from composite annual WQ monitoring, flows and water levels, and sediment transport should combine with the substrate suitability score;
- The correlations with changes in fisheries monitoring is likely to depend on the overall productivity and diversity of the aquatic biota in each of the sites and the trophic guilds of the prevalent fish species;
- An understanding of the drivers of change and causative factors influencing the aquatic biota at each site is necessary in order to answer the complex correlation questions (see Figure 6.2).

5.3.2 Recommendations applicable to the routine EHM and the CRMN

The sensitivity of the EHM method to changes in the river makes it a highly suitable monitoring tool for the Mekong, and the JEM Pilots locations complement the routine biennial EHM campaigns.

The following are recommendations regarding monitoring locations:

- The routine EHM site at Luang Prabang is several kilometres downstream of the EHM 1 at Ban Xang Hai and is now considered to lie within the influence of the Xayaburi impoundment, and so **should be discontinued in favour of EHM 1**;
- The choice of **new locations for the CRMN should their distance with regard to the locations of future dams and impoundments,** and be directly linked to the WQ sampling stations;
- It will probably not be appropriate to have multiple sampling locations downstream of dams, as has been the case for the JEM EHM sites downstream of Xayaburi; hence, **future EHM sites downstream of dams should be located within 5–10 km downstream** to allow some stretch of river to recover after the immediate impacts of the dam;
- **Collecting a good baseline condition before a dam is built** will be important to monitor changes during construction and operation.

In terms of the analysis and interpretation of the EHM results, the EHI has been specifically designed to highlight changes in WQ (e.g. from pollution). The JEM results appear to show that the biota are more sensitive to (i) changes of water level and flow due to hydropower and (ii) changes in habitat and transparency of the water due to reduced suspended sediments. While the EHI provides a general indication of the responses of the different biota types, it is suggested that a more detailed understanding be developed of the sensitivities of the taxa and species to changes induced by hydropower. It is recommended that the JEM analysis be continued to inform **identification of Mekong-specific indicator species or families among the four biota types** to monitor the detailed species found at each site.

The JEM Pilots EHM monitoring was conducted by the Lao EHM team and so species are reasonably uniform. It is certain that there are different assemblages of the biota in the tributaries and in the upstream compared to the downstream and in the Delta. However, based on the historic EHM species recorded at different sites within the LMB, there are differences in sampling and identification differences suspected to occur between the four national teams. The species database has been built from all the species recorded throughout the LMB, with full taxonomic classification to aid identification and analysis. Based on these observations it is recommended that:

- **the EHM database of species be updated each year with new species identified during the EHM campaigns;**
- **a photographic database of the species caught each year be developed a**s an aid to comparable identification of species across teams;
- as with WQ, **a shift towards standardization of EHM sampling procedures and identification throughout the basin should be made**;
- **future campaigns should be combined with joint training and refresher courses.**

5.4 FISHERIES

5.4.1 Fish abundance and diversity monitoring

The JEM Programme protocol follows the instructions of the standard sampling guidelines for FADM (section 6.2) and JEM documents (v.3 Annex 19). Implementation and analysis do not pose any major problems. The final protocol is similar to the protocol considered in the JEM Pilots Inception Report, as follows:

- What: Data gathering by three fishers in each site;
- Where: In Pha O village, Tha Deua village and Pak Houng villages (Xayaburi) and, for the monitoring of Don Sahong Dam, in Muang Saeng Nua village, Ban Hang Sadam and Ou Run in Cambodia);
- How: The procedure based on logbooks should follow instructions in Standard sampling guidelines for FADM section 6.2 and JEM documents v.3 Annex 19;
- How often: Each fisher records his catch daily;
- Data management and cleaning: Data sheets compiled weekly by a key fisher at each site, and are collected quarterly by national agency staff. During the month following data sheet collection, data are cleaned and entered in the database by

Inland Fisheries Research and Development Institute, Cambodia (IFReDI) and Living Aquatic Resources Research Centre, Lao PDR (LARREC) staff.

The primary observationon the JEM Pilots implementation is the observed data heterogeneity around Don Sahong site, in sites located 8 km apart in similar environments. These disjointed observations call for **a meeting of national FADM teams and a joint review of respective implementation and data recording modalities.** This step is needed before overall conclusions about long-term trends and dam impacts in the Don Sahong dam site can be produced.

It is not yet evident whether the Ban Hang Khone site should be maintained. It is located a few hundred metres away from Ban Hang Sadam and yet has produced very different results so far. The Ban Hang Khone site can be maintained if budget allows and if continued monitoring confirms the difference in results (e.g. very high species diversity, specifically) as reflecting a special site, rather than reflecting a site-specific difference in data gathering.

Some other points of improvement can be noted:

- The field teams noted the need for **updated photo flipcharts that better include small and new species.** Flipcharts developed for projects in Cambodia (see Fisheries Administration, 2019), and new MRC publications in fish identification (see Ngor et al., 2016) can underpin the production of new fish identification flipcharts, one for each country. These flipcharts would integrate other small species becoming frequent in catches, and could combine the best of manuals, i.e. large good photos (Lao PDR), criteria to distinguish species (Fisheries Administration, 2019), and local names in all riparian languages (Ngor et al., 2016), in addition to Roman script of local names;
- Issues about differences in fish taxonomic counts in closely located sites from different countries detailed below call for **a systematic and peer-reviewed standardized table, in each country, of equivalences between local names and the latest scientific names**. Such table should reflect the fact that one name in local language can correspond to several scientific species names and conversely;
- The procedure for sub-sampling Standard Sampling Guidelines is too complex, and fishers do not follow it. **It should be simplified, and the alternative procedure in use in Cambodia can be applied;**
- Frame surveys mentioned in the standard sampling guidelines for FADM aim to infer production and prices from individual fishers monitored to larger administrative scales. However, a review with the national teams of the demand in terms of preparation, logistics, resources, and data analysis vs. ability to credibly calculate catch and production on a large scale led to the postponing this component;
- There is an opportunity to **strengthen and harmonize the quality of data gathering and build the capacity of the national teams** by organizing a round of data gathering and data entry, during which the most experienced riparian scientists will mentor and assist colleagues from other countries.

5.4.2 Standardized gillnet monitoring

JEM guidelines recommended using a standardized scientific sampling protocol based on gillnets, according to international standards. The JEM Pilot project and national teams held in-depth discussions, documented in the Combined Annual Report, regarding the most desirable composition, size and arrangement size of fleets of nets. In particular, three different fleet configurations were tested: short panels, medium-size panels, and long panels. The conclusions were as follows:

1. Work only with sizes permitted in the region and available in local markets (i.e. 20; 30; 40; 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, and 150 mm stretched mesh).
2. Develop a larger fishing effort (350 m^2 instead of 275 m^2) by using 14 panels of 10-m length x 2.5-m height.
3. Divide the long fleet of 14 panels into three shorter sets of 4 to 5 panels, each setin different environments to adjust to size-related distribution of species, and maximize the sampling (small mesh sizes for small fish along banks, medium mesh sizes in ad hoc locations, and large mesh sizes for larger fish in the mainstream):
    - Gillnet ID1: 20-50-40-30-60 mm to be set near banks and the vegetation to target small fish in their habitat;
    - Gillnet ID2: 70-90-100-80-110 mm to be set in suitable locations decided by fishers;
    - Gillnet ID3: 120-150-140-130 mm to be set in the middle of the river to target large fish.

As a consequence, the protocol should be as follows:

- *What*: Data gathering by three fishers in each site;
- Where: In Pha O village, Tha Deua village and Pak Houng villages (Xayaburi) and, for the monitoring of Don Sahong Dam, in Muang Saeng Nua village, Ban Hang Sadam and Ou Run in Cambodia);
- H*ow*: Using 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140 and 150 mm mesh panels (size of a panel: 10m x 2.5m); 20-50-40-30-60 mm mesh size set near banks; 70-90-100-80-110 mm mesh size set in suitable locations decided by fishers; 120-150-140-130 mm set in the middle of the river;
- *How often:* Once per week at each monitoring site;
- *Data management & cleaning*: Data sheets are compiled weekly by a key fisher in each sites, and collected quarterly by national agency staff. The following months, data are entered and cleaned in the database by national agency staff.

5.4.3 Fish larvae drift monitoring

Overall, fish larvae drift monitoring (FLDM) results indicate that larval abundance shows some irregular peaks in April, May, and June corresponding to early rains; July is clearly a month of maximal larval abundance; and smaller abundance peaks corresponding to the end of the rainy season can also be observed in October. They also indicate clear differences between sampling locations that can be a few hundred metres apart within the same site.

This confirms that the **sampling effort should be particularly focused on April, May, and June (early rains), followed by July as the month of maximal larval abundance, and October as the post-rainy season important sampling date**. Results also confirm the suitability of the latest JEM sampling protocol including two sampling locations on two banks and one in the mainstream as middle location.

In 2020–2021, during the Pilots testing and learning phase, the new team from Lao PDR sampled only two stations per site. With increased experience, additional training (see below) and improved larvae identification skills and speed, **larvae sampling in three locations per site in Lao PDR should be achieved**. This is desirable to ensure a better coverage of the local heterogeneity and full compatibility with data from other sampling teams.

Midnight sampling is a problem in all sites. As a consequence, the **timing of samples would be from: 6:00/12:00/18:00/00:00 (now) to 6:00/12:00/18:00/21:00.**

On these bases, the revised protocol should be as follows:

- *What*: Data gathering by one fisher in each site;
- *Where:* In Pha O village, Tha Deua village and Pak Houng villages (Xayaburi) and, for the monitoring of Don Sahong Dam, in Muang Saeng Nua village, Ban Hang Sadam and Preah Romkel in Cambodia);
- *How:* Using a 1-m diameter, 5-m length, 1-mm mesh size net in all sites. Sampling of two banks per site and one additional sample in the mainstream (three in total per site), 2 m below the surface, for 30 minutes each time, at 6:00, 12:00, 18:00 and 21:00;
- *How often:* One day per week from August to April and two days per week from May to July;
- *Data management and cleaning:* Larvae bottles are collected monthly by national agency staff. In the following months, data are entered and cleaned in the database by Inland Fisheries Research and Development Institute, Cambodia (IFReDI) and Living Aquatic Resources Research Centre, Lao PDR (LARREC) staff.

This new protocol is dependent on data gathered by fishers. Experience shows that these **fishers need more training on how to record samples** (use of bongo nets with anchors, proper recording of flow metre data, precise identification of sample bottles).

Since the Lao team is new to larvae identification, **extensive training is required to strengthen its capacity so that 30 taxa can be routinely identified** as the lowest common denominator between all of the teams (identification ranging from family to species level depending on the taxon).

Overall, given the seasonal influences, it is necessary to sample over several years to enable the successful detection of dam impacts through larvae monitoring requires, even more so than for the catch of adult fish. The 2020–2021 period represented the pilot years of the initial phase of this protocol aimed at achieving such assessment around dam sites.

5.4.4 Fish tagging

An initial review (see the JEM Pilots Inception Report) revealed: the many options for tagging methods that could be implemented for tracking fish migration; the large diversity in tag types, prices, and the relevant conditions in which they can be used; and the often challenging and underestimated technicalities of successful implementation. A systematic review was undertaken in collaboration with several international specialists (see MRC, 2021a) to reflect these findings and ensure a solid foundation to the JEM tagging programme. The resulting summary of existing methods is presented in Table 5.1.

Table 5.1. Main conditions of use for the different electronic tagging methods

	Radio tagging	**Acoustic tagging**	**PIT tagging**
Water depth (m)	0 - 5	1.5 - 100	< 1
Usable with small fish	Moderately	Moderately (new small-size tags)	Yes
Reception range (m)	20 to 5,000	20 to 300	0.1 to 1-2
Lifespan of the tag	20 days -2 years	10 days - 1 year or more	No limit
Long-term studies (> 1y)	Medium to large fish	Medium to large fish only	All fish sizes
3D-tracking	Limited, complex (requires multidirectional array and depth loggers)	Yes	No
Cost of one tag (USD) **Cost of one receiver (USD)**	> 200 1,000 - 5,000 (40k for depth loggers) x 4 units minimum	> 300 1,500 - 2,000 x 6 units minimum (up to 70 for 36,000 ha)	1-4 > 5,000

The identified technical constraints of fish tags and monitoring equipment (mainly reception range and depth) were next compared against the characteristics of Khone Falls channels documented during the local ecological knowledge and field surveys. This led to the assessment and prioritization of channels for their suitability to host fish tagging experiments (Table 5.2).

Table 5.2. Overview of candidate channels and their suitability for tagging experiments

Channel	Wet season	Dry season
Hoo Som Yai	X	#NA
Hoo Som Pordan	XXX	#NA
Hoo Sadam	X	#NA
Hoo Xang Peuak Yai	XX	XXX

Hoo Xang Peuak Noy	XXX	XXX
Nyoi Koong	XXX	#NA
Koum Tao Hang	XX	#NA
Hoo Wai	X	XX
Luong Pi Teng	XX	#NA
Hoo Don Lai	XXX	XX
#NA: impossible candidate site ***X: unlikely***	***XX: worth trying***	***XXX: priority***

The following priority sites for wet season tagging are recommended:

- Hoo Som Pordan, Hoo Xang Peuak Noy, Nyoi Koong and Hoo Don Lai.

The following priority sites for dry season tagging are recommended:

- Hoo Xang Peuak Noy, Hoo Wai and Hoo Don Lai.

Hoo Xang Peuak Noy stands out as the only site suitable in all seasons, followed by Hoo Don Lai.

More generally, the preparatory work highlighted that the **key management questions asked (i.e. "Are mitigation measures taken to facilitate fish migration locally effective? and "Do mitigation measures ensure the sustainability of fish populations?") need to be segmented into technical questions according to the different environments,** and different tagging method requirements (adapted or not to different fish sizes). This breakdown of management questions into technical questions and associated tagging questions is provided in Table 5.3 – leading to the identification of suitable approaches.

Table 5.3. Overview of tagging methods and species tagged depending on management questions, technical questions, and environmental context

Key questions	Technical questions	Specific tagging question	Don Sahong context	Tagging possible	Species that can be tagged	Number of tags
Are mitigation measures taken to facilitate fish migration locally effective?	Do fish find the passage during their upstream migration?	Do fish locate the passage entrance?	Fish arriving from Cambodia in a wide deep river (400-1500 m wide, 10-30 m depth)	Acoustic tagging	Medium- to large-size species	Several hundred per species
		Do fish enter the passage?	Narrow and shallow channels (3-30 m wide, 0.2 – 10 m deep)	Large scale (proportion of fish entering): PIT or radio tagging	All species if PIT; large species if radio tags	Several hundred per species
				Fine scale (fish behaviour): acoustic or radio tagging	Medium to large species if acoustic tags, large if radio tags	5-10 per species
	Do fish pass the obstacle during upstream migration?	Can fish swim throughout the passage?	Narrow and shallow channels but site-, season- and hydrology-specific	PIT or radio tagging	PIT for all species; radio for large species	20-50 per species
	Do fish pass the obstacle during their downstream migration?	Fish behavior at barriers and screens?	Impoundment	Acoustic 3D tagging		5-10 per species
Do mitigation measures ensure the	Do fish keep living after the passage?	Do fish continue their migratory journey after passage?	Wide and moderately deep river (500-2000 m wide, 1-6 m depth)	Acoustic or radio tagging	Medium- to large-size fish	Several hundred fish

Key questions	Technical questions	Specific tagging question	Don Sahong context	Tagging possible	Species that can be tagged	Number of tags
sustainability of fish populations?		Which proportion of fish live long enough to breed?				1,000 or more
	Are downstream migrations sufficient for sustainability?	Can adult fish migrate downstream in sufficient proportion?		Acoustic or radio tagging	Medium- to large-size fish	1,000 or more
		Can larvae and juveniles migrate downstream in sufficient proportion?		No tagging possible		
		Do fish settle in the impoundment?	Impoundment	Tagging unnecessary: work with fishers	All species	-
		What proportion of fish passes and survives turbines or spillways?	Impoundment and downstream	Radio tagging		20-50 per species

In light of the expected level of potential resourcing, these complex sets of options for fish tracking, and in consideration of the cost of tags (USD 1 to 33 per item), the following steps for the design of a fish tag-based monitoring programme are recommended:

1. Decide on the priority questions to be addressed and the scope of the monitoring programme (duration, geographic scale, resolution, by MCs);
2. Select study sites and target species and amount of fish to be tagged (by MRCS, criteria now provided by the JEM Pilot project);
3. Identify the tagging technology and logistical aspects required to address the priority questions identified (criteria now provided by the JEM Pilot project);
4. Decide on the tagging method and equipment based on priority questions and the budget available (by the MRCS and the implementing agency);
5. Define a work plan (i.e. what, how, where, when, and by whom, with adjustments based on budget and human resources available, by the MRCS and the implementing agency);
6. Ensure procurement (e.g. tags, receptors, batteries, anaesthetics, antibiotics, software, database, etc., by the implementing agency);
7. Secure permissions (access to sites; import and use of electronic equipment; fish tagging ethical permits for publishable results; etc., by the MRCS and the implementing agency);
8. Train staff in handling and tagging fish, in use of receptors, in equipment maintenance, in data handling and analysis (by the implementing agency);
9. Supply fish to be tagged secured (how, where, by whom, when; by the field team);
10. Test methodologies (fish survival before and after tagging; lab testing of antenna design and performance; field testing of antenna performance; by the implementing agency and the field team);
11. Tag fish once logistics, sanitary requirements, and trained staff have been secured (by the field team);
12. Decide on the release of tagged fish (where, how) and consider logistical constraints (by the field team);
13. Monitor tags (put in place a recording programme or deploy field surveyors, and consider logistic aspects, by the field team);
14. Carry out on-site maintenance of the equipment (renew recorder batteries, prevent stealing, etc.) and regular data collection (by the field team);
15. Store data (in a dedicated database, or by remote transmission, by the implementing agency and the MRCS);
16. Carry out data analysis with respect to questions asked (in different degrees of data analysis complexity, from presence/absence to 3D trajectories, by the implementing team and/or specialized partners);
17. Report and answer questions asked (by the implementing agency).

5.5 COMMUNICATIONS AND GOVERNANCE

The JEM programme is the result of a long process of drafting, consultation, and commitment by the MCs since it was first agreed to in 2016. The JEM Programme is not an end in itself and will be properly integrated into the MRC future plans and upcoming programmes. First, the recommendations and lessons learned inform the revision of the MRC guidelines or Joint Environment Monitoring of Mekong Mainstream Hydropower Projects to ensure a common, standardized, and scientifically robust programme for jointly monitoring key environmental indicators. These indicators will be used for the impact assessment of Mekong mainstream HPPs on hydrology and hydraulics, sediment and geomorphology, WQ, aquatic ecology, and fisheries. This revision will be finalized in March 2022 and it is expected to be incorporated in the CRMN by December 2022.

The JEM Pilots have initiated a further productive relationship that has been strengthened through the JEM Pilots with the Xayabouri and the Don Sahong Hydropower Project. Opportunities have been identified for collaboration between the MRC and MCs monitoring teams, and the developers to jointly carry out monitoring activities. This could be formalized with these two companies and extended to other developers in the future through two of the communication measures suggested in Section 4.1:

- implementation of a central communication system to alert downstream communities and countries of impending flow releases, or other changes to operations that could affect downstream communities (e.g. low flows or high flows);
- a reporting mechanism for the operation of low-level gates at HPPs that will affect sediment transport in the river.

The JEM Pilots have identified the value of all MCs monitoring within a joint framework and standardized approach. Regular review of data management and coding by the MCs should be conducted to facilitate impact assessments as the JEM Programme is implemented.

6 INTEGRATION OF RESULTS BETWEEN DISCIPLINES

In addition to trialling methodologies for detecting changes associated with hydropower developments, the JEM Pilots aim to investigate how the resultant JEM datasets could be integrated to provide a deeper understanding of inter-discipline relationships and identify key processes that are susceptible to change due to hydropower operations. This has necessitated a 'deep-dive' into the existing distribution of monitoring sites, monitoring parameters, and monitoring frequencies across the disciplines to identify such opportunities. Further detail on the related review of JEM Pilots and routine monitoring locations and databases, and lists of potential parameters to be linked can be found in the Combined Annual Report.

In this report, this in-depth exploration is summarized by describing the high complexity of the Mekong system, some potential links between disciplines. and noting the challenges for integrating the various data sets. Due to this complexity, identifying cause-response relationships within this report with a high degree of confidence is difficult and would be premature with respect to the short duration of the JEM Pilots monitoring. This report does, however, provide a series of steps as required to design such quantitative analyses once longer records have been collected at the JEM Pilots sites. This provides a strategic blueprint for the future integration of monitoring results. Trends at each discipline, as detailed in Section 4, are then qualitatively compared according to location clusters in order to integrate the key findings as far as currently possible.

6.1 Drivers and causative factors of changes in river conditions

The highly complex nature of ecosystem processes in the Mekong must be recognized when seeking to integrate data between disciplines. Figure 6.1 shows some of the known driver-response mechanisms affecting fisheries and aquatic ecology in the LMB according to the JEM Programme document. This illustrates that there are numerous drivers and causative factors acting on each ecosystem component that can affect fisheries and aquatic ecology.

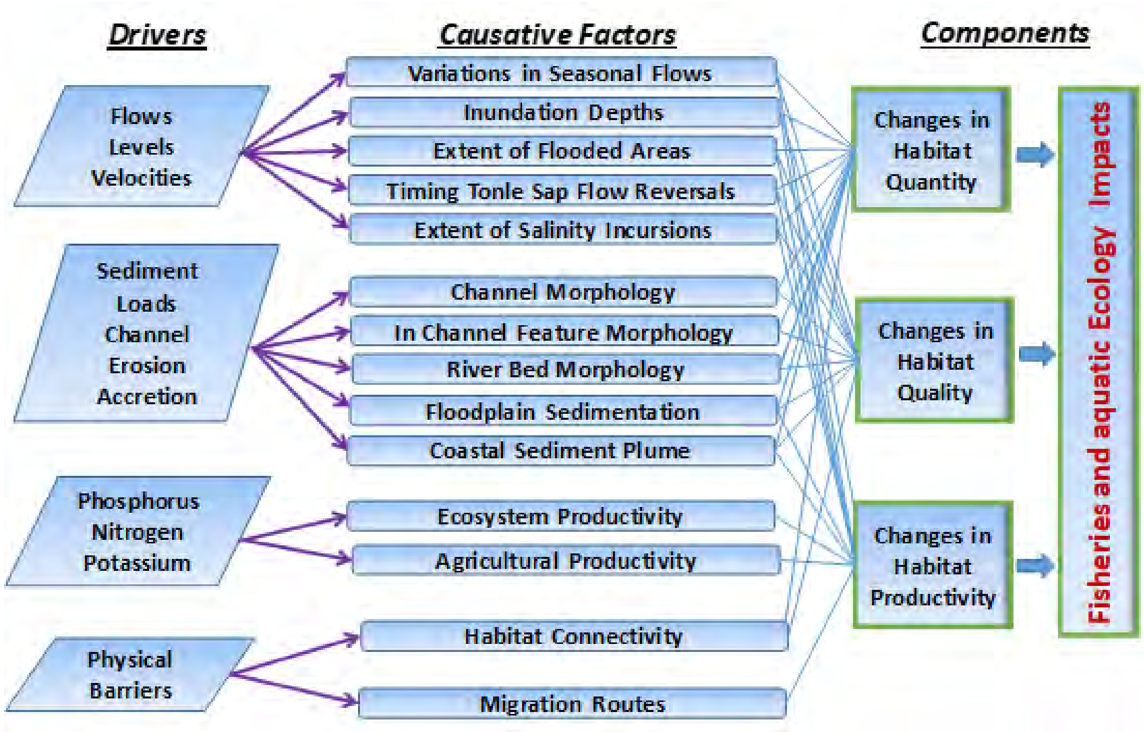


Figure 6.1. Recognized linkages between monitoring disciplines in the LMB from the JEM Guidelines

When observing the drivers of physical parameters (hydrology, sediment) and chemical parameters (WQ) as well as the lower and short-lived biological components (plankton, benthos), and finally the upper biological components (fish resources, fisheries), the system can be described as:

- an increasingly multiple factors integration;
- being complex due to interacting factors that can buffer each other;
- as reacting over a longer period of time.

Figure 6.2 shows identified links between hydrologic drivers and ecosystem components in the Mekong as identified during the MRC Biological Resource Assessment component of the Council Study. This further illustrates the integration assessment of the numerous relationships among monitored parameters.

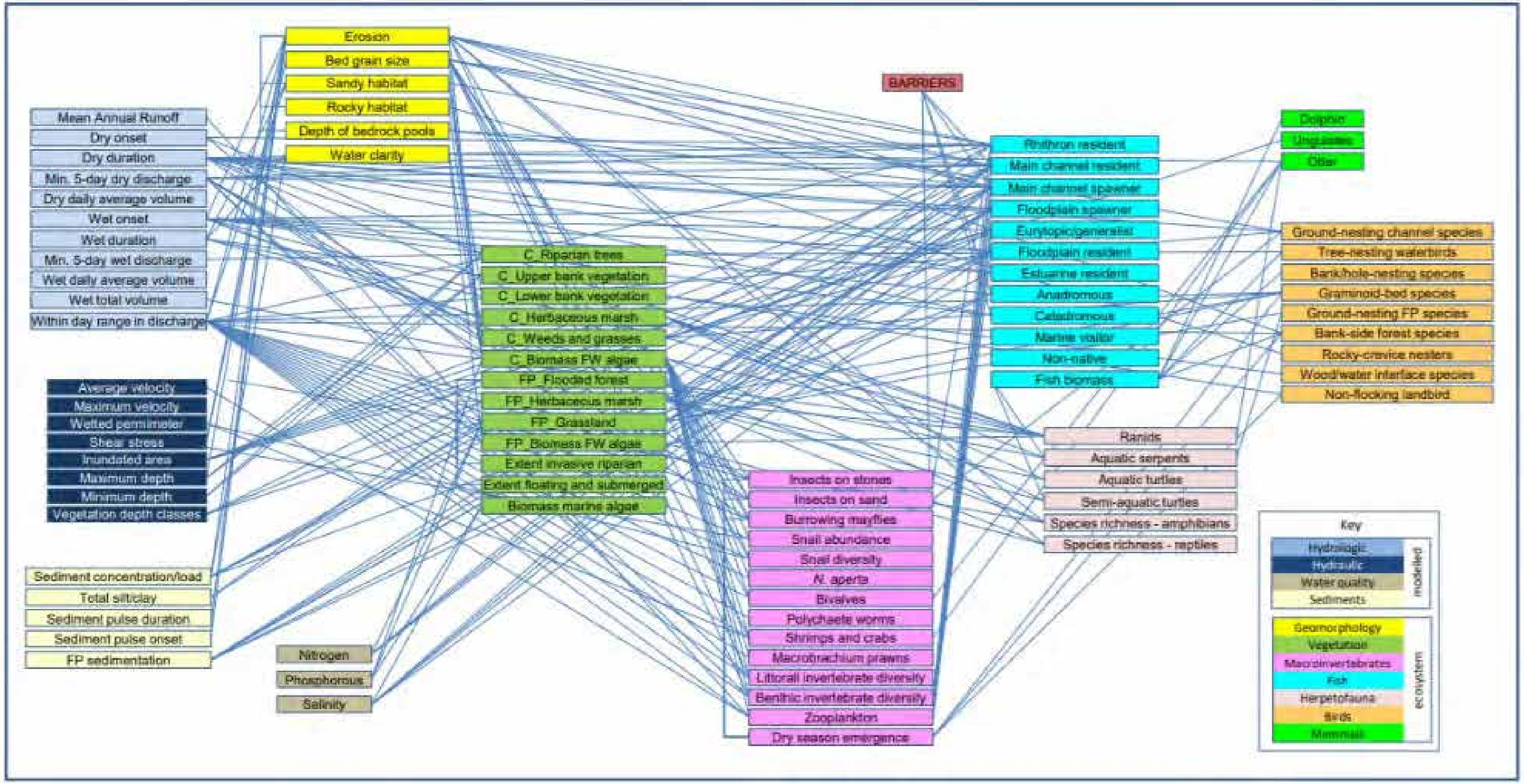


Figure 6.2. Recognized linkages between monitoring disciplines in the LMB from the Biora

An example of this building complexity at each level is as follows:

- The water level downstream of a dam can vary on an hourly basis;
- WQ following a flush can combine improved oxygen levels and worsened contaminant concentration;
- Benthos abundance and diversity mainly reflect the frequency and/or duration of negative hydrological and WQ events;
- Local fish abundance integrates the above local events but also reflects factors such as success or not of seasonal or annual breeding (also related to hydrology, sediment and nutrient supply), distant seasonal migration pulses, and possible accumulation of fish at dam outlets (an often-misleading observation);
- Fish catches also reflect fishers' choice of gears and strategies, following both progressive changes in species composition and the influence of livelihood and trade factors on fishing effort;

For these reasons, an immediate response to dam operation cannot be observed in the discipline of fisheries in the same way that it can be in hydrology or WQ. The time unit in fisheries analysis is the year, which underlines the need to keep monitoring over a long period of time. Data analysed show that five years are sufficient to observe clear trends.

The highly complex nature of the Mekong needs to be recognized when trying to integrate and interpret monitoring results since there are multiple responses and impact pathways associated with any change in hydrologic condition. The high spatial and temporal variability of natural riverine ecosystems further confounds the identification of linkages and changes associated with hydrologic drivers at each level of the system.

6.2 Approaches to integrated analysis of monitoring results

There are two possible approaches to integrated analyses that combine the results of the five disciplines:

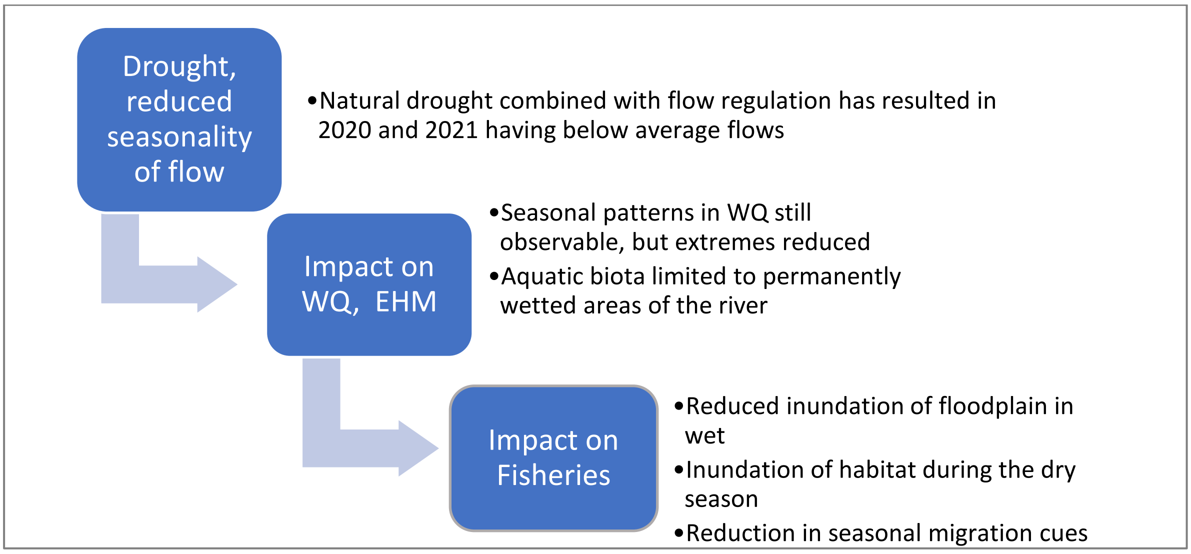
- a **qualitative** approach presenting together the results of each discipline in order to reveal patterns, explanatory factors, and chains of consequences from a basin-wide ecological perspective; and
- a **quantitative** approach, based on matching samples, a combination of variables, correlations, multivariate analyses, and statistics to test specific hypotheses about system behaviour and/or corresponding management questions. This also requires a solid ecological background to make the final interpretations.

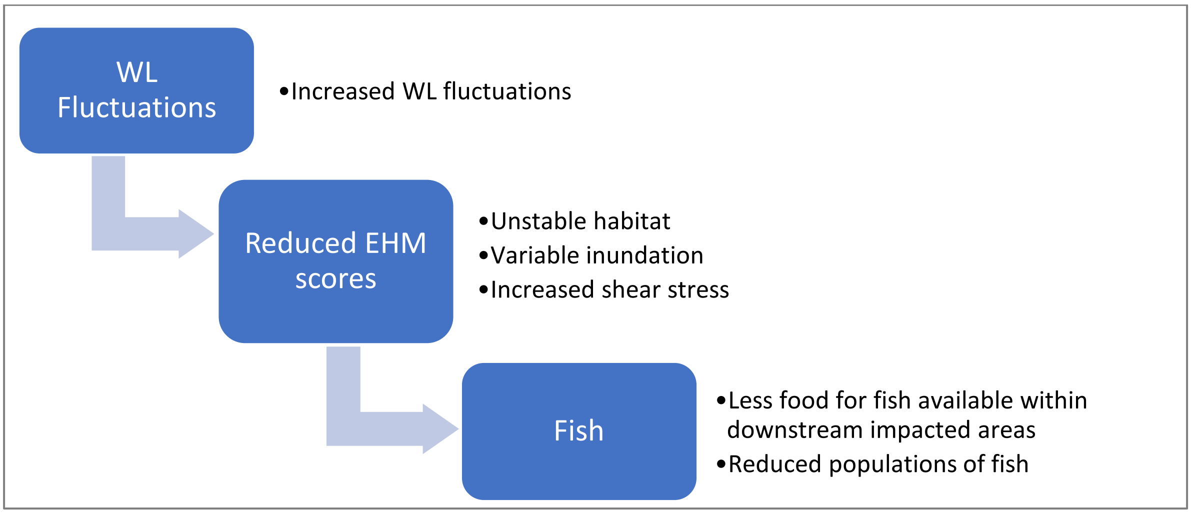
6.2.1.1 *The qualitative approach*

A qualitative approach is demonstrated in Figure 6.3 showing three cross-discipline correlations that could be illustrated using the JEM Programme monitoring results. These examples take observed trends from the JEM Pilots hydrology and sediment monitoring as a starting point and then suggest how they can be associated with corresponding impacts on

WQ, ecological health, and fisheries. Observation of these correlated trends in monitoring results across disciplines does not indicate causation but does demonstrate consistency with the understanding of how riverine ecosystems function. It should be noted that these illustrative linkages are based on knowledge of ecosystem function gained from other systems, correlations, and qualitative assessments. Longer-term monitoring is required to support these qualitative correlations at the JEM sites.

A qualitative analysis approach can be a strong aid in 'telling the story' when seeking to communicate the impacts from hydropower as derived from the monitoring parameters. In doing so, it can support discussion by multiple stakeholders of varying expertise. Qualitative approaches can further be useful support in the identification and selection of specific hypotheses regarding system function or management to then test statistically through a quantitative approach.





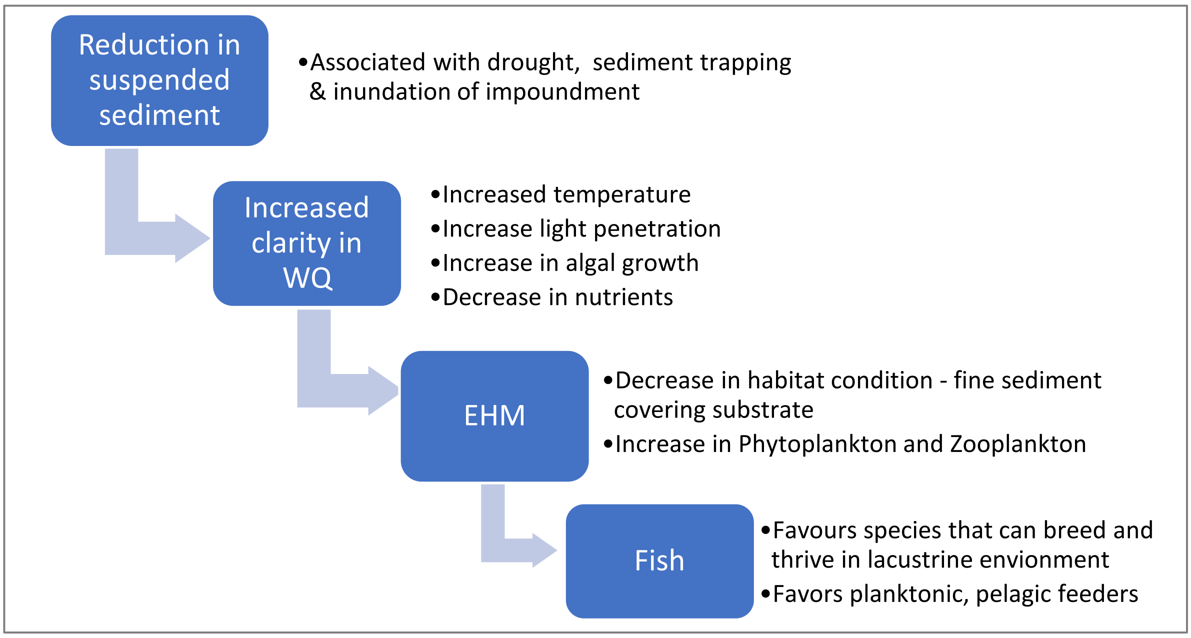


Figure 6.3. Three correlation schematics between the disciplines based on river ecosystem functioning

6.2.1.2 The quantitative approach

The natural variability of the Mekong system, regardless of any dam influence, calls for the use of sophisticated but demanding statistical analysis tools, such as detrended canonical correspondence analysis and detrended cross-correlation analysis (Podobnik, B., & Stanley, 2008; Ter Braak & Verdonschot, 1995), to allow the extraction of long-term trends and seasonal variability before analysing the short-term effects of specific external drivers. The distinction between statistically significant results and those that are environmentally significant should also be carefully considered, as evidenced by the WQ results for the impoundments of Xayaburi HPP and DSHPP (see Section 4.2) where statistical differences were found between upstream and downstream but are not environmentally significant.

The following steps are provided as guidance to design of a quantitative approach, with supporting detail provided in the Combined Annual Report:

1. **Identify the stations that can be matched based on physical proximity.** Fifteen clusters of sites have been identified from which three sites are at above the impoundments, in the impoundments and below each of the pilot dams have been considered.
2. **Identify the variables that are relevant in an interdisciplinary context.** The selection would include the most relevant ones for cross-analyses, for example: average discharge per station per month, minimum and maximum daily water level, DO, TSS, average abundance and species diversity of aquatic organisms, average tolerance of species per taxon, average monthly catch per fisher, and number of fish species caught.

3. **Summarize data availability for these variables for each site for both historical routine monitoring back to 2010 and JEM data.**
4. Consider the sampling frequency (time step) of these variables (from once every 15 minutes to once a year). Typical temporal scales of relevance to each discipline are described as follows:
   - **Hydrology** – Average daily discharge aggregated to average monthly flow, Hourly Water level;
   - **Water quality** – Monthly basis, but they are only strictly comparable to flow and water level measurements at the same time and day;
   - **EHM** – Every two years, in 2011, 2013, 2015, 2017, 2019 and 2021; and
   - **FADM (daily catch) database** – Daily records, but the standard time step is monthly to integrate high daily variability in catches; species diversity on a monthly basis in some specific cases (e.g. migration pulses), but the standard integration level for biodiversity studies is the year.
5. Identify how these variables from different disciplines can be combined to answer relevant management questions, such as:
   - **monthly fish catch per fisher vs**.
     - percentage of flow change compared to its long-term monthly average;
     - water level monthly jaggedness index;
     - monthly averaged sediment load;
     - WQ parameters averaged over the month.
   - **Annual fish species richness vs.**
     - percentage of flow change compared to its long-term annual average;
     - water level annual jaggedness index;
     - total annual sediment load;
     - EHI (score card) over the year;
     - index of WQ over the year or detail by WQ parameter.

The differences in relevant timescales within each discipline combined with the short duration of JEM monitoring limit the potential to make direct and statistically meaningful quantitative comparisons of the monitoring results at the different sites within this report. There is a need for at least one full year of monitoring, preferably several years, to have a better picture of the changes occurring and allow for fuller statistical analysis.

6.3 Qualitative comparison of JEM Pilots findings by cluster

A qualitative comparison of conditions in the five disciplines was prepared to support interpretation of changes occurring in the river by location. These changing conditions can then be integrated into an interpretation of the impacts of the HPPs. For this qualitative assessment, findings from the JEM Pilots have been mapped according to clustering of sampling locations into six sites that cover the following three areas for each of the two pilot sites:

- above the impoundment;
- within the impoundment;
- downstream of the dam.

The following series of maps presents a qualitative comparison at each of the following six clusters:

- **Figure 6.4**. Comparison of discipline findings for sites in Cluster 3 above the Xayaburi impoundment;
- **Figure 6.5.** Comparison of discipline findings for sites in Cluster 4 within the Xayaburi impoundment;
- **Figure 6.6**. Comparison of discipline findings for sites in Cluster 5, below Xayaburi dam;
- **Figure 6.7.** Comparison of discipline findings for sites in Cluster 10 above the Don Sahong impoundment;
- **Figure 6.8.** Comparison of discipline findings for sites in Cluster 11 within the Don Sahong impoundment;
- **Figure 6.9.** Comparison of discipline findings for sites in Cluster 13 below Don Sahong dam.

In each figure, the relevant sampling sites within each cluster are circled for greater clarity. Qualitative statements of the conditions observed in each the disciplines are provided by cluster to facilitate their cross-comparison.

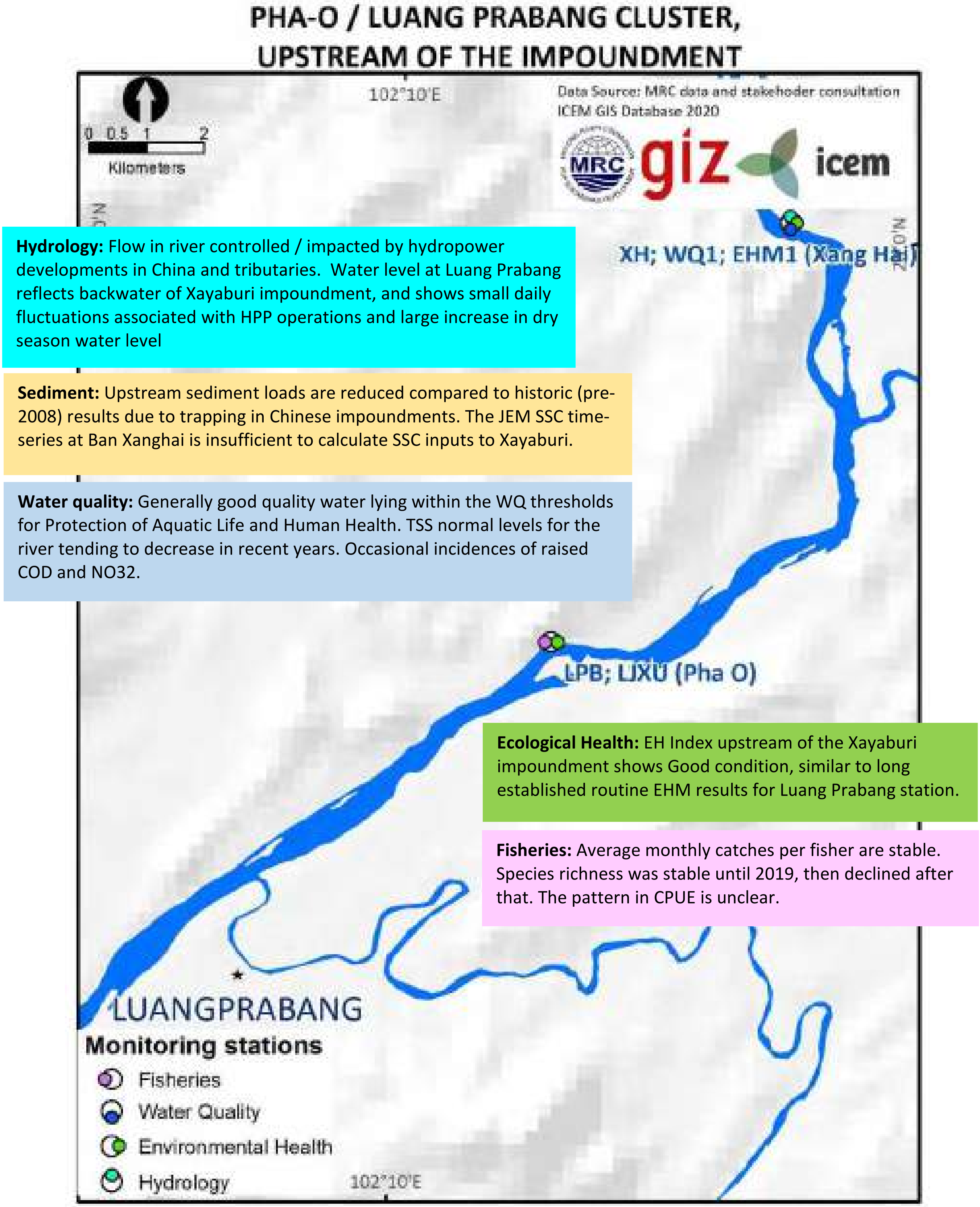


Figure 6.4. Comparison of discipline findings for sites in Cluster 3 above the Xayaburi impoundment

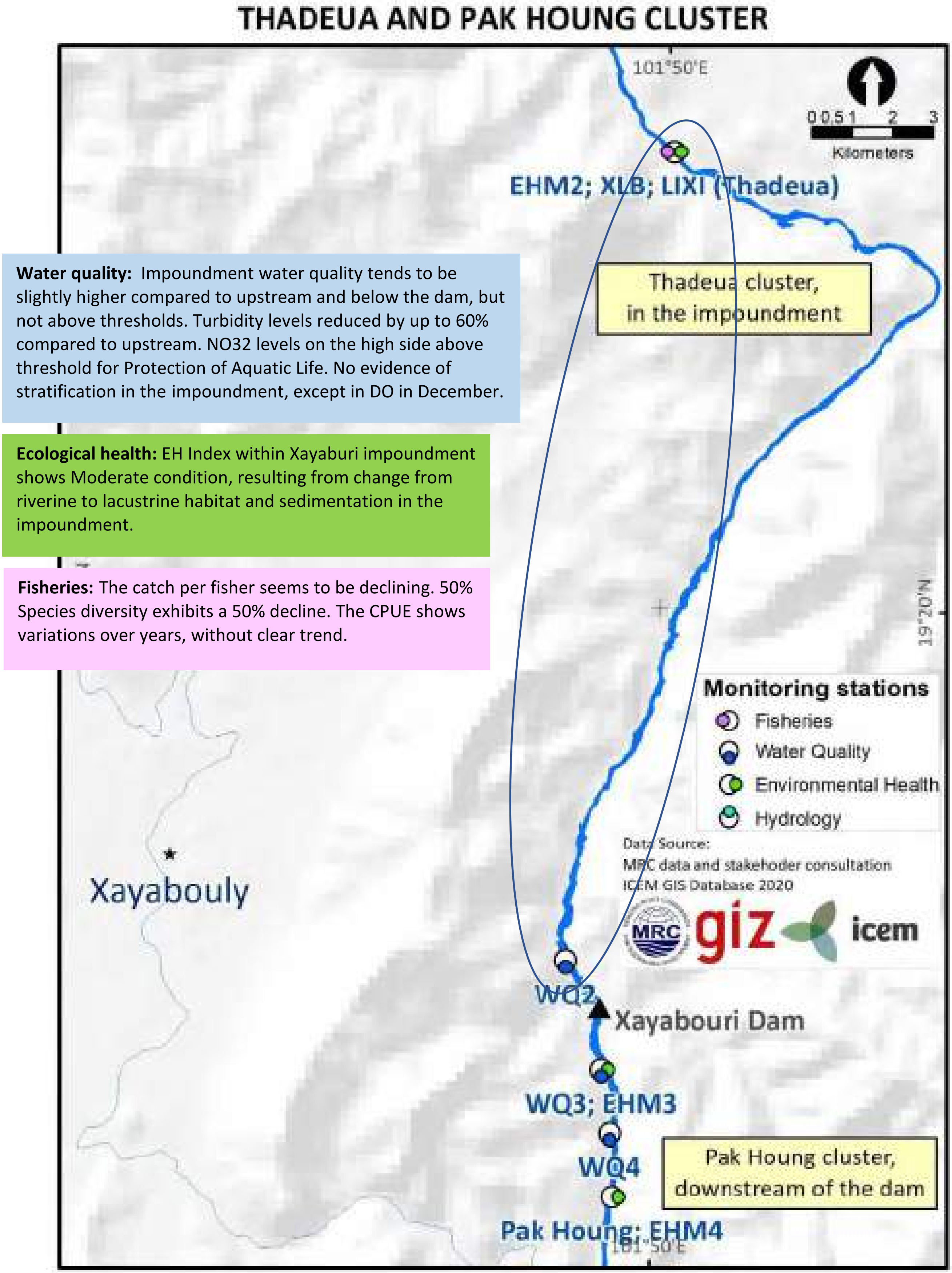


Figure 6.5. Comparison of discipline findings for sites in Cluster 4 within the Xayaburi impoundment

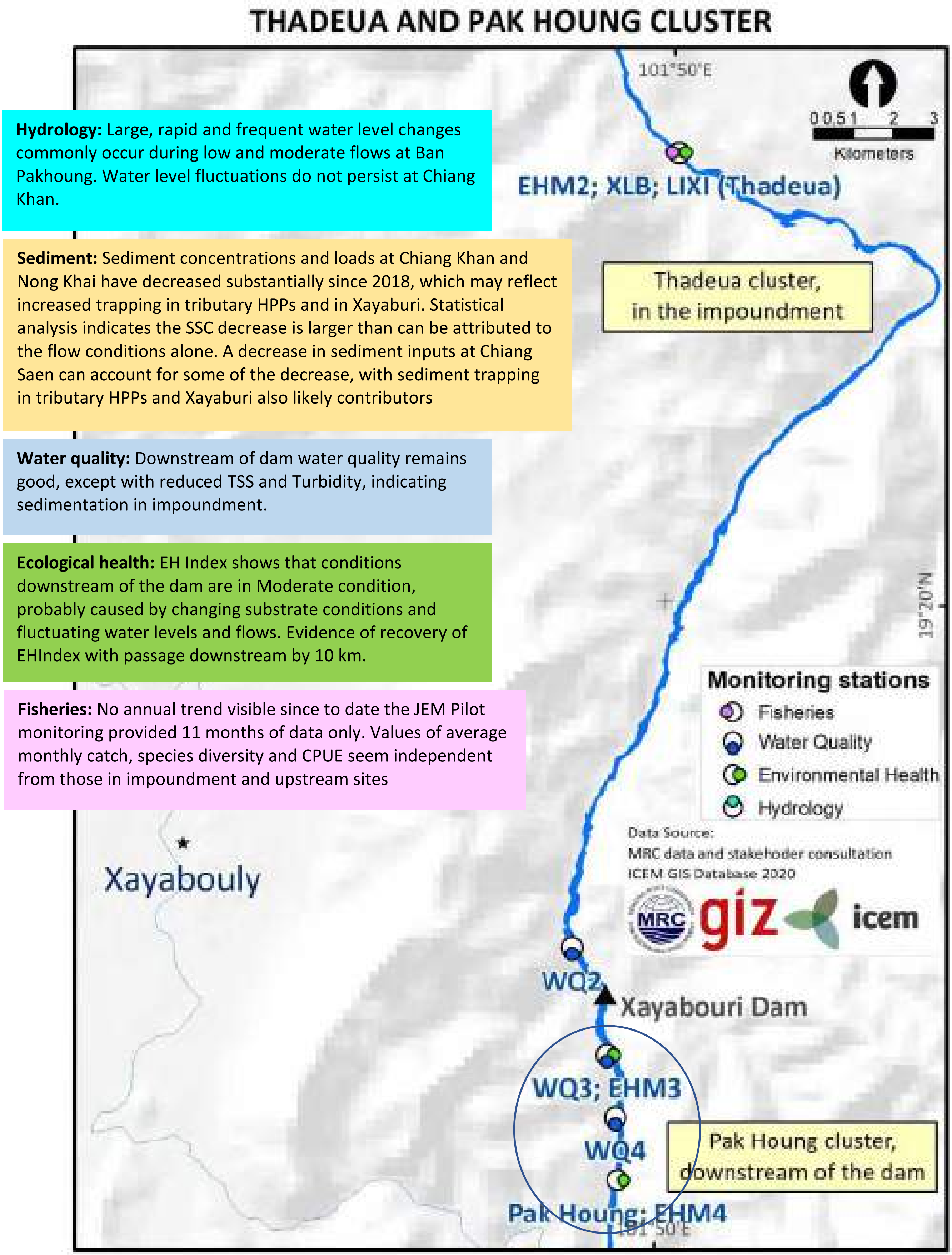


Figure 6.6. Comparison of discipline findings for sites in Cluster 5, below Xayaburi dam

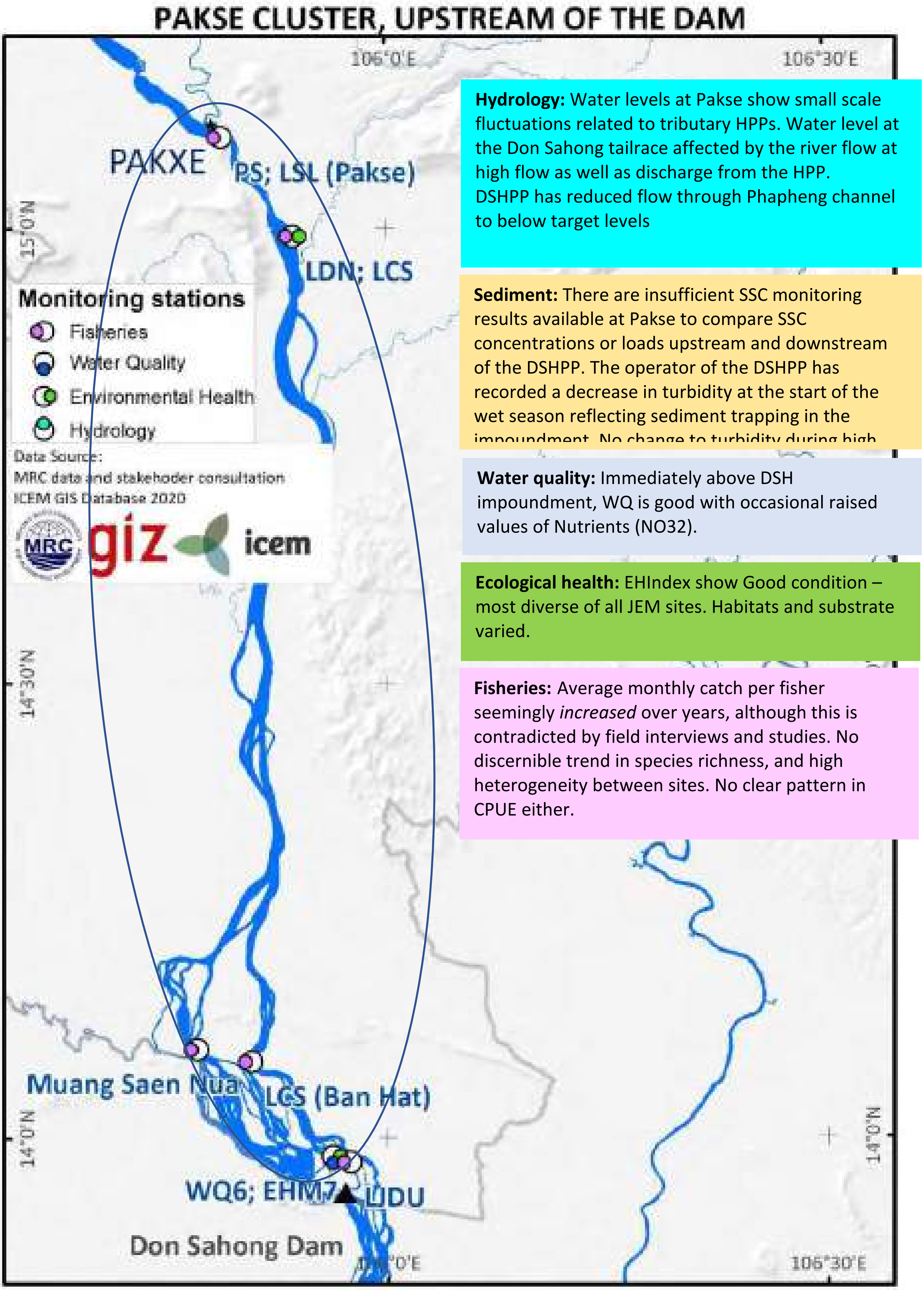
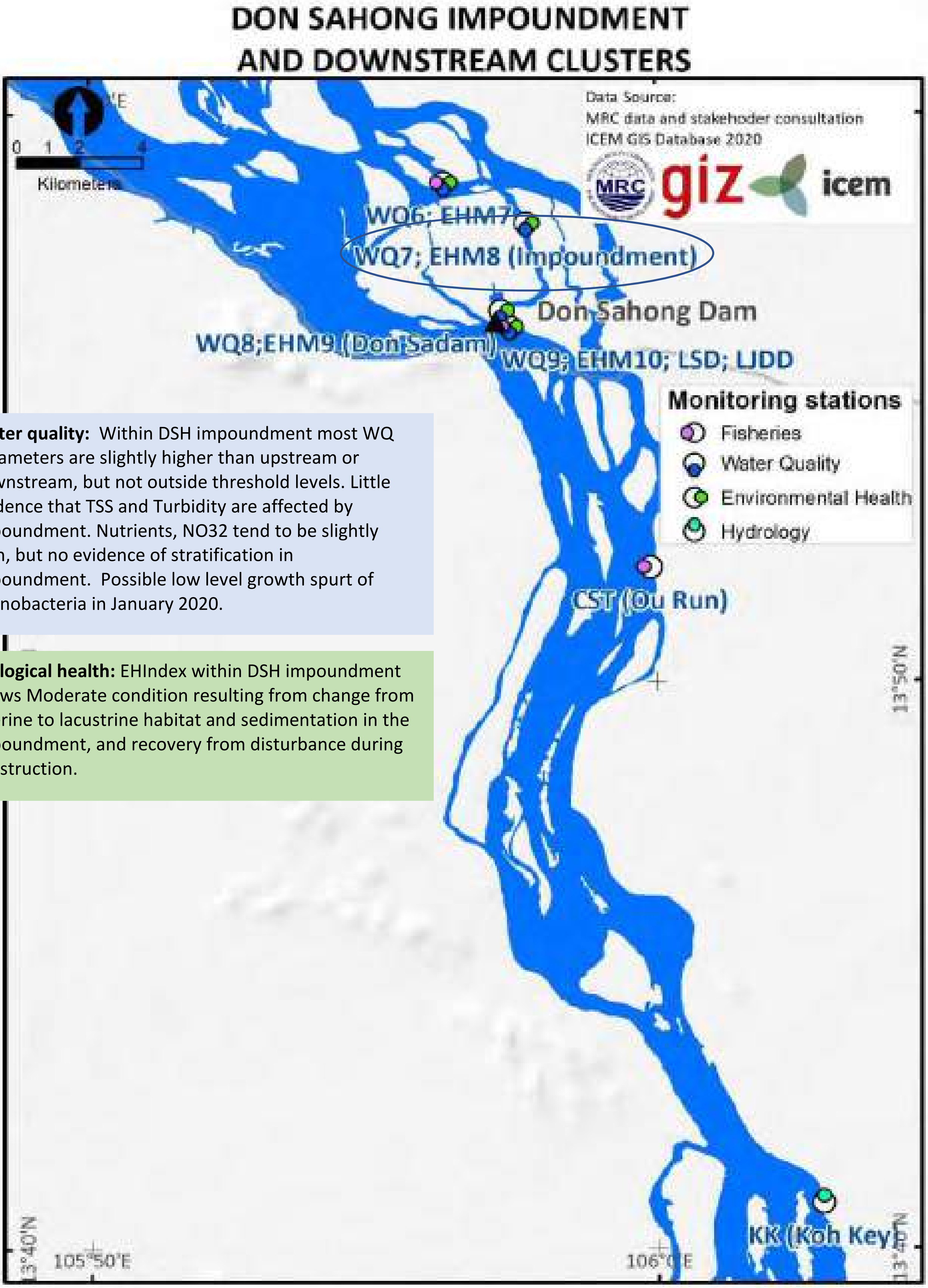


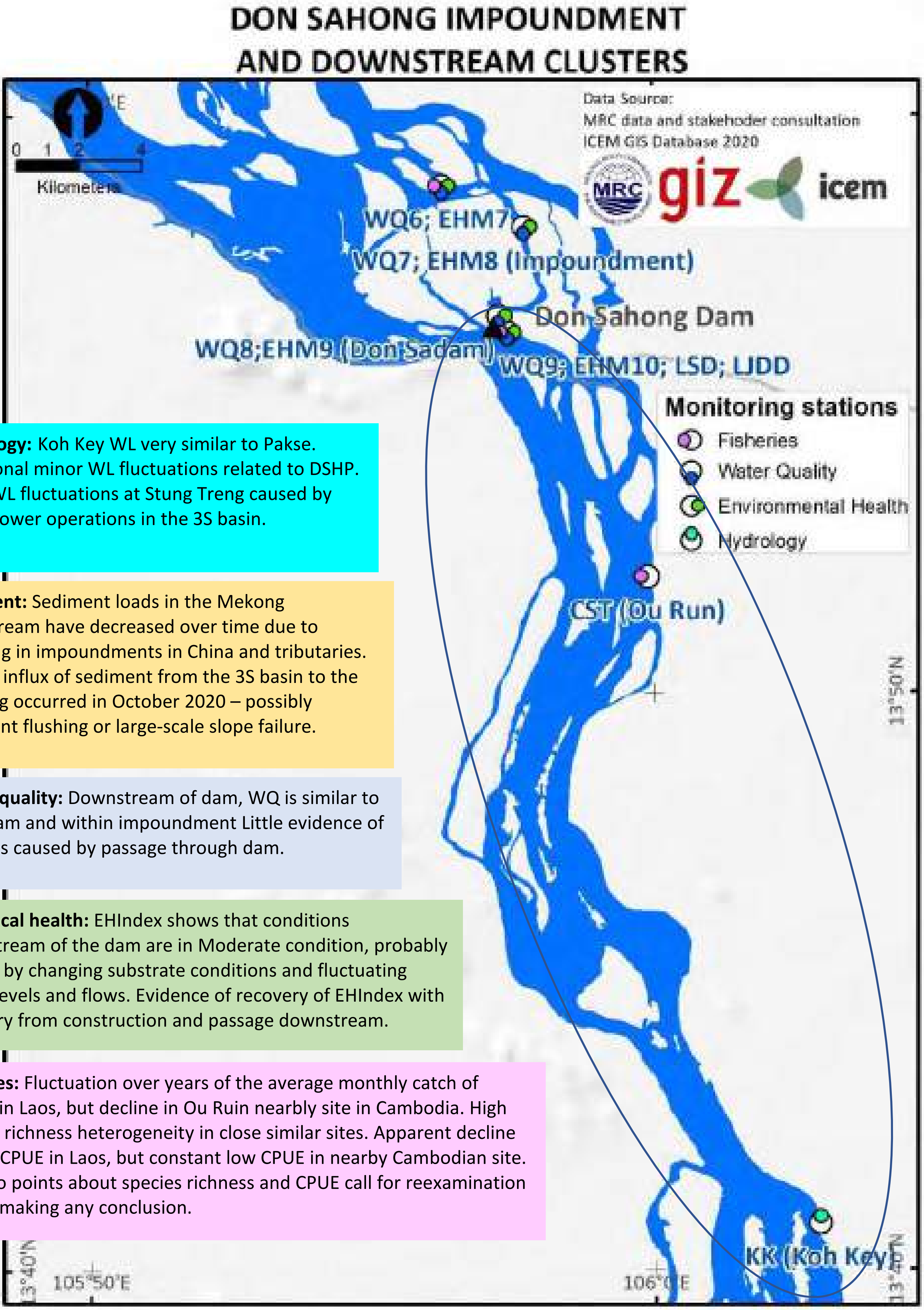
Figure 6.7. Comparison of discipline findings for sites in Cluster 10 above the Don Sahong impoundment



Water quality: Within DSH impoundment most WQ parameters are slightly higher than upstream or downstream, but not outside threshold levels. Little evidence that TSS and Turbidity are affected by impoundment. Nutrients, NO32 tend to be slightly high, but no evidence of stratification in impoundment. Possible low level growth spurt of Cyanobacteria in January 2020.

Ecological health: EHIndex within DSH impoundment shows Moderate condition resulting from change from riverine to lacustrine habitat and sedimentation in the impoundment, and recovery from disturbance during construction.

Figure 6.8. Comparison of discipline findings for sites in Cluster 11 within the Don Sahong impoundment



Hydrology: Koh Key WL very similar to Pakse. Occasional minor WL fluctuations related to DSHP. Small WL fluctuations at Stung Treng caused by hydropower operations in the 3S basin.

Sediment: Sediment loads in the Mekong mainstream have decreased over time due to trapping in impoundments in China and tributaries. A large influx of sediment from the 3S basin to the Mekong occurred in October 2020 – possibly sediment flushing or large-scale slope failure.

Water quality: Downstream of dam, WQ is similar to upstream and within impoundment Little evidence of changes caused by passage through dam.

Ecological health: EHIndex shows that conditions downstream of the dam are in Moderate condition, probably caused by changing substrate conditions and fluctuating water levels and flows. Evidence of recovery of EHIndex with recovery from construction and passage downstream.

Fisheries: Fluctuation over years of the average monthly catch of fishers in Laos, but decline in Ou Ruin nearbly site in Cambodia. High species richness heterogeneity in close similar sites. Apparent decline in high CPUE in Laos, but constant low CPUE in nearby Cambodian site. The two points about species richness and CPUE call for reexamination before making any conclusion.

Figure 6.9. Comparison of discipline findings for sites in Cluster 13 below Don Sahong dam

7 OPPORTUNITIES FOR MITIGATION AND ADAPTIVE MANAGEMENT OF DAMS

Analysis of the JEM results has provided useful insights into potential impacts associated with hydropower. However, as noted in Section 6, some of the observed changes may not indicate conclusive evidence of impact due to the high natural variability of river systems, the complex interactions between the disciplines, and the short duration of JEM monitoring. There is a need for at least one full year of monitoring, and preferably several years, to have a better picture of the changes occurring and allow for fuller statistical analysis.

The recommendations for mitigation and adaptive management of hydropower dams on the Mekong mainstream presented in this report, expressed below, flow from these initial indications of potential impacts at the pilot sites. They are based on experience from other HPPs elsewhere both in the Greater Mekong region and globally. Many of the suggestions echo those in the MRC Hydropower Mitigation Guidelines (MRC, 2020).

7.1 HYDROLOGY AND SEDIMENT

The JEM monitoring has identified changes to the hydrology and sediment transport in the mainstream Mekong associated with the development and operation of HPPs in the basin. The following recommendations for mitigation and adaptive management are relevant to the mainstream power stations monitored under JEM, and also applicable to tributary stations, because JEM monitoring has clearly demonstrated that the operation of tributary projects can affect the mainstream. Recommended mitigation approaches include the following:

- the introduction of targets or limits on the rate of water level change in the mainstream;
- implementation of a central communication system to alert downstream communities and countries of impending flow releases, or other changes to operations that could affect downstream communities (e.g. low flows or high flows);
- maintenance of environmental flows as per commitments in PNPCA documentation and/or power purchase agreements;
- joint work between the MRC and the MCs and hydropower operators to provide a reporting mechanism for the operation of low-level gates at HPPs that will affect sediment transport in the river.

Each of these are discussed in the following sections.

7.1.1 Limits on the rate of water level change

The JEM monitoring results show that rapid and frequent water level fluctuations occur downstream of the Xayaburi hydropower station, with changes of over 0.05 m/hr occurring up to 40% of the time during some months based on 15-minute water level measurements.

Rapid water level changes have been linked to negative impacts on aquatic ecosystems, increases in bank erosion, and risks to public safety (MRC, 2020). Based on this, the MRC Hydropower Mitigation Guidelines (MRC, 2020) recommend that water level changes associated with the operation of HPPs be maintained at rates of <0.05 m/hr. Controls to eliminate water level fluctuations, when possible, and minimize the rate and magnitude of change of any residual peaks should be implemented at mainstream HPPs. The water level record from Ban Pakhoung clearly shows that, although the Xayaburi HPP is described as a run-of-river station based on the small storage capacity, there are frequent and rapid water level fluctuations that can impact the downstream river. The 0.05 m/hr rate should be implemented as a goal at national boundaries to minimize transboundary impacts, and also within countries to minimise local impacts. Inflow and discharge data for Xayaburi provided by the operator shows that rapid flow changes occur downstream of the HPP in both the wet and the dry seasons (Figure 7.1).

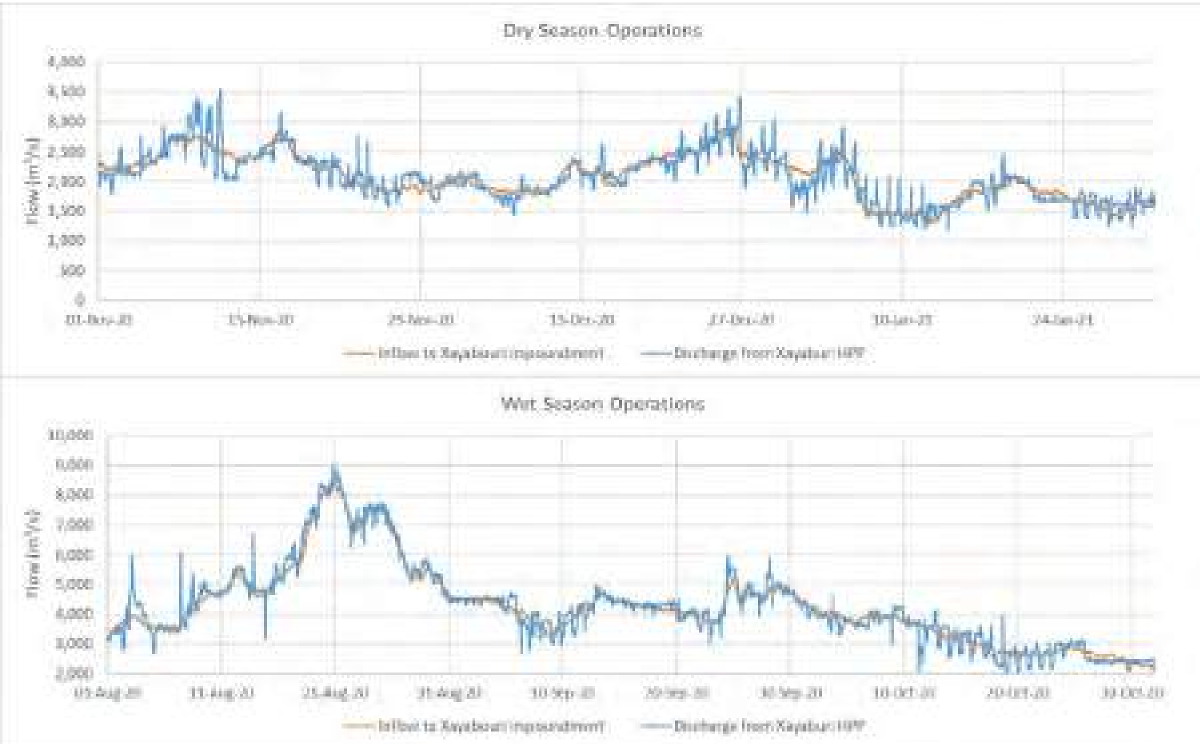


Figure 7.1. Flow rates for the inflow and discharge from the Xayaburi HPP for the (top) dry season and (bottom) wet season

Source: Data provided by the operator of Xayaburi HPP

Water level fluctuations can be mitigated through the adoption of ramping rates for turning on and off the power station. Ramping rates need to be site-specific, which should be stipulated in power purchase agreements.

7.1.2 Communication system/portal for hydropower operations

There are times when hydropower operators are forced to manage power stations outside of the usual range of flow rates or water level rates of change. This may be due to an impeding flood wave, an emergency at the site, or high flows and elevated sediment concentrations associated with sediment flushing. A transboundary communication system or regional information portal should be established to provide accurate and timely information about any pending operational changes. Ideally, information about releases from dams in China or Myanmar should also be available through the same information source.

Having a centralized and recognized source of information would be an efficient way to communicate changes, providing communities with the maximum time possible to prepare for any abrupt changes to river conditions.

7.1.3 Maintenance of environmental flows as described in PNPCA proposals

The operator of the DSHPP has participated in JEM workshops and shared information and data related to the environmental flow at the site. As proposed during the PNPCA process (Cowx et al., 2014; SMEC, 2013) a minimum of 800 m^3/s of water was to discharge over Phapheng Falls. This flow was proposed as sufficient to maintain the touristic and aesthetic values of the Khone Phapheng water falls, maintain adequate flows down the Hou Xang Pheuak Channel, and provide a minimum flow of 10 m^3/s down the modified Sadam Channel, with these channels providing fish passage around the dam.

As presented by representatives of the DSHPP, a shortage of electricity for export to Cambodia required that the project generate more power than planned during the first two dry seasons of operations (2020 and 2021), resulting in flows of <800 m^3/s at Thakho in Phapheng Channel. Daily flow data provided by the DSHPP operator suggests that discharge was less than the minimum target about 30% of the time between January 2020 and October 2021 (Figure 7.2). By applying adaptive management, the company intends to deepen the entrance to Sadam and Xang Pheuak channels to increase the likelihood of adequate flow for fish passage during the dry season, even if flows in the eastern channel continue to be <800 m^3/s.

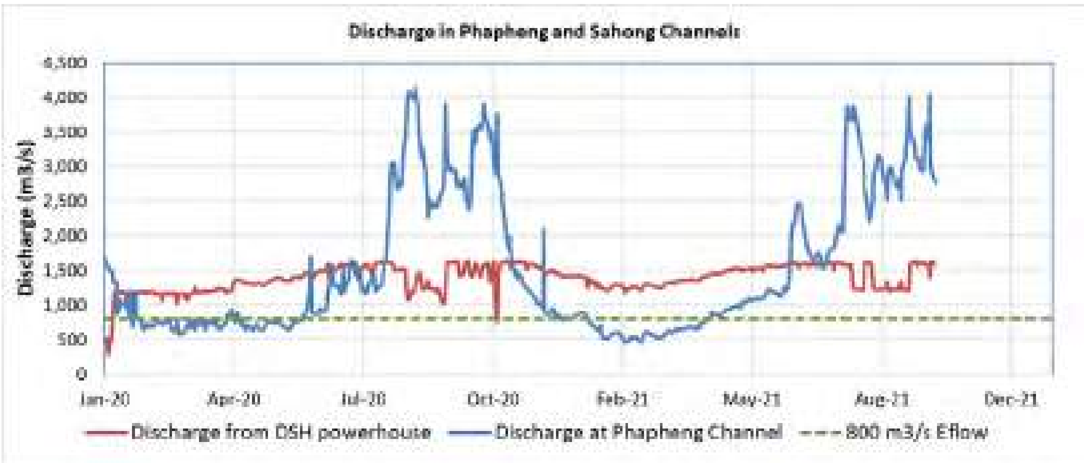


Figure 7.2. Discharge from the DSH Powerhouse and in the Phapheng Eastern Channel in 2020 and 2021

Note: The target 800 m^3/s environmental flow level is indicated

To ensure the efficacy of this fish pass mitigation measure, it is recommended that the MRC and the Pakse DSM team work collaboratively with the DSHPP operator to measure flow in the various channels under conditions of moderate and low flow using the Pakse based ADCP (Teledyne River Ray). which is suitable to the range of flow conditions in the channels. This would allow the operator to refine the rating curves used to manage flow through the DSHPP turbines, and to update the water level targets required to maintain flow in the fish pass channels following modification of the channel inlets. Understanding the distribution of flows through the complex Si Phan Don area could also assist with the interpretation of future fish pass migration studies. It is also recommended that the Pakse rating curve be reviewed and updated using available water level and discharge measurements.

7.1.4 Reporting of low-level gate operation at tributary and mainstream HPPs

Sediment transport in the Mekong is increasingly being affected by sediment trapping in impoundments. The release of sediments through the opening of low level gates can have a substantial impact on the river locally, and at a larger scale may make a substantial contribution to seasonal sediment transport.

The flushing of sediment accumulating near the dam has been dealt with in section 4.1.4. However, when the low-level gates are opened for flushing, a slug of water with very high TSS and often low DO can be released downstream. These operations need to be trialled and managed carefully so that poor WQ issues are not passed on even further downstream.

The influence of reduced sediment transport downstream of the dams can be partially offset by suitably managed flushing, but large flushes with very high sediment loads can be very damaging for the aquatic biota for many kilometres downstream, well beyond the apparent recovery zone of about 10 km.

To better understand sediment releases, it is recommended that the MRC work with MCs and HPP operators to establish a reporting system for the operation of low-level gates at HPPs, so that the timing and duration of sediment release can be understood. Ideally, the register would include the following information:

- the time and duration of opening of the low level outlets;
- the estimated volume of water released from the outlets;
- the volume of water put through the turbines during the release;
- the volume of water discharged from surface gates or spillways;
- the inflow rate of water to the impoundment at the time of release;
- the sediment concentration of the water released through the low-level outlets;
- the concentration of sediment monitored in the river before, during and after the release.

This information is relevant to sediment assessment indicators for the Basin Development Plan (BDP) indicator framework, and would contribute to the development of a basin-wide sediment management strategy as identified in the MRC Basin Development Strategy 2021–2030.

7.2 WATER QUALITY

7.2.1 Systematic water monitoring during all phases of hydropower construction and operation

The WQ monitoring conducted under the JEM Pilots does not show marked differences between areas in the upstream, in the impoundment, and downstream of the dams (with the exception of parameters such as turbidity and TSS). This does not indicate that regular WQ monitoring of HPPs is unnecessary; experience in other HPPs both in the Mekong region and elsewhere has shown that WQ monitoring at all stages of project preparation, during construction and during operation, is an essential part of adaptive management.

Ideally, a full year of baseline conditions at the sampling locations should be established before construction, followed by routine monitoring during construction and ongoing during operation. The construction period is often the time when poor WQ conditions are most evident, due to sediment disturbance and discharge of polluted waters from the construction site. As shown by the JEM Pilots during operation there have been few occasions when WQ condition is problematic as the conditions at the site stabilise.

Long-term monitoring of WQ downstream of the dam and in the impoundment profiles should be carried out so that appropriate action can be taken if poor WQ conditions emerge at different seasons or times of day due to stratification in the impoundment. A response could be managing the levels of water offtake, for example. The JEM programme results are based upon monthly spot samples that do not capture the diurnal changes in pH and DO that can occur. More frequent monitoring such as with automatic high-frequency WQ probes/monitors, or daily WQ sampling would capture these changes, especially in downstream locations.

The Don Sahong has already been measuring the following parameters – temp. (oC), pH, EC (µS/cm), DO (mg/L), turbidity (NTU), oxidation reduction potential (ORP) (mV), total dissolved solids (TDS) (mg/L) – on a weekly basis in four locations, almost identical to the JEM pilot. The difference is that the DSH site 4 is located further downstream after mixing with the channel Hou Phapheng channel, as shown in Figure 7.3. This monitoring by the developer is therefore already at a more frequent sampling than the JEM Pilot which is only monthly. In the future, this will be complemented by the high-frequency WQ monitoring station being installed by the MRC near WQ8, and DSH3. The MRC should regularly share the results of this monitoring station with Don Sahong Power Company, and immediately if certain parameters such as DO and pH exceed certain agreed thresholds.

Figure 7.3. Water quality monitoring stations applied by the Don Sahong Power Company

7.2.2 Design of sampling locations for detecting WQ changes associated with HPPs

Regular WQ monitoring should be carried out by the hydropower company in order to detect changes in WQ due to the construction and operation of the dam, and also to detect any sources of pollution entering into the impoundment, for which they may be blamed in the event of future degradation of the WQ. The basic principle of locations of sampling stations for WQ monitoring around HPPs should follow a pattern of at least:

- one upstream location;
- one location within the impoundment;
- two downstream locations – one immediately below the tailrace, and one further downstream to demonstrate recovery of the WQ condition.

The upstream site is essential to identify any poor water conditions entering the impoundment, outside the control of the hydropower company, so that any external influences may be separated from the changes due to the operation of impoundment and dam. If there are large tributaries flowing into the impoundment that may be subject to pollution, it may be advisable to monitor these inflows as well as the mainstream inflows.

Within the impoundments, the hydropower company should also carry out depth profiles of WQ out at least once a month and more frequently if there is evidence of stratification being established in the impoundment, at least down to the depth of the deepest part of the water intake. The location of the sampling site should be upstream of the water intake, but not so close that the water layers are mixed by the more turbulent flow near the water intake.

7.2.3 Management of impoundment water quality

The aim of regular WQ monitoring in the impoundment is to detect any developing poor WQ conditions, which may then be passed on downstream of the dam. This set of JEM Pilot results does not show any instances of poor WQ conditions, such as lowered DO and pH, although there are one or two instances of high COD. In terms of nutrients, the HPP is unlikely to have increased the nutrient content of the river water; however, increases in nutrients entering the river from upstream urban and agricultural run-off (such as detergents and fertilizers) are likely to affect eutrophication in the impoundment and resulting operational issues.

If there is an evident source of pollution immediately upstream or entering the impoundment, then **it is in the hydropower company's interest to ensure that appropriate treatment of the wastes is put in place**; otherwise the additional polluting load may cause WQ issues within the impoundment.

One consequence of impounding a river is that the phytoplankton have a greater opportunity to proliferate in the very slow flowing and more transparent waters in the impoundment, especially if nutrients such as nitrogen and phosphorus are also increasing. It is therefore in the interest of the hydropower company to **carry out regular monitoring of nutrients and phytoplankton in the impoundments to be aware of impending phytoplankton blooms**, even if at present this does not appear to be a problem.

If stratification of the impoundment becomes well established there may be a danger of water with low DO, low pH, high ammonium, and sulphide concentrations being released downstream through the turbines. The hydropower company should ensure that water intakes are above the level of the hypolimnion, and that if the lower gates are used for sediment flushing, the low level water is mixed with water from the upper levels. Other alternatives include measures to ensure mixing of upper and lower water levels to break up the stratification in the vicinity of the water intakes.

7.3 ECOLOGICAL HEALTH MONITORING

7.3.1 Establish an Ecological Health reference site for Mekong mainstream impoundment

The changes in the EHIs within an impoundment are an inevitable consequence of changing riverine habitats to lacustrine. It is to be expected that after some years the lacustrine conditions and biota in these impoundments will stabilize, and the important aspect to be monitored will be the continuing quality of the lacustrine habitats.

At present, there are no reference sites for impoundments on the Mekong mainstream, although there is some experience in EHM in some of the tributary reservoirs, for example Nam Theun 2, which might be used as reference sites. For Don Sahong, an **established, small, run-of river dam and impoundment in one of the tributaries would need to be identified as a reference site**. The changes in biota as reservoir habitats stabilise may be used to compare with conditions within operating mainstream impoundments in order to regularly determine their ecological health condition.

7.3.2 Set site-specific ramping rate limit

The JEM pilots have shown that the reductions in EHIs downstream of the dam appear to be related to changing water levels and flow rates due to peaking operations and reduced sediment transport downstream of the dam. The extent to which the downstream biota recovers with distance downstream of the dam will depend on the continued stress on the riverine habitats from peaking operations and reduction in sediment loads. As discussed in section 7.1.1, greater **attention needs to be paid to setting site-specific ramping rate limits and working within them** so that the biota experience more gradual changes in water level and flow rate.

7.3.3 Monitoring of downstream geomorphology and habitats

The trapping of sediment in the impoundment is an inevitable feature of creating reservoirs where the flow rate slows and allows the heavier particles to settle out. As a result, as clearly shown by the JEM Pilots, the TSS concentrations (and SSC) are much lower below the dam site than under natural conditions. This will have implications for the geomorphology and river habitats downstream until the river has picked up sufficient additional sediments as it flows further downstream. **The hydropower company should investigate the distance downstream in which the geomorphology and substrates are affected by operations and monitor the stabilization of these habitats over time after the start of operation**.

7.4 FISHERIES

7.4.1 Mitigation and adaptation at the Xayaburi site

7.4.1.1 Gear use analysis

Upstream of Xayaburi impoundment. both fish diversity and gillnet CPUE show a sharp decline; however, the total average monthly catch per fisher does not decline. Before any intervention is considered by fishers, it is recommended to undertake a gear use analysis and a field survey to confirm or negate this hypothesis. If increased fishing effort is confirmed, the possible sources of fish replenishment in this part of the river (Nam Soung, Nam Khan) deserve specific attention and protection so that remaining fish exchange between upstream sub-catchments and the upstream part of the Xayaburi reservoir are not interrupted. Management of the Nam Theun 2 upstream tributaries flowing into the impoundment provide an example and framework for such an initiative (Baran et al., 2021).

7.4.1.2 Analyse catch data by species, trophic level and commercial value

In the Xayaburi reservoir. the average monthly catch per fisher has sharply declined (i.e. fishers fish less) but the gillnet CPUE remains stable (the biomass of fish caught per m^2 per hour of fishing is constant), which questions why fishers fish less: a hypothesis is: (i) a replacement of commercially valuable running river fish species with planktivorous lacustrine fish species, abundant but of lower value; or (ii) a loss of income among fishers and a subsequent shift towards alternative livelihoods (e.g. construction, trade). Future studies should include an analysis of catch data by species, of the trophic level of dominant species, and of the commercial value of these species. If the above hypothesis is confirmed, then fisheries enhancement can be considered.

7.4.1.3 Investigate fisheries enhancement

Investing in enhanced reservoir fisheries requires a preliminary determination of the potential fishery yield, itself dependent on the nutrient load and natural food supply. Fisheries enhancement involves a blend of physical and biotic measures, including stocking of species, fertilization, fish attraction (e.g. use of brush parks) or fish sanctuaries (Bernacsek, 1997; Kolding & Zwieten, 2006). Since large reservoirs are the least productive (Bernacsek, 1997; Jackson & Marmulla, 2001), fisheries enhancement should be considered for specific zones of the impoundment, where resident fish populations can be expected to develop without necessarily colonizing the whole reservoir.

7.4.1.4 Consider constructed wetlands and sanctuaries

Thus, some areas of the Xayaburi impoundment should be considered for implementation of constructed wetlands, as proposed in the case of Nam Gnouang Reservoir (Meynell, 2013; Meynell & Chu, 2013). Sites to be considered for this purpose include Ban Long, Mouang Khai, or Pak Long downstream of Luang Prabang, and other locations 10–15 km upstream of Thadeua site; these sites feature flat banks and/or wetlands along river banks. Tilapias and carps are among the most successful tropical species used for reservoir stocking, but the use of indigenous species is highly preferable (Moreau & De Silva, 1991) such as Java barb (*Barbonymus gonionotus*), Thai river sprat *(Clupeichthys aesarnensis)*, sharkminnows (*Osteochilus spp.*) or snake skin gourami (*Trichogaster pectoralis*). Yet the broad discrepancy in reports regarding increased productivity shows that forecasts of yields are very difficult to make.

As regards fish sanctuaries, experience can be drawn from the Nam Ngum 1 reservoir, where a protected area was established by the Lao Department of Livestock and Fisheries, near the inflow of the Nam Ngum River (T. Visser, pers. comm.) and from the Nam Theun 2 reservoir (Baran et al., 2021; NTPC 2005).

7.4.1.5 Continue JEM monitoring for at least one annual biological cycle

Downstream of the dam, due to the need to complete at least one annual biological cycle to reflect fish populations' seasonal pulses and the recentness of monitoring, it is not possible to draw any sharp conclusion at this stage. However, data are likely to show a seasonal accumulation of migratory species not finding their way up and subsequent high monthly catches and CPUE – until the current age cohort dwindles. This point requires careful interpretation of CPUE monitoring data in the next few years. Thamuang site, about 400 km downstream of the dam, is characterized by an *increase* in both monthly average catch per fisher and gillnet CPUE over the 2017–2021 period. This might result from a shift in fishing gears or fishing practices and a subsequent increased fishing efficiency. Here, too, a gear analysis is recommended as a priority before conclusions are drawn about the fish stock.

7.4.2 Mitigation and adaptation at Don Sahong site

7.4.2.1 Deepening entrance to channels for fish passage despite increased water abstraction

Regardless of caveats on data underlined in sections 3.5.2 and 5.4.1, the most important lesson from the survey is that fish passages formerly operational in the dry season such as Don Sadam and/or improved by Don Sahong Power Company Ltd. to facilitate fish migrations (Hoo Som Yai, Hoo Sadam, Nyoi Koong, Koum Tao Hang) are currently dry several months a year due to flow reduction documented in section 4.1 of this report (water abstraction going beyond the reserved environmental flow of 800 m^3/s minimum in Phapheng channel). As suggested above, adaptive management would consist of deepening the entrance of these channels to increase the likelihood of adequate flow for fish passage during the dry season, even if flows in the eastern channel continue to be <800 m^3/s.

7.4.2.2 Maintain sufficient flows for fish attraction

Given the importance of Khone Phapheng waterfall as a fish attractor during migrations (although Hoo Sadam, Hoo Som Yai and Hoo Som Pordan are not operational due to low flow or dryness), it is recommended to return to a sufficient flow to attract fish at Hoo Sadam and for fish attraction and passage in Hoo Som Yai.

7.4.2.3 Consider investing in further fish pass improvement works

Two other channels, Hoo Wai and Hoo Don Lai, can be substantially improved with minimal work to better accommodate fish migrations, in particular in the dry season, as described as follows:

- The outlet of Hoo Wai downstream of Khone Lan is characterized by a sideway and backward curve sub-optimal for fish attraction; it is recommended to redesign this outlet to make it straighter;
- Don Lai channel near Somphamit waterfall is currently obstructed by a 1-m high rocky step in the dry season; its removal would substantially improve the passability of this channel without altering flows in the Don Sahong dam area.

Last, the authors' exploration of the Khone Fang area revealed the potential of two channels for improved passage in the dry season if levelling and deepening are undertaken: Hoo Khone Souang and Hoo Pataep (Figure 7.4). Here, too, an increased discharge through these channels would not reduce flow in the Don Sahong Dam area.

Figure 7.4. Hoo Khone Souang and Hoo Pataep, two channels in Khone Fang area to be considered for fish passage improvement

8 CONCLUSION

The JEM Programme has been piloted over the past two years around the two operating HPPs on the Mekong mainstream – Xayaburi and Don Sahong. This time period has largely coincided with COVID-19 pandemic, which has impacted on all aspects of the monitoring project. Impacts of the pandemic have included delays in the procurement of equipment, the need to carry out training and data sharing meetings online instead of face-to face and in the field, and domestic travel restrictions and lockdowns that have delayed or cancelled some of the monitoring visits. Perhaps the biggest disappointment has been the fact that it has not been possible to obtain a full year's monitoring results for all disciplines. Nevertheless, these challenges have been met with flexibility and adaptation by the JEM Pilots team, MCs and partners. The experience of the pilots has provided a valuable testing of the JEM principles, methods and protocols so that recommendations can be incorporated into future monitoring of mainstream HPPs and the new CRMN.

The principal objective of the JEM Pilots project in terms of trialing the JEM Programme has been achieved. In addition, chapter 5 provides a comprehensive set of recommendations for improving the JEM Programme and its monitoring protocols for all of the disciplines, and extending them to the MRC's routine monitoring and the future CRMN.

Although the monitoring data collected for five disciplines may have been relatively limited to the dry season with incomplete wet season results, it has been possible to highlight: (i) changes in the flow and sediment conditions at the different sites; (ii) WQ and ecological health changes both downstream of dams and within the impoundments; and (iii) changes in the fish monitoring results. It is not always possible with this limited data to attribute impacts related to the dams and differentiate them from other changes in conditions in the river. Nevertheless, an attempt has been made to qualitatively link the results of the different disciplines at the different locations.

Some initial and generalized suggestions have been made for mitigation and adaptation of the operation Mekong mainstream HPPs based on these pilot monitoring results. These suggestions build upon and validate earlier work of the MRC on hydropower environmental impact mitigation and risk management. The results highlight impacts that are occurring and may require mitigation.

The JEM pilots have shown the need and usefulness of continued multi-disciplinary monitoring of the river – not only around HPPs, but generally throughout the basin, in order to understand the changes that are observed, in relation to both improvements and degradation of conditions. It is recommended that JEM pilot monitoring continue for the next year, at least until the CRMN is established, at which point, some of the JEM monitoring sites are likely to be included in the wider monitoring network, with other sites specifically set up to capture the changes in river conditions around the planned mainstream HPPs. An important element of the new network will be the further training and capacity strengthening of the national teams, and particularly the standardization of monitoring methods and analysis across the basin.

9 REFERENCES

Baran, E., Visser, T., Cottet, M., Tessier, A., Guerin, E., & Guillard, J. (2021). A case study of fisheries governance and management in a reservoir of Lao PDR: Perspectives for improvement. Aquaculture and Fisheries Studies, 3(3), 1–9. https://doi.org/10.31038/AFS.2021335

Cowx, I. G., Mallen-Cooper, M., Schmutz, S., Bunthang, T., Praxaysambath, B., Sricharoendham, B., & An, V. V. (2014). Annex C: Prior Consultation for the proposed Don Sahong Hydropower Project technical assessment report. In *Fish passage and fisheries ecology base on submitted EIA project documents* (pp. C1–65). Vientiane: MRC Secretariat. https://www.mrcmekong.org/assets/Publications/Consultations/Don-Sahong/Annex-C-Fisheries-Report.pdf

Fisheries Administration. (2019). Photo of fish and information guidebook: Report for the project "Support for Fisheries and Aquatic Resources Management in Northern Cambodia". Fisheries Administration and Inland Fisheries Research and Development Institute.

Fisheries Administration. (2021). Scientific monitoring of the fish resource with community fisheries: 2019–2020 data analysis report – Report for the project "Support for Fisheries and Aquatic Resources Management in Northern Cambodia". Fisheries Administration and Inland Fisheries Research and Development Institute.

Jackson, D. C., & Marmulla, G. (2001). The influence of dams on river fisheries (FAO Fisheries Technical Paper). In G. Marmulla (Ed.), *Dams, fish and fisheries: Opportunities, challenges and conflict resolution* (pp. 1–44). FAO. http://www.friendsofmerrymeetingbay.org/cybrary/pages/20010000_UN_FAO_Dams,%20fish%20and%20fisheries.pdf#page=6

Koehnken, L. (2014). *Discharge Sediment Monitoring Project (DSMP) 2009–2013: Summary and analysis of results (final report)*. Vientiane: MRC Secretariat. https://portal.mrcmekong.org/assets/v1/documents/Report-workshop/Technical-Report_DSMP/DSMP-Report-2009_13-Final-Report-July-2014.pdf

Meynell, P. J. (2013). *Enhancing ecological diversity of reservoirs with constructed wetlands: Part I – Developing the concept* (Project report: Challenge Program on Water & Food Mekong project MK3 — Optimising multiple-use of water in cascades or system of reservoirs in small catchments Issue. International-Centre-for-Environmental-Management. https://icem.com.au/portfolio-items/optimising-cascades-or-systems-of-reservoirs-in-small-catchments-mk3-report-series/#

Meynell, P. J., & Chu, T. H. (2013). Enhancing ecological diversity of reservoirs with constructed wetlands: Part II – feasibility study in the Nam Gnouang reservoir (Project report: Challenge Program on Water & Food Mekong Project MK3 – Optimising multiple-use of water in cascades or system of reservoirs in small catchments Issue. International-Centre-for-Environmental-Management), Issue. International-Centre-for-Environmental-Management. https://icem.com.au/portfolio-items/optimising-cascades-or-systems-of-reservoirs-in-small-catchments-mk3-report-series/#

Moreau, J., & De Silva, S. S. (1991). Predictive fish yield models for lakes and reservoirs of the Philippines, Sri Lanka and Thailand (FAO Fisheries Technical Paper 319). FAO.

MRC. (2020a). The MRC Hydropower Mitigation Guidelines: Guidlines for hydropower environmental impact mitigation and risk management in the Lower Mekong mainstream and tributaries (Vol. 3). Vientiane: MRC Secretariat. https://www.mrcmekong.org/assets/Publications/Ish0306-vol3.pdf

MRC. (2020b). Piloting a Joint Environmental Monitoring (JEM) Programme on two Mekong mainstream dams: The Don Sahong and Xayaburi hydropower project: Report on three fisheries training events (February and March 2020). MRC Secretariat.

MRC. (2021a). Fish tagging options for the study of river fish migrations: A review with particular focus on the Mekong. MRC Secretariat.

MRC. (2021b). Recent fish migrations in Khone Falls (Lao PDR) according to local ecological knowledge. MRC Secretariat.

Ngor, P. B., Chhut, C., Theng, L., Ly, V., Phommakone, S., Samphawamana, T., Nguyen, H. S., Degen, P., & So, N. (2016). *Photos of common fishes in the Lower Mekong Basin*. Phnom Penh: MRC Secretariat. https://doi.org/https://www.mrcmekong.org/resource/ajg7ak

NTPC. (2005). Nakai reservoir fisheries development and management. In NTPC (Ed.), *Nam Theun 2 Project – Social Development Plan* (Vol. 2). Vientiane: Nam Theun 2 Power Company Ltd. https://www.namtheun2.com/wp-content/uploads/2021/07/Chapter-15-Nakai-Reservoir-Fisheries-Development-and-Management.pdf

Podobnik, B., & Stanley, H. E. (2008). Detrended cross-correlation analysis: A new method for analyzing two nonstationary time series. *Physical Review Letters, 100*(8), 084102. https://doi.org/10.1103/PhysRevLett.100.084102

SMEC. (20213). *Don Sahong transboundary hydraulic effects study* (Don Sahong Hydropower Project 8050001, Revision No. B). Don Sahong Hydropower Company Ltd. https://dshpp.com/wp-content/uploads/2013/12/DSHPP-Transboundary-Hydraulic-Effects_Rev-B.pdf

Ter Braak, C. J., & Verdonschot, P. F. (1995). Canonical correspondence analysis and related multivariate methods in aquatic ecology. *Aquatic Science, 57*(3), 255–289. https://doi.org/https://doi.org/10.1007/BF00877430

Annex 1: The Joint Environmental Monitoring Team

The Environmental Management Division of the Mekong River Commission (MRC) with the support of GIZ has been developing two pilot projects to trial and refine the Joint Environmental Monitoring (JEM) approach and monitoring and reporting protocols based on a two-year implementation around the Xayaburi Hydropower Plant (HPP) and the Don Sahong HPP (DSHPP). The Mekong River Commission Secretariat (MRCS) team implementing these pilots consists of:

- Dr So Nam, Chief Environment Management Officer
- Mr Hak Socheat, Director of Environmental Management Division
- Dr Kongmeng Ly, Water quality Officer
- Dr Prayooth Yaowakhan, Ecological Health Specialist
- Dr Ly Sarann Water and Climate Monitoring Specialist
- Mr Vanna Nuon, Fisheries and Aquatic Ecology Officer
- Mr Palakorn Chanbanyong, Sustainable Hydropower Specialist
- Mr Soukaseum Pichit, MRC Data Management Specialist
- Dr Anoulak Kittikhoun, Chief Strategic and Partnership Officer.

National Monitoring Teams:

Cambodia

- Mr Bunthang Touch, Acting Director of Inland Fisheries Research and Development Institute (IFReDI)
- Mr Phanara Thach, Head of Laboratory (IFReDI)
- Mr Solyda Putrea, Head of Biology Depratment (IFReDI)
- Mr Sokheng Chan, Vice Head, Technology Research Office (IFReDI)
- Dr Yin Savuth, Director General of Department of Hydrology and River Work.

Lao PDR:

- Mr Sengduangduan Phouthanoxay, Deputy Head of Hydrology Division of Department of Meteorology and Hydrology (DMH)
- Mr Chansamone Chanhthachak, Technical Officer (DMH)
- Mr Virasak Choundara, Director General of Natural Resources and Environment Statistics Research Institute (NESRI)
- Mr Sitthideth Nonthaxay, Deputy Laboratory Head (NESRI)
- Dr Niane Sivongxay, Director of Southeast Asian Ministers of Education Organization (SEAMEO) Regional Centre for Community Education Development
- Dr Chanda Vongsombath, Dean of Faculty of Natural Sciences
- Dr Kaviphone Phouthavong, Deputy Director General Department of Livestock and Fisheries
- Mr Saluemphone Chanthavong, Deputy Chief of Capture Fisheries Unit of Livestock and Agriculture Research Centre.

Thailand

- Mr Sasikan Charoensatsiri, Hydrologist of the Bureau of Research Development and Hydrology (DWR).

The GIZ team supporting this piloting of the JEM:

- Dr Bertrand Meinier
- Ms Erinda Pubill Panen
- Ms Mayvong Sayatham.

The International Center for Environmental Management (ICEM) core team:

- Dr Lois Koehnken, Hydrology and geomorphology specialist
- Dr Eric Baran, Fisheries and fish passage specialist
- Mr Peter-John Meynell, Water quality and aquatic ecology specialist, Team Leader
- Dr Apichart Termvidckakorn: Fish larvae and taxonomic specialist
- Mr Sinsamout Ounboundisane: Fisheries local knowledge specialist
- Mr Khambane Inthipunya: Database specialist
- Ms Luong Thi Quynh Mai: Procurement and Administration Officer.

Supported by the ICEM management team:

- Director/ Environmental Impact Assessment (EIA) Specialist – Dr Jeremy Carew-Reid
- Senior Environmental Specialist/Project Manager – Dr Daniel Gilfillan, replaced by Ms Leila Macadam
- Senior Environmental Specialist/ Data Management Specialist – Dr Richard Cooper
- Communications Specialist – Ms Chloe Pottinger
- Hydrologist – Mr Pham Tran Minh
- I GIS Specialist – Mr Mai Ky Vinh

Annex 2: Training events, survey and workshops conducted

ORIGINAL PLANS			CURRENT ACTUAL						
No.	**Event**	**Training Days**	**No.**	**Event**	**Training Days**	**Status**	**Official Name**	**Venue and location**	**Date**
	Total	42		Total	98				
1	Training Thadeua & LPD Lao PDR - JEM Fish Abundance & Diversity Monitoring (FADM) & FLDM Technical Training	4	1	Training Thadeua & LPD Lao PDR - JEM Fish Abundance & Diversity Monitoring (FADM) & FLDM Technical Training	4	Completed	Training 1: fisheries monitoring field training for JEM pilots	Muong Thong Hotel, Luang Prabang, Lao PDR	24 – 27 February 2020
2	Training IFReDI FNP Cambodia - First Part JEM - Laboratory Training on Larvae Monitoring and Taxonomic Identification of Fish Larvae and Juveniles	5	2	Training IFReDI FNP Cambodia - First Part JEM - Laboratory Training on Larvae Monitoring and Taxonomic Identification of Fish Larvae and Juveniles	5	Completed	Training 2: Fish Larvae Identification Training for JEM pilots	Inland Fisheries Research and Development Institute (IFReDI), Fisheries Administration (FiA), Phnom Penh, Cambodia	02 – 06 March 2020
3	Training IFReDI FNP Cambodia - In-country Review of Reporting Requirements and In-office Review of Fisheries and Larvae Drift Forms and QA/QC for Data Collection and reporting of Results to the MRC	3	3	Training IFReDI FNP Cambodia - In-country Review of Reporting Requirements and In-office Review of Fisheries and Larvae Drift Forms and QA/QC for Data Collection and reporting of Results to the MRC	3	Completed	Training 3: Data management and Analysis Training for JEM pilots	Sunway Hotel Phnom Penh, Cambodia	09 – 11 March 2020
4	Training LPB, Lao PDR - Water Quality Training Both Field and in House	3	4	Online Training 1: Water Quality Monitoring (WQM)	3	Completed	Online Training 1: Water Quality Monitoring (WQM)	Virtual	16, 17 & 19 June 2020 (13:30 - 17:30)
5	Workshop Vientiane, Lao PDR - Workshop on Chlorophyll Analysis Using Narrow Band Spectrophotometry	2	5	Online Training 2: Discharges and Sediment Monitoring (DSM)	4	Completed	Online Training 2: Discharges and Sediment Monitoring (DSM)	Virtual	22, 23, 24 & 26 June 2020 (8:30 – 12:30)
6	Training LPB, Lao PDR - Aquatic Ecology Training both Field and In-house	3	6	Online Training 3: Ecological Health Monitoring (EHM)	3	Completed	Online Training 3: Ecological Health Monitoring (EHM)	Virtual	9, 10 and 13 July 2020 (13:30 – 17:30 p.m.)
7	Training Chiang Khan, Thailand Technical Training for Sediment Transport and Discharges Measurement	5	7	First Peer-to-peer trainings in Lao PDR	8	Completed	1st peer-to-peer trainings for JEM pilots in Lao	Xayaburi, Lao PDR	20 - 27 September 2020
8	Training Pakse, Lao PDR - Fish Passage Monitoring Training Both In-house and Field Training	10	8	Second Peer-to-peer trainings in Lao PDR	7	Completed	2nd peer-to-peer trainings for JEM pilots in Lao	Xayaburi, Lao PDR	12 – 18 December 2020
9	Training Vientiane, Lao PDR - Second Part JEM-Laboratory Training on Larvae Monitoring and Taxonomic Identification of Fish Larvae and Juveniles	5	9	Third Peer-to-peer trainings in Lao PDR	3	Completed	3rd peer-to-peer trainings for JEM pilots in Lao	Pakse, Lao PDR	16 - 18 March 2021
10	Training HYCOS Sites at Xayaburi and Stung Treng after Installation - HYCOS Maintenance Training Provided by OTT	2	10	First Peer-to-peer trainings in Thailand	3	Completed	1st peer-to-peer trainings for JEM pilots in Thailand	Nong Khai, Thailand	1 – 3 October 2020
			11	Second Peer-to-peer trainings in Thailand	4	Completed	2nd peer-to-peer trainings for JEM pilots in Thailand	Nong Khai, Thailand	16 – 19 November 2020
			12	Third Peer-to-peer trainings in Thailand	3	Completed	3rd peer-to-peer trainings for JEM pilots in Thailand	Chiang Khan, Thailand	9 - 12 March 2021
			13	HYCOS Installation and Training in Lao PDR	3	Completed	HYCOS Station Equipment Installation and Training at Pakhoung Station	Xayaburi, Lao PDR	11 - 14 November 2020
			14	HYCOS Installation and Training in Cambodia PDR	3	Completed	HYCOS Station Equipment Installation and Training at Koh Key Station	Stung Treng, Cambodia	27 – 30 January 2021
			15	Local Ecological Knowledge Survey Lao PDR	21	Completed	Local ecological knowledge survey of fish migration in Khone Falls	Khone Falls, Champasak Province, Lao PDR	10 - 30 March 2021
			16	Khonefang Documentation Mission Lao PDR	5	Completed	Survey of additional channels at Khonefang area to support LEK survey	Khone Falls, Champasak Province, Lao PDR	25 - 29 June 2021
			17	Fish Larvae Identification Refresher Training in Lao PDR	5	Completed	Training for JEM Pilots - Fish Larvae Monitoring and Identification	Ban Na Fishery Research and Development Station, Khong District, Champasack Province, Lao PDR	19 - 23 July 2021
			18	PIT tag training in Lao PDR	3	Completed	PIT Tag Training for JEM Pilots	Vientiane, Lao PDR	6 - 10 September 2021
			19	Workshop Vientiane, Lao PDR – Workshop on Chlorophyll Analysis Using Narrow Band Spectrophotometry	3	Completed	Spectrophotometric determination of Chlorophyll A in the Presence of Pheophytin A	Vientiane, Lao PDR	15 - 17 September 2021
			20	Regional Workshops on Data Sharing and Analysis	5	Completed	National Workshops (4) and Regional Workshop (1) on JEM Integrated Data Analysis, Reporting, and Sharing via Videoconference	Multiple	22 September (Cambodia), 27 September (Thailand), 5 October (Vietnam), 7 October (Lao PDR) and 8 October 2021 (Regional)

Annex 3: Database structure

Hydrology and sediments monitoring database

Three parts are organized as follows:

1. **Hydrology-sedimentation**
   a. Average velocity
   b. Water level
   c. Discharge
   d. Loop test % applied
   e. Loop test velocity
   f. Suspended sediment concentration (SSC)
   g. Bedload.

2. **Hydro-timeseries monitoring**
   a. Daily water discharge monitoring
   b. Water level monitoring every 15 minutes.

3. **Sediment grain size monitoring**
   a. Median grain size
   b. Pebble (%)
   c. Very fine pebble (%)
   d. Very coarse sand (%)
   e. Median sand (%)
   f. Fine sand (%)
   g. Very fine sand (%)
   h. Median coarse silt (%)
   i. Very fine silt (%)
   j. Clay (%).

Water quality monitoring database

The design and construction of the water quality (WQ) monitoring database consists of two parts, as follows:

1. **Monthly interval WQ monitoring** of the water surface – the parameters included for monthly monitoring are:
   a. Temperature
   b. pH
   c. Total suspended solids (TSS)
   d. Turbidity
   e. Conductivity
   f. Alkalinity
   g. Acidity
   h. Cations – Ca, Mg, Na, K, Al
   i. Anions – Cl, SO4,
   j. Nitrogen – NO32NO2, NO3, NH4N, total nitrogen (TOTN)
   k. Phosphorus – PO4P, total phosphorous (TOTP)
   l. Dissolved oxygen (DO)
   m. Chemical oxygen demand (CODMN)
   n. Biological oxygen demand (BOD)

o. Phytoplankton – chlorophyll-a, cyanobacteria
p. Faecal coliforms (FC).

2. **Water quality profile monitoring** at 1-m intervals down to 20 m below the surface within the hydropower impoundments, including measurements taken by the probes for temperature, pH, conductivity, DO, turbidity, chlorophyll-a, and cyanobacteria.

The EHM database consists of two levels:

1. **EHM – level 1**: Every single species recorded at each site with total number of individuals, and the total number of samples with species present. Species lists were developed based upon all of the species of the four biota types recorded at all sites in the Lower Mekong and organized with full taxonomic classification.

2. **EHM – level 2** records at biota level; the parameters included in monitoring are:
    a. Depth
    b. Secchi disc
    c. Temperature
    d. DO
    e. pH
    f. Conductivity,
    g. Site Disturbance Score
    h. Average abundance for each biota group
    i. Average species richness for each biota group
    j. Abundance Index, Species Richness Index, and ATSPT Index.

Annex 4: Combined Annual Report for the JEM Pilot Programme: Second Pilot Site Reports and Basin Perspective on the Don Sahong and Xayaburi Hydropower Projects

Mekong River Commission

Combined Annual Report for the JEM Pilot Programme: Second Pilot Site Reports and Basin Perspective on the Don Sahong and Xayaburi Hydropower Projects

Piloting a Joint Environmental Monitoring (JEM) Programme on Two Mekong Mainstream Dams: The Don Sahong and Xayaburi Hydropower Projects

November 2021

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ABBREVIATIONS AND ACRONYMS

ADCP	Acoustic Doppler Current Profiler
ARI	Annual Return Interval
ATSPT	Average Tolerance Score per Taxon
BGSA	Bed Material Grain Size Analysis
CJDD	Preah Romkel, Downstream of Don Sahong Dam
CK	Chiang Khan
CKT	Routine EHM site - Kratie Province, Koh Khe village, Cambodia
COD	Chemical Oxygen Demand
CPUE	Catch Per Unit Effort
CS	Chiang Saen
CSK	Routine EHM site - Stung Treng Province, Pres Bang village, Cambodia
CSP	Routine EHM site - Ratanakiri Province, Day Lo village, Cambodia
CSRT	Siem Reap Province, Ti 3,4,5 village
CSS	Routine EHM site - Ratanakiri Province, Fang village, Cambodia
CST	Routine EHM site - Stung Treng Province, Ou Run village, Cambodia
DHRW	Department of Hydrology and River Works (Cambodia)
DMH	Department of Meteorology and Hydrology (of Lao PDR)
DO	Dissolved Oxygen
DSHPP	Don Sahong Hydropower Plant
DSMP	Discharge and Sediment Monitoring Program
DSS	Decision Support System
DST	Data Storage Tag
EHI	Ecological Health Index
EHM	Ecological Health Monitoring
EGEM	Expert Group on Environmental Management
EPT	Ephemeroptera, Plecoptera, Trichoptera
FADM	Fish Abundance and Diversity Monitoring
FLDM	Fish Larvae Drift Monitoring
FTU	Formazin Turbidity Unit
GIS	Geographical Information System
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GPS	Global Positioning System

HP	Horse Power
HPP	Hydropower Plant
HYCOS station	Automatic hydrological monitoring station
ICEM	International Centre for Environmental Management
ID/OD	Interior Diameter / Outside Diameter
JEM	Joint Environmental Monitoring
Lao PDR	Lao People's Democratic Republic
LAP	Attapeu Province, Saphaothong village
LARReC	Living Aquatic Resources Research Centre
LCD	Liquid Crystal Display
LCS	Champasak Province, Ban Hat village
LHT	Bokeo Province, Donekhoun village
LJDD	Champasak Province, Hang Khone village
LJDD	Hang Sadam, downstream of Don Sahong Dam
LJDU	Champasak Province, Saen Nue village
LJDU	Don Sahong, upstream of Don Sahong Dam
LJXD	Xayabouri Province, Pak Houng village
LJXD	Pak Houng, downstream of Xayabouri Dam
LJXI	Xayabouri Province, Tha Deua village
LJXI	Tha Deua, in Xayabouri Dam Impoundment
LJXU	Luangprabang Province, Pha O village
LJXU	Pha O, upstream of Xayabouri Dam
LMB	Lower Mekong River Basin
LNMC	Lao National Mekong Committee
LP	Luang Prabang
LPB	Luang Prabang
LSD	Routine EHM site - Champasack Province, Hang Sadam village, Lao PDR
MoNRE	Ministry of Natural Resources and Environment (Lao PDR)
MPN	Most Probable Number
MRC/MRCS	Mekong River Commission / Mekong River Commission Secretariat
NK	Nong Khai
NRESRI	Natural Resources and Environment Statistics and Research Institute
PIT	Passive Integrated Transponder
PK	Pakse
PMFM	Procedures for the Maintenance of Flow on the Mainstream

PO	Purchase Order
PSAT	Pop-up Satellite Archival Tag
Q	Discharge
QA/QC	Quality Assurance / Quality Control
SKB	Sekong Bridge
SKB	3S basin
SOP	Standard Operating Procedures
SSC	Suspended Sediment Concentration
SSC SGSA	Suspended Sediment Grain Size Analysis
SSC-GSA	Depth integrated suspended sediment Grain Size Distribution
ST	Stung Treng
ST-UP	Stung Treng UP
TP, Tot_P	Total phosphorus
TPH	Total Petroleum Hydrocarbons
TSS	Total Suspended Solids
USB	Universal Serial Bus
WHO	World Health Organization
WQ	Water Quality
WQMN	Water Quality Monitoring Network
WQMNL	Water Quality Monitoring Network Laboratories of Lao PDR
WQN	Water Quality Network
XPCL	Xayaburi power company

EXECUTIVE SUMMARY

The Mekong River Commission finalised the design of the Joint Environment Monitoring (JEM) Programme for Mekong Mainstream Hydropower Projects in May 2019 with the intention to provide a common basis for constructive discussions by communities and Member Countries on the implications of hydropower development. With the support of Germany, the MRC Environmental Management Division then developed 2-year pilot projects around the Xayaburi hydropower project (HPP) and the Don Sahong HPP for the purposes of trialling and refining the JEM approach, monitoring and reporting protocols.

This report fulfils two purposes. Firstly, it contains the second assessment of the pilot monitoring protocols and results carried out for the two JEM pilot sites at Xayaburi HPP and Don Sahong HPP. This assessment covers the time period from March to July 2021 as a follow up to the first pilot site report which reported results up to February 2021. This first report was recently discussed at the annual MRC's EGEM meeting in June 2021. These reports were originally scheduled at six monthly intervals during the first year of monitoring i.e. in September 2020 and March 2021. Since many aspects of the JEM Pilots have been significantly delayed by COVID-19 restrictions, the September 2020 reports were postponed to March 2021 and this second report comes in September 2021. The second purpose of this report is to present all monitoring results from the JEM Pilots within a basin-wide analysis that considers findings in the context of conditions of the Lower Mekong basin as a whole. This includes consideration to what interdisciplinary analysis opportunities are available.

Update on procurement, training and monitoring activities

Procurement activities continued across the March to August 2021 period, including a fresh batch of requests for quotation following a final review of monitoring equipment and supplies conducted by the line agency teams in Cambodia, Lao PDR and Thailand. A HYCOS/WQ monitoring HydroSystem supplied by OTT, plus buffer solutions for calibration, was delivered and installed at Don Sahong station in July 2021. Other delivered items included equipment for the adapted gillnet protocols, new microscope camera to support lab analysis of fish larvae, and supplies for Chlorophyll-a training. A substantial batch of fish tagging equipment and supporting accessories was procured by the project and delivered to Lao PDR in preparation for both training activities in September 2021 and for deployment in 2022. It became evident that it will not be possible to delivery one planned item within the project timeframe – the D-96 sediment sampler for Xayaburi pilot in Thailand originally ordered on 4 March 2020 – due to business issues with the manufacturer and their revised proposed delivery date some time in 2022. Six training events were conducted over this period as summarised in ***Table 0-1***.

Table 0-1. Summary of trainings from March to September 2021 for the JEM Pilots

Date	Location	Topic
Hydrology and sediments		
March 2021	Vientiane, Lao PDR.	Laboratory based training in the determination of SSC and the grain-size distribution of bed materials
March 2021	Pakse	Field and classroom based peer coaching
April 2021		Hydroseds monitoring regional half-day workshop
Water quality		
September 2021	Vientiane, Lao PDR	Theory of monitoring Chlorophyll-a,
Fisheries		

Date	Location	Topic
July 2021	Ban Na Hatchery Centre, Lao PDR	Refreshment training was provided on fish larvae monitoring and identification
September 2021	Vientiane, Lao PDR	PIT tag training

New monitoring results were collected by the national teams as follows:

- Feb to May 2021 results for hydrology and sediments, with some gaps due to COVID-19 travel restrictions and lockdowns.
- Feb to June 2021 water quality sampling results, with a gap in May 2021 at both sites due to COVID-19 travel restrictions preventing monitoring.
- February and March 2021 for EHM
- Feb to July 2021 for FLDM
- Feb to July 2021 for gillnets in Laos and at selected sites in Cambodia

There were no adjustments to the JEM monitoring procedures or scheduling for hydrology and sediments or water quality. For EHM, the timing of the monitoring shifted to February and March 2021 instead of the originally planned April sampling. For fisheries, Cambodia and Laos tested the adjusted methodology for standardized gillnet sampling.

Due to COVID-19 and other delays associated with the procurement, distribution and capacity building exercises required prior to initiation of the pilot monitoring protocols, fewer samples were collected than planned across the whole pilot. More generally, the JEM Pilots aims to trial protocols, assess the resulting monitoring data, demonstrate analysis approaches, and identify opportunities to improve the JEM approach. Given the limited length of the pilot period and resulting dataset, only preliminary interpretations of the results are possible in relation to the impacts of hydropower. A particular gap is limited sampling during the wet season of 2020, which has in turn impacted the ability of the JEM monitoring to quantify certain impacts such as sediment trapping in Xayaburi. Furthermore, apart from general contributions made at the EGEM meeting in June 2021, no detailed monitoring data has yet been provided by the two hydropower developers at Xayaburi and Don Sahong.

Nevertheless, as demonstrated within this report, the JEM Pilots have indeed identified the value of collecting these new datasets to improve the understanding of local impacts associated with hydropower operations at Xayaburi and Don Sahong. Examples are also provided on how hydropower monitoring data might be used collectively to validate and inform the JEM data once it is available in the future. There has also been significant effort in checking of monitoring results, review of monitoring equipment and methodology, training and knowledge sharing, leading to identification of numerous recommendations to ensure monitoring activities result in datasets suited for integration and interpretation in the context of the whole basin.

Xayaburi HPP Site Report

The additional monitoring data received for the February to July 2021 period has been assessed and analyzed for each discipline. This led to updated findings and recommendations building on the first pilot site report for Xayaburi HPP as discussed at the June 2021 EGEM meeting.

For hydrology and sediments, delays in implementation of the water level sites at Ban Xanghai and Ban Pakhoung and the delivery of equipment due to COVID-19 prevented JEM monitoring from capturing wet season conditions at the new JEM site. Results only cover the dry season. Despite these delays, new insights have been gained during the trial and the DSM teams have received valuable training. New information gained from the Xayaburi pilot are the following:

- An indication that **water level recording at Ban Xanghai can be used to measure flow entering the Xayaburi impoundment**, although additional results are required for confirmation;
- An understanding of water level fluctuations associated with the operation of the Xayaburi power station, and how the **fluctuations dissipate between Ban Pakhoung and Chiang Khan;**
- An improved understanding of water velocities at Ban Xanghai and Ban Pakhoung with **velocities remaining sufficiently high to promote bedload transport even during the dry season**. This will assist with the understanding of geomorphic change in the river.

Based on the JEM Pilot experience, a strong recommendation firstly made that manual water level gauge reading should continue at least daily at Ban Pakhoung to ensure continuity and value of the water level record. Secondly, future analysis to check whether the Ban Xanghai site is affected by backwater from the Xayaburi impoundment, once high flow results are available. Thirdly, for checking and calibration of the automatic water level recorder at Ban Pakhoung and Chiang Khan during each discharge measurement. Fourthly for derivation of rating curves at Ban Xanghai and Ban Pakhoung following the collection of additional high flow measurements, as well as review of the rating curve at Chiang Khan. A finally for review of current laboratory (and field technology) for determining the bed material grain-size distribution and for SSC grain-size distribution.

For water quality, monthly sampling was conducted with the exception of May 2021 which was hindered by COVID-19 travel restrictions. Otherwise the water quality team have not indicated any access or sampling difficulties. Findings at Xayaburi pilot site were as follows:

- The **presence of the Xayaburi dam and impoundment does not appear to be affecting most parameters of water quality measured** during the dry season months between October 2020 and June 2021. It should be noted that this is based on spot samples during the day, and do not capture changes that may fluctuate between day and night (such as DO).
- Satistical analysis of the water quality results shows that most parameters were more frequently slightly higher in the impoundment, compared to the upstream site and downstream sites, except for turbidity (and, by implication, Total Suspended Solids) which were up to 60% higher in the upstream site.
- Turbidity and TSS are the main parameters that show changes with passage through the impoundment and below the dam, indicating that **sedimentation processes in the impoundment are removing suspended solids**.
- **Nutrient levels appear to be slightly increased in the impoundment**, but not passed on downstream below the dam;
- There may be a **slight indication of higher phytoplankton levels in the impoundment** compared to downstream and a probable minor bloom of Cyanobacteria in January 2021. In no cases did the concentrations of Chlorophyll-a and Cyanobacteria approach the WHO health risk threshold for recreational waters.
- **Impoundment profiles do not show thermal or chemical stratification**, although there may be evidence of declining DO with depth during the colder months of January and February 2021.

Based on the JEM Pilot experience, recommendations are firstly that a semi-continuous water sampling programme should be installed with the flow and water level monitoring station at WQ4. This would enable capture of the diurnal changes in water quality that may occur downstream of the dam. Secondly, that the AlgaeTorch measurements of Chlorophyll-a and Cyanobacteria are providing interesting insights into the relatively low levels and dynamics of phytoplankton and should be continued. Finally, it is recommended that further measurements and analysis be conducted to confirm the relationship between TSS and turbidity for the Mekong waters and enable determination of suspended solid levels in the water without requiring laboratory analysis.

For Ecological Health Monitoring, the first annual bio-assessment monitoring was planned for April 2020. This had to be cancelled because of the COVID-19 restrictions on travel within Lao PDR. The intended scheduling for April 2021 was brought forward to February/March 2021 to allow for the identification and reporting process to be conducted in a timely manner. Analysis of the EHM results provided the following findings:

- The Ecological Health monitoring results around Xayaburi **show clear changes in the species diversity and numbers of biota present within the impoundment and downstream** compared to the upstream reference site.
- Statistical analysis showed similarities between the downstream sites, but differences between the upstream and impoundment sites for diatoms. Zooplankton are most variable between all sites. For littoral and benthic macroinvertbrates differences appeared to depend upon substrate condition.
- The Ecological Health Index (EHI) in the **impoundment and downstream are all classified as in Moderate health**, with indications of recovery with passage downstream, compared to the **upstream reference site which is classified as in Good health.**
- The changes in the impoundment and downstream **are likely to be caused by changes in the flow rates and water levels, rather than by changes in water quality**.
- The **responses of the different biota types provide greater insights** into the changes of substrate and habitat, considering the average abundance, species diversity and ATSPT for each biota type, **compared to the simple EHI**.
- The **Littoral Macroinvertebrates show the clearest changes** in species diversity and abundance with passage downstream after the dam;
- The **changes in the flow and substrate conditions occasionally make sampling difficult** and potentially unsafe, which needs to be considered in site selection and interpretation of the results.

The significance of the changes observed between the ecological health of the impoundment versus the downstream sites is difficult to analyse statistically because there is only one year of sampling at each of the JEM stations. Recommendations following from this EHM monitoring and analysis are that the EHM component of the JEM should be continued with sampling at least once a year to build up statistically strong datasets of the ecological and habitat conditions, since it appears to provide the clearest evidence of changes due to the hydropower operation. Furthermore, investigation should be conducted to assess the extent of the recovery zone downstream of the dam. Biota are probably still developing within the Xayaburi impoundment, so further investigations into the typical biota within other impoundments within the Lower Mekong is recommended to provide reference conditions. And lastly it is recommended to develop a more rapid testing method using only Littoral Macroinvertebrates, to be used in between the biennial sampling and provide data at shorter intervals.

For Fisheries, three key indicators of fisheries resource status, 1. *the catch per fisher*, 2. *annual diversity in the catch of fishers* and 3. *CPUE of gillnets used by fishers* were assessed across the dataset of 2017 to 2021 at the following sites:

- Pha-O village upstream of Xayaburi reservoir
- Thadeua site 30 km upstream of the dam, now in the reservoir
- downstream of the dam at Pak Houng

- Thamuang, about 400 km downstream of the dam

Overall, data consistently show a sharp reduction of biodiversity, by 40 to 60%, in almost all sites (comparison of 2020 full data – not the partial 2021- with species diversity 2 to 3 years earlier). This does not mean that species have disappeared yet, but they are too rare to appear and be recorded in catches. This pattern was somewhat expected as a result of the HPP development and overall human pressures on the river, however the extent and speed of change seem extremely high.

The analysis of fishery data in Pha-O village upstream of Xayaburi reservoir shows that both fish diversity in catches and gillnet CPUE feature a sharp decline; however, the total average monthly catch per fisher does not decline, which might indicate an increasing fishing effort to compensate a declining resource.

- ➔ Recommendation that this is to be further explored in data (gear use analysis) before a field survey allows a conclusion to be reached on this point.

In the Xayaburi reservoir the average monthly catch per fisher has sharply declined although the gillnet CPUE is stable. This probably reflects a diversification among fishers: fishing harvests less valuable fish, so fishers shift towards alternative livelihoods instead of increasing their effort like in Pha-O. This hypothesis is based on the fact that the creation of a reservoir favors low value planktivorous lacustrine fish species in its initial years, by replacement of former high value riverine species.

- ➔ Recommend a detailed analysis of catch data by species in relation to species diet or trophic level, to allow reaching a conclusion on this point.

In Pak Houng downstream of the dam the monitoring is too recent to allow any conclusion. This site is likely to reflect a perturbed situation for a few years, with the seasonal accumulation of migratory species not finding their way up resulting in subsequent –but short-term and unsustainable- high monthly catches and CPUE.

In Thamuang, about 400 km downstream of the dam, data reflect an *increase* in both monthly average catch per fisher and gillnet CPUE. This unusual situation, if confirmed, remains to be explained. It might be increased water productivity (which would be surprising in a context of sediment and nutrient retention by upstream dams) or a shift in fishing gears or fishing practices and a subsequent increased fishing efficiency.

- ➔ Recommendation that this be addressed by a gear analysis in existing data;
- ➔ Recommendation that conclusion from this be confirmed by a survey on site and meetings with fishers.

Don Sahong HPP Site Report

The additional monitoring data received for the February to July 2021 period has been assessed and analyzed for each discipline. This led to updated findings and recommendations building on the first pilot site report for Don Sahong HPP as discussed at the June 2021 EGEM meeting.

For hydrology and sediments - an additional water level site was installed at the outlet of the Don Sahong Hydropower Project in August 2021, with some initial results reported. Monitoring at Pakse and Koh Key / Stung Treng-Up during the JEM pilot has provided the following insights:

- Water level at Pakse shows small scale daily fluctuations in July and August 2021, consistent with hydropower operations on tributaries in the catchment.
- The water level and flow results collected from Pakse and Koh Key / Stung Treng-Up demonstrate that there are no substantial impacts on flow rates or water level from the Don

Sahong Hydropower Project on the downstream river. This does not imply that there are no local impacts.

- No water level fluctuations were recorded at the new water level site downstream of Don Sahong, however results are only available for the 2021 flood season when flow in the river exceeded 10,000 m^3/s and the DSHPP would be expected to be operating continuously.
- SSC concentrations were relatively low at Stung Treng-UP throughout the year, with all concentrations <180 mg/L. The estimated SSC annual load of 20 Mt/yr is very low compared to historical estimates.
- The surveyed cross-sections of the main Mekong channel near Preah Rumkil (Dolphin Pools) near the Lao PDR border show no major changes between the survey dates, however the reported surveys were completed at a very coarse scale making the detection of changes difficult.

Recommendations arising from a review of the results include general items also applicable to monitoring in the upper LMB. Firstly, that the compass on the ADCP units needs to be calibrated prior to every monitoring run. Secondly, that a higher density of survey points should be collected when completing river cross-sections, and the use of ADCP transects should be encouraged along with additional training on the collection of ADCP discharge measurements and the collection and application of valid loop-tests to the measurements should be completed. Data reporting procedures for discharge and sediment measurements should be reviewed and streamlined e.g. electronic reporting. And finally, high priority should be given to capacity building in laboratory methods for the determination of grain-size distribution of bed material, bedload and SSC

For water quality, monthly sampling was conducted with the exception of May 2021 which was hindered by COVID-19 travel restrictions. Otherwise the water quality team have not indicated any access or sampling difficulties. Findings were as follows:

- The **presence of the Don Sahong dam and impoundment does not appear to be affecting most parameters of water qualit**y measured during the dry season months between October 2020 and June 2021. It should be noted that this is based on spot samples during the day, and do not capture changes that may fluctuate between day and night (such as DO).
- Statistical analysis between the sites showed some differences with Dissolved Oxygen tending to be slightly lower within the impoundment compared to upstream and downstream sites, and turbidity showing marked season differences.
- Unlike the Xayaburi pilot site, **the turbidity and TSS at Don Sahong do not show clear patterns of changes** with passage through the impoundment and below the dam perhaps indicating that the smaller Don Sahong HPP has less impact on sediment trapping.
- **Nutrient levels appear to be slightly increased in the impoundment**, but not passed on downstream below the dam
- There may be a **slight indication of higher phytoplankton levels in the impoundment** compared to downstream and a probable minor bloom of Cyanobacteria in February 2021, but at no time did the Chlorophyll-a and Cyanobacteria levels approach the WHO threshold levels of risk to health in recreational waters.
- **Impoundment profiles do not show thermal or chemical stratification**, although there may be evidence of declining DO with depth during the colder months of January 2021.

Recommendations resulting from the Don Sahong monitoring activities are largely the same as for Xayaburi. The relationship between TSS and turbidity measurements reported for Xayaburi is also found at Don Sahong. This may be developed into an on-site method using Turbidity to estimate TSS levels.

For EHM, the findings of monitoring around Don Sahong echoed the findings at Xayaburi HPP. Statistical analysis shows that the biota assemblages at the Don Sahong sites are significantly different from the Xayaburi sites, and that for Diatoms and Zooplankton, all of the EHM sites 7 to 10 have different species present, but that for Littoral and Benthic macroinvertebrates sites EHM9 and 10 have similar species present, but above the impoundment and in the impoundment, the species are different. The resulting recommendations from Xayaburi are also relevant to the Don Sahong monitoring. However, in the case of Don Sahong it will not be possible to follow the direct effects of the dam further downstream due to the complexity of the hydrological and hydraulic patterns in the channels below. However, the routine EH monitoring at Kbal Koh Village (CKM) in Cambodia will be instructive to map the recovery downstream.

For Fisheries FADM, the same three key indicators of fisheries resource status were assessed across the dataset of 2017 to 2021 at the following sites:

- Ban Hat station, upstream of Don Sahong Dam
- Muang Saen Nua, upstream of Don Sahong Dam
- Ban Hang Sadam
- Ban Hang Khone (new site)
- Ou Run (Cambodia)

Overall, **data of average monthly catch per fisher over the years provide contradictory patterns**, with a sharp catch decline in Northern Cambodia over the years but a progression in the nearby downstream Lao site, and a significant increase in catches upstream of the dam. These increasing catches recorded in Laos are contradicted by interviews of fishers detailed as in report "Recent fish migrations in Khone Falls (Lao PDR) according to local ecological knowledge" prepared within this JEM Pilot. Like in species diversity, the **heterogeneity of monthly catch per fisher and of CPUE results in sites *downstream of Don Sahong* sites also raises questions** about the homogeneity of implementation of the FADM sampling protocols.

- ➔ Recommendation for a meeting of respective national FADM teams and a joint review of respective implementation and data recording modalities.
- ➔ Once this step is secured, recommendation that data be revisited, with adjustments if needed, before drawing overall conclusions about long term trends and dam impacts in Don Sahong dam site.

The analysis of species in catches around Don Sahong dam site showed a significantly lower biodiversity in sites upstream of Khone Falls compared to downstream sites, which reflects the role of the falls as an ecological barrier. Unlike in Xayaburi, **no clear trend in biodiversity can be identified** over the years. However again questions must be raised about taxonomic recording in Lao and Cambodian FADM data on review of the very high number of species recorded in downstream sites in Laos compared the nearby site of Ou Run in Cambodia despite being located only 8km away with no obstacle in-between.

- ➔ Recommendation that the two hypotheses posed by this report (difference in experience of the fishers, and difference of precision in fish naming) are further explored to enable reliable comparison of biodiversity data between countries.
- ➔ Recommendation to regularly repeat training of fishers involved in the FADM protocol, in particular those fishers newly involved in the JEM sites, to ensure consistent gathering across the years.

Both Cambodia and Laos tested the adjusted methodology proposed for standardized gillnet sampling. Cambodia produced an accompanying report while Laos provided the raw data. **R**esults from systematic testing and field observations lead to the recommendation to **keep the long nets (112m long) and group panels by mesh size into 3 different nets**.

➔ Thus, the recommendation is that the **original random distribution of mesh sizes should be abandoned** and replaced with the creation of 3 sets of nets with panels of 10x2.5 m each:

- Gillnet ID1: 20-50-40-30-60 mm to be set near banks and the vegetation to target small fish in their habitat;
- Gillnet ID2: 70-90-100-80-110 mm to be set in suitable locations decided by fishers;
- Gillnet ID3: 120-150-140-130 mm to be set in the middle of the river to target large fish

Total: 14 panels x 10 m x 2.5m = 350m^2 per gill net set

For FLDM, a large difference in biodiversity results (24 species identified in Hang Sadam and 68-91 species in Preah Romkel) was observed between the site monitored by Cambodia and the site monitored by Laos. Given that they are located less than 2 km apart, downstream of the dam, and in similar ecological environments this result must be considered with caution. It likely illustrates how larvae data and results are sensitive to taxonomic identification expertise (1 year in Laos, almost two decades in Cambodia).

➔ The recommendation for future is that additional training be conducted to share expertise between the two teams and ensure homogeneity of approach, so that results can be compared basinwide.

➔ Recommendation to repeat training of fishers involved in the FLDM monitoring, since their reliability and accuracy is essential to the accuracy of data gathered.

Cross-analysis of JEM Pilots monitoring results

Due to COVID restrictions and the resultant delays in monitoring, JEM data are insufficient as a basis for inter-disciplinary analysis. Some integration of results (discharge, sediment, water quality) has been completed, however the long-term aim of the MRC is to allow a higher level of data analysis and interpretation. Therefore a broader assessment of data availability was conducted to identify such opportunities to integrate data from different disciplines, that are collected at different sites, and at different frequencies.

Clustering of monitoring stations in different disciplines that can be matched for interdisciplinary analyses was conducted based on geographical proximity in the Mekong mainstream. This identified clusters that combine hydrological, water quality, biomonitoring and fisheries sites and data. Particular attention was paid to clusters upstream and downstream of Xayaburi and Don Sahong dam sites. The result is an overview of the availability of data by discipline, site, and year and identification of areas where there is sufficient overlap that such interdisciplinary analysis is possible in future.

A blueprint and some examples are provided for how the sites from different disciplines can be matched to allow integration, and what parameters could be derived from the data sets for cross analysis. This includes description of what database queries should be used to extract datasets for this purpose, as well as identification of useful parameters and associated time steps. What is and is not possible for cross-analysis of JEM monitoring results is also identified and noted for future, once longer datasets are available for meaningful comparison. Finally, the hydropower developers of Xayaburi and Don Sahong have provided some flow and sediment data, and water quality results from their routine monitoring, which have been summarized to compare with the JEM results.

Correlation analyses can only be done variable by variable, which leads to reviewing variables key to cross-analyses and queries possible between these variables. The specific objective considered here is an analysis of related meaningful variables from several disciplines over a long period of time and a large area throughout the basin.

Basin-wide analysis

This analysis put the JEM pilot monitoring results in the context of the longer-term routine monitoring results in the vicinity of each pilot site. The basin wide water quality, hydrology and SSC results are then combined to provide an example of how results from different disciplines can be integrated to provide a more complete understanding of riverine processes. This has drawn upon long-term monitoring results from the WQMN and the DSM because there are too few results from the JEM sites to allow integration at a large spatial or temporal scale. These results highlight that changes to flow, sediment input and other factors are controlling water quality. For EHM, it is not possible to correlate the data directly because the EHM data is only one annual or biennial assessment compared to the monthly water quality and hourly or daily water level changes. However a description is provided of some expected relationships to look for.

In the context of the basin, the initial assessment of monitored impacts from the dam operation found that:

- The hydrology of the LMB has been affected by alterations to flow entering from China, as well as low rainfall within the LMB in 2020. Compared to the PMFM, flood season water levels were very low compared to average conditions and dry season flows were generally very high. During limited periods, dry season flows at Vientiane were below the 1:20 ARI (zone 4) in 2020.
- Hydropower operations at Xayaburi causes substantial water level fluctuations downstream, which are greatly reduced, but still present at Chiang Khan. Fluctuations include dry season shaping of flows to target peak power demands, and the release of large flow volumes during large storm events and the release of water from tributary impoundments;
- The sediment load at Chiang Khan has decreased from ~15 – 36 Mt/yr to <5 Mt/yr since 2018. This is likely attributable to a decrease in sediment input from tributaries due to the commissioning of HPPs in the Nam Ou, Nam Khan and other upstream tributaries, and the trapping of sediment within the Xayaburi impoundment;
- There is only a small increase in sediment load between Chiang Khan and Nong Khai, suggesting that the availability of sediment for transport between the sites is limited;
- There continues to be a large increase in flow and SSC loads between Nong Khai and Pakse, although SSC concentrations are relatively uniform throughout the LMB;
- SSC loads at Kratie have decreased substantially compared to historic results. The estimated SSC loads at Kratie for 2019 and 2020 are 31 Mt/yr and 34 Mt/yr, which is lower than the ~100 Mt/yr recorded by DSM monitoring in the early 2010s (Koehnken, 2015) or earlier estimates of up to 160 Mt/yr at Pakse (Walling, 2005). Perhaps ~30 Mt of the decrease could be attributable to reductions in the upper LMB (China, tributary dams, Xayaburi), with the remaining reduction attributable to trapping in tributary dams downstream of Nong Khai. Decreases of this magnitude are likely to have substantial geomorphic impacts on the floodplain and delta, and affect water quality through changes in nutrient transport and light penetration into the river.
- Comparisons of the water quality indices for Protection of Aquatic Life and for protection of Human Health show that many of the sites on the Mekong mainstream above and below the Xayaburi and Don Sahong JEM sites have good quality with some occasional occurrences of meeting some thresholds.
- Comparisons of the Ecological Health indices in many of the sites on the Mekong mainstream show good EH condition, but the JEM sites within each impoundment and downstream of the dams show moderate EH condition.

Recommendations for revision to the JEM guidelines

The June 2021 EGEM meeting importantly noted that the JEM Pilots are not an end in itself and that protocols and findings will be propagated into the future plans and upcoming programmes of the MRC. The recommendations and lessons learnt inform revision of the MRC guidelines of the Joint Environment Monitoring Programme of Mekong Mainstream Hydropower Project to ensure a common, standardised and scientifically robust programme for jointly monitoring key environmental indicators for impact assessment of Mekong mainstream hydropower projects on hydrology and hydraulics, sediment and geomorphology, water quality, aquatic ecology, and fisheries. This revision will be finalised in March 2022.

The findings and recommendations of the JEM Programme will then feed into the design and establishment of the Core River Monitoring Network (CRMN). It is anticipated that the JEM Programme will be fully incorporated within the Core River Monitoring Network in December 2022.

The **recommendations for the future, and revisions to the JEM Programme are as follows,** per discipline:

Hydrology and sediments

- Discharge and SSC monitoring are recommended to continue at the new JEM sites of Ban Xanghai, Ban Pakhoung and Stung Treng-Up.
- The MRC should work with the MCs and hydropower operators to develop an effective and rapid communication system to disseminate information about potential water releases or other operations at HPPs.
- The MRC should work with the MCs and hydropower operators to provide a reporting mechanism for the operation of low-level gates at HPPs that will affect sediment transport in the river.
- Consideration should be given to transitioning from D96-depth integrated sampling for SSC to in situ based laser techniques. The lack of availability of the D96 equipment prevents wide-spread use of this technology.
- Ongoing capacity building is recommended in Field measurement of discharge using ADCP technology and Laboratory analyses associated with bed material and SSC grain-size distribution are recommended.
- Additional geomorphic investigations should be implemented, particularly for transboundary cross-sections.

Water quality

- Water quality measurements around these dams should be continued to include at least the full year of monthly results, especially during the wet season. It is noted that the water levels and flows in this wet season have been low so may not be typical of wet seasons with greater rainfall.
- Because the monthly samples are spot samples, it is recommended that continuous monitoring equipment be established at both sites as close to the dam as it is possible to get a representative sample of the water, in order to test the daily variation in different parameters.
- The relationship between Turbidity and Total Suspended Solids should be investigated to establish an equivalence curve suitable for Mekong waters.
- The proportions of dissolved and sediment-bound nutrients in the Total Nitrogen and Total Phosphorus should also be investigated to understand how much nutrients are being trapped with sediments in the impoundments.

- The results of water quality monitoring taken by the hydropower companies should be compared with the JEM results and both should be related to operation details provided by the companies.

Ecological health

- The monitoring of Ecological Health around the JEM pilot sites showed some clear indications of degradation of the aquatic biota within the impoundments and downstream of the dams, and also showing signs of recovery with distance downstream of the dams.
- The EHM method has shown that it is sensitive to the changes likely to occur in the localised habitats around hydropower.
- The correlation with results from water quality monitoring, flows and water levels and sediment transport are likely to be important in order to interpret the impacts.
- It is recommended that a quicker method of assessing the aquatic health, based upon the presence of Littoral Macroinvertebrates be developed to be used more frequently and in additional locations, in order to complement the annual or biennial monitoring campaigns.
- With a more rapid and easily deployable EH method, it is recommended that additional sites downstream of dams be assessed in order to increase our understanding of the length of the recovery zone downstream.
- It will be important in the long-term to build up a series of reference sites within reservoirs of both mainstream and tributaries, so that quality changes in the reservoirs can be compared.

Fisheries

- Undertake a gear use analysis (gears involved, mesh sizes and sizes, intensity of use) in Pha-O, Thadeua and Thamuang sites in Xayaburi to better identify the reasons for changes in average monthly catch per fisher;
- Complement the above analysis with interviews of local fishers to ensure consistency of conclusions from both approaches;
- Undertake a species analysis in reservoirs – in particular Xayaburi impoundment – to assess the extent of change in species composition and fish community dynamics;
- Cross analyze current results with socioeconomic data (e.g. from dam operators as part of resettlement and compensation programs) and fish price data to determine whether the involvement of fisher is reduced for fish availability or commercial reasons and if livelihood diversification can explain or compensate a reduced involvement in fisheries;
- Undertake a review of species diversity and their trends in the tributaries monitored by the FADM programme, in order to compare these results with those of areas under mainstream dam influence, and identify remaining sources of fish biodiversity in key tributaries for replenishment (case of mitigation activities);
- Consider a study of local fish taxonomy in both Southern Lao and Northern Cambodia, in order to identify whether the different diversity levels identified on each side of the border result or not from a difference in local fish naming.
- If that is the case, amend data by standardizing taxonomic categories in all countries.
- Similarly, standardize fishing gear names throughout the basin in the FADM database.
- Review and compare the implementation of the FADM protocol in Southern Lao and in Northern Cambodia, in order to identify possible discrepancies explaining contradictions about CPUE and average catch per fisher in close sites on each site of the border.
- As soon as possible, start the systematic implementation of the revised gillnet protocol, i.e. 3 sets of nets with 10x2.5 m panels.

1 INTRODUCTION AND SCOPE OF THE REPORT

In May 2019, the Mekong River Commission finalised its documents for Joint Environment Monitoring (JEM) Programme for Mekong Mainstream Hydropower Projects, which is aimed at providing information about the availability and condition of the water resources and their linkages with environmental conditions in the basin and how these are changing under present and future hydropower developments. This information is intended to provide a common basis for constructive discussions by communities and Member Countries on the implications of hydropower development.

The Environmental Management Division of the MRC with the support of Germany has been developing two pilot projects to trial and refine the JEM approach and monitoring and reporting protocols based upon a 2-year implementation around the Xayaburi hydropower project (HPP) and the Don Sahong HPP. In November 2019, the International Center for Environmental Management (ICEM Asia) was commissioned by GIZ and the Mekong River Commission to support the implementation of the 2-year Environmental Monitoring Pilots project for the Joint Environmental Monitoring (JEM) Programme.

This is the second progress report on the monitoring that has been carried out at the two pilots. It is noted that many aspects of the pilot projects – procurement of equipment, training of the monitoring teams and the actual field work by the teams – has been delayed significantly by the restrictions due to the COVID-19 pandemic. These reports had been scheduled as half-yearly pilot sites/stations progress reports submitted at six monthly intervals during the first year, with reports for each pilot site/station i.e. in September 2020 and March 2021. The September 2020 reports were postponed to March 2021 and the results discussed at the annual MRC's EGEM meeting in June 2021.

This second report in September 2021 combines the two pilot site reports into one together with a basin-wide analysis, which puts the results into the context of conditions of the Lower Mekong River Basin as a whole. The report thus falls into the following main chapters:

Chapter 2 – Project progress reporting, including procurement and equipment, sampling missions undertaken, and any adjustments and evolutions in the sampling procedures, and the development of the database

Chapter 3 – Report on the monitoring results around Xayaburi HPP organised by the five disciplines – Hydrology, Sediment, Water Quality, Ecological Health and Fisheries, and covering a description of the sampling stations, the results and analysis and the lessons learned for each discipline.

Chapter 4 – Report on the monitoring results around Don Sahong HPP organised by the five disciplines – Hydrology and Sediment, Water Quality, Ecological Health and Fisheries, and covering a description of the sampling stations, the results and analysis and the lessons learned for each discipline.

Chapter 5 and 6 – Annual combined basin-wide analysis, bringing together the JEM results with the MRC's routine monitoring results for other sampling stations within the Mekong mainstream. It was also intended to include a comparison with the monitoring information from the hydropower projects, but this is currently not available. In this basin-wide analysis some trial comparisons between the results of the different disciplines at related sampling locations will be examined for correlations, for future analytical reports on the condition of the river.

Chapter 7 – uses the limited initial data to provide some indications of possible impacts of dam operation after this relatively short period of monitoring. Where possible, preliminary recommendations for mitigation and adaptive management are suggested.

Chapter 8 – covers communication and governance issues for the continuation of the JEM monitoring and its incorporation into the Core basin-wide monitoring programme.

2 PROGRESS REPORTING - ACTIVITIES UNDERTAKEN DURING 2020/2021 AT PILOT SITES AND SAMPLING STATIONS

2.1 Status of equipment procurement

Equipment for the project procured across the past six months has all been for Lao PDR to support the fish tag pilot activities for Khone Falls and training activities hosted by the MRC Secretariat in Vientiane. A new batch of equipment across all three countries was also identified during this time.

2.1.1 Adjustments

The equipment needs of the JEM have further evolved in the past six months. A review of monitoring equipment and supplies conducted by the line agency teams in Cambodia, Lao PDR and Thailand identified a new batch of required equipment both to support JEM trainings, pilots and to improve their required monitoring activities. Whilst many of these items are still under a competitive quotation process as of September 2021, some have already been delivered.

A list of the 25 additional procurement packages for this equipment is provided in *Table 2-1*.

Table 2-1. Equipment delivered and installed during March to September 2021.

No.	Equipment		Status
1	Cambodia	Laptops (2) & Printer for Cambodia	Preparing evaluation report
2		DSLR camera for Cambodia	Preparing evaluation report
3		Boat Engine for Cambodia	Getting quotes
4		Lab Equipment for Cambodia (2x set of sieves, 2x soil hydrometer, water distiller, flame photometer)	Getting quotes
5		Water quality monitoring textbook	Getting quotes
6		Monitoring Meters to Cambodia (multi-parameter water quality monitoring portable meter kit, water depth measuring kit, 2x flow meter, turbidity meter kit, distilled water)	Getting quotes
7	Lao PDR	HYCOS/WQ Monitoring HydroSystem (OTT) for Don Sahong station	Delivered, installed in July 2021
8		Buffer solutions	Delivered
9		Gillnets (gillnet ID1 42m long, gillnet ID2 70m, and gillnet ID3 112m long)	Delivered
10		BestScope Microscopy, C Mount camera	Delivered
11		Lap equipment and supplies package for Chlorophyll training	Delivered
12		High-density polyethylene (HDPE) bottles for Chlorophyll training	Delivered
13		Field Laptops (4) for Lao PDR	Getting quotes
14		Camera (with GPS) and handheld GPS for Lao PDR	Getting quotes
15		Lab Equipment for Lao PDR (microscope with camera, 2x drying chambers, 3x electric scale, 20x featherweight entomology forceps, 3x digital caliper set, zooplankton counting chamber)	Getting quotes

No.	Equipment		Status
16		Water quality monitoring solutions for Lao PDR (quick calibration solution, electrolyte fill solution for DO, spare DO screw cap membranes)	Preparing evaluation report
17		High Density Polyethylene Bottles (x12) to Lao PDR	Preparing evaluation report
18		Monitoring Equipment for Lao PDR (vertical water sampler, sediment sampler and flow meter (3))	Preparing evaluation report
19		Water quality monitoring textbook (x2)	Preparing evaluation report
20		Sweep net for Lao PDR	Getting quotes
21		Bongo nets for Lao PDR (x3)	Local purchase
22		Boat propeller systems (x2) for Lao PDR	Awaiting tech specs
23		Spare winch rope (for Lao PDR)	Getting quotes
24		Glass petri dish sets (x3) for Lao PDR	Local purchase
25	Thailand	Winch Systems (2) for Thailand	Ordered
26		Multiparameter water quality monitor (OTT) for Thailand	Getting quotes
27		Water quality monitoring textbook	Getting quotes
28	Vietnam	Water quality monitoring textbook	Getting quotes

Unfortunately, it has become evident that one planned item will not be delivered within the project timeframe – the D-96 sediment sampler for Xayaburi pilot in Thailand originally ordered on 4 March 2020. Significant delays and communication difficulties occurred with the manufacturer (Ricklys) and the company was subsequently sold to Performance Results Plus Inc in mid-2021. This new owner required that any orders submitted to Ricklys would now need to be re-ordered, with no guarantee of delivery within 2021. It is suggested that the MRCS considers this equipment procurement under the Core River Monitoring Network activity.

2.1.2 Achievements

A substantial batch of fish tagging equipment and supporting accessories was procured by the project and delivered to Lao PDR between March and September 2021. The fish tagging equipment comprised thirteen different packages as listed in

Table 2-2.

Table 2-2. Fish tagging equipment ordered and delivered during the past six months (March to September 2021).

No.	Equipment packages	Status
1	PIT tag equipment package	Delivered to Lao PDR
2	Acoustic tag equipment package	Delivered to Lao PDR
3	Flotation buoys	Delivered to Lao PDR
4	Veterinary surgery equipment package	Delivered to Lao PDR
5	Spaghetti tag equipment package	Ordered for Lao PDR
6	Box closure (accessory for PIT tag equipment)	Delivered to Lao PDR
7	Solar array (accessory for PIT tag equipment)	Delivered to Lao PDR

No.	Equipment packages	Status
8	Tadiran Lithium batteries for Lao PDR	Delivered at Vientiane but not yet handed over.

All items have now been delivered to Vientiane with the exception of the spaghetti tag equipment which is currently being manufactured and is expected for delivery in October. The Tadiran Lithium batteries have been delivered but cannot yet be handed over by the supplier due to the current lockdown in Lao PDR since mid-September 2021.

For fisheries, new sets of gillnets meeting the requirements of the adapted protocols (i.e. gillnet ID1 42m long, gillnet ID2 70m, and gillnet ID3 112m long) were made upon order and delivered to the teams for study implementation. A new microscope camera was also delivered to support lab analysis of larvae.

For water quality, new Chlorophyll-a training supplies were delivered in time for training in September 2021.

A HYCOS/WQ monitoring HydroSystem supplied by OTT was delivered and installed at the Don Sahong station in July 2021 to expand the existing network. New buffer solutions were also delivered to support the calibration process. This was in addition to the new HYCOS site installed under the JEM project at Koh Key, which came online in February 2021. It should also be noted that the Pakse water level site was repaired within the past six months and re-joined the HYCOS network in June 2021.

2.1.3 Lessons

Given the complexities of procuring the specialist equipment needed for the JEM, the original timeline for procurement (across a period of four months only) was unrealistic. In addition to reasons noted in the first pilot site report, the following factors have been found to lengthen the process:

i) Project delays in other areas can subsequently delay the procurement process, since technical specification and quantities for equipment may not be finalised until after design of monitoring methodology and defining the pilot site;

ii) Initially, vague technical specifications by the requesting team means that suppliers raise many clarifications during the competitive request for quotation, which extends the length of time to collect quotes and can reduce their overall quality;

iii) Whilst vague technical specifications leave too much room for error, specifying a brand/model of equipment means it can be difficult to find suppliers who stock exactly that model. This lengthens the time required to obtain quotes, particularly if not all potential suppliers are interested to ship internationally. Instead, indicating a minimum required technical specification to be achieved by the supplier's offering allows for a bit more flexibility and also, potentially the offer of better alternatives.

iv) Requesting a small quantity of a given item means that suppliers are less motivated to participate in a competitive process and go to the effort of tax-exempt import. Again, this lengthens the time to collect the required quotes.

v) Transport restrictions and international disruptions may unexpectedly lengthen the process. The acoustic fish tags require lithium batteries and no air carriers will transport these to Lao PDR since they are "Dangerous Goods" (UN3091 contained in equipment, Class 9 packing inst. 970, fully regulated). Additional quotations were then sought for land-based transport from suppliers in the region.

As noted in the first pilot site report, projects should allow for significant buffer in scheduling for the intended use of procured equipment. If a faster procurement process is important then it is valuable to partner with specific specialist monitoring suppliers (as ICEM has done with OTT) who can take a more comprehensive role in helping to define the required technical specifications and sourcing equipment. Preferably this would be a local partner who can provide support to installation and training for the delivered items, too.

2.2 Training undertaken in the past six months

2.2.1 Hydrology and Sediment

The following training were completed since February 2021:

- Laboratory based training in the determination of SSC and the grain-size distribution of bed materials was completed in March 2021 in Vientiane, Lao PDR. Numerous DMH representatives received training in the weighing and sieving of SSC and bed material samples.
- Field and classroom-based peer coaching was completed in Pakse in March 2021. This involved the Lao PDR DSM team from Luang Prabang travelling to Pakse to provide hands-on training in the collection of depth integrated suspended sediment samples, discharge using ADCP, and bed material sampling using the pipe-dredge.

A regional half-day workshop was held in April 2021 at which each country provided an overview of the sampling completed to date, along with a description of challenges being faced to complete the monitoring.

Training materials were also prepared during this period on methodologies for analyzing monitoring data for hydrology and sediments, in preparation for the regional data sharing/data analysis workshops to be held in late September 2021.

2.2.2 Water quality

For water quality, one training event was conducted on theory of monitoring Chlorophyll-a, which is a newly introduced indicator under the JEM that requires both in-situ and laboratory analysis of field samples. So far during the JEM the monitoring of this indicator has relied on the Algae Torch for an in-situ measurement. This training was conducted to build capacity for the laboratory analytical monitoring method according to the methods recommended by the Standard Methods for Water and Wastewater Examination (SM 10200H) – 23rd Edition. A classroom-based regional training was conducted via videoconference on 15 September 2021. Participants from Lao PDR attended physically and participants from Cambodia, Thailand and Viet Nam attended remotely.

Training materials were also prepared during this period on methodologies for analyzing monitoring data for water quality and ecological health, in preparation for the regional data sharing/data analysis workshops to be held in late September 2021.

2.2.3 Fisheries

The following trainings were completed since February 2021 for the fisheries discipline:

- Refreshment training on fish larvae monitoring and identification in July 2021; and
- PIT tag training in September 2021.

For the fisheries monitoring discipline, a refreshment training was provided on fish larvae monitoring and identification from 19-23 July 2021 at the Ban Na Hatchery Centre, Khong District, Champsak Province, Lao PDR. The trainees refreshed on topics including the development stages of larvae, application of monitoring tools, key points for reporting and various laboratory and taxonomic techniques, for successful identification of Mekong fish larvae. This refresher built on the initial laboratory training that was provided to Cambodia and Lao teams the previous year at the Inland Fisheries Research and Development Institute, Phnom Penh, Cambodia.

The PIT tag training provided by the Charles Sturt University, through the Australian Water Partnership with the MRC was conducted in Vientiane, Lao PDR from the 6-9 September 2021 for Lao participants, who attended physically. This training oriented on the features of a PIT tag system, its field operation and practical instructions for database management of the resulting monitoring data.

Training materials on methodologies for analyzing fisheries data were also prepared during this period, in preparation for the regional data sharing/data analysis workshops to be held in late September 2021.

2.3 Sampling stations and Monitoring missions undertaken

2.3.1 Hydrology and Sediment

The following sampling missions in the *Table 2-3* were completed at each of the indicated JEM stations since February 2021.

Table 2-3. Summary of JEM monitoring results collected since February 2021

Site	Date	Parameters Monitored*	Results Reported*
Ban Xang Hai	8/02/2021	Q, SSC, BGSA	Q, SSC, BGSA
	9/3/2021	Q, SSC, BGSA	Q, SSC, BGSA
	18/05/2021	Q, SSC, BGSA	Q, SSC, BGSA
	24/05/2021	Q, SSC, BGSA	Q, SSC, BGSA
Ban Pakhoung	7/02/2021	Q, SSC, BGSA	Q, SSC, BGSA
	10/03/2021	Q, SSC, BGSA	Q, SSC, BGSA
	27/05/2021	Q, SSC, BGSA	Q, SSC, BGSA
Chiang Khan	17/03/2021	Q, SSC, BGSA	Q
	7/04/2021	Q, SSC, BGSA	Q
	5/05/2021	Q, SSC, BGSA	Q
	2/06/2021	Q, SSC, BGSA	Q
	9/06/2021	Q, SSC, BGSA	Q
	16/06/2021	Q, SSC, BGSA	Q
	23/06/2021	Q, SSC, BGSA	Q
Pakse	17/03/2021	Q, SSC, BGSA	Q
	20/04/2021	Q, SSC, BGSA	Q
	25/05/2021	Q, SSC, BGSA	Q, BGSA
Stung Treng - UP	26/05/2021	Q, SSC, BGSA, SSC GSA	Q, SSC, BGSA, SSC GSA
	31/05/2021	Q, SSC, BGSA, SSC GSA	Q, SSC, BGSA, SSC GSA
	6/06/2021	Q, SSC, BGSA, SSC GSA	Q, SSC, BGSA, SSC GSA

Note: *Parameters include: Discharge (Q), Depth integrated suspended sediment (SSC), Bed Material Grain Size Analysis (BGSA), SSC Grain Size Distribution (SSC-GSA)

In addition, manual water level results for the gauges at Ban Xang Hai, Ban Pakhoung, and Chiang Khan were also received.

2.3.2 Water quality

2.3.2.1 Xayaburi monitoring stations and parameters

Five monitoring stations for the monthly water quality sampling had been selected for the Xayaburi pilot site, one above Luang Prabang at the head of the impoundment, one in the impoundment itself above the Tha Deua bridge, and three downstream of the dam at 1.5 km, 5 km and 10 km downstream. These are indicated in ***Table 2-4*** and shown in ***Figure 2-1*** and in greater detail for the downstream sites in ***Figure 2-2***.

There have been no changes in the locations of the sampling stations and the water quality team have not indicated any access or sampling difficulties at these stations.

Table 2-4: Water Quality sampling stations for Xayaburi JEM Pilot.

Code	Station	River	Latitude	Longitude
WQ1	Upstream of Xayaburi around 110-km upstream of the dam.	Mekong	~20°00'07.2"N	102°14'06.7"E
WQ2	Within the Xayaburi Impoundment (at Ban Talan, 1-km above the dam wall)	Mekong	19°15'16.1"N	101°48'45.5"E
WQ3	Around 1.5-km downstream of the dam	Mekong	19°13'49.5"N	101°49'17.1"E
WQ4	Around 4-5 km downstream of the dam	Mekong	19°12'58.3"N	101°49'25.5"E
WQ5	Downstream at Pakhoung Village, around 10-km downstream of the dam	Mekong	19°09'28.0"N	101°48'50.6"E

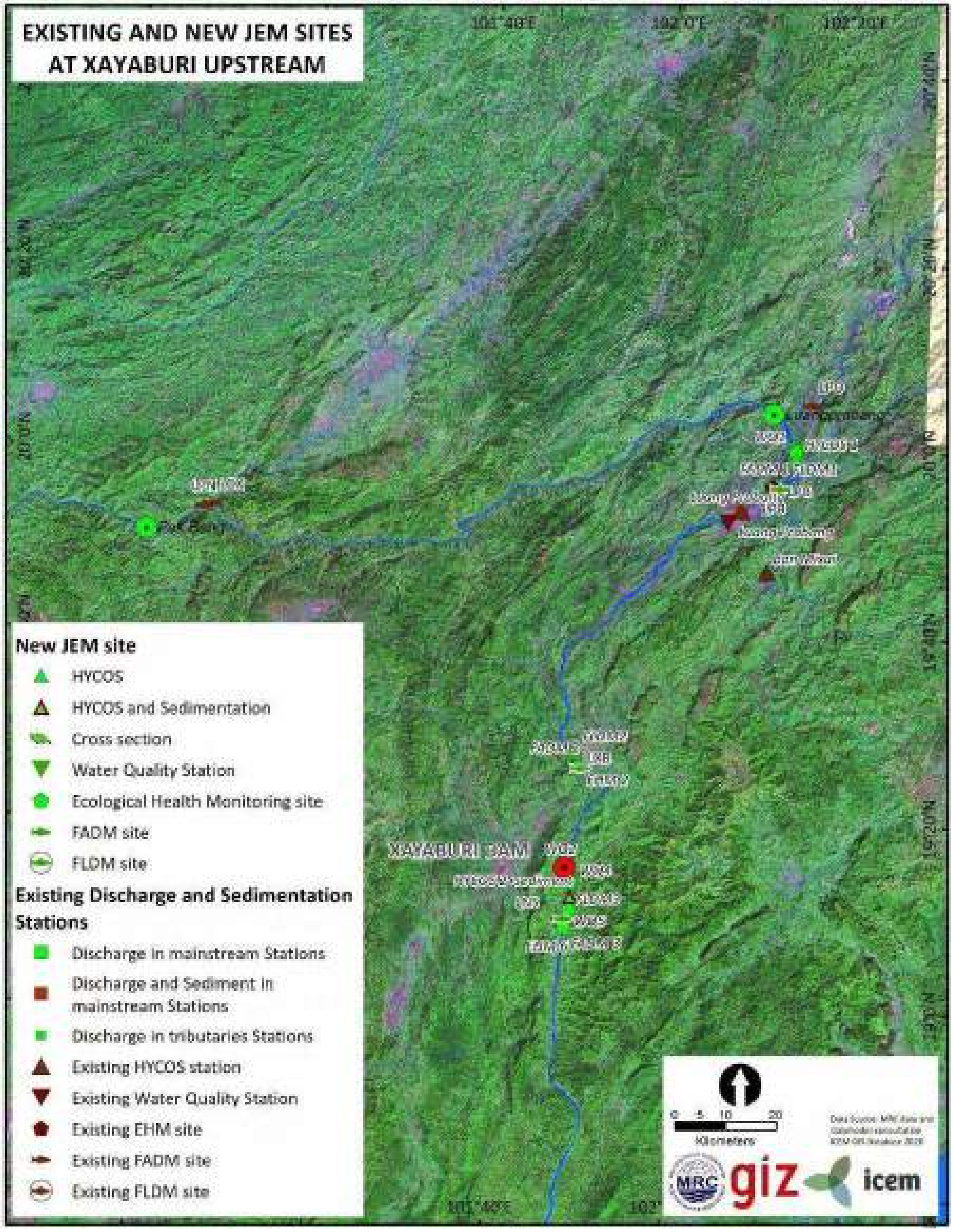


Figure 2-1: Locations of the sampling stations around Xayaburi HPP, including upstream stations

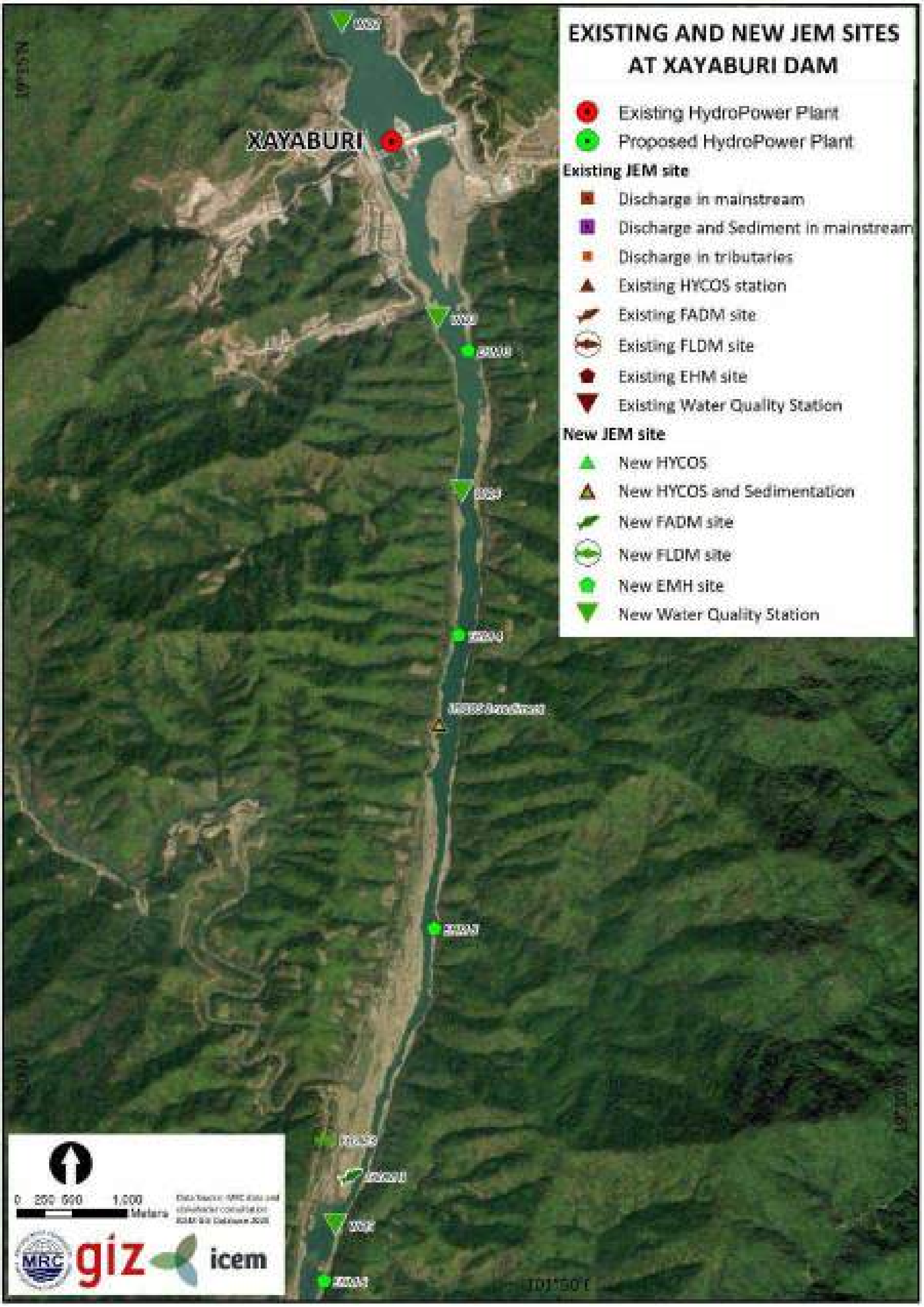


Figure 2-2: Water Quality Sampling stations downstream of the Xayaburi dam

2.3.2.2 Xayaburi Water Quality parameters

The sampling stations are scheduled to be visited by the Laos water quality team on a monthly basis and carry out measurements using both water quality probes and taking samples for analysis in the laboratory at each site. The parameters measured are identical to the parameters used in the MRC's Water Quality Monitoring Network (WQMN), except for the new JEM measurements of turbidity, Chlorophyll-a and Cyanobacteria which are carried out using the Algae Torch, procured by the pilot project. ***Table 2-5*** shows the parameters measured at each site, some with the full complement of parameters measured and others with a more restricted set. In addition, at the impoundment site, a depth profile using the water quality probe and Algae Torch lowered at 1 m intervals to 20 m and 10 m respectively. There have been no changes to these parameters and analyses and no constraints identified by the Lao water quality monitoring team.

Table 2-5: Water quality monitoring parameters measured at each of the Xayaburi monitoring stations

Parameter	Frequency	Probe	Lab	H011200	WQ1	WQ2	WQ2	WQ3	WQ4	WQ5	H011901
Sampling Type				WQMN	JEM Full	JEM IMP	IMP Prof	JEM short	JEM Full	JEM Short	MWQMN
				Luang Prabang	Upstream of XBR around 110-km upstream of the dam.	Within the XBR Impoundment (at Ban Talan,1-km above the dam wall)		Around 1.5km downstream of the dam)	Around 4-5 km downstream of the dam	Downstream at Pakhoung Village, around 10km downstream of the dam	Vientiane
				Mekong	Mekong	Mekong	Depth profile	Mekong	Mekong	Mekong	Mekong
				19.9	~20°00'07.2" N	19°15'16.1" N		19°13'49.5" N	19°12'58.3" N	19°09'28.0" N	17.9281
				102	102°14'06.7" E	101°48'45.5" E		101°49'17.1" E	101°49'25.5" E	101°48'50.6" E	102.62
Temperature	Monthly	x		x	x	x	x	x	x	x	x
pH	Monthly	x		x	x	x	x	x	x	x	x
Conductivity (Salinity)	Monthly	x		x	x	x	x	x	x	x	x
Dissolved Oxygen (DO)	Monthly	x		x	x	x	x	x	x	x	x
Alkalinity/ Acidity	Monthly		x	x	x				x		x
Total phosphorous (TP)	Monthly		x	x	x	x		x	x	x	x
Total Nitrogen (TN)	Monthly		x	x	x				x		x
Ammonium (NH_{4+}-N)	Monthly		x	x	x				x		x
Nitrite +Nitrate (NO_2+$_3$-N)	Monthly		x	x	x	x		x	x	x	x
Fecal Coliforms	Monthly		x	x	x				x		x
Total Suspended Solids (TSS)	Monthly		x	x	x				x		x
Chemical Oxygen Demand (COD)	Monthly		x	x	x				x		x
Calcium (Ca)	Monthly for 7 months		x	x	x				x		x
Magnesium (Mg)	Monthly for 7 months		x	x	x				x		x
Sodium (Na)	Monthly for 7 months		x	x	x				x		x
Potassium (K)	Monthly for 7 months		x	x	x				x		x
Sulphate (SO42-)	Monthly for 7 months		x	x	x				x		x
Chloride (Cl^-)	Monthly for 7 months		x	x	x				x		x
Turbidity	Monthly	x			x	x	x	x	x	x	
Chlorophyll *a*	Monthly	x	x		x	x	x	x	x	x	
Cyanobacteria	Monthly	x			x	x	x	x	x	x	

Note: Blue = routine WQ monitoring, Green = measurement in the laboratory, Yellow = measurement in the field by probe.

2.3.2.3 Xayaburi Monitoring missions

The Laos Water quality monitoring team provided by NRESRI, MoNRE (Mr. Sounthaly Mountha; Ms. Soulisay Xayachak; Mr. Sengtong Bounsavath); and DoNRE of Luang Prabang (Mr. Vueyang Yangxengyang) have visited the Xayaburi sampling stations on the following occasions as listed in ***Table 2-6.***

Table 2-6: Dates of sampling visits to Xayaburi pilot sampling stations

Sampling stations	2020			2021					
Month	**10**	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**
WQ1	1.11	15.11	11.12	13.01	15.2	13.3	6.4	N/A	21.6
WQ2	2.11	16.11	11.12	13.01	14.2	14.3	7.4	N/A	22.6
WQ3	2.11	16.11	11.12	13.01	14.2	14.3	7.4	N/A	22.6
WQ4	2.11	16.11	11.12	13.01	14.2	14.3	7.4	N/A	22.6
WQ5	2.11	16.11	11.12	13.01	14.2	14.3	7.4	N/A	22.6

During May 2021, sampling visits were not possible due to COVID-19 travel restrictions. Sampling has been continued in July, August and September 2021, but the results have not yet been analysed due to reporting timeframes and project constraints.

2.3.2.4 Don Sahong monitoring stations

Four monitoring stations for the monthly water quality sampling had been selected for the Don Sahong pilot site, one above Khone Falls at the head of the impoundment, one in the impoundment itself about 600 m from the dam wall, and two downstream of the dam at 250 m and 1 km downstream. These are indicated in ***Table 2-7*** and shown in ***Figure 2-3.***

There have been no changes in the locations of the sampling stations and the water quality team have not indicated any access or sampling difficulties at these stations.

Table 2-7: Water Quality sampling stations for Don Sahong JEM Pilot.

Code	Station	River	Latitude	Longitude
WQ6	Upstream of Don Sahong Dam, at the impoundment inlet point	Mekong	13°58'41.8"N	105°57'16.2"E
WQ7	Within the impoundment (around 1.2-km upstream of the dam wall)	Mekong	13°56'38.8"N	105°57'42.5"E
WQ8	Downstream of Don Sahong (around 250-m downstream of the dam)	Mekong	13°56'31.7"N	105°57'15.8"E
WQ9	Downstream Monitoring #2 of Don Sahong (around 1-km downstream of the dam)	Mekong	13°56'14.7"N	105°57'25.7"E

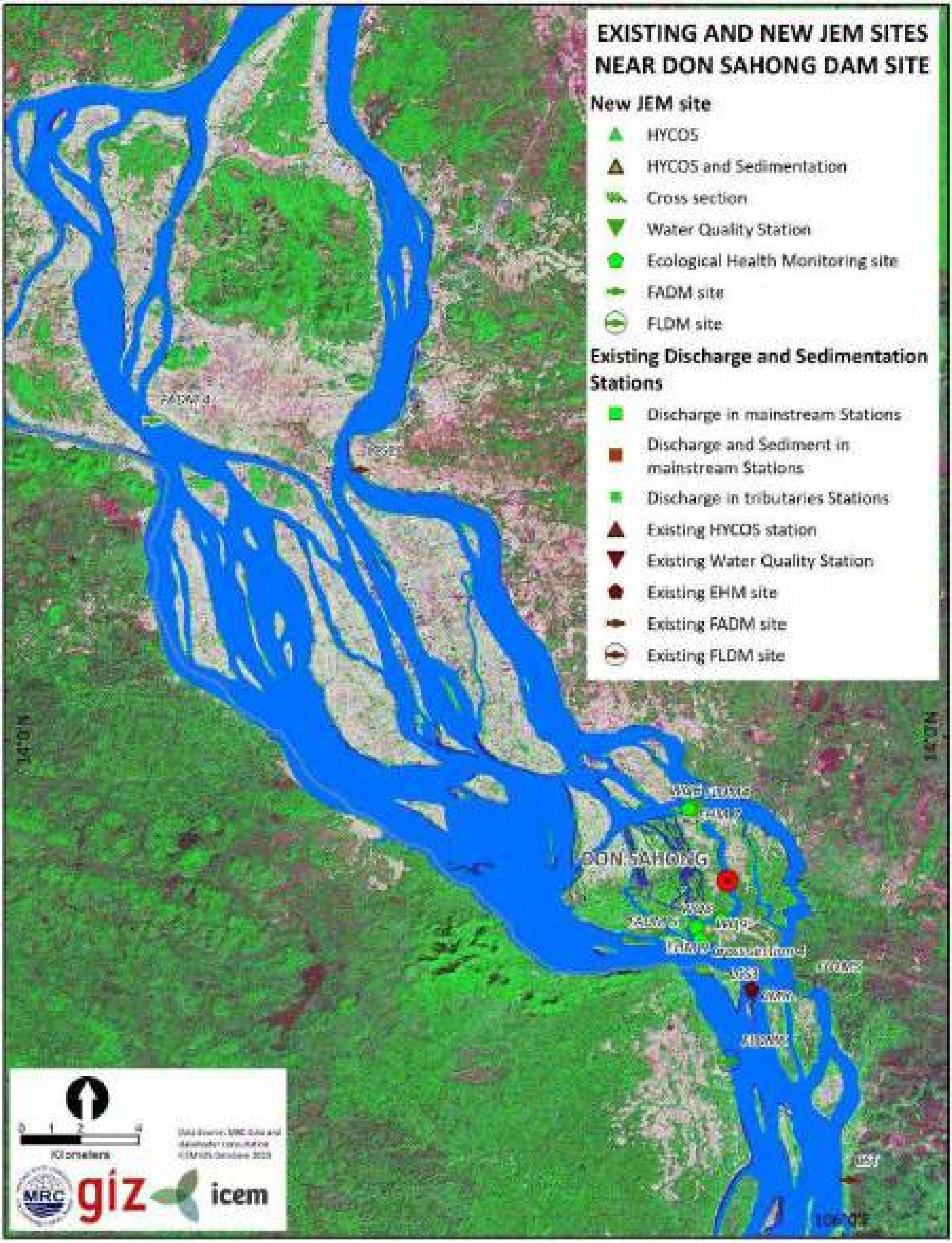


Figure 2-3: Water Quality Sampling stations downstream of the Don Sahong dam

2.3.2.5 Don Sahong monitored parameters

The sampling stations are scheduled to be visited by the Lao water quality team on a monthly basis to carry out measurements using water quality probes as well as taking samples for analysis in the laboratory at each site. The parameters measured are identical to the parameters used in the MRC's routine water quality monitoring programme (WQMN). The new parameters of Turbidity, Chlorophyll-a and Cyanobacteria measurements are carried out using the Algae Torch, procured by the pilot project, or by taking water samples for spectrophotometric analysis, (when the training in the spectrophotometer has been delivered). *Table 2-8* shows the parameters measured at each site, some with the full complement of parameters measured and others with a more restricted set. In addition, at the impoundment site, a depth profile using the Water quality probe and Algae Torch lowered at 1 m intervals to 20 m and 10 m respectively. There have been no changes to these parameters and analyses and no constraints identified by the Lao water quality monitoring team.

Table 2-8. Water quality monitoring parameters measured at each of the Don Sahong monitoring stations

Parameter	Unit	Frequency	Probe	Lab	H013900	WQ6	WQ7	WQ7	WQ8	WQ9	H014501
					Pakse	Upstream of DSH Dam, at impoundment inlet point	Within the impoundment (c. 600 m upstream of the dam wall)		Downstream of DSH (around 250 m downstream of the dam)	Downstream Monitoring #2 of DSH (c1-km downstream of the dam)	Stung Treng
					Mekong	Mekong	Mekong	Depth profile	Mekong	Mekong	Mekong
					15.1206	13°58'41.8"N	13°56'38.8"N		13°56'31.7"N	13°56'14.7"N	13.545
					105.7837	105°57'16.2"E	105°57'42.5"E		105°57'15.8"E	105°57'25.7"E	106.0164
Temperature	TEMP_°C	Monthly	x		x	x	x	x	x	x	x
pH	pH	Monthly	x		x	x	x	x	x	x	x
Conductivity (Salinity)	COND_mS/m	Monthly	x		x	x	x	x	x	x	x
Alkalinity/Acidity	ALK_meq/L	Monthly		x	x	x				x	x
Dissolved Oxygen (DO)	DO_mg/L	Monthly	x		x	x	x	x	x	x	x
Total phosphorous (TP)	TOTP_mg/L	Monthly		x	x	x	x		x	x	x
Total Nitrogen (TN)	TOTN_mg/L	Monthly		x	x	x				x	x
Ammonium (NH_{4+}-N)	NH4N_mg/L	Monthly		x	x	x				x	x
Nitrite+Nitrate (NO_{2+3}-N)	NO32_mg/L	Monthly		x	x	x	x		x	x	x
Fecal Coliforms	FC_MPN/100ml	Monthly		x	x	x				x	x
Total Suspended Solids (TSS)	TSS_mg/L	Monthly		x	x	x				x	x
Chemical Oxygen Demand (COD)	CODMN_mg/L	Monthly		x	x	x				x	x
Calcium (Ca)	Ca_meq/L	Monthly for 7 months		x	x	x				x	x
Magnesium (Mg)	Mg_meq/L	Monthly for 7 months		x	x	x				x	x
Sodium (Na)	Na_meq/L	Monthly for 7 months		x	x	x				x	x
Potassium (K)	K_meq/L	Monthly for 7 months		x	x	x				x	x
Sulphate (SO42-)	SO4_meq/L	Monthly for 7 months		x	x	x				x	x
Chloride (Cl^-)	Cl_meq/L	Monthly for 7 months		x	x	x				x	x
Turbidity	FTU	Monthly	x								
Chlorophyll *a*	micrograms/l	Monthly	x	x		x	x	x	x	x	
	cell count/l										
Cyanobacteria	micrograms/l	Monthly	x								
	cell count/l										

Note: Blue = routine WQ monitoring, Green = measurement in the laboratory, Yellow = measurement in the field by probe.

2.3.2.6 Don Sahong monitoring missions

The Laos Water quality monitoring team provided by NRESRI, MoNRE (Mr. Vanhna Phanpongsa; Mr. Xayphavanh Pengkhamhuck); DoNRE of Champasak (Mr. Sitthideth Phannavong) have visited the Xayaburi sampling stations on the occasion as listed in *Table 2-9.*

Table 2-9. Dates of sampling visits to Don Sahong pilot sampling stations

Sampling stations	2020			2021					
Month	10	11	12	1	2	3	4	5	6
WQ6	27.10	13.11	14.12	15.01	17.02	15.03	9.04	N/A	24.06
WQ7	27.10	13.11	14.12	15.01	17.02	15.03	9.04	N/A	24.06
WQ8	27.10	13.11	14.12	15.01	17.02	15.03	9.04	N/A	24.06
WQ9	27.10	13.11	14.12	15.01	17.02	15.03	9.04	N/A	24.06

During May 2021, sampling visits were not possible due to COVID-19 travel restrictions. Sampling has been continued in July, August and September 2021, but the results have not yet been analysed due to reporting timeframes and project constraints.

2.3.3 Ecological Health Monitoring

2.3.3.1 Xayaburi Sampling Sites

The first annual bio-assessment monitoring was planned for April 2020, but this had to be cancelled because of the COVID-19 restrictions on travel within Lao PDR. It was not possible to carry out the 2020 field mission later in the year because biomonitoring has to be done when river levels are low, and the indicator groups will not have been dispersed by rising water levels and flash flows at the beginning of the wet season. The campaign for 2021, originally planned for April 2021 was brought forward to February/March 2021 to allow for the identification and reporting process to be conducted in a timely manner. Confirmed sites are shown in *Table 2-10* and shown in *Figure 2-4*.

Table 2-10: Confirmed sites for JEM bio-assessment at Xayaburi

Site No.	Name of site	River	Latitude N	Longitude E
Xayaburi				
EHM1	Right upstream of Xayaburi Impoundment	Mekong	20°00'07.2"N	102°14'06.7"E
EHM 2	Within the impoundment	Mekong	~19°26'05.1"N	101°50'05.1"E
EHM 3	Xayaburi downstream around 2 km	Mekong	19°13'49.6"N	101°49'27.4"E
EHM 4	Xayaburi downstream around 5 km	Mekong	19°12'07.7"N	101°49'28.0"E
EHM 5	Xayaburi downstream around 8 km	Mekong	19°10'49.5"N	101°49'19.5"E
EHM 6	Xayaburi downstream around 12 km	Mekong	19°09'05.0"N	101°48'47.2"E

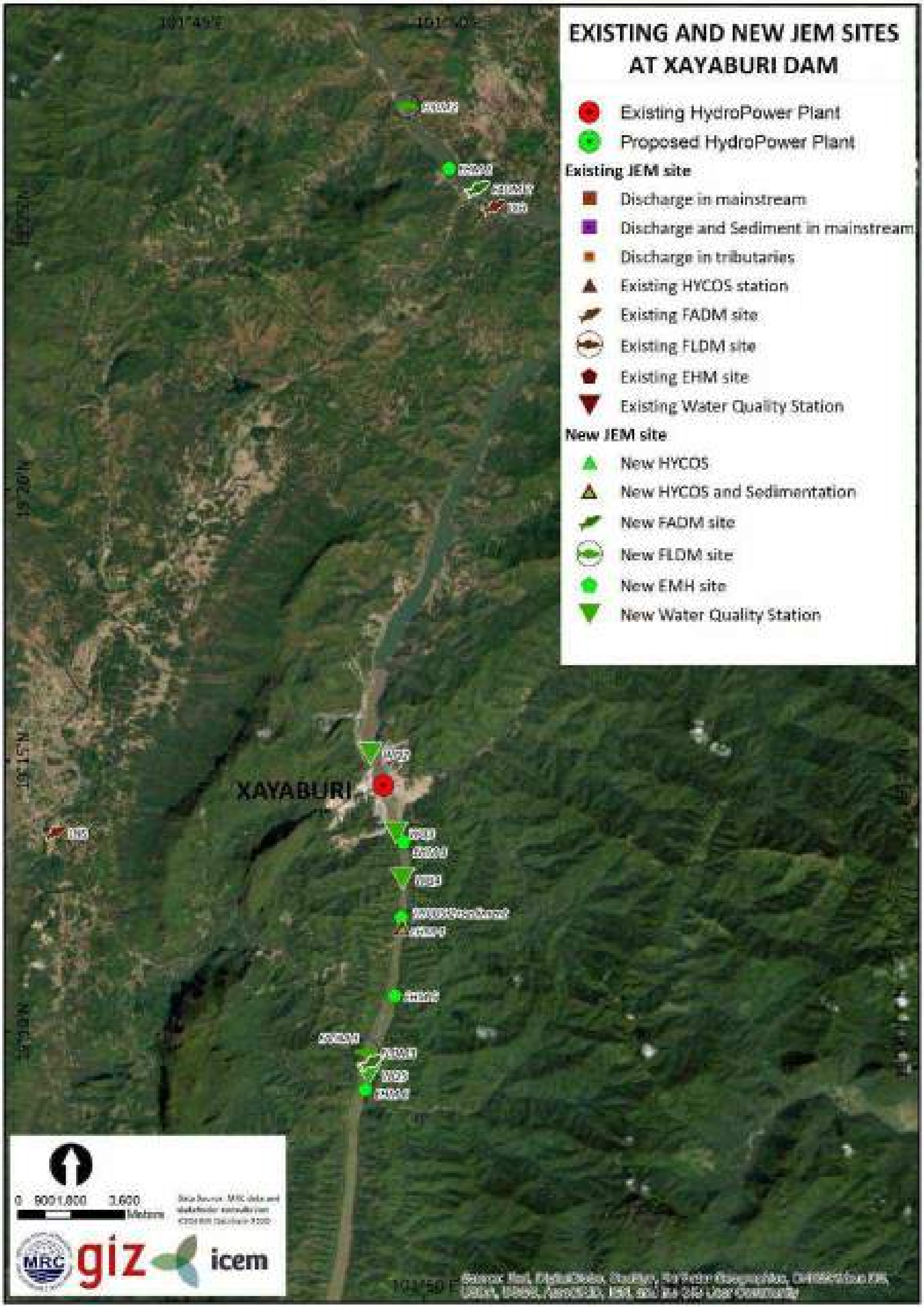


Figure 2-4: Bioassessment monitoring sites around Xayaburi HPP

2.3.3.2 Don Sahong sampling sites

The EHM sites around Don Sahong include one site above the impoundment (EHM7), in the same location as the water quality monitoring station (WQ6), one site within the impoundment (EHM8), and two sites below the dam. These are listed in ***Table 2-11*** and illustrated on ***Figure 2-5***. During sampling visits, two small changes to the exact locations of EHM7 and EHM8. The original location for EHM7 was found to be difficult and unsafe to access and so was relocated to a more accessible site. The original location for EHM8 within the impoundment was found to be unsuitable for the biota because of construction activities and was moved closer to the top of the impoundment. New coordinates are provided in the table.

Table 2-11. Confirmed EHM sampling sites around Don Sahong

Site No.	Name of site	River	Latitude N	Longitude E
Don Sahong				
EHM 7	Don Sahong upstream at inlet of impoundment	Mekong	13°58'42.6"N	105°57'07.4"E
	Changed to		13°57'58.1"N	105°56'55.3"E
EHM 8	Don Sahong impoundment	Mekong	13°56'40.1"N	105°57'43.6"E
	Changed to		13°58'04.0"N	105°57'42.9"E
EHM 9	Downstream Don Sahong at round 2 km	Mekong	13°56'33.0"N	105°57'15.2"E
EHM 10	Downstream Don Sahong at around 4 km	Mekong	~13°56'19.1"N	105°57'19.9"E

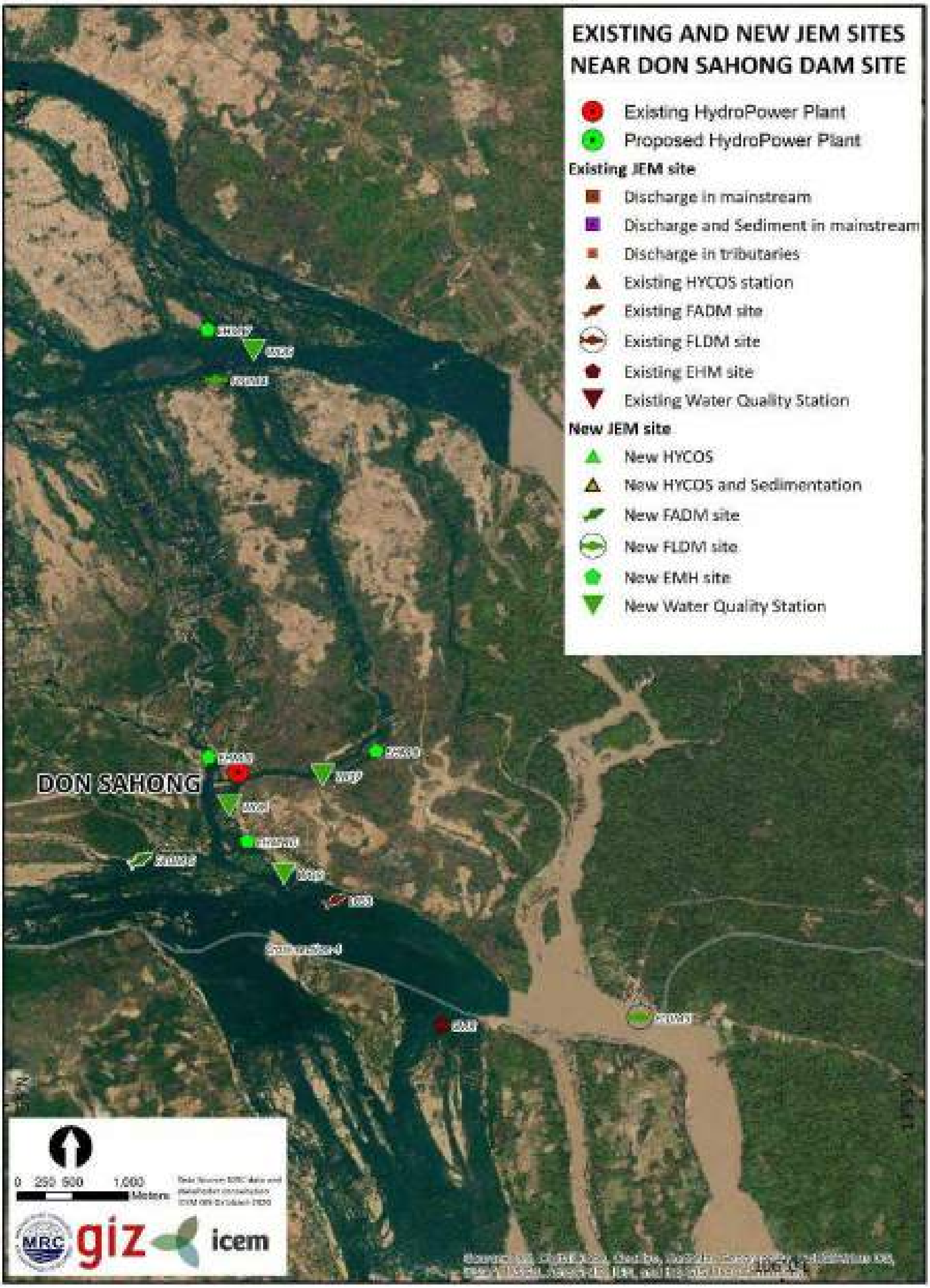


Figure 2-5: Bioassessment monitoring sites around Don Sahong HPP

2.3.3.3 Bio-monitoring missions

Bio-monitoring at the two pilot sites was carried out by the Lao EHM team between 24 February to 7 March 2021 shown in *Table 2-12* and *Table 2-13*.

Table 2-12: Dates of EHM sampling missions

Site No.	Name of site	Date sampled
Xayaburi		
EHM1	Right upstream of Xayaburi Impoundment	5 March 2021
EHM 2	Within the impoundment	4 March 2021
EHM 3	Xayaburi downstream around 2 km	3 March 2021
EHM 4	Xayaburi downstream around 5 km	3 March 2021
EHM 5	Xayaburi downstream around 8 km	2 March 2021
EHM 6	Xayaburi downstream around 12 km	2 March 2021
Don Sahong		
EHM 7	Don Sahong upstream at inlet of impoundment	26 February 2021
EHM 8	Don Sahong impoundment	26 February 2021
EHM 9	Downstream Don Sahong at round 2 km	25 February 2021
EHM 10	Downstream Don Sahong at around 4 km	25 February 2021

Table 2-13: Lao EHM Team members

No.	Name	Position	Professional/ Field of Expertise	Xayaburi	Don Sahong
1	Dr. Niane Sivongxay	Team Leader	Zooplankton	X	X
2	Dr. Chanda Vongsombath	Member	Benthic macro-invertebrate	X	X
3	Ms. Chanthima Polthalith	Member	Benthic Diatoms	X	X
4	Ms. Viengkhone Vannachak	Member	Littoral macro-invertebrates	X	X
5	Mr. Sopha Keo-inpeng	Member	Water quality	X	X
6	Mr. Thathasith	Member	Biology student	X	X
7	Mr. Manolom Vongsombath	Member	Biology student	X	X
8	Mr. Thongvanh	Member	Biology student	X	X
9	Ms. Namfon	Member	Biology student		X
10	Mr. Khamla Insounun	Member	PONRE (Xayaburi Province)	X	
11	Mr. Thanongsack	Member	DONRE (Xayaburi Province)	X	
12	Mr. Bounpone	Member	PONRE (Champasak Province)		X
13	Mr. Nouhak	Member	DONRE (Khong District)		X
14	Mr. Bounphanh Saisipaseuth	Member	LNMCS		X
15	Mr. Thongphet	Member	MEMs		X
16	Mr. Vongphet	Member	MEMs	X	

2.3.4 Fisheries

2.3.4.1 Fish Abundance and Diversity Monitoring (FADM)

FADM data have been gathered in Laos in stations detailed in ***Table 2-14***, and in Cambodia in stations detailed in ***Table 2-15***. Of these stations, we retained for dam impact analysis the stations detailed in ***Table 2-16***.

An overview of the amount of data available by year and by site (see section 5.6) reveals that, for most sites, complete to semi-complete data (at least 8 months of sampling per year) is only found from 2017 onwards.

Thus, in the present report results will only be detailed for the above period (2017-2021) based on data collected from the following sites, which are relevant to the monitoring of the dams covered by the JEM-Pilot project:

Table 2-14: Sites of FADM monitoring in Laos.

Province	District	Village	Code	MRC FADM	JEM new sites	JEM dam monitoring
Borkeo	Huay xai	**Huay tap**	LHT	Yes		No (downstream of China)
Borkeo	Huay xai	**Donekoun**	LDK	Yes		No (tributary)
Oudomxay	Pak Beng	**Pak ngery**	LPN	Yes		No
Oudomxay	Pak Beng	**Pakbeng**	LOX	Yes		No
Luangphrabang	Luangphrabang	**Pha-O**	LPB, LJXU	Yes	Yes	Upstream of Xayaburi
Luangprabang	Pak Ou	**Hadgna**	LPO	Yes		No
Xayyabouly	Xayyabouly	**Thadeua**	XLB	Yes		Upstream of Xayaburi
Xayyabouly	Xayyabouly	**Phaxang Na xam**	LNS	Yes		No
Vientiane	Hatxayfong	**Thamuang**	LVT	Yes		Downstream of Xayaburi
Borikhamxay	Pak sanh	**Sinhxay**	LBX	Yes		No
Champasak	Phonthong	**Hatsalao**	LSL	Yes		No
Champasak	Khong	**Hat**	LCS	Yes		Upstream of Don Sahong
Champasack	Khong	**Hangsadam**	LSD,	Yes	Yes	Downstream of Don Sahong
Xekong	Lamam	**Navasaen**	LXK	Yes		No (tributary)
Attapeu	Samakhixay	**Saphaothong**	LAP	Yes		No (tributary)
Champasak	Khong	**Hangkhone**	LJDD		Yes	Downstream of Don Sahong
Champasak	Khong	**Mouangsen (nua)**	LJDU		Yes	Upstream of Don Sahong
Xayyabouly	Xayyabouly	**Pakhoung**	LJXD		Yes	Downstream of Xayaburi

Note: Remaining coding uncertainties are flagged in red

Table 2-15: Sites of FADM monitoring in Cambodia.

Province	District	Commune	Village	Implementation	JEM dam monitoring
Battambang	Ek Phnom	Koh Chiveang / Prek Torl	Anlongtaour	TSA	
Battambang	Ek Phnom	Koh Chiveang / Prek Torl	Prek Torl	TSA	
Kandal	Ponhea Leu	Kampong Loung	Sang Var	FIA	
Kompong Chhnang	Boribo	Chhnok Tru	Chhnok Tru	TSA	
Kompong Thom	Kompong Svay	Phat Sanday	Neang Sav	TSA	
Kompong Thom	Staung / Stuang	Peam Bang	Peam Bang	TSA	
Kompong Thom	Staung	Peam Bang	Pich Chikrey	TSA	
Kra Tie	Sambo	Ou Krieng	Koh Khne	FIA	Cross-analyses
Pursat	Kro Kor / Krakor	Kompong Loung	Ti1	TSA	
Pursat	Kro Kor / Krakor	Kompong Loung	Ti2	TSA	
Pursat	Kro Kor / Krakor	Kompong Loung	Ti3	TSA	
Ratanakiri	Lum Phat	Chey Udom	Day Lo	FiA	
Ratanakiri	Veounsai	Banpong	Fang	FiA	
Siem Reap	Prasat Bakorg / Prasat Bakorng	Kg Pluk / Kg Phluk	Kompong Pluk	TSA	
Siem Reap	Prasat Bakorg / Prasat Bakorng	Kg Pluk / Kg Phluk	Thort Kambot	TSA	
Siem Reap	Siem Reap	Chong Khneas	Ti 4	TSA	
Siem Reap	Siem Reap	Chong Khneas	Ti 5	TSA	
Siem Reap	Siem Reap	Chong Khneas	Ti 3	TSA	
Stung Treng	Thalarborivat	Ou Svay	Ou Run	FIA	Downstream of Don Sahong
Stung Treng	Siem Pang	Tmar Keo	Pres Bang	FiA	

Note: Remaining coding uncertainties are flagged in red

Table 2-16: Sites considered for dam impact analysis over the 2017-2021 period

Province	Village	Code	JEM dam monitoring
Laos	**Pha-O**	LPB	Upstream of Xayaburi
Laos	**Thadeua**	LXB	Upstream of Xayaburi
Laos	**Thamuang**	LVT	Downstream of Xayaburi
Laos	**Pakhoung**	LJXD	Downstream of Xayaburi
Laos	**Hat**	LCS	Upstream of Don Sahong
Laos	**Mouangsen (nua)**	LJDU	Upstream of Don Sahong
Laos	**Hangsadam**	LSD	Downstream of Don Sahong
Laos	**Hangkhone**	LJDD	Downstream of Don Sahong
Cambodia	**Ou Run**	CST	Downstream of Don Sahong

2.3.4.2 Gillnet sampling

In Laos, gillnet sampling appears to be totally regular, with sampling in 9 sites, 3 sets of gillnets per site, and data currently from September 2020 to July 2021 as listed in *Table 2-17*.

Table 2-17: Sampling done with gillnets in each site in Laos during the JEM Pilot project.

Year	Month	LAP	LCS	LHT	LJDD	LJDU	LJXD	LJXI	LJXU	LSD
2020	Sep	12	12	12	12	12	12	12	12	12
	Oct	12	12	12	12	12	12	12	12	12
	Nov	12	12	12	12	12	12	12	12	12
	Dec	12	12	12	12	12	12	12	12	12
2021	Jan	12	12	12	12	12	12	12	12	12
	Feb	12	12	12	12	12	12	12	12	12
	Mar	12	12	12	12	12	12	12	12	12
	Apr	12	12	12	12	12	12	12	12	12
	May	12	12	12	12	12	12	12	12	12
	Jun	12	12	12	12	12	12	12	12	12
	Jul	12	12	12	12	12	12	12	12	12

Note: LAP: Attapeu Province, Saphaothong village; LCS: Champasak Province, Ban Hat village; LHT: Borkeo Province, Donekhoun village; LJDD: Champasak Province, Hang Khone village; LJDU: Champasak Province, Saen Nue village; LJXD: Xayabouri Province, Pak Houng village; LJXI: Xayabouri Province, Tha Deua village; LJXU: Luangprabang Province, Pha O village; LSD: Champasack Province, Hang Sadam village.

An analysis of the gillnet sampling done in Cambodia shows that data start in June 2020 with a sampling site for JEM at the Ou Run village near the Lao border. Sampling (*Table 2-18* and *Table 2-19*) was regular in 4 sites in October 2020, but was only sustained in Ou Run village until May 2021 (and beyond, as sampling continued). That latter village is the site with the most constant gillnet sampling, but gillnets were also tested in different environments and conditions (e.g. in Siem Reap and Ratanakiri provinces).

Table 2-18: Sampling done with gillnets in each site in Cambodia during the JEM Pilot project.

		CKT 1	CKT 2	CKT 3	CSK 1	CSP 1	CSP 2	CSP 3	CSR T3	CSS 1	CSS 2	CSS 3	CST 1	CST 2	CST 3
2020	Jun												2	2	2
	Jul												4	4	4
	Aug												5	5	4
	Sep												4	4	4
	Oct	2	2	2		2	2	2		2	2	2	5	5	5
	Nov	4	4	4		4	4	4	1	4	4	4	4	4	4
	Dec	4	4	4		4	4	4		4	4	4	4	4	4
2021	Jan	1	1	1						5	5	5	5	5	5
	Feb								1	4	5	5	4	4	4
	Mar									1	2	2	4	4	4
	Apr												4	4	4
	May												5	5	5

Note: CKT: Kratie Province, Koh Khne village; CSK: Stung Treng Province, Pres Bang village; CSP: Ratanakiri Province, Day Lo village; CSRT: Siem Reap Province, Ti 3,4,5 village; CSS: Ratanakiri Province, Fang village; CST: Stung Treng Province, Ou Run village. Indices 1,2,3 indicate the use of several gillnet types in one site

Table 2-19: Sampling done with gillnets in each site in Cambodia during the JEM Pilot project.

	Month	CKT	CSK	CSP	CSR	CSS	CST
2020	Jun						6
	Jul						12
	Aug		1				14
	Sep						12
	Oct	6		6		6	15
	Nov	12		12	1	12	12
	Dec	12		12		12	12
2021	Jan	3				15	15
	Feb				1	14	12
	Mar					5	12
	Apr						12
	May						15

Note: CKT: Kratie Province, Koh Khne village; CSK: Stung Treng Province, Pres Bang village; CSP: Ratanakiri Province, Day Lo village; CSRT: Siem Reap Province, Ti 3,4,5 village; CSS: Ratanakiri Province, Fang village; CST: Stung Treng Province, Ou Run village. Indices 1,2,3 indicate the use of several gillnet types in one site

2.3.4.3 Fish Larvae Drift Monitoring (FLDM)

The fish larvae sampling done in Laos (***Table 2-20***) indicates a protocol regularly implemented. 32 samples were produced each month during rising water and high-water level months, and 16 samples were produced monthly during the dry seasons. One site stands out though as having 50% less samples than others in the wet season: LJDD = Hang Sadam, downstream of Don Sahong Dam, between September and December 2020. This problem was fixed in May 2021 and later.

Table 2-20: Sampling done in FLDM in Laos during the JEM Pilot project

	Months / Stations	LJDD	LJDU	LJXD	LJXI	LJXU
2020	Sep	16	32	32	32	32
	Oct	16	32	32	32	32
	Nov	16	32	32	32	32
	Dec	16	32	32	32	32
2021	Jan	16	16	16	16	16
	Fev	16	16	16	16	16
	Mar	16	16	16	16	16
	Apr	16	16	16	16	16
	May	32	32	32	32	32
	Jun	32	32	32	32	32
	Jul	32	32	32	32	32

Note: LJDD = Hang Sadam, downstream of Don Sahong Dam; LJDU = Don Sahong, upstream of Don Sahong Dam; LJXD = Pak Houng, downstream of Xayabouri Dam; LJXI = Tha Deua, in Xayabouri Dam Impoundment; LJXU = Pha O, upstream of Xayabouri Dam

In Laos, the JEM Pilot national team collected 1376 FLDM samples in 5 site between September 2020 and July, i.e. between 224 and 288 samples per site, in different locations at each site and at different times of the day and night (*Table 2-21)*. These samples produced 1690 taxonomic identifications.

Table 2-21: Detail of the fish larvae surveys documenting larval presence at two dam sites

Dam site	Site	Samples
Xayaburi	**Phao, upst. of XY**	
	Left bank	64
	Right bank	224
	Thadeua, XY impoundment	
	Left bank	223
	Right bank	64
	Pakhoung, downst. of XY	
	Left bank	224
	Right bank	64
Don Sahong	**Hang Sadam, downst. of DS**	
	Left and Right banks	95
	Right bank	128
	Seng Nuea, upst. of DS	
	Left bank	224
	Right bank	64

In Cambodia JEM FADM is implemented for 2020-2021 in one station only coded CJDD = Preah Romkel, Downstream of Don Sahong Dam (*Table 2-22*).

Table 2-22: Sampling done in FLDM in Cambodia during the JEM Pilot project.

	Month	CJDD
2020	Jul	60
	Aug	54
	Sep	50
	Oct	51
	Nov	40
	Dec	42
2021	Jan	40
	Feb	49
	Mar	48
	Apr	48
	May	48
	Jun	80

Note: CJDD = Preah Romkel in Stung Treng Province, downstream of Don Sahong Dam.

Data show an irregular distribution reflecting sampling issues already discussed in the first Pilot site report from March 2021 (current too strong in the site in the rainy season, anchors stolen, sample identification issues among fishers). The report then recommended the sampling station to be slightly moved and fishers to be further trained.

The Cambodian annual FLDM report illustrates the stations sampled in Cambodia near the Lao border 2 km downstream of Don Sahong as part of the JEM pilot monitoring (*Figure 2-6*).

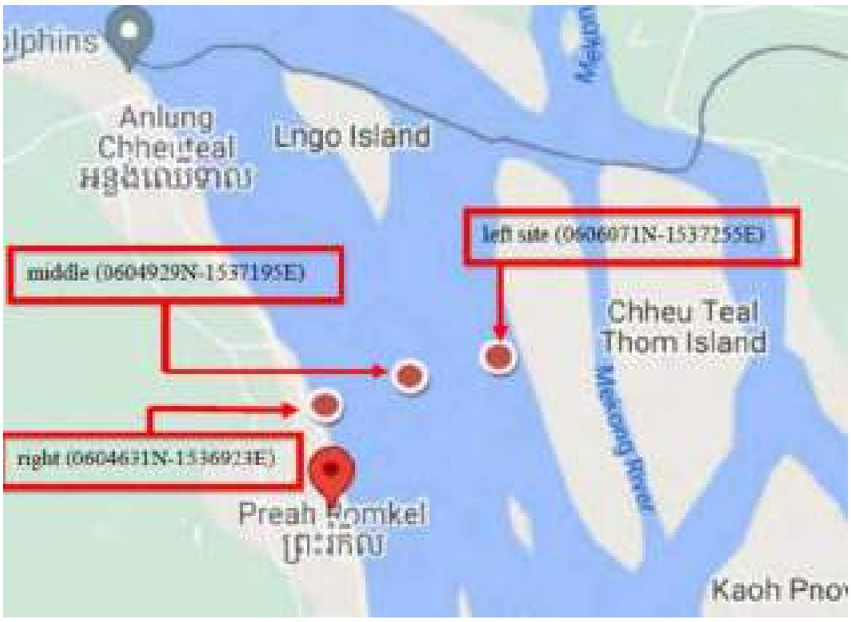


Figure 2-6: FLDM station in Cambodia for the JEM Pilots

2.4 Adjustments and evolutions

2.4.1 Hydrology and Sediment

No adjustments to the monitoring schedule or monitoring procedures were implemented. Covid-19 continued to present challenges to the implementation of the JEM monitoring, with travel restrictions limiting the number of sampling missions able to be completed within the JEM period.

2.4.2 Water quality

No adjustments to the monitoring schedule or the parameters measured have been made during the last six months. Monitoring visits to all the JEM sites were not possible in May 2021 due to COVID travel restrictions.

2.4.3 Ecological Health Monitoring

The adjustments to the precise locations of the sampling sites for the four biota groups were reported on in the first pilot site reports. These depended upon finding the most suitable sampling locations depending upon the substrate and flow conditions at the time of sampling. Originally it had been planned that there would be two annual sampling occasions at the JEM sites, but the 2020 campaign was cancelled due to COVID travel restrictions and the 2021 campaign brought forward to February and March 2021.

2.4.4 Fisheries

No adjustments to the monitoring schedule or the parameters measured have been made during the last six months.

A review of variables in fisheries databases, combined with an analysis of data that can be processed basin-wide, led to calculating the following **three key indicators of the fishery resource status**:

- **Monthly catch per fisher in each site and each year.** This indicator assumes that fishers deploy all the gears they can to permanently adapt to the fish variability and maximize their catch. The annual time step integrates seasonal variability and migration pulses.
- **Number of species caught each year in each site.** This indicator represents the local biodiversity accessible to fishers and the trend in diversity). The annual time step also integrates seasonal variability and fish movements in and out of the area surveyed.
- **Average CPUE (biomass caught by square meter of gillnet by hour fishing) each year in each sites.** Gillnets are the dominant gear all over the region and are subject to specific attention because comparisons between the catch of individual fishers in the FADM protocol can be made in standardized conditions, as long as gillnet catch, gillnet area and fishing time is known. Ultimately the reference unit for fish abundance is **CPUE** = Catch Per Unit Effort = grams of fish per square meter of net per hour fishing**.** CPUE is calculated for gillnets only as it is too complicated to calculate a composite CPUE when several different gears such as big traps, small straps or lines with hooks are involved.

2.5 Developing the database

Over the past year, Microsoft Access databases for the four disciplines have been developed, and these are described in Chapter 5.4. This has required several iterations in order to achieve the most useful sets of tables and database queries. The databases have been populated with both the JEM data and relevant results from the historic, routine monitoring carried out by the MRC in all four disciplines.

3 XAYABURI

3.1 Hydrology and Sediment

3.1.1 Hydrology – Results at JEM sites

JEM monitoring has included the new monitoring sites of Ban Xang Hai and Ban Pakhoung and monitoring of additional parameters at the ongoing DSM site of Chiang Khan. The location of these sites is shown in ***Figure 3-1***. Results from the other sites shown, Chiang Sean and Nong Khai, are included in the basin wide analysis presented in Section 5.

In this section, the results collected from the JEM sites that were not summarised in the March 2021 JEM report are summarised. All JEM results are integrated with results from other DSM sites in Section 5.

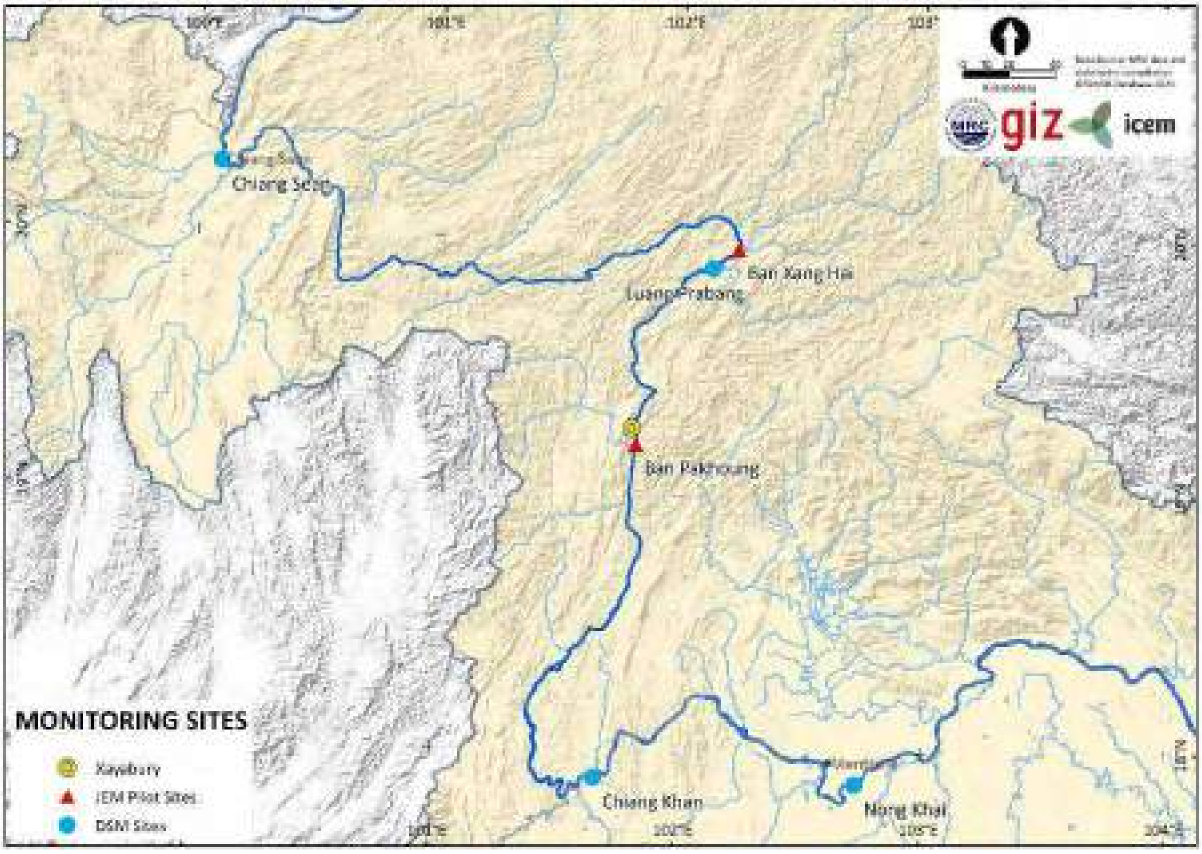


Figure 3-1. JEM and ongoing discharge and sediment monitoring sites (DSM) included in JEM data analysis.

3.1.1.1 Water level at sites

Channel cross-sections and the available water level data for the period 1 July 2020 to 30 June 2021 are shown in ***Figure 3-2*** to ***Figure 3-7*** for Ban Xang Hai, Ban Pakhoung and Chiang Khan.

The surveyed cross-section at Ban Xang Hai shows a fairly uniform channel with the thalweg on the left side of the channel (***Figure 3-2***). Water levels recorded at the site between February and June 2021 ranged from ~1.5 to 4.0 m, equivalent to 270 m to 273m on the cross-section (***Figure 3-3***). This is a relatively small range and only reflects dry season flows. Subsequent monitoring by the Lao PDR team has measured flows at water levels up to 7.3 m.

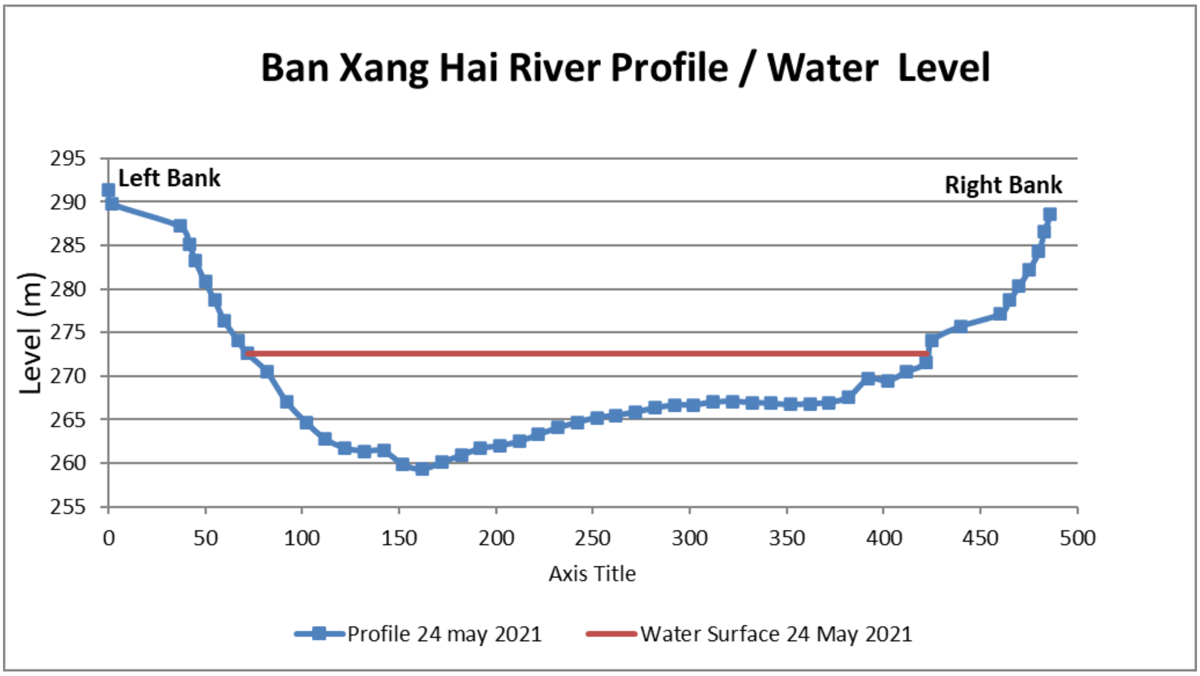


Figure 3-2. Channel cross-section at Ban Xang Hai, 24 May 2021.

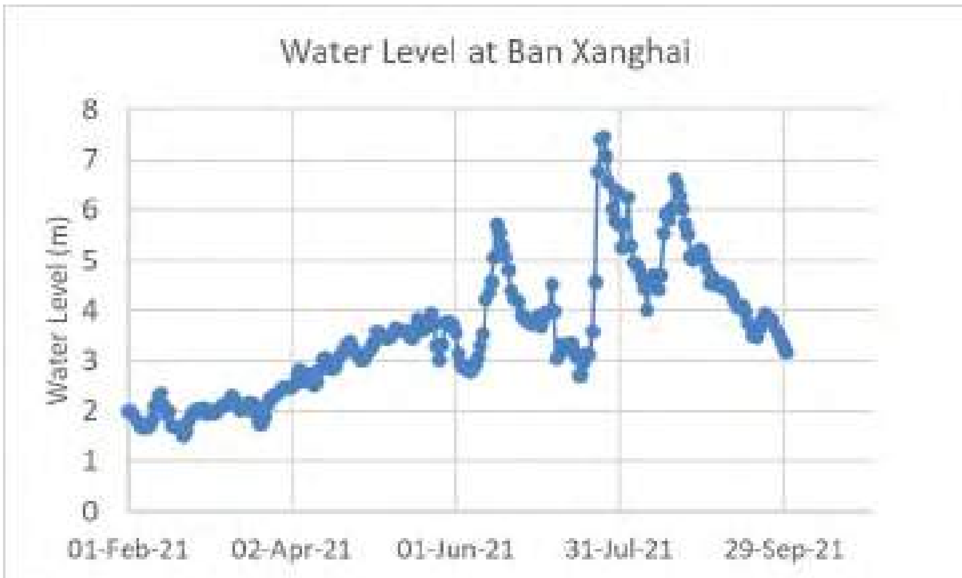


Figure 3-3. Average daily water level at Ban Xang Hai 1 Feb 2021 to October 2021.

Ban Xang Hai was developed as a manual water level station because it was unknown how the backwater from the Xayaburi impoundment affected the area. Comparing the water level collected at Ban Xang Hai with Chiang Khan, a site known not to be affected by backwater, shows strong similarities, although the range of water levels at Ban Xang Hai is considerably smaller as compared to Chiang Khan. Based on the water level results, there is an approximate 2-day delay between the two sites under low flow conditions. The potential for deriving a rating curve at the site is discussed in Section 3.1.1.2.

Figure 3-4. Comparison of water level measurements at Ban Xang Hai and Chiang Khan.

The Ban Pakhoung site was surveyed in May 2021 (*Figure 3-5*), and shows a uniform channel with steep banks. Water level at the site ranged from 1.17 m to 10.24 m.

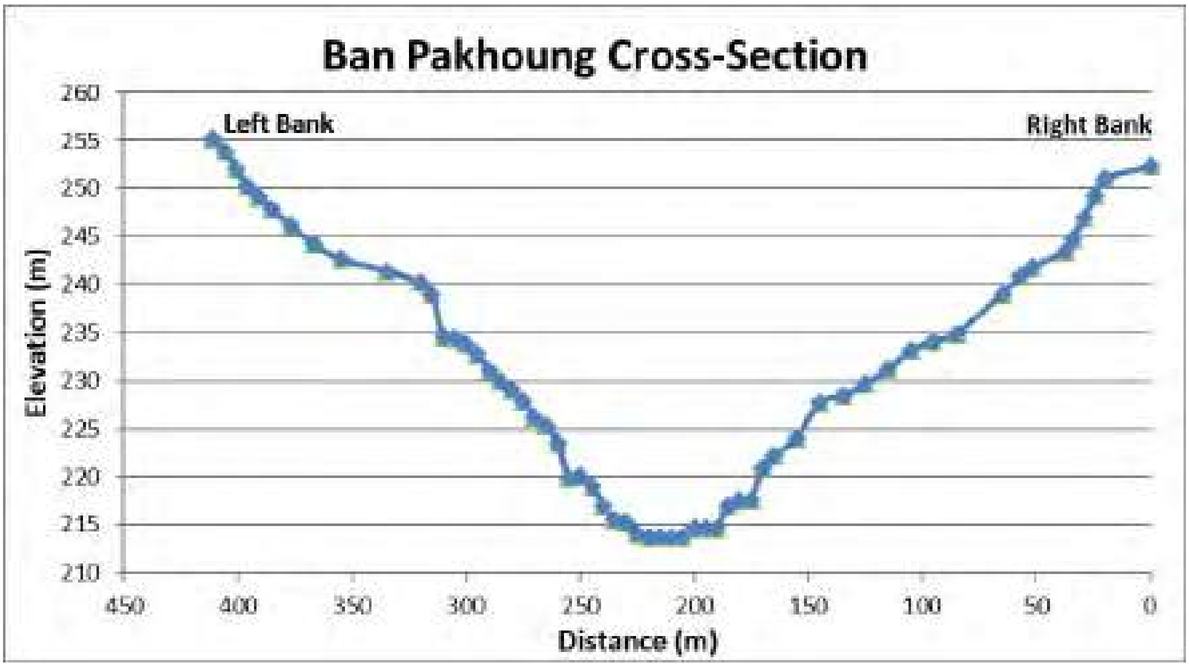


Figure 3-5. Surveyed cross-section at Ban Pakhoung completed on 29 May 2021.

Manual Daily water level results are not being collected routinely at Ban Pakhoung due to the remoteness of the site and the difficulty in finding a local person to read the gauge. The available telemetered data from the site is shown in *Figure 3-5* and shows the gauge was not functioning between the end of April and late June, which was due to equipment failure. Covid related travel bans contributed to the delay in repairing the site. The water level at Chiang Khan is provided for comparison.

At Ban Pakhoung, the water level ranged from about 2.9 m to 7.2 m between the installation of the gauge and 30 June 2021 (the JEM monitoring year). The water level record shows strong similarities with Chiang Khan, albeit with a larger number and higher magnitude water level fluctuations. A discussion of rates of water level change is included in Section 5 along with a high flow event in July 2021, when water levels at Ban Pakhoung increased to 14.3 m.

Figure 3-6. Water level record for Ban Pakhoung (blue) station from February 2021 to Aug 2021.

Note: Probe was non-functional for period between mid-April and late June. Chiang Khan water level (green) provided for reference.

The river cross-section at Chiang Khan shows an elevated section mid-channel, which divides the river into two sub-channels. Water level at the site ranged from ~3.5 to 11 m, with the highest flow occurring in late August 2020.

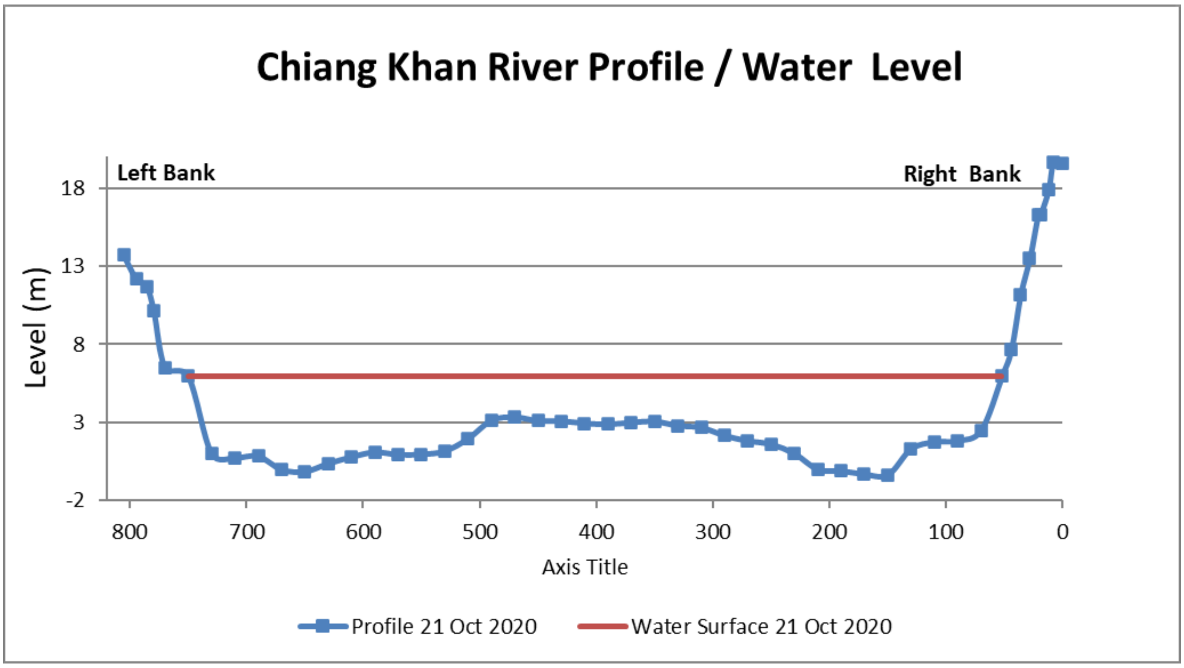


Figure 3-7. Channel cross-section at Chiang Khan.

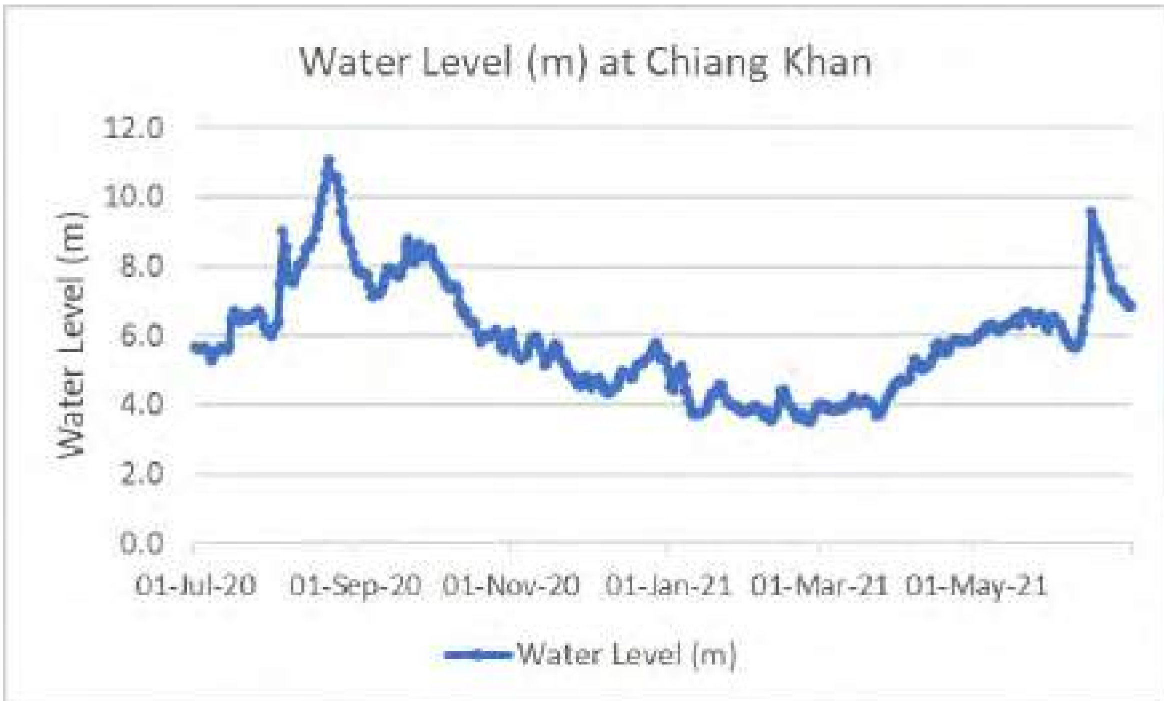


Figure 3-8. Average daily water level at Chiang Khan 1 July 2020 - 1 July 2021.

3.1.1.2 Rating curves from discharge measurements

Twenty six discharge measurements have been completed at Ban Xanghai. Of these, the first four were completed in October 2020 to Jan 2021 when the water level gauge was not finalised, and the recorded water levels are approximate only. The measurements and water level results collected since February 2021 have been used to construct a provisional rating curve for the site (***Figure 3-7***). Based on the provisional curve, flow at Ban Xanghai ranged from 1,229 m^3/s on Feb 21, 2021 to 7,360 m^3/s on 25 July 2021. Additional flow measurements at high flow (>6,000 m^3/s) are required to further refine the relationship, but based on the initial results, the site does not appear to be strongly affected by backwater effects, and may be suitable for a long term water level monitoring site. A long-term monitoring site in this location would be advantageous as it records the flow from Nam Ou as well as the upper Mekong, and is projected to remain within a free-flowing river reach even if the full northern Lao PDR cascade is constructed.

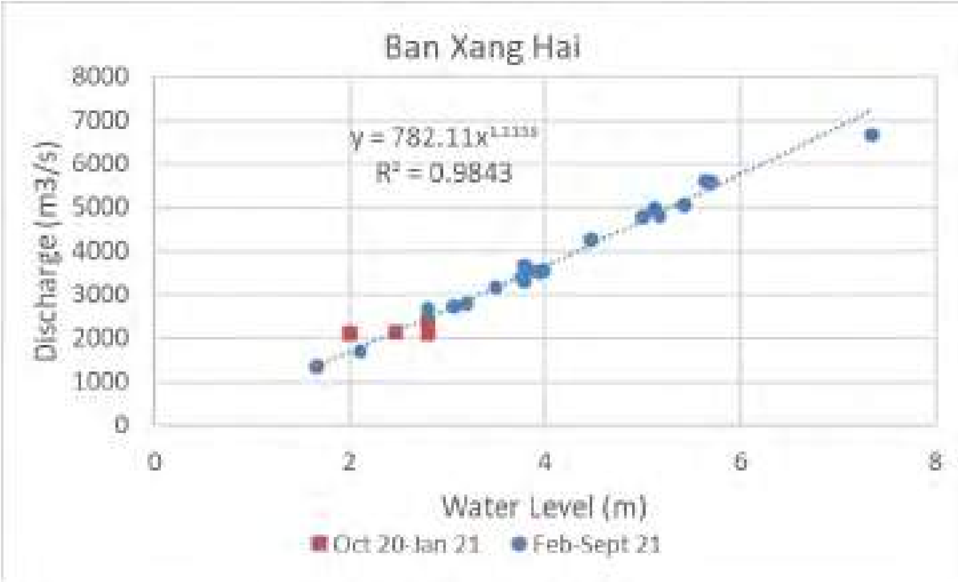


Figure 3-9. Provisional rating relationship for Ban Xanghai

Note: Relationahip is based on the water level and ADCP discharge measurements (blue dots).

At Ban Pakhoung, discharge and water level measurements have been collected between November 2020 and September 2021, with the results shown in *Figure 3-11*. There is a ood relationship between the water level and flow results when all measurements are included (left plot), but there are stronger relationships when the results are grouped by water level greater than and less than 9 m. This may be due to the short-term variability in flow rates at low flows associated with turbine operations at Xayaburi, or the geometry of the river channel. Additional data collection and analysis is required before a reliable rating curve can be derived for the site.

Comparisons of inflow to the Xayaburi impoundment and discharge from the power station are provided in Section 5.9.1.1.

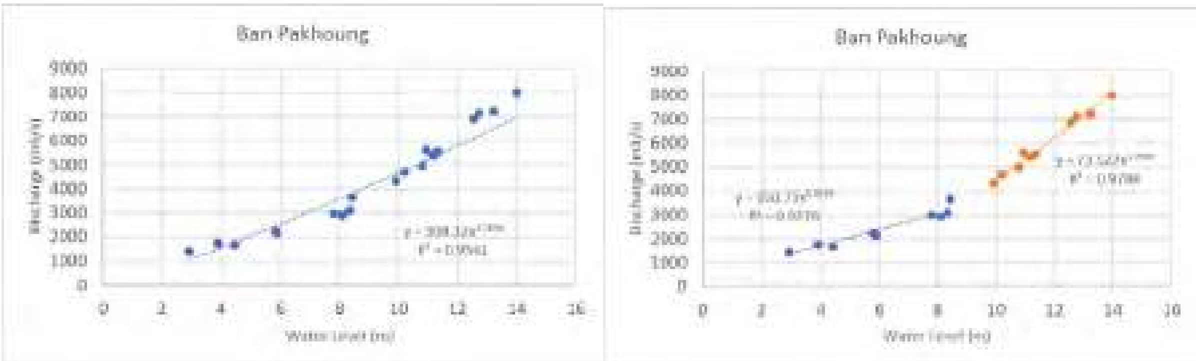


Figure 3-10. Water level and measured discharge at Ban Pakhoung, Nov 2020 to May 2021.

At Chiang Khan, the 2020 to 2021 results are compared to the published rating curve for the site. The recent measurements show lower discharge compared to the rating curve, which was based on 2009-2012 discharge results collected with a current meter. The difference between the curves equates to a 13% lower discharge in the recent results as compared to the rating curve. At the maximum flow rates recorded in the monitoring year, this difference exceeds 1,700 m3/s (rating curve = 10,171 m3/s and ADCP curve=8,446 m3/s). This difference could be attributable to an over-estimation of flow in the 2009-2012 discharge results, channel changes altering the relationship of flow and water depth over the past decade, or an under-estimation of the ADCP measurements. Between October 2020 and March 2021, the ADCP measurements were not corrected for a moving bed due to invalid loop-test results. This period was characterised by low flow, and it is unlikely that the measurements required correction. The higher flow measurements in 2020 and 2021 have all been corrected, with adjustments of up to 9% applied.

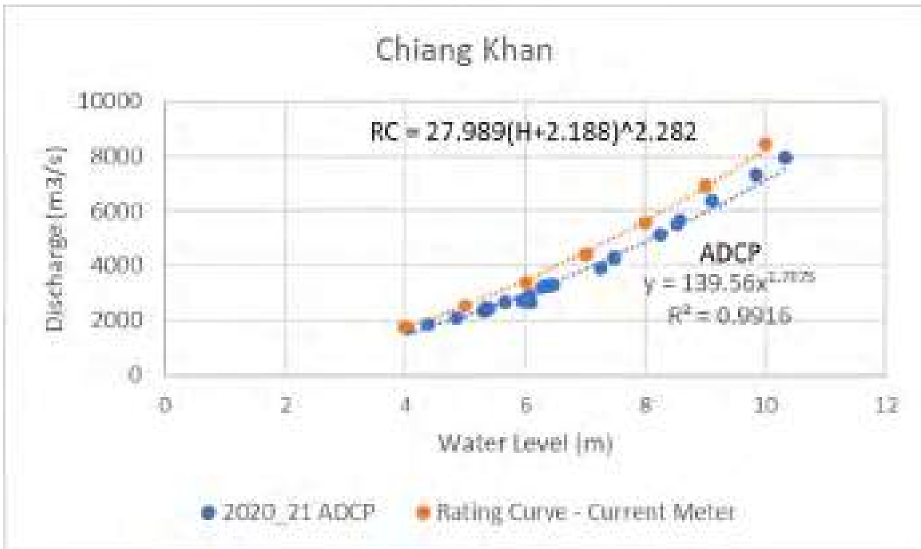


Figure 3-11. Comparison of 2020 -2021 ADCP discharge results with rating curve.

Note: This rating curve was established for the site by Someth et al., 2013.

The calculated discharge rates at Ban Pakhoung, Ban Xanghai and Chiang Khan for a period when results are available for all three sites is shown *Figure 3-12.* The higher frequency of flow changes due to power generation is evident at Ban Pakhoung. During low flows, discharge rates are similar at all sites, reflecting low inflows.

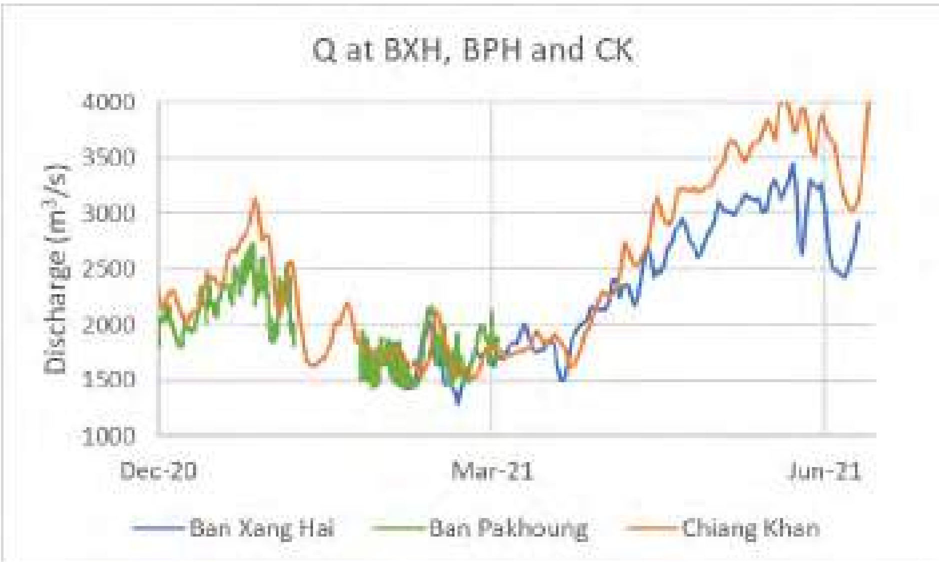


Figure 3-12. Comparison of flow at Ban Xanghai, Ban Pakhoung and Chiang Khan based on rating curves for a period of overlap between the sites.

3.1.2 Sediment results

At Ban Xanghai and Ban Pakhoung, suspended sediment and bed material sediment results Xanghaiwere reported for February to June 2021. At Chiang Khan, suspended sediment has been reported for July 2020 to May 2021, but no bed material results are available. A summary of the JEM sites is presented here, and a basin wide summary of all JEM results integrated with other DSM stations is presented in Section 5.

3.1.2.1 Suspended sediment concentrations (SSC)

The SSC results for the three JEM sites are shown in ***Figure 3-13***. Flood season results are only available from Chiang Khan, with concentrations highly variable and ranges between 30 mg/L and 125 mg/L. Since October 2020, all results except one at Ban Xanghai have been below 60 mg/L. There is no apparent relationship between concentrations at Ban Xanghai and Ban Pakhoung, but because concurrent results are limited to January to June 2021, the dry season, it is not surprising. There are very few sampling periods that overlap between Ban Pakhoung and Chiang Khan, so it is not possible to identify changes associated with potential sediment trapping in the Xayaburi impoundment.

There is no temporal overlap of available SSC results from Ban Pakhoung and Chiang Khan, so no analyses of the change to sediment transport between these sites can be made.

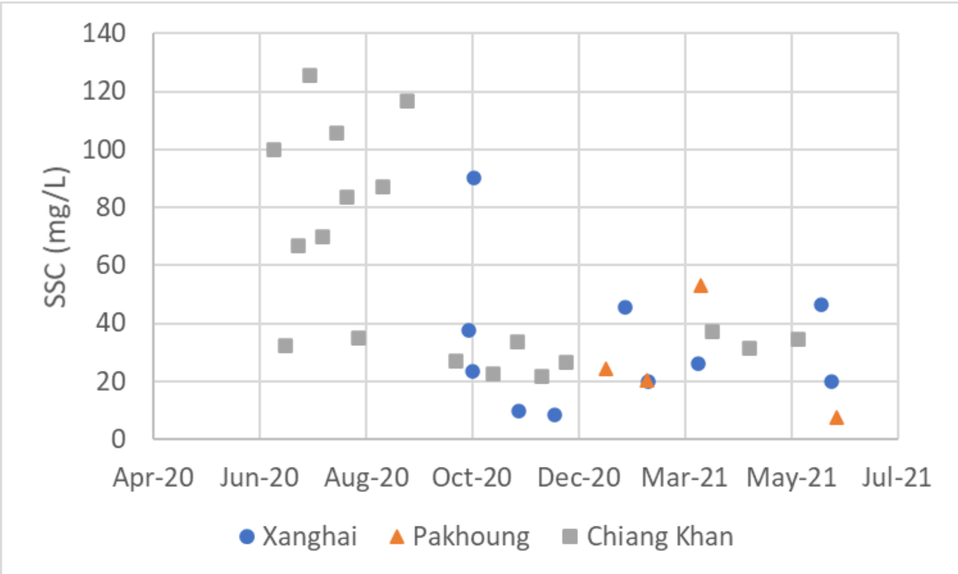


Figure 3-13. SSC results reported for the JEM sites, 1 July 2020 to 30 Jun 2021.

3.1.2.2 Comparison of SSC load and estimated bed load transport

The SSC loads recorded at Ban Xanghai and Ban Pakhoung over the monitoring year (***Figure 3-14)*** are limited to dry season conditions and show SSC loads were in the 2,000 to 10,000 tonnes/day range, and bedload estimates were in the 100 to 2,000 tonnes/day range. The bedload should be considered an order of magnitude estimate only, as it is based on the extrapolation of bed movement rates detected by ADCP loop-tests. The rates for both the SSC and bed load are very low, and a longer data set is required for estimation of annual SSC loads.

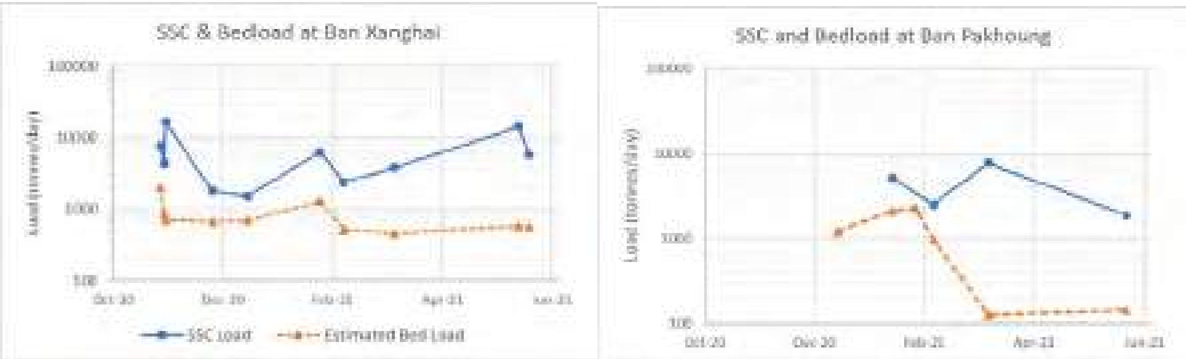


Figure 3-14. Comparison of SSC load and estimated bedload at Ban Xanghai and Ban Pakhoung

More complete SSC results are available for Chiang Khan, which show that during the 2020 flood season SSC loads ranged up to 50,000 tonnes/day, but during the dry season were as low as 3,000 tonnes/day (*Figure 3-15*). Bedload during the flood season is estimated at up to 5,000 tonnes/day, but during the dry season, is only a few hundred tonnes/day.

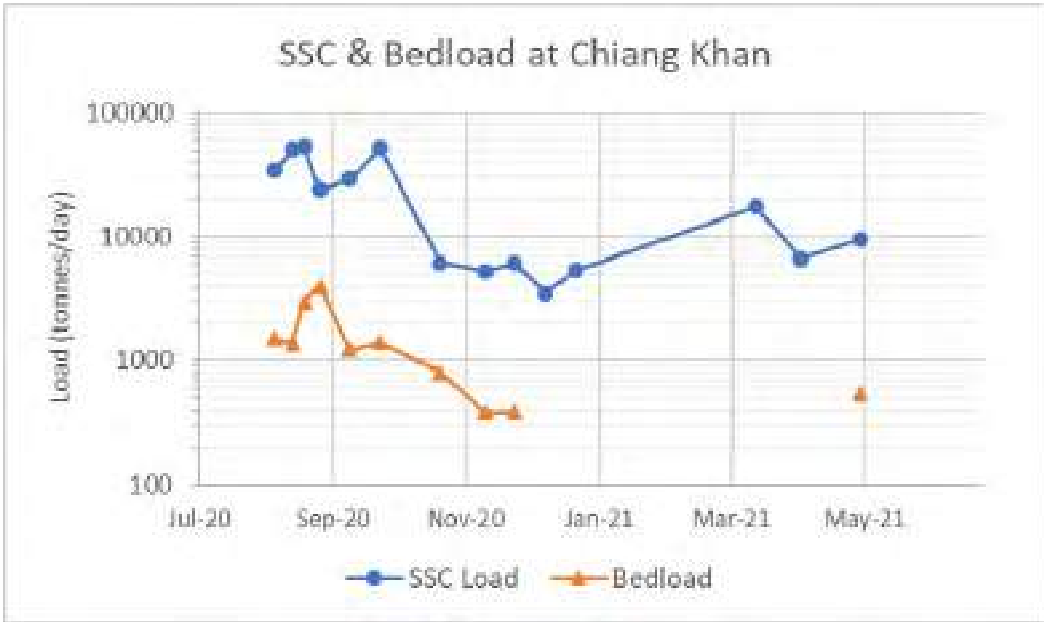


Figure 3-15. Comparison of SSC load and estimated bedload at Chiang Khan from July 2020 to Jun 2021.

Compared to the long-term SSC load measurements at Chiang Khan (*Figure 3-16*), the July 2020 to June 2021 results are similar to the 2019 results, with both years having the lowest recorded loads on record. These years have been very dry, which accounts for some of the reduction compared to historical values. However, the increase in the number of operating tributary dams located upstream of Chiang Khan, and the commissioning of Xayaburi in 2018 are also likely to have contributed to the decrease.

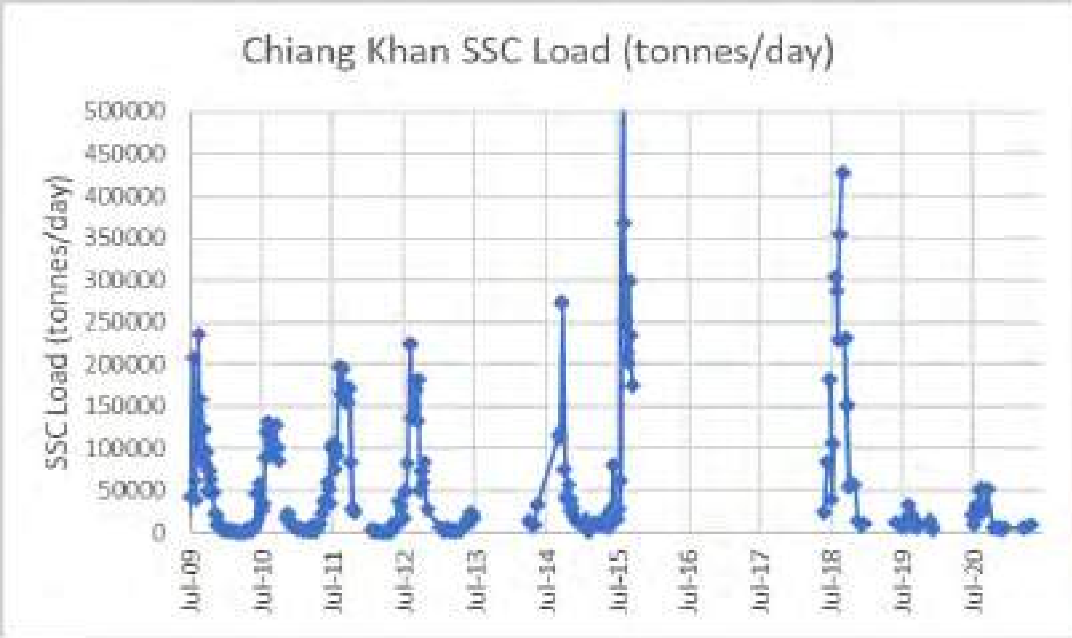


Figure 3-16. Long-term SSC results for Chiang Khan based on DSM sampling.

3.1.3 Lessons learned and Recommendations

The implementation of the water level sites at Ban Xanghai and Ban Pakhoung and the delivery of equipment required longer than expected due to Covid related delivery, distribution and training constraints. This prevented JEM monitoring from capturing wet season conditions at the new sites. In spite of this, new insights have been gained during the trial and the DSM teams have received valuable training. New information includes:

- An indication that water level recording at Ban Xanghai can be used to measure flow entering the Xayaburi impoundment, although additional results are required for confirmation
- An understanding of water level fluctuations associated with the operation of the Xayaburi power station, and how the fluctuations dissipate between Ban Pakhoung and Chiang Khan
- An improved understanding of water velocities at Ban Xanghai and Ban Pakhoung with velocities remaining sufficiently high to promote bedload transport even during the dry season. This will assist with the understanding of geomorphic change in the river

Additional 'lessons learned' are provided following the basin wide analysis in Section 5.

Based on the JEM Pilot experience the following recommendations are provided:

- An in-depth analysis of water level changes at Ban Xanghai should be completed once there are water level results available for high flow as well as low flow to determine whether the site is affected by backwater from the Xayaburi impoundment, and if so, under what conditions;
- Every effort should be made to contract someone to manually read the water level gauge at Ban Pakhoung at least once per day to ensure continuity of the water level record;
- It is recommended that the automatic water level recorder at Ban Pakhoung and Chiang Khan be checked and calibrated during each discharge measurement to minimise the risk of equipment failure. Ongoing capacity building in the maintenance of the water level gauge should be provided to the field teams to ensure high quality measurements are continually collected and the continuity of measurement is maintained;

- Rating curves at Ban Xanghai and Ban Pakhoung should be derived following the collection of additional high flow measurements. This will allow the conversion of the continuous water level readings into flow measurements;
- The rating curve at Chiang Khan should be reviewed using results collected since the curve was derived in 2013. The review should review and compare measurements collected with a current meter and ADCP to establish whether there is a systematic change since the change to the ADCP technology. The curve should be updated as required, and continually reviewed due to the shifting nature of the river bed near the station;
- Laboratory review / training in the determination of bed material grain-size distribution analyses should be completed to ensure the methodology is being accurately implemented

3.2 Water quality

3.2.1 Water Quality Results and data analysis

3.2.1.1 Surface water results

The results of the analyses of the surface water samples at the Xayaburi JEM sites (WQ1 to WQ5) are presented in ***Table 3-1*** to ***Table 3-3***. They are presented with the corresponding monthly routine WQMN analyses for the Luang Prabang and Vientiane sites (above and below Xayaburi) for reference. These are analysed in three different groupings – i) General water quality parameters, ii) nutrients and phytoplankton, and iii) indicators of poor water quality.

General water quality parameters

Table 3-1 shows the median, maximum and minimum and standard deviation of the Xayaburi pilot site results for Temperature, pH, Conductivity, Total Suspended Solids (TSS) and Turbidity, for the months of October 2020 to June 2021 for the related stations from upstream to downstream of Xayaburi. The monthly results for the same period are shown in Annex 2, with a gap for May 2021, when no samples could be taken due to COVID travel restrictions. Turbidity readings were not taken for the two routine monitoring sites of Luang Prabang and Vientiane, and TSS measurements were not made for WQ2, WQ3 and WQ5.

These results have been plotted as box and whisker charts for each site over the complete set of eight monthly readings from October 2020 to June 2021.

There are some consistently obvious difference between the routine WQMN results at Luang Prabang and Vientiane compared to the JEM pilot stations around Xayaburi, which may be due to sampling equipment differences, for example in ***Figure 3-17*** which shows higher Temperatures being recorded at Luang Prabang and Vientiane compared to the JEM WQ stations, and the slightly higher pH readings above 8 of the JEM sites compared to below 8 at the WQMN sites. In the future, WQMN and JEM sampling equipment should be calibrated appropriately, and if necessary, compared to confirm or eliminate these differences.

Within the set of JEM stations around Xayaburi, there are very little differences shown above, in the impoundment and below the dam in Temperature and pH, although there is a slightly higher Temperature range at the stations in the impoundment and below the dam compared to WQ1 above the impoundment. pH is very consistently the same in the impoundment and below the dam, albeit higher than at WQ1.

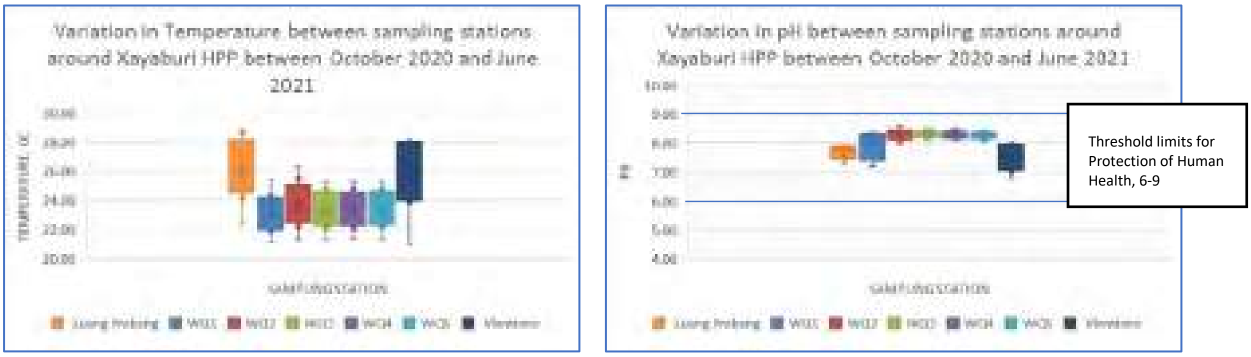


Figure 3-17: Box and whisker charts of Temperature and pH results between October 2020 to June 2021.

Note: On left) Temperature. Right) pH for sampling stations above and below Xayaburi.

Considering *Figure 3-17* showing the box and whisker charts for Conductivity and Dissolved Oxygen, the results for the WQMN station at Vientiane shows a much greater range of results for Conductivity, while the other stations have medians between 25 and 30 mS/m. For Dissolved Oxygen (DO) there are very little differences between the medians of any of the sites ranging between 6 and 8 mg/l, and in no case does the minimum fall below the 5 mg/l threshold of the Aquatic Health Guideline. In October 2020, the DO levels at the two downstream stations, WQ4 and 5, fell below 6 mg/l, but these lower levels have not been repeated.

Table 3-1: Xayaburi JEM Pilot Results for Temperature, pH, Conductivity, Dissolved Oxygen (DO), Total Suspended Solids (TSS) and Turbidity, October 2020 to June 2021

Station Name	Statistic	TEMP_°C	pH	COND_mS/m	DO_mg/L	TSS_mg/L	Turbidity_FTU
Threshold for Protection of Human Health			6-9	70 - 150	>4		
Threshold for Protection of Aquatic Life			6-9	>150	>5		
Luangprabang	Median	25.95	7.75	29.15	7.39	50.22	
	Max	28.80	7.91	46.20	8.09	92.52	
	Min	22.36	7.30	20.30	6.80	2.90	
	Standard Deviation	2.01	0.21	7.62	0.44	29.56	
WQ1	Median	23.2	8.24	26.70	7.1	21.7	16.2
	Max	25.4	8.42	37.57	8.0	50.2	32.2
	Min	21.1	7.18	18.90	6.1	9.6	9.0
	Standard Deviation	1.3	0.5	5.8	0.7	13.4	8.70
WQ2	Median	23.3	8.41	29.45	7.0		6.4
	Max	26.4	8.61	37.00	8.8		8.1
	Min	21.3	7.96	23.00	6.5		3.5
	Standard Deviation	1.6	0.2	4.0	0.8		1.40
WQ3	Median	23.4	8.37	29.50	7.3		6.7
	Max	25.3	8.54	36.79	8.8		9.8
	Min	21.3	8.12	22.80	6.1		4.4

Station Name	Statistic	TEMP_°C	pH	COND_mS/m	DO_mg/L	TSS_mg/L	Turbidity_FTU
	Standard Deviation	1.2	0.1	4.3	1.1		1.70
WQ4	Median	23.4	8.41	29.50	7.3	6.1	6.3
	Max	25.3	8.51	38.20	8.8	111.0	9.7
	Min	21.4	8.14	22.80	5.8	3.0	4.4
	Standard Deviation	1.2	0.1	5.0	1.1	41.6	1.60
WQ5	Median	23.4	8.36	29.50	7.5		6.1
	Max	25.3	8.45	38.17	9.0		9.4
	Min	21.3	8.04	22.90	5.4		4.4
	Standard Deviation	1.2	0.1	4.9	1.2		1.50
Vientiane	Median	26.7	7.63	30.75	7.0	11.8	
	Max	28.1	7.97	32.90	8.5	88.3	
	Min	20.9	6.79	10.40	6.0	5.0	
	Standard Deviation	2.4	0.4	9.2	0.8	28.7	

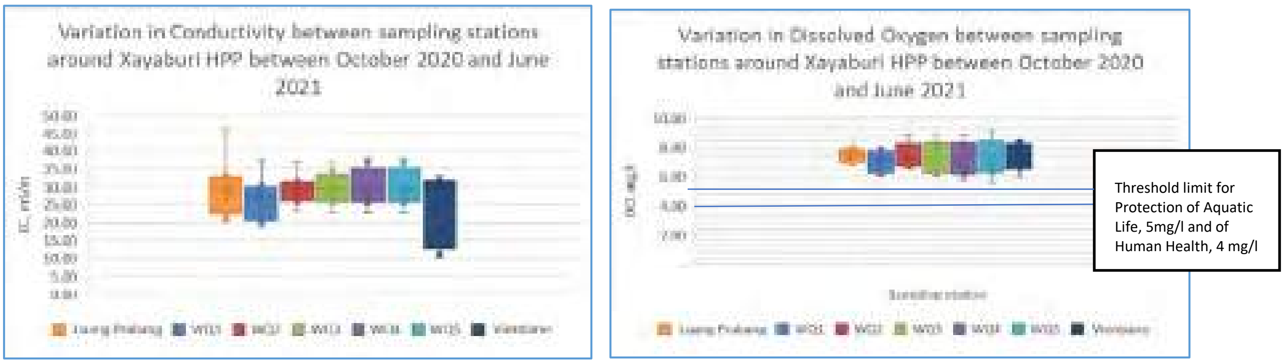
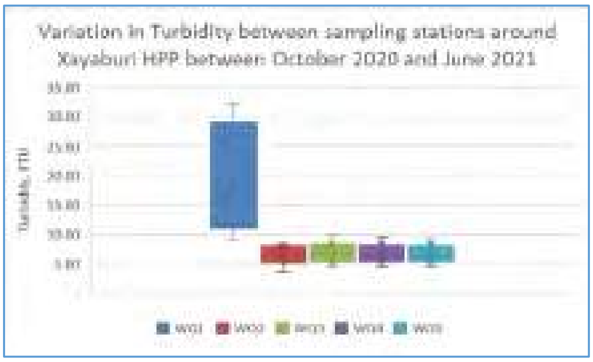


Figure 3-18: Box and whisker charts for Conductivity and DO results between October 2020 to June 2021.

Note: On left) Conductivity. Right) Dissolved Oxygen for sampling stations above and below Xayaburi.

Figure 3-18 shows the box and whisker charts for turbidity and TSS. The turbidity readings at WQ1 are much higher (median reading of 16 FTU) than in the impoundment and three downstream stations which have very similar medians around 6 FTU. The statistical analysis described in section 3.2.1.2, indicates that there is significant difference between the upstream turbidity readings and those in the impoundment and downstream sites. This reflects the sedimentation process in the slower moving water of the impoundment passing lower sediment concentrations to downstream stations, with reduced FTUs.

The picture shown by the TSS results is less easy to interpret, since the Luang Prabang and WQ1 site should be similar, but nevertheless they are both higher than the medians of WQ4 downstream of the Xayaburi dam, and the Vientiane WQMN station. Despite a large range in TSS at WQ 4 the median TSS is under 5 mg/l and 7.3 mg/l at Vientiane. The large range at WQ4 could reflect some operational event or bank erosion caused by fluctuations in water levelat Xayaburi in November 2020, but since we do not have an information about operations at Xayaburi during this time, it is hard to interpret. The lower TSS content at Vientiane compared to Luang Prabang may reflect the sedimentation within the impoundment, since there is very little opportunity for addition of TSS between Xayaburi and Vientiane from tributaries, especially during this low flow period.



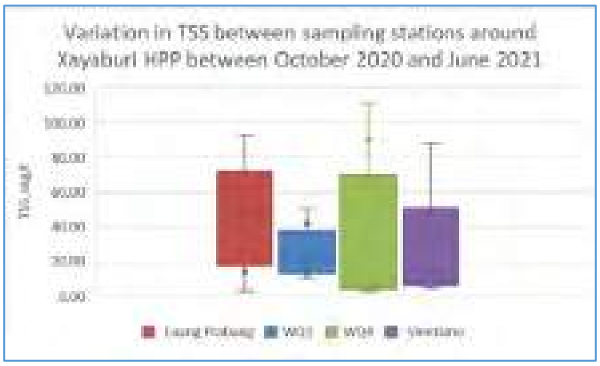


Figure 3-19: Box and whisker charts for Turbidity and TSS results between October 2020 to June 2021.

Note: On left) Turbidity, and right) Total Suspended Solids for sampling stations above and below Xayaburi.

Nutrients and Phytoplankton

The median, maximum, minimum and standard deviation monitoring results for nutrients and phytoplankton around the Xayaburi sampling stations between October 2020 and June 2021 are shown in *Table 3-2* with detailed monthly results shown in Annex 2, noting that phytoplankton measurements were not made at the routine WQMN stations of Luang Prabang and Vientiane, and Total Nitrogen (Tot_N) was not analysed at WQ2, 3 and 5.

Table 3-2: Xayaburi JEM Pilot Results for Nutrients and Phytoplankton, October 2020 to June 2021

Station Name	Statistic	NO32_mg/L	ToTN_mg/L	TotP_mg/L	Chlorophyll A_ug/L	Cyano Bacteria_ug/L
Threshold for Protection of Human Health		5		NA		
Threshold for Protection of Aquatic Life		0.5		0.13		
Luangprabang	Median	0.30	0.70	0.02		
	Max	0.55	3.22	0.12		
	Min	0.03	0.34	0.01		
	Standard Deviation	0.18	0.87	0.04		
WQ1	Median	0.44	1.16	0.04	1.2	0.0
	Max	0.66	4.18	0.09	3.2	1.2
	Min	0.29	0.35	0.01	-	-
	Standard Deviation	0.1	1.1	0.03		
WQ2	Median	0.44		0.02	1.4	0.1
	Max	0.72		0.07	3.2	1.3
	Min	0.25		0.01	0.2	-
	Standard Deviation	0.1		0.02		
WQ3	Median	0.38		0.04	0.6	-
	Max	0.90		0.05	1.7	1.2
	Min	0.29		0.01	-	-
	Standard Deviation	0.2		0.01		

Station Name	Statistic	NO32_mg/L	ToTN_mg/L	TotP_mg/L	Chlorophyll A_ug/L	Cyano Bacteria_ug/L
WQ4	Median	0.46	0.98	0.03	0.6	0.0
	Max	0.84	3.44	0.10	1.9	1.1
	Min	0.15	0.33	0.01	-	-
	Standard Deviation	0.2	0.9	0.03		
WQ5	Median	0.52		0.02	0.5	-
	Max	0.85		0.06	1.6	1.3
	Min	0.30		0.01	-	-
	Standard Deviation	0.2		0.02		
Vientiane	Median	0.22	0.43	0.02		
	Max	0.37	3.53	0.05		
	Min	0.06	0.36	0.01		
	Standard Deviation	0.1	1.0	0.02		

These results have been plotted as box and whisker charts of the median, maximum and minimum results for each site over the complete set of eight monthly readings from October 2020 to June 2021.

Figure 3-20 shows the box and whisker charts for the two nutrients nitrate/nitrite (NO32) and Total Phosphorus (TotP). In March 2021 at WQ3 and WQ4, the NO32 results show outliers of 1.69 and 1.54 mg/l, but still below the threshold of 5 mg/l for Protection of Human Health. The very high TotP in December 2020 in WQ1, 2 and 3 (between 4.2 and 6.5 mg/l) have been eliminated as probable sampling errors, since these high values were not picked up in the Luang Prabang and Vientiane samples during that month. These high TotP values are more than between 2 – 4 times higher than have ever been recorded in the WQMN since 2010 as shown in *Table 3-3.* The Lao WQ team have indicated that at the time of sampling in December 2020 there was heavy use of the river for washing and bathing, which may have introduced phosphate from detergents, but this would not necessarily account for the high values also recorded at Don Sahong during December 2020.

Table 3-3: Occasions when TotP concentrations have been recorded above 1.00 mg/l

StationID	MRC_WQMStandardCode	CollectedDate	Year	Month	TOTP_mg/L
H010500	LA_010500_[Houa Khong]	7/25/2014	2014	7.00	2.20
H010500	LA_010500_[Houa Khong]	8/25/2015	2015	8.00	1.08
H011200	LA_011200_[Luang Prabang]	7/18/2014	2014	7.00	1.40
H011901	LA_011901_[Vientiane KM4]	5/21/2014	2014	5.00	1.50
H013900	LA_013900_[Pakse]	2/16/2015	2015	2.00	1.10
H013900	LA_013900_[Pakse]	8/20/2015	2015	8.00	2.00
H014501	KH_014501_[Stung Treng]	6/25/2014	2014	6.00	1.15
WQ1	LA_010701_[Ban Xangha]	12/14/2020	2020	12.00	**4.65**
WQ2	LA_011502_[Ban Talan]	12/18/2020	2020	12.00	**6.50**
WQ3	LA_011503_[Xayaburi Dam 2km_down]	12/15/2020	2020	12.00	**4.20**
WQ5	LA_011506_[Ban Pakhoung 5km_down]	12/15/2020	2020	12.00	**1.04**
WQ7	LA_013307_[Don Sahong_Impoundment]	12/15/2020	2020	12.00	**4.60**
WQ9	LA_013309_[Don Sahong_DonSadam2]	12/16/2020	2020	12.00	**8.20**

The medians for NO32 at Luang Prabang and Vientiane (between 0.3 and 0.2 mg/l respectively) are consistently lower than at the JEM WQ stations, which showed variation between 0.35 to 0.5 mg/l, with little pattern of increase or decrease between the upstream and downstream of Xayaburi. The TotP results show medians of between 0.02 and 0.04 mg/l with no obvious pattern between upstream and downstream sites. The Total Nitrogen figures which represent nitrogen, both dissolved and bound on the solids are shown in *Figure 3-21.* The medians all lie within the range of 0.5 to 1.25 mg/l, although outlying high values were recorded at all sites in November 2020, at the same time as relatively high values of Total Suspended Solids.

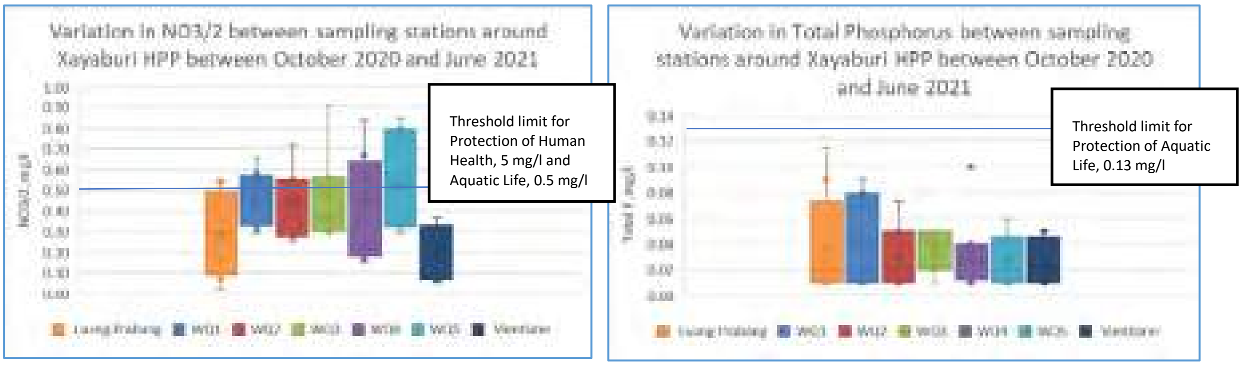


Figure 3-20: Box and whisker charts for NO32 and TP results between October 2020 to June 2021.

Note: On left) NO32 and right) Total Phosphorus for sampling stations above and below Xayaburi. Large outlier results in both Nitrate/nitrite and TotP have been eliminated from these charts

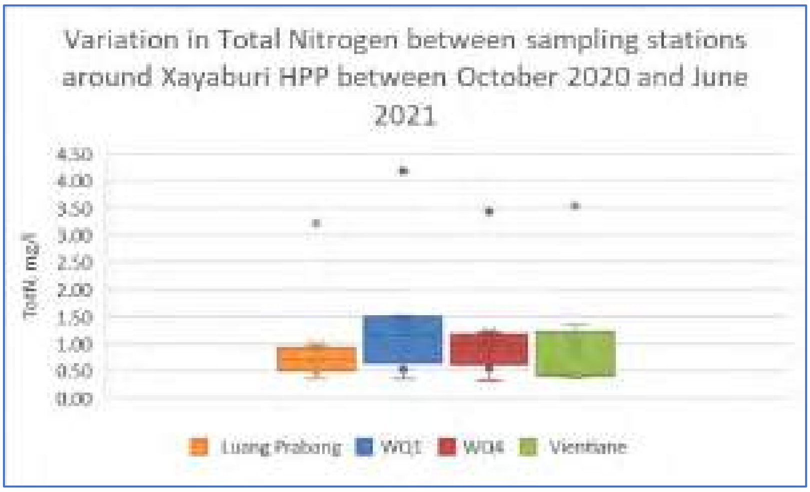


Figure 3-21: Box and whisker chart for TN results between October 2020 to June 2021 at sampling stations above and below Xayaburi.

The variation in phytoplankton - Chlorophyll-a and Cyanobacteria - in the five JEM sites around Xayaburi are shown in *Figure 3-22*. The median values for Chlorophyll-a for WQ1 and in the impoundment are relatively higher than in the three downstream sites, with WQ1 and WQ2 ranging between 1.2 to 1.5 micrograms/litre, compared to 0.5 to 0.6 micrograms/litre for WQ3, WQ4 and WQ5. The statistical analysis reported below shows that the Chlorophyll-a in the impoundment (WQ 2) is more frequently significantly higher than WQ1 and WQ3 and WQ4 and 5 are less frequently different from WQ3. This would indicate the tendency for algal growth to occur within the impoundment.

For Cyanobacteria, the median levels are generally very low for all sites below the dam, but there are much higher values recorded at all sites during January 2021, seen as the outliers in ***Figure 3-22***, which reflects a possible Cyanobacteria bloom event. This event will be discussed later when considering the monthly changes between sites as seen in ***Figure 3-27***.

There is a well-established relationship that relates nutrient concentrations to the occurrence of Cyanobacteria. A Water Quality Research Australia (2010) states that “the maximum population size or “carrying capacity‟ of a lake is controlled by the concentration of total phosphorus. As a simple guide, a total phosphorus level of 10 – 25 µg/l presents a moderate risk to support the growth of Cyanobacteria. For levels of less than 10 µg/l there is a low risk of Cyanobacterial growth, and a level greater than 25 µg/l provides high growth potential.”

Table 3-4: Assessment of the potential for Cyanobacterial growth based on environmental parameters

	Environmental factor			
Potential for Cyanobacterial Growth	History of Cyanobacteria	Water Temperature (°C)	Nutrients Total Phosphorus (µg L^{-1})	Thermal Stratification
Very Low	No	<15	<10	Rare or Never
Low	Yes	<15-20	<10	Infrequent
Moderate	Yes	20-25	10-25	Occasional
High	Yes	>25	25-100	Frequent and persistent
Very High	Yes	>25	>100	Frequent and persistent/strong

Source: Water Quality Research Australia Limited (2010). Management Strategies for Cyanobacteria (Blue-Green Algae) and their Toxins: a Guide for Water Utilities. Research Report 74.

In this context the median TotP results ranging between 0.02 and 0.04 mg/l or between 20 and 40 µg/l with occasional higher values of TotP in some months would indicate that there is a moderate to high risk of Cyanobacteria blooms occurring. The very high values of TotP recorded in December 2021, may have given rise to the higher Cyanobacteria concentrations in January 2021.

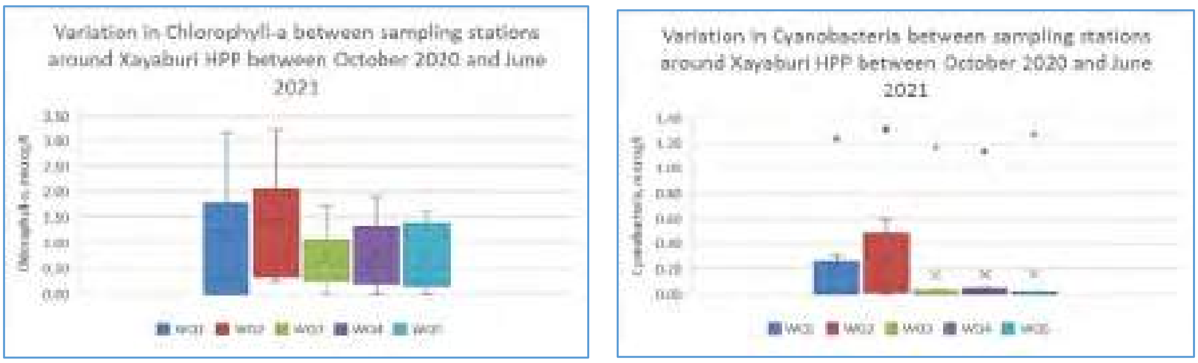


Figure 3-22: Box and whisker charts for Chlorophyll-a and Cyanobacteria results between October 2020 to June 2021.

Note: Shown on left) Chlorophyll-a and right) Cyanobacteria for sampling stations above and below Xayaburi. All the outliers of Cyanobacteria indicated on the chart occurred on 13 January 2021.

Indicators of poor water quality

The median, maximum, minimum and standard deviation of the monthly results for Ammonium, Chemical Oxygen Demand and Faecal coliforms for the Xayaburi JEM sites are shown in *Table 3-5***.** The detailed monthly results are shown in Annex 2. These measurements have only been made at the Luang Prabang station, WQ1, WQ4 and at Vientiane. Box and whisker charts for COD and Ammonium are presented in *Figure 3-23*. For Ammonium the median values are relatively low up to about 0.05 mg/l, but with one outlier at WQ4 in October 2021 recorded at 0.45 mg/l, which is above the threshold guideline for aquatic life (0.1 mg/l) but below the threshold guideline for protection of human health (0.5 mg/l).

Table 3-5: Xayaburi JEM Pilot Results for indicators of poor water quality, October 2020 to June 2021

Station Name	Statistic	NH4N_mg/L	CODMN_mg/L	FC _MPN/100ml
Threshold for Protection of Human Health		0.5	5	1,000cells/100ml
Threshold for Protection of Aquatic Life		0.1	NA	
Luangprabang	Median	0.01	1.26	40.00
	Max	0.06	4.93	220.00
	Min	0.01	0.10	18.00
	Standard Deviation	0.02	1.39	63.48
WQ1	Median	0.03	1.9	110.0
	Max	0.07	8.1	180.0
	Min	0.01	0.4	45.0
	Standard Deviation	0.0	2.3	42.0
WQ2	Median			
	Max			
	Min			
	Standard Deviation			
WQ3	Median			
	Max			
	Min			
	Standard Deviation			
WQ4	Median	0.01	1.3	45.0
	Max	0.45	3.2	110.0
	Min	0.01	0.4	18.0
	Standard Deviation	0.1	0.9	34.2
WQ5	Median			
	Max			
	Min			
	Standard Deviation			
Vientiane	Median	0.01	1.2	31.9
	Max	0.05	9.3	78.0
	Min	0.01	0.4	110.0
	Standard Deviation	0.0	2.7	20.0

For COD, the median values for all sites vary between 1 and 2 mg/l, but with occasional outliers at Luang Prabang, WQ1 and Vientiane. These occur at Vientiane in October with a COD of 9.3 mg/l, at

WQ1 in February 2021 with a COD value of 8.11 mg/l, and at Luang Prabang in January 2021 with COD at 4.93 mg/l. These are approaching or over the threshold values for the protection of Human Health, representing occasional pollution events. These higher COD events do not occur downstream of the Xayaburi dam.

For Faecal Coliforms, the median results for Luang Prabang, WQ1 and WQ4 are shown in ***Figure 3-24***, with Luang Prabang and WQ4 showing below 50 MPN/100 ml, with one outlier of 220 MPN/100 ml at Luang Prabang in January 2021. For WQ1 the median value is about 110 MPN/100 ml. At all of these sites the values are lower than the Protection of Human health threshold value of 1,000 MPN/100 ml recommended for water activities, e.g. boating and fishing. The site at WQ4 downstream of the dam shows are limited range of values between 0 and 100 MPN/100 ml.

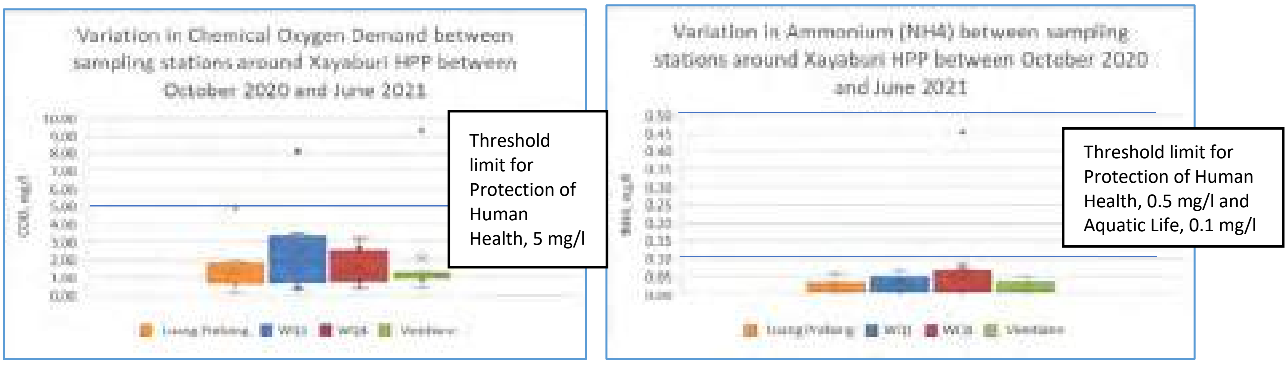


Figure 3-23: Box and whisker charts for COD and Ammonia results between October 2020 to June 2021.

Note: shown on left) COD and right) Ammonium for sampling stations above and below Xayaburi.

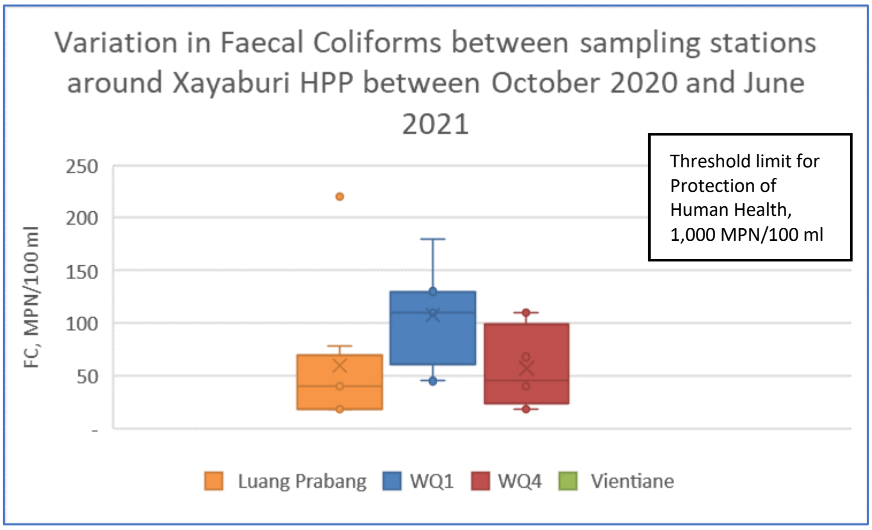


Figure 3-24: Box and whisker charts for Faecal Coliform results between October 2020 to June 2021.

Note: Shown for Faecal Coliforms for sampling stations above and below Xayaburi.

3.2.1.2 Statistical analysis

Changes in water quality parameters based on field measurements in the vicinity of Xayaburi dam were statistically evaluated. For each parameter there were 7 measurements taken at each of 5 sites which allowed difference between sites to be assessed using t-tests to establish whether differences were likely to be due to differences between the sites or simply due to random variation. The null hypothesis tested in each comparison was that there was no difference, and a probability value of $p < 0.05$ was taken as evidence that there was a difference.

For the purposes of comparison all Dissolved Oxygen measurements were converted to percent saturation thus eliminating the confounding effects of Temperature and salinity, both of which influence Oxygen solubility in water. Results were available for 8 months.

General patterns evident:

The statistical results are presented in Annex 4, and ***Figure 3-25*** shows the statistical comparisons between adjacent sites over the 8 month period. Over the course of the sampling program the most substantial changes occurred between sites 1 and 2 and between sites 2 and 3. An indication of the extent of the change is in the proportion of parameters that were statistically significantly different between the pairs of sites. With data available for 8 months and 7 parameters allowing 56 comparisons there were 38 significantly different pairs of measurements between sites 1 and 2 and 39 significantly different between sites 2 and 3. Between sites 3 and 4 and sites 4 and 5 there were 16 and 19 significantly different pairs respectively. That is not surprising. Site 2 was located within the impoundment and was thus expected to be the most different to riverine sites although the data suggest that site 1 may not always have been a riverine site.

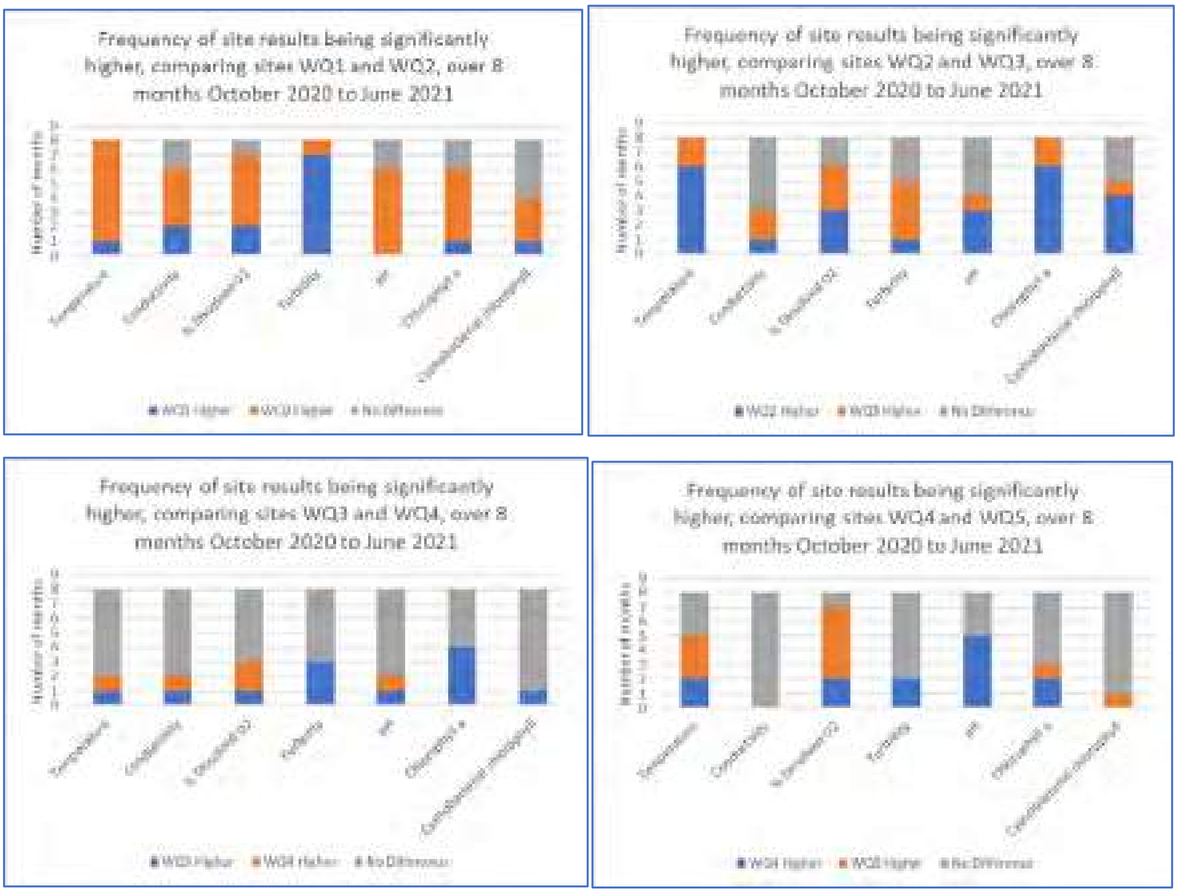


Figure 3-25: Comparing frequency of results being significantly higher in sites across Xayaburi HPP

Between Sites 1 and 2.

Water Temperature increased as the water flowed from site 1 to site 2 in 6 of the 8 months, decreased in June and was unchanged in March. Presumably the reduced turbulence and slower water movement in the impoundment allows the water to warm up as it passes downstream. A similar increase was seen between sites 2 and 3, which also included water passing through the impoundment. There was not such a strong pattern between sites downstream of site 3.

Conductivity generally increased or remained unchanged between sites 1 and 2. On one occasion, in April, it decreased. The salts which contribute to Conductivity are conservative. Unlike nutrients or gasses they remain within the water and are not lost and only gained if saline water enters the river. The increases in Conductivity between sites 1 and 2 in November, December, January and June were presumably a consequence of evaporative loss of water from the pondage, and the decrease in April must have been caused by inflows of lower conductivity water from the two tributaries between the sites. Changes in conductivity were also evident between sites 2 and 3, which would also have been due to impoundment evaporation. There we no changes evident between sites 4 and 5, and the changes between sites 3 and 4 were very small (< 0.3%), and not environmentally significant.

Turbidity dropped significantly between the two sites in every month. Chlorophyll concentrations increased between the sites in 5 months and dropped on one. Chlorophyll levels were generally relatively high at site 2, and the increase in pH between the sites in six of the eight months is probably reflective of algal production. Algae, as they grow, extract CO_2 from the water which makes the water less acidic. Algae, as they photosynthesize and grow, release Dissolved Oxygen to the water which probably explains the increase in oxygen saturation in 5 months.

The saturation of Dissolved Oxygen in a turbulent river is normally maintained at more than about 80% because of physical aeration. When river water flows into an impoundment the turbulence decreases and the saturation of oxygen will fall. If there is active phytoplankton photosynthesis in the impoundment the oxygen saturation may increase, at least during the day, with maximum saturation reached at the downstream end of the impoundment. Water exiting the impoundment, if it is not withdrawn from a deoxygenated layer near the bed of the reservoir, may be well saturated with oxygen, and due to turbulent reaeration downstream will re-equilibrate with the atmosphere.

The comparatively low percentage saturation of oxygen at site 1 in December, February, March and April suggests that this site may have been located within the impoundment at those times. The upstream boundary of the pondage will vary depending on the water level in the impoundment, moving upstream when the impoundment water level is higher, and downstream when the impoundment water level is lower.

Between Sites 2 and 3.

Temperature mostly decreased between site 2, in the impoundment, and site 3, about a kilometre downstream. That may have been due to evaporative cooling during the slow movement of the water through the impoundment downstream of site 2 prior to exiting the to the river channel and flowing to site 3. Turbidity was significantly higher at site 3 on 6 of the eight months, presumably because the turbulent water maintained more particulates in suspension. The other parameters showed less consistent changes.

Between sites 3 and 4

As noted only 19 of the 56 parameter comparisons showed statistically significant differences between the sites, and for most parameters the differences were inconsistent. The exception was pH which was significantly higher at site 4 on 4 occasions and showed no difference on the remaining 4. The data for January are not reliable, identical values were entered for pH, Conductivity, turbidity and Temperature for both sites 4 and 5 which must indicate an error in data entry.

Dam Impacts

One means of identifying the impact of the dam on water quality is to compare between the data collected at site 1, the upstream site and the combined data for sites 4 and 5 the most downstream riverine sites. We can test for statistical differences in results between the sites, but also look to see whether any statistically significant differences are large enough to be environmentally important. We have done comparisons for the data from March and April, when river discharges are low and October, a month when discharges are higher. There are no data from July to September which is usually the highest flow season.

In March and April all but one of the parameters were statistically significantly different between site 1 and sites 4 and 5. The sole exception being Cyanobacterial chlorophyll in March which showed no difference. During the low flow months Temperatures were similar between the upstream and downstream sites, and the pattern differed between the two months, so was probably influenced more by the time of day when sampling occurred than by the impoundment. Conductivity was consistently higher at the upstream site, indicating that during low flow periods there was sufficient lower conductivity water entering the river from tributaries to reduce Conductivity. That was not the case during the high flow month, when the inflow of tributary water would have constituted a substantially lower proportion of the total stream flow.

Dissolved Oxygen and pH were both lower at the upstream site than the downstream sites in the low flow months, and the differences were appreciable. Presumably oxygen was being increased, and pH decreased due to algal primary production in the impoundment. Chlorophyll was higher at the upstream site, indicating higher algal biomass. None of these parameters were different between sites in October when flow was higher, and presumably the passage time of the water through the impoundment was reduced.

By far the largest impact evident from the impoundment was the change in turbidity which dropped very substantially, by more than 40% in each sample set, indicating that the impoundment is trapping large volumes of suspended material at both high and low flows.

3.2.1.3 Monthly changes across Xayaburi JEM pilot sites

The detailed results shown in ***Table 3-1*** to ***Table 3-3*** have been expressed as charts showing the changes in water quality with progress from upstream of the impoundment, within the impoundment itself and downstream of the dam each month. This analysis helps to understand the effects that impoundment and dam operation may have upon the water quality. The charts for Temperature, pH, Conductivity, Dissolved Oxygen and COD are found in ***Figure 3-25*** and the charts for TSS and Turbidity, Nutrients and Phytoplankton are found in ***Figure 3-26***.

There appears to be very little difference in the water Temperature and pH above, in the impoundment and below the dam in any of the months, apart from the generally higher Temperatures already noted at Luang Prabang and Vientiane, and the generally higher pH values at WQ1 to WQ5. Effectively, the Xayaburi dam and impoundment is having very little effect upon the surface Temperatures and pH in the river.

Conductivity changes with passage between WQ1 to WQ5 show very little differences in all months ranging from 20 to 25 mS/m in the last quarter of 2020, and increasing slightly during the dry season months of 2021 to between 30 to 40 mS/m. There is no evidence that the Xayaburi dam and impoundment is affecting the Conductivity of the water.

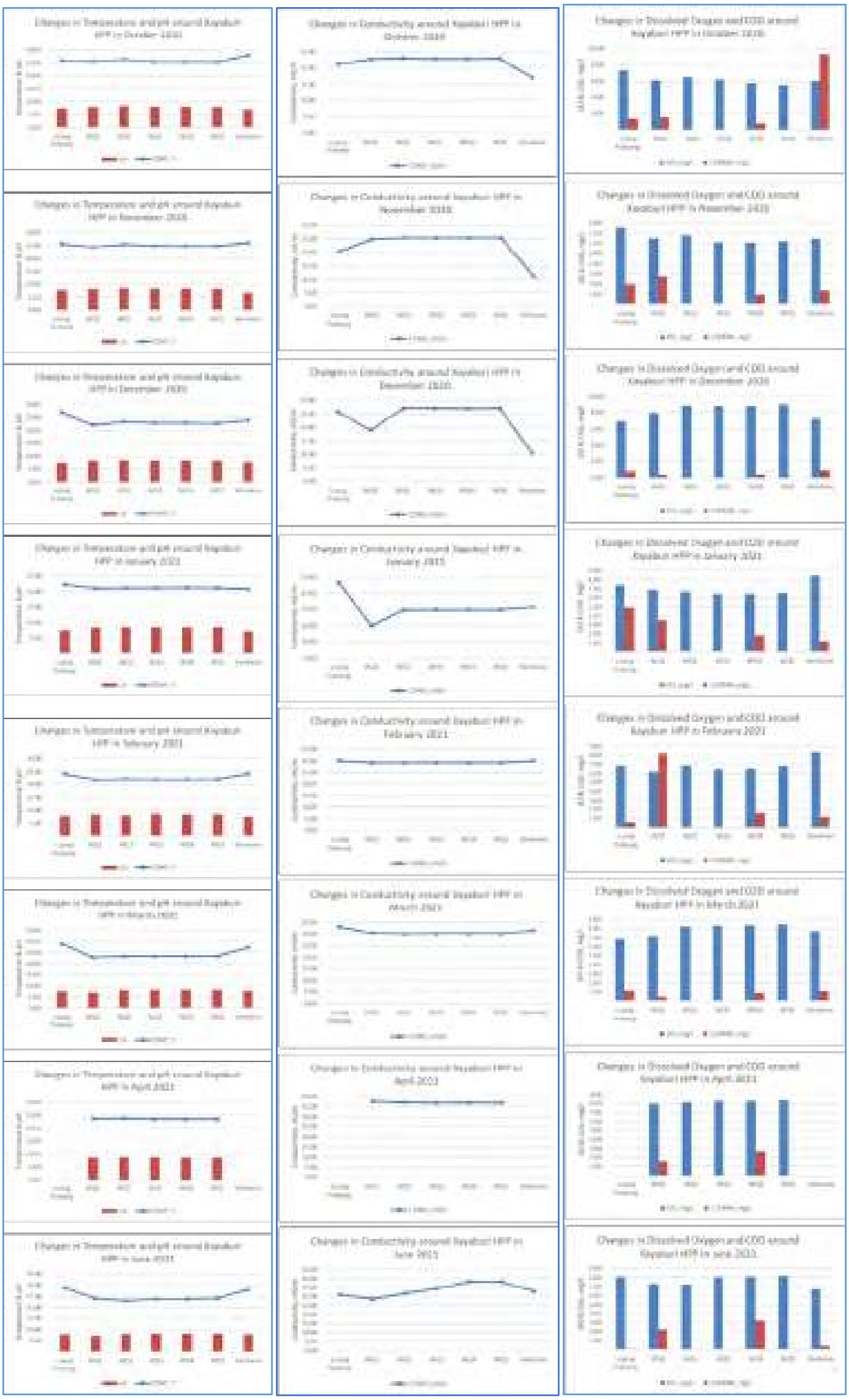


Figure 3-26: Monthly changes in Temperature, pH, Conductivity, DO and COD parameters with passage downstream from WQ1 to WQ5.

Note: Shown on Left) Temperature and pH; Centre) Conductivity and Right) Dissolved Oxygen; and COD. October 2020 to June 2021

Dissolved Oxygen values likewise do not change significantly with passage through the impoundment and downstream of the dam, generally maintaining high DO concentrations of between 6 to 8 mg/l apart from slight reduced values below 6 mg/l in October 2020 at WQ4 and WQ5. Generally all the DO contents of the surface waters are above the threshold for Aquatic Health of 5 mg/l.

For COD, the WQ1 values tend to mirror higher values measured at Luang Prabang, as would be expected, and COD values at WQ4 downstream of the dam are generally lower than those at WQ1, except in April and June 2021, but in no months does the COD at WQ4 downstream of the dam exceed the 5 mg/l threshold for Water Quality Guidelines for the Protection of Human Health[1]. It is concluded that during this period, the impoundment and dam has not had any negative effect upon the COD levels.

Figure 3-26 shows the changes downstream each month for Total Suspended Solids and Turbidity. The patterns to be observed here, with some exceptions, are that the TSS and turbidity are generally higher at WQ1 and Luang Prabang than in the impoundment and downstream of the dam (W2 to WQ5). The TSS at the Vientiane site is more variable, sometimes being low and at other times being comparable to the Luang Prabang site. The high TSS exceptions at WQ4 in November and December 2020, when the TSS values range from 110 to 90 mg/l respectively, can not be immediately explained, and are not complemented by raised Turbidity levels. Generally, the observed pattern of reduced TSS and turbidity values through the impoundment and dam reflect significant sedimentation in the impoundment with little sediment being picked up immediately downstream of the dam.

The changes in nutrients – NO32 and TotP with passage downstream each month do not show very evident patterns of either accumulation within the impoundment or depletion, though during October to December, the values of NO32 are slightly higher in the impoundment and downstream compared to WQ1, while in January and February they are more or less the same, and in March 2020 there are some exceptionally high values (between 1.5 and 1.8 mg/l) at WQ2, 3 and 5. In April and June, there is no distinguishable pattern in the NO32 values.

Similarly for TotP, relatively low levels are maintained with passage downstream in most months, with an exception being the much higher values (>0.2 mg/l) in TotP being recorded at WQ5. No explanation for these high TotP values at this location, unless this is due to the higher TSS values recorded at this time, reflecting the phosphorus content bound to the suspended solids.

The Chlorophyll-a and Cyanobacteria levels seem to show similar or higher Chlorophyll-a content in the impoundment to the inflowing water at WQ1, and generally higher than the downstream sites. The initial three months (October to December 2020) do not show particular patterns, but from February 2021 through to June 2021, the levels of Chlorophyll-a in the upstream and in the impoundment are two to three times higher than the downstream sites.

The one month in which there is a definite pattern is January 2021, when phytoplankton levels are more or less the same throughout the sites (between 1.1 and 1.8 micrograms/l) but with a significantly high proportion of Cyanobacteria. These are the outlier values shown in ***Figure 3-22***. In WQ1 Cyanobacteria make up 66% of the phytoplankton, rising to 82% in WQ2 and then falling to between 60 and 80% at WQ3, 4 and 5. This would indicate that in January there was a minor bloom of blue-green algae throughout this section of the river. However, in all months the Chlorophyll-a concentration was never above 3 and generally below 2 micrograms/l, well below the WHO risk to human health threshold of 50 micrograms/l and below the WHO level of 10 micrograms/l for

[1] MRC (2013) Technical Guidelines on the implementation of the Procedures for Water Quality.

protection from health outcomes not due to cyanotoxin toxicity but to irritative or allergenic effects of other Cyanobacterial compounds. (See Box with WHO threshold levels below)

Box 3-1: WHO recommended threshold levels of Cyanobacteria in freshwater for recreational waters (not drinking water).

"For protection from health outcomes not due to cyanotoxin toxicity, but rather to the irritative or allergenic effects of other Cyanobacterial compounds, a guideline level of 20,000 Cyanobacterial cells/ml (corresponding to 10 µg Chlorophyll-a/litre under conditions of Cyanobacterial dominance) can be derived. A level of 100,000 Cyanobacterial cells/ml (equivalent to approximately 50 µg Chlorophyll-a/litre if Cyanobacteria dominate) represents a guideline value for a moderate health alert in recreational waters. The presence of Cyanobacterial scum in swimming areas represents the highest risk of adverse health effects, due to abundant evidence for potentially severe health outcomes associated with these scums."

Source: World Health Organization. (2003) Guidelines for safe recreational water environments. Volume 1, Coastal and fresh waters.

A study using an Algae Torch was carried out in the Vietnam sections of the Mekong Delta between January and April 2015 by Trung Bui-Ba et al. (2016)[2]. Concentrations of Cyanobacteria were from 3.7 to 14.0 µg Chlorophyll-a/l in upper Delta (An Giang) and from 3.0 to 7.1 µg Chlorophyll-a/l in downstream provinces. A bloom of Cyanobacteria (Microcystis) was found with Chlorophyll-a content of Cyanobacteria of 28.9 µg/l in Travinh province in April. Heavy rain events can disturb Cyanobacterial blooms which can explain decrease of Cyanobacteria in Mekong delta in rainy season.

[2] Trung Bui-Ba, Thanh-Son Dao, Thanh-Son Nguyen, Thi-My-Chi Vo,Lan-Chi Do-Hong, Miquel Lurling (2016). Blue-Green Algae (Cyanobacteria) in Mekong River, Vietnam. Institute for Environment and Resources, Vietnam

Figure 3-27: Monthly changes in TSS, Turbidity, Nutrients, Chlorophyll-a and Cyanobacteria parameters with passage downstream from WQ1 to WQ5.

Note: shown on Left) TSS & Turbidity; Centre) Nutrients (NO32 & TotP) and Right) Chlorophyll-a & Cyanobacteria. October '20 to June '21

3.2.1.4 Impoundment profiles

The impoundment profile, measuring water quality parameters of Temperature, pH, Conductivity and Dissolved Oxygen, turbidity and phytoplankton with depth down to 20 m below the surface each month is used to indicate whether the water in the impoundment is stratifying with cooler and poorer quality water being trapped at lower levels. The monthly water quality profiles for the Xayaburi impoundment at WQ2 are shown in ***Figure 3-29***.

The almost horizontal line plots of Temperature with depth in all months between October 2020 and June 2021 would indicate that there is no thermal stratification. And the pH and Conductivity lines show that there is little chemical stratification in the Xayaburi impoundment. The Dissolved Oxygen content is more or less constant during most months, although in December 2020 and perhaps in January 2021 there is an indication of a decline in DO content with depth falling from about 8 mg/l at the surface to about 5 mg/l at 20 m depth, but even at 20 m the DO content does not fall below the 5 mg/l threshold guideline for Protection of Aquatic Life. This may indicate the beginning of stratification during the colder months of the year, becoming more mixed in February to June. During the wet season months from July to October, the water Temperature is higher with greater flow and increased mixing of inflowing waters, with a lower risk of stratification occurring; however this would need to be confirmed by wet season monitoring. The length of the probe cable at 20 m limits the measurement to this depth, so it is not possible to predict what the water quality will be like near the bottom of the impoundment which is estimated at 35 m.

The more detailed charts of Turbidity and Chlorophyll-a and Cyanobacteria down to 10m depth are shown in ***Figure 3-30***. The turbidity measurements appear to be slightly more variable with depth, and the phytoplankton measurements down to 10 m, generally show variable levels throughout the water column, but without any definite patterns such as declining or increasing with depth. It is clear that generally the Chlorophyll-a has a much higher value than the Cyanobacteria, except in January 2021, when the same high proportions of blue-green algae are found in the water column as at the surface. In other months, there may be a slight increase in Cyanobacteria with depth, but these appear to be marginal increases. Seasonally there may be a tendency for the Cyanobacteria to reduce at the beginning of the rainy season in June 2021, but this would have to be confirmed with analysis of wet season sampling.

A more detailed inspection of the results of other water quality parameters shown in ***Figure 3-26*** and ***Figure 3-27*** in December 2020 and January 2021 has been conducted to consider whether the January 2021 increases in the proportion of Cyanobacteria may be explained. Consideration of seasonal changes in Temperature, shows a decrease in the impoundment from 24^{o}C to 21^{o}C, while pH remains quite stable between December and January; Conductivity and Dissolved Oxygen do not show much difference between December and January, COD shows higher values in WQ1 in January compared to December, but not above the threshold values of 5 mg/l, compared to February when values of 8 mg/l are recorded at WQ1. The Turbidity comparisons between WQ1 and WQ2 in December and January show that there is a consistent decline in Turbidity with passage into the impoundment in both months, though January WQ2 has a slightly lower Turbidity reading through the water column than December (see ***Figure 3-30***). The nutrients may be a factor, NO32 results at WQ2 in both December and January were reading around 0.4 mg/l, but TotP results for WQ2 in December were very high – 6.5 mg/l – compared to 0.01 mg/l in January. These abnormally high results in December had been considered as outliers possibly due to sampling error, but if they were real, this could account for an increase in Cyanobacteria in January.

In addition to considering the chemical parameters, the changes in the water levels of the impoundment in December 2020 to January 2021 are considered in ***Figure 3-28***. The water level in January 13 at the time of monitoring visit was more or less at the mean value of 277 masl. Earlier the water level had been just under 278 masl and was beginning to fall, though the variation in water level during the monitoring period generally was between 276 and 278 masl. There is no marked change in water level that might explain the Cyanobacteria bloom.

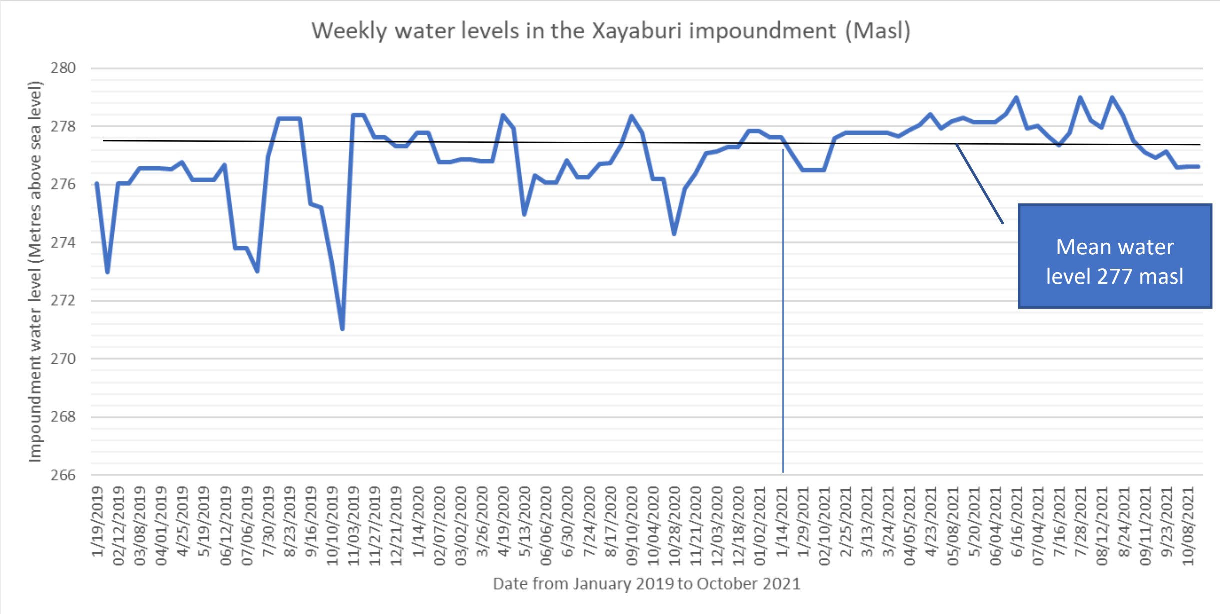


Figure 3-28: Weekly water levels in the Xayaburi impoundment, from Mekong Dam Monitor (Stimson Centre).[3]

[3] https://www.stimson.org/project/mekong-dam-monitor/

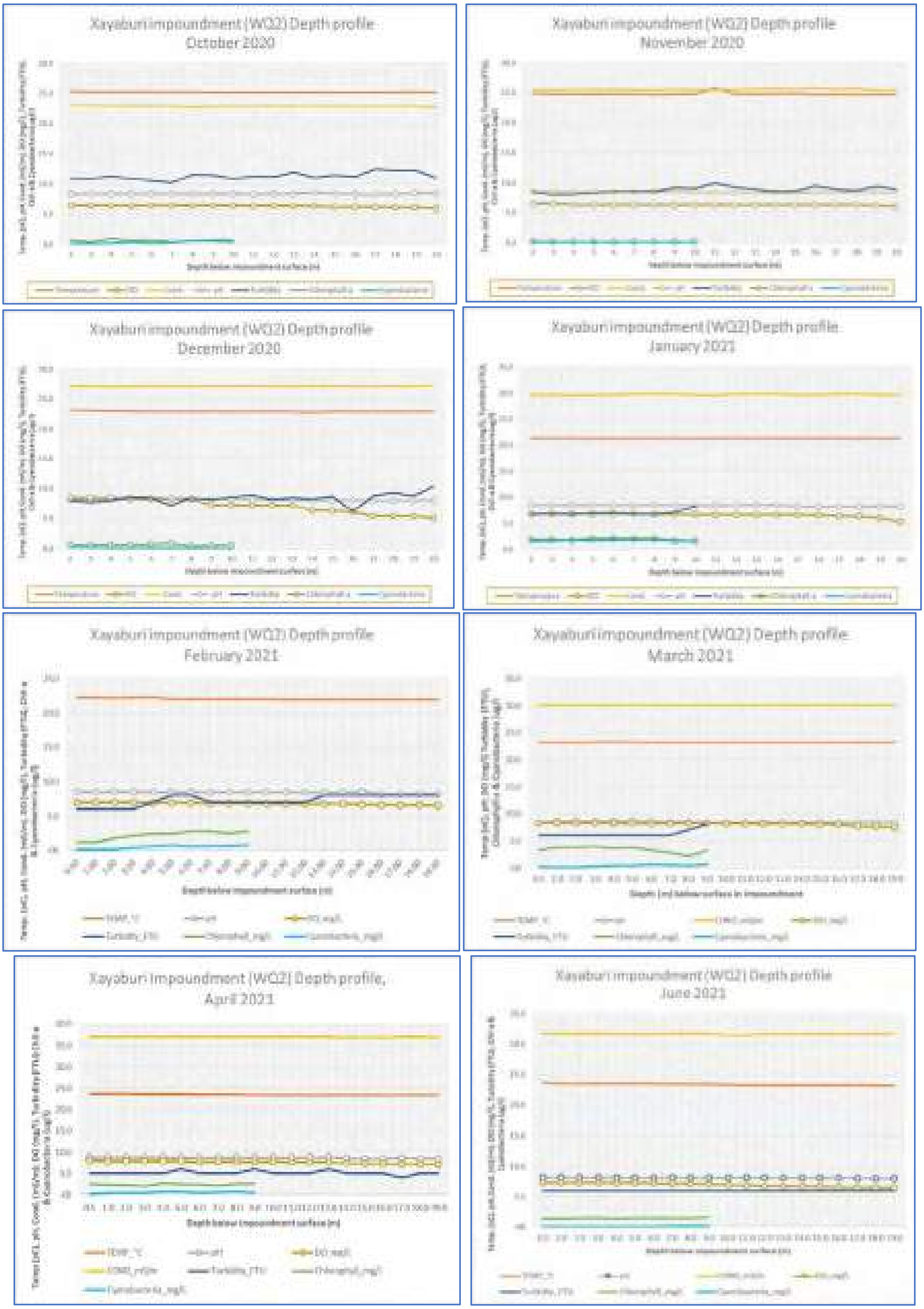


Figure 3-29: Xayaburi impoundment profiles between October 2020 and June 2021

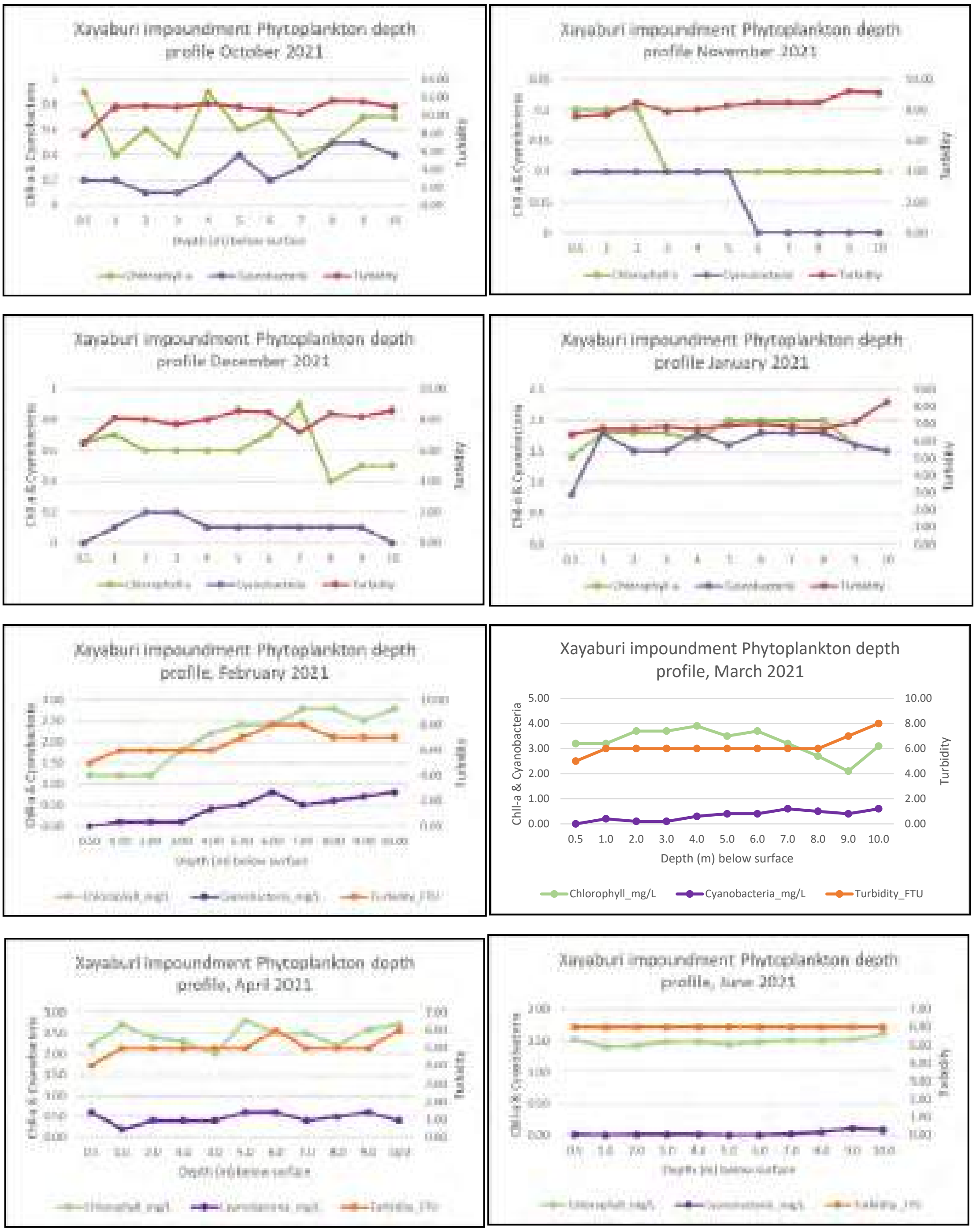


Figure 3-30: Xayaburi impoundment Phytoplankton depth profiles between October 2020 and June 2021

3.2.2 Lessons learned and Recommendations

WQ monitoring in the vicinity for the Xayaburi HPP pilot site has provided the following insights:

- The presence of the Xayaburi dam and impoundment does not appear to be affecting most parameters of water quality measured during the dry season months between October 2020 and June 2021
- The main qualification being that water quality measurements are taken from spot samples during the late morning and early afternoon. They do not capture any changes in water quality

such as Dissolved Oxygen that may fluctuate during the day and night, with lower levels often being recorded at night.

- The main parameters that show changes with passage through the impoundment and below the dam are turbidity and TSS indicating sedimentation processes in the impoundment removing suspended solids.
- Nutrient levels appear to be slightly increased in the impoundment, but not passed on downstream below the dam, though abnormally high levels of Total Phosphorus, as recorded in December 2020, need to be watched in conjunction with phytoplankton blooms.
- There may be a slight indication of higher phytoplankton levels in the impoundment compared to downstream and a probable minor bloom of Cyanobacteria in January 2021.
- Impoundment profiles do not show thermal or chemical stratification, although there may be evidence of declining DO with depth during the colder months of January and February 2021.

These insights lead to the following recommendations for the WQ monitoring protocols:

- In order to capture the diurnal changes in water quality that may occur downstream of the dam, especially in DO, Turbidity and pH a semi-continuous water sampling programme should be installed with the flow and water level monitoring station at WQ4.
- The AlgaeTorch measurements of Chlorophyll-a and Cyanobacteria are providing interesting insights into the relatively low levels and dynamics of phytoplankton, especially in the management of the impoundment.
- There is a relationship between TSS and Turbidity which can be used to determine suspended solid levels in the water, which would allow an immediate value to be recorded without requiring laboratory analysis. The current results of both TSS and Turbidity from the period October to June have few high TSS and Turbidity measurements to compare as shown in *Figure 3-31.* Further measurements are required to confirm this relationship for the Mekong waters, so that it can be used to provide an immediate assessment of the sediment being transported in suspension, rather than taking water samples for upon laboratory analysis. It is noted that the Don Sahong carry out weekly routine measurements of Turbidity, rather than TSS.

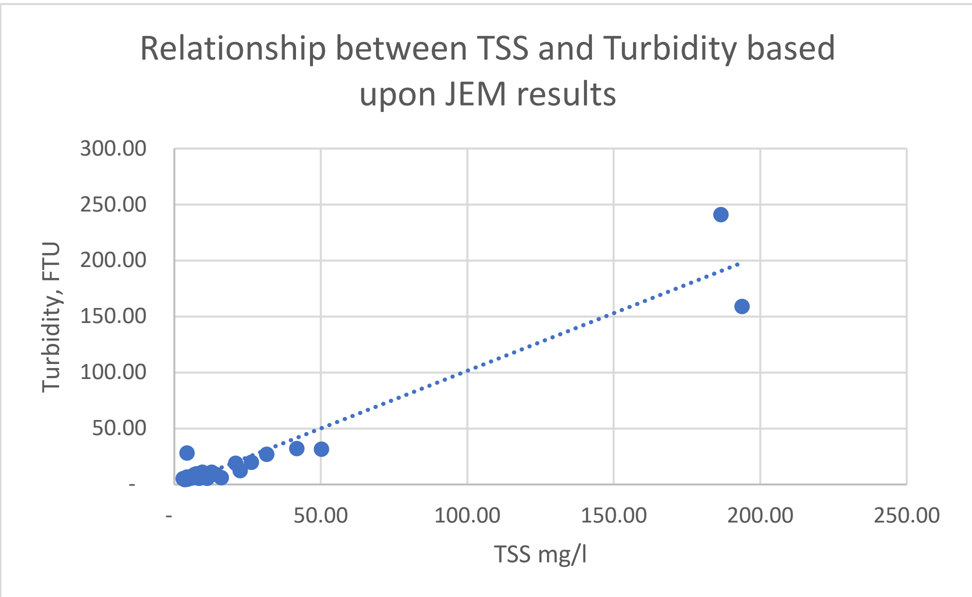


Figure 3-31: Relationship between TSS and Turbidity based on JEM results between October 2020-June 2021

Note: the dots represent the correlated TSS and Turbidity readings on the same samples

3.3 Ecological Health Monitoring

3.3.1 EHM Results and data analysis

3.3.1.1 EHM species counts and EH Index at JEM sites

The Ecological Health Monitoring consists in collecting and identifying the species of four different groups of biota – Benthic Diatoms, Zooplankton, Littoral Macroinvertebrates and Benthic Macroinvertebrates at each of the EHM site. The reference lists in the database contain 435 Diatom species, 360 Zooplankton species, 1,009 Littoral Macroinvertebrate species and 751 Benthic Macroinvertebrate species taken from the whole of the Lower Mekong Basin. These collections are complemented by assessment of the site conditions – suitability of the substrate and site disturbance, and the measurement of environmental parameters such as, Temperature, Dissolved Oxygen (DO), pH, Conductivity, and Secchi Disc (measuring transparency of the water).

The substrate characteristics score is an assessment of the suitability of the river bed habitats for aquatic biota. It is carried out by the team at the time of sampling and is based on their observations of substrate cover in the littoral zone, the embeddedness of the littoral zone substrate, sediment deposition, and the substrate of the deepwater channel. It reflects the geomorphology of the river bed, and is likely to be affected by changes in flow and sediment transport. Variation in the substrate character of the sampling sites is one of the main causes of variability in the EHM results.

The Site Disturbance Score is an assessment of the degree of anthropogenic disturbance at each site such as water diversions, channel alterations, bank stability, riparian vegetation, water level fluctuations, human activities e.g. sand mining, waste water discharge and run-off at the site, and between 2 and 10 km upstream of the site. The team carry out their observations and scoring, which is then factored into the calculations. It has been noted that there is no reference to impoundment as a site disturbance because the system was originally designed to monitor flowing rivers. There is not necessarily any connection between substrate character and site disturbance.

It is necessary to note the site conditions reported for each of the EHM sites during the monitoring missions, since the understanding of these conditions helps in interpretation of the results. These are shown in ***Figure 3-29*** and ***Figure 3-30***. The overall substrate condition scores show that all the sites lie in the Moderate suitability range for aquatic biota, except for EHM2 in the impoundment which was rated at Poor condition; EHM4 was marginally worse than the other three sites. In terms of Site Disturbance Scores (SDS), all sites were considered to be in the Moderate stress range with EHM3 and EHM4 having a higher stress score than the other three sites.

In terms of environmental parameters, the readings largely correspond to the results from the water quality analysis showing little change between the six sites for Temperature, Dissolved Oxygen (DO), pH and Conductivity, but with some differences in the transparency of the water as measured by Secchi Disc. Thus, the transparency upstream and in the impoundment is lower than in the downstream sites which would correlate with trapping of sediment in the impoundment and lower Total Suspended Solids downstream.

The lists of identified species, numbers of individuals in the sub-samples are then analysed to provide the Average Abundance and the Species Richness for the site. A third variable is the Average Tolerance Score per Taxon (ATSPT) which is a reflection of the sensitivity of the species present in the sample to the site disturbance as measured by the Site Disturbance Score (SDS). The scores of each of these three variables are calculated for the four biota types and then the extent to which they meet the defined thresholds of the EHM Guidelines, allows the classification of the Ecological Health Index (EHI) for the site into four classes, Excellent, Good, Moderate and Poor.

Figure 3-32: Overall Substrate Condition and Site Disturbance Scores for each of the Xayaburi EHM sites

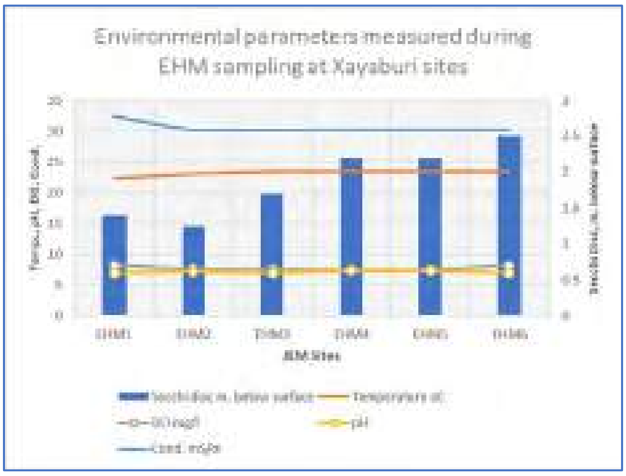


Figure 3-33: Environmental parameters measured at each of the Xayaburi EHM sites

Table 3-6 shows the results of the Abundance, Species Richness and ATSPT for the four biota types for each of the EHM sites above (EHM1), in the impoundment (EHM2) and downstream of Xayaburi dam (EHM3, EHM4, EHM5 and EHM6). The calculation of the EH Index for each of the sites shows that EHM1 and EHM6 are both classified as being in Good condition while the impoundment, and the three sites immediately downstream of the dam are all classified as being in Moderate condition. There is a clear change occurring within the impoundment and below, showing a gradual recovery with passage downstream.

The comparison of the three variables for each biotic type also illustrates these changes in more detail and these are considered in comparison with the historic EHM results in the other mainstream sites in chapter 5.1.4.

Table 3-6: Ecological Health Index classifications for the EHM sites around Xayaburi

Site					EHM1	EHM2	EHM3	EHM4	EHM5	EHM6
Year					**2021**	**2021**	**2021**	**2021**	**2021**	**2021**
Site Disturbance Score SDS					1.46	1.41	2	1.92	1.5	1.46
Average Abundance										
	Benthic diatoms	BD			667.5	1954.0	1026.6	982.6	1283.8	1479.2
	Zooplankton	ZPT			25.33	39.6	32.00	26.33	15.00	12.60
	Littoral macroinvertebrates	LM			160.8	9.1	4.2	7.7	148.9	39
	Benthic macroinvertebrates	BM			2.75	3.08	2.25	1.25	2.58	3.16
Richness	Benthic diatoms	BD			13.6	2.7	26.6	26.6	28	30.5
	Zooplankton	ZPT			8.66	5.66	10.33	7.33	7.00	5.66
	Littoral macroinvertebrates	LM			6.3	1.4	1.5	2	5.2	6.7
	Benthic macroinvertebrates	BM			1.66	1.58	1.16	1.00	1.58	1.25
ATPST	Benthic diatoms	BD			39	39	42	40	39	38
	Zooplankton	ZPT			33	30	42	37	32	31
	Littoral macroinvertebrates	LM			31	31	32	28	30	33
	Benthic macroinvertebrates	BM			34.5	31.8	33.7	28.1	29.4	21.3
Ecosystem Health index Calculations										
		10th percentile	**90th percentile**	**Guideline**						
Abundance	Benthic diatoms	136.22	376.34	>136.22	1	1	1	1	1	1
	Zooplankton	22.33	174.07	>22.33	1	1	1	1	FALSE	FALSE
	Littoral macroinvertebrates	46.68	328.56	>46.48	1	FALSE	FALSE	FALSE	1	FALSE
	Benthic macroinvertebrates	5.37	56.34	>5.37	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Richness	Benthic diatoms	6.54	11.78	>6.54	1	FALSE	1	1	1	1
	Zooplankton	9.8	20.2	>9.8	FALSE	FALSE	1	FALSE	FALSE	FALSE
	Littoral macroinvertebrates	5.37	18.48	>5.37	1	FALSE	FALSE	FALSE	FALSE	1
	Benthic macroinvertebrates	1.87	7.88	>1.87	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
ATPST	Benthic diatoms	30.85	38.38	<38.38	FALSE	FALSE	FALSE	FALSE	FALSE	1
	Zooplankton	34.83	41.8	<41.8	1	1	FALSE	1	1	1
	Littoral macroinvertebrates	27.8	33.58	<33.58	1	1	1	1	1	1
	Benthic macroinvertebrates	31.57	37.74	<37.74	1	1	1	1	1	1
	Total number of parameters meeting threshold				8	5	6	6	6	7
Quality	**Classification**	**Score**			**B**	**C**	**C**	**C**	**C**	**B**
Excellent	**A**	>10								
Good	**B**	>7			8					7
Moderate	**C**	>4				5	6	6	6	
Poor	**D**	<4								

Considering the JEM sampling sites for Xayaburi in ***Table 3-6***, it is clear that Benthic Diatoms meet the Abundance thresholds for all sites but only fail the Species Richness thresholds in EHM2 in the impoundment, but fail the ATSPT threshold for all sites except EHM6, i.e., the species represented are generally more tolerant species.

For Zooplankton, generally Abundance scores are higher than the threshold, except for EHM5 and 6, but the species richness generally fails at all sites except EHM3 immediately below the dam, while the ATSPT scores meet the threshold in all sites except EHM3, where the only more tolerant species are found.

For the Littoral Macroinvertebrates, the Abundance is above the threshold in EHM1, but falls below the threshold in the impoundment and for 2 stations below the dam. Abundance recovers at EHM5, but fails again at EHM6. Species Richness is above the threshold at EHM1 but falls below the threshold for the impoundment and the three stations below the dam, recovering by EHM6. The ATSPT scores for Littoral macroinvertebrates show that it meets the threshold for all sites.

For Benthic macroinvertebrates, the Abundance and Species Richness fails to meet the threshold in all sites but meets the threshold for ATSPT.

3.3.1.2 Statistical analysis

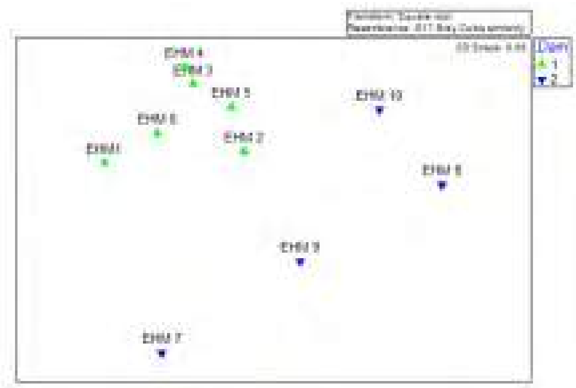
The pooled EHM data showing presence/absence of the different species at each sampling site have been analysed statistically, using non-metric multidimensional scaling on square root transformed data. Analysis of Similarities (ANOSIM) has been used to test whether there were significant differences between the samples collected around each of the two dams. ANOSIM gives two outputs - a Global R which ranges from 0 (completely identical) to 1 (completely different), and with p less than 0.05 being significant. The R and p values for the four biota groups are shown in ***Table 3-7***. All four biota groups showed significant differences between the biota collected between the two dams, indicating that they are indeed different assemblages of aquatic organisms, with zooplankton and diatoms more different than the littoral and benthic macroinvertebrates.

Table 3-7: ANOSIM comparison between EHM sampling sites around Xyaburi and Don Sahong

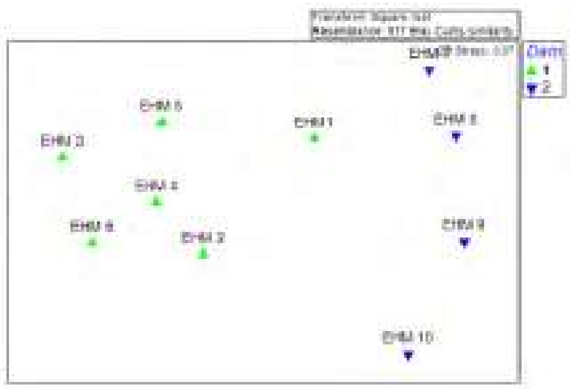
Biota group	Global R	p
Diatoms	0.73	0.05
Zooplankton	0.877	0.005
Littoral invertebrates	0.516	0.01
Benthic invertebrates	0.496	0.005

When the results for the different sites within each of the dam sites are plotted on non-parametric charts to illustrate the similarities (***Figure 3-34)***, the closeness of the individual sites indicates similarity between them. The two dam sites show distinct groupings (Xayaburi = dam 1, Don Sahong = dam 2).

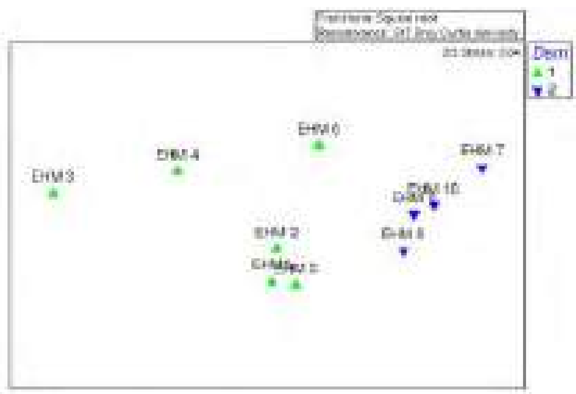
<u>Diatoms</u>



<u>Zooplankton</u>



<u>Littoral macroinvertebrates</u>



<u>Benthic macroinvertebrates</u>

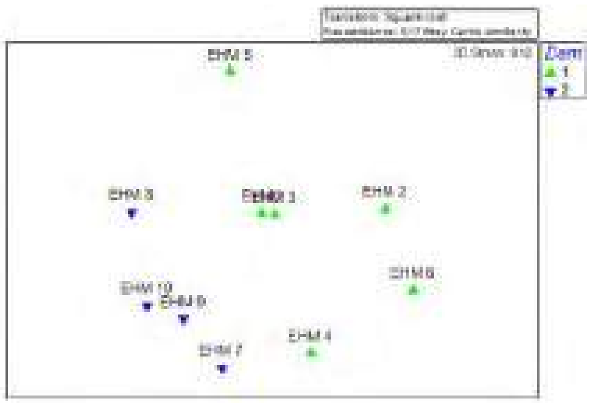


Figure 3-34: Non-parametric ANOSIM charts to show similarities between EHM sampling sites at both Xayaburi and Don Sahong dams

Considering the Xayaburi grouping of EHM sites, for Diatoms, EHM 1 and EHM 2 appear to be the most distant, i.e. least similar, while EHM3, 4 and 5 form a similarity cluster, with EHM6 being more similar to EHM1. In Don Sahong the diatoms in all sites appear to be dissimilar. For Zooplankton the results are most variable in both dam sites, with no apparent clusters.

For Littoral macroinvertebrates, in Xayaburi, the closest sites appear to be EHM 1, 2 and 5, while EHM3, 4 and 6 are widely separated. In the Don Sahong site, EHM 7 and 8 are widely separated, but EHM 9 and 10 are located closer together. This pattern in Don Sahong is repeated for Benthic macroinvertebrates and reflects the spatial and characteristic differences of the four sites (EHM7 above the impoundment, EHM8 in the impoundment and EHM 9 and 10 both downstream of the dam. In Xayaburi, EHM 1 and 3, above the impoundment and immediately below the dam appear to be most similar for Benthic macroinvertebrates, while the other sites have different assemblages of species present.

This statistical analysis reflects the similarities in terms of the species present and does not include the abundance – the numbers of individuals counted. It is probable the differences might be explained by the differences in substratum in each site, since all these organisms are very sensitive to the substrate character.

3.3.1.3 Comparison of species represented for each biotic type

A deeper dive into the differences in species composition in each site helps to understand what the impacts of the hydropower project may be having on the biota, particularly identifying which biotic orders are present or absent from each site. ***Figure 3-35*** shows the marked increase in species numbers of certain orders of Benthic diatoms downstream of Xayaburi.

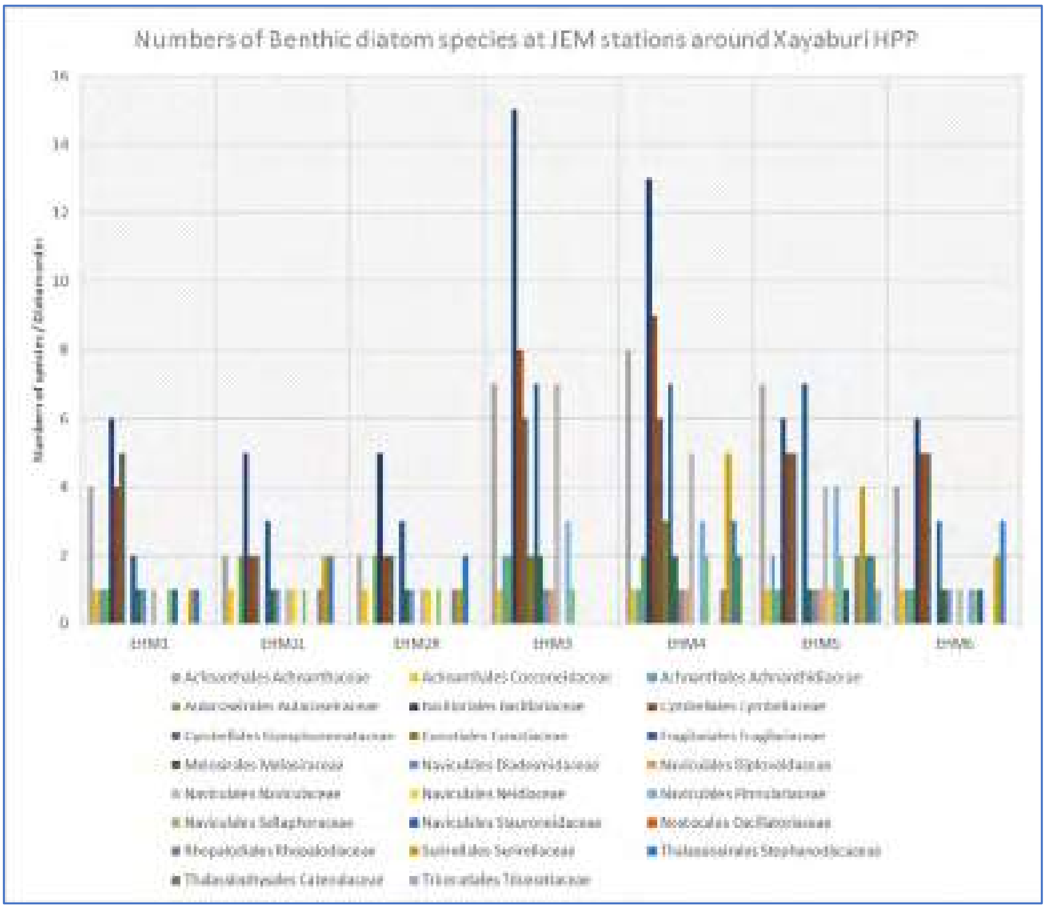


Figure 3-35: Numbers of species of Benthic Diatoms in different Orders and Families recorded around the Xayaburi pilot site

This is especially the case for Bacillariaceae in EHM3 and EHM4 and to some extent EHM5, but settles back to upstream levels by EHM6. This may be caused by fluctuations in the water level. Hydropeaking downstream of Xayaburi regularly exposes some of the rocks on which the diatoms are growing, and some forms are able to survive this, whilst others are more sensitive. Some diatom species cannot tolerate rapid changes in water level, but many species of the Bacillariaceae family have high tolerance score such as *Achnanthes* spp., *Gomphonema* spp., *Nitzschia* ssp., *Navicula* spp. Because of the high-water flow downstream of the dam the substrates were less suitable for diatoms, and in the impoundment the sediment can cover diatom habitats. EHM5 and EHM6 are also disturbed by rapid changes of water level every night.

Figure 3-36 shows that for zooplankton populations at Xayaburi, abundance increases immediately downstream, especially for *Ploima* spp., and then gradually goes back to upstream levels by the time EHM6 is reached. The fewer Zooplankton species found in EHM5 and EHM6 compared to other sites at upstream might be caused by water level fluctuations, downstream of the dam. The downstream zooplankton populations may be depleted by the varying flow rates associated with hydropeaking.

Within the impoundment, zooplankton appears to be more impoverished than upstream, except for the vertical tow which shows raised numbers of *Diplostraca* spp. Zooplankton within the impoundment appears to be impoverished compared to upstream. Impoundment is likely to alter the zooplankton community structure, providing a slower moving, stable environment in which different species of zooplankton feeding on the phytoplankton predominate compared to more rapidly flowing riverine environments. For the vertical tow, raised numbers of cladocerans were found - these zooplankton groups can live in most layers of the water column.

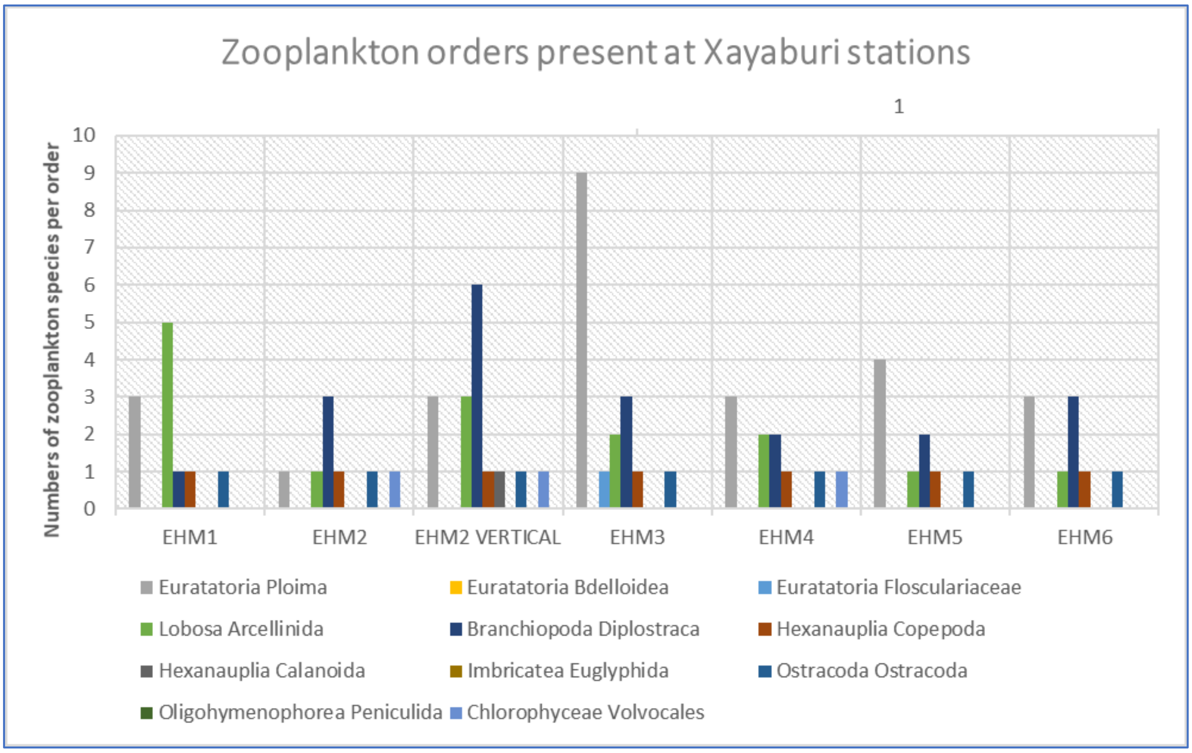


Figure 3-36: Numbers of species of Zooplankton in different Orders and Families recorded around the Xayaburi pilot site

In *Figure 3-37* the Littoral Macroinvertebrates found at the Xayaburi HPP show a very clear picture of marked decrease in species downstream with only 5 species of Diptera occurring at EHM3, and gradually recovering to upstream levels of diversity by EHM6. *Coleoptera* spp. and *Trichoptera* spp.

appear in the downstream sites, but are absent from upstream sites and in the impoundment. This may reflect the conditions in EHM1 being affected by the backwater from the Xayaburi impoundment with a gradual recovery of flowing water species with passage downstream.

The monitoring team noted that the environmental conditions downstream are not stable, since the water level changes during day and night, at EHM5 and EHM6. According to local people the water level changes by around 1-1.5 m every day. As described in Section 3.1.1.1, the water level at Ban Pakhoung ranged from about 2.9 m to 7.2 m with a larger number and higher magnitude water level fluctuations compared to the hydrological moonitoring station at Chiang Khan.

The sample locations of downstream of Xayaburi HPP do not have very diverse substrates with little or no vegetation noted in the in the field observations. EHM3 is close to the dam and here the riverbed, substrates and sediments are disturbed by rapid changes in water level and flow as described above. This may account for the very low diversity at this site. The EHM team noted that EHM4 and EHM5 also have less diverse habitats with substrates consisting of mud, clay, some sand, and bed rock which are less suitable for macroinvertebrates. The substrates are more diverse at EHM6 but the habitats are still disturbed by rapid changes of water level every day. Sampling at times when the water level is high may result in lower numbers of species being collected, because the biota, especially littoral macroinvertebrates, do not have time to move back into the top water levels. In upstream EHM1 and impoundment EHM2 sites, the habitats have also seen changes in water level. EHM1 may be affected by the backwater from the Xayaburi impoundment.

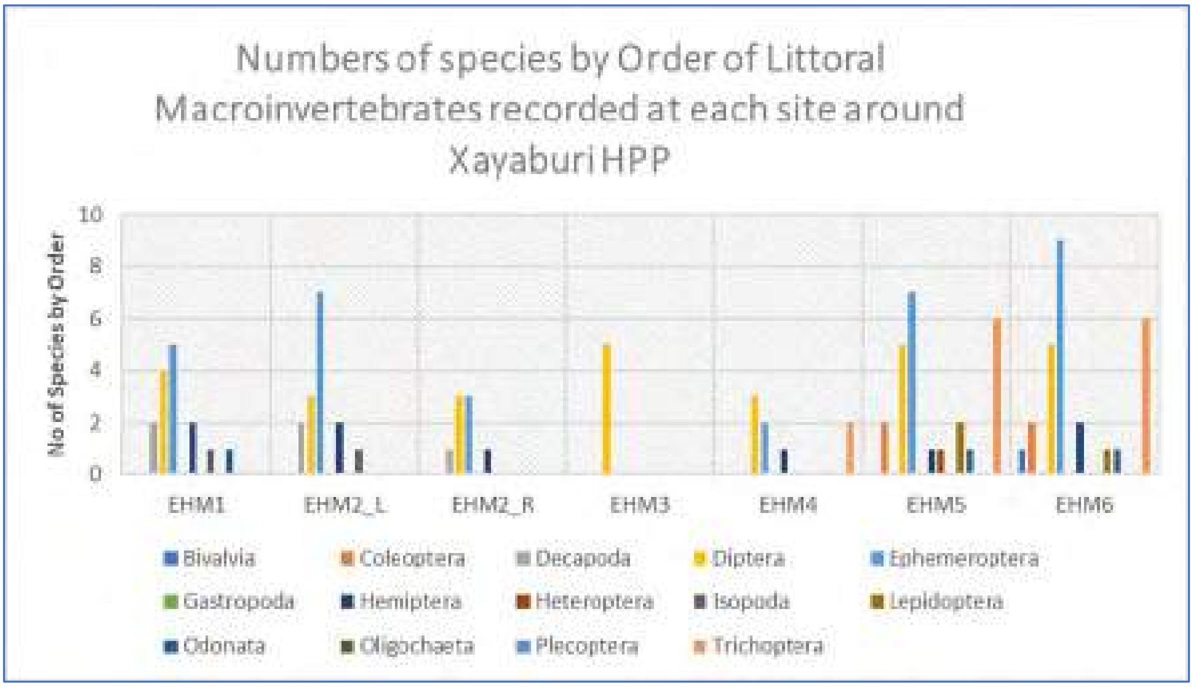


Figure 3-37: Numbers of species of Littoral Macroinvertebrate in different Orders recorded around the Xayaburi pilot site

Figure 3-38 shows that there is a clear fall in abundance and species richness of Benthic Macroinvertebrates in the two downstream sites EHM3 and EHM4. Diptera have the most numbers of benthic species and these are reduced to just one species in EHM3, with also loss of all Coleoptera, Ephemeroptera and Trichoptera, etc. There is some recovery downstream with Diptera recovering by EHM6 but diversity of different orders is still low.

At Xayaburi, the species richness and abundance of Benthic Macroinvertebrates are declining at various sampling sites downstream of the dam, possibly due to:

a) a strong current flowing throughout the water column varying between 1,400 and 2,200 m^3/sec at Ban Pak Houng;
b) the substrates in the channel are mostly sandy and clay, that are less suitable habitats for macroinvertebrates;
c) the sampling in some locations was difficult, which is likely to influence the results.

EHM3 is the first site downstream of the dam. The substrate in the left and right banks are around 90% of silts, while in the middle its sandy around 70% and 30% of boulders. There is a clear decline for both species richness and abundance compared to the silt areas. At EHM4 the decline of individuals is caused by the predominant clay substrate. Overall, the benthic macroinvertebrates show a trend towards recovery with distance downstream of the dam.

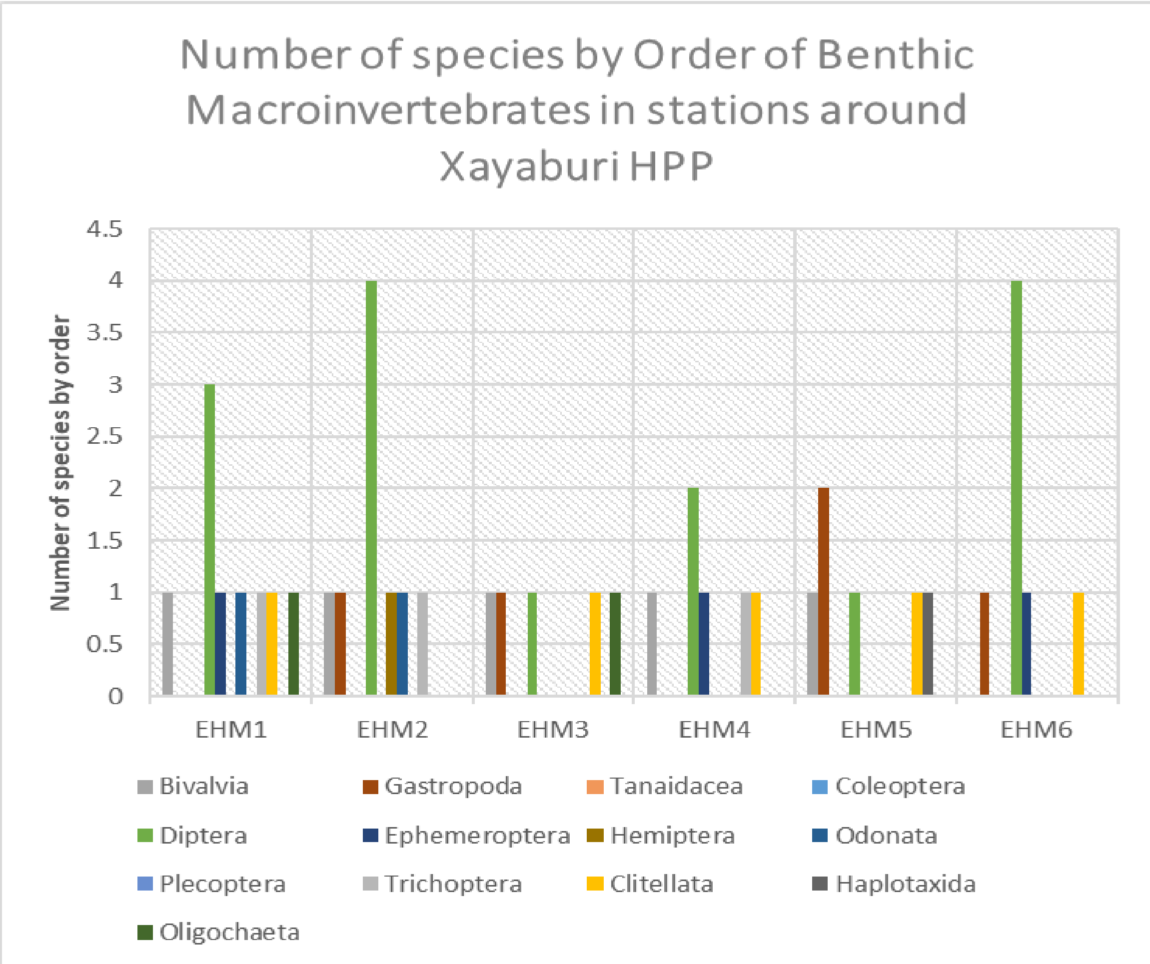


Figure 3-38: Numbers of species of Benthic Macroinvertebrate in different Orders recorded around the Xayaburi pilot site

3.3.1.4 Using ecological indicator species

The use of indicator species may explain the differences between sites, such as the numbers of EPT species (Ephemeroptera, Plecoptera and Trichoptera) and the number of filter feeding species present at each site. The EPT species (Mayflies, Stoneflies and Caddisflies), which are part of the Littoral Macroinvertebrates, are recognised as being particularly sensitive to poor environmental conditions, and so presence or absence, numbers of species and numbers of individuals per site are useful indicators of the prevailing conditions at each site. Similarly, the passive filter feeders – the Diptera Simuliidae and the Trichoptera Hydropsychidae – are sensitive to the availability of organic material in the flowing waters. The results for the Xayaburi EHM sites are shown in ***Figure 3-39.***

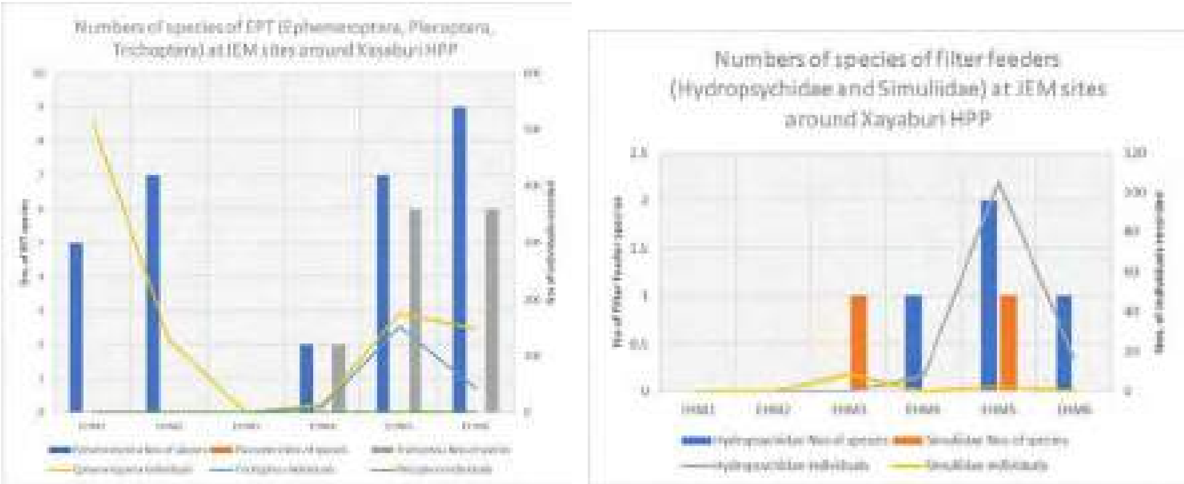


Figure 3-39: Left) Numbers of Ephemeroptera, Plecoptera, Trichoptera and Right) Filter feeding macroinvertebrates at the JEM sites around Xayaburi.

Considering the changes in the number of species and individuals of EPT it is clear that EHM1 contains 5 species of Ephemeroptera with about 500 individuals collected in the samples. In the impoundment, the numbers of Ephemeroptera species increases to 7 but the number of individuals decreases to about 100. This is indicative of changing conditions in the impoundment compared to the original river, e.g. raised water levels, reduced flow rate and more sediment accumulating on the bottom. Immediately after the dam, there are no EPT species recorded, indicative of the harsher conditions of variable water levels and flow rates. At EHM 4, there are the signs of recovery, with two species of Ephemeroptera and of Trichoptera, but in very small numbers. By EHM 5, about 5 km below the dam, there are 7 and 6 species Ephemeroptera and Trichoptera respectively with about 150 individuals in each. Recovery is further enhanced by EHM6 (10 km downstream) when we have 9 and 6 species of Ephemeroptera and Trichoptera and similar numbers of individuals.

A similar pattern may be observed in the numbers of species and individuals of filter feeding macroinvertebrates. With none of these families being recorded above and in the impoundment and then a gradual recovery downstream of the dam. It may be that because EHM1 lies at the very top and within the backwater of the impoundment, the flow conditions are not suitable for filter feeders. Downstream of the dam at EHM3 there are a few individuals of the Simuliidae present, and at EHM4 the Hydropsychidae are present, and at EHM 5 both Simuliidae and Hydropsychidae are present in larger numbers. This progression is also indicative of the gradual recovery of the aquatic biota with distance downstream of the dam.

3.3.2 Lessons learnt and Recommendations

Monitoring of EHM in the vicinity of the Xayaburi HPP has provided the following insights:

- The Ecological Health monitoring results around Xayaburi show clear changes in the species diversity and numbers of biota present within the impoundment and downstream compared to the upstream reference site.
- The Ecological Health Index (EHI) in the impoundment and downstream are all classified as in Moderate health, with indications of recovery with passage downstream, compared to the upstream reference site which is classified as in Good health.

- The changes in the impoundment and downstream are likely to be caused by changes in the flow rates and water levels at the sites with resultant changes in the substrate and habitat conditions, rather than by changes in water quality.
- The responses of the different biota types provides greater insights into the changes of substrate and habitat, considering the average abundance, species diversity and ATSPT for each biota type, compared to the simple EHI.
- The Littoral Macroinvertebrates show the clearest changes in species diversity and abundance with passage downstream after the dam, but the responses of Benthic Diatoms, Zooplankton and Benthic Macroinvertebrates in the impoundment and downstream are all useful indicators.
- Deeper investigation of the Littoral Macroinvertebrates, using Ephemeroptera, Plecoptera, Trichoptera (EPT) and filter feeding invertebrates can help to explain the changes observed.
- The changes in the flow and substrate conditions occasionally make sampling difficult and potentially unsafe, which needs to be considered in site selection and interpretation of the results
- Statistical analysis of the species present at each site indicates some similarities between some of the sites which it is considered to reflect the variation in substrate conditions. The significance of the changes is difficult to analyse statistically because there is only one year of sampling at each of the JEM stations, and no baseline results with which to compare such changes.

These insights lead to the following recommendations for the EHM protocols:

- The EHM component of the JEM should be continued with sampling at least once a year to build up statistically strong datasets of the ecological and habitat conditions both in the impoundment and downstream of the dam, since it appears to provide the clearest evidence of changes due to the hydropower operation.
- It is recognised that the sampling and identification of the biota is a lengthy and expert process which may be difficult to repeat at shorter intervals, but the development of a more rapid testing using only Littoral Macroinvertebrates should be considered between the biennial sampling.
- The extent of the recovery zone downstream of the dam should be investigated further, by taking samples of Littoral Macroinvertebrates at 10 km intervals down the Chiang Khan Hycos station
- Because conditions within the impoundment are very different from a free-flowing river and the biota are probably still developing within the Xayaburi impoundment, further investigations into the typical biota within other impoundments within the Lower Mekong is recommended to provide reference conditions.

3.4 Fisheries

3.4.1 Preliminary results and initial analysis

As detailed in section 2.4.4, the review of FADM monitoring results between 2017 and 2021 (period of complete data sets in most sites) was done to answer the following questions:

- **What is the evolution of monthly catch per fisher in each site over the years?**
- **What is the trend in number of species caught each year in each site?**
- **What is the trend in average CPUE of gillnets used by fishers in each site?** (fish biomass caught by square meter of gillnet by hour fishing)

3.4.1.1 Trends in monthly catch per fisher

The catch per fisher (***Figure 3-40***):

- is stable at about 20 kg/fisher/month and shows no sign of decline in Pha-O village upstream of Xayaburi reservoir;
- shows a downward trend in Thadeua site 30 km upstream of the dam, now in the reservoir, from 50 kg/fisher/month to now about 20 kg/fisher/month;
- cannot yet be analysed downstream of the dam at Pak Houng, as the time series in this new site is too short. The current catch reaches 34 kg/fisher/month for the 11 months of monitoring between its start and June 2021 (plotted here under 2021);
- tends to increase in Tha Muang, from 22 to 32 kg/fisher/month. The reason for this increase is unknown.

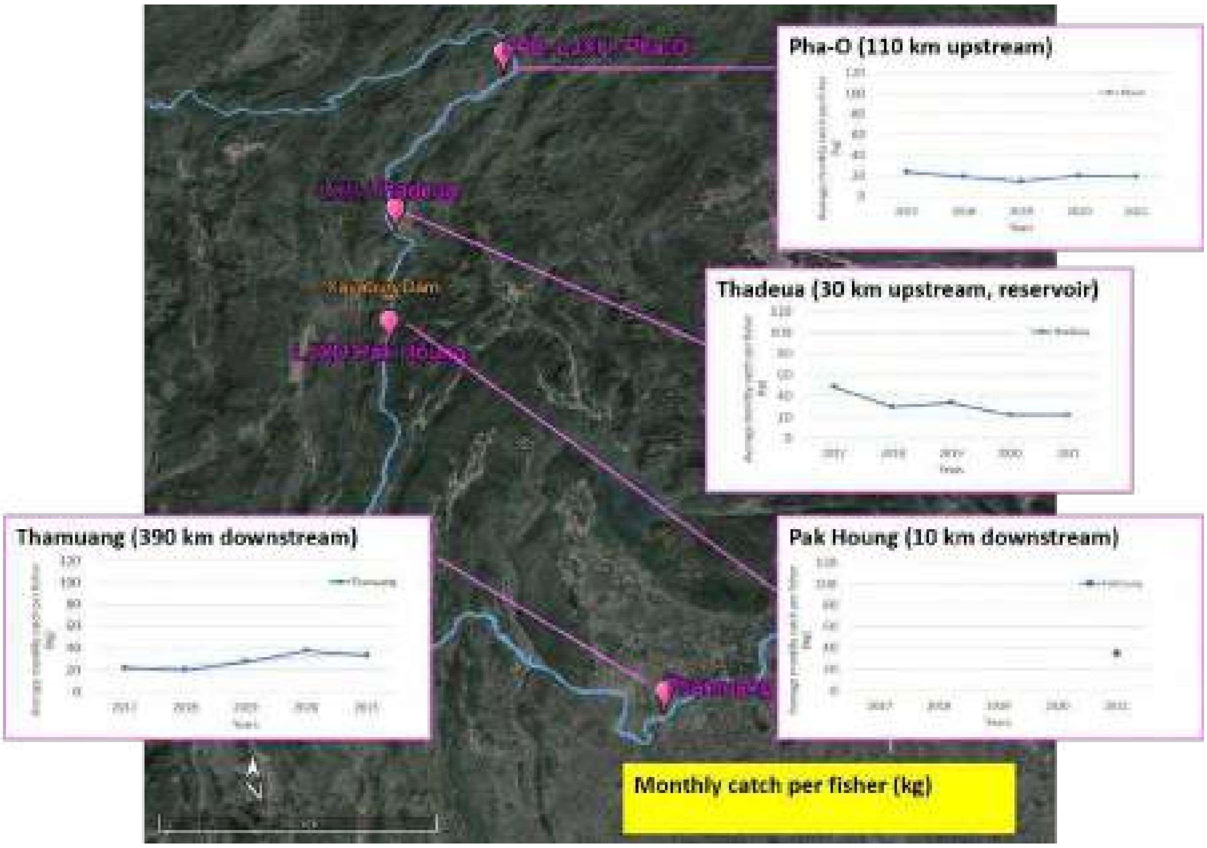


Figure 3-40: Monthly catch per fisher in fish monitoring stations upstream and downstream of Xayaburi Dam

Thus, recent data just downstream of Xayaburi dam do not allow concluding yet about the possible impact of the dam; at the upstream tip of the reservoir the catch is stable, but in the reservoir it has declined.

3.4.1.2 *Trends in species diversity in catches*

The annual diversity in the catch of fishers (***Figure 3-41***):

- shows a sharp decline from 50-60 species in 2017-2019 down to 22 species in 2021 in Pha-O village upstream of Xayaburi reservoir; the causes of this decline should be further analyzed in relation to local and upstream development;
- exhibits an even sharper decline from 88 to 22 species in Thadeua site, now located in the reservoir;
- cannot be analysed yet downstream of the dam at Pak Houng, as the time series in this new site is too short. The current diversity reaches 84 species (measured over 11 months of sampling), a high value;
- also displays a decline from 48 to 14 species only in Thamuang, about 400 km downstream of the dam

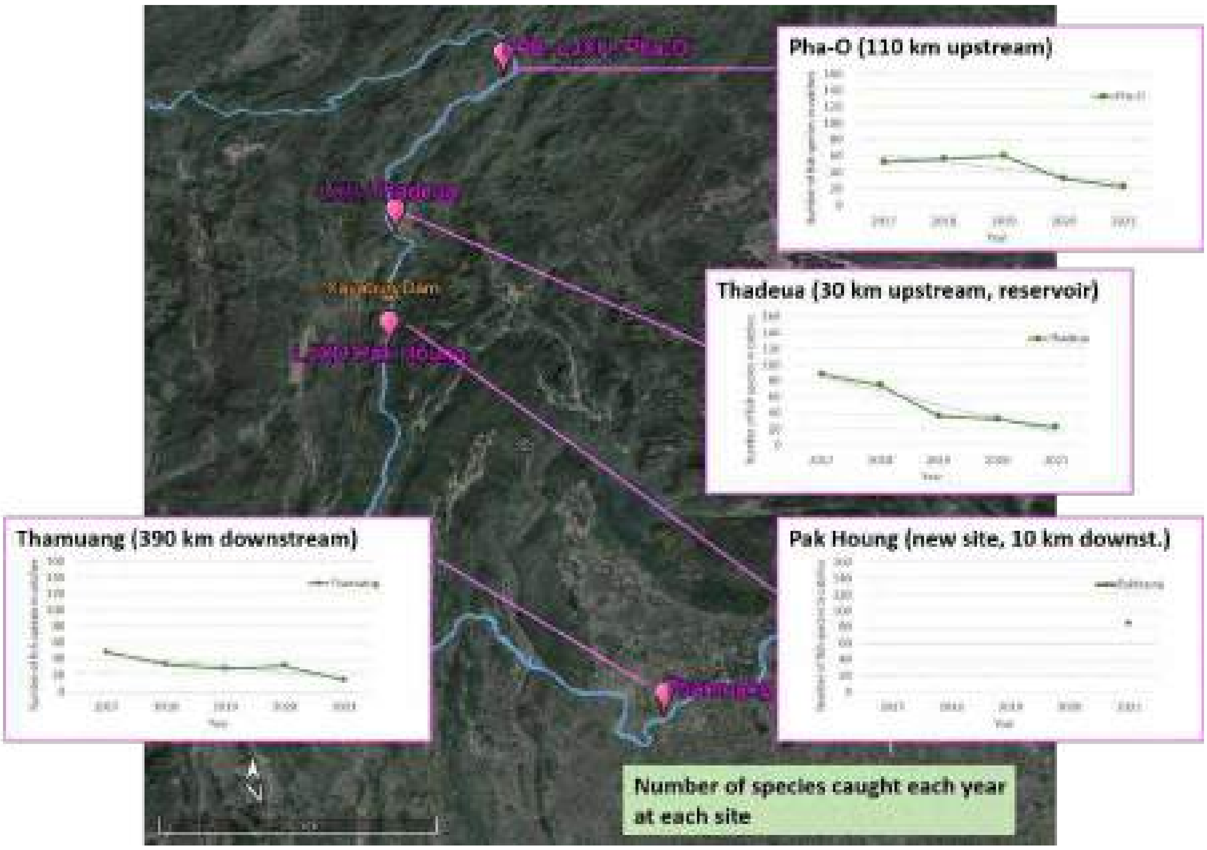


Figure 3-41: Number of fish species caught in fish monitoring stations upstream and downstream of Xayaburi Dam

However, the species diversity for the last point in graphs (in 2021) in Pha-O, Thadeua and Thamuang is not fully reliable yet, as sampling is on-going and the year only includes six months of fishing instead of 12 for the other years.

3.4.1.3 *Trends in gillnet Catch per Unit Effort*

The CPUE of gillnets used by fishers (***Figure 3-42***):

- shows a sharp decline in Pha-O village upstream of Xayaburi reservoir, from very high values to now medium values;
- is rather stable at a low value in Thadeua site, now located in the reservoir;
- is low at Pak Houng downstream of the dam and similar to that of the reservoir (1 vs. 1.3 grams of fish/m^2 of gillnet/hour of fishing), but again the time series in this new site is too short for any conclusion at this stage;
- seems to be increasing in Thamuang, about 400 km downstream of the dam. This reflects the increasing average monthly catch per fisher.

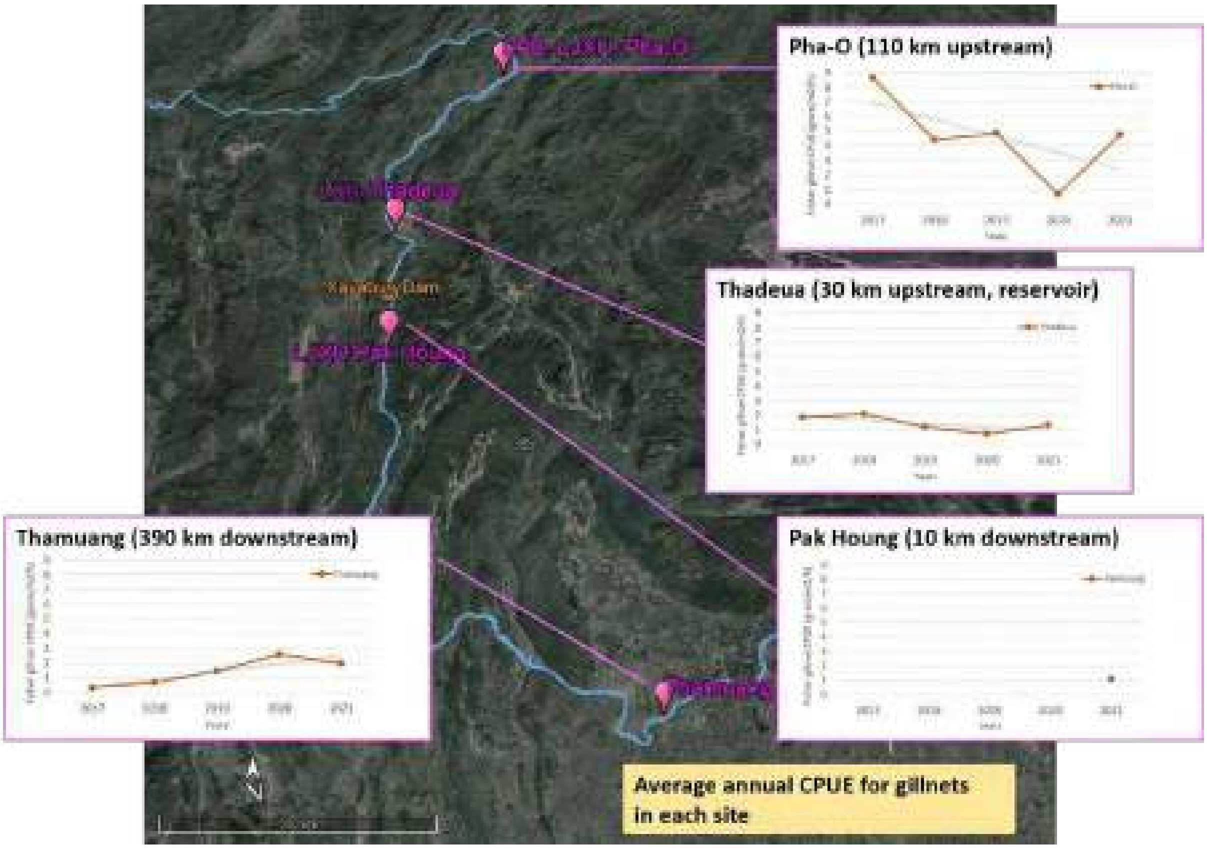


Figure 3-42: Catch Per Unit Effort (grams per m^2 of gillnet per hour fishing) in fish monitoring stations upstream and downstream of Xayaburi Dam

3.4.2 Lessons learnt and Recommendations

The analysis of fishery data in Pha-O village upstream of Xayaburi reservoir shows that both fish diversity in catches and gillnet CPUE feature a sharp decline; however, the total average monthly catch per fisher shows a very limited decline, which might indicate an increasing fishing effort to compensate a declining resource. This is to be further explored in data (gear use analysis) before a field survey allows reaching a conclusion about this point.

In the Xayaburi reservoir the average monthly catch per fisher has sharply declined although the gillnet CPUE is stable. This possibly reflects a diversification among fishers: fishing harvests less valuable fish, so fishers shift towards alternative livelihoods instead of increasing their effort like in

Pha-O. This hypothesis is based on the fact that the creation of a reservoir favors low value planktivorous lacustrine fish species in its initial years, by replacement of former high value riverine species. A detailed analysis of catch data by species in relation to species diet or trophic level would allow reaching a conclusion on this point.

In Pak Houng downstream of the dam the monitoring is too recent to allow any conclusion, and this site is likely to reflect a perturbed situation during a few years, with the seasonal accumulation of migratory species not finding their way up and subsequent –but short-term- high monthly catches and CPUE. This paradoxical and unsustainable situation of abundance, already noted in other dams of the region (e.g. Pak Mun in Thailand or Stung Chinit in Cambodia,; Amornsakchai et al. 2000; Baran et al. 2007, might be witnessed during the lifespan of the cohort of migratory species involved, i.e. a few years long.

In Thamuang, about 400 km downstream of the dam, data reflect an *increase* in both monthly average catch per fisher and gillnet CPUE. This unusual situation, if confirmed, remains to be explained; it might be increased water productivity (which would be surprising in a context of sediment and nutrient retention by upstream dams) or a shift in fishing gears or fishing practices and a subsequent increased fishing efficiency. This could be addressed by a gear analysis in existing data (e.g. possible evolution from traditional traps towards more modern and efficient gears, or shift in the past 5 years towards smaller gillnet mesh sizes harvesting more small fish, i.e. higher biomass per effort unit if not higher value. Here again, conclusions should be confirmed by a survey on site and meetings with fishers.

Overall, data consistently show a sharp reduction of biodiversity, by 40 to 60%, in almost all sites (comparison of 2020 full data – not the partial 2021- with species diversity 2 to 3 years earlier). The above figure does not mean that species have disappeared yet, but they are too rare to appear and be recorded in catches. This pattern was expected following the transformation of the formerly running river upstream of Xayaburi, the changes in flow regime and sediment/nutrient load resulting from developments and the overall human pressure on the river, but the extent and speed of change seem extremely high.

When the impact analysis is done from the perspective of fish larvae, the Lao FLDM monitoring under JEM Pilots provides a new and very valuable set of data that initiates a long term monitoring. A preliminary analysis of this data set (863 samples to date, data collection and data analysis are on-going) show that upstream of Xayaburi, the site has been characterized so far by 31 fish genus in 18 families (***Figure 3-43***) leading to taxonomic identification at the species level for 17 species (***Figure 3-44***). In the impoundment, larvae diversity is more limited, with 30 genus in 15 families (15 species identified). Downstream of the dam at Pak Houng site, taxonomists identified 35 genus in 17 families, with 23 species identified. Although based on a large number of samples, these initial results display 16% difference between sites only, but may point at a slightly lower diversity in the reservoir. Additional years of sampling will allow confirmation (or not) of this hypothesis, once the fish community structure has stabilized under the new environmental conditions.

Following from these preliminary analyses, data could be combined in future either with existing FLDM data in existing databases, or with additional samples to be collected in Xayaburi site for deeper exploration to:

i) compare larval densities, abundance variability between locations and impact of sampling time on results, and
ii) taxonomic differences with other dam sites and with the mainstream not directly subject to dam influence.

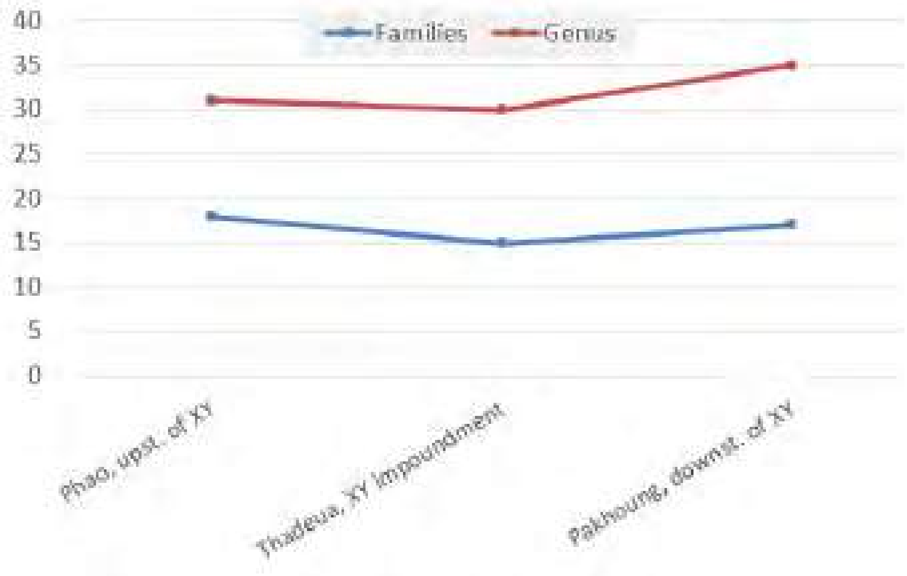


Figure 3-43: Number of families and genus in 3 sites around Xayaburi Dam

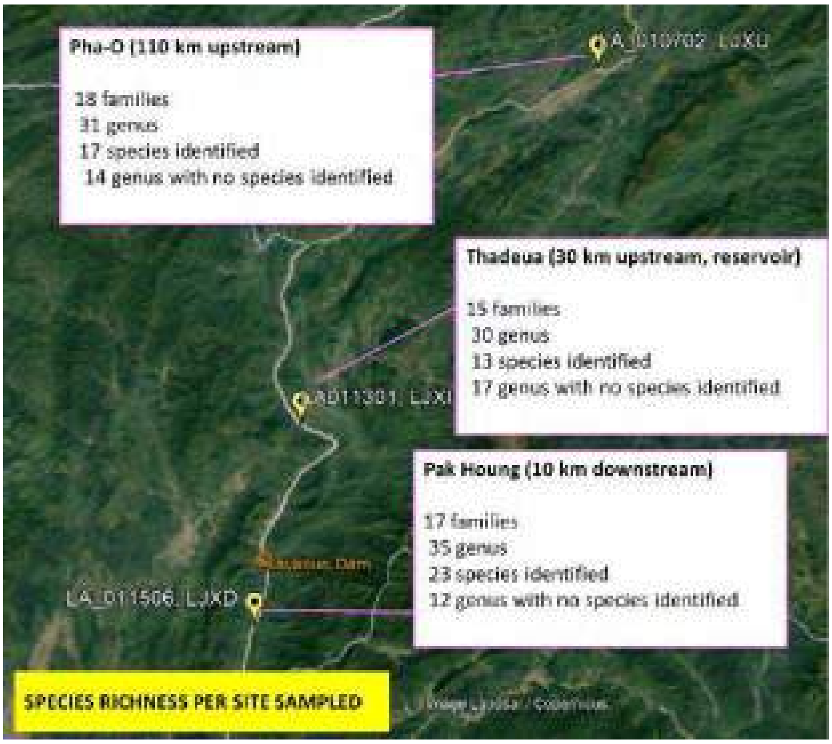


Figure 3-44: Taxonomic diversity of fish larval stages around Xayaburi Dam site

4 DON SAHONG

4.1 Hydrology and Sediment

4.1.1 Hydrology – Results at JEM sites

For the Don Sahong component of the JEM pilot, hydrology and sediment monitoring has focussed on Pakse and two new sites established within Cambodia. Koh Key is a HYCOS water level recording site located 30 km downstream of the Lao PDR-Cambodian border, and Stung Treng-UP is a discharge and sediment monitoring site located approximately 15 km downstream of Koh Key, 4 km upstream of the confluence with the Sekong River. This section of the report summarises the results from these three sites. Integration of the information with the other DSM sites of Sekong Bridge (SKB) and Stung Treng is presented in Section 5.

An additional water level site was installed at the outlet of the Don Sahong Hydropower Project in August 2021, and the initial results are included in this section.

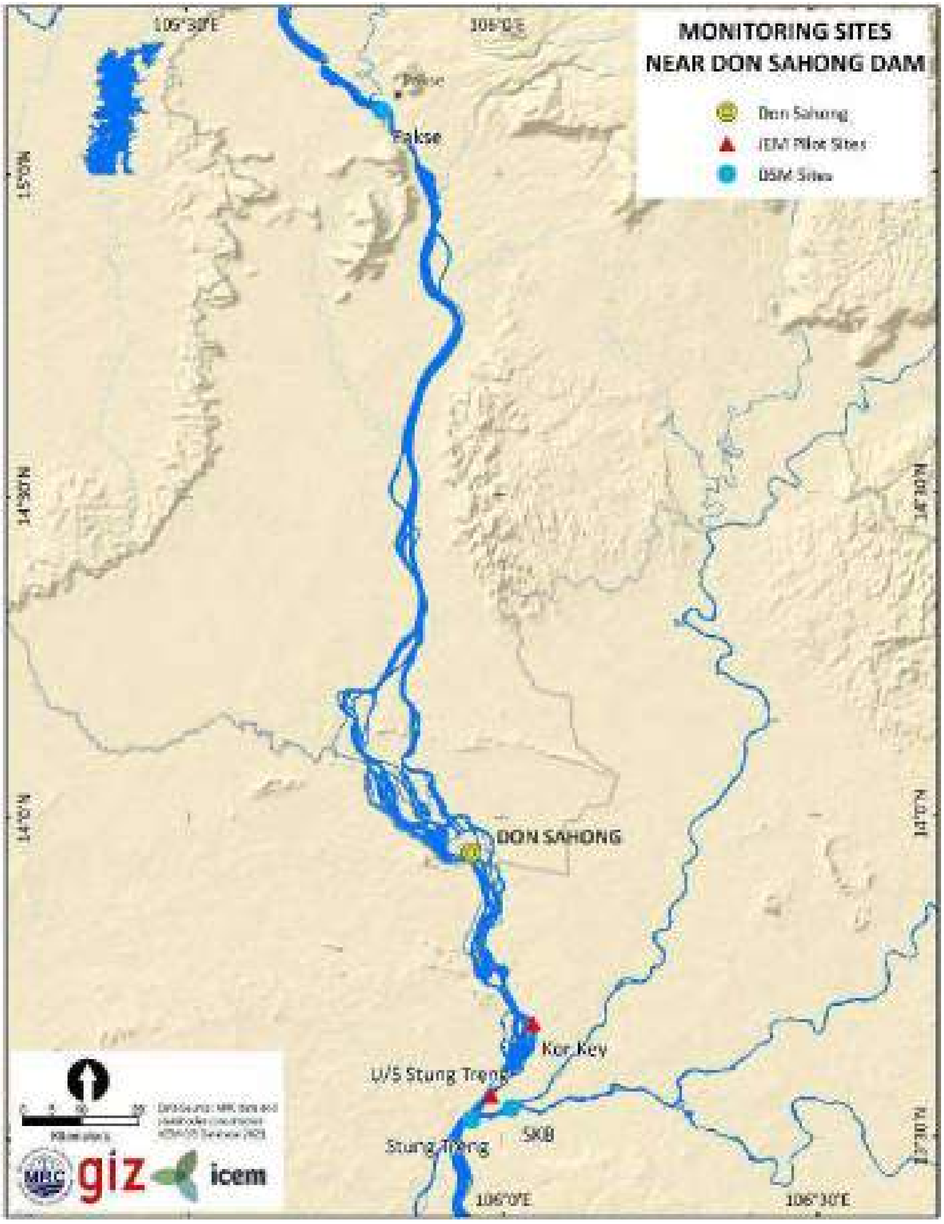


Figure 4-1. Monitoring sites included in the JEM pilot. Red triangles indicate new JEM sites.

4.1.1.1 Water level at JEM sites

A surveyed cross-section of the Pakse monitoring site shows that the channel is about 800 m wide, uniform in shape and is over 20 m in depth (***Figure 4-2***). Manual (daily) water level results during July 2020 to June 2021 JEM monitoring year (***Figure 4-3***) ranged from 0.78 m to 8.06 m, equivalent to a level of 87.3 to 94.6 m on the cross-section. The maximum water level change based on the daily readings was 1.79 m/day and occurred on 20 September 2020. The minimum water change was -0.67 m/day.

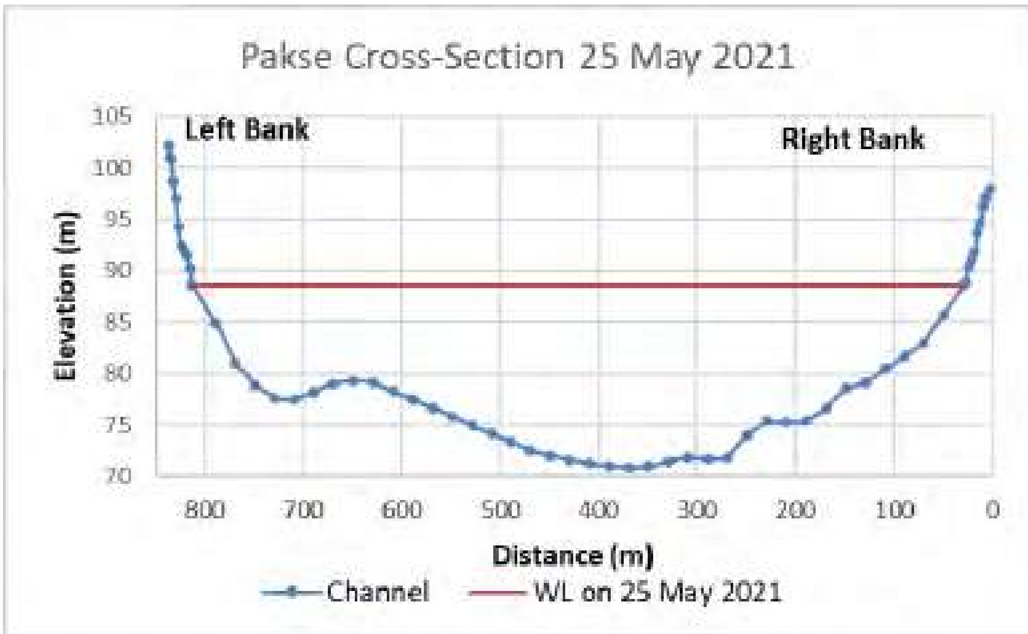


Figure 4-2. Surveyed cross-section at Pakse completed in May 2021 by Lao PDR DMH team.

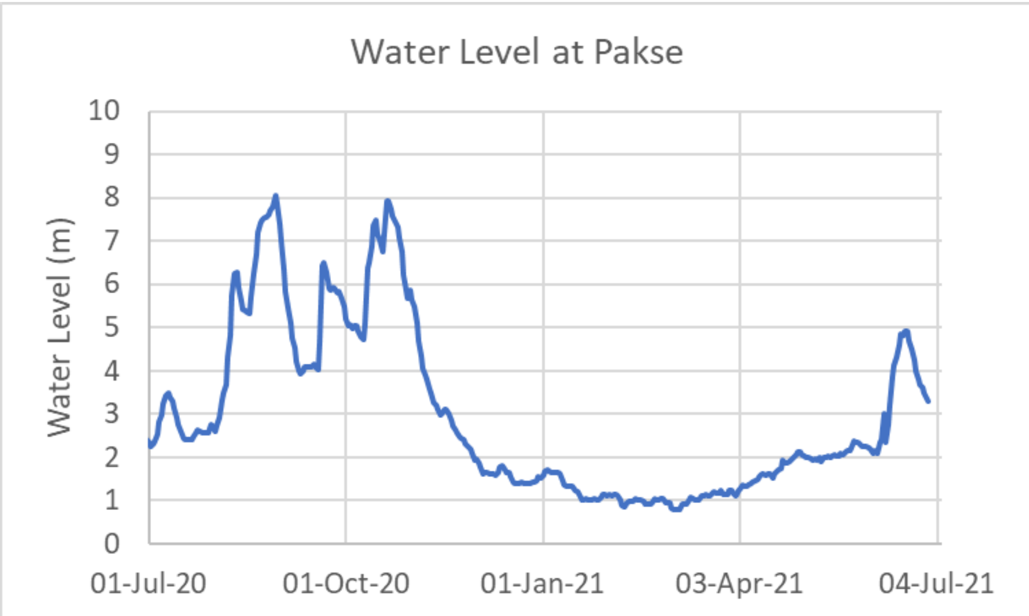


Figure 4-3. Water level at Pakse based on daily manual results.

Continuous water level results at Pakse are available beginning in July 2021 (*Figure 4-4*), and show that there are frequent, small water level fluctuations. The recorded fluctuations are about 0.05 m in amplitude, with a frequency of about 24 hours. Lower water levels generally occur between 08:00 and 10:00 with the maximum level occurring in the evening, between 20:00 and 22:00. These fluctuations are undoubtedly related to operation of one or more tributary power stations. The water level changes are well within the MRC Hydropower Guideline recommendation of 0.05 m/hr (MRC, 2020).

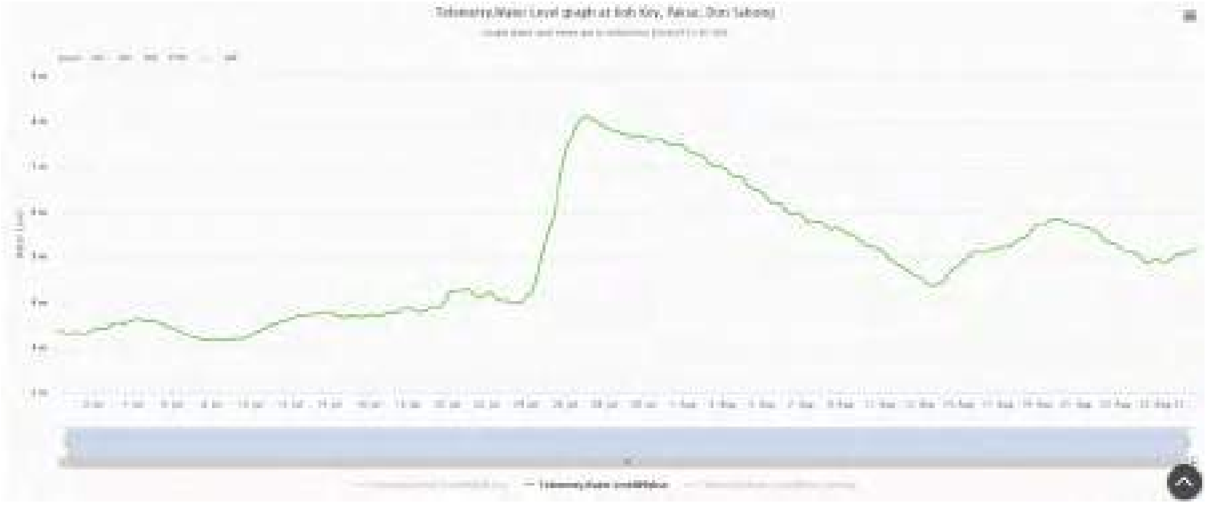


Figure 4-4. Continuous water level at Pakse recorded at HYCOS site, July to August 2021.

There are no cross-sections available for the Koh Key water level site. The continuous water level record collected since installation of the gauge in February 2021 is shown in *Figure 4-5*, along with the daily levels at Pakse for comparison. Comparing the sites suggests there is no major change to flow attributable to the operation of Don Sahong. Maximum rates of water level increase at Koh Key during the July 2020 to Jun 2021 monitoring year were 0.021 m/15 minute and 0.046 m/hr. Maximum decreases were -0.016 m/15-min and -0.012 m/hr. The large high flow event in July 2021 had higher rates of water level increase, and are discussed in the basin wide assessment (Section 5).

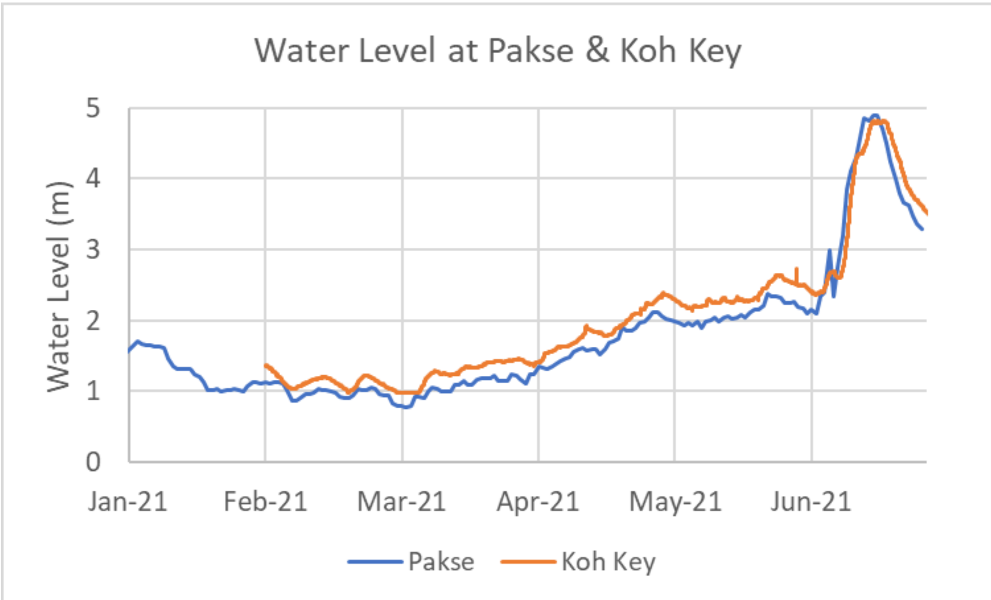


Figure 4-5. Water level recorded at Koh Key since installation of the gauge.

Note: Pakse daily water level included for reference. Note the two sites do not have the same zero reference level.

Comparing the period of overlap of continuous water level results at Pakse and Koh Key (*Figure 4-6*) demonstrates that the small water level fluctuations present at Pakse are absent at Koh Key, which is consistent with the river flowing through the hydraulically complex Siphandone area.

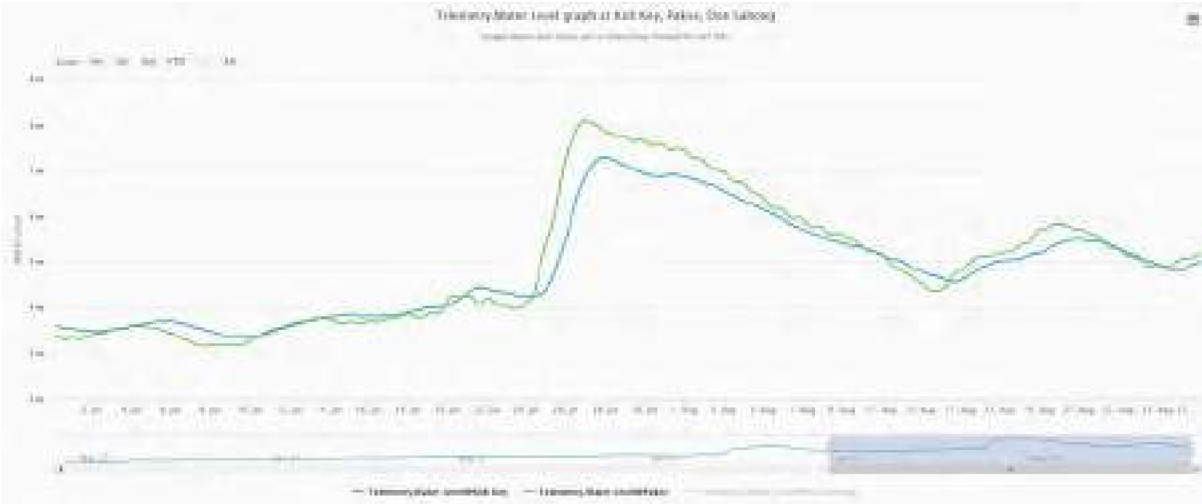


Figure 4-6. Continuous (15-minute) water level at Pakse (green) and Koh Key (blue).

In August 2021 a continuous water level gauging was installed downstream of the outlet from the Don Sahong hydropower project. The few weeks of results that are available are compared to the recorded water level at Pakse and at Koh Key (*Figure 4-7*) and show the same pattern of water level change as at the upstream and downstream sites. During August 2021, flow in the Mekong has consistently exceeded 10,000 m3/s, well above the 1,600 m3/s maximum inflow of the DSHPP, and it is likely that the station has been in continuous operation. There is one minor water level fluctuation at the Don Sahong site on 9 August with a small reduction registered at Koh Key a few hours later. This may be related to power station operations at Don Sahong. A longer record is required to gain an understanding of the relationship between flow at the three sites.

Figure 4-7. Water level at Pakse (Green), Don Sahong (Blue), and Koh Key (Red) in August 2021.

Note: The flat portion of the Don Sahong record indicate the water level was lower than the minimum recording level of the probe (6 m).

4.1.1.2 Discharge Measurements

Discharge measurements from Pakse and Stung Treng-UP are shown in ***Figure 4-8*** along with the calculated discharge at Pakse based on manual water level readings. There is good agreement between the sites, and between the measurements and the calculated discharge. Flow at Pakse ranged from 2,100 m^3/s to 21,700 m^3/s. Peak flow in the 2020-2021 monitoring year was very low compared to the previous 15-years, and the dry season flows in 2020 and 2021 are also lower than most previous years (***Figure 4-8***).

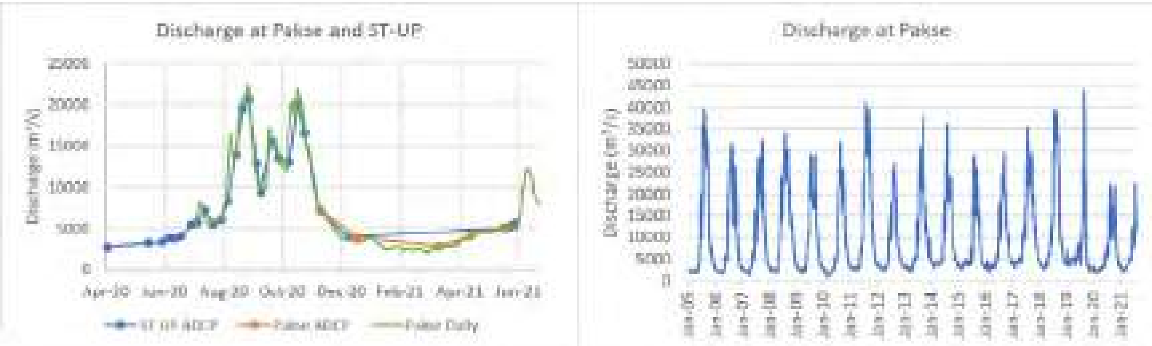


Figure 4-8. (left) Discharge measurements at Pakse and Stung Treng UP (dots) and daily flow at Pakse based on manual readings (right) long-term discharge record at Pakse through August 2021.

4.1.1.3 Water level discharge relationship

The discharge measurements collected at Pakse show reasonable agreement with the existing rating curve for the site at discharge rates <10,000 m^3/s, but at high flow the recent ADCP measurements show lower discharge as compared with the rating equation (***Figure 4-9***). A review of the rating at the site should be completed.

Only three discharge measurements have been completed at Stung Treng-UP since commissioning of the Koh Key water level site in February 2021. Flow rates were in a narrow range of 5,200 to 5,600 m3/s, and do not show a positive correlation with water levels at the site; the lowest water level of 2.389 m is associated with the highest flow (***Figure 4-9***). This may be due to early adjustments to the site which may not be reflected in these preliminary results, or it could indicate that the Stung Treng-UP site is affected by backwater from the inflow of the 3S. It is recommended that a review of results and derivation of a rating curve been completed once more results are available. If Stung Treng-UP is affected by backwater effects, then a different site will need to be identified to provide a rating for the Koh Key water level.

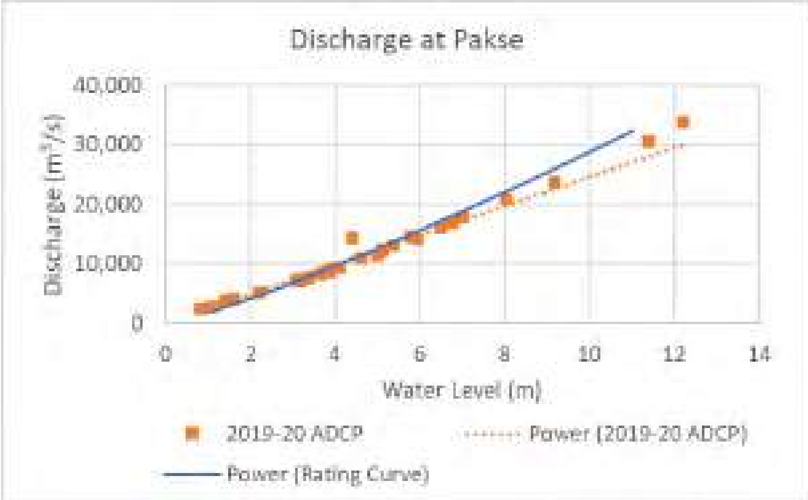


Figure 4-9. Comparison of ADCP discharge measurements from Pakse with existing discharge rating curve.

Table 4-1. Water level at Koh Key and measured discharge at Stung Treng Up in May and June 2021.

Date	Water Level	ADCP Discharge at ST-UP
26/05/2021	2.542	5,055
31/05/2021	2.537	5,293
6/06/2021	2.389	5,646

4.1.2 Sediment results

4.1.2.1 Suspended sediment concentrations and loads

No SSC results have been reported for Pakse during the JEM monitoring year. SSC results for Stung Treng-UP (*Figure 4-10*) show concentrations ranged from 6 mg/L to 179 mg/L during the monitoring period. The highest SSC concentrations are occurred during the flow peaks in August and September.

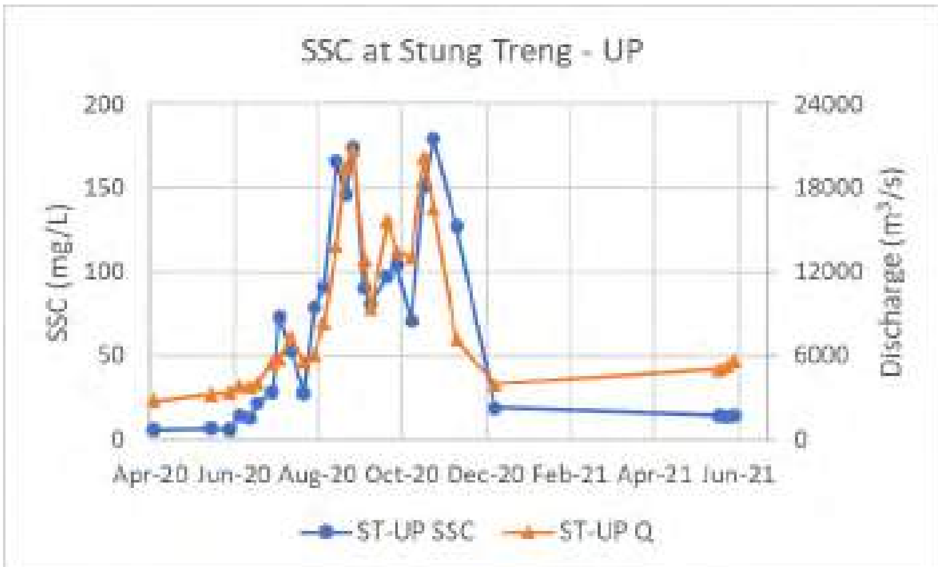


Figure 4-10. SSC concentrations and discharge measurements from Stung Treng UP between April 2020 and June 21.

Note: The gap is due to travel restrictions related to Covid-19. Results collected by DHRW, Cambodia.

Combining the discharge and SSC results yields SSC loads for each monitoring run (*Figure 4-11)*. The loads ranged from 1,500 tonnes/day (April 2020) to 312,000 tonnes/day (August 2020). Interpolating between the monitoring dates provides an estimate of ~20 Mt/yr of SSC transport at the site for the period June 2020 to June 2021. This is a very low estimate compared to historic estimates at Pakse that ranged up to 160 Mt/yr and is discussed in Section 5.

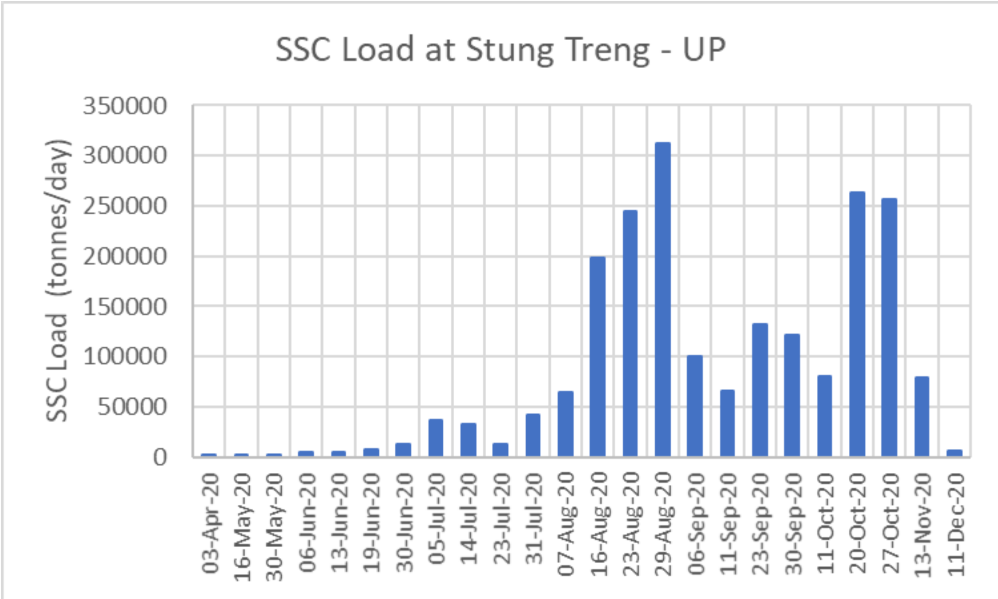


Figure 4-11. SSC load at Stung Treng-UP based on discharge measurements and SSC results. Results collected by DHRW, Cambodia.

4.1.2.2 SSC grain-size distribution

Grain-size distribution results are only available for Stung Treng-UP. The grain-size distribution of SSC samples collected at the site is dominated by coarse and medium silt, contributing between 56% and 80% of the total load. Very fine and fine sand contribute most of the remaining load (*Figure 4-12)*. The contribution from sand increases during the wet season, consistent with higher flows and river energy during this period. Applying the percentages to the SSC load shows that during the period of maximum SSC transport in August 2020, of the 310,000 tonnes/day being transported, 200,000 were coarse and medium silt, and another 100,000 was very fine and fine sand.

Figure 4-12. Grain-size distribution results at Stung Treng-UP.

Note: shown on (left) Grain-size distribution of SSC at Stung Treng-UP by percent distribution (right) SSC sediment load by grain-size class at Stung Treng-UP. Results collected by DHRW, Cambodia.

4.1.2.3 Bedload transport

Estimates of bedload transport are only available for Pakse for the period October 2020 to May 2021 (***Figure 4-13***). The dry season results show very low estimated rates of bedload, ranging from ~250 to 2,000 tonnes/day. These rates are similar to values estimated at the sites in the upper LMB and are attributable to the low flows at the site during sampling. At Stung Treng-UP, no bedload estimates can be made as there are insufficient valid ADCP loop-tests upon which to base the estimate.

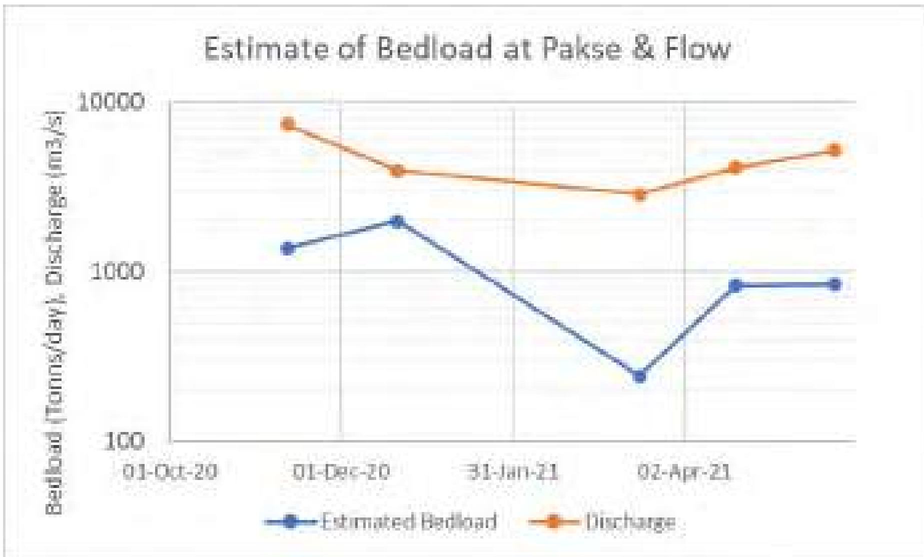


Figure 4-13. Estimates of bedload transport at Pakse in October 2020 to May 2021.

Note: Discharge also shown.. Results collected by Lao PDR DMH. Bed material grain-size is discussed in the basin wide analysis.

4.1.2.4 Repeat cross-sections at the Dolphin Pools

The JEM monitoring protocol included the collection of repeat channel cross-sections in the main channel of the Mekong near the national border with Lao PDR. Two surveys at Preah Rumkil, near the Dolphin Pools were completed by DHRW (Cambodia). The location and results of the surveys are shown in ***Figure 4-14*** and ***Figure 4-15***, respectively. The surveys show variability but similarities with respect to the width and shape of the channel and position of the thalweg. The survey points were spaced at 100 m intervals, which is too coarse to be able to identify small scale changes.

Figure 4-14. Google Earth image of the Mekong downstream of DSHPP (visible in top of photo).

Note: Yellow line is border between Lao PDR and Cambodia. Blue, grey, orange and yellow show tracks for cross-sections in October and December 2020 for JEM monitoring at the Dolphin Pools (Preah Rumkin).

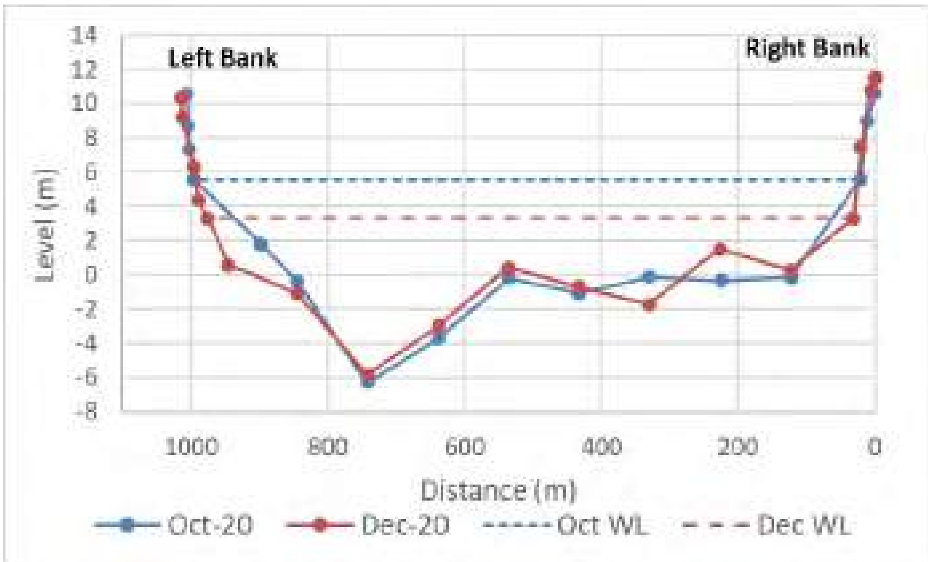


Figure 4-15. Surveyed cross-sections of the Mekong near Preah Rumkil in October and December 2020.

Extracting the river bed profile from the ADCP transects provides additional detail about the cross-section (*Figure 4-16*). The thalweg is towards the left side of the channel (viewing from upstream to downstream), consistent with the majority of flow entering the channel being directed towards this side of the river channel. The right side of the channel shows more variability and is likely reflecting sandy shoals as are apparent in dry season aerial images (*Figure 4-17*). The December cross sections show a higher mid-channel bar, and higher deposits on the right side of the channel. This could reflect deposition during the end of the wet season and into the dry season. In October, maximum water velocities near the thalweg were about 1.5 m/s, whereas in December maximum velocities were about half this value, which could promote deposition.

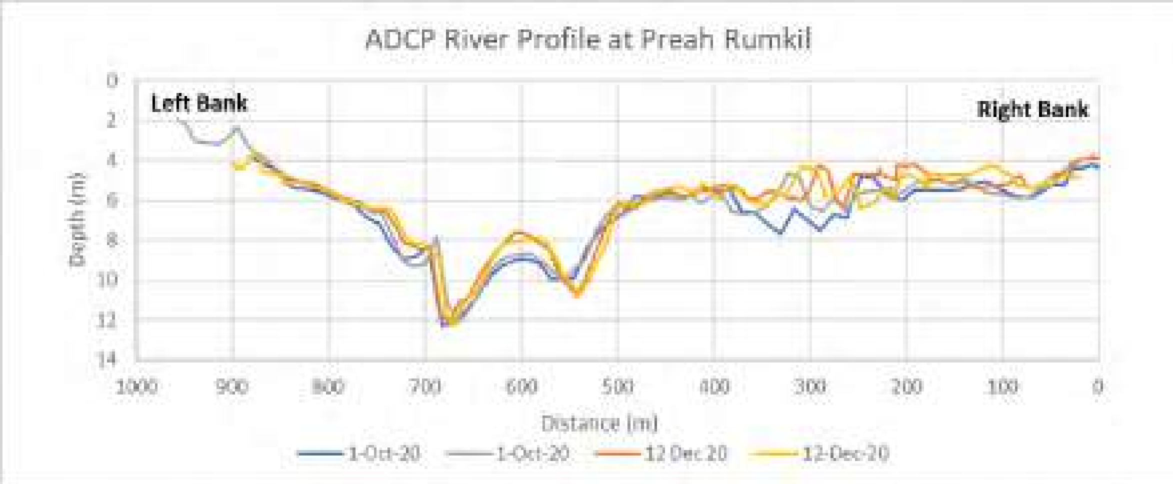


Figure 4-16. Comparison of ADCP bottom track at Preah Rumkil in October and December 2020. Levels corrected for differences in water level.

Figure 4-17. Google Earth image from March 2010 showing shoals on right side of channel (red circle) near location of cross sections.

4.1.3 Lessons learned and Recommendations

Monitoring at Pakse and Koh Key / Stung Treng-Up during the JEM pilot has provided the following insights:

- Water level at Pakse shows small scale daily fluctuations in July and August 2021, consistent with hydropower operations on tributaries in the catchment.

- The water level and flow results collected from Pakse and Koh Key / Stung Treng-Up demonstrate that there are no substantial impacts on flow rates or water level from the Don Sahong Hydropower Project on the downstream river. This does not imply that there are no local impacts, but rather there are no apparent flow alterations at a distance of 30 km downstream of the dam site as compared to Pakse.
- All water level fluctuations recorded at the new water level site downstream of Don Sahong have been below the 0.05 m/hr rate recommended in the MRC Hydropower Guidelineshowever results are only available for the 2021 flood season when flow in the river exceeded 10,000 m^3/s and the DSHPP would be expected to be operating continuously.
- The Pakse discharge measurements are in good agreement with the existing rating curve, but the measurements are limited to low flow only.
- SSC concentrations were relatively low at Stung Treng-UP throughout the year, with all concentrations <180 mg/L. Most of the material being transported is coarse and medium silt, with lesser amounts of fine and very fine sand. The estimated SSC annual load of 20 Mt/yr is very low compared to historical estimates.
- The surveyed cross-sections of the main Mekong channel near Preah Rumkil (Dolphin Pools) near the Lao PDR border show no major changes between the survey dates, however the reported surveys were completed at a very coarse scale making the detection of changes difficult. It is recommended that the surveys continue to be completed in the future but at a finer resolution (e.g. based on the ADCP cross-sections)

Recommendations arising from a review of the results are listed below. These recommendations also include general items also applicable to monitoring in the upper LMB:

- The compass on the ADCP units needs to be calibrated prior to every monitoring run to ensure the accuracy of the discharge results and to allow estimates of bed load transport to be made based on ADCP loop-test results.
- Capacity building in laboratory methods for the determination of grain-size distribution of bed material, bedload and SSC should be a high priority in future training plans to ensure samples are being properly analysed.
- Cross-sectional surveys of the river at the sites upstream of Vientiane and at Preah Rumkil should be included in future monitoring with survey information collected at a resolution of at least 1 depth measurement per metre across the channel (e.g. measurement extracted from the ADCP cross-sections every 1 m or less). A higher density of survey points should be collected when completing river cross-sections at all sites, and the use of ADCP transects should be encouraged to provide a continuous profile of the river bottom. Preliminary capacity building in this was provided during JEM, and subsequent training should be included in future capacity building exercises.
- Additional training on the collection of ADCP discharge measurements and the collection and application of valid loop-tests to the measurements should be completed, as this process is not being consistently applied at the monitoring sites.
- The data reporting procedures for discharge and sediment measurements should be reviewed and streamlined. Reporting should move towards electronic reporting that could be directly uploaded into a database following final QA/QC by the MRC.

4.2 WATER QUALITY

4.2.1 Water Quality Results and data analysis

4.2.1.1 Surface water results

The results of the analyses of the surface water samples at the Don Sahong JEM sites (WQ6 to WQ9) are presented in ***Table 4-2***. They are presented with the corresponding monthly routine WQMN analyses for the Pakse and Stung Treng sites (above and below Don Sahong) for reference. These are analysed in three different groupings – i) General water quality parameters, ii) nutrients and phytoplankton, and iii) indicators of poor water quality.

General water quality parameters

Table 4-2 shows the median, maximum and minimum and standard deviation of the Don Sahong pilot site results for Temperature, pH, Conductivity, Total Suspended Solids and Turbidity, for the months of October 2020 to June 2021 for the related stations from upstream to downstream of Don Sahong. The monthly results for the same period are shown in Annex 5, with a gap for May 2021, when no samples could be taken due to COVID travel restrictions. Turbidity readings were not taken for the two routine monitoring sites of Pakse and Stung Treng, and TSS measurements were not made for WQ7 and WQ8.

These results have been plotted as box and whisker charts of the median, maximum and minimum results for each site over the complete set of eight monthly readings from October 2020 to June 2021.

There are some consistently obvious difference between the routine WQMN results at Pakse and Stung Treng compared to the JEM pilot stations around Don Sahong, which may be due to sampling equipment differences, for example in ***Figure 4-18*** which shows higher Temperatures being recorded at Stung Treng compared to the JEM WQ stations, and the slightly higher pH readings above 8 of the JEM sites compared to below 8 at the WQMN sites. In the future WQMN and JEM sampling equipment should be calibrated appropriately, and if necessary compared to confirm or eliminate these differences.

Within the set of JEM stations around Don Sahong, there are very little differences shown above, in the impoundment and below the dam in Temperature and pH, although there is a higher Temperature range at the Stung Treng stations compared to the Pakse and Don Sahong sampling stations. pH is very consistently the same in the impoundment and below the dam.

Table 4-2: Don Sahong JEM Pilot Results for Temperature, pH, Conductivity, Dissolved Oxygen (DO), Total Suspended Solids (TSS) and Turbidity, October 2020 to June 2021

Station Name	Statistic	TEMP_°C	pH	COND_mS/m	DO_mg/L	TSS_mg/L	Turbidity_FTU
Threshold for Protection of Human Health			6-9	70 - 150	>4		
Threshold for Protection of Aquatic Life			6-9	>150	>5		
Pakse	Median	26.9	7.35	23.10	7.1	19.8	
	Max	28.9	8.25	26.60	7.9	195.3	
	Min	22.8	6.57	16.88	6.0	5.5	
	Standard Deviation	1.9	0.6	3.6	0.7	59.7	
WQ6	Median	26.9	7.98	25.60	7.7	8.1	5.9
	Max	28.9	8.58	27.45	8.9	186.6	241.0
	Min	22.7	5.87	10.70	7.0	4.3	4.6
	Standard Deviation	1.9	0.8	5.2	0.5	58.9	77.10
WQ7	Median	26.8	8.11	25.52	7.5		7.2
	Max	29.2	8.55	29.41	8.5		253.0
	Min	23.0	5.94	10.20	6.0		5.1
	Standard Deviation	1.9	0.8	5.6	0.7		80.79
WQ8	Median	27.1	8.17	25.54	8.0		7.8
	Max	29.5	8.64	26.93	8.7		156.0
	Min	22.7	6.67	10.60	7.3		5.0
	Standard Deviation	2.1	0.6	5.1	0.4		48.76
WQ9	Median	27.1	8.30	25.35	8.0	6.4	6.8
	Max	29.9	8.61	26.90	9.2	193.8	159.0
	Min	22.9	7.31	10.70	6.6	4.0	5.1
	Standard Deviation	2.1	0.4	5.1	0.8	61.8	49.92
Stung Treng	Median	29.5	7.57	24.30	7.5	11.1	
	Max	31.0	7.86	28.54	8.2	244.0	
	Min	28.5	6.64	13.23	7.1	3.4	
	Standard Deviation	0.8	0.4	3.9	0.3	72.6	

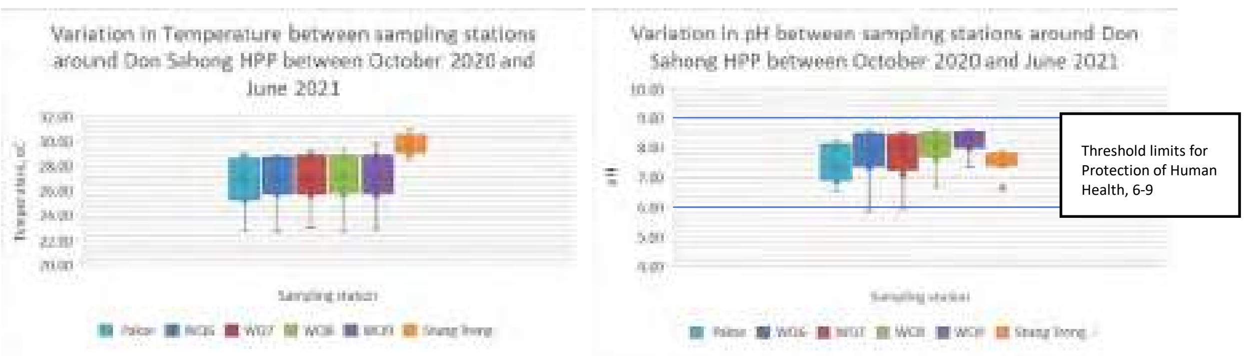


Figure 4-18: Box and whisker charts for WQ results between October 2020 to June 2021 left) Temperature and right) pH for sampling stations above and below Don Sahong.

Considering *Figure 4-19* showing the box and whisker charts for Conductivity and Dissolved Oxygen, the Conductivity results for the WQMN station at Pakse are very slightly lower than the WQ 6 – 9 and Stung Treng results (with medians around 25 mS/m), which also record some much lower outliers (around 10 mS/m). For Dissolved Oxygen there are very little differences between the medians of any of the sites ranging between 7 and 8 mg/l, and in no case does the minimum fall below the 5 mg/l threshold of the Aquatic Health Guideline.

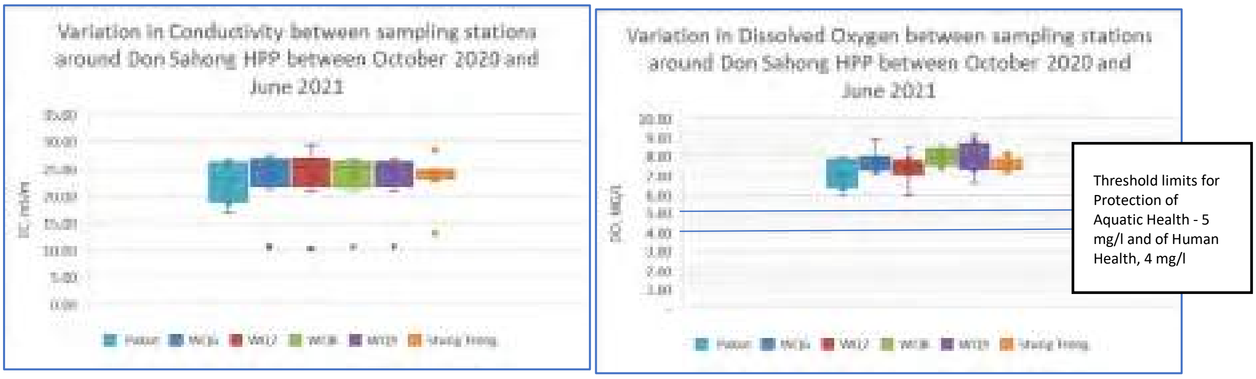


Figure 4-19: Box and whisker charts for WQ results between October 2020 to June 2021 left) Conductivity and right) Dissolved Oxygen for sampling stations above and below Xayaburi.

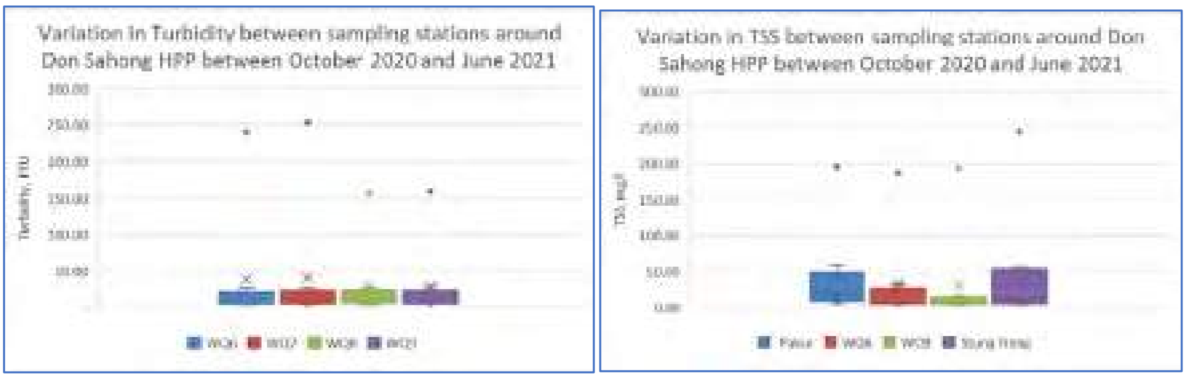


Figure 4-20: Box and whisker charts for WQ results between October 2020 to June 2021 left) Turbidity and right) Total Suspended Solids for sampling stations above and below Don Sahong.

Figure 4-20 shows the box and whisker charts for turbidity and TSS. The turbidity readings at all four sites are generally very similar above, in the impoundment and below the Don Sahong dam (median reading between 6 and 7 FTU). In all four stations there are some very high outliers (with turbidities ranging from 150 to 250 FTU) recorded in October 2020 when the TSS was also very high at the end of the wet season. The TSS results show that the medians for all sites range from 19 mg/l at Pakse, 8 mg/l at WQ7 and 6mg/l at WQ9 and 11 mg/l at Stung Treng. Again there are very high outliers in all four sites relating to the October 2020 sampling, with TSS ranging between 186 and 196 mg/l at Pakse and WQ7 and 9, and 244 mg/l at Stung Treng. These reflect the wet season high suspended sediment flows.

Nutrients and Phytoplankton

The median, maximum, minimum and standard deviation monitoring results for nutrients and phytoplankton around the Don Sahong sampling stations between October 2020 and June 2021 are shown in *Table 4-3*. The monthly monitoring results for nutrients and phytoplankton around the Don Sahong sampling stations are shown in Annex 5, noting that phytoplankton measurements were not made at the routine WQMN stations of Pakse and Stung Treng, and Total Nitrogen (TotN) was not analysed at WQ7 and 8.

Table 4-3: Don Sahong JEM Pilot Results for Nutrients and Phytoplankton, October 2020 to June 2021

Station Name	Statistic	NO32_mg/L	TotN_mg/L	TotP_mg/L	Chlorophyll A_ug/L	Cyano Bacteria_ug/L
Threshold for Protection of Human Health		5		NA		
Threshold for Protection of Aquatic Life		0.5		0.13		
Pakse	Median	0.19	0.52	0.03		
	Max	0.35	1.75	0.06		
	Min	0.03	0.39	0.01		
	Standard Deviation	0.1	0.4	0.01		
WQ6	Median	0.45	0.83	0.04	0.2	-
	Max	0.58	1.85	0.07	1.1	0.4
	Min	0.08	0.32	0.01	-	-
	Standard Deviation	0.2	0.5	0.02		
WQ7	Median	0.42		0.02	0.3	0.0
	Max	0.75		0.06	1.5	0.6
	Min	0.06		0.01	-	-
	Standard Deviation	0.2		0.02		
WQ8	Median	0.33		0.02	0.3	0.0
	Max	0.72		0.04	1.4	0.4
	Min	0.10		0.01	-	-
	Standard Deviation	0.2		0.01		
WQ9	Median	0.47	0.74	0.03	0.3	0.0
	Max	0.76	2.22	0.06	1.4	0.4
	Min	0.06	0.25	0.01	-	-
	Standard Deviation	0.2	0.6	0.02		
Stung Treng	Median	0.04	0.10	0.04		
	Max	0.40	0.50	0.08		
	Min	0.03	0.08	0.02		
	Standard Deviation	0.1	0.2	0.02		

These results have been plotted as box and whisker charts of the median, maximum and minimum results for each site over the complete set of eight monthly readings from October 2020 to June 2021.

Figure 4-21 shows the box and whisker charts for the two nutrients nitrate/nitrite (NO32) and Total Phosphorus (TotP). The very high TotP results in December 2020 in WQ7 and 9 (4.6 and 8.2 mg/l respectively) have been eliminated as probable sampling errors, since these high values were not picked up in the other samples taken during that month. As shown in *Table 3-3*, the only occasions when TotP readings exceeded 1 mg/l were in Pakse in February and August 2015 and at Stung Treng in June 2014. The readings on those occasions were 4 times lower than those recorded at Don Sahong in December 2020.

The medians for NO32 at Pakse and Stung Treng (less than 0.2 mg/l respectively) are consistently lower than at the JEM WQ stations, which showed variation between 0.3 to 0.5 mg/l, with little pattern of increase or decrease between the upstream and downstream of Don Sahong. The TotP results show medians of between 0.02 and 0.04 mg/l with no obvious pattern between upstream and downstream sites. The Total Nitrogen figures which represent nitrogen, both dissolved and bound on the solids are shown in *Figure 4-22*. The medians all lie within the range of 0.3 to 0.5 mg/l, with Stung Treng levels being much lower at 0.04 mg/l, although maximum values were recorded at all sites in October and November 2020, at the same time as relatively high values of Total Suspended Solids. This shows that at the Don Sahong sites the NO32 levels lie between the thresholds for the Protection of Human Health and Aquatic Life, exceeding the Protection of Aquatic Life thresholds and sometimes exceeding the protection of Human Health threshold. While unlikely to be caused by the Don Sahong HPP, this does raise concern about increasing nutrient levels in this area.

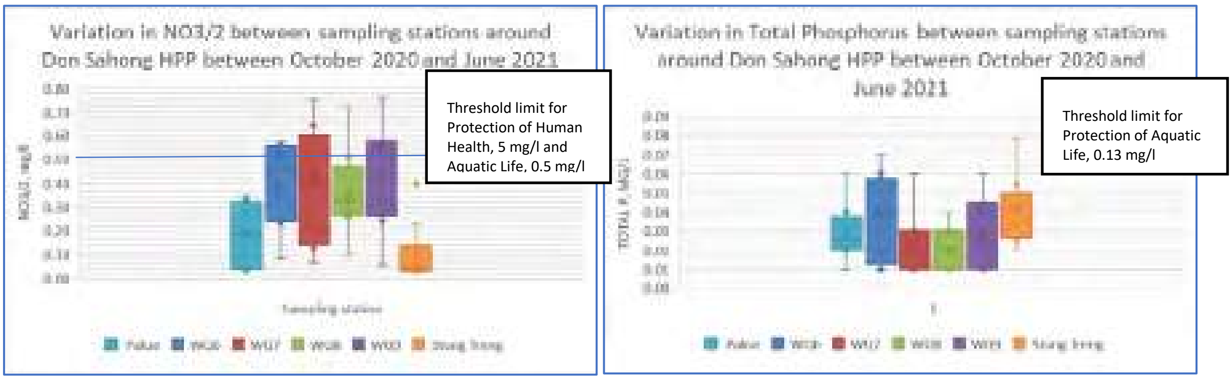


Figure 4-21: Box and whisker charts for WQ results between October 2020 to June 2021 left) NO32 and right) Total Phosphorus for sampling stations above and below Don Sahong.

Note - large outlier results in TotP for December 2020 have been eliminated from the chart

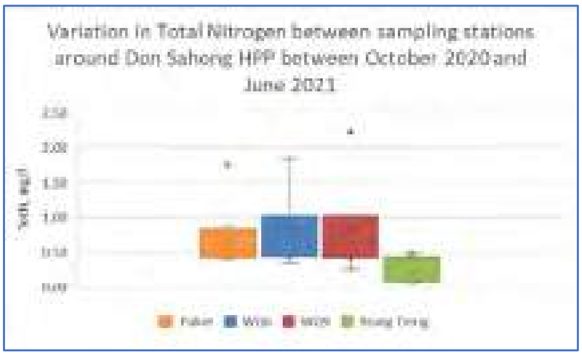


Figure 4-22: Box and whisker charts for WQ results between October 2020 to June 2021 for Total Nitrogen for sampling stations above and below Don Sahong.

The variation in phytoplankton - Chlorophyll-a and Cyanobacteria - in the four JEM sites around Don Sahong are shown in *Figure 4-23*. The median values for Chlorophyll-a for all four sites range between 0.2 to 0.3 micrograms/l, with little to choose between them, but with generally higher values in January and February (between 1.5 and 2.5 micrograms/l). For Cyanobacteria, the median levels are generally very low for all sites below the dam (between 0 and 0.04 micrograms/l), but there are much higher outlier values recorded at all sites on 17th February 2021, when the Cyanobacteria concentrations ranged between 0.4 and 0.57 micrograms/l. It is noted that a similar set of high Cyanobacteria values were recorded in Xayaburi on 13 January 2021. This event will be discussed later when considering the monthly changes between sites.

The relationship between nutrient concentration and Cyanobacteria growth has been outlined in section 3.2.1. The outlying high TotP results in December 2020 are unlikely to have caused the Cyanobacteria bloom in February.

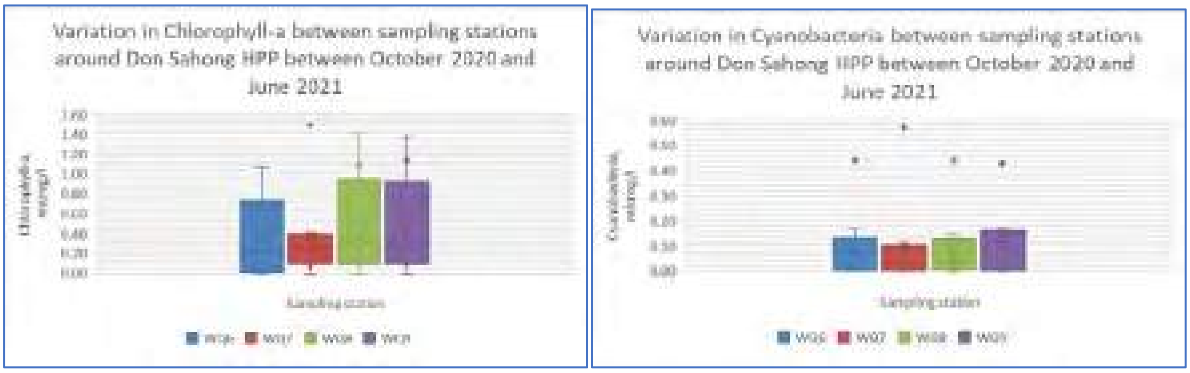


Figure 4-23: Box and whisker charts for WQ results between October 2020 to June 2021 left) Chlorophyll-a and right) Cyanobacteria for sampling stations above and below Xayaburi.

Note: all the outliers of Cyanobacteria indicated on the chart occurred in February 2021

Indicators of poor water quality

The median, maximum, minimum and standard deviation of the monthly results for Ammonium, Chemical Oxygen Demand and Faecal coliforms for the Don Sahong JEM sites are shown in *Table 4-4*. The detailed monthly results are shown in Annex 5. These measurements have only been made at the Pakse station, WQ1, WQ4 and at Stung Treng. Box and whisker charts for COD and Ammonium are presented in *Figure 4-24*. For Ammonium the median values are relatively low between 0.02 and 0.04 mg/l, but the medians for Pakse and Stung Treng are slightly higher than in the WQ6 and 9 stations, and the ranges and maxima at Stung Treng are generally wider and higher than in the other stations.

Table 4-4: Don Sahong JEM Pilot Results for indicators of poor water quality, October 2020 to June 2021

Station Name	Statistic	NH4N_mg/L	CODMN_mg/L	FC _MPN/100ml
Threshold for Protection of Human Health		0.5	5	1000cells/100ml
Threshold for Protection of Aquatic Life		0.1	NA	
Pakse	Median	0.03	1.7	120.0
	Max	0.06	10.6	230.0
	Min	0.02	0.8	20.0
	Standard Deviation	0.0	3.1	72.7
WQ6	Median	0.02	1.7	45.0
	Max	0.05	3.3	110.0
	Min	0.01	0.2	18.0
	Standard Deviation	0.0	1.0	31.0
WQ7	Median			
	Max			
	Min			
	Standard Deviation			
WQ8	Median			
	Max			
	Min			

Station Name	Statistic	NH4N_mg/L	CODMN_mg/L	FC _MPN/100ml
	Standard Deviation			
WQ9	Median	0.03	1.6	45.0
	Max	0.04	3.9	130.0
	Min	0.01	1.2	28.0
	Standard Deviation	0.0	0.8	36.3
Stung Treng	Median	0.04	1.0	
	Max	0.12	2.7	
	Min	0.02	0.6	
	Standard Deviation	0.0	0.6	

For COD, the median values for all sites vary between 1 and 2 mg/l, but with occasional outliers at Pakse and WQ9. These occur at Pakse in October with a COD of 10.6 mg/l, and the high at WQ9 in November at 3.86 mg/l, which is still lower than the threshold values for the Guideline on Human Health at 5.0 mg/l.

For Faecal Coliforms, the median results for Pakse, WQ6 and WQ9 are shown in ***Figure 4-25***, with Pakse showing a greater variability in the FC results and a higher median at 120 MPN/100ml and WQ6 and 9 with median values below 50 MPN/100 ml. The higher range of values at Pakse indicates greater risks of contamination and correlates with the higher variability in the COD readings. At all of these sites the values are lower than the Human health threshold value of 1,000 MPN/100 ml recommended for water activities, e.g. boating and fishing. The results from WQ9 downstream of the dam generally slightly lower than WQ7, but with one outlier in June 2021 when it reached 130 MPN/100ml.

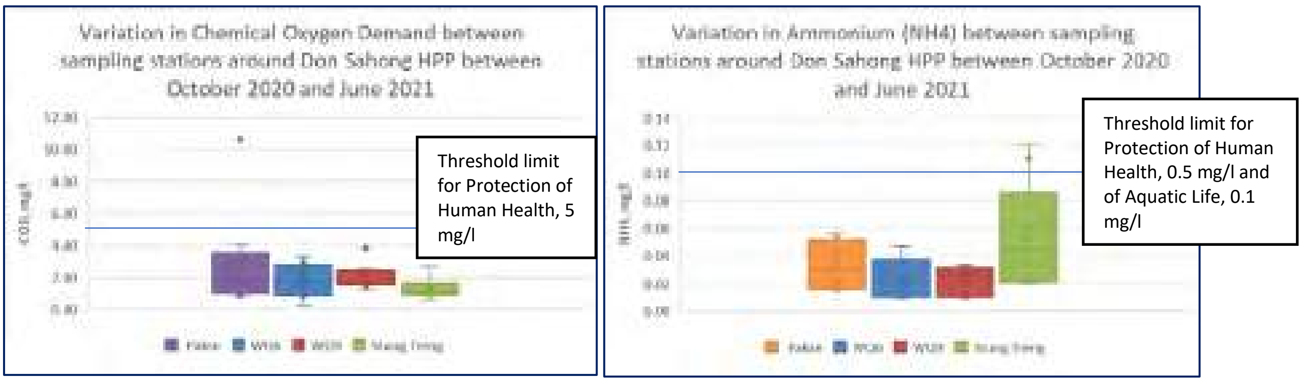


Figure 4-24: Box and whisker charts for WQ results between October 2020 to June 2021 left) COD and right) Ammonium for sampling stations above and below Don Sahong.

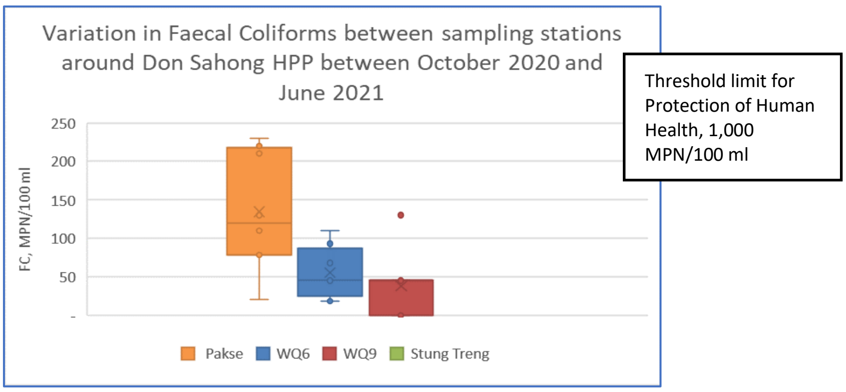


Figure 4-25: Box and whisker charts for WQ results between October 2020 to June 2021 for Faecal Coliforms for sampling stations above and below Don Sahong.

4.2.1.2 Statistical analysis

The results from each site were compared in each month for 11 monthly sampling events between October 2020 and September 2021. Where the difference between the means was sufficiently large as to be ecologically or environmentally important, the difference between the means was tested for statistical significance. Where the means were sufficiently close that the difference was considered to be not of environmental or ecological importance, whether or not it was statistically significant, a test of statistical significance was usually not carried out. Results may be statistically significant even if they have no environmental importance, and results that are not statistically significant are never environmentally important. For example in February the average % saturation of oxygen at site 6 was 99.6%, and the average saturation at site 7 was 97.16%, but the two were not statistically different because of the variation within the measurements at each site, so we reject the hypothesis that there was any real difference between the two on this occasion, even though on other occasions, such as January, the difference between the two was not much larger (4%), but was significant.

Several patterns were evident:

- Dissolved Oxygen saturation tended to be lower at WQ7, within the impoundment, than at WQ6 or WQ8 (***Figure 4-26***). The difference with site WQ6 was significant in 8 months but not in February, March and August.
- In February, March and August the Dissolved Oxygen saturation was significantly higher at WQ8 than at WQ7, as it was in every other month with the exception of January. (***Table 4-5***)

Table 4-5: Significance comparison of Dissolved Oxygen % saturation at Don Sahong sampling stations WQ6, WQ7 and WQ8

Month	Mean at WQ6	Mean at WQ7	*P for 6 vs 7*	Mean at WQ8	*P for 7 vs 8*
October	87.7	79.5	0.001	92.4	<0.0001
November	89.2	85.8	0.02	107.0	<0.0001
December	97.8	93.5	<0.0001	99.1	<0.0001
January	103.5	99.5	<0.0001	100.5	**0.22**
February	99.6	97.1	**0.13**	102.3	0.02
March	101.7	101.4	**0.36**	104.1	<0.0001
April	94.9	91.6	0.0006	95.2	<0.0001
June	97.6	92.8	<0.0001	98.5	<0.0001
July	96.3	95.1	<0.0001	97.1	<0.0001
August	83.7	83.5	**0.33**	85.0	0.001
September	89.1	86.9	<0.0001	89.1	<0.0001

Note: P values in red indicate tests where the difference between sites was *not* statistically significant.

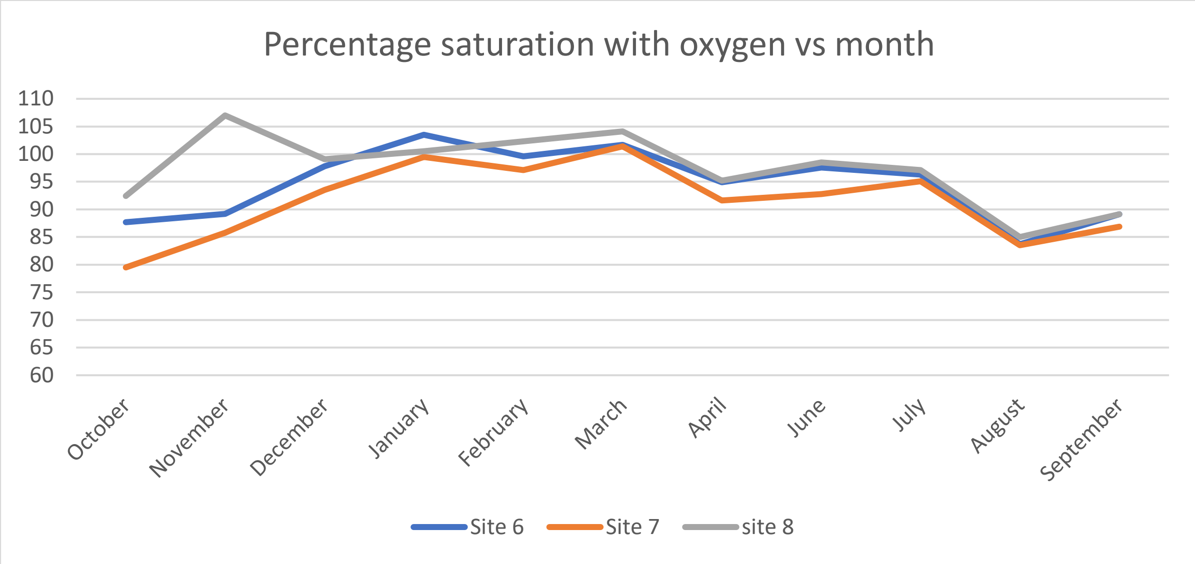


Figure 4-26: Percentage Dissolved Oxygen saturation at Don Sahong sampling stations between October 2020 to September 2021

Also evident were the following observations:

- Turbidity was lower at site 6 than site 7 in December, January, February March, April, June, and July, but not in September, October, November or August (*Table 4-6* and *Figure 4-27*)
- Results for pH were variable, but often higher at site 8, for example in July, August, September, October, November and June, and sometimes at site 9.
- Higher levels of primary production raise pH, as CO_2 is taken from the water through photosynthetic activity.
- In many months chlorophyll concentrations were not measurable at any site but it was high at site 7 in September, and low at site 6 in June and dropped between sites 6 and 7 in January.

Table 4-6: Significance comparison of Turbidity at Don Sahong sampling stations WQ6, WQ7 and WQ8

Month	Mean at 6	Mean at 7	*P for 6 vs 7*	Mean at 8	*P for 7 vs 8*
October	241	253	0.05	156	<0.0001
November	27.0	27.2	**0.42**	26.8	**0.39**
December	7.6	8.1	0.03	8.3	**0.18**
January	5.4	7.0	**0.06**	9.0	0.04
February	6.4	7.3	0.03	7.4	**0.33**
March	4.6	5.1	<0.0001	5.0	**0.34**
April	5.3	6.1	0.003	6.1	**0.38**
June	5.5	5.7	<0.0001	6.7	<0.0001
July	6.1	6.3	<0.0001	6.3	<0.0001
August	62.2	58.4	0.002	64.4	0.0002
September	68.4	54.3	<0.0001	73.6	<0.0001

P values in red indicate tests where the difference between sites was *not* statistically significant.

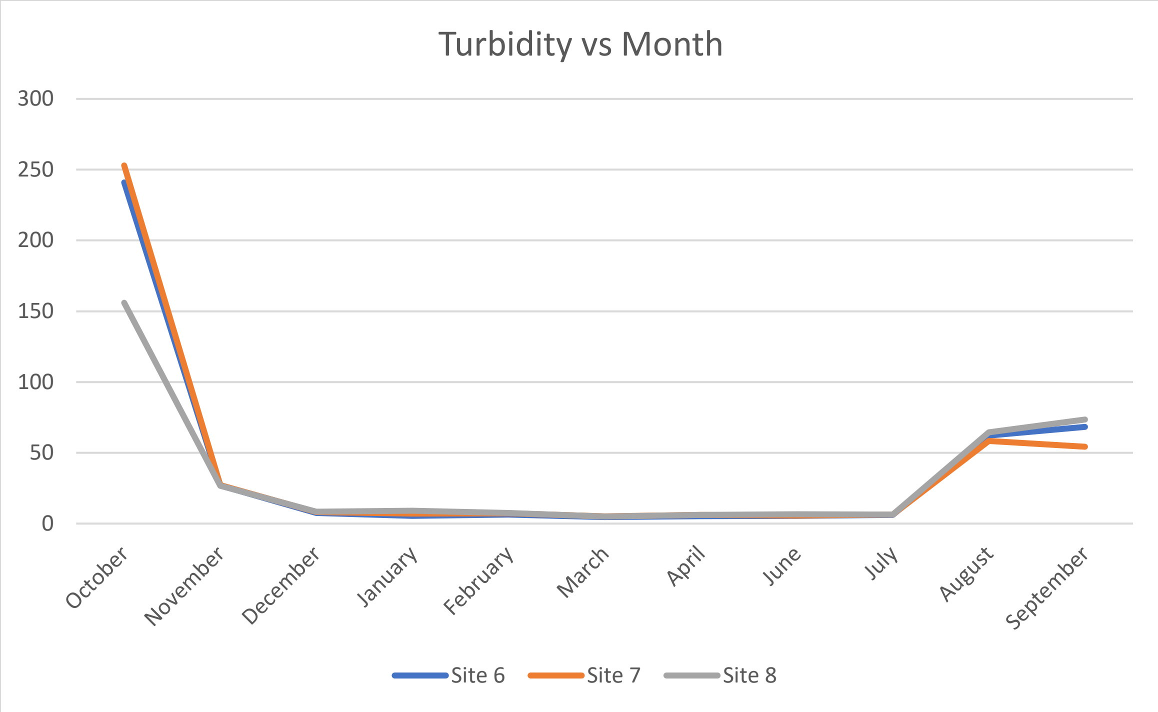


Figure 4-27: Turbidity at Don Sahong sampling stations between October 2020 to September 2021

4.2.1.3 Monthly changes across Don Sahong JEM pilot sites

The detailed results shown in *Table 4-2* to *Table 4-4. Table 0-7* have been expressed as charts showing the changes in water quality with progress from upstream of the impoundment, within the impoundment itself and downstream of the dam each month. This analysis helps to understand the effects that impoundment and dam operation may have upon the water quality. The charts for Temperature, pH, Conductivity, Dissolved Oxygen and COD are found in *Figure 4-26* and the charts for TSS and Turbidity, Nutrients and Phytoplankton are found in *Figure 4-27.*

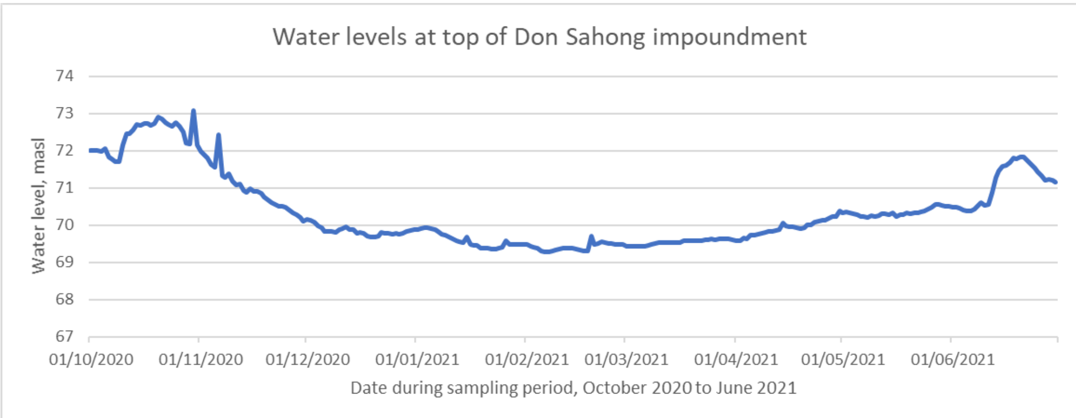


Figure 4-29: Changes in water level at the top of the Don Sahong impoundment

Source: Don Sahong Power Company

There appears to be very little difference in the water Temperature and pH above, in the impoundment and below the dam in any of the months, apart from the generally higher Temperatures already noted at Stung Treng, and the slightly higher pH values at WQ7 to WQ9, although the November pH values at WQ6 and 7 are slightly lower than pH 6 threshold for good quality. Effectively, the Don Sahong dam and impoundment is having very little effect upon the surface Temperatures and pH in the river.

Apart from the occasional differences between the readings in Conductivity at Pakse and Stung Treng, the changes with passage between WQ6 to WQ9 show very little differences in all months ranging from 10 in October 2020 increasing to between 21 to 27 mS/m during the drier months. There is no evidence that the Don Sahong dam and impoundment is affecting the Conductivity of the water.

Dissolved Oxygen values likewise do not change significantly with passage through the impoundment and downstream of the dam, generally maintaining high DO concentrations of between 6 to 8 mg/l apart from slight reduced values below 6 mg/l in October 2020 at WQ7. Generally all the DO contents of the surface waters are above the Water Quality Guidelines for the Protection of Aquatic Health of 5 mg/l.

For COD, the WQ7 values are lower than those measured at Pakse, as would be expected since the WQ7 is 100 km below Pakse, and COD values at WQ9 downstream of the dam are variable, sometimes higher and sometimes lower than those at WQ7. In no months does the COD at WQ7 and WQ9 downstream of the dam exceed the 5 mg/l threshold for Water Quality Guidelines for the Protection of Human Health. It is concluded that during this period, the impoundment and dam has not had any negative effect upon the COD levels.

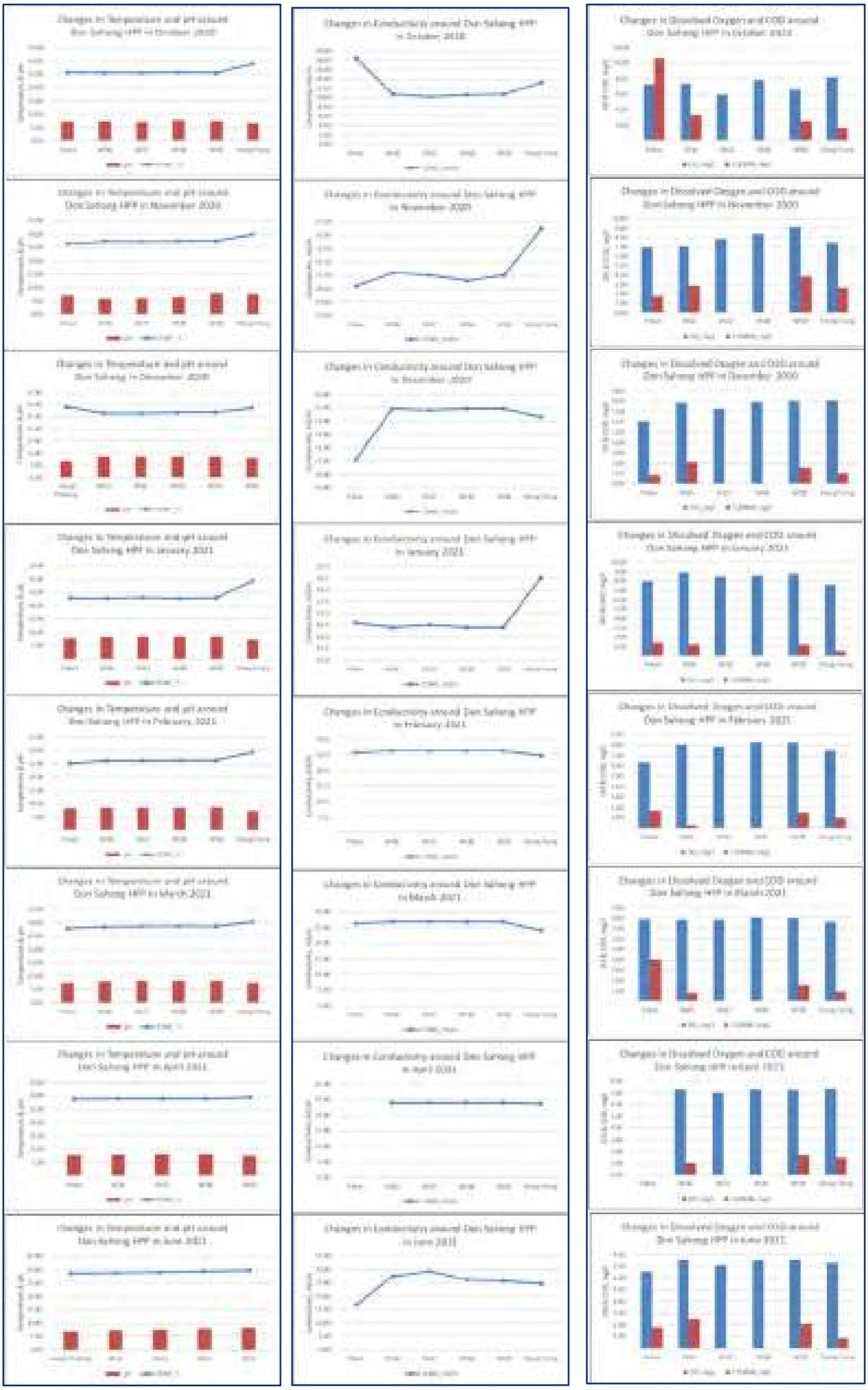


Figure 4-28: Monthly changes in Temperature, Conductivity, DO and COD parameters with passage downstream from WQ7 to WQ9, October 2020 to June 2021

Note: Shown on Left) Temperature and pH; Centre) Conductivity and Right) Dissolved Oxygen; and COD.

Figure 4-29 shows the changes downstream each month for Total Suspended Solids and Turbidity. During October 2020, when the TSS levels are high, just under 200 mg/l, there appear to be little differences between WQ7 and WQ9, while in November there is a reduction in TSS through the dam with WQ7 being 34 mg/l, reducing to 4 mg/l in WQ9. Thereafter, there appears to be limited differences in TSS concentration between the two sites above and below the dam. The Turbidity generally follow the TSS levels, demonstrating the relationship between the two, with little distinct patterns to show either increase or reduction in the two measures with passage downstream.

The changes in nutrients – NO32 and TotP with passage downstream each month do not show very evident patterns of either accumulation within the impoundment or depletion, with much lower values for NO32 in February 2021, compared to the other months (less than 0.1 mg/l compared to ranges between 0.4 and 0.7 mg/l in other months.

Similarly for TotP, relatively low levels are maintained with passage downstream in all months, with an exception of the very high values for TotP in December 2020, which have been removed from the charts as anomalies.

The Chlorophyll-a and Cyanobacteria levels do not show any definite patterns of change with passage downstream, with Chlorophyll-a content generally varying between 0.1 and 0.5 micrograms/l between the sites and only reaching 1.4 micrograms/l in January and February 2021. The one month in which there is a definite pattern is February 2021, when phytoplankton levels are more or less the same throughout the sites (between 1.1 and 1.4 micrograms/l) but with a significantly high proportion of Cyanobacteria. In WQ6 Cyanobacteria make up 41% of the phytoplankton, 38% in WQ7, 40% in WQ8 and then falling 31% at WQ9. This would indicate that in February there was a minor bloom of blue-green algae throughout this section of the river, possibly carried downstream from the bloom recorded around Xayaburi on 13th January 2021. Changes in water level in the impoundment shown in *Figure 4-29*, show that the water level had been at low level 69.5 masl without much variation in the month before 17th February 2021, so this is unlikely to be related to the Cyanbacteria bloom. However, in all months the Chlorophyll-a concentration was rarely above 1.5 micrograms/l, well below the WHO risk to human health threshold of 50 micrograms/l, described in section 3.2.1.

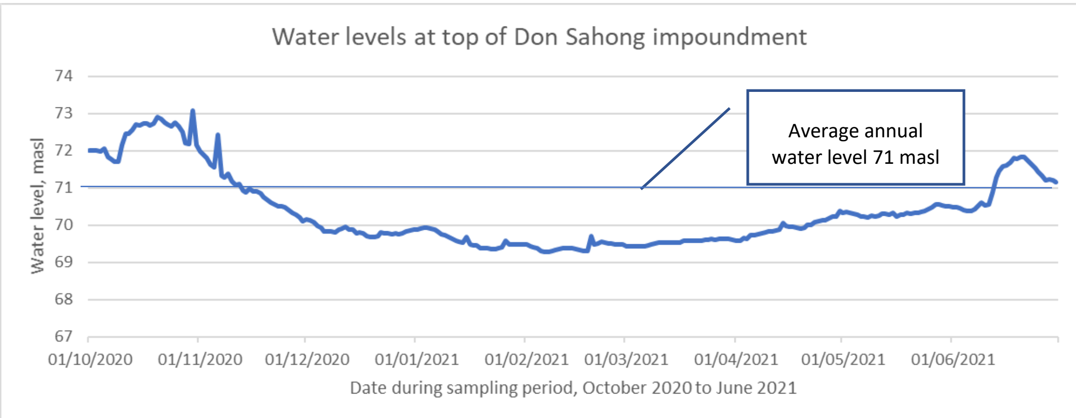


Figure 4-29: Changes in water level at the top of the Don Sahong impoundment

Source: Don Sahong Power Company

Figure 4-30: Monthly changes in WQ parameters with passage downstream from WQ1 to WQ5, October '20 - June '21.

Note: Left) TSS & Turbidity; Centre) Nutrients (NO32 & TotP) and Right) Chlorophyll-a & Cyanobacteria. Differences in scales and high outlier in TotP in December has been removed.

4.2.1.4 Don Sahong Impoundment profiles

The impoundment profile, measuring water quality parameters of Temperature, pH, Conductivity and Dissolved Oxygen, turbidity and phytoplankton with depth down to 20 m below the surface each month is used to indicate whether the water in the impoundment is stratifying with cooler and poorer quality water being trapped at lower levels. The monthly water quality profiles for the Don Sahong impoundment at WQ2 are shown in ***Figure 4-31***.

The almost horizontal line plots of Temperature with depth in all months between October 2020 and June 2021 would indicate that there is no thermal stratification. And the pH and Conductivity lines show that there is little chemical stratification in the Xayaburi impoundment. The Dissolved Oxygen content is more or less constant during most months, although in January 2021 there is a decline in DO content with depth falling from about 8 mg/l at the surface to about 5 mg/l at 20 m depth, but even at 20 m the DO content does not fall below the 5 mg/l threshold for aquatic life. This may indicate the beginning of stratification during the colder months of the year, becoming more mixed in February to June. This is a similar pattern to Xayaburi impoundment in December 2020 and January 2021. The length of the probe cable at 20 m limits the measurement to this depth, but the height of the Don Sahong dam is 22.5 m, so it is likely that the probe will be recording water quality conditions very close to the bottom of the impoundment.

The turbidity measurements appear to be slightly more variable with depth, especially in November 2020, and the phytoplankton measurements down to 10 m, generally show similar levels throughout the water column, with Chlorophyll-a being a much higher value than the Cyanobacteria, except in January 2021, when the same high proportions of blue-green algae are found in the water column as at the surface.

The more detailed charts of Turbidity, Chlorophyll-a and Cyanobacteria down to 10m depth are shown in ***Figure 4-32***. The turbidity measurements appear to be more variable with depth, and the phytoplankton measurements down to 10 m generally show variable levels throughout the water column, with some months (November 2020 and April 2021) showing some high and low values within one metre. In January, March and June 2021, there appears to be tendency for Chlorophyll-a to increase with depth.

It is clear that generally the Chlorophyll-a has a much higher value than the Cyanobacteria, except in November and December 2020, and April 2021, when the Cyanobacteria concentration increases at depth and sometimes matching the Chlorophyll-a readings. This would indicate that in some months the Cyanobacteria may tend to concentrate at depths.

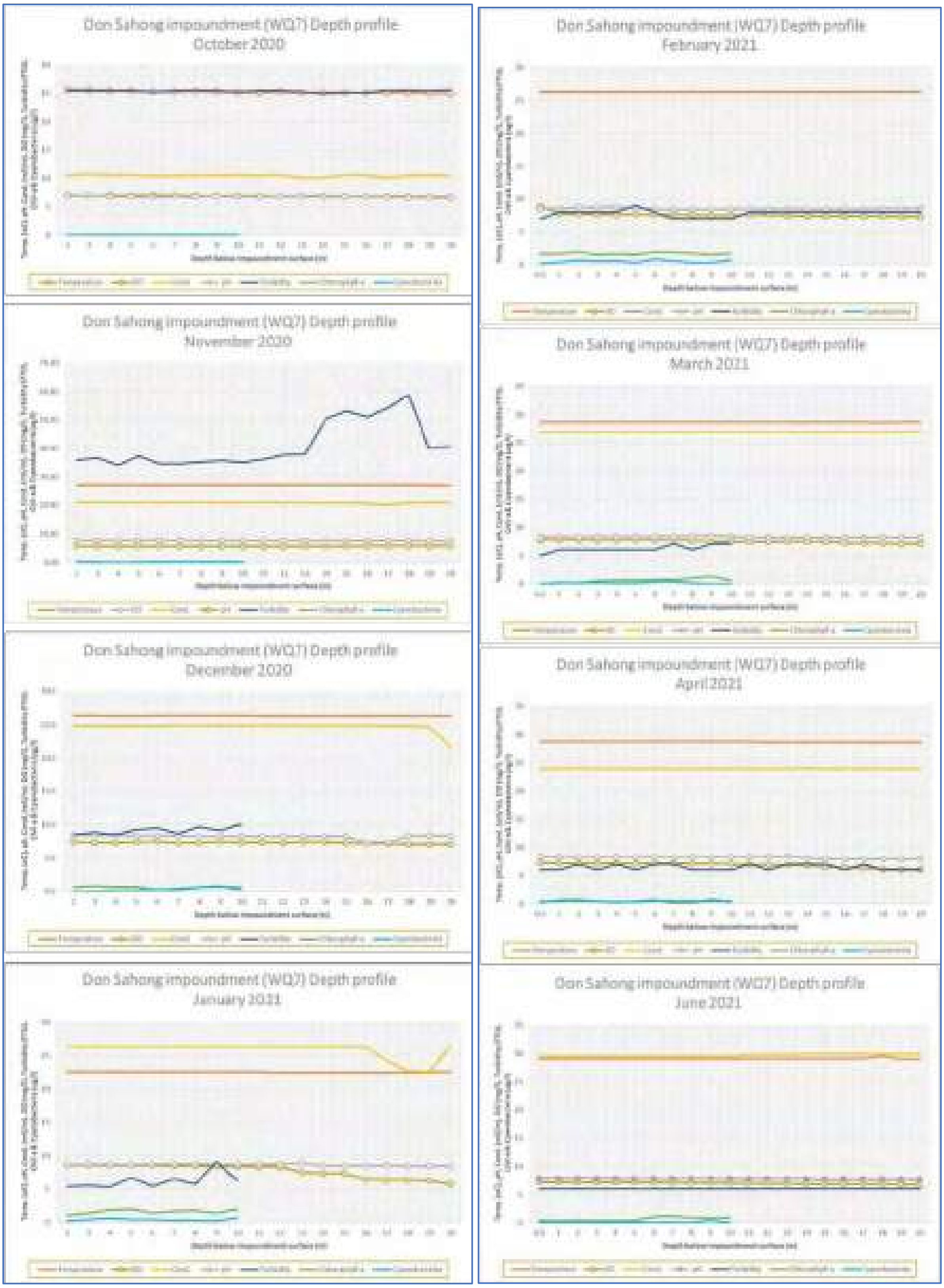


Figure 4-31: Don Sahong impoundment (WQ7) profiles between October 2020 and June 2021

Figure 4-32: Don Sahong impoundment Phytoplankton depth profiles between October 2020 and June 2021

4.2.2 Lessons learned and Recommendations

The following lessons learnt follow from the water quality monitoring and analysis at Don Sahong HPP:

- The presence of the Don Sahong dam and impoundment does not appear to be affecting most parameters of water quality measured during the dry season months between October 2020 and June 2021

- The main qualification being that water quality measurements are taken from spot samples during the late morning and early afternoon. They do not capture any changes in water quality such as Dissolved Oxygen that may fluctuate during the day and night, with lower levels often being recorded at night.
- Unlike the Xayaburi pilot site, the turbidity and TSS do not show clear patterns of changes with passage through the impoundment and below the dam perhaps indicating that the low residence time in the small Don Sahong impoundment does not allow sediment to settle out.
- Nutrient levels appear to be slightly increased in the impoundment, but not passed on downstream below the dam
- There may be a slight indication of higher phytoplankton levels in the impoundment compared to downstream and a probable minor bloom of Cyanobacteria in February 2021.
- Impoundment profiles do not show thermal or chemical stratification, although there may be evidence of declining DO with depth during the colder months of January 2021.

Resulting recommendations for water quality monitoring protocols are as follows:

- In order to capture the diurnal changes in water quality that may occur downstream of the dam, especially in DO, turbidity and pH a semi-continuous water sampling programme should be installed with the flow and water level monitoring station at WQ4.
- The AlgaeTorch measurements of Chlorophyll-a and Cyanobacteria are providing interesting insights into the relatively low levels and dynamics of phytoplankton
- The relationship between TSS and turbidity measurements reported for Xayaburi is also found at Don Sahong. This may be developed to develop an on-site method using Turbidity to estimate TSS levels.
- Before future sampling campaigns, all monitoring equipment should be appropriately calibrated and where there are several sets of equipment being used the trial results should be compared to identify potential differences. This is suggested in order to avoid differences due to sampling equipment which may be apparent from WQMN and JEM results.

4.3 ECOLOGICAL HEALTH MONITORING

4.3.1 EHM Results and data analysis

4.3.1.1 EHM species counts and EH Index at JEM sites

The measurements taken for the Ecological Health Monitoring have been described at the start of section 3.3. together with the relevance of the substrate conditions, site disturbance scores and environmental parameters. The site conditions reported for each of the EHM sites during the monitoring missions, are shown in ***Figure 4-33*** and ***Figure 4-34***. The overall substrate conditions scores show that EHM7 above the impoundment lies in the Good suitability range for aquatic biota (which is reflected in its high EHI score), and EHM8 in the impoundment and EHM9 and EHM10 downstream of the dam were rated as having Moderate substrate suitability, with EHM10 almost in the Good suitability range. In terms of Site Disturbance Scores, EHM7 was considered to be in the Light stress range and the other three sites were considered to be in the Moderate stress range.

In terms of Environmental parameters, the readings largely correspond to the results from the Water Quality analysis showing little change between the four sites for Temperature, Dissolved Oxygen (DO), pH and Conductivity, but slight differences in the transparency of the water as measured by Secchi

Disc. The transparency in the upstream site at EHM7 is marginally higher than in the other three sites, but in all sites the Secchi disc could be read at between 1.75 and 2.25 m.

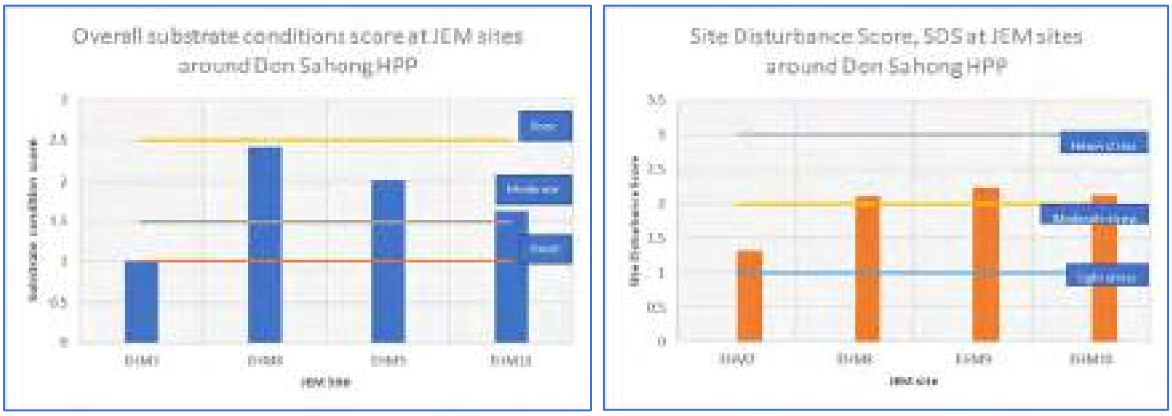


Figure 4-33: Overall Substrate Condition and Site Disturbance Scores for each of the Xayaburi EHM sites

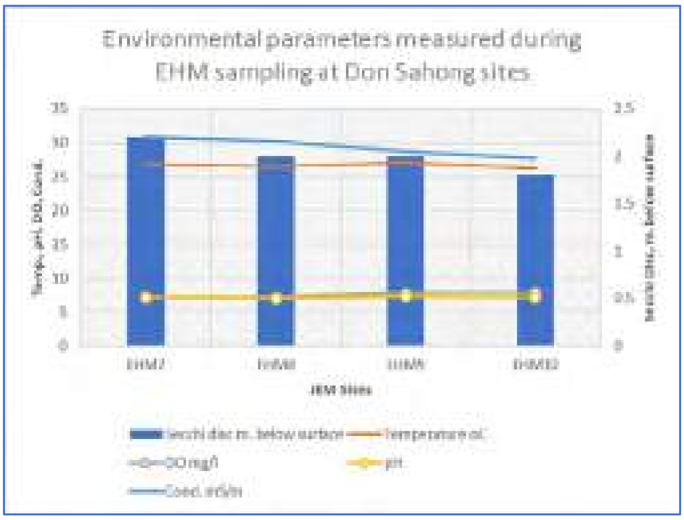


Figure 4-34: Environmental parameters measured at each of the Xayaburi EHM sites

Table 4-7 shows the results of the Abundance, Species Richness and ATSPT for the four biota types for each of the EHM sites above (EHM7), in the impoundment (EHM8) and downstream of Don Sahong dam (EHM9 and EHM10). The calculation of the EH Index for each of the sites shows that EHM7 is classified as being in Good condition with a high score of 9 threshold levels achieved, while in the impoundment the EHI score is only 5 threshold levels, and the two sites immediately downstream of the dam (scoring 6 threshold levels achieved) are all classified as being in Moderate condition. There is a clear change occurring within the impoundment and below, showing the impact of the dam on the populations of aquatic biota.

The comparison of the three variables for each biotic type also illustrates these changes in more detail and these are considered in comparison with the historic EHM results in the other mainstream sites in chapter 5.1.4.

The statistical analysis of the EHM results of the Don Sahong sampling sites have been discussed in section 3.3.1.2. This shows that the biota assemblages at the Don Sahong sites are significantly different from the Xayaburi sites, and that for Diatoms and Zooplankton, all of the EHM sites 7 to 10 have different species present, but that for Littoral and Benthic macroinvertebrates sites EHM9 and 10 have similar species present, but above the impoundment and in the impoundment, the species are different.

Table 4-7: Ecological Health Index classifications for the EHM sites around Don Sahong

Site					EHM7	EHM8	EHM9	EHM10
Year					**2021**	**2021**	**2021**	**2021**
Site Disturbance Score SDS					1.33	2.1	2.25	2.13
Average Abundance								
	Benthic diatoms	BD			1162	6238.4	1264.5	3653.4
	Zooplankton	ZPT			14.00	22.66	16.00	17.00
	Littoral macroinvertebrates	LM			77.3	134.2	96.3	66.0
	Benthic macroinvertebrates	BM			5.16	7	12.25	10.58
Richness	Benthic diatoms	BD			15	4.1	25	36.2
	Zooplankton	ZPT			6.33	5	6.00	5.66
	Littoral macroinvertebrates	LM			17.5	3	9.3	12.6
	Benthic macroinvertebrates	BM			2.41	1.91	3.90	5.16
ATPST	Benthic diatoms	BD			37	47	46	47
	Zooplankton	ZPT			28	47	47	47
	Littoral macroinvertebrates	LM			29	42	45	42
	Benthic macroinvertebrates	BM			36.6	48.7	47.8	49.9
Ecosystem Health index Calculations								
		10th percentile	**90th percentile**	**Guideline**				
Abundance	Benthic diatoms	136.22	376.34	>136.22	1	1	1	1
	Zooplankton	22.33	174.07	>22.33	FALSE	1	FALSE	FALSE
	Littoral macroinvertebrates	46.68	328.56	>46.48	1	1	1	1
	Benthic macroinvertebrates	5.37	56.34	>5.37	FALSE	1	1	1
Richness	Benthic diatoms	6.54	11.78	>6.54	1	FALSE	1	1
	Zooplankton	9.8	20.2	>9.8	FALSE	FALSE	FALSE	FALSE
	Littoral macroinvertebrates	5.37	18.48	>5.37	1	FALSE	1	1
	Benthic macroinvertebrates	1.87	7.88	>1.87	1	1	1	1
ATPST	Benthic diatoms	30.85	38.38	<38.38	1	FALSE	FALSE	FALSE
	Zooplankton	34.83	41.8	<41.8	1	FALSE	FALSE	FALSE
	Littoral macroinvertebrates	27.8	33.58	<33.58	1	FALSE	FALSE	FALSE
	Benthic macroinvertebrates	31.57	37.74	<37.74	1	FALSE	FALSE	FALSE
	Total number of parameters meeting threshold				9	5	6	6
Quality	**Classification**	**Score**			B	C	C	C
Excellent	A	>10						
Good	B	>7			9			
Moderate	C	>4				5	6	6
Poor	D	<4						

In the Don Sahong JEM sites shown in *Table 4-7*, a close analysis highlights the differences in responses of the four biota types. Thus, for Benthic Diatoms, Abundance meets the threshold in all sites, Species Richness fails in the impoundment (EHM8), and fails in ATSPT in all sites except the control site above the impoundment (EHM7).

For Zooplankton, Abundance thresholds are only met in the impoundment (EHM8), but fail in other sites, Species richness thresholds are failed in all sites, and for ATSPT, all sites fail except at EHM7 above the impoundment.

For Littoral Macroinvertebrates, Abundance thresholds are met in all sites, as is Species Richness thresholds, except within the impoundment, and ATSPT thresholds are only met in EHM 7.

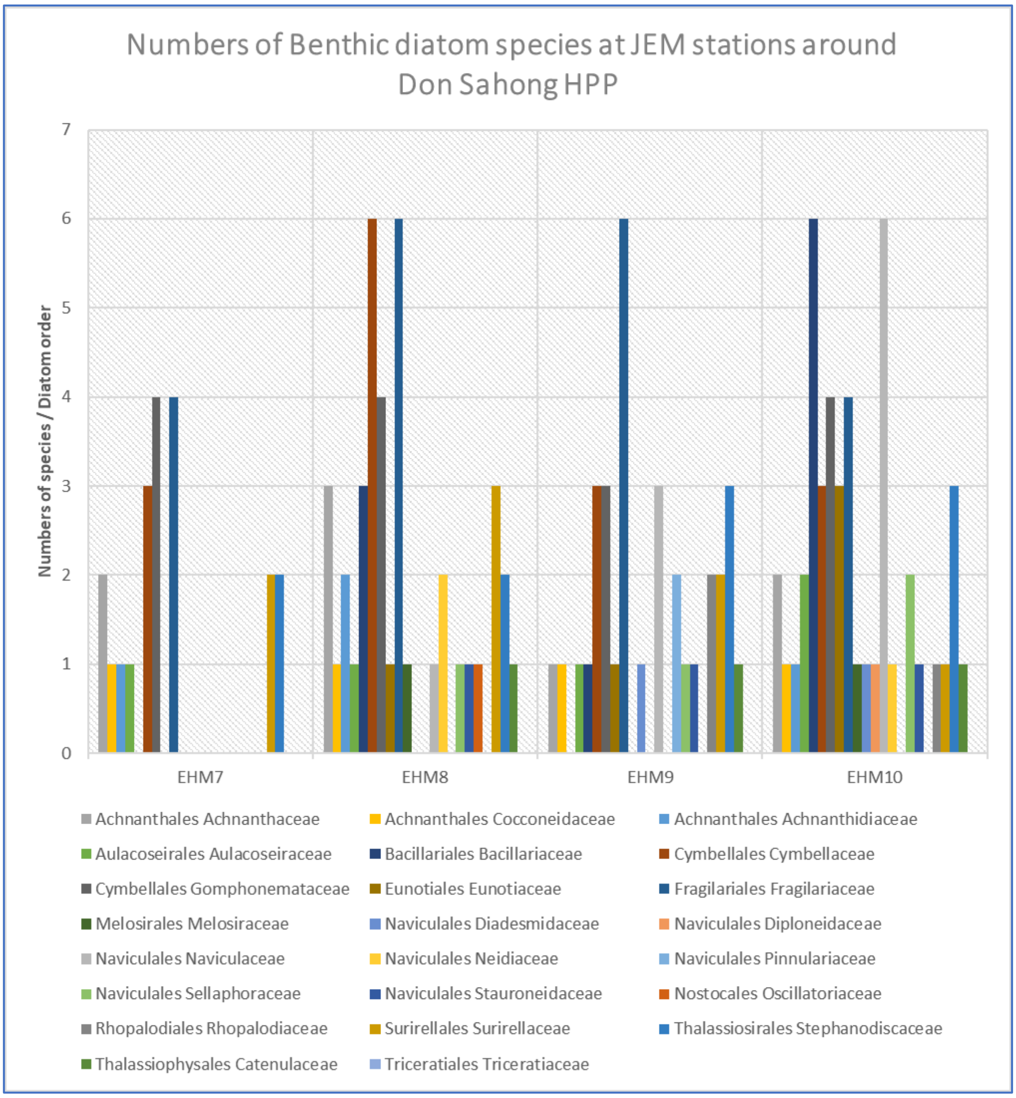
For Benthic Macroinvertebrates, EHM7 fails to meet the Abundance threshold, but all the other sites meet it. The Species Richness thresholds are met in all sites, but the ATSPT threshold is only met in EHM7.

4.3.1.2 Comparison of species represented for each biotic type

A deeper dive into the differences in species composition in each site helps to understand what the impacts of the hydropower project may be having on the biota, particularly identifying which biotic Orders are present or absent from each site.

In ***Figure 4-35***, the Benthic Diatom species identified in EHM7 appear to be less diverse than in the impoundment EHM8 and the two downstream sites EHM9 and EHM10. Observation during the visit indicated that the upstream site has embedded rocks, with deep and quite strong water flow and was less suitable for diatoms to grow. The two downstream sites contain flows from the dam and from the side stream, which may mask the direct effects of the dam flows. There are certain families that appear to predominate in the impoundment such as the Fragilariaceae, Cymbellaceae and Gomphonemataceae, whereas downstream the Bacilariaceae and Naviculaceae families appear to thrive.

Amongst the zooplankton families, the most striking aspect is the raised numbers of Arcellinida spp., and presence of Diplostraca spp., within the impoundment and downstream, compared to upstream. The monitoring team found many dead carapaces of the cladocerans, Diplostraca spp., in the impoundment, but noted that at the upstream site of EHM7, it was difficult to collect zooplankton samples because of the very strong flows, which would account for the relatively poor diversity of zooplankton at that site.



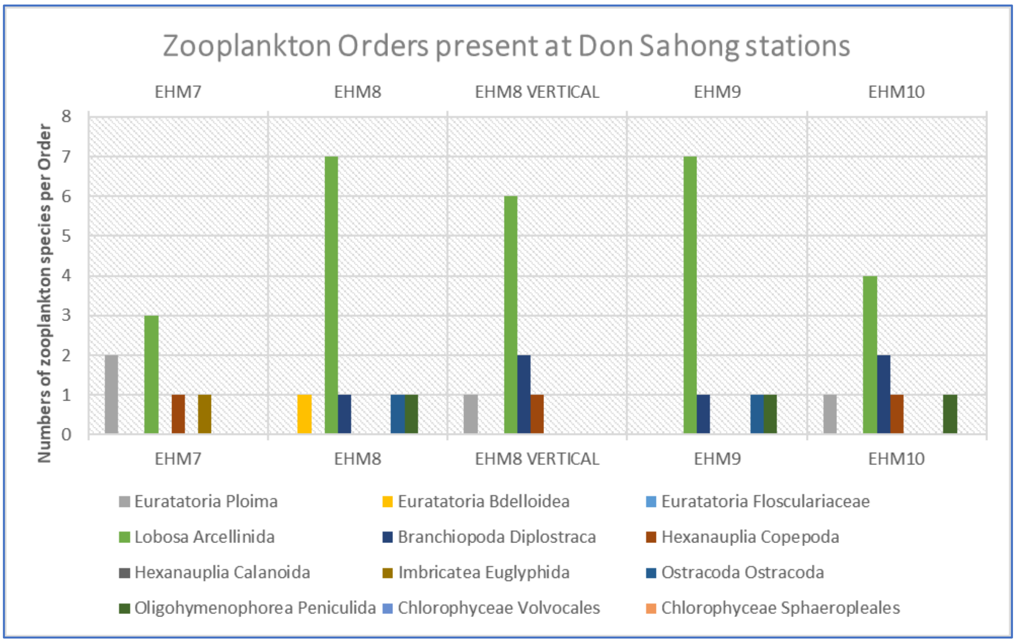


Figure 4-35: Top) Numbers of Benthic Diatom species by Order and Bottom) Numbers of Zooplankton species by Order present at Don Sahong EHM site

For littoral macroinvertebrates (***Figure 4-36***), the upstream site EHM7 is the most diverse and the pattern of decreasing diversity within the impoundment and immediately downstream is apparent, Coleoptera disappear in the impoundment, and only start to return downstream. The monitoring team note that EHM7 is very good and suitable site for macroinvertebrates, with diverse substrates, and with vegetation in river and along the river bank. The river has riffles, runs and pool areas.

By contrast in the impoundment, the diversity of families is reduced with Trichoptera spp., being depleted; they show increasing numbers of species downstream of the dam in EHM9 and EHM10. Plecoptera disappear in the impoundment, Ephemeroptera are most abundant and show a slight reduction in the impoundment and then recover similar numbers downstream. The impoundment has created new habitats with a river bed are covered by mud, steep shorelines and deep water with no vegetation. In places in the impoundment there is high flow of water. Only some groups of macroinvertebrates are found in the impoundment, especially some genus of Ephemeroptera.

At downstream sites EHM9 is close to the dam, the habitat has been disturbed by construction activity and high flow of water. There are narrow areas that can provide access for collecting samples, but in other areas the channel is wide and deep. EHM10 has more diverse habitats than EHM9.

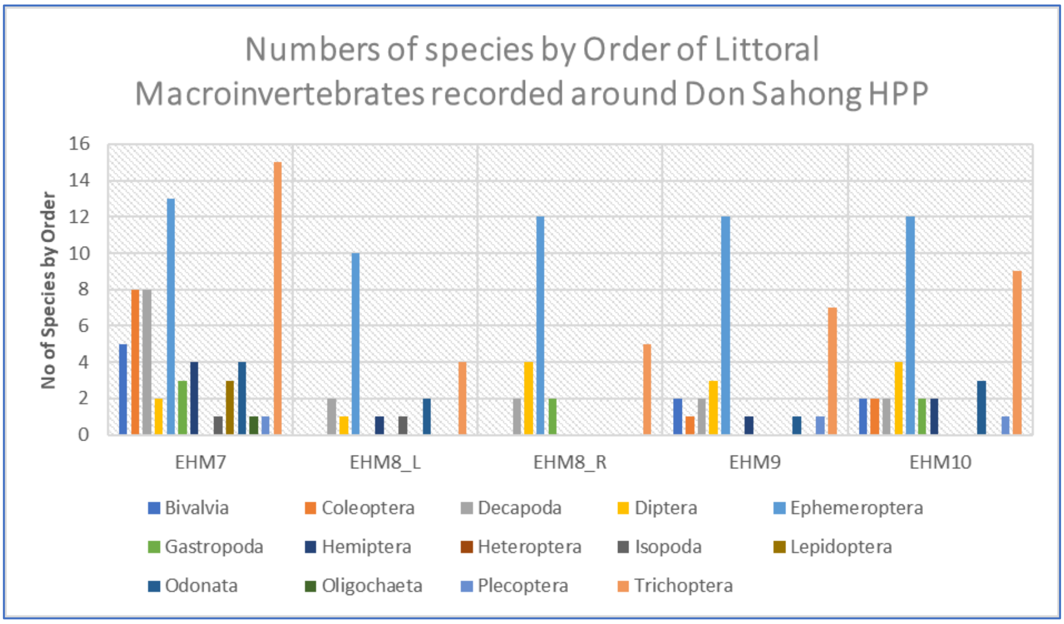
With the Benthic Macroinvertebrates (***Figure 4-36***), Ephemeroptera species appear to increase in the impoundment compared to upstream and downstream, Diptera decrease in the impoundment and Gastropods do not appear in the impoundment. Downstream EHM10 is more diverse than EHM9 and greater than EHM7, with Bivalves, Gastropods and Trichoptera all registering 4 different species.

The monitoring team observe that at EHM7 the substrate is mostly 80 – 90% silt and clay. The Benthic macroinvertebrates present are those that prefer this type of substrate, e.g., some dominant species of Diptera and aquatic worms (Clitellata, Haplotaxida and Oligochaeta).

Within the impoundment area there are various substrate types. Clay covers about 90% with the other substrate types being pebble, gravel, sand, and silt. Those substrates are suitable for different groups such as Ephemeroptera, Gastropoda, Trichoptera. However, the water current in many areas of impoundment is strong and deep which also affects sample collection.

For the last two downstream sites both species richness and abundance are increasing, especially EHM10 which has more variability in substrate type compared to the other sites. There is covering by cobbles by about 50 % on the left bank and about 90% silt in the middle and on the right bank. These characteristics provide better conditions for greater species diversity, as evidenced by the species of Trichoptera, Ephemeroptera and Gastropods.

In case of Don Sahong the results between upstream and downstream sites show clear differences in terms of species richness and abundance. In terms of sensitive and tolerant species the monitoring team found that the group of tolerant species as Aquatic worms, Diptera and Gastropods were more widely distributed and had a greater number than the more sensitive species as Ephemeroptera and Trichoptera.



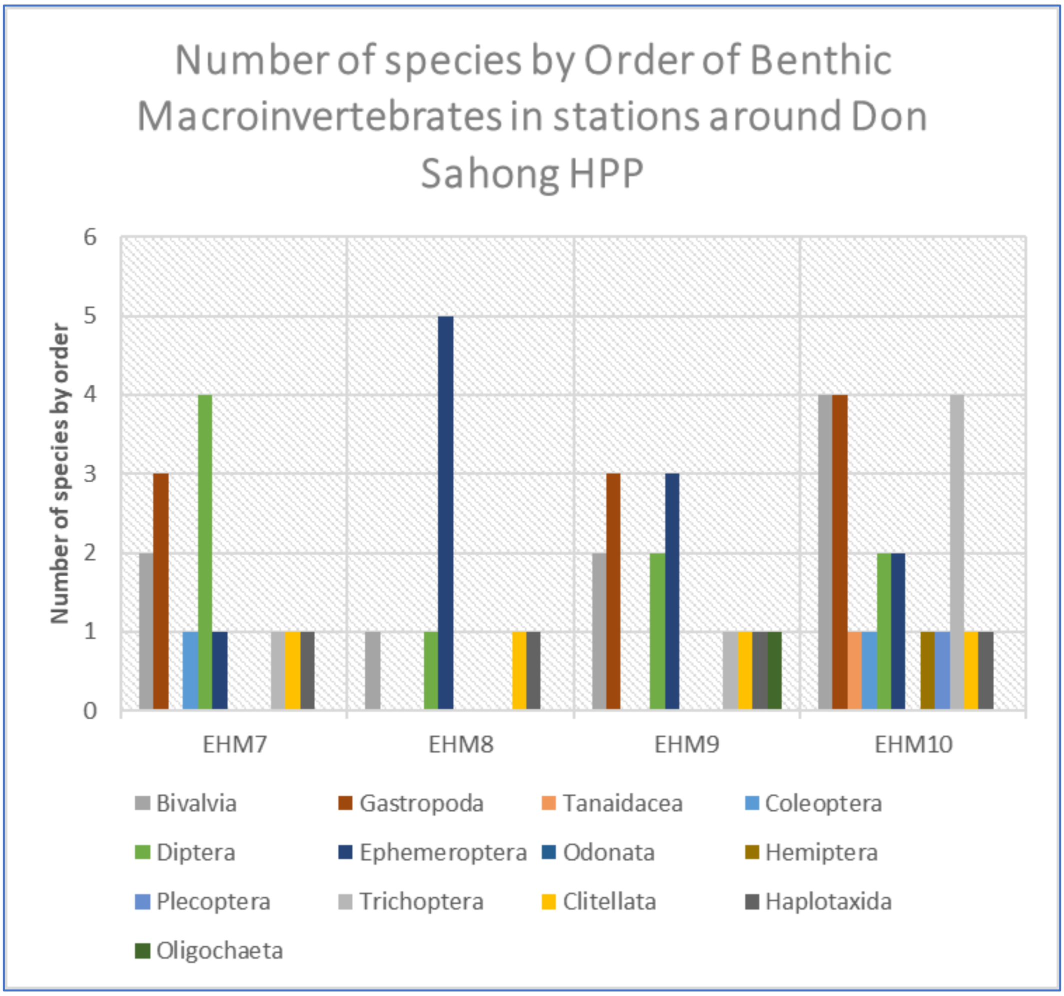


Figure 4-36: Don Sahong EHM site results

Note: Top) Numbers of Littoral Macroinvertebrate species by Order and Bottom) Numbers of Benthic Macroinvertebrate species by Order

This deep dive into the distribution of species in the different biotic groups illustrates how the EHM monitoring reflects the flow conditions, habitat and substrate types and the extent to which they have been changed in the impoundment and downstream of the dam. It also notes that ease and safety of access and collection of appropriate samples can be a factor affecting the species diversity and numbers.

4.3.1.3 Using ecological indicator species

The results for the analysis of the EPT species (Ephemeroptera, Plecoptera and Trichoptera) and the number of filter-feeding species present (described in section 3.3.1.4.) at each of the Don Sahong EHM sites are shown in ***Figure 4-37***. Considering the changes in the number of species and individuals of EPT it is clear that EHM7 contains 13 species of Ephemeroptera with about 200 individuals, 15 species of Trichoptera with about 200 individuals, and small numbers of individuals of one species of Plecoptera collected in the samples. Within the impoundment at EH8, the numbers of Ephemeroptera species remains the same but the number of individuals increases to nearly 600; the Plecoptera disappear and the Trichoptera species fall to 6 with very few individuals being collected. This is indicative of changing conditions in the impoundment compared to the original river, e.g. raised water levels, reduced flow rate and more sediment accumulating on the bottom, favouring certain species of Ephemeroptera, while eliminating the Plecoptera and some species of Trichoptera. Immediately after the dam at EHM9 and EHM10, there are the signs of recovery, with twelve species and about 250 individuals of Ephemeroptera; the Plecoptera species returns and the Trichoptera show and increase in numbers of species and individuals - 7 species increasing to 9 species of Trichoptera at EHM9 and 10 respectively with an increase in the number of individuals from about 100 to 250 being collected at these two sites.

A similar pattern may be observed in the numbers of species and individuals of filter feeding macroinvertebrates. EHM 7 contains 7 species of the Trichopteran Hydropsychidae but no Dipteran Simuliidae. However, within the impoundment at EHM8 the Hydropsychidae species numbers fall to 4 with only 30 individuals caught and a very few individuals of one species of Simulium. Downstream of the dam at EHM9 and EHM10 the numbers of Hydropsychidae increase again with between 4 and 5 species. This progression is also indicative of the gradual recovery of the aquatic biota with downstream of the dam.

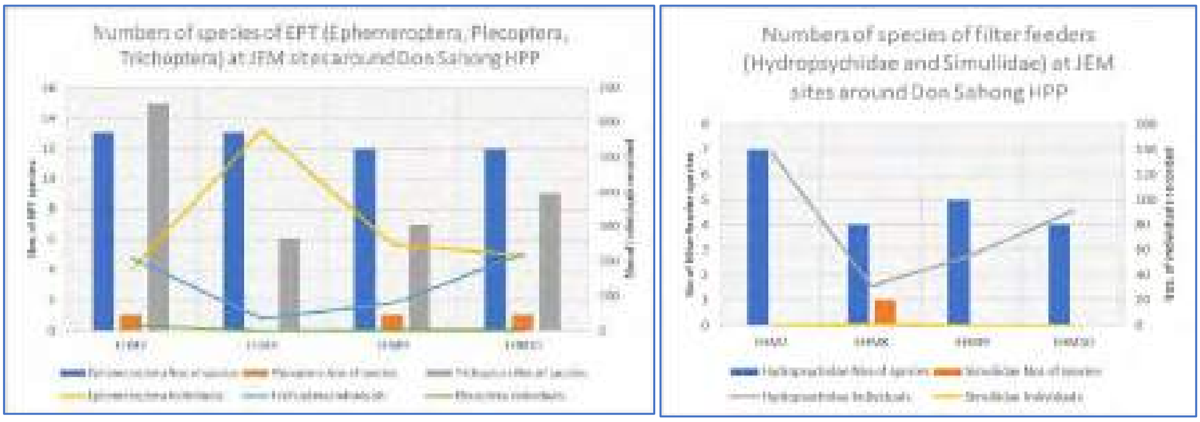


Figure 4-37: Left) Numbers of Ephemeroptera, Plecoptera, Trichoptera and Right) Filter feeding macroinvertebrates at the JEM sites around Don Sahong.

4.3.2 Lessons learnt and Recommendations

The following lessons learnt follow from the water quality monitoring and analysis at Don Sahong HPP:

- The Ecological Health monitoring results around Don Sahong show clear changes in the species diversity and numbers of biota present within the impoundment and downstream compared to the upstream reference site.
- The Ecological Health Index (EHI) in the impoundment and downstream are all classified as in Moderate health, with indications of recovery with passage downstream, compared to the upstream reference site which is classified as in Good health.
- The changes in the impoundment and downstream are likely to be caused by changes in the flow rates and water levels at the sites with resultant changes in the substrate and habitat conditions, rather than by changes in water quality.
- The responses of the different biota types provides greater insights into the changes of substrate and habitat, considering the average abundance, species diversity and ATSPT for each biota type, compared to the simple EHI.
- The Littoral Macroinvertebrates show the most clear changes in species diversity and abundance with passage downstream after the dam, but the responses of Benthic Diatoms, Zooplankton and Benthic Macroinvertebrates in the impoundment and downstream are all useful indicators.
- Deeper investigation of the Littoral Macroinvertebrates, using Ephemeroptera, Plecoptera, Trichoptera (EPT) and filter feeding invertebrates can help to explain the changes observed.
- The changes in the flow and substrate conditions occasionally make sampling difficult and potentially unsafe, which needs to be considered in site selection and interpretation of the results
- The significance of the changes is difficult to analyse statistically because there is only one year of sampling at each of the JEM stations.

Resulting recommendations for water quality monitoring protocols are as follows:

- The EHM component of the JEM should be continued with sampling at least once a year to build up statistically strong datasets of the ecological and habitat conditions both in the impoundment and downstream of the dam, since it appears to provide the clearest evidence of changes due to the hydropower operation.
- It is recognised that the sampling and identification of the biota is a lengthy and expert process which may be difficult to repeat at shorter intervals, but the development of a more rapid testing using only Littoral Macroinvertebrates should be considered between the biennial sampling.
- Because of the complexity of the hydrological and hydraulic patterns in the channels below Don Sahong, it will not be possible to follow the direct effects of the dam further downstream. However, the routine EH monitoring at Kbal Koh Village (CKM) in Cambodia will be instructive to map the downstream impacts and recovery from Don Sahong, because it is slightly further downstream from EHM9 and EHM10 with a baseline from before the dam was constructed.
- Because conditions within the impoundment are very different from a free-flowing river and the biota are probably still developing within the Don Sahong impoundments, further investigations into the typical biota within other impoundments within the Lower Mekong is recommended to provide reference conditions.

4.4 FISHERIES

4.4.1 Preliminary results and initial analysis

4.4.1.1 Fish Abundance and Diversity Monitoring (FADM)

As with Xayaburi, the analysis was done in Don Sahong to answer the following questions:

- What is the evolution of monthly catch per fisher in each site over the years?
- What is the trend in number of species caught each year in each site?
- What is the trend in average CPUE of gillnets used by fishers in each site?

4.4.1.2 Trends in monthly catch per fisher

Analysis of monitoring results indicate that the monthly catch per fisher (***Figure 4-38***):

- has steadily *increased* in these past years in Ban Hat station, upstream of Don Sahong Dam. That catch level seems to have evolved from 14 to 46 kg per fisher and per month on average between 2017 and 2021, which remains to be confirmed by interviews of local fishers;
- cannot be much commented in Muang Saen Nua, as this is a new station with only 11 months of sampling over two years. The point plotted here under 2021 represents 11 months of sampling from the start of the monitoring until June 2021, and reaches 28 kg/fisher/month.
- has seemingly *increased* in Ban Hang Sadam, from 23 to 38 kg/fisher/month between 2017 and 2021; however this result is contradicted by interviews of fishers who all point at a sharp decline in catches. Data need to be examined in detail by the teams in charge for confirmation.
- cannot be detailed in Ban Hang Khone, as this is a new site like Muang Saen Nua. The point plotted under 2021 reflects 11 months of monitoring and reaches 47 kg/fisher/month;
- has sharply declined in Ou Run, from 115 kg/fisher/month in 2018 down to 53 in 2021.

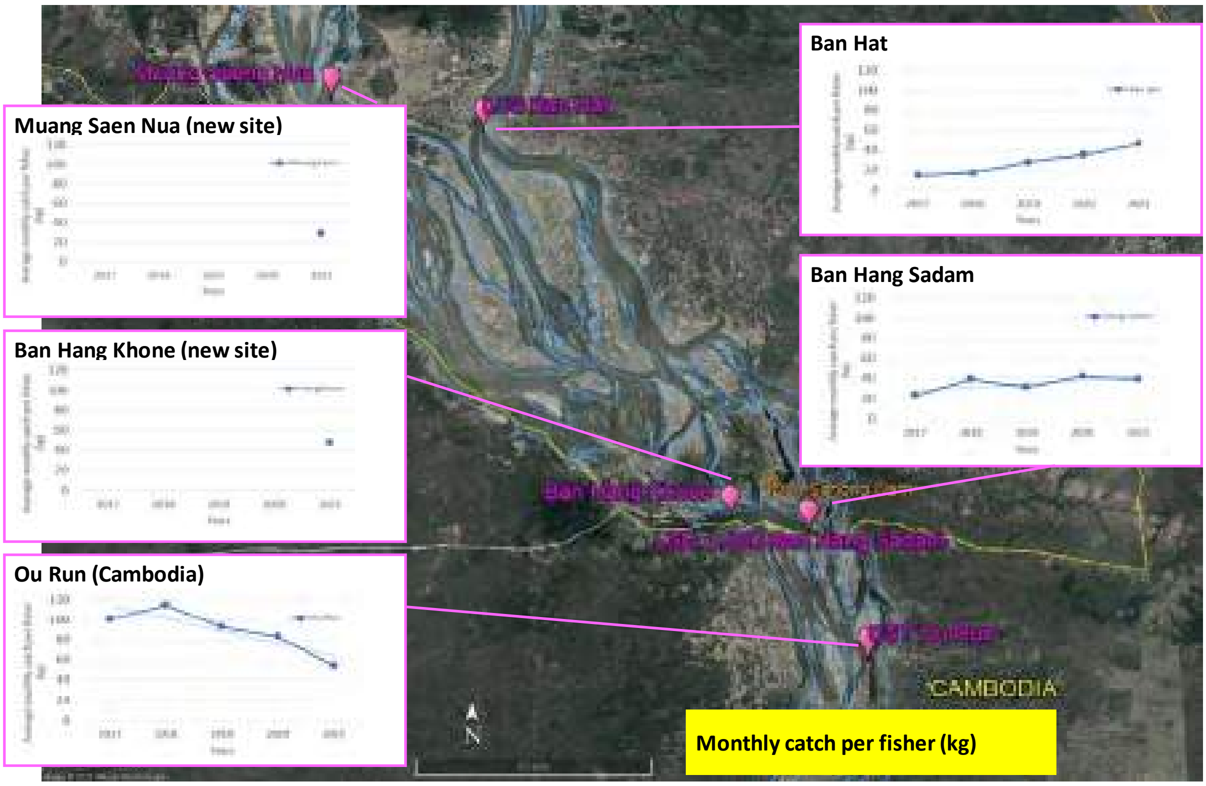


Figure 4-38: Monthly catch per fisher in fish monitoring stations upstream and downstream of Don Sahong Dam

Overall, data of average monthly catch per fisher over the years provide contradictory patterns, with a sharp catch decline in Northern Cambodia over the years but a progression in the nearby downstream Lao site, and a significant increase in catches upstream of the dam, the two latter situations being contradicted by local interviews documented in other surveys.

4.4.1.3 Trends in species diversity in catches

Analysis shows that the species diversity in fishers' catches (***Figure 4-39***):

- varies between 38 and 60 species per year in Ban Hat upstream of Don Sahong but does not display any trend;
- amounts to a similar 60 species per year in nearby Muang Saen Nua (value based on 11 mounts of sampling, all plotted here under 2021) but data gathering in this new JEM site is too recent to allow plotting any long-term trend;
- varies over the years between 107 and 124 species in Ban Hang Sadam site, with no clear trend.
- reaches a very high 160 species count in the new JEM site of Ban Hang Khone (diversity of the last 11 months of sampling plotted here under 2021);
- displays a downward trend in Ou Run site in Cambodia from 70-90 species in 2017-2018 down to 50-60 species in 2019-2020 (the incomplete 2021 sampling is not considered here) This trend will have to be confirmed once the 2021 year sampling is completed.

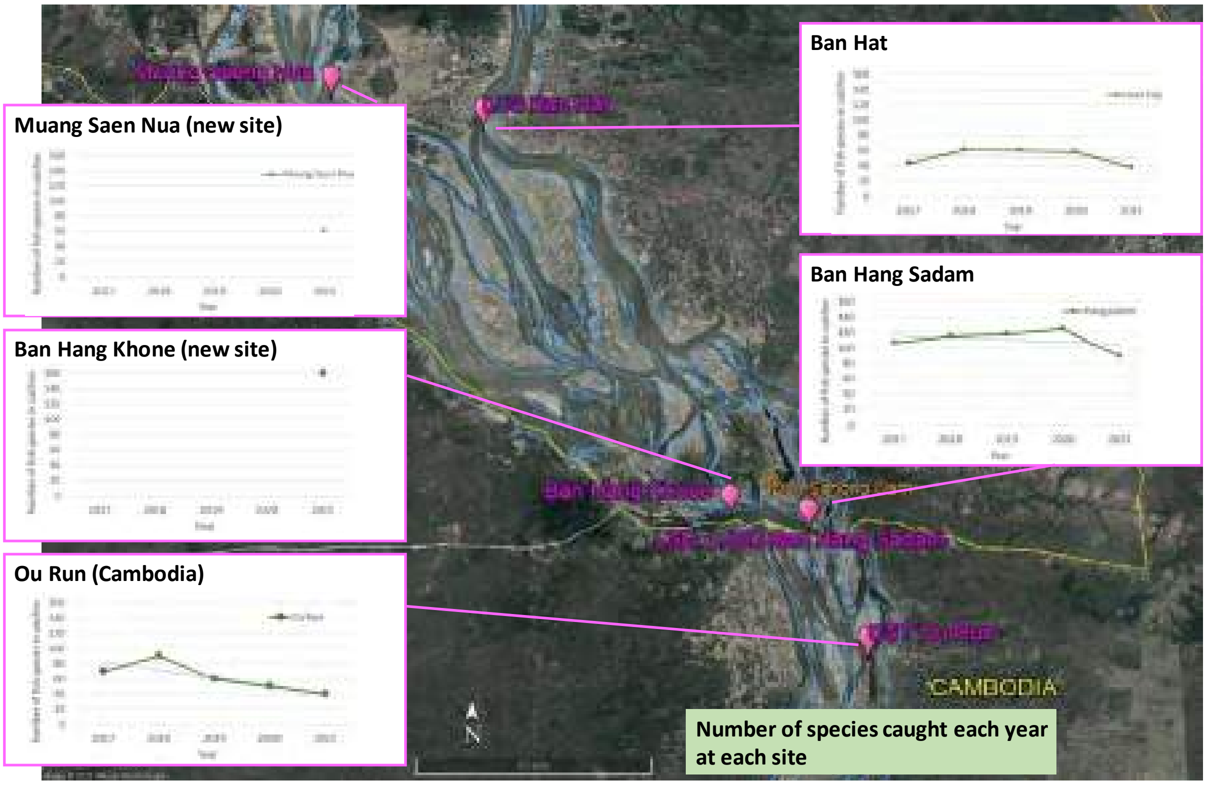


Figure 4-39: Number of fish species caught in fish monitoring stations upstream and downstream of Xayaburi Dam

Thus, the analysis of species in catches around Don Sahong dam site shows a significantly lower biodiversity in sites upstream of Khone Falls compared to downstream sites, which reflects the role of the falls as an ecological barrier. Unlike in Xayaburi, no clear trend in biodiversity can be identified over the years.

4.4.1.4 Trends in gillnet Catch per Unit Effort

Results for the CPUE of gillnets used by fishers (*Figure 4-40*):

- indicates a decline over years from 2017 to 2021 in Ban Hat, from 2.9 to 1.7 grams of fish per m^2 of gillnet per hour fishing.
- in the new monitoring site of Muang Saen Nua also located upstream of the dam, data do not allow plotting a trend, but 2020-2021 data indicate a CPUE of 1.2 grams of fish per m^2 of gillnet per hour fishing, similar to the nearby site of Ban Hat at the same period;
- has drastically and steadily declined over years in Ban Hang Sadam downstream of the dam, from 6.2 down to 1.3 $g/m^2/h$
- reaches 1.1 $g/m^2/h$ in Ban Hang Khone in 2021, a value similar to that of the very close Ban Hang Sadam site for the same year;
- is almost constant over the year at about 0.3 $g/m^2/h$ in Ou Run in Cambodia. Here again, the discrepancy between Ou Run and Ban Hang Khone or Ban Hang Sadam sites (about 1.1 $g/m^2/h$) raises questions about the homogeneity of data recording as these sites are only 8 km apart.

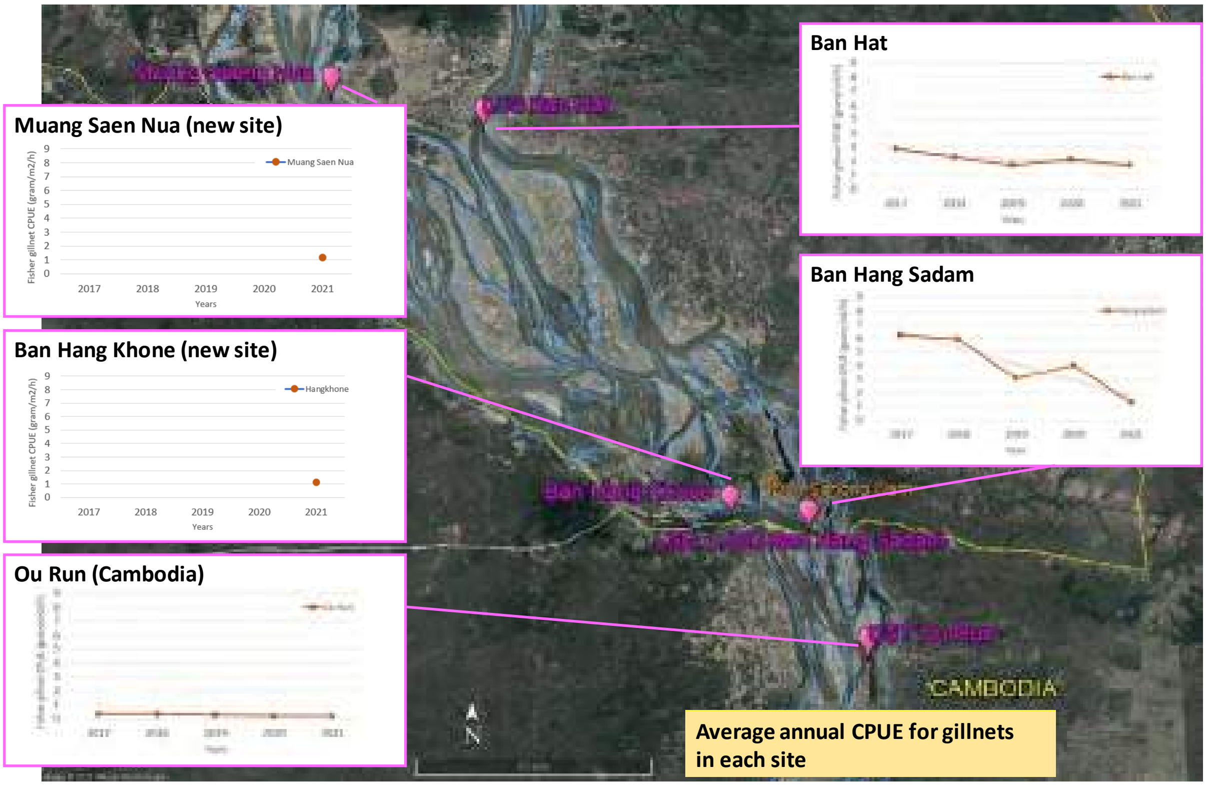


Figure 4-40: Catch Per Unit Effort (grams per m^2 of gillnet per hour fishing) in fish monitoring stations upstream and downstream of Xayaburi Dam

4.4.1.5 Standardized gillnet testing

Both Cambodia and Laos tested the adjusted methodology proposed for standardized gillnet sampling.

Multi-panel gillnets are set 4 times per month at monitoring site. Each fleet of nets is made of 14 panels (mesh sizes: 20; 30; 40; 50; 60; 70; 80; 90; 100; 110; 120; 130; 140; 150 mm stretched mesh). Three gillnet dimensions were tested:

- a fleet in which each panel is 3 m long and 2.5 m high (stretched mesh dimensions), and a total length reaching 42 m); ID1
- a fleet in which each panel is 5 m long and 2.5 m high, the total length reaching 70 m; ID2;
- a fleet in which each panel is 8 m long and 2.5 m high, total length 112m (ID3)

Cambodia produced a report for verification ,while Laos provided raw data for analysis. In Cambodia, the monthly total catch is highest for the 70m long net (ID2 as shown in *Figure 4-41*)

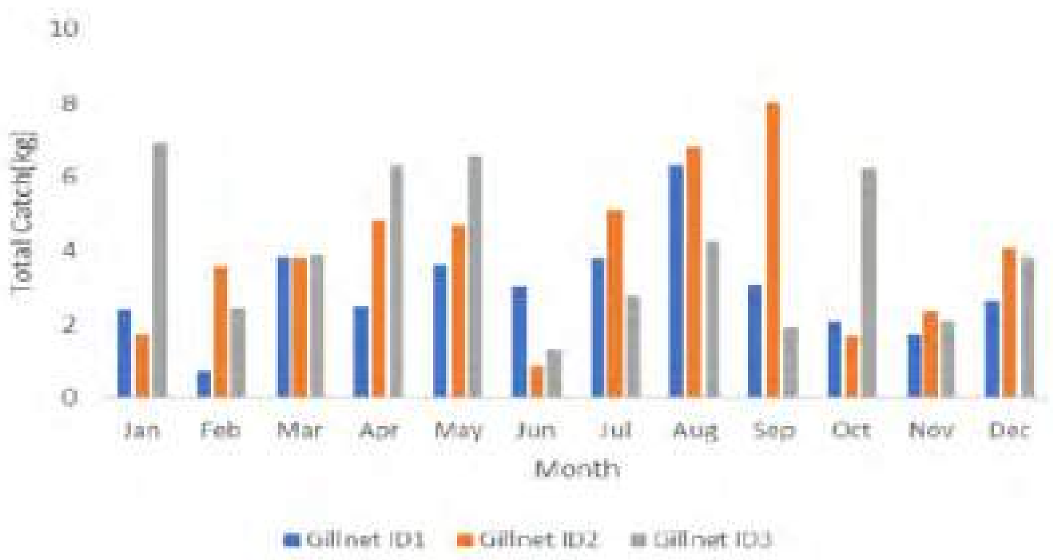


Figure 4-41: Total catch per gillnet type during the trial in Cambodia

In Laos, there is no significant difference between 42 and 70m long gillnets (ID1 and ID2 respectively types, but the catch is lower for the longest 112m net (ID3) as shown in *Figure 4-42*.

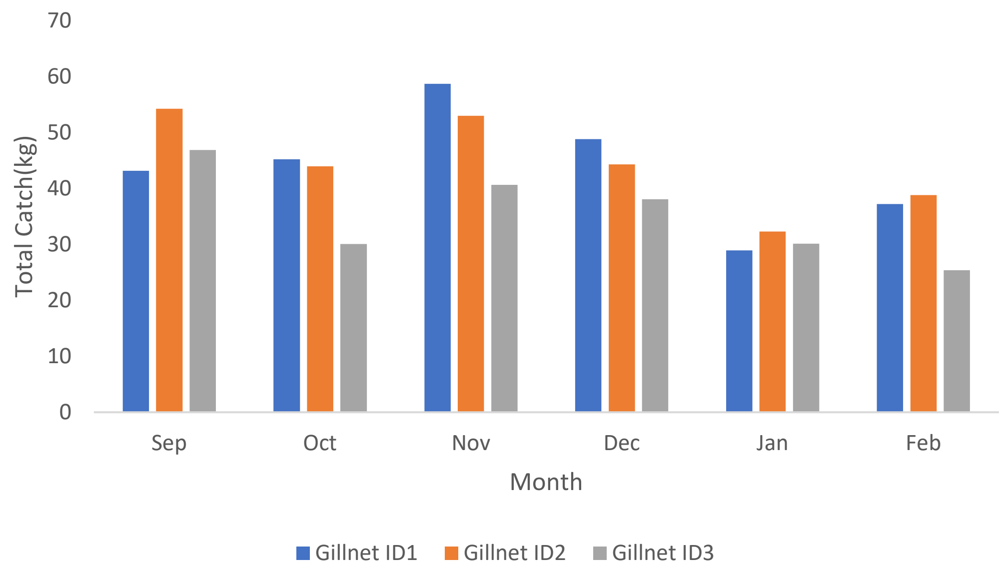


Figure 4-42: Total catch per gillnet type during the trial in Laos

In Cambodia, the catch rate of each gear type over the months does not exhibit any significant pattern (different catch rate each month for each gear type) as shown in *Figure 4-43*.

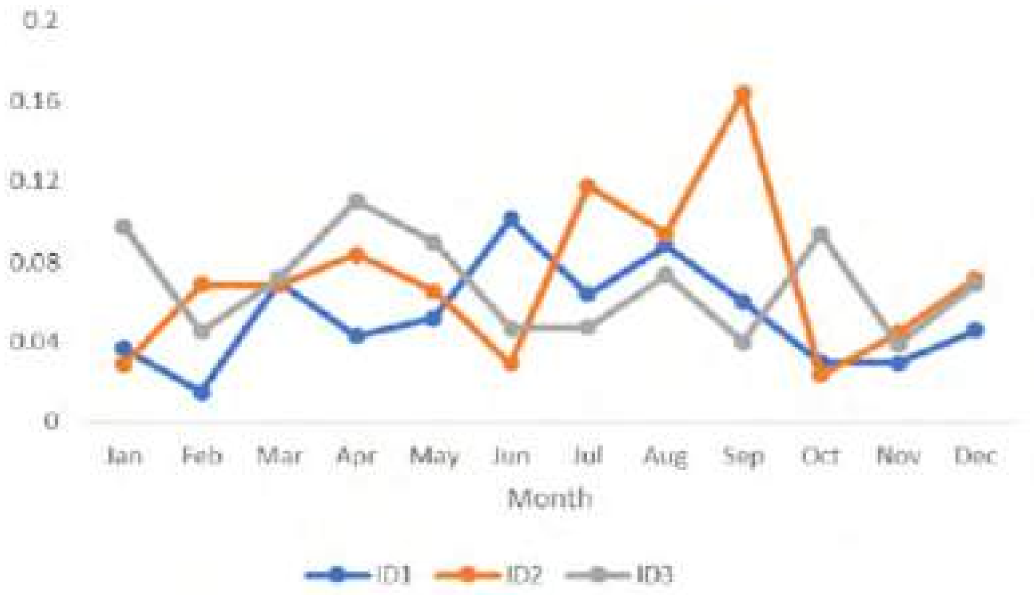


Figure 4-43: Catch rate of each gear type during the trial in Cambodia

A pattern is more visible in Laos, with similar behaviours over months and a usually higher catch rate for the short net (42m, ID 1) and a lower one for the long one (112m, ID3) as shown in ***Figure 4-44***.

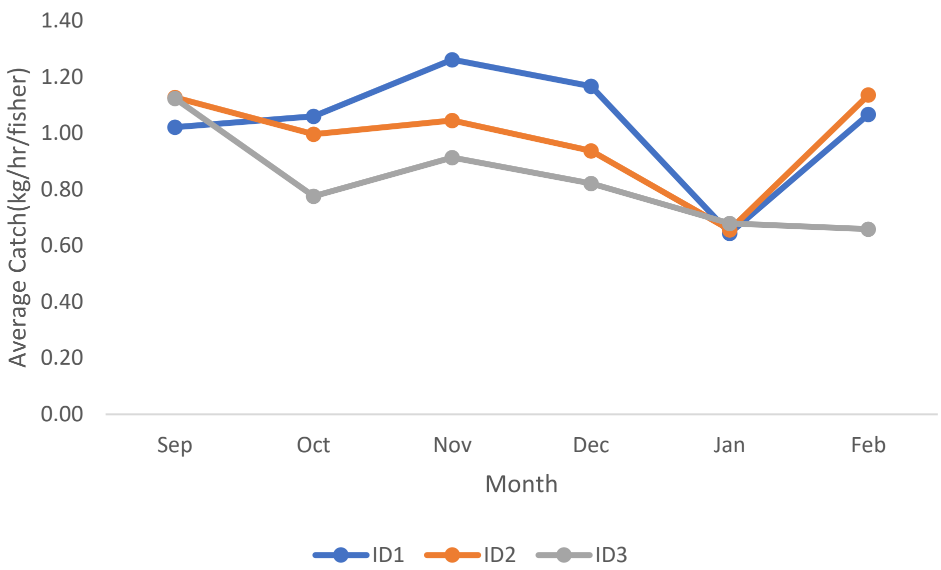


Figure 4-44: Catch rate of each gear type during the trial in Laos

When the selectivity of each gillnet type is examined (number of species caught per gear), Cambodia data show a higher biodiversity in the longest net (112m, ID3) as shown in *Figure 4-45.*

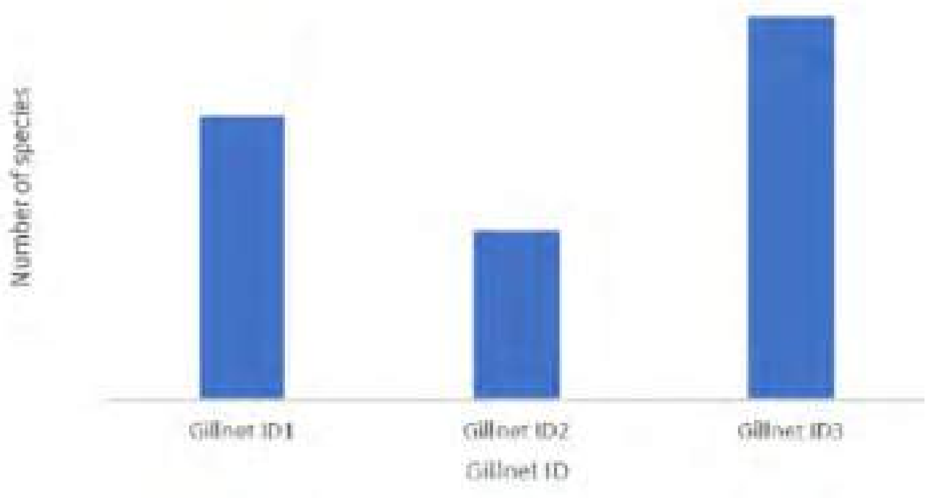


Figure 4-45: Number of species caught per gillnet type in Cambodia

The same analysis in Laos confirms this pattern as shown in *Figure 4-46*.

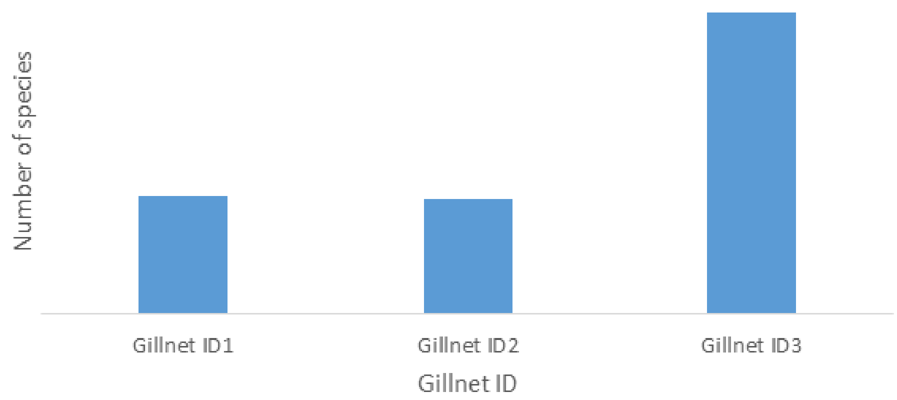


Figure 4-46: Number of species caught per gillnet type in Laos

Beyond numerical analyses, experience also showed that the longest net gets stuck in trees by the banks and is difficult to set because of few suitable places, e.g. with beaches, can be found for such long net. This induces a bias by selection of long empty places only. Also, in panel gillnets set near river and island banks in shallow water, large mesh sizes remained empty. However, fishers usually set large mesh sizes in the middle of the river to catch large fish swimming in deeper water.

Conversely, if the full net is set in the middle of the river then no small fish is caught.

4.4.1.6 Fish Larvae Drift Monitoring (FLDM)

A preliminary analysis of the Lao FLDM dataset (*Figure 4-47*) collected upstream and downstream of Don Sahong site (511 samples to date, data collection and data analysis are on-going) show that upstream of Don Sahong, the site has been characterized so far by 40 fish genus in 18 families, leading to taxonomic identification at the species level for 23 species. Downstream of the dam, taxonomists identified 31 genus in 16 families, with 24 species identified. These initial results correspond to a 30% difference between upstream and downstream sites, with less diversity downstream. However, more years of sampling will be necessary to confirm or infirm this hypothesis and distinguish the impact of the dam from that of the natural ecological barrier of Khone Falls, reflected in the diversity of adults detailed above.

After these very preliminary analyses, the large set of Lao FADM data can be combined with existing FLDM data in existing databases and will provide a much strengthened basis for the assessment of dam impacts on larval fish communities.

Figure 4-47: Taxonomic diversity of fish larval stages around Don Sahong dam site

The FLDM drift monitoring was analyzed for Cambodia and provided the following results.

On the western bank, 91 species of larval fish belonging to 20 families were identified (48 species of Cyprinidae =57%, 8 species of Pangasiidae = 9%, 5 species of Bagridae = 6%, 5 species of Clupeidae and Mastacembelidae each (5%) and 15 other species (18%).

On the eastern bank in Cambodia, diversity was less but with similar dominances: 68 species belonging to 13 families, with 39 species of Cyprinidae = 58%, 7 species of Pangasidae =10%, 5 species of Bagridae =7%, 3 species of Soleidae, Siluridae and Mastacembelidae respectively (5%) and 10% of remaining species in 7 other families.

The middle site in the mainstream featured 72 species belonging to 15 families, with 37 species of Cyprinidae (55%), 7 species of Pangasidae (10%), 6 species of Bagridae (9%), 5 and 3 species of Siluridae and Chandidae respectively, and 10 other species belonging to other families

These results indicate the following:

- Species diversity is high among the larvae sampled
- larvae of Cyprinidae are dominant everywhere and represent around 55% of species; they are followed by catfishes (Pangasiidae, Bagridae, Siluridae) as next dominant species in larval sampling;
- Diversity varies from bank to bank or site to site by as much as 30%, which justifies the current JEM sampling including sampling stations on two banks and one in the mainstream

The large difference in biodiversity results between 2 sites located less than 2 km apart downstream of the dam (one in Laos at Hang Sadam, one in Cambodia at Preah Romkel), in similar ecological environments, with 24 species identified in Hang Sadam and 68-91 species in Preah Romkel, illustrates how larvae data and results are sensitive to taxonomic identification expertise (1 year in Laos, almost two decades in Cambodia). This indicates that FLDM results are to be considered with caution, and the JEM Pilots have been an opportunity to start adjusting the expertise of all regional taxonomists a a similar level, so that results can be compared basinwide in the future.

In Cambodia, the Shannon species diversity index (that combines species diversity and distribution of abundance by species) indicates that species on the western bank are more diverse than the eastern bank and the mainstream middle station.

The analysis of larval densities indicates that:

- Abundance peaks are noted in July and April on the western bank station (678 individuals per 1000 m^3,and 510 individuals /1000 m^3 respectively;
- In the mainstream middle station, peaks occur in July, May and October, with densities ranging between 658 and 968 individuals /1000 m3
- these peaks are not so clear on the eastern bank station; they are somehow identified in July and April too, but also in June.

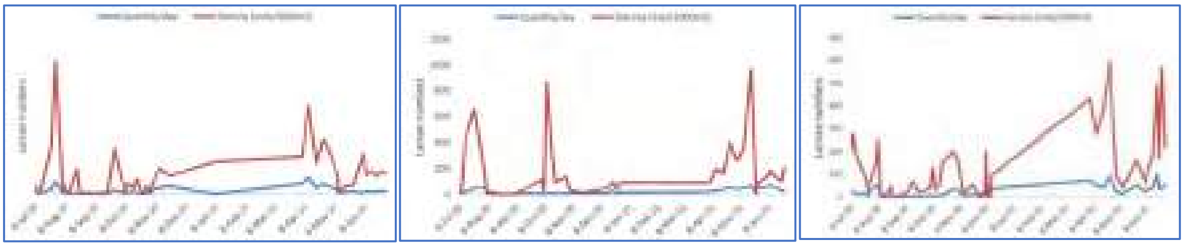


Figure 4-48: Fish larvae densities over time in western, middle and eastern sampling sites in Preah Romkel site in Cambodia

These results indicate that:

- July is clearly a month of maximal larval abundance,
- there are other peaks in April, May and June corresponding to early rains
- although smaller, there can also be an abundance peak in October corresponding to the end of the rainy season

Length analyses performed on *Pangasius macronema* and *Cyclocheilichthys repasson* show that the individuals surveyed were around 25 days old, indicating breeding sites upstream in the Mekong, largely upstream of Khone Falls for these two species.

4.4.2 Lessons learnt and Recommendations

The very high number of species recorded in downstream sites in Laos (160 in Ban Hang Khone, 107 to 124 in Ban Hang Sadam) compared the nearby site of Ou Run in Cambodia (90 species maximum), located only 8km away with no obstacle in-between, raises questions about taxonomic recording in Lao and Cambodian FADM data. Either fishers are inclined to recording a high diversity of fish names in Hang Sadam and Hang Khone – in particular in the latter site where they are new to monitoring-, or the higher species diversity could reflect the difference of precision in Lao vs. Khmer fish names, with more fish names being commonly used in Khone Falls than in Cambodia (the exceptionally developed local ecological knowledge of Khone Falls fishers has been underlined in several publications). These two hypotheses need to be further explored if reliable biodiversity data are to be compared between countries.

Like in species diversity, the heterogeneity of monthly catch per fisher and of CPUE results in sites *downstream of Don Sahong* sites raises questions about the homogeneity of implementation of the FADM sampling protocols. Thus, sites *8 km apart* display:

- an *increasing* average monthly catch per fisher in Laos but a sharp decline in Cambodia
- a gillnet CPUE of 1.3 to 6.2 $g/m^2/h$ declining in Laos, while it amounts to 0.3 $g/m^2/h$ and is stable in Cambodia.

Increasing catches in Laos are contradicted by interviews of fishers detailed in report "Recent fish migrations in Khone Falls (Lao PDR) according to local ecological knowledge" and evidence of change in livelihood activities (former fishers moving to other jobs or to alterative livelihood activities such as shell gathering). These observations call for a meeting of respective national FADM teams and a joint review of respective implementation and data recording modalities. Once this step is secured, data can be revisited, with adjustments if needed, before drawing overall conclusions about long term trends and dam impacts in Don Sahong dam site.

Regarding gillnet sampling, results from systematic testing and field observations lead to the recommendation to keep the long nets (112m long) and group panels by mesh size into 3 different nets: i) one of small mesh sizes for shallow woody environments with small fish, ii) one of medium mesh sizes in suitable sites, and iii) one of large mesh size in the middle of the river for large fish. Thus, the original random distribution of mesh sizes should be abandoned, and replaced with the creation of 3 sets of nets with panels of 10x2.5 m each:

- Gillnet ID1: 20-50-40-30-60 mm to be set near banks and the vegetation to target small fish in their habitat;
- Gillnet ID2: 70-90-100-80-110 mm to be set in suitable locations decided by fishers;
- Gillnet ID3: 120-150-140-130 mm to be set in the middle of the river to target large fish

Total: 14 panels x 10 m x 2.5m = 350m^2 per gill net set.

In FLDM, results show that under the same protocol implemented by the same team and on the same day, larval diversity in a given site can vary by as much as 30% depending on the sampling location. Results also show that the species count can vary between 24 and 68-91 species for two sites 2 km apart only. These two results can reflect either the hydrological variability of the river (e.g. strong water currents carrying and/or concentraing larvae in specific parts of the river) or the taxonomic expertise of the team identifying larvae, with a progressively acquired ability to identify more fish down to the species level. Whichever the explanation, these results underline the potential fragility of rapid conclusions based on an immedation reading of larvae results, and the need to limit these conclusions to samples as standardized as possible. Thus, sampling locations might be chosen based on a preliminary measurement and assessment of flow conditions in a given season, to avoid sampling in one site in still waters with few larvae and in another site in a whirlpool concentrating larvae. Intersite comparisons will also be more reliable when larvae identification originates from the same team of larvae specialists – which is the situation in the case of Don Sahong and Xayaburi both monitored by the same Lao team.

5 COMBINED BASIN-WIDE ANALYSIS

5.1 Overview

One objective of JEM is to improve the integration and analysis of data collected from the different monitoring programs and projects implemented through the MRC (HYCOS, DSM, WQ, EHM, Fisheries). The data collected through JEM was to be integrated with the existing long-term data sets available for each discipline, and between disciplines to provide a more in-depth understanding of trends in the river, with a focus on those that may be related to the operations of hydropower stations.

Due to COVID restrictions and the resultant delays in monitoring, there are insufficient JEM data upon which to base an inter-disciplinary analysis. As presented in other sections of this report, some integration of results (discharge, sediment, water quality) has been completed, however the long-term aim of the MRC is to allow a higher level of data analysis and interpretation.

This chapter focusses on the approach required to integrate data from different disciplines, that are collected at different sites, and at different frequencies. It provides a blueprint and some examples of how the sites from different disciplines can be matched to allow integration, and what parameters could be derived from the data sets for cross analysis.

Importantly, it also provides an overview of the availability of data by discipline, site, and year so that areas where there is sufficient overlap can be identified, with future data analysis potentially focusing on these areas.

The approach for integrating and cross-analysing data sets can be summarized as follows:

- identify the stations that can be matched based on physical proximity and flow similarities
- identify variables that are relevant in an interdisciplinary context
- summarize the data availability for these variables for each site (e.g., number of years of data, number of measurements per year, frequency of data collection, distribution through the monitoring year)
- indicate how this information can be used to guide future data analysis, include the creation of queries that can link the individual databases and extract relevant information from each.

5.2 Clustering of stations for multidisciplinary analyses

The clustering of monitoring stations in different disciplines that can be matched for interdisciplinary analyses is initially based on geographical proximity in the Mekong mainstream. That mapping required:

- the compilation and integration of multiple files recording station names in all monitoring programs;
- updating station names as the latter have evolved over the years in a number of cases;
- selecting reference codes or names in case of conflict between records
- the compilation and integration of other files including geographic coordinates of these stations;
- the conversion of GPS coordinates recorded in different units.

The result of this mapping is detailed in Annex 1. Note that the coding of some sites remains problematic, as detailed in ***Table 5-1***.

After this cleaning and compilation phase, mainstream stations were clustered by geographic proximity, while identifying clusters that combine hydrological, water quality, biomonitoring and fisheries sites and data. A particular attention was paid to clusters upstream and downstream of Xayaburi and Don Sahong dam sites. The result is displayed in ***Table 5-2***.

Notes

- LA_010702 (LPB, LJXU) could be matched with EHM and fisheries sites at LPB, LIXU, but note that this has now been permanently within the Xayaburi impoundment.
- LP DSM and HYCOS site is now flooded due to backwater from the Xayaburi impoundment. The water level data is not included in the database.
- LA_011302 (EHM2, LXB) is now within the impoundment, with only EHM and fisheries sampling. The corresponding water quality site with which it can be connected is at Ban Talan, so LA_011502 can be linked to LA_011302

Table 5-1: **Stations whose identification or coding remain problematic**

Country	StationID	Station_Code	Site_name	Test
Cambodia	014001	KH_014001/014003	CMR, CJDC?	Duplicate coding. In the Larvae database, CJDC might be CJDD (no other JEM FLDM site in Cambodia)
Cambodia	014001	KH014001	CJDC?	CJDC code is to be confirmed
Cambodia	020110	KH020110	Row 14	Same code KH020110 for different locations (11.8685, 104.7878 and 12.717089, 104.429344)
Cambodia	020110	KH020110	CPT	Same code KH020110 for different locations (11.8685, 104.7878 and 12.717089, 104.429344)
Laos	013305	LA013305	LJDU	Both LA 13505 and LA 13506 have this code in FADM In FLDM this refers to a site in the Don Sahong impoundment (13.973109°, 105.957523°), whereas the village name (Muang Saen Nua, 14° 5'51.11"N, 105°47'2.18"E) refers to a site 22 km upstream
Laos	011302	LA_011302	EHM2, XLB	site called XBR in some fisheries files
Laos	011905	LA_011905	LVT?	LVT corresponds to 1 sites (LA_011905 and LA_012001)
Laos	012001	LA_012001	NK, LVT?	LVT corresponds to 1 sites (LA_011905 and LA_012001)
Laos	013306	LA_013306	WQ6, EHM7	Both LA 13505 and LA 13506 have this code in FADM
Laos	013309	LA_013309	WQ9, EHM10, LSD, LJDD	LSD is also Hang Sadam in FADM (13°56'12.10"N, 105°57'26.62"E) and Ban Hae on Se Done River near Pakse in EHM (X=585939, Y=1674638) The FADM database mistakenly records LJDD and LSD at two distinct sites on the same location Also, site LJDD refers to Ban Kang Khone in the gillnet databse at 13°56'15.59"N, 105°56'54.32"E, whereas LJDD is also Hang Sadam in FADM (13°56'12.10"N, 105°57'26.62"E)
Laos	013902	LA_013902	LDN, LCS	Site coded LCS in the gillnet database but the location (Ban Morphou, 14.990929 105.894687) is 103 km upstream of Ban Hat (14.083781°, 105.845402°)
Laos	014300	LA014300	LMK	The site could be at 14.802000° 105.918725° (Champasack Pathomphone Tormortha MRC Site Upstream of Don Sahong Dam 14°48'7.20"N 105°55'7.41"E according to FADM Lao database)
Laos	No code	No code	Muang Saen Nua	No code (14.097530° 105.783938°)
Laos	No code	No code	Ban Hang Khone	No code (13.938409°, 105.948121°)
Laos	No code	No code	SKB	New site, no station ID
Laos	No known code	No known code	LCS	LCS corresponds to Ban Hat in Champasak in MRC FADM data, but the code is used for LA_013902 (Ban Morphou, 14.990929 105.894687), 103 km upstream of Ban Hat, in the Lao gillnet database
Vietnam	033405	VN033405	VAP	Same code VN033405 for different locations (10.798814, 105.079664 and 10.920333, 105.097)
Vietnam	033405	VN033405	VQT	Same code VN033405 for different locations (10.798814, 105.079664 and 10.920333, 105.097)

Table 5-2: Monitoring stations by discipline, code, location and geographic coordinates.

Cluster	C	Code 1	Code 2	Full site coding	DSM_	EHM	WQ	Fishing	Location	Latitude	Longitude
1= downs-tream China	LA	LA_010803	LHT	LA_010803; LHT				LHT	Bokeo, Houay Tab / Huey Xai	20.327467	100.380856
	LA	LA060101	LDK	LA060101; LDK				LDK	Bokeo, Donekoun	20.367703	100.372783
	TH	TH_010501	CS	TH_010501; CS	CS		TH_010501		Chiang Saen	20.27430	100.08840
	TH	TH_010502	TCS	TH_010502; TCS		TCS			TCS Chiang Saen	20.259484	100.09832
2	LA	LA_010902	LPN	LA_010902; LPN				LPN	Oudomxay, Pak Ngeuy	19.889122	101.121747
2	LA	LA090101	LOX	LA090101; LOX				LOX	Oudomxay	19.891589	101.138236
3=up-stream XY Dam	LA	LA_010701	XH, WQ1, EHM1	LA_010701; XH, WQ1, EHM1	XH	JEM_EHM1	JEM_WQ1		Xayaburi, Ban Xang Hai	20.003005	102.230979
	LA	LA_010702	LPB, LJXU, Pha-O	LA_010702; LPB, LJXU		LPB		LPB, LJXU	Luang Prabang, Pak Ou, Pha O (Don Chor). LPB=MRC long term site now flooded	19.936916	102.192499
	LA	LA_11201	LP	LA_11201; LP	Now flooded in the impoundment				Luang Prabang	19.89266	102.13389
4	LA	LA_011302	EHM2, XLB	LA_011302; EHM2, XLB		JEM_EHM2		XLB	Xayaburi, Ban Thadeua	19.434750	101.834750
4	LA	LA_011502	WQ2	LA_011502; WQ2			JEM_WQ2		Ban Talan	19.254472	101.812639
4	LA	LA011301	LJXI	LA011301; LJXI				LJXI	Xayaboury	19.4269	101.8447
4	LA	LA011304	LJXI	LA011304; LJXI				LJXI	Xayaboury	19.553556	101.820661
5= down-stream XY Dam	LA	LA_011503	WQ3, EHM3	LA_011503; WQ3, EHM3		JEM_EHM3	JEM_WQ3		Xayaburi Dam 1 km downstream	19.230417	101.821417
	LA	LA_011501	Pak Houng, EHM4	LA_011501; Pak Houng, EHM4	Pak Houng	JEM_EHM4			Downstream Xayaburi, Ban Pak Houng, about 5 km downstream	19.202139	101.824444

Cluster	C	Code 1	Code 2	Full site coding	DSM_	EHM	WQ	Fishing	Location	Latitude	Longitude
	LA	LA_011504	WQ4	LA_011504; WQ4			JEM_WQ4		Xayaburi Dam about 5 km downstream	19.216194	101.82375
	LA	LA_011505	EHM5	LA_011505; EHM5		JEM_EHM5			Ban Pak Houng 7 km_down	19.180417	101.822083
	LA	LA_011506	WQ5, EHM6, LJXD	LA_011506; WQ5, EHM6, LJXD		JEM_EHM6	JEM_WQ5	LJXD	Ban Pak Houng 10 km_down	19.157778	101.814056
6	TH	TH_011902	TCK	TH_011902; TCK				TCK	Loei, Ban Noy	17.910733	101.696058
6	TH	TH_011903	CK	TH_011903; CK	CK				Chiang Khan	17.89971	101.67018
7	LA	LA_011901	VTE	LA_011901; VTE	VTE		LA_011901		Vientiane KM4	17.93093	102.61578
7	LA	LA_011905	LVT	LA_011905; LVT		LVT			Ban Huayhome, Vientiane	17.971296	102.543779
7	LA	LA_012001	NK, LVT	LA_012001; NK, LVT	NK			LVT	Tha Mouang, Vientiane	17.890797	102.746072
8	TH	TH_013001	TSM	TH_013001; TSM		TSM			Nakorn Phanom, Songkhram and Mekong River Junction	17.6528	104.467536
8	TH	TH_013002	TUT	TH_013002; TUT				TUT	Nakhon Phanom, Ban Tha Dok Kaeo	17.623797	104.517419
8	TH	TH_013101	NP	TH_013101; NP	NP		TH_013101		Nakhon Phanom	17.42511	104.77371
8	TH	TH_013103	TNP	TH_013103; TNP		TNP			Nakorn Phanom City, TNP	17.424562	104.77713
9	LA	LA_013900	LA_013900	LA_013900			LA_013900		Pakse	15.12	105.78
9	LA	LA_013901	PS, LSL	LA_013901; PS, LSL	PS			LSL	Champasak, Pakse city, Hatsalao	15.099760	105.813187
9	LA	LA_013902	LDN, LCS	LA_013902; LDN, LCS		LDN		LCS	Champasak, Done Ngew or Ban Hat	14.990929	105.894687
10=upstream DS Dam	LA	LA_013306	WQ6, EHM7	LA_013306; WQ6, EHM7	No DSM. Use Pakse	JEM_EHM7	JEM_WQ6	LJDU	Don Sahong, upstream of the impoundment	13.978278	105.9545
	LA	No code	Muang Saen Nua	No code				Muang Saen Nua	FADM_JEM	14.097530°	105.783938°
	LA	No known code	Pakse	LCS				LCS	FADM_MRC	14.083781°	105.845402°
	LA	LA013305	LJDU	LA013305; LJDU				LJDU	Champasak, Hoo Sahong	13.973317	105.957614
11	LA	LA_013307	WQ7, EHM8	LA_013307; WQ7, EHM8		JEM_EHM8	JEM_WQ7		Don Sahong impoundment	13.944111	105.961806

Cluster	C	Code 1	Code 2	Full site coding	DSM_	EHM	WQ	Fishing	Location	Latitude	Longitude
11	KH	KH_014003	KK	KH_014003, KK	KK				Koh Key, Downstream of Don Sahong, upstream of Sesan confluence	13.680028	106.048533
12	LA	LA_013308	WQ8,EHM9	LA_013308; WQ8,EHM9	No DSM. Use KK	JEM_EHM 9	JEM_ WQ8		Don Sadam, just downstream of DS dam	13.942139	105.954389
13= down-stream DS Dam	LA	LA_013309	WQ9, EHM10, LSD, LJDD	LA_013309; WQ9, EHM10, LSD, LJDD	No DSM. Use KK	JEM_EHM 10	JEM_ WQ9	LSD, LJDD	Don Sahong site, Hang Sadam or Hang Khone WQ: Don Sadam, downstream of DS dam	13.937417	105.957139
	KH	KH_430104	CKM	KH_430104		CKM			Kbal Koh, Stung Treng. South bank of the dolphin pool. Not in Sekong Long term MRC site	13.919733	105.984247°
14	CAM	KH_014002	CST	KH_014002; CST	ST			CST	Stung Treng, Ou Run	13.866703	105.998308
14	CAM	KH_014501	ST	KH_014501, ST	ST		ST		Stung Treng, downstream of Sesan confluence for hydrology	13.522047	105.933548
15	CAM	KH_014001 /014003	CMR, CJDC	KH_014001/014003; CMR, CJDC?		CMR		CJDC	Kratie (Kampi pool)	12.603476	106.021155
15	CAM	KH_014901	KT, KH_014901	KH_014901	KT		KH_014901		Kratie	12.48141	106.01762

Note: *These stations are clustered by geographic proximity allowing the coordination between stations highlighted in orange. Remaining issues are flagged in red.*

5.3 Review of variables recorded in the various databases

The following sections outline the structure and lists all of the variables that are contained in the data base for each theme. The variables that are considered the most useful for interrogating the database and establishing inter-disciplinary relationships are identified and discussed.

5.3.1 Hydrology and sediment databases

The hydrology and sediment data are contained in two independent data bases. The information has been split due to the very large number of hydrology records associated with monitoring sites in the LMB. In the future, it is recommended that instead of extracting hydrologic records from the Aquarius database and duplicating them in a separate database, that future data bases for sediment, water quality, EHM and fisheries be linked to the Aquarius data base such that relevant records can be extracted when and as required. This is advantageous for QA/QC of hydrologic data as well, as it maintains Aquarius as the sole repository for hydrologic information.

Figure 5-1 shows the tables that are included in the hydrology database. There are independent tables for each site for daily discharge, and for either daily water level or hourly water level. The database contains discharge and water level information detailed in *Table 5-3*.

Table 5-3. Summary of discharge and water level information included in the JEM hydrology database.

Site	Discharge (Daily) 2009 - 2021	Water Level (15-minute) 2016-2021	Water Level (Daily) 2016-2021
Chiang Saen	X		X
Ban Xang Hai			X
Luang Prabang	X (post 2018 flow results are erroneous due to influence of Xayaburi backwater		X (WL affected by backwater from 2018 onwards)
Ban Pakhoung		X (Nov 2020 – June 2021)	
Chiang Khan	X	X	
Vientiane Km 4	X		X
Nong Khai	X		X
Nakhon Phanom	X		
Mukdahan	X		
Pakse	X	X	
Koh Key		X (31 Jan 2020 – 29 Jun 2021)	
Stung Treng	X	X	
Kratie	X		

Figure 5-1: Tables included in the JEM Hydrology database.

The Sediment database contains the Tables shown in *Figure 5-2*. Data base Table Tb2_HydroDisADCPSedimentation contains the field measurements completed at the sites shown in *Table 5-4* that lists the number of measurements completed under the JEM monitoring pilot projects, and measurements completed at some of the routine DSM sites. The data extends back to 2009 where available. shows the parameters that are most likely to be of use in the analysis of the results, but other parameters are included, such as the ADCP correction factor, and the estimated bed velocity based on the ADCP loop-tests.

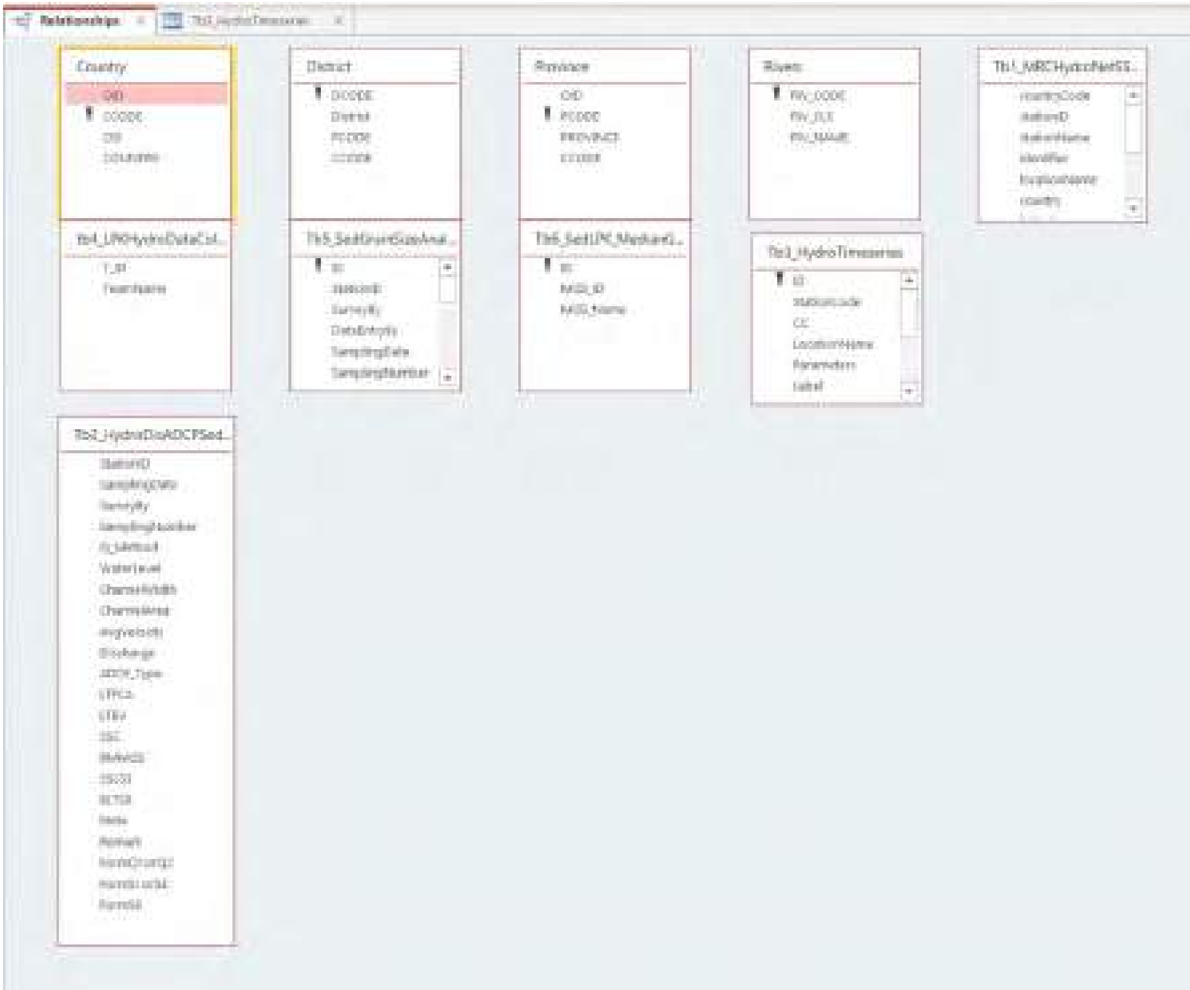


Figure 5-2: Tables contained in the JEM Sediment database

Other tables in the data base are related to site locations, and monitoring teams. Three tables are included in the database that have not been populated with results. These are the sediment grain size analysis table and the sediment median grain size table. There are very few JEM results available for these tables, but they are included such that additional or historic data could be added at a later date. There is also a Hydrology Time-series table (Tb3_HydroTimeseries) which was initially included in the design of the data base, but because of the large number of hydrology records, the separate Hydrology database was developed.

Table 5-4. Number of measurements for each parameter contained in the JEM sediment database.

Site Code/Name	Water Level (m)	Channel Width (m)	Channel Area (m^2)	Average Velocity	Discharge (m^3/s)	SSC (mg/L)	SSC Load (Tonnes	Bedload (Tonnes/
TH_010501_[Chiang Saen]	215	38	39	39	217	214	214	
LA_010701_[Ban Xanghai]	8	10	10	10	10	10	10	10
LA_011201_[Luang Prabang]	117	87	87	87	117	114	114	
LA_011501_[Ban Pakhoung]	5	9	9	9	9	4	7	9
TH_011903_[Chiang Khan]	283	104	81	104	273	257	255	55
TH_012001_[Nong Khai]	417	368	350	368	429	408	387	18
LA_013901_[Pakse]	181	160	157	177	182	104	104	5
KH_014003_[Koh Key]/Stung Treng UP	27	27	27	27	27	27	27	
KH_SKB_[Sekong Bridge]	26	55	55	55	55	45	45	
KH_014501_[Stung Treng]	203	55	55	80	203	192	192	
KH_014901_[Kratie]	192	55	55	55	192	181	181	

5.3.2 Water quality database

The Water Quality database contains the following important tables, shown in ***Figure 5-3***:

- Tb3_WQMSite lists the water quality monitoring stations considered under the JEM Pilots including the routine mainstream stations together with their MRC Standard code.
- Tb3_WQMSite_StandardCode lists all of the MRC's WQMN sites
- Tb1_WQM_DWQMForm1 contains the water quality results for all parameters potentially measured at each station organized by year and month. All the routine monthly results from the MRC's WQMN stations dating back to 2010 are presented in this table as well as the more recent JEM water quality monitoring. The JEM WQ stations can be specified by selecting in the column WQMJEM. The nationally involved data validation process using the ion balance is inserted into this form after all the primary results.
- Tb11_WQM_JEMProfileMonitor presents the monitoring results of the water quality profiles in the two impoundments of Xayaburi and Don Sahong (WQ2 and WQ7) at the surface and at 1 meter intervals down to 20 m depth.

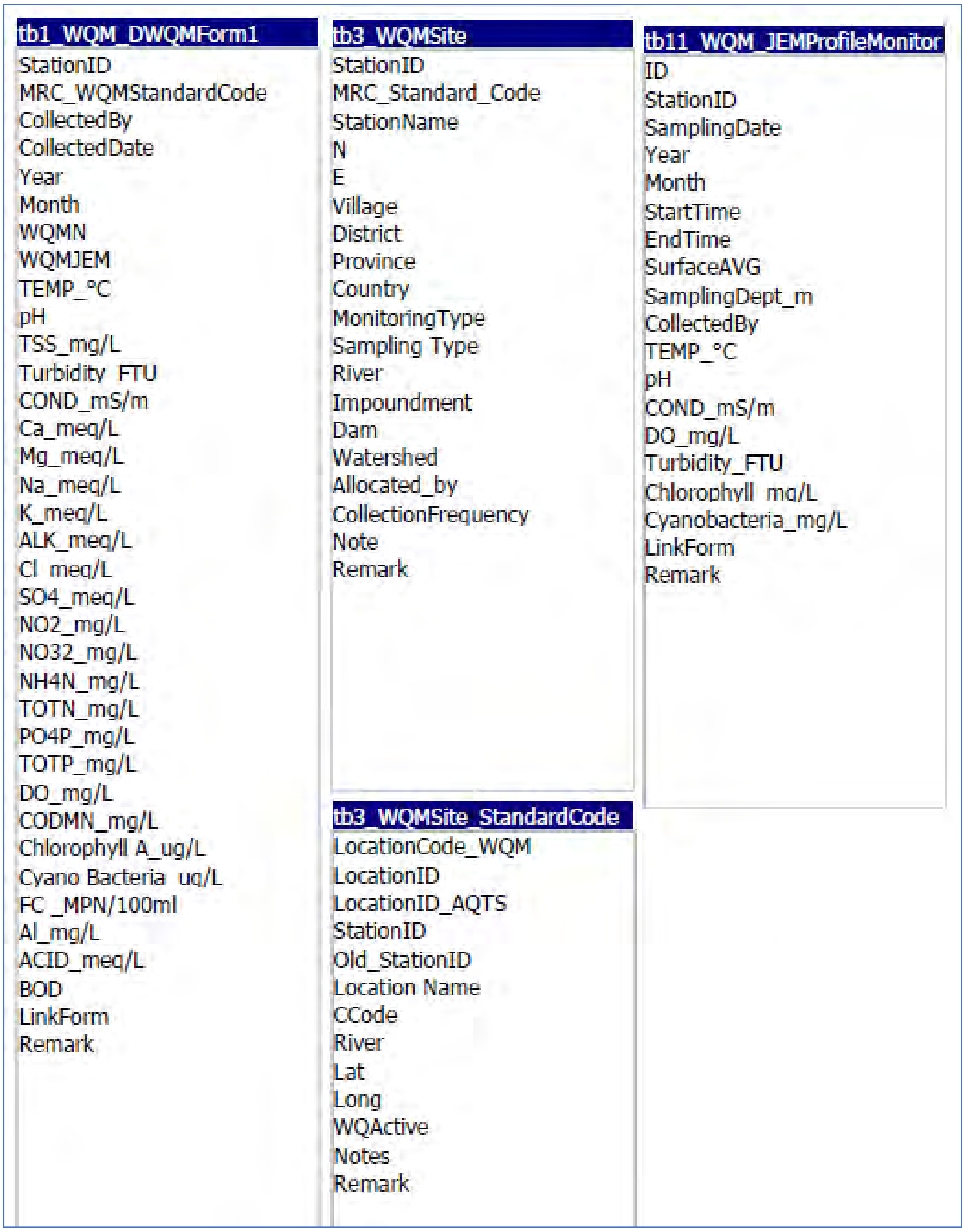


Figure 5-3: Key tables of the Water quality database

5.3.3 Ecological Health monitoring database

The most important tables and queries of the EHM database are shown below in *Figure 5-4*.

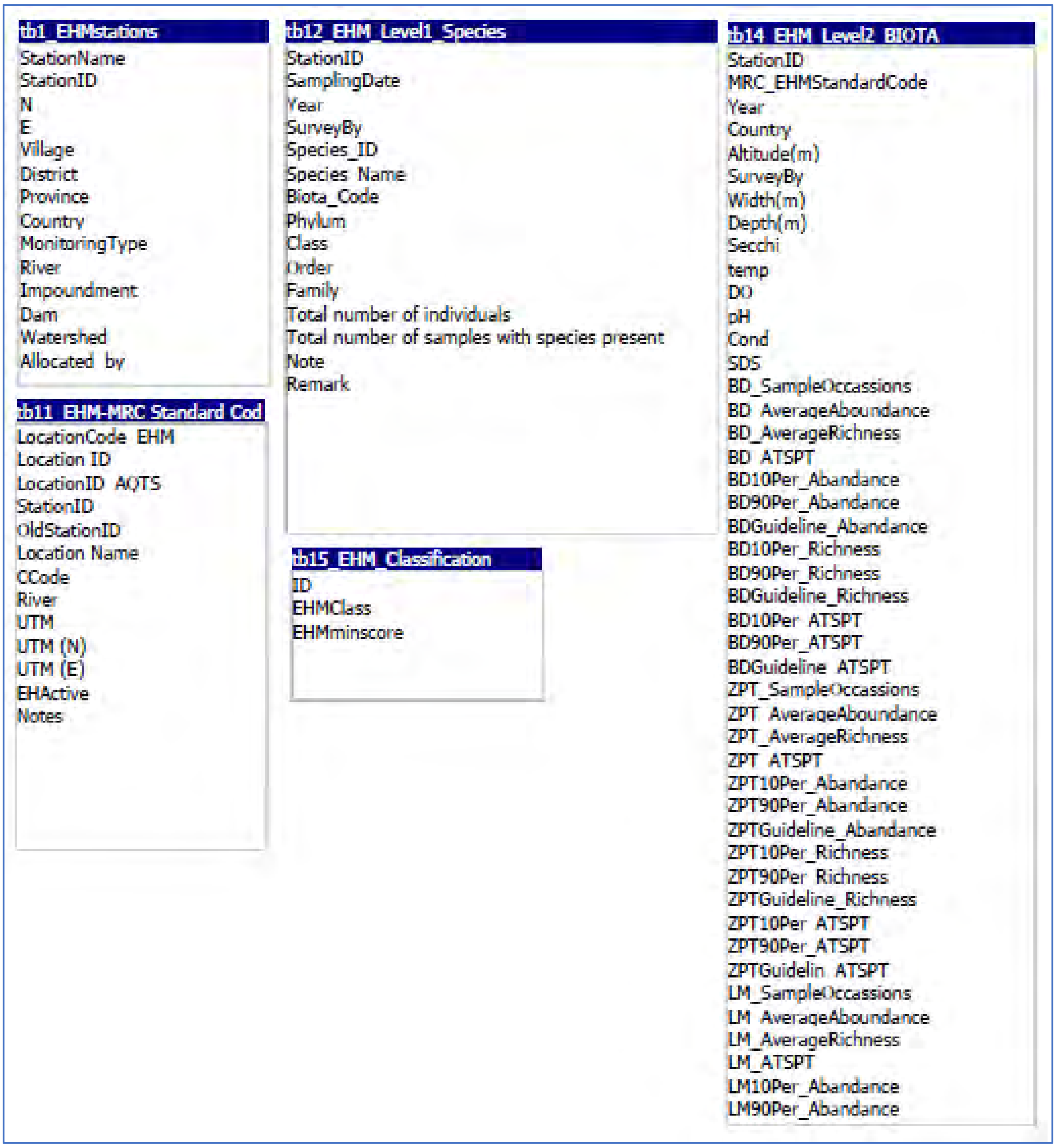


Figure 5-4: Important tables and queries of the EHM database

- **tb1_EHM** stations lists the stations on the Mekong mainstem that have been considered in the JEM EHM assessments, these include the specific JEM pilot sites and the biennial routine EHM measurements along the Mekong mainstem.
- **Tb11_EHM-MRC** Standard code links these sites with their MRC standard codes for each site, including other EHM sites used for the routine monitoring.
- **Tb12_EHM_Level1** species contains the primary data for each site of the numbers of individual species and numbers of sub-samples in which the species is counted for each of the

four biotic types – benthic diatoms, zooplankton, littoral macroinvertebrates and benthic macroinvertebrates. Each species has been classified by its Phylum, Class, Order and Family, so that the species results can be queried for specific orders of families, e.g. for separating out Ephemeroptera, Plecoptera and Trichoptera from other Littoral macroinvertebrates

- **Tb14_EHM_Level2_Biota** uses the data for each site from Level 1 to record the Environmental parameters recorded during the sampling, the Site Disturbance Score and the calculated scores for Abundance, Species diversity and Average Tolerance Score per Taxon (ATSPT) for each of the biotic types. This table also records the guideline percentiles and thresholds for calculating the Ecological Health Index.
- **Tb15_EHM_Classification** provides the minimum numbers of times in which the three scores for each biotic type meet the threshold guidelines so that the EHI classification can be calculated, e.g. Excellent, Good, Moderate and Poor EH classes.
- **QryEHM5_Index_Calculation**. There is also a query table that calculates the EHI class for each site and year.

5.3.4 FADM (fisher daily catch) database

The key data tables in FADM databases are detailed below in ***Figure 5-5***.

- **Site code** to identify the place and map results later on (in most databases this variable is absent, and sites are identified by the Province/District/Commune/village suite instead)
- **Fisher ID** to be able to count how many fishers were involved each month and each site, and what their gear was
- **Date fishing**
- **Total catch:** key variable (in kg)
- **Gear code** = fishing gear name (not a code actually)
- **Width** and **Height** refer mainly to gillnets, for the calculation of gear dimensions (surface area fishing, for the calculation of CPUE).
- **Hour_fishing** i.e. number of hours each gear is in operation, for the calculation of CPUE.
- **Species name** = individual fish name
- **N_fish** = number of fishes of the same species
- **Weight** = weight of each fish of a given species in a given fishing operation. When data are clean the sum of weights of fish for a given operation is equal to the total catch of that fishing operation. However, this is not always the case (if so, the value kept for analyses is Total catch).

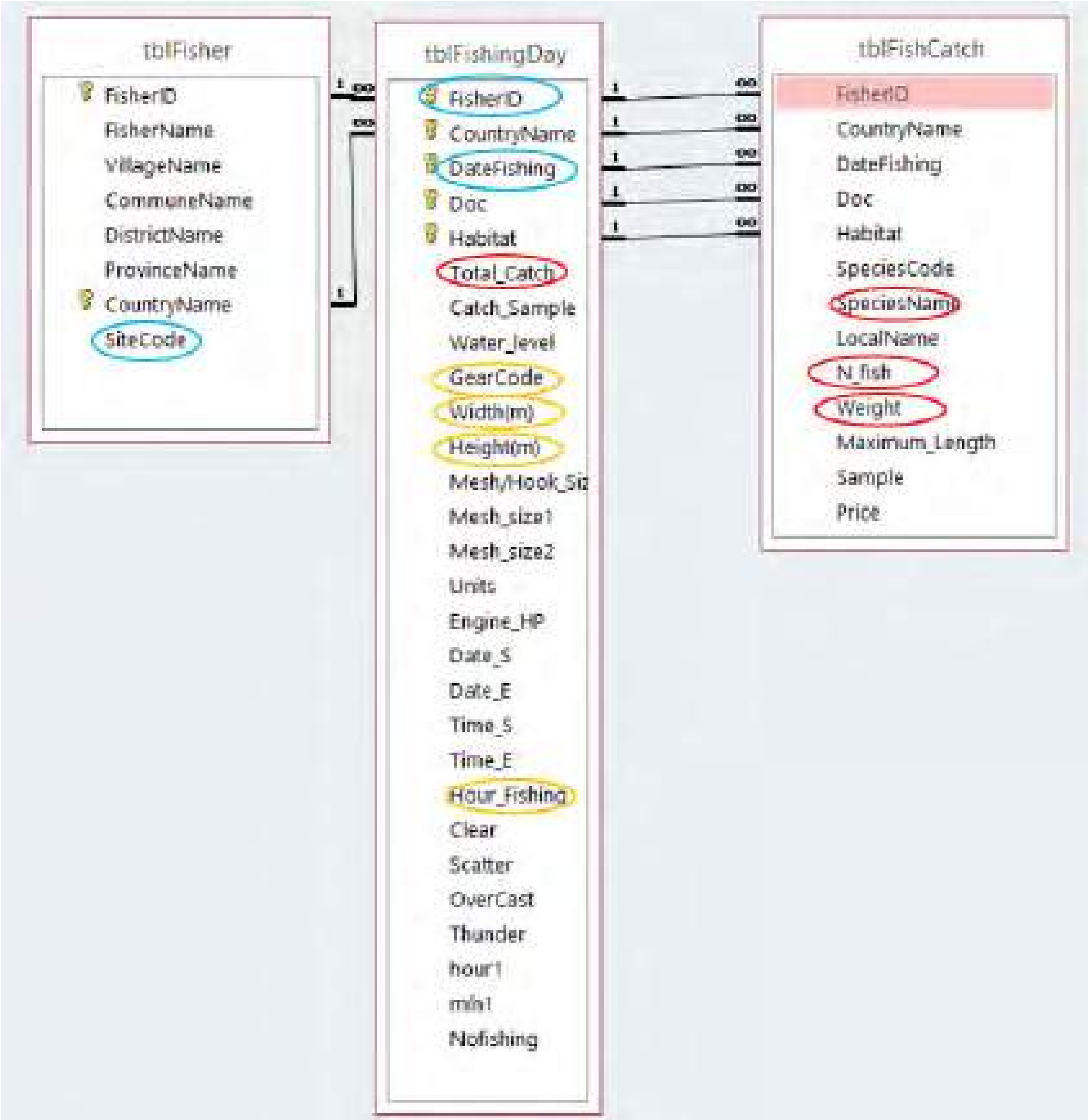


Figure 5-5: Important variables in the FADM databases

5.3.5 Gillnet database

The gillnet database is derived from the FADM database and includes the same variables as detailed in the section above (same comments) – although the overall structure of the database is simpler (see *Figure 5-6*).

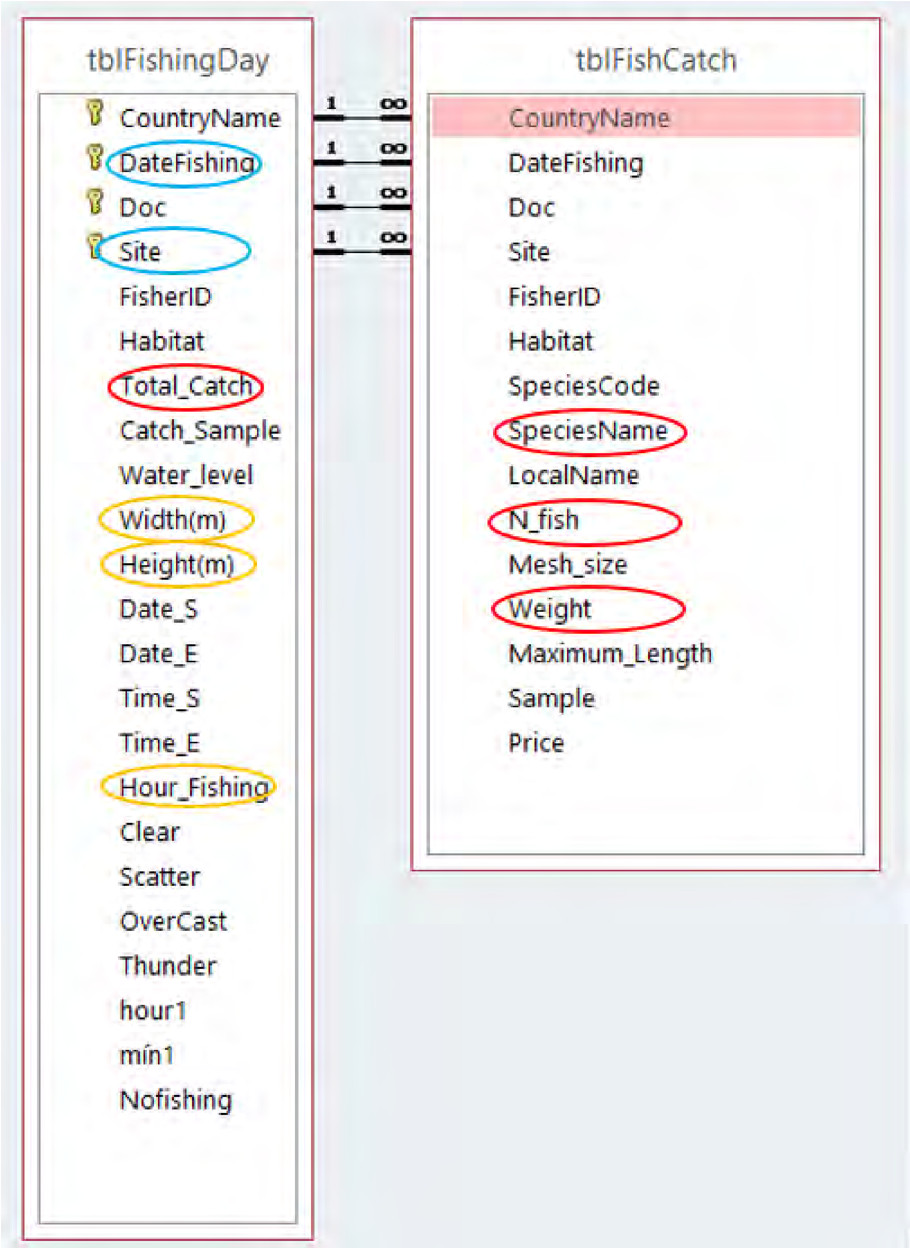


Figure 5-6: Important variables in the gillnet database

5.3.6 Fish larvae database

The key data tables in FADM database are illustrated in *Figure 5-7* and important variables are detailed below:

- In Table "Sample Info", **Site**, **date** and **location** and **Sample number** identifying and mapping each sample

- The volume of water filtered **Volume** is derived from the duration of sampling, itself derived from start and stop time; it allows calculating the density of larvae in 1000 m^3 of water.
- **Wtotal** is the total weight of the sample.
- In table "Spp data" the taxonomy of larvae and juveniles of species harvested is detailed, to the finest level possible. This includes in formation in variables **Family name**, **Genus name** and **Species name**
- In complementary table "Length", data correspond to the **length** of some larvae and juveniles, in order to determine their age and distance to breeding sites.

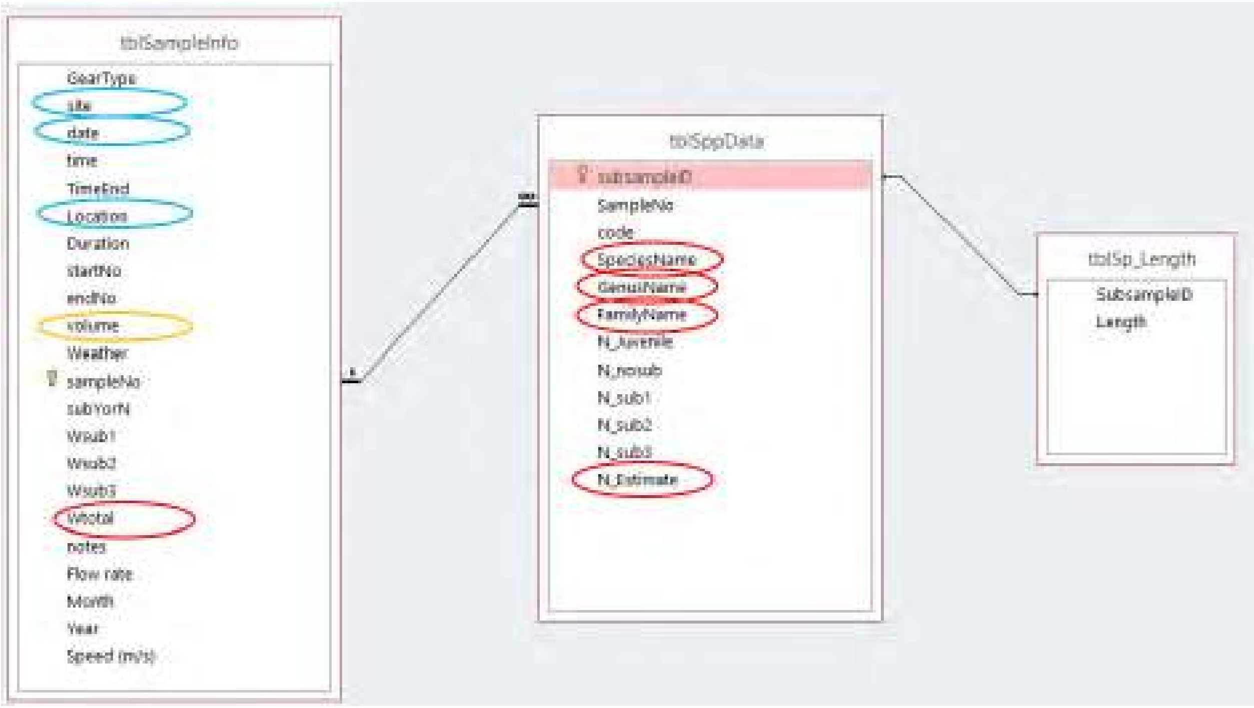


Figure 5-7: Important variables in the FLDM database

5.4 Key variables for possible cross-analyses

Correlation analyses can only be done variable by variable, which leads to reviewing variables key to cross-analyses and queries possible between these variables. The specific objective considered here is an analysis of related meaningful variables from several disciplines over a long period of time and a large area throughout the basin. Some examples of cross analyses are shown in Chapter 6.

5.4.1 Hydrology and sediment database

The hydrologic and sediment data can be used to develop hydrologic and sediment transport indicators that can support the Basin Indicator Framework and be used to interpret water quality, ecological health and fisheries results. Due to the short duration of the JEM monitoring trials, there are insufficient EHM and fisheries results available to perform in-depth analyses linking the hydrologic condition of the river with the results of the EHM or fisheries monitoring.

The following dotpoints summarise a few hydrologic parameters that are likely to be useful in the long-term for integrating and interpreting monitoring results from other disciplines. The hydrologic data base also contains some in-built queries that extract summary hydrologic statistics that can be used to interpret other results:

- **Average discharge per station per month**: The average monthly discharge provides a measure of seasonal flow patterns, and indicates whether the month was dry, normal or wet. The average monthly values can be compared with long term historic results and the PMFM thresholds. A query in the hydrologic data base provides this information for the JEM sites.
- **Average annual discharge at a station**: The average annual discharge provides a measure of whether the year was above or below average. This is useful for interpreting ecological monitoring as wet years tend to inundate larger areas and transport more sediment which can contribute to biological activity. A query in the hydrologic data base provides this information for the JEM sites.
- **Min and max daily water level** provides an indication of the variability of water level change. High rates of water level change can increase erosion and have a negative impact on the aquatic ecosystem by stranding organisms as water levels fall, or providing false 'clues' for important life cycles such as migrating and spawning.
- **Average SSC** per month provides an indication of sediment transport. Trends over time show the impact of the altered and changing flow regime (flow regulation, climate change, shifting monsoonal patterns) and sediment trapping in tributary and mainstream hydropower impoundments. Nutrient loads are strongly linked to sediment loads, so understanding sediment transport can provide insights to changes in nutrient delivery to the ecosystem.

5.4.2 Water quality variables

The key parameters to use in cross-analysis are likely to be:

Temperature It is to be expected that Temperature of water at different depths in the impoundment may show cooler water with lower depths. If this cooler water is then released through the dam, the water emerging from the turbines will be cooler than it should be naturally, and will then stabilize with the ambient Temperature with passage downstream. The results indicate little Temperature change in the depth profiles and in comparison with between the upstream and downstream surface water sites. – At this stage not worth using for cross analysis.

pH does not show much variation between the different sites, but if it falls below pH 6 it is indicative of increasing acidity of the water, which may be reflected from the release of poor quality water with low Dissolved Oxygen from the bottom of impoundments.

Conductivity does not show very much variation between the different sites, but tends to increase slightly during low flow seasons. A changing Conductivity would also be reflected in changing concentrations of dissolved salts (cations and anions).

Dissolved Oxygen: as with Temperature, water taken from lower down in the impoundment may show reduced Dissolved Oxygen, and if released through the turbines, water with less than 5 mg/l may cause water quality problems for aquatic biota and mortality. As the low oxygen water passes downstream, it is re-oxygenated depending upon the flow and turbulence of the river. The results do not indicate much change in oxygen levels between upstream and downstream sites, nor in the impoundment profiles, so DO is not worth using for cross analysis at this stage. Also note that WQ spot samples are usually taken in late morning, early afternoon, and so do not reflect the daily variation in DO, when the levels may be lower at night.

TSS Total Suspended Solids is a measure of water quality within the spot sample of water taken. It is probably less than the SSC calculations, which is averaged across the river cross section and depths. Comparison of TSS above, in the impoundment and downstream of the dam, are an indication of the settlement of sediment with passage through the impoundment. An increase of sediment downstream of the dam may indicate flushing or release of sediment through the dam, but we would need information on dam operation at the time of sampling for interpretation of this. With passage downstream of the dam, it may be expected that water with depleted TSS may actively entrain sediment from bed and banks and gradually stabilize. In our samples TSS does show significant differences between upstream and downstream, but because we do not have records at the height of the wet season when TSS is highest, it will be difficult to make predictions of trapping.

Turbidity Turbidity relates to the passage of light through the water sample. With higher colloidal or suspended sediments the light passing through the water is scattered and less light passes through. The turbidity (measured in FTU) can be correlated with both the TSS and Secchi Disc measurements which measure the depth of transparency of the water. Turbidity measurements are also taken to factor into concentrations of Chlorophyll-a and Cyanobacteria, because phytoplankton themselves reduce the transparency of the water and scatter the light. We have been able to develop a simple correlation curve between the measurements of TSS and turbidity which we can use for extrapolating where we do not have TSS measurements. This is shown in ***Figure 3-32***, which remains to be further verified.

NO3 / NO2 Oxides of nitrogen are a measure of one of the main nutrients in the water, and can be used as a measure of eutrophication of the water, possibly indicating if phytoplankton blooms may become a problem in the impoundments. The threshold for Oxides of Nitrogen for human health index is 0.5 mg/l and for aquatic health is 0.1 mg/l. In our samples, the nutrient content occasionally exceeds these thresholds but without a real pattern, so some of the high value results may be anomalies.

Total P Total Phosphorus is the second key measure of nutrients that may be used as an indicator for eutrophication and possible phytoplankton blooms in the impoundment. The threshold for Total P in the water is 0.13 mg/l for the aquatic health index, and again there are occasions when the Total P content exceeds this, both in the JEM results and in the mainstream Mekong results. Unlikely that the dams are exacerbating this.

Chlorophyl A Chlorophyll-a is a measure of the concentration of algal cells in the water usually expressed in micrograms/liter or in cells per liter. It combines all the different groups of algae containing chlorophyll. Impoundments slow the water down and allow Phytoplankton to reproduce faster than in flowing water, so increase the likelihood that algal blooms may occur with adequate availability of nutrients. Algal blooms can be problematic for water quality in that they can deplete oxygen in the water at night when they are not photosynthesizing, and at the end of a bloom when the algal cells are breaking down. In our samples we have not seen any indication of algal blooms in the water. It has been considered that the green/blue colour of the river at times of very low flow may have been caused by phytoplankton, but this does not appear to be the case since chlorophyll concentrations have been consistently low. It may be that the green/blue colouration comes from filamentous algae growing on the bottom.

Cyanobacteria or Blue-green Algae are one of the components of phytoplankton, containing Chlorophyll-a. Their presence may become problematic if algal blooms contain a high proportion of Cyanobacteria, because they can produce toxins that can be dangerous for fish and for mammals drinking the water including humans. The World Health Organisation's risk threshold is 50 micrograms of Chlorophyll-a per liter with a high proportion of Cyanobacteria. In our samples we have not approached these levels at all, although in January 2021 the proportion of Cyanobacteria in the river upstream and in the Xayaburi impoundment and downstream approached 80% of the Chlorophyll-a content.

5.4.3 Ecological Health Monitoring

The first level of analysis of the Ecological Health is the calculation of the EH Index and class that can be provided in the database using the **QryEHM5_Index_Calculation**.

The stations can also be analysed according to the component scores for the EH Index, which provides greater sensitivity on the responses of the different biotic groups to the changes occurring in the river, e.g. changes in flows and water levels or changes in pollution levels. These are found in the database **Tb14_EHM_Level2_Biota.**

Table 5-5: Component scores for EH Index

Benthic diatoms	BD_AverageAboundance
	BD_AverageRichness
	BD_ATSPT
Zooplankton	ZPT_AverageAboundance
	ZPT_AverageRichness
	ZPT_ATSPT
Littoral Macroinvertebrates	LM_AverageAboundance
	LM_AverageRichness
	LM_ATSPT
Benthic macroinvertebrates	BM_AverageAboundance
	BM_AverageRichness
	BM_ATSPT

These are factors of biotic productivity and ecological health

- **Average Abundance** is a measure of the number of individuals of the different aquatic organisms found in standard sample.
- **Species Richness** is a measure of the numbers of species present in the standard sample.
- **ATSPT** is the Average Tolerance of Species Per Taxon which indicates the proportion of more tolerant species found in the samples. Tolerance is usually based upon the ability to survive in more polluted or disturbed waters.

The different taxonomic groups respond differently to conditions in the river, and within these groups there will be variations in the species that can survive and proliferate under these different conditions. An examination of the different Orders or Families of certain species can be instructive to see the differences between the sampling sites.

Benthic diatoms prefer shallower water that can be penetrated by light and so do not grow well in the deeper parts of the impoundment but can survive downstream growing on rocks that are exposed to daily water levels, provided that they do not dry out. They provide food source for benthic and grazing algal feeding fish.

Zooplankton should survive and proliferate in the impoundment because the slower water speed allows them to reproduce and take advantage of the phytoplankton growth. They will be washed downstream in similar numbers to the impoundment concentrations and should be higher than at the head of the impoundment. They provide good food source for pelagic and surface water feeding fish.

Littoral and Benthic macroinvertebrates are the insect larvae, molluscs, and crustaceans that live in the littoral or bank areas and benthos of the river and impoundment, which provide a significant source of food for fish. The diversity of macroinvertebrate species will respond to changes in the river such as in the impoundment, where the conditions will favor those species that prefer slow moving or stationary water. Within the main body of the impoundment only benthic macroinvertebrates will survive the lower oxygen contents of the benthos, whereas littoral and benthic macroinvertebrates in the river may have higher oxygen availability. Downstream of the dam, daily fluctuations in water level will expose the littoral macroinvertebrates so that only more tolerant littoral species will survive peaking operations. Benthic macroinvertebrates will be able to survive peaking operations more easily because they will be permanently underwater.

In terms of fish feeding behavior, the Benthic diatoms are grazed by Phytivorous and Periphytivorous. The zooplankton are consumed by the pelagic and Zooplanktivorous species. The littoral and benthic macroinvertebrates will be consumed by the Detritivorous and Zoobenthivorous fish species, and the smaller fish will be consumed by larger Piscivorous species. The increase in relative abundance of these taxonomic groups at different sites will indicate which trophic groups of fish are likely to dominate the fish populations.

The numbers of species and individuals of Ephemeroptera, Plecoptera and Trichoptera, are also used as indicator groups since they are the most sensitive Littoral Macroinvertebrates. Also, passive filter-feeding species, such as the Trichopteran Hydropsychidae and the Dipteran Simuliidae may also be used as indicators.

5.4.4 FADM (daily catch) database

As detailed in section 2.4.4, the variables identified in the previous sections can be combined to calculate and plot on a background map the following variables:

- **average monthly catch per fisher in each site and for each year** (i.e. trend in fishers' individual catches);
- **number of species caught each year at each site** (i.e. trend in biodiversity, indication whether a rarefaction process is taking place). Additional analyses combining species composition and abundance per species can be combined into ecological indices (e.g. Simpson's index) indicating whether the catch is made of all equally abundant species (high evenness, i.e. stable community) or of a few ultra-dominant species (low evenness generally sign of an unstable situation), and if an evolution is taking place in a given direction. Reducing evenness is considered an indicator of risky ecological situation preceding species loss.
- **average annual CPUE for gillnets** (i.e. standardized comparison of fish catches). **Gillnet** is the dominant gear all over the region and is subject to specific attention because comparisons between sites can be made in standardized conditions, as long as we know the catch (grams), the size of the gillnet (square meters), and how long it kept fishing (hours). Ultimately the reference unit for fish abundance is **CPUE** = Catch Per Unit Effort = grams of fish per square meter of net per hour fishing**.** In the case of FADM data, CPUE is calculated for gillnets only (it is too complicated to calculate a composite CPUE when several different gears such as big traps, small straps or lines with hooks are involved)
- **percentage of 3 to 5 meaningful species in catches of each site each year.** Meaningful species here can be either commercially important, species present all over the basin, or on the contrary species suspected of rarefaction. Specific analyses can be done with these different perspective in mind by selecting different meaningful species in each case.

As opposed to the above selection of species common to multiple sites, our attempt to plot the five dominant species in each site and their percentage each year in the catch of that site (i.e. identification of possible changes among the abundance of these species in individual sites) was not conclusive, as the output is heavy (e.g. 6 sites x 5 species x 10 years = 300 results to be plotted) and the variability among different dominant species in different sites (e.g. floodplain sites vs. upstream or delta sites) cannot be easily interpreted.

Some variables monitored are part of the protocol as possible explanatory variables in the case of future deepened analyses, but are not essential to monitoring trends on a regular basis:

- **Habitat** (the monitoring does not try to relate catch to standard habitats)
- **Water level** (rising, static or falling, as approximately noted by fishers; precise water levels and their variability can be obtained from nearby hydrology stations)
- **Mesh/Hook size, Engine HP** (these variables pertain to fishing efficiency research –e.g. species composition by mesh size, fish size in relation to engine power- but do not influence or cannot be related to the catch being monitored);
- **Weather of the day** (cloud cover, thunder, etc.): these variables are possibly relevant to studies of fish behavior on a daily time step, but not to the assessment of impact of dams on the fish resource.
- **Price** is a variable relevant to socioeconomic monitoring, but not directly to the impact of dams on the fish resource.

5.4.5 Gillnet database

Since the gillnet database is a subset of the FADM database, only with a more standardized fishing protocol, the same key monitoring variables apply here as well:

- average monthly catch per fisher in each site and for each year
- number of species caught each year at each site
- average annual CPUE for gillnets
- percentage of 3 to 5 meaningful species in catches of each site each year.

5.4.6 Fish larvae database

In the FLDM database, the key information is the taxonomy of species in their larval stage. This information corresponds to **Family name**, **Genus name** and **Species name** variables and allows identifying the number of taxa in each site (biodiversity, variability between sites and stations, identification of high larvae diversity hotspots, ecological indices of species distribution). That qualitative information is complemented with a quantitative aspect: the **number of larvae/juveniles per 1000 cubic meters of water** sampled in a given place (density). The latter information allows plotting high density peaks in time, e.g. breeding periods or larvae pulses at dam sites, or, in space, concentration of larvae in some sites or stations – but practically this larvae density is subject to extremely high variability and is not considered very reliable. Last, the **length** of some larvae and juveniles allows determining their age and, depending on estimated larval drift speed, distance to breeding sites.

5.5 Data availability per discipline and site over the years

Not all monitoring sites have been put in place at the same time, and in each site the number of records varies from year to year depending on technical, financial, logistical and accidental factors (e.g. site discontinued, gauge moved, recorder breakdown, gear stolen, loss of participating fishers, etc.). This results in a high heterogeneity of records density in databases, and integrating this heterogeneity is essential to combining data, often on the basis of the smallest common denominators. Data available by site in MRC databases are detailed below.

5.5.1 Hydrology and sediments

Table 5-6 summarises the number of measurements in the Discharge and Sediment measurement data base. *Table 5-7* shows the number of field measurements completed at each site during each year.

Table 5-6: Number of measurements available at each site for each parameter in the discharge and sediment database.

Site Code/Name	Water Level	Channel Width	Channel Area	Mean Velocity	Discharge	SSC	SSC Load	Bedload
TH_010501 [Chiang Saen]	215	38	39	39	217	214	214	
LA_010701 [Ban Xanghai]	8	10	10	10	10	10	10	10
LA_011201 [Luang Prabang]	117	87	87	87	117	114	114	
LA_011501 [Ban Pakhoung]	5	9	9	9	9	4	7	9
TH_011903 [Chiang Khan]	283	104	81	104	273	257	255	55
TH_012001 [Nong Khai]	417	368	350	368	429	408	387	18
LA_013901 [Pakse]	181	160	157	177	182	104	104	5
KH_014003 [Koh Key]/Stung Treng UP	27	27	27	27	27	27	27	
KH_SKB [Sekong Bridge]	26	55	55	55	55	45	45	
KH_014501 [Stung Treng]	203	55	55	80	203	192	192	
KH_014901 [Kratie]	192	55	55	55	192	181	181	

Table 5-7. Number of monitoring runs completed each year at each site under DSM ongoing monitoring and JEM.

	Number of Field Measurements Each Year										
Site Code/Name	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2018**	**2019**	**2020**	**2021**
TH_010501_[Chiang Saen]	36	38	27	11	15	10	34	20	26		
LA_010701_[Ban Xanghai]										5	5
LA_011201 [Luang Prabang]			21	32	14	27	6		17		
LA_011501[Ban Pakhoung]										4	17
TH_011903_[Chiang Khan]	47	41	35	28	14	17	25	23	31	15	7
TH_012001_[Nong Khai]	77	82	55	57	28	17	8	38	28	25	15
LA_013901_[Pakse]	34	37	20	22	14	30	6		15	2	18
KH_014003_[Koh Key]										24	3
KH_SKB_[Sekong Bridge]									19	26	10
KH_014501_[Stung Treng]			22	26	16	30	36	18	19	26	10
KH_014901_[Kratie]			21	16	16	30	36	18	19	26	10

5.5.2 Water quality

Because the Water Quality monitoring is based upon monthly spot samples, the most usual form of analysis is based upon calculations of the annual median, maximum and minimum results often expressed in box and whisker charts. Monthly results can be compared between sample sites taken in the same month, which is useful to see how the WQ conditions are changing through the impoundments and downstream of dams. It would also be useful to link these changes with operation of the dams and release of bottom water during sediment flushing events.

Data available in Tb1_WQM_DWQMForm1 contains the spot surface water results measured by both probe on site and in samples taken for analysis in the laboratory. The numbers of samples taken at each station during the JEM WQ campaign between October 2020 and June 2021 are shown below (*Table 5-8*).

Table 5-8: Number of measurements available at each site for each parameter between October 2020 and June 2021 in the water quality database.

STATID	TEMP _°C	pH	TSS_mg/L	Turbidity_FTU	COND _mS/m	NO32_mg/L	NH4N _mg/L	TOTN _mg/L	TOTP _mg/L	DO _mg/L	CODMN _mg/L	Chlorophyll A _ug/L	Cyano Bacteria_ug/L	FC _MPN/100ml		
H011200	8	8	8	-	8	8	8	8	8	8	8	5	-	-		
WQ1	8	8	8	8	8	8	8	8	8	8	8	8	8	8		
WQ2	8	8	-	8	8	8	-	-	8	8	-	8	8	-		
WQ3	8	8	-	8	8	8	-	-	8	8	-	8	8	-		
WQ4	8	8	8	8	8	8	8	8	8	8	8	8	8	6		
WQ5	8	8	-	8	8	8	-	-	8	8	-	8	8	-		
H011901	8	8	8	-	8	8	8	8	8	8	8	7	-	-		
H011901	8	8	8	-	8	8	8	8	8	8	8	8	-	-		
WQ6	8	8	8	8	8	8	8	8	8	8	8	8	8	6		
WQ7	8	8	-	8	8	8	-	-	8	8	-	8	8	-		
WQ8	8	8	-	8	8	8	-	-	8	8	-	8	8	-		
WQ9	8	8	8	8	8	8	8	8	8	8	8	8	8	5		
H014501	9	9	9	-	9	9	9	9	9	9	9	-	-	-		

The WQMN and JEM monitoring also measures several cations and anions during wet season months. The table below shows the number of samples that were taken for this analysis, but because the full year sampling was not possible, only 3 sets of measurements were made at each site during the JEM campaign. Because so few results are available and because the Conductivity does not show significant variation, these results have not been analysed.

Table 5-9: Data about cations and anions during wet season months in the water quality database.

STATID	Ca_meq/L	Mg_meq/L	Na_meq/L	K_meq/L	ALK_meq/L	Cl_meq/L	SO4_meq/L
H011200	3.0	3.0	3.0	3.0	8.0	3.0	3.0
WQ1	3.0	3.0	3.0	3.0	8.0	3.0	3.0
WQ2	-	-	-	-	-	-	-
WQ3	-	-	-	-	-	-	-
WQ4	3.0	3.0	3.0	3.0	8.0	3.0	3.0
WQ5	-	-	-	-	-	-	-
H011901	3.0	3.0	3.0	3.0	8.0	3.0	3.0
H011901	3.0	3.0	3.0	3.0	8.0	3.0	3.0
WQ6	3.0	3.0	3.0	3.0	8.0	3.0	3.0
WQ7	-	-	-	-	-	-	-
WQ8	-	-	-	-	-	-	-
WQ9	3.0	3.0	3.0	3.0	8.0	3.0	3.0
H014501	9.0	9.0	-	-	9.0	9.0	9.0

The data available in Tab 11 of the database, Tb11_WQM_JEMProfileMonitor, has the results from the probe monitoring at the surface in the river sampling stations and of the profiles of the two impoundments at WQ2 and WQ7 for a total of eight months between October 2020 and June 2021, except for May 2021.

Table 5-10: Numbers of samples taken about probe monitoring at the surface and impoundment profiles

Station	TEMP_ °C	pH	COND_ mS/m	DO_mg /L	Turbidity_FTU	Chlorophyll_ mg/L	Cyanobacteria _mg/L
WQ1	8	8	7	8	8	8	8
WQ2	172	172	66	152	162	96	96
WQ3	8	8	7	8	8	8	8
WQ4	8	8	7	8	8	8	8
WQ5	8	8	7	8	8	8	8
WQ6	8	8	8	8	8	8	8
WQ7	172	172	66	152	162	96	96
WQ8	8	8	8	8	8	8	8
WQ9	8	8	8	8	8	8	8
Total	**204**	**204**	**153**	**204**	**184**	**124**	**124**

Note that Chlorophyll-a and Cyanobacteria are only possible to measure down to 10 m, the length of the probe cable.

The numbers of water quality monitoring visits taken each month in the years between 2020 and 2021 is shown in *Table 5-11*.

Table 5-11: Number of water quality samples each month between 2020 and 2021:

Year 2010 - 2021												
Months	10	11	12	13	14	15	16	17	18	19	20	2021	Total
H010500	6	6	8	12	12	12	12		12	12	12	5	109
H010501	6	6	12	12	12	12	12	12	12	12	12	6	126
H011200	6	6	8	12	12	12	12	12	12	12	12	5	121
H011901	6	6	8	12	12	12	12	12	12	12	12	5	121
H013101	6	6	12	12	12	12	12	12	12	12	12	6	126
H013401	6	6	8	12	12	12	12	12	12	12	12	5	121
H013801	6	6	12	12	12	12	12	12	12	12	12	6	126
H013900	6	6	8	12	12	12	12	12	12	13	12	5	122
H014501	6	6	12	12	12	12	12	11	12	12	11		118
H014901	6	6	12	12	12	12	12	11	12	12	11		118
H019801	6	6	12	12	12	12	12	11	12	12			107
H019802											11		11
WQ1											3	5	8
WQ2											3	5	8
WQ3											3	5	8
WQ4											3	5	8
WQ5											3	5	8
WQ6											3	5	8
WQ7											3	5	8
WQ8											3	5	8
WQ9											3	5	8
Grand Total	**66**	**66**	**112**	**132**	**132**	**132**	**132**	**117**	**132**	**133**	**156**	**88**	**1398**

5.5.3 Ecological Health Monitoring

For the JEM pilot sites, there is only one set of samples taken in February/March 2021. The routine EHM sampling is carried out every 2 years, with comprehensive data on Mekong mainstream sites from 2011, 2013, 2015, 2017 and 2019, as shown in *Table 5-12*.

Table 5-12: EHM sampling sites and monitoring years

EHM Site	Site Name	2011	2013	2015	2017	2019	2021
LMX	Ban Xieng Kok	x	x	x	x	x	
TCS	Chiang Saen	x	x	x	x	x	
LPB	Done Chor	x	x	x	x	x	
EHM1							x
EHM2							x
EHM3	Xayaburi						x
EHM4							x
EHM5							x
EHM6							x
LVT	Ban Huayhome	x	x	x	x	x	
TNP	Nakhon Phanom	x	x	x	x	x	
TKC							
LDN	Don Ngiew	x	x	x	x	x	
EHM7							x
EHM8	Don Sahong						x
EHM9							x
EHM10							x
CKM	Kbal Koh		x	x	x	x	
CKT	Stung Treng		x	x	x	x	
CMR	Kratie		x	x	x	x	

5.5.4 Fisheries monitoring data

Data availability for fisheries (FADM and FLDM) of the amount of data available by year and by site is detailed in *Table 5-13*, courtesy Vanna Nuon at MRCS. 2021 being still work in progress, this year is not displayed here.

Table 5-13: Months of FADM data available by year and by site. Green: full monthly sampling; Orange: at least two-thirds of the year sampled; Red: less than two-thirds of the year sampled

Country	Village	Site Code	New Code	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
CAM	Prek Torl	CBT						1	12	12	12	12		12	12	12	12
CAM	Chhnouk Trou	CKC						1	12	12	12	12		12	12	12	12
CAM	Neang Sav; Pheam Bang; Pich Chikreng	CKTh	CPT					1	12	12	12	12		12	12	12	12
CAM	Ti 1, 3,4	CPS						1	12	12	12	12		12	12	12	12
CAM	Ti 3,4,5	CSR						1	12	12	12	12		12	12	12	12
CAM	Koh Khne	CKT		7	12	12	12	11	12	12	7	11	11	8	12	12	12
CAM	Sang Var	CKD		7	12	12	12	11	12	12	7	11	11	8	12	12	12
CAM	Fang	CRK1	CSS	7	12	12	12	11	12	12	7	11	12	8	12	12	12
CAM	Day Lo	CRK2	CSP	7	12	12	12	11	12	12	7	11	11	8	12	12	12
CAM	Pres Bang	CST1	CSK	7	12	12	12	11	12	12	7	11	11	8	12	12	12
CAM	Ou Run	CST2	CST	7	12	12	12	11	12	12	7	11	11	8	12	12	12
LAO	Saphaothong	LAP												8	12	12	12
LAO	Sinhxay	LBX		1	12	12	12	8	10	12	4			8	12	12	12
LAO	Huay tap	LBK1	LHT							10	4			8	12	12	12
LAO	Donekoun	LBK2	LDK							10	4			8	12	12	12
LAO	Hangsadam	LCS1	LSD											8	12	12	12
LAO	Hat	LCS2	LCS						1	12	4			8	12	12	12
LAO	Hatsalao	LCS3	LSL							12	4			8	12	12	12
LAO	Pha O	LPB1	LPB		10	12	12	12	12	12	4			8	12	12	12
LAO	Hadgna	LPB2	LPO		9	12	12		1	10	4			8	12	12	12

Country	Village	Site Code	New Code	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
LAO	Pak ngery	LOX1	LPN							10	4			8	12	12	12
LAO	Pakbeng	LOX2	LOX							10	4			8	12	12	12
LAO	Thamuang	LVT			9	12	12	6	8	12	4			8	12	12	12
LAO	Thadeua	LXB2	LXB							12	4			8	12	12	12
LAO	Na xam	LXB1	LNS							10	4			8	12	12	12
LAO	Navasaen	LXK												8	12	12	12
TH	Ban Noy	TCK		6	12	6		4	12	12					12	12	12
TH	Ban Tha Bho	TSK		6	10	6		3	12	12				1	12	12	12
TH	Ban Tha Dok Kaeo	TUT		6	12	7		3	12	12				1	12	12	12
TH	Thadaeng	TNK		6	12	7		3	12	12					12	12	12
TH	Ladjalean	TKR		6	12	7		2	12	12				1	12	12	12
VN	Ap 2	VAG1	VAP	6	12	12	12	12	12	12	1			9	12	12	12
VN	My Thuan	VAG3	VCM	6	8	12	12	12	12	12	1		2	12	12	12	12
VN	Tay Son	VAG2	VTS	6	12	12	12	12	12	12	4		5	12	12	12	12
VN	My Thuan	VCT						4	12	12	1		4	12	12	12	12
VN	Khom 3	VTV1	VTV	7	12	12	12	12	12	12	4		3	12	12	12	12
VN	Long Tri	VTV2						4	12	12	1			9	12	12	12
VN	Lang	VVL		7	12	12	12	12	12	12	1		1	12	12	12	12

5.6 Time step of key variables

5.6.1 Hydrology and sediment database

Hydrologic information is available from HYCOS sites at 15-minute time steps. This information has not been included at this detail in the JEM data base, due to the large number of records that would be required to be included.

For cross-analysis with other disciplines, the hydrologic water level and discharge results could be aggregated to monthly, daily or hourly steps. Useful parameters and time-steps for hydrologic variables includes:

- **Average daily discharge aggregated to average monthly flow**
- **Hourly Water level** to be used to identify daily minimum, daily maximum and daily change. These values can be used to derive daily or monthly minimum and maximum rates of water level change.

Suspended sediment concentrations (SSC) are collected at variable time-steps, with a higher frequency of sampling occurring during the flood season when the majority of sediment transport occurs. For cross-analysis with other disciplines the results can be aggregated to monthly average SSC

5.6.2 Water quality database

The water quality monitoring is carried out on a monthly basis at each of the routine and JEM sampling stations. These are spot samples which only reflect the conditions at the time of sampling and in the specific location. The samples are made up of aggregates of samples taken on both banks and in the centre of the mainstream in order to get a more representative measurement of the conditions in the river as a whole.

Generally all the 12 annual samples are considered together, calculating the median, maximum and minimum values. The water quality indices (For Aquatic Life and Human Health) are calculated on these 12 annual samples based upon the number of measurements that exceed threshold levels of key parameters.

Water quality may also change throughout the 24 hours of day and night, especially parameters such as Dissolved Oxygen which may show lower levels during the night, when phytoplankton are not photosynthesising. The spot samples are taken during the middle of the day, and so will rarely capture lower levels of DO or other sensitive parameters.

Because they are taken over a short time period on the day, they are only strictly comparable to flow and water level measurements at the same time and day, which may in turn reflect the daily operations of the hydropower plant.

5.6.3 Ecological Health Monitoring

The routine Ecological Health monitoring has been carried out systematically every two years in 2011, 2013, 2015, 2017, 2019 and 2021 in most of the sampling locations. It had been planned to carry out the JEM EHM sampling at the 10 sampling sites in two successive years 2020 and 2021, but because of COVID travel restrictions it was not possible to carry out the 2020 monitoring campaign. There is thus only one set of results for EHM for the JEM sites.

5.6.4 FADM (daily catch) database

Routine FADM monitoring is taking place on a daily basis, as fishers record their catch for each of their fishing operations. This time step could be used for very specific analyses (e.g. impact of sediment releases on the fish fauna) but **by default the standard time step is the month**, which integrates normal and high daily variability in catches.

Analyses of species diversity and of variability in the presence of species can be done on a monthly basis in some specific cases (e.g. migration pulses) – but **the standard integration level for biodiversity studies is the year**, which reflects seasonal variability and seasonal migrations.

The gillnet monitoring protocol produces data on the same basis.

5.6.5 Fish larvae database

Larvae are sampled on a monthly basis although not with the same intensity each month. Larvae are sampled one day per week from August to April and two days per week from May to July. In each site, three samples are collected in **three stations**: two banks and the middle of the river. Samples are also should be collected **4 times a day**: at 6:00, 12:00, 18:00 and 24:00, during 30 minutes each time. This produces 12 samples per week between August and April and 24 samples per week between May and July.

5.7 Integrating JEM monitoring results

5.7.1 Hydrology and sediments

The hydrology and sediment results collected at the JEM sites during 2020-2021 have been integrated with the DSM monitoring results collected at other sites in the LMB to provide an analysis of hydrologic patterns and sediment transport in the LMB between Chiang Saen and Kratie in 2020 – 2021 in Section 6.1. This includes assessment of flow compared to the PMFM guidance, the determination of sediment loads, and analysis of water level changes associated with hydropower operations.

Hydrologic information has been integrated with water quality information at a basin wide scale in Section 6.2, to provide time-series of nutrient loads throughout the LMB between 2009 and 2020/21. The large scale trends in flow, sediment transport and nutrients can provide a context for reviewing trends in EHM and fisheries, even if only at a qualitative level. Due to the late delivery of fisheries data, these comparisons have not been possible within JEM, but can be pursued in the future.

5.7.2 Water quality

Water Quality data is collected as monthly spot samples which reflect the conditions at the time and place of collection. The measurements are made using a) probes and meters for on the site measurements taken in up to 5 repeats within the sampling station, and b) representative samples for laboratory analysis. The constraint within such a sampling regime is that it does not capture all the daily or hourly changes that occur between the sampling visits. It is appreciated that there may be significant changes between night and day, e.g. in Dissolved Oxygen, or when changes in the operation of the dam affect water quality, e.g. turbine ramping up or down, or sediment flushing.

Ideally it would be useful to correlate flow rates and water levels around the time of sampling, if information on dam operation is not available. However, changes in water quality with passage downstream do not appear to be very large and with no apparent pattern, except for changes in TSS and Turbidity. Occasional high values of TSS and turbidity downstream of the dam may be the result of releases of sediment during operation.

The water quality profiles within the impoundments can not be related to hydrological or sediment data, since these are not measured at these locations.

5.7.3 Ecological Health

The Ecological Health monitoring at the JEM sites has been carried out once during the pilot project period, and routine EHM sampling has been done once every 2 years. The practice is based upon the assumption that the biota at each sampling site reflects the long-term changes in the flows, habitats, and water quality over the past year, including occasional pollution or flood events. Depending on when or if these events take place, the biota present will reflect the changes that have occurred and their recovery afterwards.

With such an occasional sampling frequency it is difficult to correlate the EHM results quantitatively with flows or water quality, or even with the fisheries data. Correlation with the results from other disciplines has to be done qualitatively, interpreting trends and events in flows and flow rates, and sediment transport with changes in the habitat and substrate, and the patterns of water quality changes at each site. The locations of the JEM WQ sites and EHM sites are closely related and so such trends can be compared easily, while the hydrological stations are often reflecting broader rather than local changes in flows.

5.7.4 Fisheries

The steps achieved and presented above allow identifying the types of cross-discipline analyses that can be developed in the future (***Table 5-14***).

In fisheries, the main cross-discipline analyses possible are:

Monthly fish catch per fisher vs.:

- percentage of flow change compared to its long-term monthly average;
- monthly water level jaggedness index;
- monthly averaged sediment load;
- water quality parameters averaged over the month

Annual fish species richness vs.

- percentage of flow change compared to its long-term annual average;
- annual water level jaggedness index;
- total annual sediment load;
- Ecological health index (score card) over the year;
- index of water quality over the year or detail by water quality parameter

Table 5-14: Possible types of cross-discipline analyses that can be developed in the future

Cluster	Stations to be combined	Years of full annual data in these stations				Data frequency				Cross-analyses doable
		DSM	EHM	WQ	Fisheries	DSM	EHM	WQ	Fisheries	
#1 Downstream China	**HYD** **DSM:** CS; **EHM:** TCS; **WQ**: TH_010501 **FADM**: LHT	2010-21 2010-19	2011, 2013, 2015, 2017, 2019	2010 - 2021	2017-2021		Every 2 years	Monthly	Monthly	**Monthly fish catch per fisher vs.** i) percentage of flow change compared to its long-term monthly average; ii) water level monthly jaggedness index; iii) monthly averaged sediment load; iv) water quality parameters averaged over the month **Annual fish species richness vs.** i) percentage of flow change compared to its long-term annual average; ii) water level annual jaggedness index; iii) total annual sediment load; iv) Environmental health index (score card) over the year; v) index of water quality over the year or detail by water quality parameter
#3 Upstream of Xayaburi	**HYD** **DSM:** XH; **EHM:**; EHM1 **WQ**: WQ1; **FADM**: LJXU, LPB	2020-21 2020-21	2020-21	2020-21	2009-2013, 2017-2021		1x	Monthly	Monthly	
#5 Downstream of Xayaburi	**HYD** **DSM:** Pak Houng **EHM:** EHM6; **WQ**: WQ5 ; **FADM**: LJXD	2020-21 2020-21	2020-21	2020-21	2020-21		1x	Monthly	Monthly	
#10 Upstream of Don Sahong	**HYD** **DSM:** Pakse ; **EHM:** EHM7; **WQ**: WQ6; **FADM**:	2010-21 2009-15,19,21	2020-21	2020-21	2020-21		1x	Monthly	Monthly	

Cluster	Stations to be combined	Years of full annual data in these stations				Data frequency				Cross-analyses doable
		DSM	EHM	WQ	Fisheries	DSM	EHM	WQ	Fisheries	
	Muang Saen Nua or LJDU									
#13 Downstream of Don Sahong Dam	**HYD DSM:** KK; **EHM:** EHM10; **WQ**: WQ9; **FADM**: LSD or LJDD	2021 2020-21	2020-21	2020-21	2017-2021		1x	Monthly	Monthly	

5.8 Monitoring information from other relevant MRC monitoring programmes

5.8.1 Hydrology & sediments

The ongoing Discharge and Sediment Monitoring results collected during 2020 have been analysed and included in the basin wide assessment of hydrology and sediment trends in the catchment. The DSM (non-JEM) used in the basin wide analysis include: Chiang Saen, Nong Khai, Stung Treng, Sekong Bridge and Kratie. These sites reflect what is occurring within the riverine portion of the LMB, with the results at Stung Treng and Kratie providing a measure of the flow and sediment entering the Cambodian floodplain. Downstream of Kratie, flow is affected by tidal influences, there are no established rating curves for the DSM monitoring sites and the system is overall more complex.

5.8.2 Water Quality

The routine WQMN results for the mainstream sites from Houa Khong, Chiang Saen, Luang Prabang, Vientiane, Nakhon Phanom, Savannahket, Khong Chiam, Pakse, Stung Treng, Kratie and Kampong Cham have been included into the JEM database. These records start in 2010 with monitoring taking place every 2 months until 2014 when monthly monitoring was started. Since then until 2021 sampling has taken place on a monthly basis. The parameters measured are the same as in the JEM, except that Turbidity, Chlorophyll-a and Cyanobacteria are not being measured.

5.8.3 Ecological Health

The results of the Ecological Health monitoring at the mainstream sites from Ban Xieng Kok (LMX), Chiang Saen (TCS), Done Chor (LPB), Ban Huayhome (LVT), Nakhon Phanom (TNP), Kong Chiam (TKC), Don Ngiew (LDN), Kbal Koh (CKM), Stung Treng (CKT), Kratie (CMR) have been included into the JEM database. The EH monitoring at all these monitoring sites started in 2011 and has been continued every two years – in 2011, 2013, 2015, 2017, 2019.

5.8.4 Fisheries

In Cambodia, the FADM is produced by two different authorities: the Tonle Sap Authority and the Fisheries Administration.

ICEM was provided on 31 August 2021 the whole set of FADM data available for Cambodia, consisting in 5 different databases:

- *FADM-Tonle Sap Authority 2011-15*
- *FADM-Tonle Sap Authority 2017-18*
- *FADM-Tonle Sap Authority 2019*
- *FADM-Tonle Sap Authority 2020-21*
- *FADM-Fisheries Administration 2017-21*

The information provided only stipulated that "the unit used by the Tonle Sap Authority from 2011 to 201 is grams" unlike the FiA using kilograms for fish catch and fish weight.

Any analysis over several years or several sites of data scattered among several files therefore requires the initial compilation of the 5 files into a single one – which was done. The resulting matrix includes 65,861 fishing operations. A first review by site revealed the discrepancy between site names, not standardized so far. If not fixed, these discrepancies prevent the analysis of results per site. 22,214 site names were fixed.

The presence of data per site and per year was then reviewed (***Table 5-15***). This analysis shows that:

- The Tonle Sap Authority has consistently monitored four sites between 2011 and 2021: Anlongtaour and Prek Torl in Battambang, Chhnok Tru in Kompong Chhnang, and Ti2 in Pursat. Some other sites have been monitored over a few years but discontinued:
    - Neang Sav in Kompong Thom, Ti1 in Pursat, Ti 3, Ti 4 and Ti 5 in Siem Reap (2011-2015 period)
    - Ti3 in Pursat (2011-2020)
    - Pich Chikrey in Kompong Thom, Thort Kambot in Siem Reap and Kompong Pluk in Siem Reap (2017-2020 period)
- Peam Bang in Kompong Thom is a site that has been monitored by the TSA since 2017 until now; it can be added to Anlongtaour, Prek Torl, Chhnok Tru and Ti2 in the list of sites currently monitored.
- The Fisheries Administration has been consistently monitoring 6 sites since 2017: Sang Var in Kandal, Koh Khne in Kra Tie, Day Lo and Fang in Ratanakiri, Ou Run and Pres Bang in Stung Treng

Thus, 13 sites are of particular value:

- **Continuous monitoring, by the TSA, from 2011 until now in four sites**: Anlongtaour and Prek Torl in Battambang, Chhnok Tru in Kompong Chhnang, and Ti2 in Pursat
- **Continuous monitoring, by the TSA or the FIA, from 2017 until now, in 9 sites**: Anlongtaour and Prek Torl in Battambang, Sang Var in Kandal, Chhnok Tru in Kompong Chhnang, Peam Bang in Kompong Thom, Koh Khne in Kra Tie, Ti2 in Pursat, and Day Lo and Fang in Ratanakiri

An analysis of fishing gears reveals discrepancies between gear names used; these discrepancies prevent analysing data by gear, and fixing them all was not possible within the time frame of the current analysis

Table 5-15: Presence of data per site and per year

	TSA 2011-2015					TSA 2017-2018		TSA 2019	TSA 2020-21		FIA 2017-21				
Battambang															
Anlongtaou	x	x	x	x	x	x	x	x	x	x					
Prek Tor	x	x	x	x	x	x	x	x	x	x					
Kandal															
Sang Va											x	x	x	x	x
Kompong Chhnang															
Chhnok Tru	x	x	x	x	x	x	x	x	x	x					
Kompong Thom															
Neang Sav	x	x	x	x	x										
Peam Ban						x	x	x	x	x					
Pich Chikrey						x	x	x	x						
Kra Tie															
Koh Khne											x	x	x	x	x
Pursat															
Ti1 in Pursat	x	x	x	x	x										
Ti2 in Pursat	x	x	x	x	x	x	x	x	x	x					
Ti3 in Pursat	x	x	x	x	x	x	x	x	x						
Ratanakiri															
Day Lo											x	x	x	x	x
Fang											x	x	x	x	x
Siem Reap															
Thort Kambot						x	x	x	x						
Ti 4	x	x	x	x	x										
Ti 5	x	x	x	x	x										
Kompong Pluk						x	x	x	x						
Ti 3 in Siem Reap	x	x	x	x	x										
Stung Treng															
Ou Run											x	x	x	x	x
Pres Bang											x	x	x	x	x

Table 5-16: Data availability and quality in long-term Cambodian FADM data, by site

	2011	2012	2013	2014	2015	2017	2018	2019	2020	2021
Battambang										
Anlongtaour	1	12	12	12	12	12	12	12	12	2
Prek Torl	1	12	12	12	12	12	12	12	12	2
Kandal										
Sang Var						8	12	12	12	5
Kompong Chhnang										
Chhnok Tru	1	12	12	12	12	12	12	12	12	6
Kompong Thom										
Neang Sav	1	12	12	12	12					
Peam Bang						12	12	12	12	5
Pich Chikrey						12	12	12	12	
Kra Tie										
Koh Khne						8	12	12	12	5
Pursat										
Ti1	1	12	12	12	12					
Ti2	1	12	12	12	12	12	12	12	12	5
Ti3	1	12	12	12	12	12	12	12	12	-
Ratanakiri										
Day Lo						8	12	12	12	5
Fang						8	12	12	12	5
Siem Reap										
Kompong Pluk						12	12	12	10	
Thort Kambot						12	12	12	12	-
Ti 3	1	12	12	12	12					
Ti 4	1	12	12	12	12					
Ti 5	1	12	12	12	12					
Stung Treng										
Ou Run						8	12	12	12	5
Pres Bang						8	12	12	12	4

A review based on fishers shows that not all sites involve the same number of fishers. **Only recent FiA sites (Sang Var in Kandal, Koh Kneh in Kratie, Day Lo in Ratanakiri and Ou Run and Pres Bang in Stung Treng) and one TSA site (Chhnok Tru in K. Chhnang) involve three fishers as per JEM protocol like in other countries**. Some sites require attention though: Chhnok Tru and Pres Bang (loss of one fisher in 2021), but also Pich Chikrey in Kampong Thom, Ti3 in Pursat, Kompong Pluk and Thort Kambot in Siem Reap, for a discontinued sampling after several continuous years of monitoring.

Table 5-17: Review of the number of fishers involved in each FADM monitoring site

Count of Fishers										
Row Labels	**2011**	**2012**	**2013**	**2014**	**2015**	**2017**	**2018**	**2019**	**2020**	**2021**
Battambang										
Anlongtaour	1	1	1	1	1	2	2	2	2	2
Prek Torl	2	2	2	2	2	1	1	1	1	1
Kandal										
Sang Var						3	3	3	3	3
Kompong Chhnang										
Chhnok Tru	3	3	3	3	3	3	3	3	3	2
Kompong Thom										
Neang Sav	2	3	3	3	3					
Peam Bang						2	2	2	2	1
Pich Chikrey						1	1	1	1	xx
Kra Tie										
Koh Khne						3	3	3	3	3
Pursat										
Ti1 in Pursat	1	1	1	1	1					
Ti2 in Pursat	1	1	1	1	1	2	2	2	2	1
Ti3 in Pursat	1	1	1	1	1	1	1	1	1	
Ratanakiri										
Day Lo						3	3	3	3	3
Fang						2	2	2	2	2
Siem Reap										
Kompong Pluk						1	1	1	1	
Thort Kambot						2	2	2	2	
Ti 3 in Siem Reap	1	1	1	1	1					
Ti 4 in Siem Reap	1	1	1	1	1					
Ti 5 in Siem Reap	1	1	1	1	1					
Stung Treng										
Ou Run						3	3	3	3	3
Pres Bang						3	3	3	3	2

A combination of data availability over a long period of time (*Table 5-16*) and of sampling intensity per site (*Table 5-17*) allows flagging the following sites of high quality for long-term monitoring and comparisons (*Table 5-18*):

Table 5-18: Cambodian FADM stations with optimal combination of monitoring duration and sampling intensity

	2011	2012	2013	2014	2015	2017	2018	2019	2020	2021
Chhnok Tru in Kompong Chhnang										
Day Lo in Ratanakiri										
Koh Khne in Kra Tie										
Ou Run in Stung Treng										
Pres Bang in Stung Treng										
Sang Var in Kandal										

Under the JEM pilots focused on Xayaburi and Don Sahong Dams, the Chhnok Tru and Sang Var data will not be considered here, and the optimal combination of monitoring duration and monitoring intensity corresponds to the five following stations: Day Lo in Ratanakiri, Koh Khne in Kra Tie, Ou Run and Pres Bang in Stung Treng, and Sang Var in Kandal.

Last, and importantly, a review of the catch per fisher and per month provides results (

Table 5-19) that include an important hiatus:

- The catch in sites sampled by the TSA protocol is systematically higher than the catch in sites sampled by the FiA, and the former is unrealistically high (average: 409 kg/fisher/month in average for TSA vs. 90 kg/fisher/month for FiA).
- Yet the difference cannot be explained by the recording of catches in grams by TSA and in kg by FiA (409 grams per fisher per month would not be realistic either).
- The distribution of data points exhibits abnormal patterns (*Figure 5-8*)and:
  - o many data points whose value is superior to 100, which is impossible if data were recorded in kg;
  - o all data points (except three not plotted here) with a value inferior to 1000, which would correspond to 1000 grams = 1 kg per fishing operation, a value that would be common if catches were recorded in grams.

This calls for an in-depth re-examination and cleaning of data beyond the scope of the current analysis.

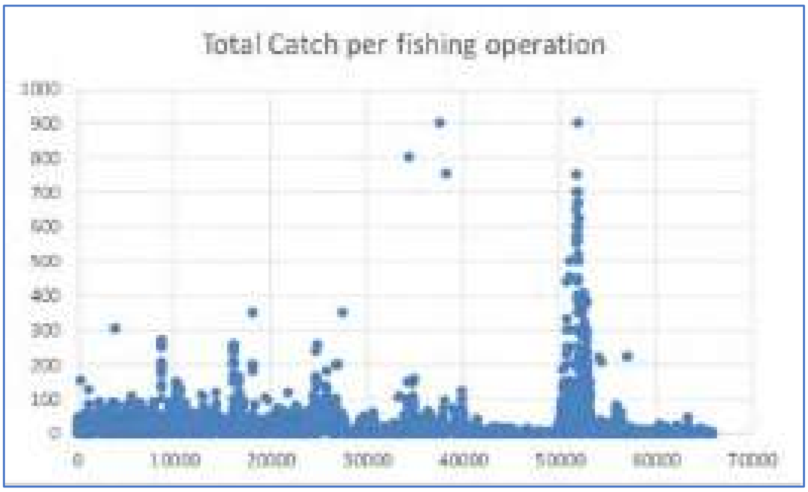


Figure 5-8: Plotting of catch biomass per fishing operation in the combined TSA+FiA FADM data set for Cambodia

Table 5-19: Total catch per fisher and per month with data from TSA monitoring (light blue) and from FiA monitoring (dark blue)

Row Labels	2011	2012	2013	2014	2015	2017	2018	2019	2020	2021
Battambang										
Anlongtaour in Battambang	231.0	553.8	417.0	460.6	377.9	415.4	396.9	165.3	113.1	145.5
Prek Torl in Battambang	129.5	503.0	500.4	407.9	357.4	501.2	659.1	246.9	88.3	149.0
Kandal										
Sang Var in Kandal						218.6	211.3	170.1	168.1	49.0
Kompong Chhnang										
Chhnok Tru in Kompong Chhnang	87.5	353.0	308.2	326.3	232.2	359.8	265.1	269.3	179.3	156.3
Kompong Thom										
Neang Sav in Kompong Thom	58.1	495.5	443.0	419.5	400.5					
Peam Bang in Kompong Thom						285.8	670.2	900.2	660.1	992.6
Pich Chikrey in Kompong Thom						537.5	622.0	738.8	559.2	
Kra Tie										
Koh Khne in Kra Tie						63.0	92.2	99.3	83.4	56.1
Pursat										
Ti1 in Pursat	56.5	324.5	290.7	313.7	321.2					
Ti2 in Pursat	172.0	559.5	331.8	342.4	344.8	223.0	415.4	307.9	174.2	93.9
Ti3 in Pursat	46.0	284.7	321.9	374.7	355.4	189.3	299.0	359.3	314.6	
Ratanakiri										
Day Lo in Ratanakiri						80.0	92.7	80.6	69.1	27.1
Fang in Ratanakiri						55.7	93.0	138.0	142.8	65.6
Siem Reap										
Kompong Pluk in Siem Reap						258.6	555.6	815.1	188.4	
Thort Kambot in Siem Reap						461.5	2209.1	1315.2	978.2	
Ti 3 in Siem Reap	60.0	297.3	246.8	196.8	151.2					

Row Labels	2011	2012	2013	2014	2015	2017	2018	2019	2020	2021
Ti 4 in Siem Reap	30.8	95.7	81.3	285.1	245.6					
Ti 5 in Siem Reap	105.0	181.7	330.5	305.1	240.1					
Stung Treng										
Ou Run in Stung Treng						101.9	114.8	93.1	83.5	53.3
Pres Bang in Stung Treng						60.5	50.0	34.2	26.7	29.4

In conclusion, the following should be noted:

- The FADM dataset in Cambodia is still composed of multiple discrete databases that need to be harmonized and put together into one single matrix if large-scale analyses are to be done;
- that process will require i) the harmonization of site names and ii) the standardization of gear names into standardized categories (needed in particular for the calculation of CPUEs), as well as iii) name cleaning and taxonomic updating (old and updated names cannot coexist in different files for the same species);
- catch analyses needs integrate the variability in sampling effort (from 1 to 3 fishers and from 8 to 12 months a year depending on sites)
- maximal data quality combining long-term monitoring and large number of fishers per site is achieved in 5 sites: Day Lo in Ratanakiri, Koh Khne in Kra Tie, Ou Run and Pres Bang in Stung Treng, and Sang Var in Kandal
- Six sites require attention because of a monitoring getting discontinued or reduced in 2021: Chhnok Tru in Kompong Chhnang, Pich Chikrey in Kampong Thom, Ti3 in Pursat, Kompong Pluk and Thort Kambot in Siem Reap and Pres Bang in Stung Treng;
- importantly, the unit of total catch needs to be clarified and standardized between all sources of records before analyses can be performed on a large scale.

5.9 Monitoring information shared by HPP developers

As part of JEM, a request was made by the MRC to the operators of Xayaburi and Don Sahong for the monitoring data listed below. The results were requested to allow comparison of the JEM results and to provide a longer time-series and context for the results collected during the JEM pilot studies. The data requested is specified in Annex 5.

At the EGEM meeting in June 2021 the operator of the Don Sahong HPP provided some general inforatmion and at the data sharing workshop in October 2021, provided hydrologic and water quality monitoring results. Subsequent to the data sharing workshop, both operators have submitted monitoring results to the MRCS.

5.9.1 Xayaburi

5.9.1.1 Hydrology information shared by Xayaburi

The operator of Xayaburi provided a table of hourly flow data for 1/ January 2019 to 16 September 2021 for Luang Prabang, Xayabuir HPP inflow and Xayaburi HPP outflow, although the exact location of the monitoring sites was not provided. ***Figure 5-9*** shows compares inflow and outflow from

Xayaburi in the 2020-2021 dry season and during the 2020 wet season. The results show that outflow from the station shows frequent flow changes as compared to the inflow, under most conditions.

Figure 5-9. Hourly inflow to and outflow from the Xayaburi Hydropower station during the dry season (top) and wet season (bottom) based on hourly flow data. Data provided by the operator of Xayaburi.

The hourly flow results have been analysed to quantify the hourly changes in flow entering the impoundment and discharged from the station (***Figure 5-10***). Hourly flow fluctuations entering the impoundment are within the range of ±50 m^3/s 99% of the time. Downstream of the station, flow changes are within this range about 70% of the time, with larger changes occurring about 30% of the time.

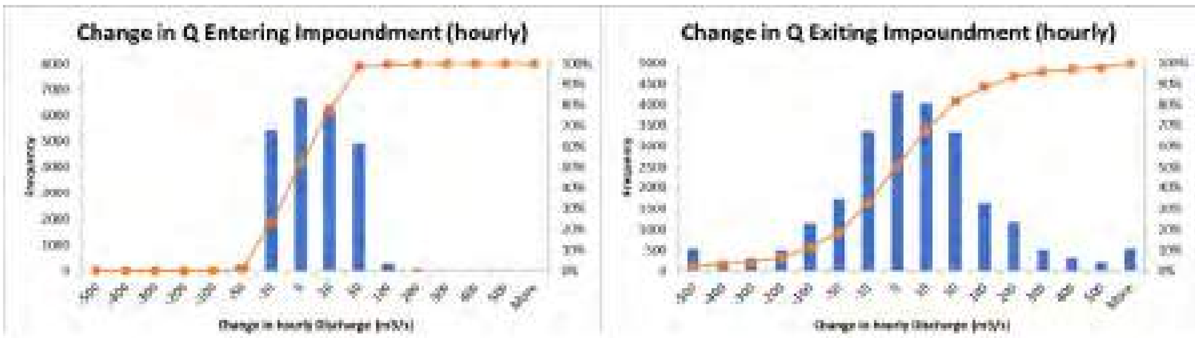


Figure 5-10. (left) Hourly changes in flow rate entering the impoundment and (right) discharged from the Xayaburi HPP. Data provided by the operator of Xayaburi.

Using the same hourly results to calculate flow changes over 4 hours (***Figure 5-11***) shows that inflow rates of change are within ±50 m^3/s about 77% of the time, whereas the outflow is within this range less than half (46%) of the time. These changes in flow rate are consistent with the water level fluctuations recorded at the Ban Pakhoung site.

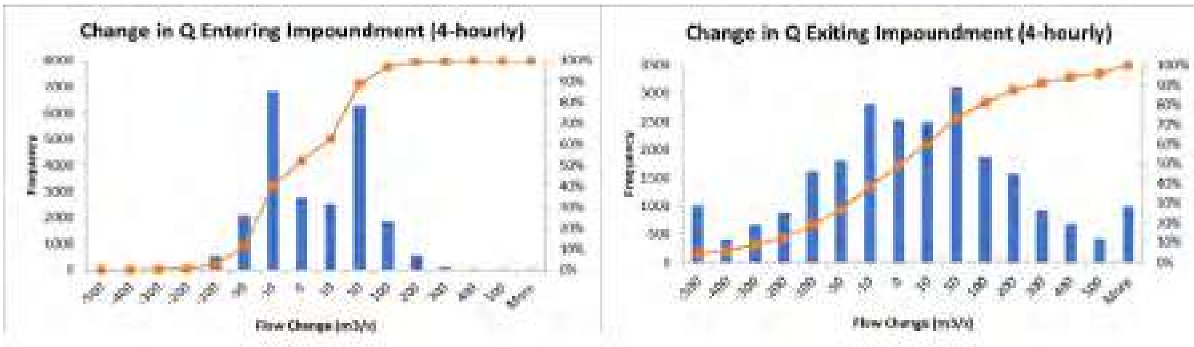


Figure 5-11. (left) Four-hourly changes in flow rate entering the impoundment and (right) discharged from the Xayaburi HPP. Data provided by the operator of Xayaburi.

Comparing the water level results recorded at Ban Pakhoung with the discharge results provided by the operator of Xayaburi (*Figure 5-12*) shows there is a non-linear relationship between flow and water level over the range of conditions monitored at the site. A flow change of 1,500 to 3,000 m^3/s will increase water levels by 4 m, where as a flow changes of 5,000 to 6,500 m^3/s will only increase levels 1.5 m. This demonstrates that mitigation measures aimed at miniminising water level fluctuations will need to be appropriate to the flow rate of the hydropower station, e.g. different constraints would need to be implemented for different flow ranges.

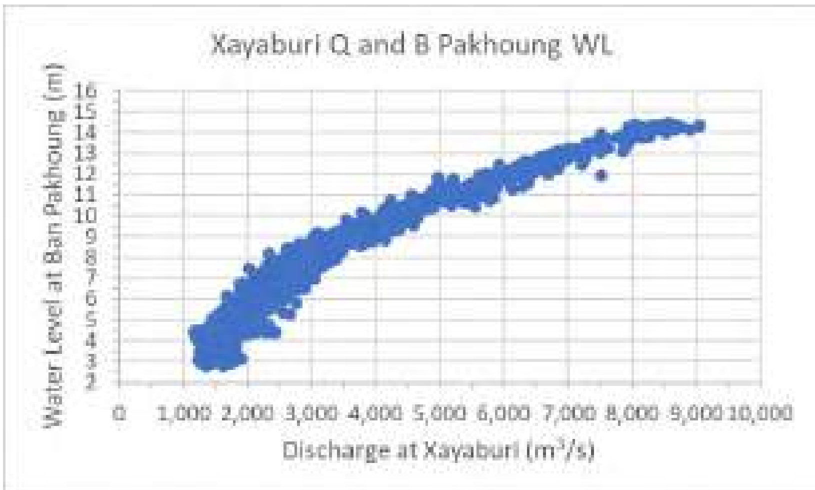


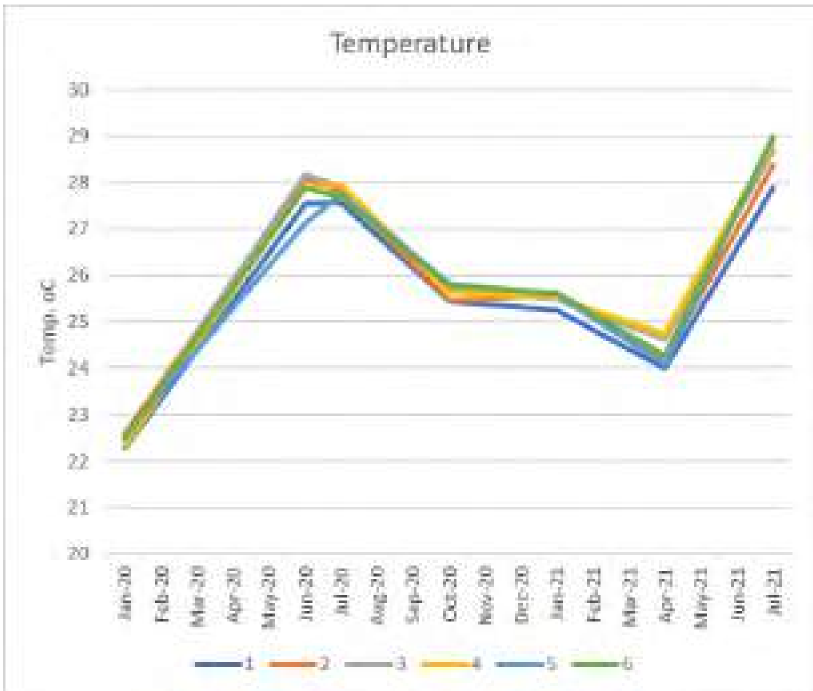
Figure 5-12. Discharge at Xayaburi and water level at Ban Pak Houng for the period November 2020 to August 2021. Discharge data provided by the operators of Xayaburi.

5.9.1.2 Water quality monitoring information

The operators of the Xayaburi HPP take water quality samples every 3 months at a total of six stations at 3 different depths (5, 10 and 15 m). Four of the stations are located within the impoundment and two stations downstream of the dam. Their station 2 is equivalent to WQ2, and threir stations 5 and 6 are equivalent to WQ3 and WQ4. The parameters measured include Temperature, Conductivity, Dissolved Oxygen, pH, NH4-N, NO3_N, TotP, Total Suspended Solids, Total Dissolved Solids, Total Solids, Fecal Coliform, COD.

Examples of the results at 5m are shown in the following charts:

- *Figure 5-13*
    - the variation in Temperature reflects seasonal variation, without distinct pattern between the sampling stations.
    - The variation in pH is between 7.4 and 8.5, with greater variation between the stations during the wet season. The more upstream stations sometimes appear to have lower pH compared to downstream stations.



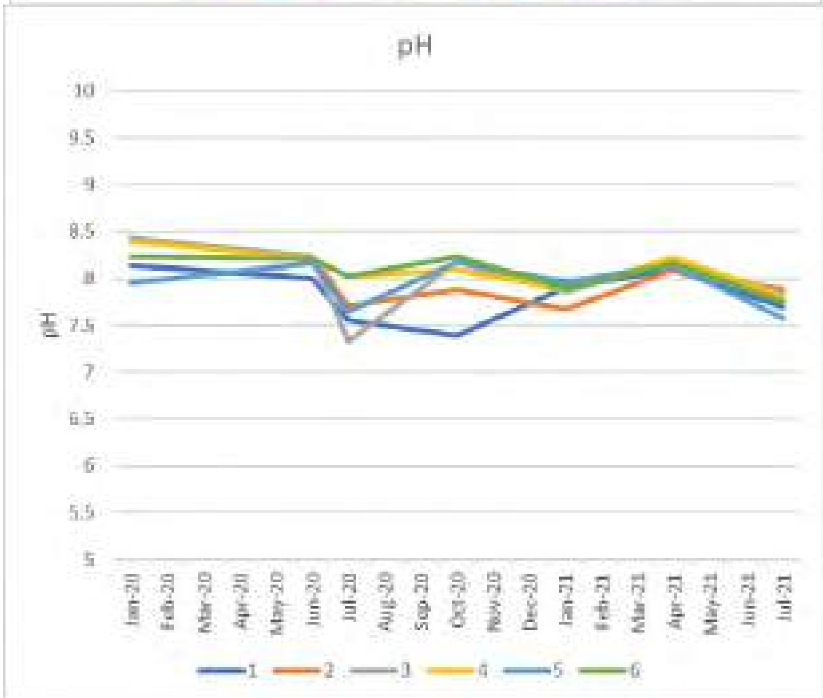
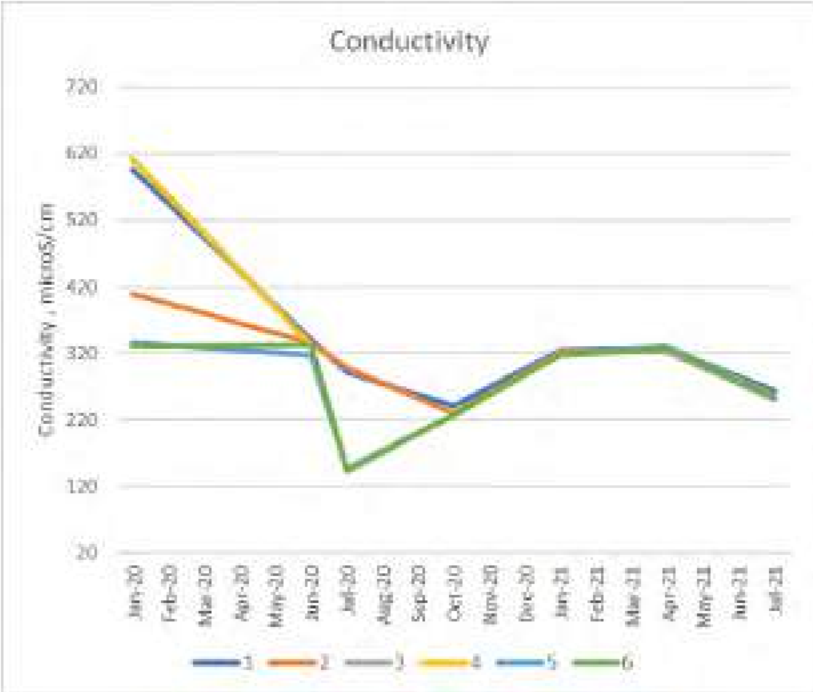


Figure 5-13: Variation in Temperature and pH at the Xayaburi HPP monitoring stations 1 to 6 from Jan 20 to July 21

- *Figure 5-14*
  - the variation in Conductivity appears to show separation between the results in the first two readings, with upstream stations recording higher values of Conductivity compared to downstream, but becoming more consistent during 2020/21.
  - Dissolved Oxygen shows one very low reading in October 2020 at station 1, below the Guideline for Protection of Aquatic Life, but otherwise varying between 6 and 8 mg/l, with downstream stations tending to have slightly higher readings.



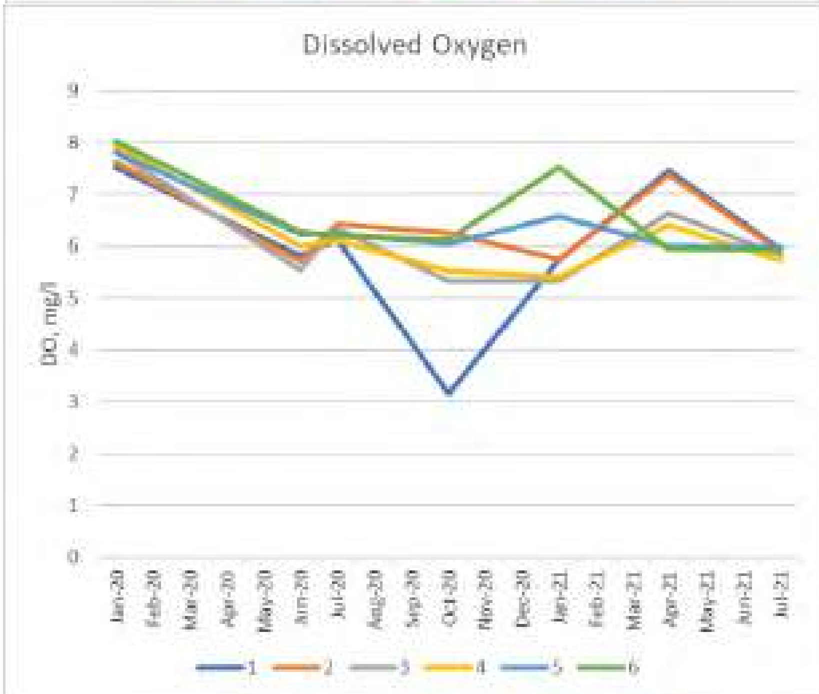


Figure 5-14: Variation in Conductivity and Dissolved Oxygen at the Xayaburi HPP monitoring stations 1 to 6 from Jan 20 to July 21

- ***Figure 5-15***
  - The variation in Total Suspended Solids shows recognisavble seasonal differences with higher TSS in the wet season comnpared to the dry season, and with the station furthest upstream (1) tending to have the highest TSS values, and the two downstream staions tending to have lower TSS values. This is to be expected with settlement of TSS in the impoundment.
  - Chemical Oxygen Demand shows some very high values up to 25 mg/l in June 2020, which is well above the Guideline for Protection of Human Health (5mg/l), with other dates showing around the threshold or lower, with no pattern between the stations. This indicates a significant pollution event in June 2020, unlikely to have been caused by the hydropower project.

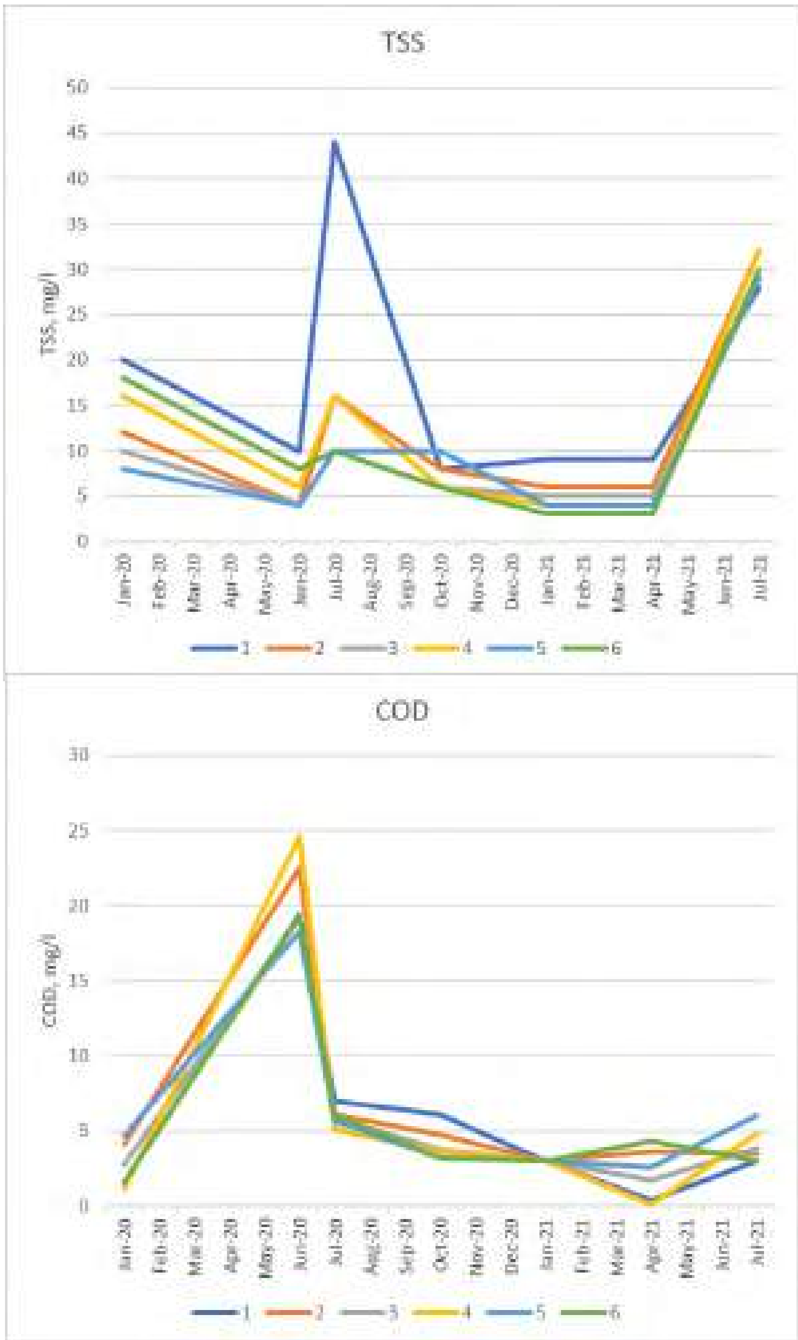


Figure 5-15: Variation in TSS and COD at the Xayaburi HPP monitoring stations 1 to 6 from Jan 20 to July 21

- *Figure 5-16 – nutrients*
    - There are some gaps in the nitrate results and variation between both dates and stations. The readings for nitrate are well above the Guideline threshold levels for protection of Human Health of 0.5 mg/l, and above the JEM results.
    - The TotP monitoring has been discontinued since October 2020, but recorded some high phophorus values within the impoundment, and all are well above the Guideline threshold values of 0.13 mg/l, agaimn higher than most of the JEM results.

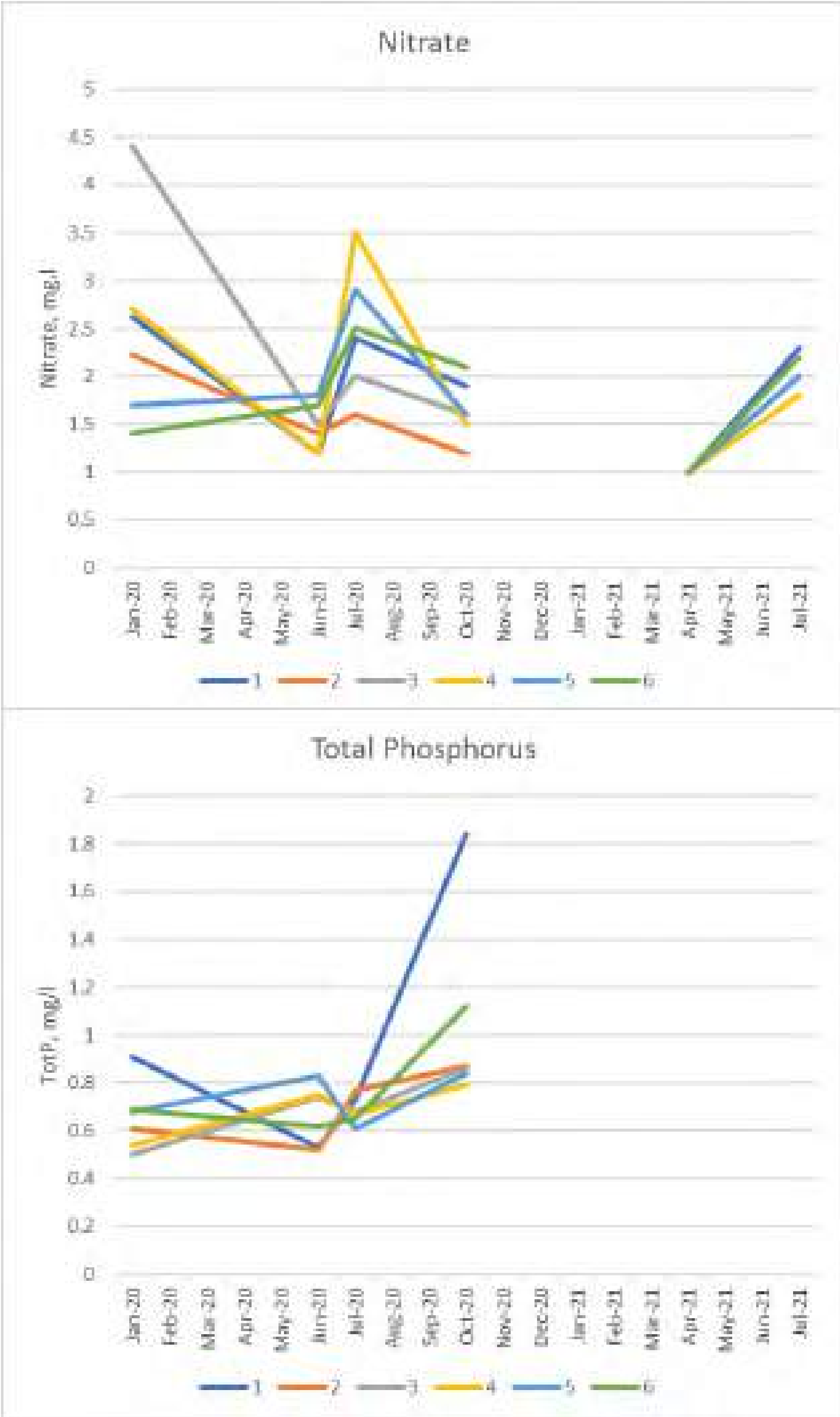


Figure 5-16: Variation in Nitrate and Total Phosphorus at the Xayaburi HPP monitoring stations 1 to 6 from Jan 20 to July 21

5.9.2 Don Sahong

5.9.2.1 Hydrology information shared by Don Sahong

The operators of the Don Sahong HPP provide daily water level, discharge and power generation information for the period 1 January 2020 to 4 October 2021. Water level information was provided for Dan Tan (AR1), Thakho (AR2), Hang Khone Nyuak (AR3), AR4, AR5, Upstream of the Powerhouse and at the Tailrace (*Figure 5-17*).

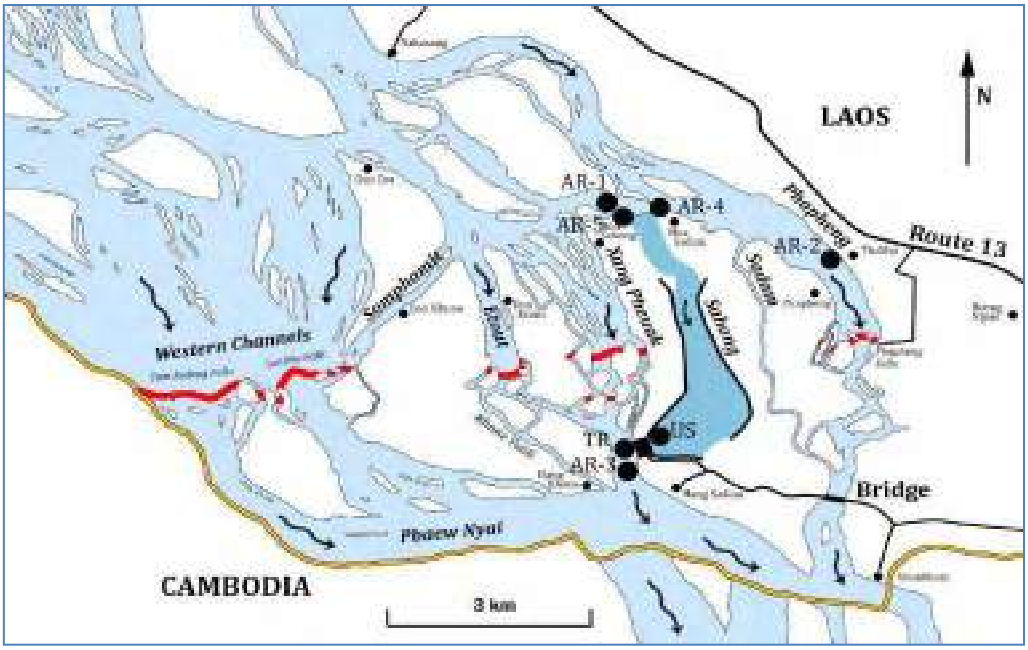


Figure 5-17. DSHPP monitoring locations for water level. Map provided by DSHPP.

The water level results (*Figure 5-18*) show occasional spikes at the upstream of Powerhouse site and in the tailrace, but overall the flow patterns are similar to those recorded at Pakse (*Figure 5-19*). The results provided by the operator also show that the water level in the tailrace does not correlate with the discharge from the powerhouse, or energy production (*Figure 5-20*), suggesting the discharge from DSHP has little impact on local water levels.

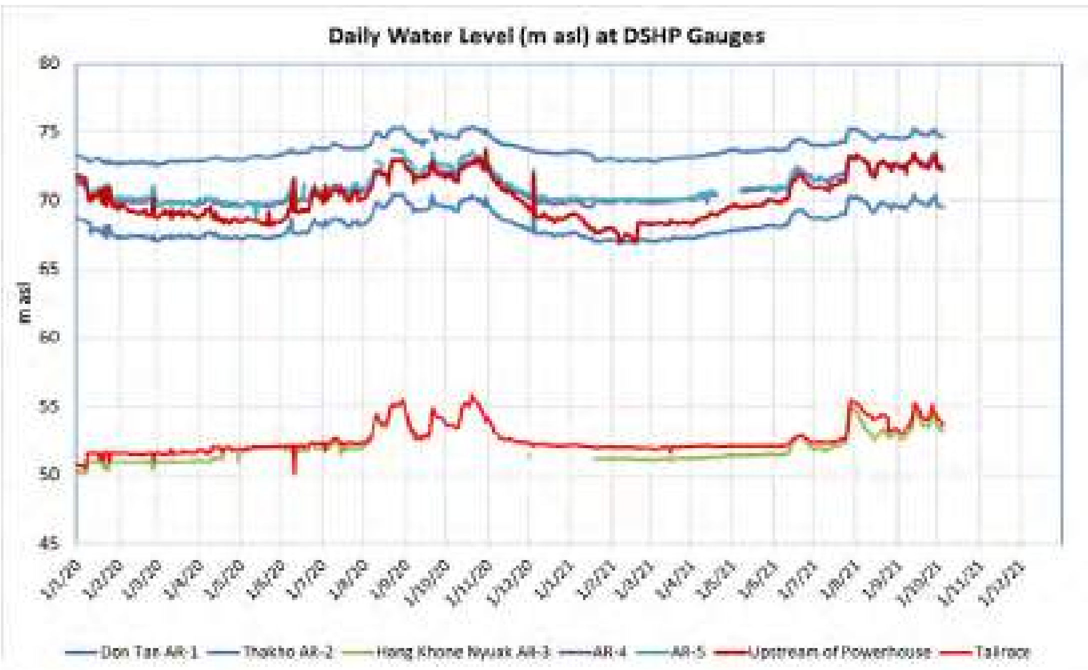


Figure 5-18. Water level results at the DSHP monitoring sites. Data provided by the operator of DSHP.

During the dry season, the diversion of flow into the hydropower impoundment results in low flow rates at Thakho (AR2). The DSHP was proposed to operate such that flow at Thako exceeded 800 m^3/s throughout the year, but this has not occurred. This has implications for the functioning of bypass channels that have been modified to promote fish passage, and is discussed in the Final JEM Report in more detail.

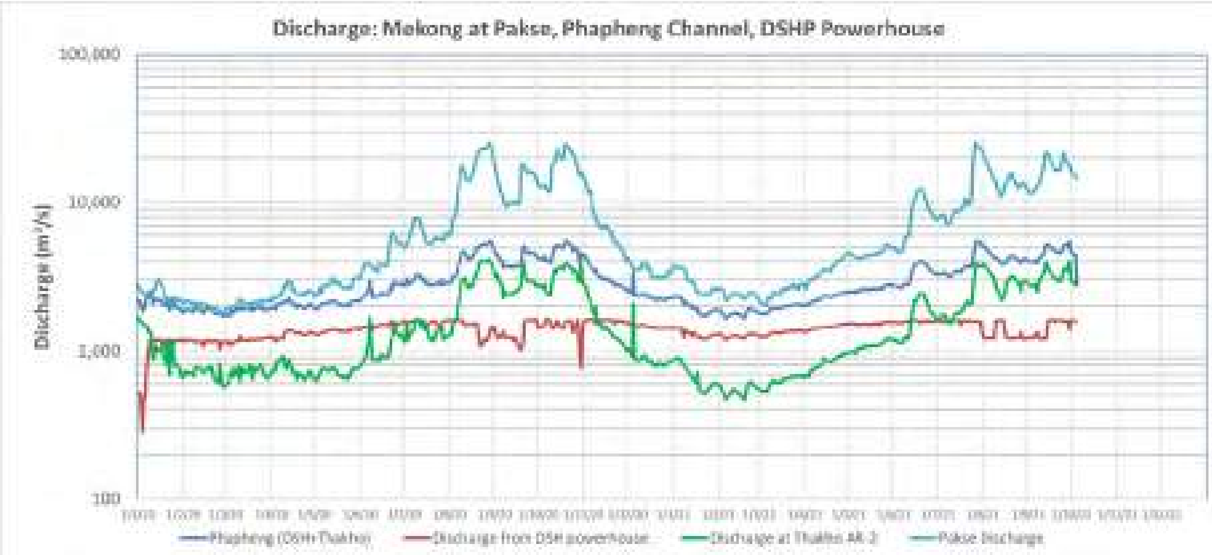


Figure 5-19. Discharge at Pakse, Phapheng, Thakho and the DSH Powerhouse as reported by the operators of DSHP. Note log scale.

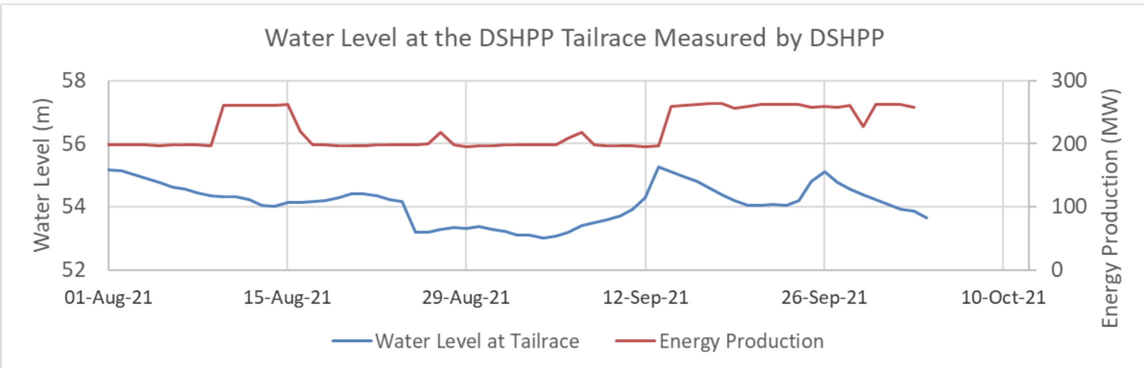


Figure 5-20. Comparison of energy production at DSHP and water level in the tailrace. Data provided by the operator of the DSHP.

5.9.2.2 Water quality monitoring information

The Don Sahong HPP monitors water quality on a weekly basis at four locations shown in *Figure 5-21*. The first three are very similar to WQ6, WQ7 and WQ8, while the fourth is located downstream of the Khone Phapheng channel. They sample the water with a probe at about 30 cm below the surface measuring Temperature, pH, Conductivity, Dissolved Oxygen, Turbidity and Oxidation Reduction Potential (ORP).

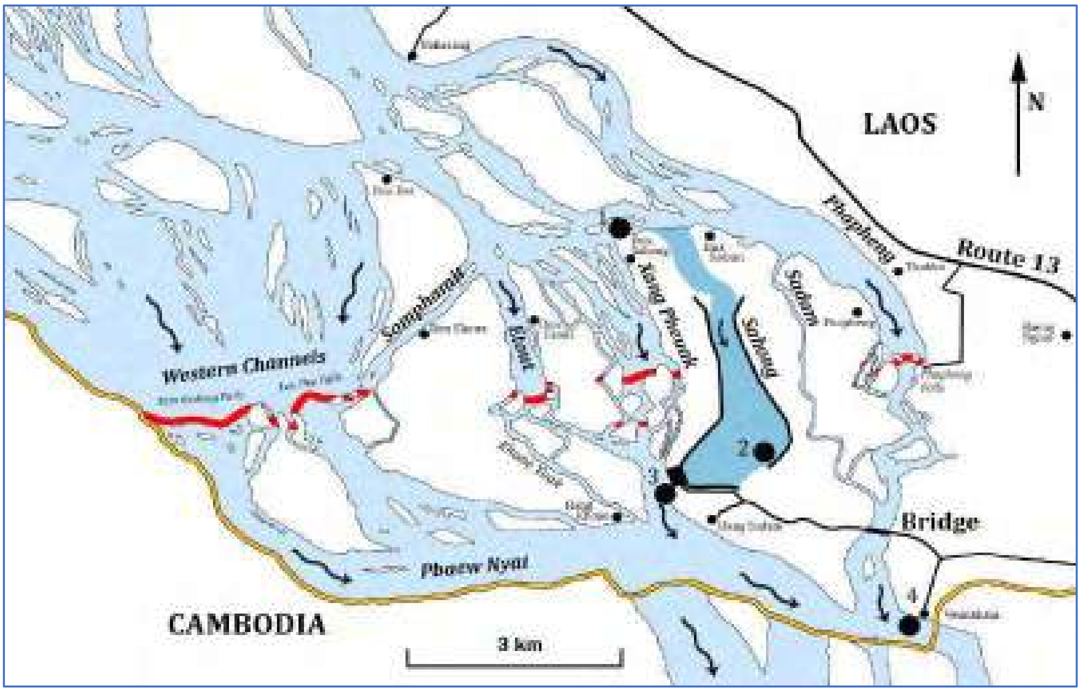


Figure 5-21: Water Quality monitoring locations carried out by Don Sahong HPP

Results from this monitoring were presented at the regional data sharing workshop in October 2021. Overall the water quality varies little during flow through the DSHP headpond, as expected from its small size and short residence time of 3-4 hours. There are some obvious seasonal changes in Temperature, Conductivity and turbidity. Oxygen concentrations are apparently higher downstream of Phapheng Waterfall than at the other 3 sites. In broad terms, the results are very comparable to the JEM Water Quality monitoring presented in section 4.2.

Looking in detail by parameter, the following observations can be drawn:

- The Temperature sequence is shown in *Figure 5-22*. The seasonal variation is as expected with no consistent difference between the sites.
- *Figure 5-23* shows the variation in pH which shows no consistent difference between the sites, though some seasonal variation may be discerned.
- *Figure 5-24* shows the weekly variation in electrical Conductivity which can be correlated with Total Dissolved Solids (TDS); seasonal effects are apparent, but with no consistent pattern between sites.
- *Figure 5-25* shows the Dissolved Oxygen concentrations. Sites 1 to 3 rather similar with some variation, though site 2 in the impoundment tends to be slightly lower than the sites above and below the dam. Site 4 generally has higher DO - downstream of Phapheng Waterfall, where DO is supersaturated.
- *Figure 5-26* shows the Turbidity readings. All sites seem rather similar, with a strong seasonal effect from wet-season TSS.

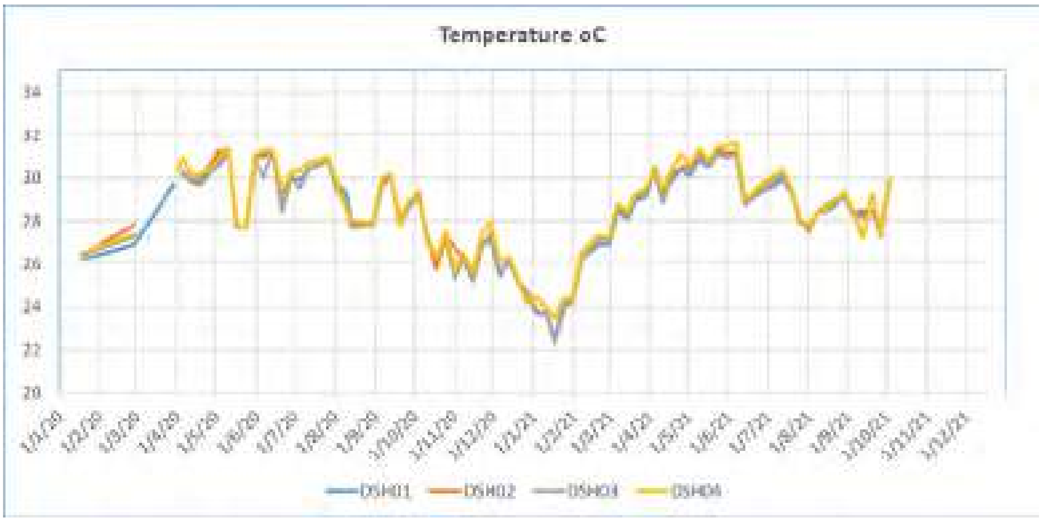


Figure 5-22: Don Sahong weekly measurements of Temperature

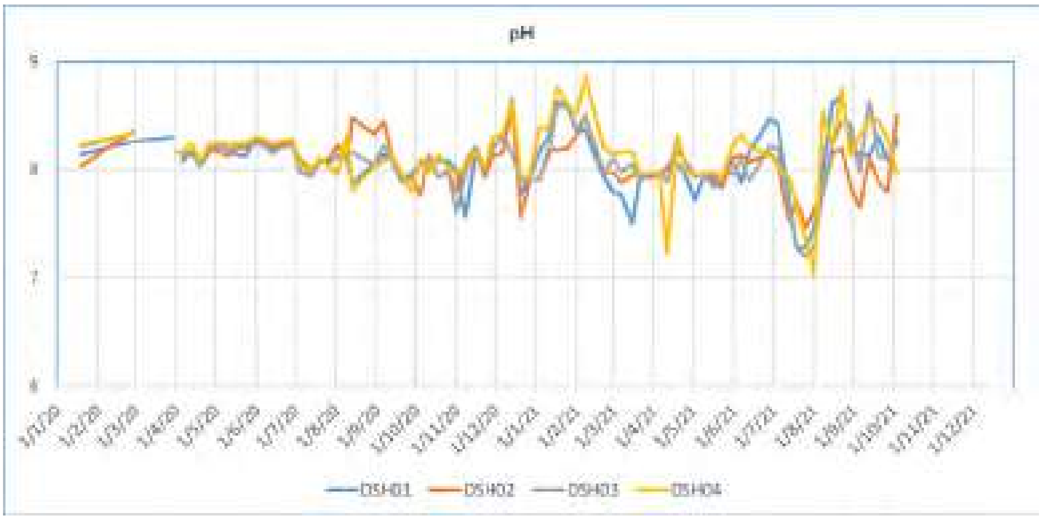


Figure 5-23: Don Sahong weekly measurements of pH

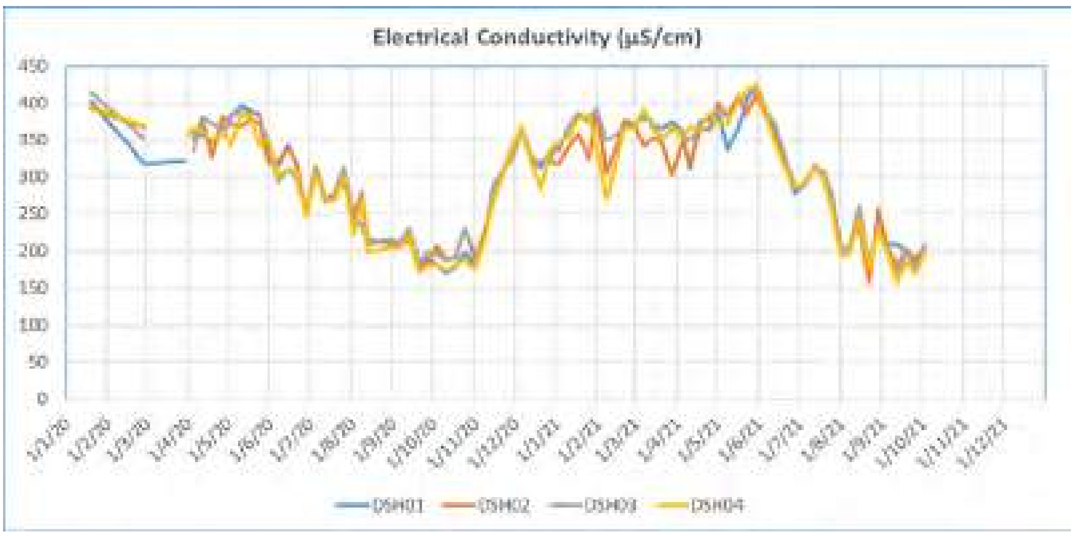


Figure 5-24: Don Sahong weekly measurements of Electrical Conductivity

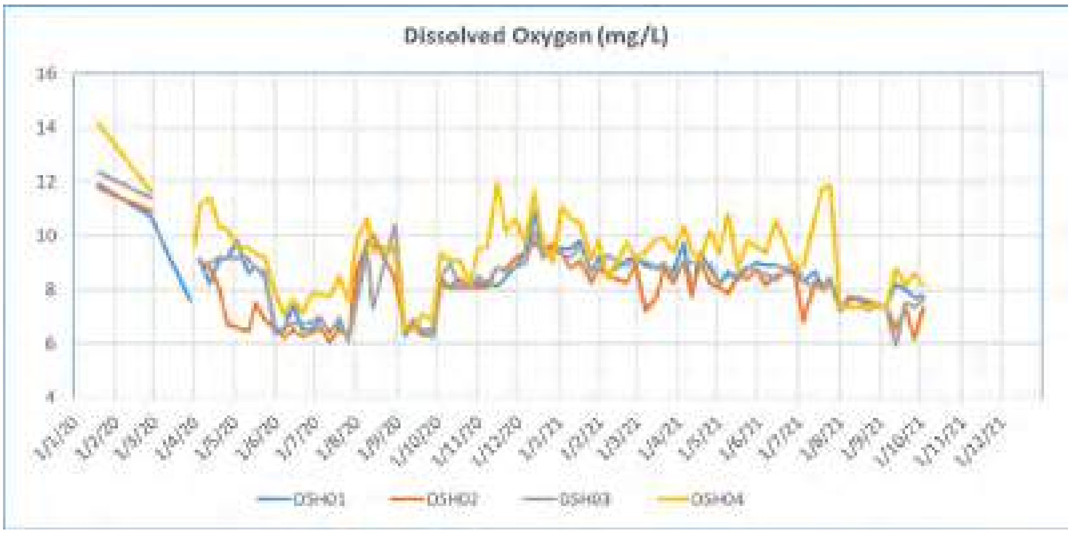


Figure 5-25: Don Sahong weekly measurements of Dissolved Oxygen

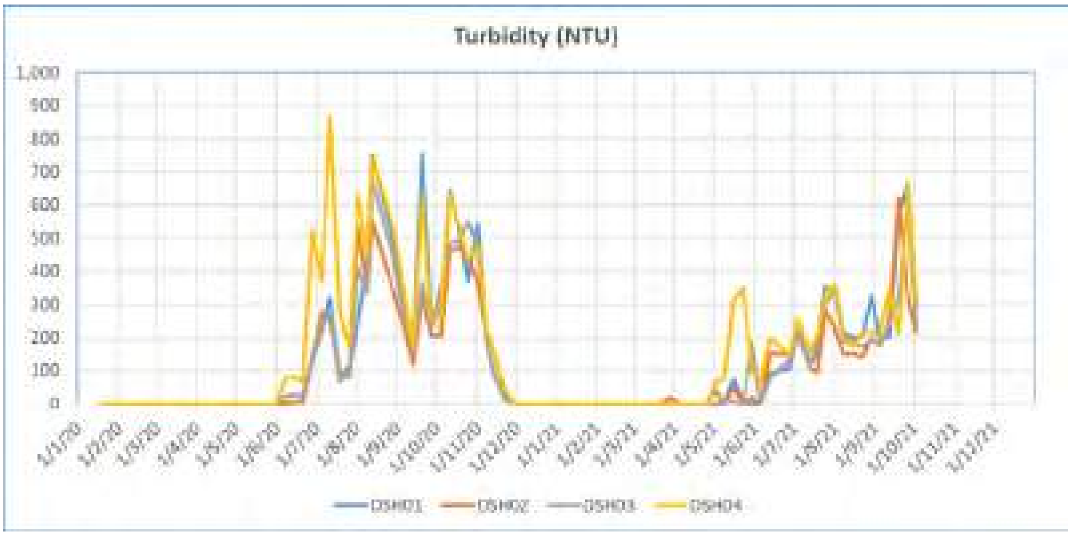


Figure 5-26: Don Sahong weekly measurements of Turbidity

6 COMBINED JEM AND ROUTINE MONITORING RESULTS

6.1 Hydrology

The basin wide review focuses on two areas of the LMB – Chiang Saen to Nong Khai, and Pakse to Kratie. The first area captures flow and sediment characteristics associated with input from China and changes associate with the Lancang cascade, tributary dams, Xayaburi and other water resource projects in Northern Thailand and Northern Lao PDR. The second area shows the net impact of mainstream and tributary dams within the LMB, what is occurring locally around Don Sahong and shows the flow and sediment patterns and loads entering the Cambodian floodplain. Observations are made about changes occurring between these two areas (e.g. Nong Khai to Pakse) at a general level.

6.1.1 Discharge

Hydrographs for DSM sites in the northern area (***Figure 6-1*** to ***Figure 6-3***) and southern area (***Figure 6-4***, ***Figure 6-5***) show flow during the July 2020 to Jun 2021 JEM monitoring year, and over the previous six years (2015 – 2021). In both areas of the Mekong, the highest flows during the monitoring year occurred in August 2020, and the hydrology of the monitoring period was similar to 2019, with both the 2019 and 2020 being dry years compared to the past five years.

In the northern region, the results in ***Figure 6-1*** show generally higher discharge at Chiang Khan as compared to Nong Khai. This should not be the case as Nong Khai is further downstream, and there are tributary inflows between the sites. As previously recommended, the established rating relationships within the LMB should be reviewed. In the upper LMB there are large additional flow inputs between Chiang Saen and Chiang Khan and Nong Khai during the flood season, whereas during the dry season, flows are similar at all sites. This is consistent with the long term understanding of the hydrology of the river with glacial/snow melt in China contributing a majority of flow during the dry season (MRC , 2004). Average monthly flow at Chiang Saen varied from 1,119 m^3/s in February 2021 to 2,821 m^3/s in August 2020. This range is considerably lower than the historic flow range reported by the MRC (2004), with average monthly flow ranging from 830 m^3/s in February to 6,480 m3/s in August based on 1960 to 2004 data. The 2020 – 2021 range of average monthly flow rates was 1,700 m3/s, only about 25% of the previously reported range (6,480 m^3/s).

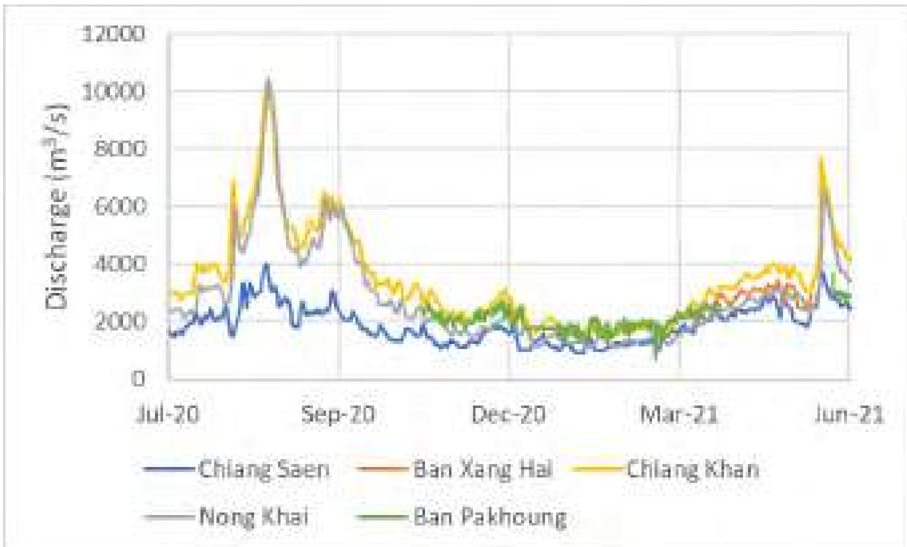


Figure 6-1. Hydrographs from DSM and JEM sites for July 2020 – June 2021. Ban Xang Hai and Ban Pakhoung results estimated based on the provisional rating curves.

An enlargement of the time period for which there are flow estimates for Ban Xang Hai and Ban Pakhoung (***Figure 6-2***) shows good agreement between the sites and Chiang Khan. Ban Pakhoung has substantial flow fluctuations that are not present at the other sites. The maximum hourly increase in flow at Ban Pakhoung is estimated at 183m^3/s/hr. Water level fluctuations associated with these flow changes are discussed in Section 6.1.3.

Figure 6-2. Comparison of discharge at Ban Xang Hai, Ban Pakhoung and Chiang Khan.

Note: Discharge at Ban Xang Hai and Ban Pakhoung based on estimated provisional rating relationships.

Compared to previous six years, the 2020 to 2021 year was drier than all except 2019. In 2020 there was a slightly wetter flood season at Chiang Khan as compared to 2019, when there was little increase in flow during the wet season, but overall 2020 was a very dry year.

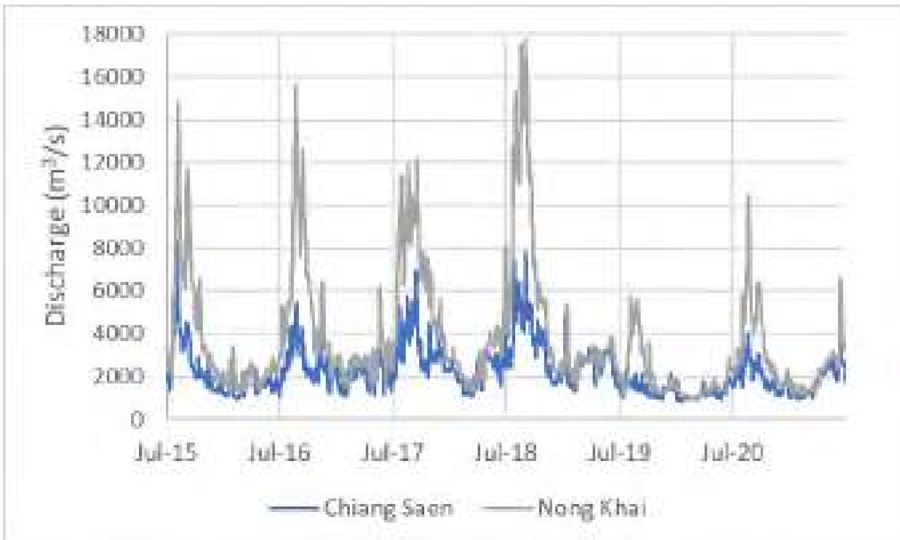


Figure 6-3. Hydrographs from Chiang Saen and Nong Khai July 2015 to Jun 2021 showing annual variability.

Hydrographs comparing flow at Pakse and Stung Treng to Chiang Saen and Nong Khai (***Figure 6-4***) show there was a large influx of water between Nong Khai and Pakse during the wet season, with smaller inputs during the dry season. There was an additional flood peak in October 2020 at the lower sites, which is not present in the upper LMB, and attributable to the NE monsoon delivering rainfall to the lower LMB (MRC, 2005). At Pakse, the average annual discharge ranged from 2,094 m^3/s in February 2021 to 27,809 in August 2020. The low flows are similar to historic values of 2,220 m^3/s in February, but the recorded high flows are lower than the historic average monthly flow of 36,700 m^3/s in September (MRC, 2005). The reduction in high flows is likely attributable to both reduced precipitation and the storage of water within impoundments.

Flow in the lower area during the 2020 to 2021 JEM monitoring year was lower than the previous four years, but similar to 2015 (***Figure 6-5***).

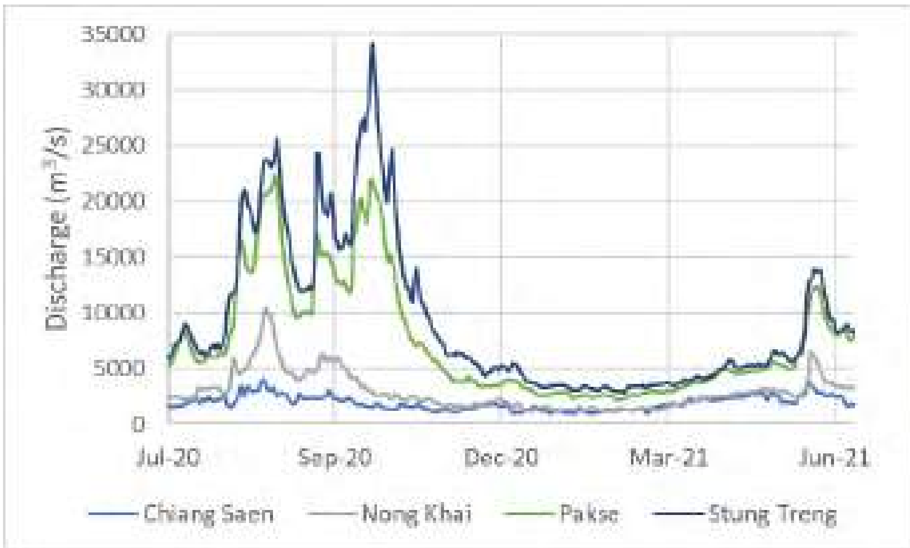


Figure 6-4. Hydrographs for Chiang Saen, Nong Khai, Pakse and Stung Treng, July 2020 - June 2021.

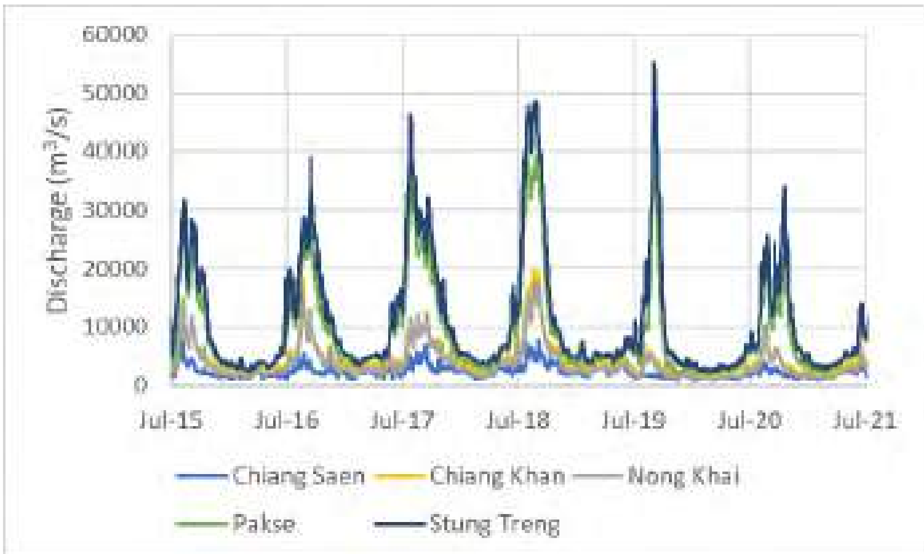


Figure 6-5. Hydrographs from sites in the upper and lower LMB July 2015 to Jun 2021 showing annual variability.

6.1.2 PMFM at Chiang Saen and Vientiane

The Procedures for the Maintenance of Flows on the Mainstream (PMFM) include flood and dry season targets for flow at Chiang Saen, upstream of the JEM monitoring sites, and at Vientiane, Pakse and Stung Treng. The results for the flood and dry seasons encompassing July 2020 to July 2021 are shown for these sites in ***Figure 6-6*** to ***Figure 6-9***. The 2021 flood season to date is included in the graphs for comparison.

The flood season flows in 2020 and so far in 2021 are all within the PMFM Flood Season Zone 1, defined as flows below the ARI (Annual Return Interval) of 1:2. For 2020 to 2021 dry season, water level fell within Dry Season Zone 4, defined as below the 1:20 ARI, at Vientiane in early December. Flow increased at Vientiane to Zones 3 and 2 in late December and early January, and after mid-January flow was consistently within or above Zone 1. At the other three sites, there were short periods when flow decreased to Zone2 or Zone 3 levels and at Pakse dipped into Zone 4 for one day. Otherwise, flows have generally been well above the Zone 1 threshold. The pattern of dry season flows deviates substantially from the shape of the long-term average flow rates, and is now much 'flatter' as compared to historic conditions. This is consistent with greater flows being released via mainstream hydropower projects in China and tributaries in the Mekong.

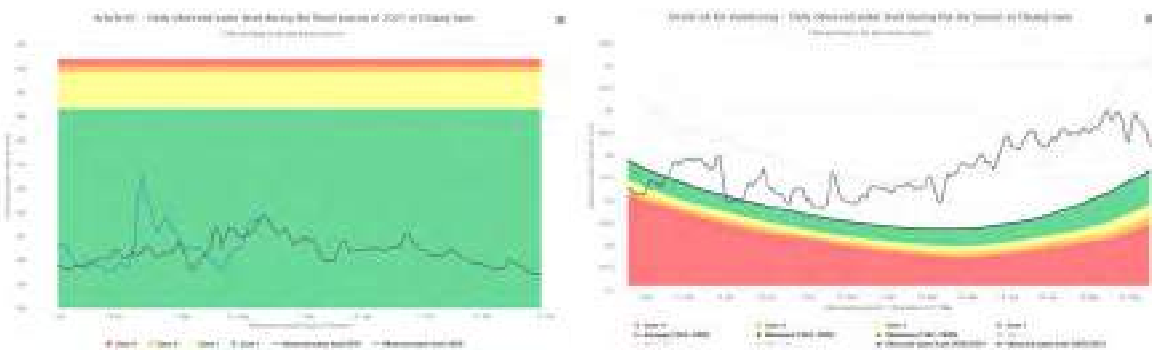


Figure 6-6. Comparison of water level at Chiang Saen to the PMFM criteria for the (left) flood seasons in 2020 and 2021 and (right) dry season in 2020 to 2021

Source: https://pmfm.mrcmekong.org/

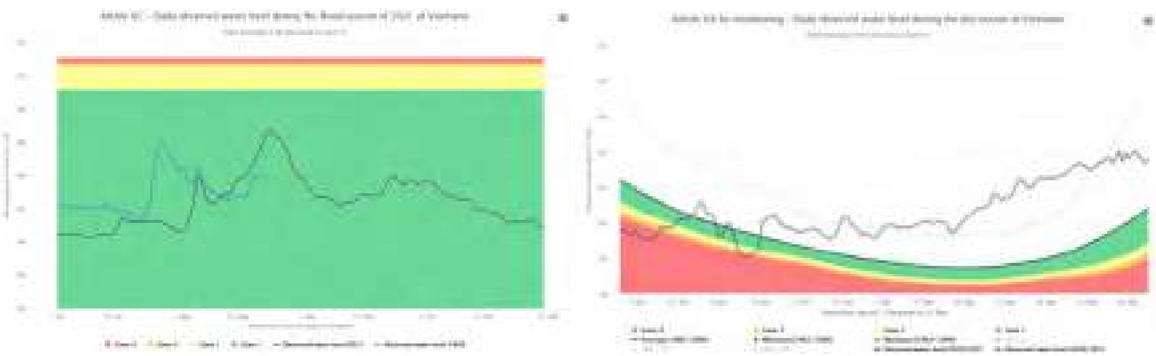


Figure 6-7. Comparison of water level at Vientiane to the PMFM criteria for the (left) flood seasons in 2020 and 2021 and (right) dry season in 2020 to 2021

Source: https://pmfm.mrcmekong.org/

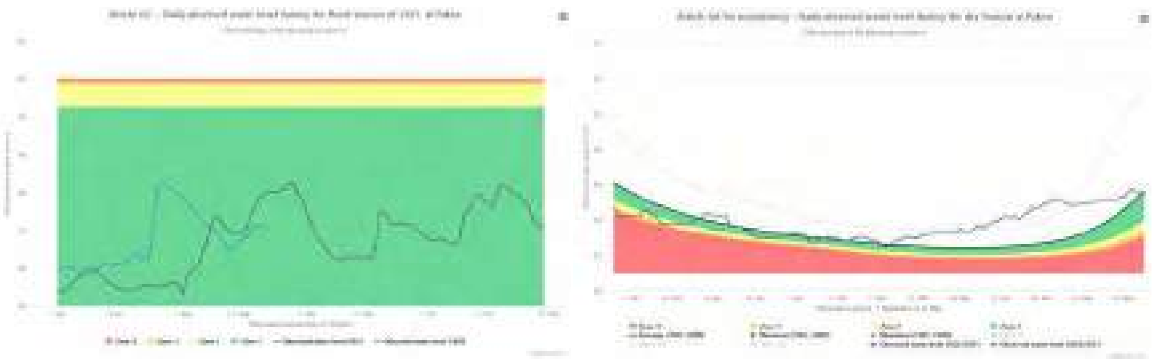


Figure 6-8. Comparison of water level at Pakse to the PMFM criteria for the (left) flood seasons in 2020 and 2021 and (right) dry season in 2020 to 2021

Source: https://pmfm.mrcmekong.org/

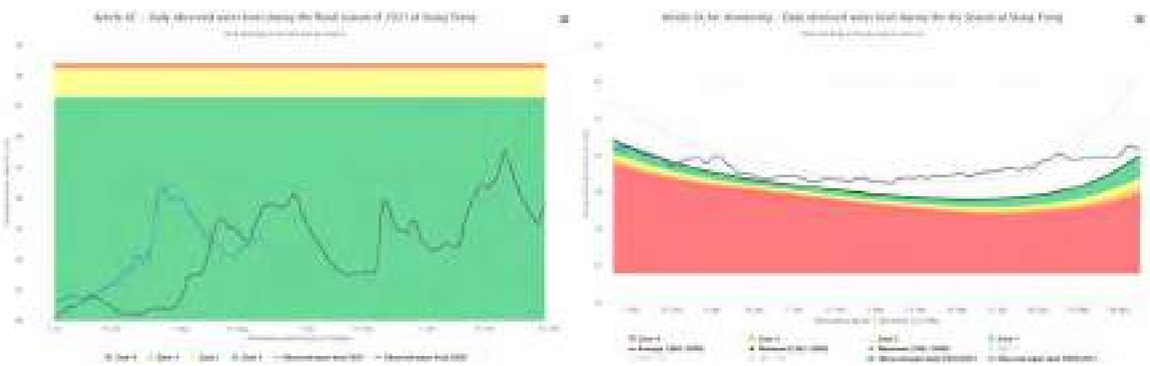


Figure 6-9. Comparison of water level at Stung Treng to the PMFM criteria for the (left) flood seasons in 2020 and 2021 and (right) dry season in 2020 to 2021

Source: https://pmfm.mrcmekong.org/

6.1.3 Water level fluctuations associated with hydropower operations

A benefit of hydropower is that generation can be rapidly changed to meet market conditions. The impact of this energy flexibility is to create rapid water level fluctuations downstream of hydropower projects. Water level fluctuations are deleterious to river systems as they can increase the rate of bank erosion and can have negative impacts on the aquatic ecosystem (MRC, 2020). The MRC Hydropower Mitigation Guidelines (2020) recommend maximum hourly water level changes do not exceed 0.05 m/hr.

Short-duration water level fluctuations are present in the 15-minute water level record at Ban Pakhoung (*Figure 6-10*). The water level changes have been statistically analysed to quantify the distribution of rates of change, with the maximum, 90th, 80th, 50th, 20th and 10th percentile rates of change determined (*Table 6-1*). The same analysis has been completed based on hourly rates of change (*Table 6-2*). In both Tables, rates that exceed the MRC Hydropower Guideline of 0.05 m/hr are highlighted. For the 15-minute data set, the threshold value of 0.0125 m/15-minute, equivalent to 0.05 m/hr was used.

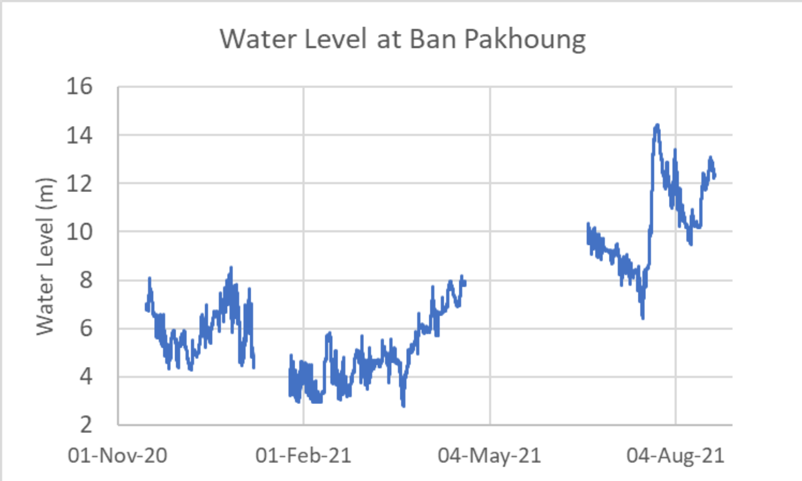


Figure 6-10. Continuous (15-minute) water level record for Ban Pakhoung at HYCOS site. Data from MRC database.

The 15-minute results show that the MRC (2020) guideline value of 0.05 m/hr is exceeded almost 40% of the time, with most of the 80th and 20th percentile values exceeding the threshold. The results also show that the magnitude of maximum monthly increase exceeds the maximum rates of decrease, suggesting either the recession rate in the river is naturally slower than the increase, or that power generation is decreased at a lower rate than it is increased. The 90th and 80th percentile values are similar in magnitude to the 10th and 20th percentile values, respectively.

Table 6-1. Water level change at Ban Pakhoung based on 15-minute water level data.

Month	n=	Max Increase	90th %tile	80th %tile	Median	20th %tile	10th %tile	Max Decrease
Nov	1533	0.337	0.026	0.009	-0.002	-0.016	-0.029	-0.149
Dec	2975	0.280	0.033	0.016	0.000	-0.015	-0.034	-0.198
Jan	1246	0.271	0.052	0.029	0.000	-0.032	-0.058	-0.233
Feb	2688	0.358	0.025	0.011	0.000	-0.011	-0.028	-0.161
Mar	2974	0.251	0.031	0.016	0.000	-0.017	-0.031	-0.207
Apr	1995	0.201	0.031	0.018	-0.001	-0.018	-0.028	-0.17
Jun	916	0.692	0.026	0.012	-0.001	-0.015	-0.027	-0.472
Jul	2976	0.249	0.028	0.014	0.000	-0.013	-0.025	-0.183
Aug	2147	0.562	0.028	0.014	-0.001	-0.015	-0.030	-0.318

Note: Shaded cells show values that exceed the MRC Hydropower Guideline of 0.05 m/hr, equivalent to 0.0125 m/15-min. n indicates how many measurements are available for the month. All values in m/15 minute.

Source: Data from MRC database

The same analysis using hourly rates of change shows that the maximum increase, 90th, 10th and maximum decrease rates of change exceed the 0.05 m/hr threshold for all months except April 2021, but the 80th and 20th percentile values are below the threshold, except in January 2021. This demonstrates that many of the rapid changes detected in the 15-minute data were limited in duration to <1 hour.

In both data sets, the maximum rates of water level change occurred during the flood season, rather than the dry season when hydropeaking commonly occurs. These high flow water level changes are discussed in the next section.

Table 6-2. Water level change at Ban Pakhoung based hourly water level data.

Month	n=	Max Change	90th Percentile	80th Percentile	Median	20th Percentile	10th Percentile	Max Decrease
Nov 20	1530	0.717	0.085	0.032	-0.004	-0.048	-0.105	-0.427
Dec	2975	0.491	0.107	0.049	0.000	-0.040	-0.114	-0.571
Jan 21	1243	0.703	0.189	0.101	0.001	-0.102	-0.197	-0.661
Feb	2688	0.647	0.090	0.039	0.001	-0.034	-0.100	-0.488
Mar	2971	0.490	0.080	0.040	0.001	-0.036	-0.081	-0.447
Apr	1995	0.500	0.055	0.031	-0.001	-0.027	-0.049	-0.399
Jun	913	0.662	0.071	0.037	0.001	-0.040	-0.097	-0.416
Jul	2976	0.744	0.090	0.040	-0.001	-0.038	-0.080	-0.459
Aug	2147	1.016	0.084	0.041	-0.001	-0.039	-0.080	-0.800

Note: Shaded cells show values that exceed the MRC Hydropower Guideline of 0.05 m/hr. n indicates how many measurements are available for the month. All values in m/hr.

Similar analyses for the 15-minute (*Table 6-3*) and hourly (*Table 6-4*) water level changes at Chiang Khan show that fluctuations are substantially smaller at the downstream site.

Table 6-3.Water level change at Chiang Khan based on 15-minute water level data from HYCOS site.

Month	n=	Max Increase	90th %tile	80th %tile	Median	20th %tile	10th %tile	Max Decrease
July 20	2971	0.063	0.004	0.003	0.000	-0.003	-0.004	-0.079
Aug	2976	0.035	0.009	0.005	0.001	-0.004	-0.007	-0.036
Sept	2865	0.074	0.006	0.004	0.000	-0.003	-0.005	-0.04
Oct	2946	0.126	0.010	0.005	-0.001	-0.006	-0.011	-0.135
Nov	2876	0.063	0.007	0.004	0.000	-0.005	-0.008	-0.141
Dec	2973	0.065	0.007	0.004	0.000	-0.004	-0.007	-0.058
Jan 21	2976	0.063	0.014	0.007	0.000	-0.007	-0.015	-0.079
Feb	2687	0.092	0.009	0.004	0.000	-0.003	-0.009	-0.53
Mar	2974	0.209	0.013	0.004	0.000	-0.003	-0.012	-0.15
Apr	2880	0.194	0.014	0.003	0.000	-0.003	-0.015	-0.163
Jun	2974	0.149	0.013	0.005	0.000	-0.006	-0.014	-0.148
Jul	2880	0.153	0.013	0.005	0.000	-0.005	-0.012	-0.142

Note: Shaded cells show values that exceed the MRC Hydropower Guideline of 0.05 m/hr, equivalent to 0.0125 m/15-min. n indicates how many measurements are available for the month. All values in m/15 minute.

Source: Data from MRC Catalogue.

In the 15-minute data set, the maximum increase and maximum decrease values, and some of the 90th and 10th percentile values exceed the ±0.0125 m/15-min threshold, but all other results are within the guideline. The hourly results show that only the maximum increase and maximum increase monthly values exceed the 0.05 m/hr threshold, with the 90th to 10th percentile values falling within the recommended range. Also similar to Ban Pakhoung, most of the highest values occurred within the flood season, rather than the dry season when hydropeaking was prevalent.

Table 6-4. Water level change at Chiang Khan based hourly water level data.

Month	n=	Max Increase	90th %tile	80th %tile	Median	20th %tile	10th %tile	Max Decrease
July 20	2971	0.091	0.010	0.006	0.000	-0.006	-0.011	-0.105
Aug	2976	0.099	0.027	0.017	0.003	-0.015	-0.025	-0.058
Sept	2862	0.103	0.018	0.011	0.000	-0.010	-0.017	-0.081
Oct	2943	0.171	0.016	0.010	-0.003	-0.015	-0.023	-0.234
Nov	2876	0.141	0.015	0.009	-0.001	-0.013	-0.019	-0.171
Dec	2970	0.09	0.014	0.010	0.002	-0.008	-0.014	-0.086
Jan 21	2976	0.081	0.016	0.009	-0.001	-0.013	-0.021	-0.114
Feb	2684	0.127	0.011	0.006	0.001	-0.005	-0.012	-0.653
Mar	2974	0.226	0.017	0.007	0.001	-0.005	-0.017	-0.152
Apr	2880	0.259	0.020	0.010	0.001	-0.007	-0.017	-0.257
Jun	2974	0.19	0.023	0.011	0.000	-0.012	-0.023	-0.18
Jul	2880	0.242	0.030	0.014	-0.002	-0.014	-0.032	-0.238

Note: Shaded cells show values that exceed the MRC Hydropower Guideline of 0.05 m/hr. 'n' indicates how many measurements are available for the month. All values in m/hr.

6.1.4 Water level changes during high flow events

In the hourly data set of water level change, maximum increases occurred in July and August 2021, and are not associated with dry season hydro-peaking, but rather high rainfall and emergency water releases events (***Figure 6-11***). In July, high rainfall associated with tropical storm Cempaka combined with the emergency release of water from the Nam Ou cascade and at Xayaburi led to the flow rates of 8,000 m^3/s downstream of Xayaburi, resulting in a 4 m increase in river level at Ban Pakhoung over a four-day period (Bangkok Post, 2021; MRC, 2021). This event affected the entire upper LMB, as evidenced by the large increase in flow at Chiang Saen. In early August there was another high flow event recorded at Ban Pakhoung and Chiang Khan, but there was no similar increase in water level at Chiang Saen.

Notification of these releases were made in the Laotian Times and were repeated on social media and the foreign press.

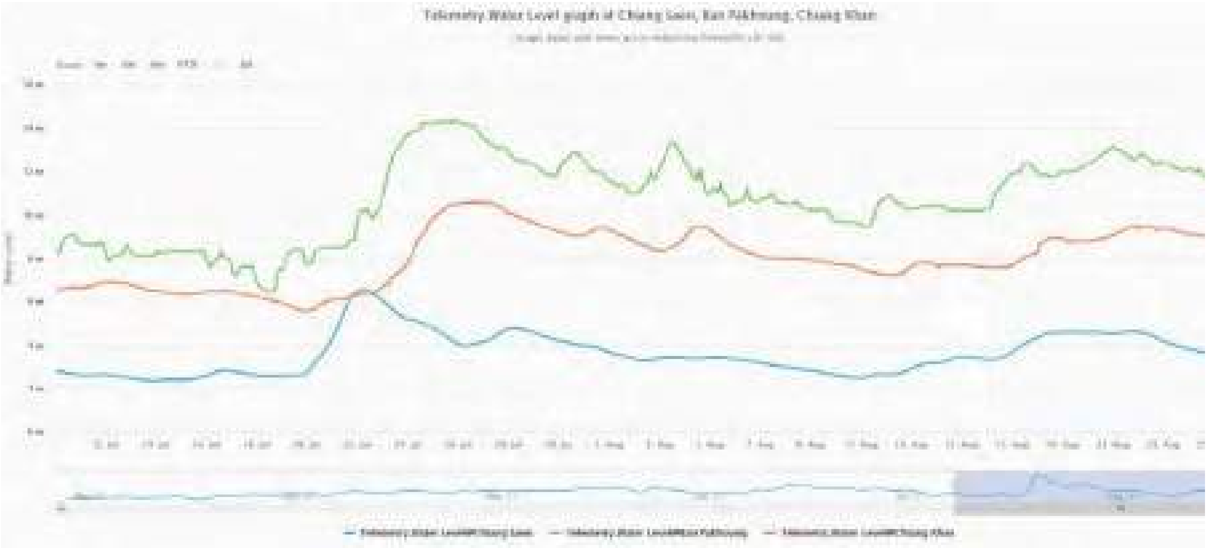


Figure 6-11. Water level at Chiang Saen, Ban Pakhoung and Chiang Khan in July and August 2021.

6.2 Sediment and geomorphology

6.2.1 SSC concentrations at monitoring sites

A time-series of SSC at the monitoring sites shows that SSC concentrations typically range between 10 mg/L and 200 mg/L at the sites, and increase during the wet season (*Figure 6-12*). Concentrations are relatively similar between sites, and do not show a strong increase or decrease with distance downstream. The downstream sites of Stung Treng-Up and Stung Treng show a second SSC peak later in the flood season, consistent with the second peak recorded in the hydrology (*Figure 6-4*).

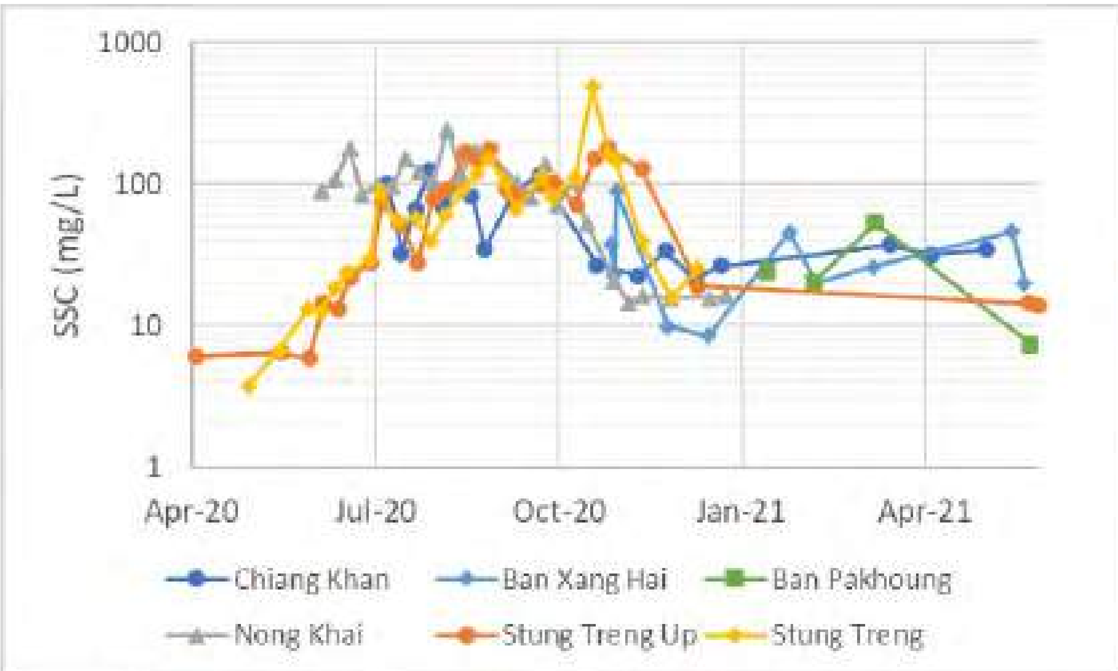


Figure 6-12. SSC concentrations (mg/L)recorded in 2020 by DSM monitoring teams.

The available 2019 and 2020 SSC and flow rates for sites in the upper LMB (Chiang Saen, Luang Prabang, Chiang Khan, Nong Khai) and in the middle LMB (Pakse, Stung Treng-up, Stung Treng) are shown in *Figure 6-13*. The results show in the upper LMB, there is very poor correlation between SSC and flow, whereas in the downstream sites of Stung Treng-UP and Stung Treng, the correlation is stronger. This is consistent with flow alterations and sediment trapping in impoundments causing a disconnect between flow and sediment delivery in the upper LMB. In the lower catchment, inflows retain some seasonality with higher SSC concentrations associated with higher loads. As discussed in 6.2.3, most of the very high SSC concentrations are associated with discrete events, which are likely due to either a large landslip in the catchment, or the opening of low-level gates at a HPP.

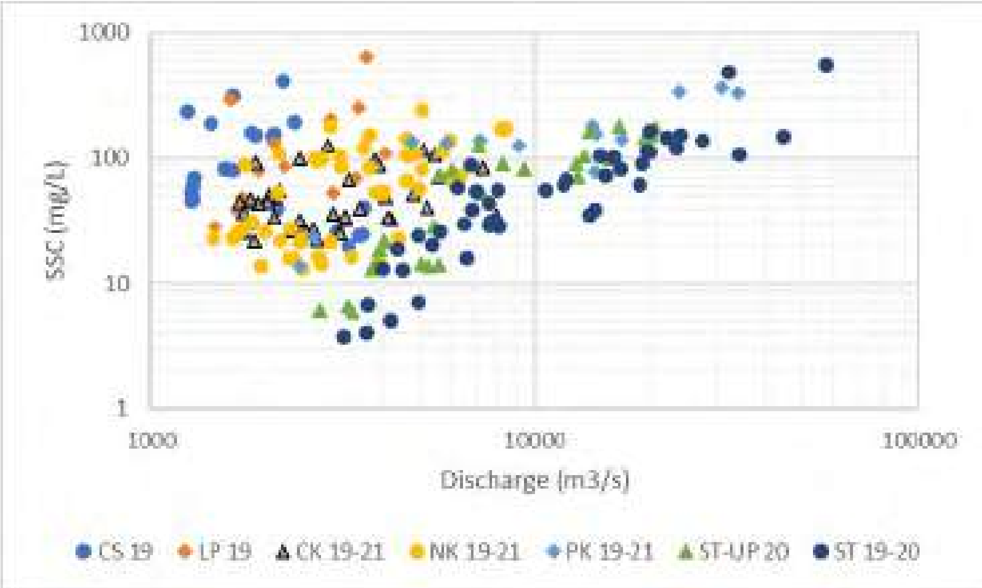


Figure 6-13. SSC (mg/L) and discharge at CS = Chiang Saen, LP = Luang Prabang, CK=Chiang Khan, NK = Nong Khai, PK = Pakse, ST-UP= Stung Treng UP (above 3S confluence), ST = Stung Treng.

6.2.2 SSC sediment loads

The objectives of the JEM include understanding how hydropower development and operations affect the Mekong River at a local scale, and at a regional scale. The SSC and discharge measurements collected by the MCs in 2019 and 2020 have been used to estimate annual sediment transport at select sites between Chiang Saen and Kratie and combined with previous monitoring results to provide a big picture understanding of howe SSC sediment transport varies with distance down the Mekong, and how it has changed over time.

For the 2019 and 2020 results, the SSC and discharge measurements collected during each monitoring run have been combined to derive the SSC sediment load on the monitoring date. An estimate of annual sediment transport has been calculated by interpolating between the monitoring dates. The results are summarised in *Table 6-5* and shown charts in *Figure 6-14* to *Figure 6-17.* The results should be considered as estimates only.

Table 6-5. Estimates of SSC transport (Mt/yr) in the LMB based on discharge and SSC measurements.

Units = Mt/yr	2009	2010	2011	2012	2013	2014	2015	2018	2019	2020
Chiang Saen	14.9	7.3	12.8	9.8	9.1			18.3	3.9	
Luang Prabang	20.3	18.9	22.8	24.8	24.6	15.2	13.8		5.4	
Chiang Khan	14.7	14.1	18.7	18.1	20.5	28.4	24.7	36.7	2.1	4.3

Units = Mt/yr	2009	2010	2011	2012	2013	2014	2015	2018	2019	2020
Nong Khai	11.1	14.3	35.5	16.3	17.0			23.0	2.9	7.3
Pakse	64.0	62.1	70.8	54.1	77.8	61.3	41.8		26.9	
Stung Treng	84.2	48.0	95.9	56.1	99.7	63.3	27.7	76.0	43.2*	29.8*
Kratie	80.7	44.2	98.5	52.0	87.2	76.4	32.6	70.6	30.8	34.3
Sekong Bridge (3S)				8.5				13.6	13.5*	13.6*

Note: Estimates from 2009 – 2018 based on sediment rating curves and / or interpolation. Estimates for 2019 and 2020 based on interpolation. Results collected by hydrology teams in each MC.

*Results may be skewed due to short duration, very high sediment loads recorded at SKB

SSC load for sites in the upper LMB (*Figure 6-14*) show the following characteristics:

- Prior to 2019, sediment loads increased between Chiang Saen and Nong Khai, but results from Luang Prabang and Chiang Khan were frequently higher than recorded at Nong Khai. This may be due to inaccurate rating curves, or the use of undersized equipment at Chiang Khan, or variability during monitoring.
- Prior to 2019, SSC loads at Chiang Saen ranged from about 8 to 18 Mt/yr, and loads at Nong Khai ranged from about 11 to 23 Mt/yr;
- In 2019, loads at all of the sites were the lowest recorded, with loads at Chiang Khan reducing from 37 Mt/yr to about 2 Mt/yr. These reductions are most likely attributable to low loads entering from China, and sediment trapping in tributary dams and in Xayaburi.
- Results for 2020 are not available for Chiang Saen or Luang Prabang. At Chiang Khan and Nong Khai, loads remained extremely low relative to historic values. Some of the reduction is attributable to another dry year in the river, but sediment trapping is undoubtedly an additional contributor to the large scale reduction;
- There is little increase in SSC load between Chiang Khan and Nong Khai, suggesting there is a limited amount of sediment resident in the river channel that is available for transport. In 2019 there was <1 Mt/yr increase between the sites. In 2020, the difference was 3 Mt/yr.

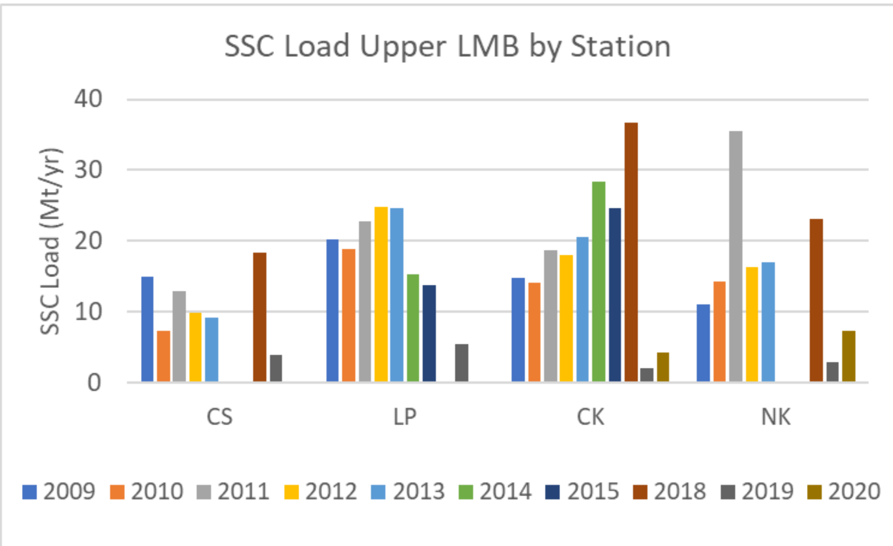


Figure 6-14. Estimated annual SSC loads in the upper LMB 2009 – 2020. CS = Chiang Saen, LP = Luang Prabang, CK = Chiang Khan and NK = Nong Khai. Estimates from 2009 – 2018 based on sediment rating curves and / or interpolation. Estimates for 2019 and 2020 based on interpolation.

SSC results from the middle LMB (*Figure 6-15*) show the following characteristics:

- Compared to the upper LMB, SSC loads increase considerably between Nong Khai and Pakse, with historic loads at Stung Treng and Kratie ranging up to 100 Mt/yr;
- The sites also show recent decreases in SSC load, with the 2015, 2019 and 2020 results all being substantially lower as compared to years. 2018 was a very wet year, which can account for the higher transport rates in this year;
- The 2019 and 2020 results from Stung Treng and Kratie suggest that only 20 to 40 Mt/yr of SSC is entering the Cambodian floodplain;
- The input from the 3S basin (SKB) is estimated at about 13 Mt/yr for the past three years. Closer examination of the SKB record shows that in each year there was a limited period of extremely high sediment input, with SSC concentrations in the range of 700 to 1,300 mg/L, which contributed a large proportion of the total sediment load (See Section 6.2.3) and may reflect the opening of low level gates at the Lower Sesan 2 HPP or at another HPP;
- The contribution from the 3S may be contributing about 30% of the total SSC load entering the Cambodian floodplain. This is a large increase compared to 2012 when the input from the 3S was estimated to contribute about 10% of the SSC load.

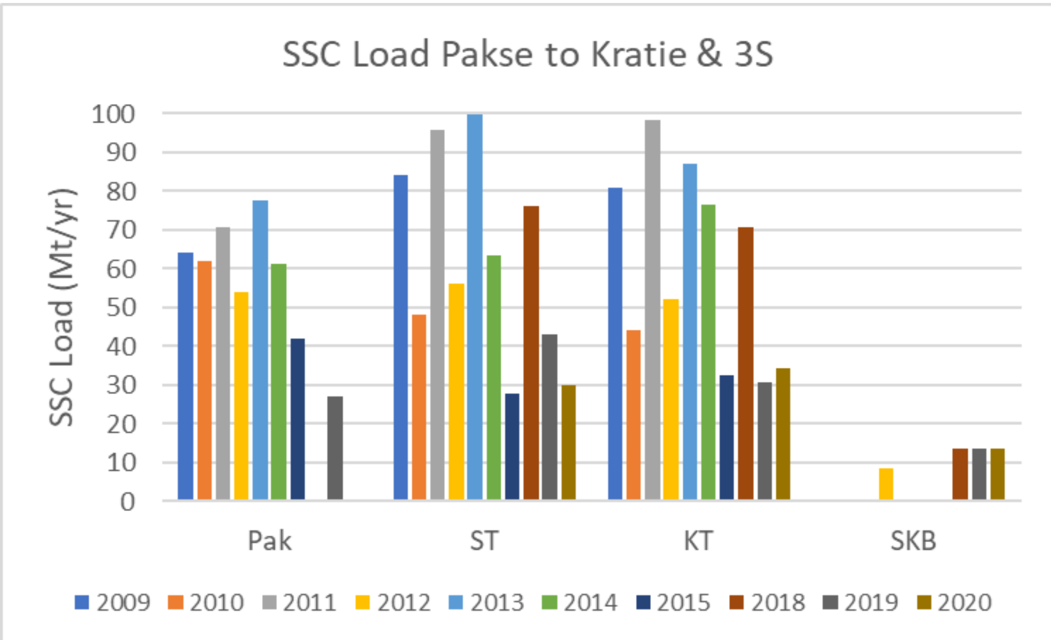


Figure 6-15. Estimated annual SSC loads in the middle LMB 2009 – 2020.

Note: Pak = Pakse, ST = Stung Treng, KT = Kratie, SKB = input from the 3S at Sekong Bridge. Estimates from 2009 – 2018 based on sediment rating curves and / or interpolation. Estimates for 2019 and 2020 based on interpolation.

The combined data set is shown in *Figure 6-16* by site, and in *Figure 6-17* by year. The large increase in sediment input between Nong Khai and Pakse is evident, as is the overall reduction in SSC transport in 2019 and 2020 relative to previous years.

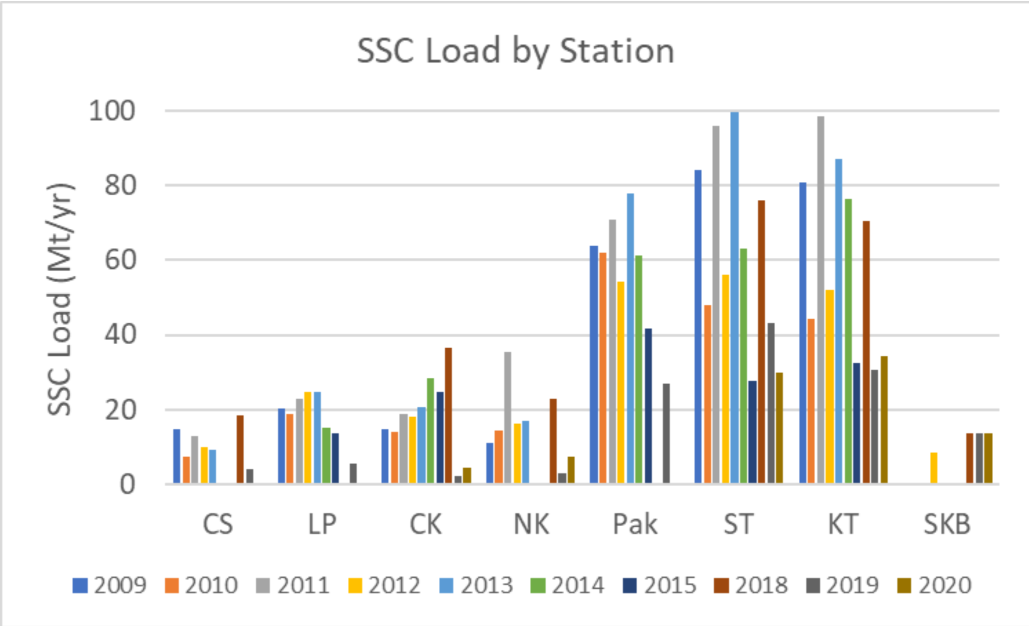


Figure 6-16. SSC load by station at sites shown in Figure 6-14 and Figure 6-15 combined for comparison.

The three wettest years included in the data set were 2011 (Q = 502 km^3), 2018 (Q = 453 km^3, and 2013 (Q = 410 km^3). Comparing the SSC loads for these years (*Figure 6-15*) shows that 2018 had considerably lower loads as compared to the other wet years. This is consistent with increased sediment trapping in upstream dams and possibly the depletion of stored sediment within the river channel.

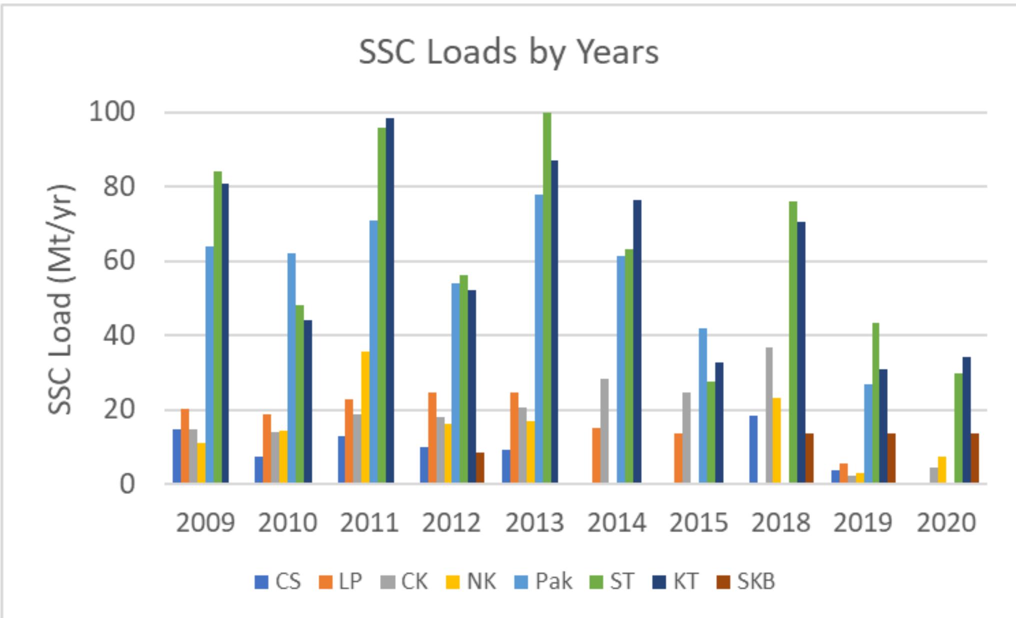


Figure 6-17. SSC load by year for sites shown in Figure 6-16.

6.2.3 Sediment balance at the 3S confluence

The JEM monitoring has provided more detail about the sediment processes occurring around the 3S confluence. The SSC and flow results collected at Stung Treng-UP, the SKB site and at Stung Treng allow derivation of flow and sediment balances for the confluence.

The monitoring results show an excellent flow balance across the three sites, with the combined flow recorded at Stung Treng-Up and SKB equivalent to the flow measured at Stung Treng (*Figure 6-18*). The results show the increased relative inflow from the 3S as the flood season progresses.

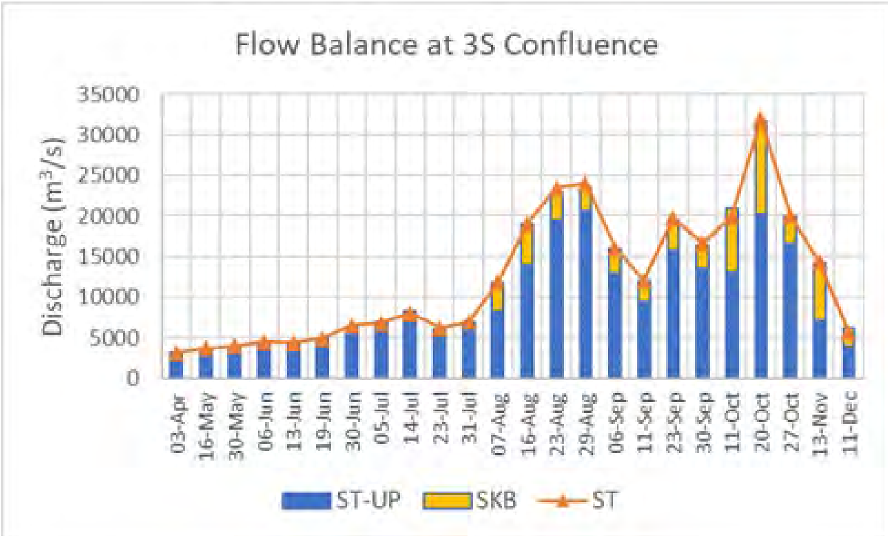


Figure 6-18. Flow balance between Stung Treng-Up, SKB and Stung Treng in 2020.

Source: Results collected by DHRW, Cambodia.

The sediment balance is good, except in October 2020 when sediment input from the 3S is very high (*Figure 6-19*). These conditions result in the uneven distribution of sediment in the river channel at the Stung Treng site, leading to inaccurate measurements and poor agreement. The SSC concentrations recorded at the SKB site in October ranged from 700 to 1300 mg/L, which are far higher than previously recorded at the site. It is probable that these high loads were either the result of a large mass failure within the catchment, or the release of sediment from hydropower projects.

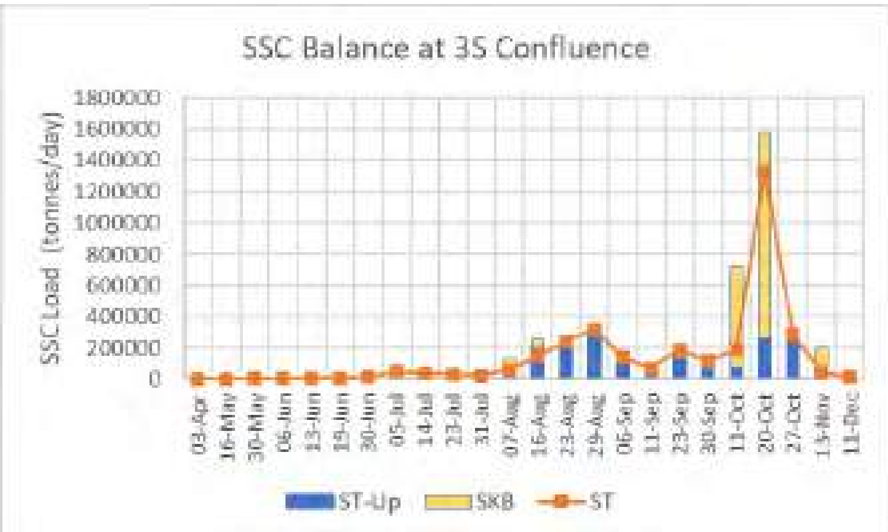


Figure 6-19. SSC load balance between Stung Treng-Up, SKB and Stung Treng in 2020.

Source: Results collected by DHRW, Cambodia.

6.2.4 SSC Grain size distribution entering Cambodian floodplain

The grain-size distribution of SSC at Kratie reflects the material that enters the Cambodian floodplain. This is the material that may be stored on floodplains, be transported into the Tonle Sap during the flow reversal, and that enters and replenishes the Vietnamese delta. The relative proportions of the different size fractions by percent and proportionate to the SSC load are shown in *Figure 6-20* and *Figure 6-21*, respectively. Coarse silt contributes the largest proportion to the SSC load, with fine and very fine sand the next most abundant. Based on the estimated SSC load of 34.3 Mt/yr and the average percent grain-size distribution, there were 17.5 Mt of coarse silt, 6 Mt of very fine sand and 5.5 Mt of fine sand delivered to the lower LMB in 2020, with the remaining 6 Mt of SSC divided between fine silt/clay and medium sand. These are very low delivery rates compared to estimates of sand extraction occurring within Cambodia and Vietnam (Bravard et al., 2013, Jordan et al, 2019).

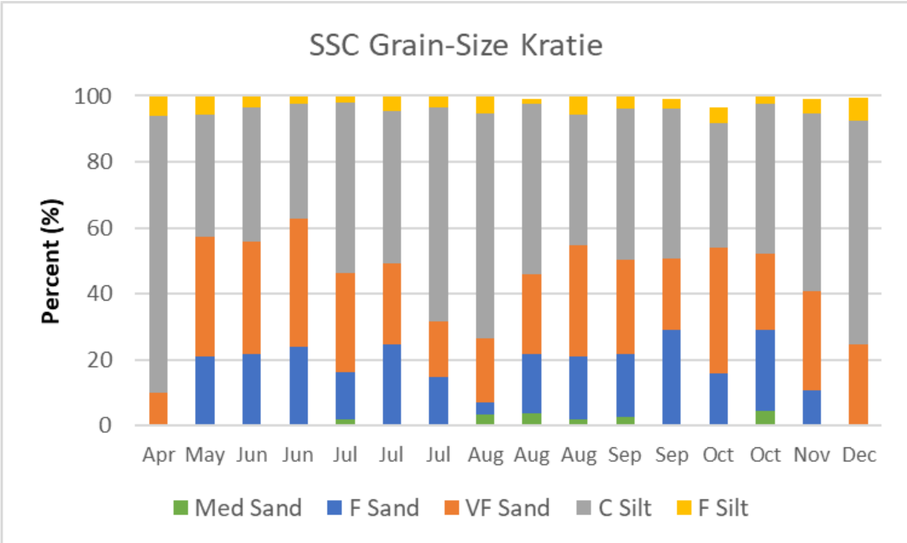


Figure 6-20. Grain-size distribution of SSC collected at Kratie in 2020.

Source: Samples and results completed by DHRW.

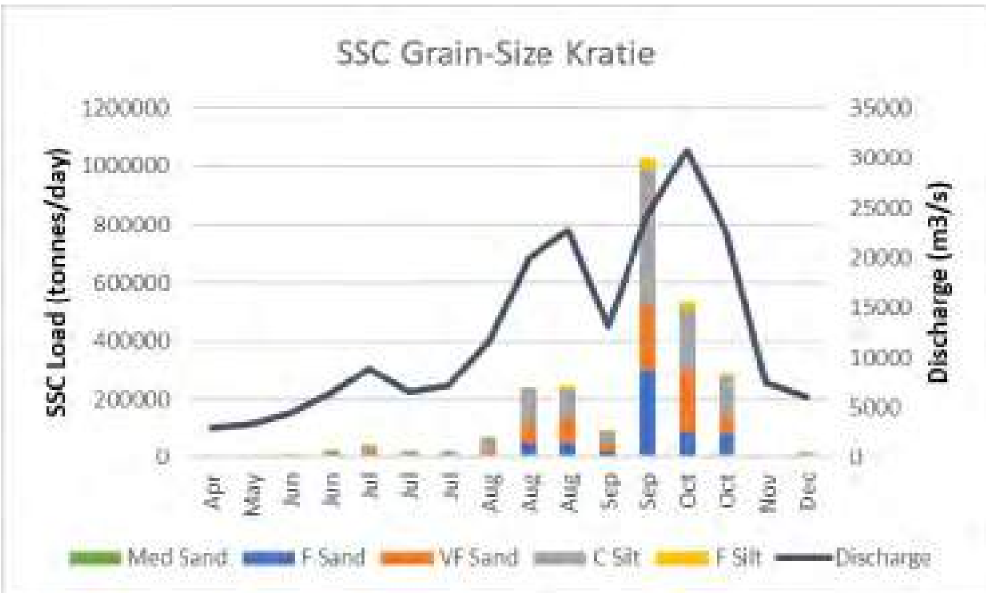


Figure 6-21. Grain-size distribution by sediment load at Kratie. Discharge shown on secondary axis.

6.2.5 Bed material Grain-size distribution

Bed material grain-size distribution results are available for Chiang Saen, Ban Xang Hai, Ban Pkahoung, Nong Khai, Pakse and Stung Treng UP (*Figure 6-22*).

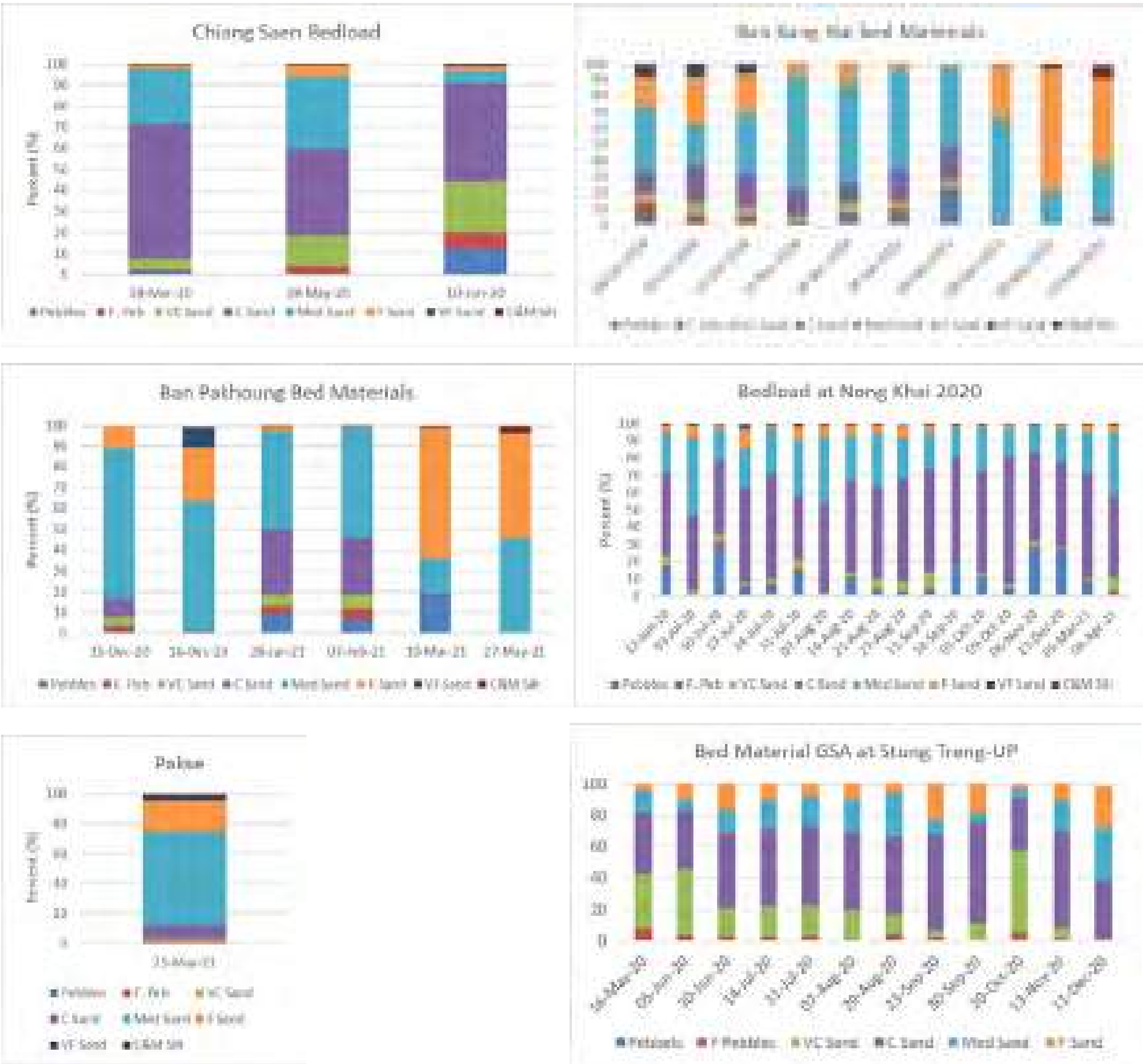


Figure 6-22. Bed material or bedload (Chiang Saen, Nong Khai) grain-size distribution collected in 2020 and 2021.

The results show the following characteristics:

- Chiang Saen has the coarsest bed material, with coarse and very coarse sand comprising the majority of the samples. This may reflect the higher slope and stream energy in the upper river resulting in a coarser bed due to the winnowing of fine material;
- At Ban Xang Hai between October 2020 and February 2021 relatively coarse material was present in the channel, along with medium and fine sand. The samples collected in 2021 show a large reduction in the coarser fractions, with an associated increase in fine sand. Ban Pakhoung shows similar trends. The influx of fine material during the dry season could reflect the settling of fine material under conditions of low flow. A longer record is required to understand the variability;
- Bedload at Nong Khai consists of predominantly coarse sand, indicating this size material is still moving through the upper river. During the wet season there are higher percentages of very coarse sand, with the occasional presence of gravels;

- The one recent sample available at Pakse shows that medium and fine-sand comprise the majority of the sample. This suggests a fining of the bed material grain-size between Nong Khai and Pakse, but more samples are required to better identify trends;
- Stung Treng-Up shows higher percentages of very coarse sand as compared to the upstream sites, suggesting that the bedrock controlled, steep Siphandone area in Lao PDR is a contributor of coarse sand to the river system.

Overall, the results show that the bed and bedload materials in the LMB are considerably coarser as compared to the SSC load, and that bedload is the predominant transport pathway for sand and coarser material in the river.

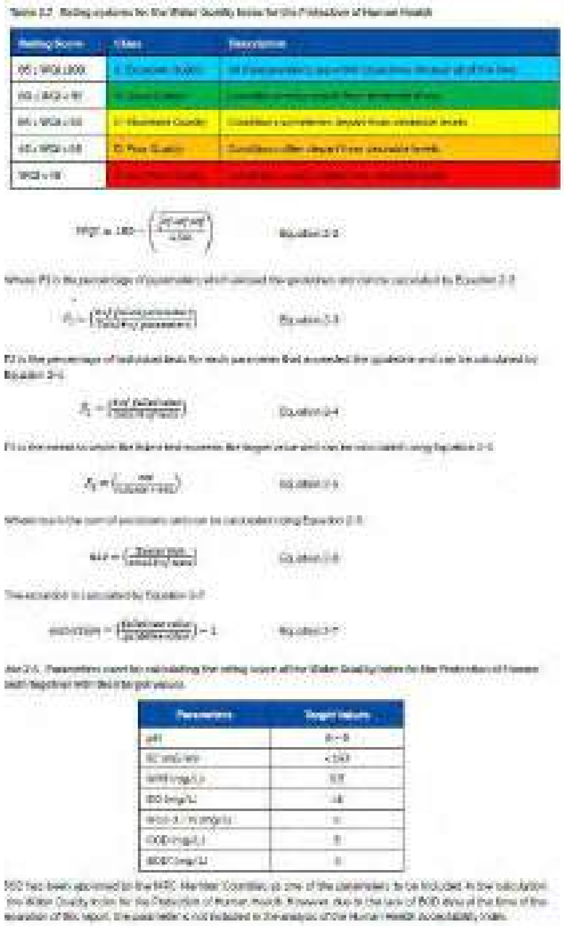
6.3 Water Quality

In the earlier sections, the water quality results from the JEM Pilot sites at Xayaburi and Don Sahong have been compared with the same monthly results from the routine WQMN monitoring at the mainstream sites above and below the two dams. In this section we compare the results from the other WQMN mainstream stations from Houa Khong to Kampong Cham on an annual basis using the two Water Quality indices – for Protection of Aquatic Health and Protection of Human Health.

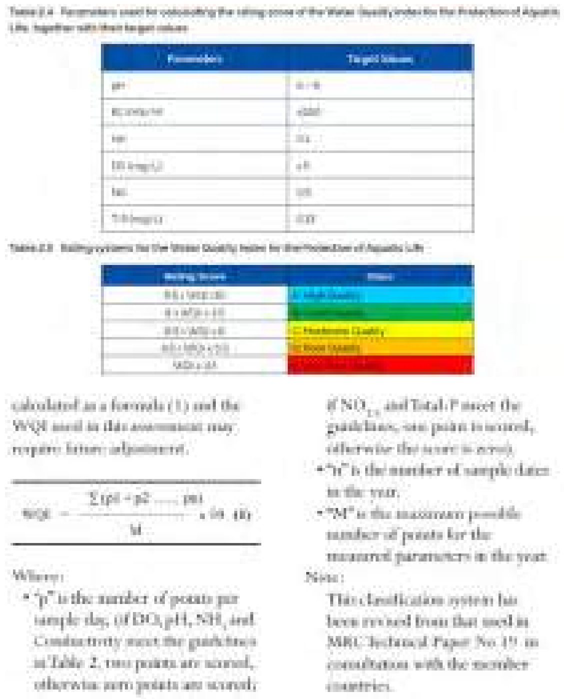
These two indices are calculated from the number of occasions each year when thresholds set by target values for WQ parameters are exceeded, and the extent to which they are exceeded. The calculations and scoring are shown in Box 6-1.

Box 6-1: Calculations for WQ Indices for Protection of Human Health and Aquatic Life

Calculations for WQ Index for protection of Human Health



Calculations for WQ Index for protection of Aquatic Life



The calculations have been done for the two years previous to the JEM pilots i.e. 2019 and 2020 with 11 or 12 monthly samples being taken. By comparison the 8 samples taken from the JEM pilot sites from October 2020 to June 2021 have been aggregated together as the 2021 figures, noting that these do not include any substantive wet season figures. The results of both WQ indices are shown in ***Table 6-6***, together with the parameters that have failed by exceeding the target values. The results show that most stations including all the JEM stations can be classified as having High or Excellent quality for both WQ Index for Aquatic Health and for Human Health. However, Stung Treng and Kratie scored lower classification to Good Quality in 2019 and 2020, failing to meet the Aquatic Health thresholds on one or two occasions for Ammonium and Total Phosphorus. Pakse and Stung Treng were classified lower to Good Quality for the WQ Index for Human Health in 2020, failing to meet the COD thresholds on one or two occasions.

Although the JEM pilot sites are classified as being of WQ Index Excellent or High Quality, the results also show several instances when the thresholds are exceeded at all sites. Principally the failing parameters at the Xayaburi JEM sites are NO32 and TotP for WQ Index of Aquatic Health and COD at WQ1 for WQ Index for Human Health. At the Don Sahong site the failing parameters are pH and NO32 and TotP.

Table 6-6: WQ Indices for all mainstream WQ stations and JEM stations for 2019, 2020 and 2021

		WQ Index Aquatic Health				WQ Index Human Health			
WQ sampling station	**ID**	**2019**	**2020**	**2021**	**Failing parameter**	**2019**	**2020**	**2021**	**Failing parameter**
Houa Khong	H010500	**9.92**	10	10	NO32	100	100	100	
Chiang Saen	H010501	10	**9.64**	10	NH4, NO32, TotP	100	100	100	
Luang Prabang	H011200	**9.92**	10	10	NO32	100	100	100	
Xayaburi	WQ1			**9.88**	TotP			**95.83**	COD
	WQ2			**9.63**	NO32, TotP			100	
	WQ3			**9.63**	NO32, TotP			100	
	WQ4			**9.63**	NH4, TotP			100	
	WQ5			**9.25**	NO32, TotP			100	
Vientiane	H011901	**9.75**	**9.82**	10	Cond, NO32, TotP	100	**95.8**	100	COD
Nakhon Phanom	H013101	**9.75**	10	**9.67**	NH4, TotP	**99.09**	100	100	COD
Savannakhet	H013401	**9.92**	**9.73**	**9.60**	DO, NO32	100	100	**99.85**	DO
Khong Chiam	H013801	10	**9.73**	10	NH4, NO32	100	**96.53**	100	COD
Pakse	H013900	10	**9.91**	10	TotP	100	94.66	100	COD
Don Sahong	WQ6			**9.75**	pH			**99.80**	pH
	WQ7			**9.5**	pH, NO32, TotP			**97.08**	pH
	WQ8			**9.75**	NO32, TotP			100	
	WQ9			**9.625**	NO32, TotP			100	
Stung Treng	H014501	**9.33**	**8.82**		NH4, TotP	100	94.98		COD
Kratie	H014901	**8.92**	**9.55**		NH4, TotP	100	100		
Kampong Cham	H019802		**9.36**		NH4, TotP		100		

The WQ indices do not take into account any changes in Total Suspended Solids, but this is the one parameter that is showing significant changes both within the JEM pilot sites and indeed within the LMB as a whole over the years. ***Figure 6-23*** shows a series of annual median TSS concentrations at each of the mainstream WQMN stations from 2010 to 2021, together with appropriate trend lines. The marked variability between the years reflects a combination of the different rainfall contributions to the flows each year and hence the different TSS concentrations in wet and dry years, but nevertheless trends in TSS can be observed. Since we do not have such long time series for the JEM Pilots, the 2021 values for WQ1 are shown on the Luang Prabang chart, for WQ4 on the Vientiane chart, and the WQ6 on the Pakse chart and WQ9 values on the Stung Treng chart. Invariably these JEM results are much lower than the full annual results from WQMN, because they do not include the wet season results when the TSS would have been much higher.

The TSS levels also show similar levels as the SSC concentrations discussed in 6.2.1, though because they are spot samples they should not be used to estimate sediment loads. The annual median time series at all sites above Stung Treng show downward trends in the suspended solids concentrations over the past decade; it is assumed that this in part has been contributed by trapping of sediments in the hydropower dams in the mainstream and tributaries.

This downward trend in annual median values of TSS at all stations is reversed at Stung Treng and Kampong Cham where there is a generally upward trend. Such trends have been noticed since measurements of sediments have started (see Walling, D., 2005) and reflects the general dilution of sediments coming from the upper parts of the basin, i.e. from China with water from the tributaries with lower sediment load in the LMB, until Stung Treng when the sediment load from the 3S rivers creates the upward trend noted.

Figure 6-23: Plots of variation in median annual TSS concentrations in Mekong mainstream sites

6.4 Ecological Health

The Ecological Health Indices and classification for all the mainstream sites from 2011 to 2019 are shown in *Table 6-7*. These are then combined into an average for the decade of 5 biennial monitoring occasions which are then compared to the JEM pilot sites monitored in 2021. This comparison clearly indicates that the two sites upstream of Luang Prabang at Ban Xieng Kok (LMX) and Chiang Saen (TCS) are of Moderate and Poor EH condition respectively, and that the mainstream sites at Luang Prabang (LPB) and EHM1 are in Good condition. The Xayaburi impoundment and three downstream sites show a decline into Moderate condition, which recovers by EHM6.

The three sites downstream of Vientiane to Siphandone have varying EH scores over the decade, averaging Moderate conditions, but in Siphandone at Don Ngiew (LDN) the condition to Moderate is restored. This is confirmed by the high Good condition score at EHM7 and at Kbal Koh (CKM) on the border between Cambodia and Lao PDR. However, the scores for the Don Sahong impoundment (EHM8) and the two downstream sites (EHM9 and EHM10) fall into the Moderate condition class. Further downstream at Stung Treng (CKT) and Kratie (CMR), the average EHI scores fall into the Good condition class.

Table 6-7: Comparing Decadal average of EH Index scores for mainstream sites from the Ban Xieng Kok to Kratie with the 2021 JEM sites above and below Xayaburi and Don Sahong HPPs.

EHM Site	Site Name	2011	2013	2015	2017	2019	Decadal Average/ 2021
LMX	Ban Xieng Kok	4	5	4	6	6	5
TCS	Chiang Saen	6	4	3	2	3	3.6
LPB	Luang Prabang	11	5	8	8	7	7.8
EHM1	Xayaburi						8
EHM2							5
EHM3							6
EHM4							6
EHM5							6
EHM6							7
LVT	Vientiane	8	2	7	6	8	6.2
TNP	Nakhon Phanom	5	7	6	5	6	5.8
TKC		8	5	3	3	4	4.6
LDN	Don Ngew	11	5	7	6	8	7.4
EHM7	Don Sahong						9
EHM8							5
EHM9							6
EHM10							6
CKM	Kbal Koh	N/D	7	8	10	8	8.25
CKT	Stung Treng	N/D	8	10	9	8	8.75
CMR	Kratie	N/D	6	11	9	7	8.25

EH Condition	Classification	Score
Excellent	A	10 - 12
Good	B	7 - 10
Moderate	C	4 - 7
Poor	D	1 - 4

The detailed calculations of these EHI scores for all mainstream sites over the past decade are shown in Annex 6. The plots of changes in the 2019 scores for Average Abundance, Species Richness, and Average Tolerance Score per Taxon (ATSPT) for each of the biota types are shown in ***Figure 0-15***; these are compared to the JEM sites monitored in 2021. These graphical comparisons are useful because they show at a glance which of the variables for each biotic type are meeting the Guideline threshold values (above the line for Abundance and Species Richness and below the line for ATSPT). Failure to meet the guideline thresholds is also shown in the tables by the "False" notice. For the JEM sites this has been described in sections 3.3.1.1 and 4.3.1.1.

This analysis helps in understanding the responses of the biota to different habitat and flow conditions both in the impoundment and in the downstream sites compared to the upstream site, and also can be used to indicate recovery with passage downstream.

6.5 Fisheries – FADM, FLDM

The fisheries monitoring questions asked (average monthly catch per fisher, annual species diversity in catches and gillnet CPUE) have been set on an annual time scale in order to integrate the high monthly variability observed in natural conditions (day-to-day variability in catches, seasonal fish migration pulses, lesser catchability of fish in the wet season, reduced access to fishing sites in the dry season, change of gears between seasons, etc.). The constraints inherent to annual ecological cycles as a reference are illustrated by the production, by member countries, of annual reports on FADM monitoring, fish larvae or Dai fishery.

For this reason, relying solely on JEM data whose collection started of mid-2020 and was on-going in June 2021 (month of the latest data analysed, 11 months after the first sampling) was not sufficient. The integration of Routine monitoring sites (e.g. Pha-O, Ban Hat, Hang Sadam) was therefore a natural process reflecting the dovetailing and continuity of the new JEM protocols with the former ones implemented by the MRC for more than a decade. This integration is illustrated by the combination, in section 4.4. of both MRC and FADM stations, between 2017 and 2021, at dam monitoring sites.

The selection of 2017 as a starting point for integration of MRC routine monitoring with JEM monitoring results from the analysis of data available by year, and the identification of 2017-2021 as being the key period allowing a combination of solid MRC Routine data and JEM new data (***Table 5-11***). Ultimately, it is the combination **of these** different sources of information (MRC FADM Laos, MRC FADM Cambodia and JEM FADM Laos) that allowed analysing long-term fisheries trends in 9 stations upstream and downstream of Xayaburi and Don Sahong sites (sections 4.4.1 and 4.4.2).

6.6 Integration of hydrology, sediment transport and water quality information

The basin wide water quality, hydrology and SSC results have been combined to provide an example of how results from different disciplines can be integrated to provide a more complete understanding of riverine processes. This example has drawn upon long-term monitoring results from the WQMN and the DSM because there are too few results from the JEM sites to allow integration at a large spatial or temporal scale.

The analysis has focussed on total phosphorus (TotP), and total and dissolved nitrogen parameters (TotN, nitrate + nitrite=NO_{32}) at sites on the Mekong where results are available between 2010 and 2020. The analyses include derivation of SSC and nutrient load time-series, estimation of annual nutrient loads.

6.6.1 Time series of SSC and nutrient loads.

Total phosphorus and total and dissolved nitrogen loads were derived for each monitoring day at Chiang Saen, Vientiane, Pakse and Stung Treng using the water quality result and the average daily discharge at the corresponding site to provide a picture of changes over time at each site and with distance down the river. These daily loads are presented in ***Figure 6-24*** to ***Figure 6-26***, along with the calculated SSC load from the site over the same time period. The results show the following characteristics:

- All nutrient loads and SSC loads show seasonality, with high flows during the flood season delivering the highest loads. The seasons are most pronounced during the first few years of monitoring, and become less distinct in the last few years. This is consistent with higher dry season flows and lower wet season flows that have occurred in the LMB over the past few years;
- Nutrient and SSC loads increase with distance downstream. Note the maximum value on the y-axes increases from 1,000,000 to 10,000,000 at Nong Khai for nitrogen parameters and at Stung Treng for total phosphorus;
- The nutrient and SSC loads show a decrease since 2018, likely attributable to reduced flows trapping in impoundments

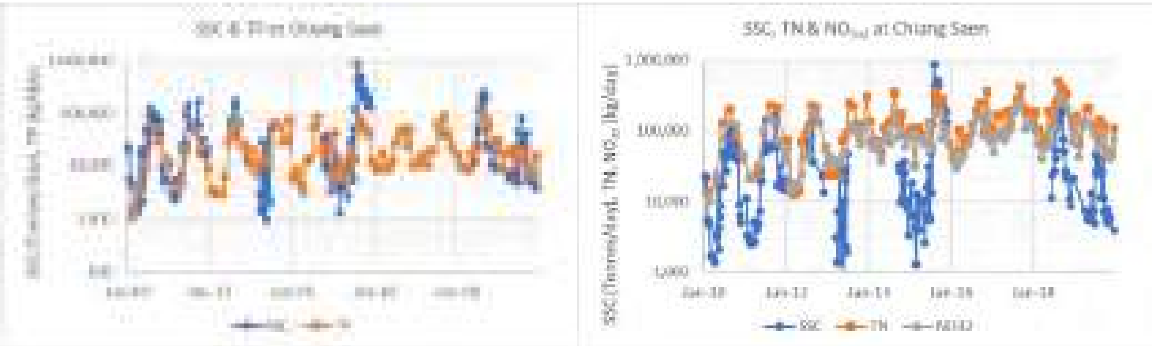


Figure 6-24. Time-series of SSC load compared to (left) TP load and (right) TN and NO32 load at Chiang Saen from 2010 to 2020.

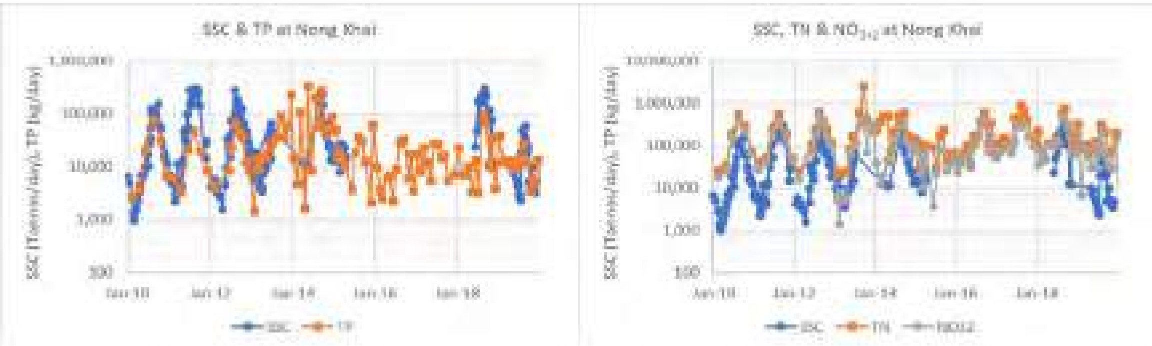


Figure 6-25. Time-series of SSC load compared to (left) TP load and (right) TN and NO32 load at Nong Khai from 2010 to 2020.

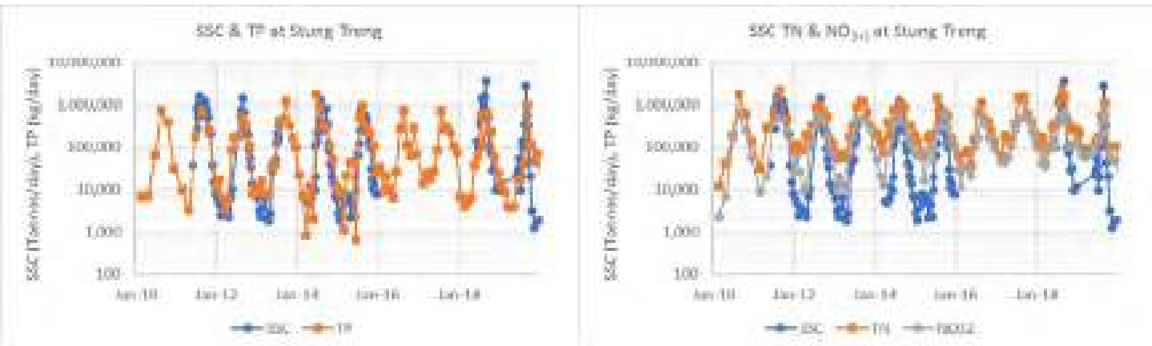


Figure 6-26. Time-series of SSC load compared to (left) TP load and (right) TN and NO32 load at Nong Khai from 2010 to 2020.

6.6.2 Annual nutrient loads

The nutrient load time-series were used to estimate annual nutrient loads at each site. The estimated annual load was derived by interpolating between the monitoring dates, using the average nutrient load calculated on successive monitoring dates. The results for each site for the period 2010-2021, along with the average annual flow at each of the monitoring sites is shown in ***Figure 6-27*** and ***Figure 6-28***. A comparison of total and dissolved nitrogen parameters is presented in ***Figure 6-29***.

The results show an increase in average flow and generally an increase in nutrient loads at successive sites. For total phosphorus, there is a generally a very large increase between Pakse and Stung Treng, which likely reflects the inflow of the large 3S basin. Depending on where the sample is collected, it may be reflecting the Sekong more than the Mekong, and over estimate of nutrient load in Mekong.

The dissolved nitrogen results are lower than the total loads, as would be expected. At Chiang Saen, the dissolved parameters account for about 50% of the total. This value decreases downstream, with dissolved nitrogen accounting for about 40% at Vientiane and Pakse and 20% at Stung Treng. This decrease is most likely due to the inflow of sediments that transport additional particulate nitrogen.

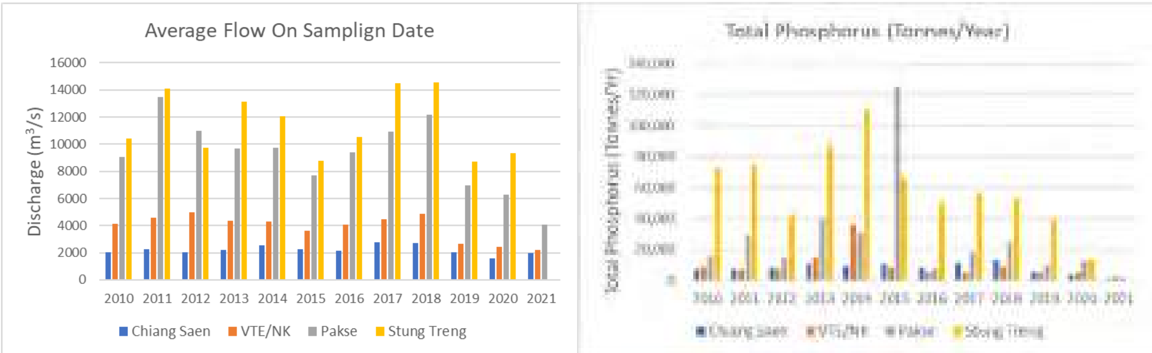


Figure 6-27. (left) Average annual flow at the water quality monitoring sites 2010-2021.

Note: No results are available for Stung Treng in 2021 (right) estimated annual total phosphorus load at monitoring sites 2010-2021.

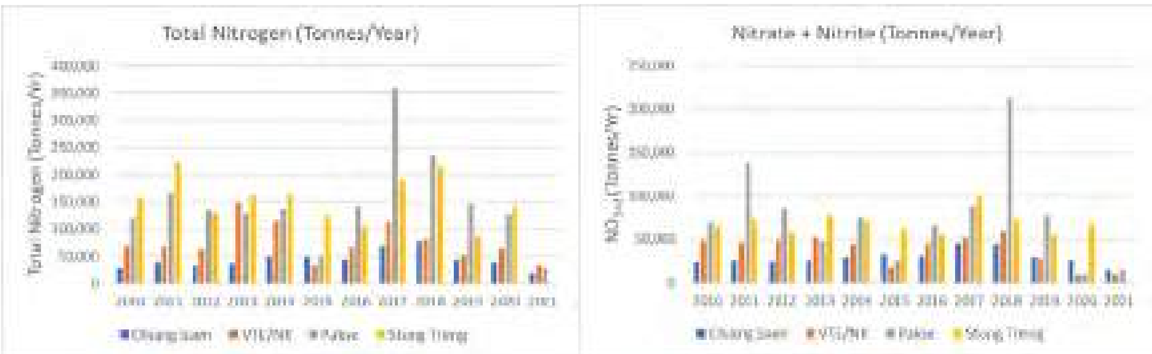


Figure 6-28. (left) Estimated annual total nitrogen load and (right) estimated dissolved nitrogen load at monitoring sites, 2010-2021.

Note: Note different scales on graphs.

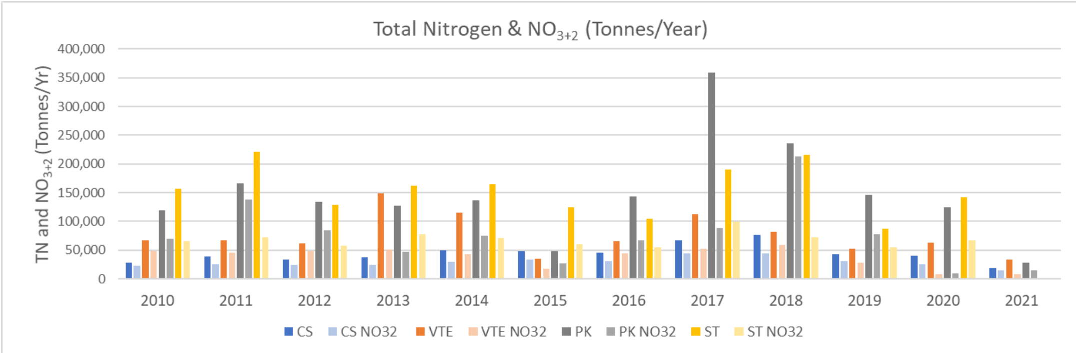


Figure 6-29. Comparison of total and dissolved nitrogen loads at the monitoring sites, 2010-2021.

The average annual flow results show a distinct decrease since 2018, which is also reflected in the total phosphorus load results and to a lesser extent in the nitrogen results. To investigate whether the decrease in nutrient loads is solely attributable to a reduction in flow, or whether the concentration of nutrients has also changed, the water quality results were compared by dividing the results into 2010-2015 and 2016-2020 groupings (*Figure 6-30*). The total phosphorus concentrations show a marked decrease between the 2010-2015 and 2016-2020 at all sites except Chiang Saen, and a decrease in variability of concentrations. In contrast, the total nitrogen results show increased concentrations in the 2016-2020 group at all sites except Stung Treng, with dissolved nitrogen showing variable changes. These results highlight that changes to flow, sediment input and other factors are controlling water quality. Potential factors affecting water quality include land use (agriculture, forestry, mining), and industrial and municipal waste water discharges.

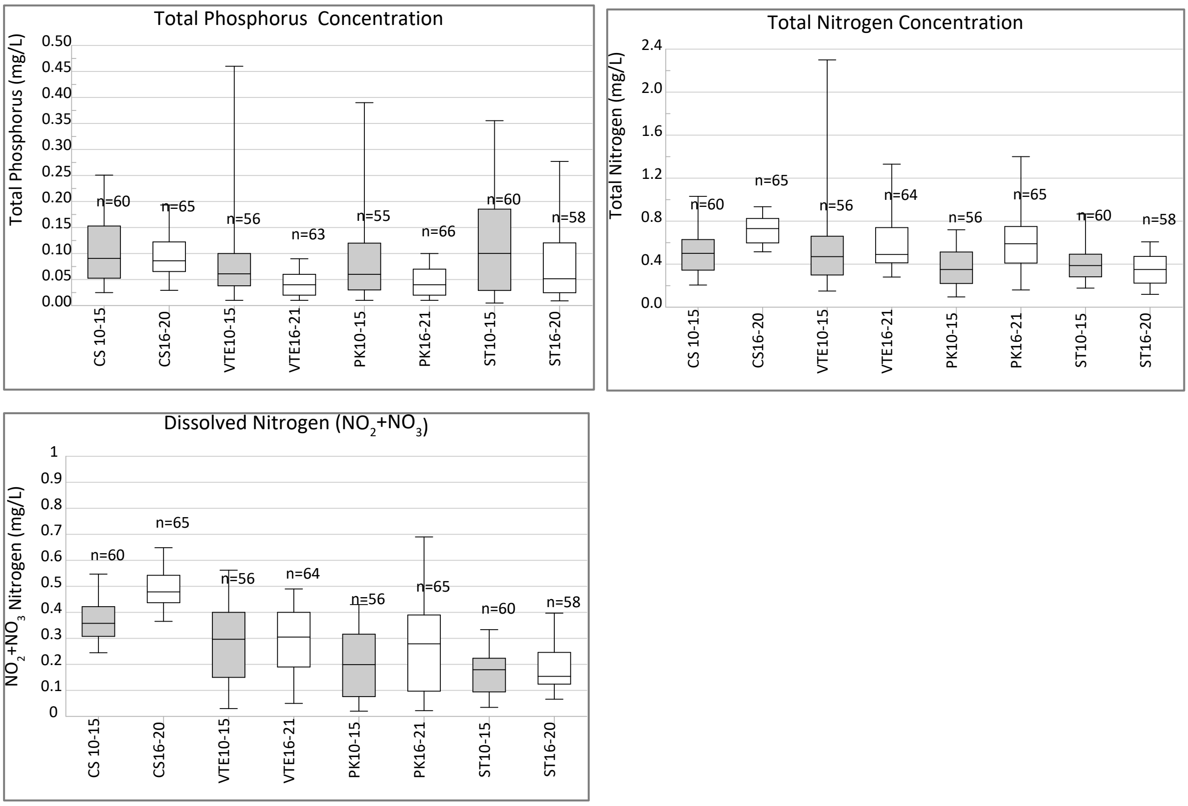


Figure 6-30. Box and whisker plots comparing nutrient concentrations between 2010-2015 and 2016-2020/21.

Note: The box encompasses the 25th to 75th percentile values, and the whiskers extend to the 1th and 95th percentile values.

6.6.3 Explaining the changes in the Ecological Health Index

The Ecological Health Index scores for the sites within the impoundments and downstream of both Xayaburi and Don Sahong dams show a fall in the quality of the biota in those sites compared to the upstream sites, as well a progressive recovery downstream. A comparison with both the Water Quality data and the hydrological and sediment data in associated sampling stations may help to explain these changes in the impoundment and downstream of the dams. It is not possible to correlate the data directly because the EHM data is only one annual or biennial assessment compared to the monthly water quality and hourly or daily water level changes. The EHM data is supposed to reflect the prevailing conditions of water quality, flows and habitat conditions over the past year, although it can be immediately responsive to larger pollution or flood events.

6.6.3.1 Comparing water quality parameters

Considering first water quality changes in the impoundment and downstream of both dams reported in chapters 3.2.1 and 4.2.1. The monthly water quality results and the medians for the sampling period, show no marked patterns of change with passage downstream through the dams, and parameters such as Dissolved Oxygen (DO), pH, and Conductivity are more or less the same above and below the dams. This indicates that water quality is not the determining factor for changing the EH Indices, and while there are one or two indications of some occasional pollution events e.g., raised COD and Faecal Coliforms, the scale and frequency of such events is not considered sufficient to cause these EHI changes.

Generally it is considered that the EHM results reflect the overall conditions within the river over the previous year. However, the possibility exists that a poor water quality event that occurred three weeks before the EHM sampling date, which was not picked up during the monthly water quality monitoring, could have given rise to depleted EHM samples and low EHM index scores. In order to remove such uncertainties it would be necessary to carry out semi-continuous water quality monitoring at a permanent installation (e.g. with a HYCOS station) which would pick up such poor water quality events.

Within both impoundments, the depth profiles indicate that the water layers are generally well mixed, except perhaps in January and February where there may be indications of some stratification of Dissolved Oxygen (DO) at deeper levels, but the DO down to 20m is not sufficiently low to threaten aquatic life (i.e., not lower than 5 mg/l).

The Phytoplankton content in the impoundments are generally at very low levels, with occasional higher proportion of Cyanobacteria, but not sufficient to cause toxicity problems either within the impoundment or downstream (see Box with WHO threshold levels in section 3.2.1)

The one water quality parameter that does change is Total Suspended Solids (TSS) with marked reductions downstream of the dams. These changes will be considered with the Hydrology and Sediment sections.

6.6.3.2 Changing flows and water levels

Both Xayaburi and Don Sahong HPPs, affect the flows, flow rates and water levels at the different EHM sites. Within the impoundments the water level is raised to a more or less steady level throughout the year, more than 20 or 30 metres above the original water level in the river. The flow rates within each impoundment are slowed down, although in Don Sahong impoundment the flow rate can be higher than in Xayaburi because it has a much lower retention volume. The riverine habitat is changed to a lacustrine habitat, which favours some biota compared to others, thus benthic diatoms tend to be restricted to the edges of the impoundment, and they cannot survive in the deeper parts where the light cannot reach, but the zooplankton have a greater opportunity to multiply in the slower moving waters. Littoral macroinvertebrates are also restricted to the edges and the species will tend to be those that prefer to live in still or slower moving water such as some mayfly larvae species and beetles. Changes to Benthic macroinvertebrate species will probably reflect the oxygen deficient water layers in the deeper parts of the impoundment, but with less change in the shallower areas.

In both impoundments, the Littoral macroinvertebrates show the greatest changes in Abundance, and all biota show reductions in Species Richness. This is likely to have implications for the changing fish species diversity and abundance in the impoundments as reported in Sections 3.4. and 4.4. which will be affected by the availability of food macroinvertebrate species and zooplankton for the fish.

Downstream of the dams, water levels and flow rates are also very influential upon the habitat and aquatic biota. Reference to ***Figure 6-10*** and ***Table 6-1*** shows that at the Ban Pakhoung HYCOS station, which is equivalent to EHM4 (and the other Xayaburi downstream sites), there is a rapid fluctuation in water level and rapid rates of change of flow on an hourly basis. This has been confirmed by the Lao EHM team in discussion with local villagers who say that the water level may change, rising and falling by up to a metre on a daily basis.

The effects of such changes on the aquatic biota can be dramatic, both in real terms and in sampling. Littoral macroinvertebrates cannot survive the daily exposure of the habitat, and so will tend to move towards the deeper areas downstream which are not uncovered each day, so the populations will be limited in abundance as well as species richness. If sampling occurs at the time when the water levels are higher, generally during the middle of the day, then they will be recording low populations in those areas which are exposed when the water level falls usually at night.

Conversely the benthic diatoms, which grow upon the rocks and stones in the river bed, can survive limited exposure, provided that they do not dry out completely when the water level falls. They will benefit from the sunlight falling on them during the day and grow well under these conditions of regularly rising and falling water levels.

The effects of changing water levels will be gradually moderated with passage downstream, which is why there is an apparent recovery of the Ecological Health Index at the further downstream sites at EH6 below Xayaburi and EH10 below Don Sahong.

6.6.3.3 Changing sediment loads

Both the Total Suspended Solids (TSS) and Turbidity WQ measurements and the Suspended Sediment Concentrations measured under the Hydrology and Sediment monitoring may help to explain the changes in the biota both in the impoundment and the downstream of the dams.

Reference to ***Figure 3-19*** and ***Figure 3-27*** shows the marked reduction in TSS with passage downstream at Xayaburi and ***Table 6-5*** shows how the overall sediment load being transported down the river at different sites has been reducing each year as sediment becomes trapped in both mainstream and tributary dams.

Within the impoundments, the lower flow rates experienced will tend to allow sediment to fall to the bottom. This will cover the rocky and stony habitats in the river bed, making them unsuitable for both diatoms and littoral macroinvertebrates, so tending to impoverish the populations. Benthic macroinvertebrates and zooplankton will be less affected.

Downstream of the dams, the combination of high rates of flow change with water that has a lower TSS or SSC will increase the bed and bank erosion, so that the river will try to pick up the sediment that has been trapped in the impoundment. The habitats and substrate downstream will become less suitable for many species, especially littoral macroinvertebrates, including the filter feeding insect larvae, with the result that populations become impoverished and species richness declines. The river and its sediment loads begin to stabilize with progress downstream, allowing recovery of the biota and EH Indices.

7 INITIAL ASSESSMENT OF MONITORED IMPACTS FROM DAM OPERATION

These two JEM Pilots have only been collecting data for about 8 months, mostly during the dry season. These is insufficient data to capture longer term changes and an absence of baseline data in some locations in the impoundments and downstream of the dams. It is therefore difficult to make definitive assessment of impacts of the dam operation. Nevertheless, even with the data that has been collected it has been possible to identify possible changes caused by the operation of the two dams, and to make suggestions for adaptive management.

7.1 Hydrology and sediments

7.1.1 Xayaburi

The JEM monitoring has captured water level fluctuations at the Ban Pakhoung water level site associated with the operation of the Xayaburi HPP. The monitoring results show that large water level fluctuations occur throughout the year, and frequently exceed the MRC (2020) Hydropower Guideline recommendation of 0.05 m/hr. Fluctuations occur during the dry season due to the shaping of power generation to maximize energy production during peak periods, and during the flood season during the rapid release of large volumes of water. The water level fluctuations are greatly reduced, but still present at Chiang Khan.

The impact of sediment trapping in the Xayaburi impoundment was not able to be quantified, due to the low number of SSC measurements collected during the JEM investigations, the measurements being collected predominantly in the dry season, and the lack of temporal overlap between the upstream (Ban Xang Hai) and downstream (Ban Pakhoung) monitoring results. The very low SSC loads estimated at Chiang Khan in 2019 and 2020 (2 - 4 Mt/yr) are an abrupt change from previous years, when estimates of up to 36 Mt/yr were made during wet years. The marked decrease strongly suggests that sediment trapping increased around 2018 / 2019, which coincides with the commencement of operations of Xayaburi. It also coincides with the commissioning of HPPs in the Nam Ou, Nam Khan and other upstream tributaries, so it is not possible to identify the source of the reduction based on available information. A longer data set from Ban Xang Hai and Ban Pakhoung will allow quantification of the sediment loads entering and exiting the Xayaburi impoundment.

7.1.2 Don Sahong

Water level recordings at Koh Key downstream of Don Sahong do not show water level fluctuations that are attributable to Don Sahong. In contrast both the Pakse and Stung Treng water level record show clear short duration fluctuations that are undoubtedly associated with hydropower operations. At Pakse, the fluctuations may reflect operation of the nearby Pak Mun station, or other sites in the upstream tributary. At Stung Treng, it is likely that the fluctuations are associated with operation of the Lower Sesan 2 HPP. At Pakse and Stung Treng the water level fluctuations in the Mekong are below the 0.05 m/hr MRC Hydropower guideline recommendation, but may be higher within the tributaries.

The SSC results from Stung Treng-Up provide an estimate of ~20 Mt/yr of SSC derived from the Mekong River. The SSC results from the Sekong, show very high sediment input events occurring each of the last 3 years, which may reflect the opening of low level gates on tributary HPPs.

7.2 Water Quality

7.2.1 Xayaburi

The water quality results with passage through the impoundment and downstream of the dam do not show any obvious patterns of changes, either in the general WQ parameters of Temperature, pH, Conductivity and Dissolved Oxygen, or in the pollution indicators of Ammonium, COD and Faecal coliforms. This would indicate that the operation of the Xayaburi HPP has not affected these parameters, at least at the time of visits for the 8 monthly samples. It must be noted that these parameters, especially DO and pH, may vary over a 24 hour period, and the sampling time is usually during the middle of the day, when oxygen levels would be expected to be higher.

There are occasional instances when pollution indicators are raised in the samples, and these probably reflect relatively small upstream pollution events, rather than being caused by the impoundment or dam.

The main differences between upstream and downstream occur in the results of Total Suspended Solids and Turbidity, with the impoundment and downstream results generally being much lower than upstream (see ***Figure 3-19*** and ***Figure 3-27***), with median values falling by up to 60%. This indicates a major role in trapping of sediments in the impoundment, which are thus removed from the sediment load transported downstream. There is one higher value of TSS in WQ4 downstream site which might be caused by a minor flushing event by the hydropower operation in November 2020 or downstream bank erosion caused by water fluctuations , but without information on the operation at the time it is impossible to make this correlation.

The parameters for nutrients and phytoplankton are more variable each month, but generally reflect incoming nutrient levels, which are occasionally in excess of threshold levels. However, the median levels for Chlorophyll-a in the impoundment is generally higher than downstream, indicating that phytoplankton, especially Cyanobacteria, are being concentrated in the impoundment, but the concentrations recorded are well below guideline risk levels of 50 micrograms/litre. There is one month (January 2021) when the proportion of Cyanobacteria in the river generally is very high – up to 80% of the Chlorophyll-a in the impoundment – indicating a bloom of blue-green algae – although the concentrations are still very low.

The other set of parameters that are important for the operation of the Xayaburi HPP are the impoundment profiles to see whether stratification is occurring. If stratification is present and the dam offtake is located at depths below the levels where Temperature, pH and Dissolved Oxygen are reduced, this can be one of the causes of poor water quality passing downstream. During the sampling period from October 2020 to June 2021, most of the parameters showed that there was no difference in the measurements made at different depths down to 20 m, indicating that stratification was not occurring, except during the month of December 2020, when DO fell progressively with depth from about 8.0 mg/l, to about 5.0 mg/l. The same pattern occurred to a more limited extent in January 2021.

7.2.2 Don Sahong

The water quality results with passage through the impoundment and downstream of the Don Sahong dam do not show any obvious patterns of changes, either in the general WQ parameters of Temperature, pH, Conductivity and Dissolved Oxygen, or in the pollution indicators of Ammonium, COD and Faecal coliforms. This would indicate that the operation of the Don Sahong HPP has not affected these parameters, at least at the time of visits for the 8 monthly samples. It must be noted that these parameters, especially DO and pH, may vary over a 24 hour period, and the sampling time is usually during the middle of the day, when oxygen levels would be expected to be higher.

There are occasional instances when pollution indicators are raised in the samples, and these probably reflect relatively small upstream pollution events, rather than being caused by the impoundment or dam.

Unlike in Xayaburi, there are no marked differences between upstream and downstream in the results of Total Suspended Solids and Turbidity, with the impoundment and downstream results generally having similar values as at WQ6 upstream (see ***Figure 4-20*** and ***Figure 4-30***). This would indicate that smaller impoundment at Don Sahong, with a much lower residence time, is not trapping sediments to the same extent. The braided channels around Khone Falls on one of which Don Sahong is located, will carry much of the sediment in the river around Don Sahong. The TSS and the Turbidity results tell the same story, which confirms their use in verifying the results of each method of measurement.

The parameters for nutrients and phytoplankton are more variable each month, but generally reflect incoming nutrient levels, which are occasionally in excess of threshold levels. The median nitrate/nitrite levels around Don Sahong tend to be higher than at Pakse and at Don Sahong, but this may be due to sampling and equipment differences, rather than reflecting changes due to plant operation. Total Phosphorus concentrations tend to be lower within the impoundment and immediately downstream compared to upstream which may reflect some trapping of Phosphorus in the impoundment. However, unlike in Xayaburi JEM sites, the median levels for Chlorophyll-a are generally very similar upstream and downstream. Similarly with Cyanobacteria, although there are some higher outlier values, e.g. in February 2021 when the proportion of Cyanobacteria in the river generally is very high – up to 40% of the Chlorophyll-a in the river – indicating a bloom of blue-green algae – although the concentrations are still very low.

The other set of parameters that are important for the operation of the Don Sahong HPP are the impoundment profiles to see whether stratification is occurring. If stratification is present and the dam offtake is located at depths below the levels where Temperature, pH and Dissolved Oxygen are reduced, this can be one of the causes of poor water quality passing downstream. During the sampling period from October 2020 to June 2021, most of the parameters showed that there was no difference in the measurements made at different depths down to 20 m, indicating that stratification was not occurring, except on 15 January 2021, when DO fell progressively with depth from about 8.0 mg/l, to slightly greater than 5.0 mg/l. This also mirrors the pattern experienced in Xayaburi on 15 December 2020, but a month later.

7.3 Ecological Health

7.3.1 Xayaburi

The changes in the Ecological Health Index and individual biota parameters within the Xayaburi impoundment, and three of the downstream sites closest to the dam compared to the upstream reference site, indicates that the ecological health quality is being impacted by the dam. Correlation with the absence of patterns in the water quality parameters with passage downstream suggests that the changes in EHM are not related to changes in water quality, but rather to changes in the flow and water level regime and reduction in sediment transport.

Within the impoundment the raised but relatively steady water levels has changed the riverine habitat to a lacustrine habitat, thus changing the species composition and population number of the biota, as well as their tolerance characteristics. The trapping of sediment within the impoundment will also tend to cover substrates that might have been more attractive to riverine biota.

Downstream of the dam, the effects of peaking operation, raising, and lowering the water levels by at least one meter during day, has apparently had an impact upon the biota, tending to encourage the benthic diatoms, that can withstand short periods of exposure to the air, whiles significantly reducing the species and populations of littoral macroinvertebrates immediately downstream of the dam. This impact is combined with the reduction in sediments being transported downstream of Xayaburi, so that the bed and bank habitats will tend to be eroded and degraded for littoral and benthic macroinvertebrates. The EHM results at Xayaburi indicate that there is progressive recovery downstream of the dam, so that by 10 kms downstream (EHM6), the aquatic biota appears to be comparable to the upstream site, above the impoundment.

7.3.2 Don Sahong

As with Xayaburi, the Don Sahong EHM sites indicate a marked reduction in the quality of the biota within the impoundment and downstream of the dam, with potential indications of improvement in the further downstream site. The situation is marked because the upstream site has a much higher scoring for all parameters, i.e., it is very rich, and close to the top of the impoundment. Within the impoundment not only has there been an increase in water level, but also extensive disturbance during construction which will have reduced the habitat and substrate quality. Because of its size, the flow rate through the impoundment is much faster than through the Xayaburi impoundment, which tends to reduce the sedimentation process.

Downstream of the dam the aquatic biota is exposed to similar changes in water level and flow rates, which will tend to depress the populations and affect the species richness. As the water from the Don Sahong dam mixes with water from other channels downstream of Khone Phapheng Falls, so the recovery of the habitats and aquatic biota would be expected to be quicker than at Xayaburi where the whole river passes through the dam.

7.4 Fisheries

7.4.1 Xayaburi

The analysis of fishery data in Xayaburi site indicates a sharp decline in harvested fish diversity in the reservoir, from 88 species in 2017 down to 32 in 2020 (-64%). By comparison there is also a decline upstream and downstream of the reservoir, but to a lesser extent (-38% and -35% respectively). This loss of species diversity could not yet be analyzed in detail, but is common worldwide in new impoundments (Bernacsek 1997, Marmulla 2001), as it corresponds to the disappearance of diverse benthic carnivorous fish communities typical of running rivers (e.g. Cobitidae, Sisoridae, etc.) and the proliferation of a few opportunistic pelagic planktivorous species typical of ponds and lakes (e.g. Clupeidae). The case of Xayaburi reservoir would require such analysis of species in catches and the trophic guild they belong.

In the Xayaburi reservoir the average monthly catch per fisher has sharply declined from 48 down to 22 kg of fish per fisher and per month on average between 2017 and 2021 (-54%). Three reasons can explain such loss: either there is less fish to catch, or fishers work fish less because the value of the catch is not of interest to them any longer, or they have better new opportunities elsewhere. Data do not allow selecting one explanation at this stage.

However, when gillnet Catch Per Unit Effort is calculated, it shows a lesser decline, from 1.8 g/m2/hour in 2017 down to 1.3 g/m2/hour in 2021 (-28%). Combining this result to the previous one indicates that water productivity has certainly declined, but not enough to explain the reduced monthly catch per fisher. Therefore, the later probably results from a combination of factors, i.e. reduced fish abundance but also less involvement in fishing. A reduced fishing effort could be explained by a reduced value of the catch, if the replacement of large riverine carnivorous valuable species by small planktivorous pelagic species of lesser value is confirmed. A reduced fishing effort could also be identified in data, by working on the trend in the number of gears and fishing hours per fisher over

Since trends in fisheries data require integration over several annual cycles, the impact of the dam in the close downstream site of Pak Houng since mid-2020 could not be identified yet. As detailed in another section, a momentary increase in the catch based on stranded migratory fishes not finding their way up can be expected this year and during a few years.

Monitoring in the site located 400 km downstream of the dam does not indicate negative impact on average monthly catch per fisher and gillnet CPUE (these two parameters tend to increase, for reasons that remain to be confirmed and identified). However, a decrease in the diversity of the catch can be noted (-35%), like in all other sites – be it a consequence of the dam or of other factors.

7.4.2 Don Sahong

The analysis of species diversity in catches upstream and downstream of Don Sahong dam site shows a significantly higher biodiversity downstream of the site, which can be related the bottleneck effect of the falls, and to the higher number of species in the mainstream section linked to the large Cambodian floodplains and the Vietnamese delta.

However, as noted in section 4.4., fisheries monitoring results around Don Sahong site are characterized by conflicting indications, with increasing monthly catch per fisher in Laos contradicted by other surveys and by monitoring in Cambodia, by trends in catch per fisher (increasing) contradicted by trends in gillnet CPUE (decreasing), and by very different values of species diversity and CPUE between sites only a few km apart in a similar environment.

These elements call for a re-examination of data before any conclusion is drawn about the impact of Don Sahong Dam on fisheries resources.

7.5 Initial proposals for mitigation and adaptive management

7.5.1 Hydrology and sediments

- Implement limits for water level fluctuations downstream of power station on the mainstream Mekong associated with operation of mainstream HPPs and tributary HPPs. At a minimum, these limits should be achieved at the boundary with neighbouring countries. How these limits can be incorporated into the operating controls and PPAs of the HPPs should be investigated. It is recommended that hourly water level data be the basis for this guidance. If agreed by the MCs, an additional water level change parameter could be included in the Procedure for the Maintenance of Flows on the Mainstream. Any guidance would need to recognise that on occasion limits may need to be exceeded to ensure the safety of infrastructure during extreme high flow events;
- Develop an LMB wide notification system to rapidly and efficiently alert the community of pending dam operations that will have an impact on downstream flows. An example of this occurred in July 2021 when large flows occurred in the upper LMB and Nan Ou and Xayaburi released water. Notices were issued and broadcast in the press and on social media, but there should be a clear understanding and agreement of where and how this information is communicated to the local community and neighbouring countries. An effective transboundary notification system will potentially save lives and property;
- To assist with understanding and interpreting sediment transport in the LMB, HPPS should provide a list of dates and durations when low-level gates are opened and sediment transport could be expected to increase. Due to the high degree of sediment trapping in the LMB, these local releases may contribute a substantial portion of the annual sediment load. Understanding the timing and distribution of the releases would assist in the prediction and interpretation of geomorphic change in the river.

7.5.2 Water Quality

For water quality, the principal suggestions for mitigation and adaptive management are that more frequent monitoring of water quality downstream of the dam and in the impoundment profiles be established, for example as the HFWQL equipment being installed downstream of Don Sahong. With the potential of measuring water quality for parameters such as Temperature, pH, DO, Conductivity and Turbidity every hour poor water quality conditions emerging at different seasons or times of day, e.g. due to stratification in the impoundment, may be detected and appropriate action can be taken, e.g. levels of water offtake.

The trapping of sediment in the impoundment is an inevitable feature of creating reservoirs, and the flushing of sediment accumulating near the dam has been dealt with above. However, when the low level gates are opened for flushing, a slug of water with very high TSS and often low Dissolved Oxygen can be released downstream, so such operations need to be trialed and managed carefully so that poor water quality issues are not passed on even further downstream.

Regular monitoring of nutrients and phytoplankton in the impoundments is also suggested in order to be aware of impending phytoplankton blooms, even if at present this does not appear to be a problem.

7.5.3 Ecological Health

The changes in the Ecological Health indices within an impoundment is an inevitable consequence of changing riverine habitats to lacustrine. It is to be expected that after some years the lacustrine conditions and biota in these impoundments will stabilise, and the important aspect to be monitoring will be the continuing quality of the lacustrine habitats. At present there are no reference sites for impoundments on the Mekong mainstream, so it is difficult to compare a good quality reservoir biota with changes in these impoundments.It is possible that the longer term EHM monitoring on reservoirs in the tributaries, e.g. Nam Theun 2 could be used as references for a more stable conditions within the impoundments, though the locations of these reservoirs would be likely to hold different assemblages of biota, so that they would not necessarily be directly comparable.

Since the reductions in EH indices downstream appears to be related to changing water levels and flow rates due to peaking operations, much greater attention needs to be paid to working within the ramping rate limits, so that the biota experience more gradual changes in water level and flow rate.

The influence of reduced sediment transport downstream of the dams can be partially offset by suitably managed flushing, but large flushes with very high sediment loads can be very damaging for the aquatic biota for many kilometres downstream, well beyond the apparent recovery zone of about 10 km.

7.5.4 Fisheries

Since fisheries data are constrained by the fact that one annual cycle ultimately constitutes one data point only, it is too early to draw clear conclusions from fish catches monitoring about the impact of each dam on the resource, and possible mitigation options against such impacts.

However, a detailed analysis of fishing activities and fish catches of a finer time scale – either monthly, weekly or daily – can be considered in relation to dam operation. Thus, detailed analysis of data from which natural variability has been removed (e.g. using statistical methods based on residuals) could indicate to what extent fishing activity and fish catch are influenced by hydropeaking or by dam operation of a short time scale. Similar analyses can be considered in relation to sediment and water quality in some critical sites (e.g. just downstream of the dam) in order to assess whether the impact on fisheries can be modulated in relation to a more progressive release of turbined water.

In all cases, these are operations to be considered after more data points and years of data gathering have been secured. Meanwhile, the global and MRC literature on reservoir management and management of the impact of dam operation on fish offers more opportunities to propose mitigation options by drawing from decades of experience worldwide.

8 COMMUNICATION AND GOVERNANCE MECHANISMS

8.1 Communications

The JEM pilot projects have prepared communication materials to share the progress and lessons learnt to enhance transboundary environmental modelling. This has comprised a promotional video and one set of policy briefs.

8.1.1 Promotional video

The promotion video for the JEM was published on the MRC website in August 2020 and can be viewed here. This video achieves the intended objectives to:

(i) introduce JEM and its application in the pilot project sites/stations of Xayaburi and Don Sahong, and

(ii) emphasize the JEM's potential value in enhancing riverine health and transboundary water cooperation across the five key discipline areas in relation to hydropower development in the Mekong basin.

Key to this video were appearances by experts from the MRC and those participating in the JEM from the line agencies of the Member Countries. Each interviewee shared their perspective on the unique importance of the JEM Programme.

8.1.2 Policy briefs and factsheets

A factsheet[4] was prepared and published to introduce and provide an overview of the JEM Programme and methodology. A policy brief was also prepared and published by the MRC to describe the JEM process[5], its goals and expected outputs. These were translated into the four member country languages.

A second set of policy brief and factsheet will be prepared across the remaining months to completion of the pilots. These final communications products will present the outcomes of the pilots including provisional recommendations.

8.1.3 Training materials package

The JEM programme has generated an impressive set of training materials covering all five disciplines. In the final months, this will be summarised into a set of key materials that can be used by the MRC and Member Countries to facilitate training refreshers or guide the onboarding of new monitoring staff. These materials will be translated into the four languages of the Member Countries.

8.1.4 Regional data sharing/data analysis workshop

As the JEM Programme nears completion, a key communication mechanism is a series of workshops to be run in late September 2021 with MCs and developers to reflect on the data collected across the five disciplines and how its analysis can lead to new insight on the pilot projects. Firstly a national workshop will be facilitated with the monitoring teams of each Member Country. These national workshops provide a valuable opportunity for each monitoring team to reflect on and clarify the scientific outputs that their work is contributing to across the monitoring period from October 2020 to June 2021. Key topics include:

[4] Jem-factsheet.pdf (mrcmekong.org)

[5] jem-policy-brief.pdf (mrcmekong.org)

- The importance of good monitoring practice to provide a high quality dataset;
- Data management and databases;
- Standard data analysis approaches to assess the changes associated with operation of the hydropower dams and impoundments for each discipline, and
- Suggestions for further analysis and lessons learnt.

Lastly a regional workshop will be conducted where each of the national teams shares their expert advice and lessons learnt from the JEM pilots alongside facilitated discussions regarding data sharing. The developers will also be invited to attend and present results from their own monitoring activities at the two pilot hydropower sites.

8.2 Governance

The JEM programme is the result of a long process of drafting, consultation and commitment by the Member Countries since it was first agreed to in 2016. Its implementation is overseen by the Expert Group on Environmental Management (EGEM). The EGEM met first in May 2021 following a long postponement due to the COVID-19 pandemic and delays to initiating the pilot monitoring. Also in attendance were representatives from the CK Power Public Company Limited and the Don Sahong Hydropower Project. A second and final EGEM meeting is planned for November 2021 where the final results of the JEM Pilots will be reported alongside the inception report for the Core River Monitoring Network.

The objectives of the first EGEM were to:

(i) present the first results and initial recommendations from the JEM pilots;
(ii) present the final fish pass monitoring methodology and approach to be tested at Don Sahong dam;
(iii) have a common understanding of the current status of the JEM pilots and the remaining process and timeline for the finalization of the JEM Programme; and
(iv) discuss and agree on the concept and proposed approach to kick off the inception phase for the assessment and redesign of the MRC Core River Monitoring Network in the LMB.

This EGEM meeting importantly noted that the JEM Pilots are not an end in itself and will be propagated into the future plans and upcoming programmes of the MRC. Firstly, the recommendations and lessons learnt inform revision of the MRC guidelines of the Joint Environment Monitoring Programme of Mekong Mainstream Hydropower Project to ensure a common, standardised and scientifically robust programme for jointly monitoring key environmental indicators for impact assessment of Mekong mainstream hydropower projects on hydrology and hydraulics, sediment and geomorphology, water quality, aquatic ecology, and fisheries. This revision will be finalised in March 2022.

The findings and recommendations of the JEM Pilots will also feed into the design and establishment of the Core River Monitoring Network (CRMN). This upcoming initiative will address recommendations of the MRC's "Mid-Term Review (MTR) of the Decentralization of Core Basin Management Function Activities" finalized in February 2019 with review, analysis, re-design and establishment of a harmonized and integrated system for a more effective Lower Mekong Basin Monitoring Network. Further consideration to integration of the JEM Programme with the CRMN will be given at the April 2022 meeting of the Joint Committee of the MRC, with anticipated full incorporation by December 2022. The full roadmap for this process can be seen in ***Figure 8-1***.

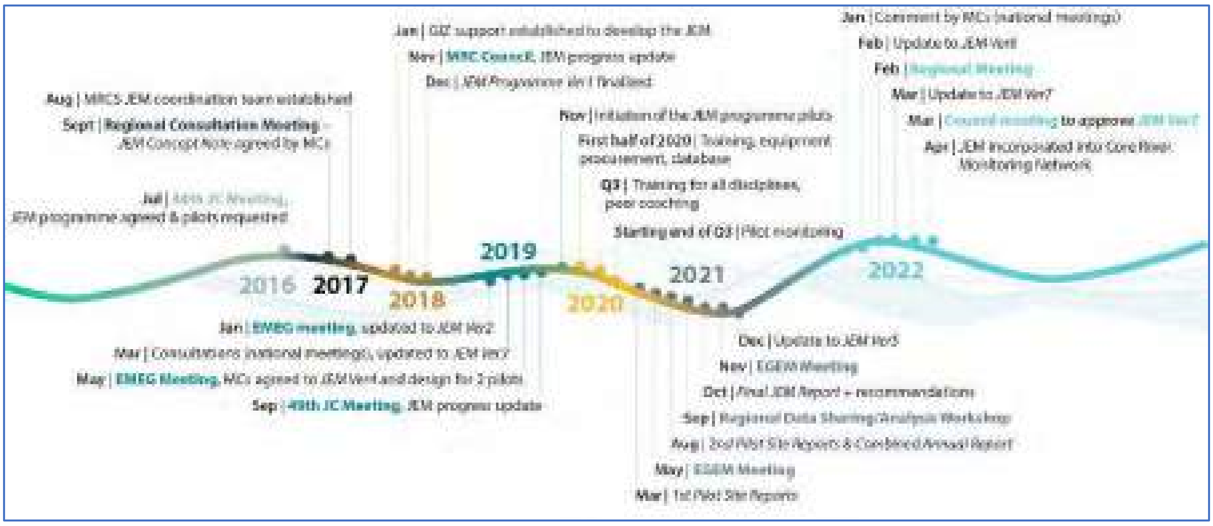


Figure 8-1. Roadmap for the JEM Programme

9 CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions of JEM monitoring

The JEM monitoring has been successful at improving the understanding of local impacts associated with hydropower operations at Xayaburi and Don Sahong. Due to Covid and other delays associated with the procurement, distribution and capacity building exercises associated with the planned JEM monitoring schedule, fewer samples were collected than planned, with sampling during the wet season of 2020 limited. This has limited the ability of the JEM monitoring to quantify some impacts such as sediment trapping in Xayaburi. Regardless, the JEM monitoring has found the following:

- The hydrology of the LMB has been affected by alterations to flow entering from China, as well as low rainfall within the LMB in 2020. Compared to the PMFM, flood season water levels were very low compared to average conditions and dry season flows were generally very high. During limited periods, dry season flows at Vientiane were below the 1:20 ARI (zone 4) in 2020.
- Hydropower operations at Xayaburi causes substantial water level fluctuations downstream, which are greatly reduced, but still present at Chiang Khan. Fluctuations include dry season shaping of flows to target peak power demands, and the release of large flow volumes during large storm events and the release of water from tributary impoundments;
- The sediment load at Chiang Khan has decreased from ~15 – 36 Mt/yr to <5 Mt/yr since 2018. This is likely attributable to a decrease in sediment input from tributaries due to the commissioning of HPPs in the Nam Ou, Nam Khan and other upstream tributaries, and the trapping of sediment within the Xayaburi impoundment;
- There is only a small increase in sediment load between Chiang Khan and Nong Khai, suggesting that the availability of sediment for transport between the sites is limited;
- There continues to be a large increase in flow and SSC loads between Nong Khai and Pakse, although SSC concentrations are relatively uniform throughout the LMB;
- SSC loads at Kratie have decreased substantially compared to historic results. The estimated SSC loads at Kratie for 2019 and 2020 are 31 Mt/yr and 34 Mt/yr, which is lower than the ~100 Mt/yr recorded by DSM monitoring in the early 2010s (Koehnken, 2015) or earlier estimates of up to 160 Mt/yr at Pakse (Walling, 2005). Perhaps ~30 Mt of the decrease could be attributable to reductions in the upper LMB (China, tributary dams, Xayaburi), with the remaining reduction attributable to trapping in tributary dams downstream of Nong Khai. Decreases of this magnitude are likely to have substantial geomorphic impacts on the floodplain and delta, and affect water quality through changes in nutrient transport and light penetration into the river.

9.2 Hydrology and sediment recommendations

The following are recommended to continue to enhance the understanding of hydrology and sediment transport in the LMB, and to maximise the investment that has been made in the JEM pilot projects:

- Discharge and SSC monitoring are recommended to continue at the new JEM sites of Ban Xang Hai, Ban Pakhoung and Stung Treng-Up. Additional monitoring at Ban Xang Hai will quantify how much sediment remains in the upper LMB upstream of Xayaburi, and the second will measure how much is being transported through the impoundment. Monitoring at Stung Treng Up quantifies the flow and sediment load in the Mekong upstream of the 3S input, and provides a measure of the cumulative change to hydrology and sediment input upstream of this major confluence.

- Rating curves at all HYCOS sites should be reviewed using data collected since 2012. The review should be based on ADCP measurements corrected for bed movement where possible. Rating curves provide the crucial link between water level and water flow in the river, and constant checking and revision are required to ensure accurate flow records in the river. This is critical for the PMFM, flood forecasting and understanding changes due to hydropower and other water resource developments.
- The MRC should work with the MCs and hydropower operators to develop an effective and rapid communication system to disseminate information about potential water releases or other operations at HPPs to relevant stakeholders.
- The MRC should work with the MCs and hydropower operators to provide a reporting mechanism for the operation of low-level gates at HPPs that will affect sediment transport in the river.
- Consideration should be given to transitioning from D96-depth integrated sampling for SSC to in situ based laser techniques. The lack of availability of the D96 equipment prevents wide-spread use of this technology. A period of overlap between technologies should be included in any transition to provide an understanding of how the new measurements relate to the historic SSC results.
- Ongoing capacity building is recommended in the following areas:
    - Field measurement of discharge using ADCP technology. Many of the reported discharge measurements are not accurately collected due to incomplete compass calibration, lack of correction for a moving bed or other issues;
    - Laboratory analyses associated with bed material and SSC grain-size distribution are recommended. If possible, investment should be made in lab or field based grain-size analysers such that accurate results can be obtained with a low investment in time.
- Additional geomorphic investigations should be implemented. The JEM strategy included photo monitoring at each of the sites, and the collection of repeat cross-sections at several sites (deep-pool areas) between Chiang Khan and Nong Khai. No photos have been reported by the monitoring groups and due to Covid, the trans-boundary cross sections could not be completed. These types of geomorphic investigations should be pursued under future monitoring.

9.3 Water Quality recommendations

The water quality monitoring has shown some interesting results in both Xayaburi and Don Sahong, even if these do not show impacts with passage through the impoundments and downstream, and with very little evidence of stratification of the impoundments.

Water quality measurements around these dams should be continued to include at least the full year of monthly results, especially during the wet season. It is noted that the water levels and flows in this wet season have been low so may not be typical of wet seasons with greater rainfall.

Because the monthly samples are spot samples, it is recommended that continuous monitoring equipment be established at both sites as close to the dam as it is possible to get a representative sample of the water, in order to test the daily variation in different parameters. It is noted that a continuous WQ monitoring probe is being constructed at Don Sahong, measuring Temperature, pH, Dissolved Oxygen, Conductivity and Turbidity.

Other important parameters are Total Suspended Solids, nutrients and the Chlorophyll-a and Cyanobacteria. The relationship between Turbidity and Total Suspended Solids should be investigated to establish an equivalence curve suitable for Mekong waters. The proportions of dissolved and sediment-bound nutrients in the Total Nitrogen and Total Phosphorus should also be investigated to understand how much nutrients are being trapped with sediments in the impoundments.

The results of water quality monitoring taken by the hydropower companies should be compared with the JEM results and both should be related to operation details provided by the companies.

9.4 Ecological Health Recommendations

The monitoring of Ecological Health around the JEM pilot sites showed some clear indications of degradation of the aquatic biota within the impoundments and downstream of the dams, and also showing signs of recovery with distance downstream of the dams.

The EHM method has shown that it is sensitive to the changes likely to occur in the localised habitats around hydropower. The correlation with results from water quality monitoring, flows and water levels and sediment transport are likely to be important in order to interpret the impacts. The correlation with changes in fisheries monitoring is likely to depend upon the overall productivity of the sites and the trophic guilds of the prevalent fish species.

Monitoring of the aquatic biota requires both time and effort, and expertise, which means that it can only be realistically done once a year at times of low flow. It is recommended that a quicker method of assessing the aquatic health, based upon the presence of Littoral Macroinvertebrates be developed to be used more frequently and in additional locations, in order to complement the annual or biennial monitoring campaigns. The results from the JEM pilots indicate that the Littoral Macroinvertebrates are the most sensitive of the biota to the changes in the river typical of hydropower.

With a more rapid and easily deployable EH method, it is recommended that additional sites downstream of dams be assessed in order to increase our understanding of the length of the recovery zone downstream.

The EHM biota for inundation and reservoir areas are likely to be very different from riverine areas with different tolerances. It will be important in the long-term to build up a series of reference sites within reservoirs of both mainstream and tributaries, so that quality changes in the reservoirs can be compared.

9.5 Fisheries recommendations

Deepening the initial results and preliminary conclusions presented here is possible through the development of the following recommended activities:

- Undertake a gear use analysis (gears involved, mesh sizes and sizes, intensity of use) in Pha-O, Thadeua and Thamuang sites in Xayaburi to better identify the reasons for changes in average monthly catch per fisher;
- Complement the above analysis with interviews of local fishers to ensure consistency of conclusions from both approaches;
- Undertake a species analysis in reservoirs – in particular Xayaburi impoundment – to assess the extent of change in species composition and fish community dynamics;
- Cross current results with socioeconomic data (e.g. from dam operators as part of resettlement and compensation programs) and fish price data to determine whether the involvement of fisher is reduced for fish availability or commercial reasons and if livelihood diversification can explain or compensate a reduced involvement in fisheries;
- Undertake a review of species diversity and their trends in the tributaries monitored by the FADM programme, in order to compare these results with those of areas under mainstream dam influence, and identify remaining sources of fish biodiversity in key tributaries for replenishment (case of mitigation activities);

- Consider a study of local fish taxonomy in both Southern Lao and Northern Cambodia, in order to identify whether the different diversity levels identified on each side of the border result or not from a difference in local fish naming– and amend data accordingly if that is the case, by standardizing taxonomic categories in all countries.
- Similarly, standardize fishing gear names throughout the basin in the FADM database;
- Review and compare the implementation of the FADM protocol in Southern Lao and in Northern Cambodia, in order to identify possible discrepancies explaining contradictions about CPUE and average catch per fisher in close sites on each site of the border;
- Start as soon as possible the systematic implementation of the revised gillnet protocol, i.e. 3 sets of nets with 10x2.5 m panels (Gillnet ID1: 20-50-40-30-60 mm to be set near banks; Gillnet ID2: 70-90-100-80-110 mm to be set in suitable locations decided by fishers; and Gillnet ID3: 120-150-140-130 mm to be set in the middle of the river).

10 REFERENCES

Amornsakchai S., Annez P., Vongvisessomjai S., Choowaew S., Kunurat P., Nippanon J., Schouten R., Sripapatrprasite, P., Vaddhanaphuti C., Vidthayanon C., Wirojanagud W., Watana E. (2000). Pak Mun dam, Mekong River Basin, Thailand. A WCD Case Study prepared as an input to the World Commission on Dams, Cape Town, South Africa. [Online: www. dams. org]. 191 pp.

Bangkok Post (2021) Power plant shares effects of Cempaka storm, 27 July 2021, https://www.bangkokpost.com/thailand/general/2155675/power-plant-shares-effects-of-cempaka-storm?fbclid=IwAR09znDNqOKGjwpoEY1qI6E_8Fbe777A8iGxKg_r41RxTkj93_PLu6wsArI

Baran E., P. Starr, and Y. Kura. (2007). Influence of built structures on Tonle Sap fisheries. Cambodia National Mekong Committee and the WorldFish Center. Phnom Penh, Cambodia. 44 pages.

Bernacsek G. M. 1997. Large dam fisheries of the Lower Mekong countries: review and assessment. Main Report. Project on Management of Fisheries Reservoirs in the Mekong Basin, Mekong River Commission, Phnom Penh, Cambodia. 1;118 pp.

Bravard, J., Goichot, M. & Gaillot, S., (2013). Geography of Sand and Gravel Mining in the Lower Mekong River. *EchoGéo,* Volume 26.

Jordan, C. et al., 2019. Sand mining in the Mekong Delta revisited - current scales of local sediment deficits. *Scientific Reports nature research,* Volume 9:17823.

Koehnken, L (2015) Discharge Sediment Monitoring Project (DSMP) 2009 – 2013 Summary & Analysis of Results. Final Report. Report for the MRC Secretariat.

Marmulla G. (ed.). (2001). Dams, fish and fisheries: opportunities, challenges and conflict resolution. Fisheries Technical Paper 419, FAO, Rome, Italy. 170 pp.

Mekong River Commission (2021) Mekong River levels see strong pulse due to heavy rain, dam releases. News & Events , July 28, 2021. https://www.mrcmekong.org/news-and-events/news/pr-20210728/?fbclid=IwAR1BcSLc7N-1r-aA-g7aefMqgfcjpJVpoBFNthLPwthuq2VcQeyekqwTNzI

Mekong River Commission. (2005). Overview of the Hydrology of the Mekong Basin. Mekong River Commission, Vientiane, November 2005. 73pp.

Mekong River Commission. (2020). The MRC Hydropower Mitigation Guidelines. Guidelines for hydropower environmental impact mitigation and risk management in the Lower Mekong mainstream and tributaries (vol. 3), Vientiane, MRC Secretariat.

Mekong River Commission (2013) Technical Guidelines on the implementation of the Procedures for Water Quality.

Someth, P., Seebacher, F., Khem, S., Kong, S., Preap, S. (2013) Preliminary analysis – Rating curves for mainstream and tributaries of the Mekong River, Information and Knowledge Management Programme (IKMP), Mekong River Commission Secretariat (MRCS).

Trung Bui-Ba, Thanh-Son Dao, Thanh-Son Nguyen, Thi-My-Chi Vo,Lan-Chi Do-Hong, Miquel Lurling (2016). Blue-Green Algae (Cyanobacteria) in Mekong River, Vietnam. Institute for Environment and Resources, Vietnam

Walling, D., (2005). Evaluation and Analysis of sediment data from the Lower Mekong River. Final Report. Report to the Mekong River Commission.

Water Quality Research Australia Limited (2010). Management Strategies for Cyanobacteria (Blue-Green Algae) and their Toxins: a Guide for Water Utilities. Research Report 74.

World Health Organization. (2003) Guidelines for safe recreational water environments. Volume 1, Coastal and fresh waters.

ANNEXES

Annex 1: Mapping of monitoring stations in different disciplines per zone

Table 0-1: Caption of monitoring sites mapped

TH 013101: NP	**Light blue: DSM monitoring sites (hydrology)**
LA 011502: WQ2	**Purple: water quality monitoring sites**
TH 010502: TCS	**Green: environmental biomonitoring sites**
KH 014002: CST	**Pink: FADM (fisher monitoring) sites**
LA014300: LMK	**Yellow: FLDM (fish larvae) monitoring**

Figure 0-1: Monitoring sites downstream of the border between China and Laos

Figure 0-2: Monitoring sites near Pak Beng

Figure 0-3: Monitoring sites north of Luang Prabang

Figure 0-4: Monitoring sites upstream of Xayaburi dam site

Figure 0-5: Monitoring sites downstream of Xayaburi site

Figure 0-6: Monitoring sites downstream of Sanakham site

Figure 0-7: Monitoring sites near Vientiane

Figure 0-8: Monitoring sites near Thakhek / Nakhon Phanom

Figure 0-9: Monitoring sites around Pakse

Figure 0-10: Monitoring sites upstream of Don Sahong site

Figure 0-11: Monitoring sites at Don Sahong dam reservoir

Figure 0-12: Monitoring sites downstream of Don Sahong reservoir

Figure 0-13: Monitoring sites in Cambodia between Don Sahong site and Stung Treng

Figure 0-14: Monitoring sites in Cambodia around Kratie

Annex 2 : Monthly Water Quality results for Xayaburi

Table 0-2: Xayaburi JEM Pilot Results for Temperature, pH, Conductivity, Dissolved Oxygen (DO), Total Suspended Solids (TSS) and Turbidity, October 2020 to June 2021

Station Name	STATID	DATE	Year	Month	TEMP_°C	pH	COND_mS/m	DO_mg/L	TSS_mg/L	Turbidity_FTU
Water Quality Guideline threshold (Human Health)					**Natural**	**6 - 9**	**70 - 150**	**>4**	**-**	**-**
Water Quality Guideline threshold (Aquatic Life)					**Natural**	**6 - 9**	**>150**	**>5**	**-**	**-**
Luang Prabang	H011200	October 20, 2020	2020	10	25.80	7.50	21.20	7.32	37.83	
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	October 15, 2020	2020	10	25.40	8.04	22.70	6.09	41.83	32.20
Within the Xayaburi Impoundment, 1 km above dam	WQ2	October 18, 2020	2020	10	26.40	8.42	23.00	6.51		8.09
Xayaburi downstream around 1-2 km from dam	WQ3	October 14, 2020	2020	10	25.30	8.12	22.80	6.17		9.81
Xayaburi downstream around 4 km from dam	WQ4	October 18, 2020	2020	10	25.30	8.15	22.80	5.76	7.50	9.66
Pakhoung Village, 10-km downstream of dam	WQ5	October 16, 2020	2020	10	25.30	8.04	22.90	5.41		9.39
Vientiane	H011901	October 16, 2020	2020	10	28.00	7.03	17.10	6.00	51.33	
Luang Prabang	H011200	November 25, 2020	2020	11	25.60	7.80	20.30	7.55	92.52	
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	November 14, 2020	2020	11	24.30	8.18	24.80	6.51	50.20	31.70
Within the Xayaburi Impoundment, 1 km above dam	WQ2	November 15, 2020	2020	11	25.50	8.44	25.40	6.80		8.05
Xayaburi downstream around 1-2 km from dam	WQ3	November 11, 2020	2020	11	24.84	8.31	25.30	6.11		8.43
Xayaburi downstream around 4 km from dam	WQ4	November 19, 2020	2020	11	24.81	8.29	25.30	6.09	111.00	8.43
Pakhoung Village, 10-km downstream of dam	WQ5	November 15, 2020	2020	11	24.79	8.24	25.30	6.24		8.23
Vientiane	H011901	November 16, 2020	2020	11	26.10	6.79	11.30	6.50	14.87	
Luang Prabang	H011200	December 18, 2020	2020	12	26.60	7.30	25.80	7.01	26.90	
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	December 14, 2020	2020	12	22.11	8.36	18.90	7.90	20.90	20.90
Within the Xayaburi Impoundment, 1 km above dam	WQ2	December 18, 2020	2020	12	23.30	8.47	27.10	8.81		7.18
Xayaburi downstream around 1-2 km from dam	WQ3	December 15, 2020	2020	12	22.90	8.41	27.10	8.76		7.34
Xayaburi downstream around 4 km from dam	WQ4	December 16, 2020	2020	12	22.90	8.44	27.00	8.80	90.11	7.03
Pakhoung Village, 10-km downstream of dam	WQ5	December 15, 2020	2020	12	22.80	8.34	27.10	9.04		6.56
Vientiane	H011901	December 11, 2020	2020	12	23.90	7.69	10.40	7.33	8.80	
Luang Prabang	H011200	January 14, 2021	2021	1	22.4	7.46	46.20	7.45	70.28	
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	January 13, 2021	2021	1	21.14	8.29	20.00	6.90	26.33	20.00
Within the Xayaburi Impoundment, 1 km above dam	WQ2	January 13, 2021	2021	1	21.30	8.39	296.00	6.66		6.57
Xayaburi downstream around 1-2 km from dam	WQ3	January 13, 2021	2021	1	21.33	8.37	297.00	6.35		7.17
Xayaburi downstream around 4 km from dam	WQ4	January 13, 2021	2021	1	21.36	8.41	29.7	6.38	4.30	6.76
Pakhoung Village, 10-km downstream of dam	WQ5	January 13, 2021	2021	1	21.34	8.38	297.00	6.49		6.93
Vientiane	H011901	January 15, 2021	2021	1	20.90	7.11	31.50	8.45	7.30	
Luang Prabang	H011200	February 15, 2021	2021	2	24.2	7.88	30.20	6.80	2.90	
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	February 15, 2021	2021	2	21.88	8.34	29.31	6.18	9.60	11.03
Within the Xayaburi Impoundment, 1 km above dam	WQ2	February 13, 2021	2021	2	22.19	7.96	29.30	6.84		5.57
Xayaburi downstream around 1-2 km from dam	WQ3	February 13, 2021	2021	2	22.06	8.44	29.30	6.48		6.14
Xayaburi downstream around 4 km from dam	WQ4	February 13, 2021	2021	2	22.07	8.42	29.30	6.54	4.60	5.90
Pakhoung Village, 10-km downstream of dam	WQ5	February 13, 2021	2021	2	22.15	8.39	29.30	6.76		5.69
Vientiane	H011901	February 18, 2021	2021	2	24.20	7.57	30.20	8.35	5.00	
Luang Prabang	H011200	March 18, 2021	2021	3	28.80	7.72	33.20	6.90	13.80	
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	March 13, 2021	2021	3	22.82	7.22	30.43	7.22	14.20	9.04
Within the Xayaburi Impoundment, 1 km above dam	WQ2	March 14, 2021	2021	3	23.35	8.22	29.92	8.22		5.21
Xayaburi downstream around 1-2 km from dam	WQ3	March 14, 2021	2021	3	23.30	8.37	30.00	8.33		5.29
Xayaburi downstream around 4 km from dam	WQ4	March 14, 2021	2021	3	23.32	8.40	30.00	8.35	3.00	5.39
Pakhoung Village, 10-km downstream of dam	WQ5	March 14, 2021	2021	3	23.33	8.41	30.00	8.44		5.36
Vientiane	H011901	March 19, 2021	2021	3	27.20	7.97	31.60	7.71	6.00	
Luang Prabang	H011200	N/M	2021	4						
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	April 6, 2021	2021	4	23.66	8.42	37.57	7.95	12.75	11.11
Within the Xayaburi Impoundment, 1 km above dam	WQ2	April 7, 2021	2021	4	23.86	8.61	37.00	8.11		3.50
Xayaburi downstream around 1-2 km from dam	WQ3	April 7, 2021	2021	4	23.48	8.54	36.79	8.22		4.41
Xayaburi downstream around 4 km from dam	WQ4	April 7, 2021	2021	4	23.47	8.51	36.80	8.25	3.60	4.44
Pakhoung Village, 10-km downstream of dam	WQ5	April 7, 2021	2021	4	23.46	8.45	36.77	8.30		4.40
Vientiane	H011901	N/M	2021	4						
Luang Prabang	H011200	May 18, 2021	2021	5	26.1	7.91	28.10	7.90	71.50	
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	N/M	2021	5						
Within the Xayaburi Impoundment, 1 km above dam	WQ2	N/M	2021	5						
Xayaburi downstream around 1-2 km from dam	WQ3	N/M	2021	5						
Xayaburi downstream around 4 km from dam	WQ4	N/M	2021	5						
Pakhoung Village, 10-km downstream of dam	WQ5	N/M	2021	5						
Vientiane	H011901	May 20, 2021	2021	5	28.00	7.97	31.30	6.66	49.12	
Luang Prabang	H011200	June 15, 2021	2021	6	28.7	7.77	31.10	8.09	62.60	
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	June 21, 2021	2021	6	23.89	7.18	28.60	7.30	22.50	12.30
Within Xayaburi Impoundment, 1 km above dam	WQ2	June 22, 2021	2021	6	23.06	8.07	31.80	7.25		6.31
Xayaburi downstream around 1-2 km from dam	WQ3	June 22, 2021	2021	6	23.74	8.22	34.39	8.04		5.48
Xayaburi downstream around 4 km from dam	WQ4	June 22, 2021	2021	6	23.72	8.14	38.20	8.08	8.50	5.45
Pakhoung Village, 10-km downstream of dam	WQ5	June 22, 2021	2021	6	24.06	8.14	38.17	8.18		5.49
Vientiane	H011901	June 11, 2021	2021	6	28.10	7.91	32.90	6.69	88.25	

Table 0-3: Xayaburi JEM Pilot Results for Nutrients and Phytoplankton, October 2020 to June 2021

Station Name	STATID	DATE	Year	Month	NO32_mg/L	TOTN_mg/L	TOTP_mg/L	Chlorophyll A_ug/L	Cyanobacteria_ug/L
Water Quality Guideline threshold (Human Health)					**5.00**	**-**	**-**	**> 50 micrograms/l**	**Predominance**
Water Quality Guideline threshold (Aquatic Life)					**0.50**	**-**	**0.13**	**-**	**-**
Luang Prabang	H011200	October 20, 2020	2020	10	0.03	0.50	0.12		
Upstream of Xayaburi c. 110 km upstream of da	WQ1	October 15, 2020	2020	10	0.40	1.10	0.08	0.00	0.00
Within Xayaburi Impoundment, 1 km above da	WQ2	October 18, 2020	2020	10	0.72		0.02	0.30	0.07
Xayaburi downstream around 1-2 km from dam	WQ3	October 14, 2020	2020	10	0.90		0.04	0.00	0.00
Xayaburi downstream around 4 km from dam	WQ4	October 18, 2020	2020	10	0.49	1.01	0.04	0.00	0.00
Pakhoung Village, 10-km downstream of dam	WQ5	October 16, 2020	2020	10	0.80		0.26	0.00	0.00
Vientiane	H011901	October 16, 2020	2020	10	0.07	0.44	0.01		
Luang Prabang	H011200	November 25, 2020	2020	11	0.17	3.22	0.01		
Upstream of Xayaburi c. 110 km upstream of da	WQ1	November 14, 2020	2020	11	0.44	4.18	0.04	0.00	0.00
Within Xayaburi Impoundment, 1 km above da	WQ2	November 15, 2020	2020	11	0.55		0.03	0.23	0.10
Xayaburi downstream around 1-2 km from dam	WQ3	November 11, 2020	2020	11	0.56		0.04	0.20	0.00
Xayaburi downstream around 4 km from dam	WQ4	November 19, 2020	2020	11	0.67	3.44	0.02	0.11	0.00
Pakhoung Village, 10-km downstream of dam	WQ5	November 15, 2020	2020	11	0.52		0.25	0.10	0.01
Vientiane	H011901	November 16, 2020	2020	11	0.07	3.53	0.05		
Luang Prabang	H011200	December 18, 2020	2020	12	0.07	0.72	0.09		
Upstream of Xayaburi c. 110 km upstream of da	WQ1	December 14, 2020	2020	12	0.58	1.22	4.65	0.00	0.00
Within Xayaburi Impoundment, 1 km above da	WQ2	December 18, 2020	2020	12	0.38		6.50	0.40	0.00
Xayaburi downstream around 1-2 km from dam	WQ3	December 15, 2020	2020	12	0.30		4.20	0.41	0.00
Xayaburi downstream around 4 km from dam	WQ4	December 16, 2020	2020	12	0.15	1.03	0.10	0.70	0.00
Pakhoung Village, 10-km downstream of dam	WQ5	December 15, 2020	2020	12	0.58		1.04	0.30	0.00
Vientiane	H011901	December 11, 2020	2020	12	0.06	1.35	0.05		
Luang Prabang	H011200	January 14, 2021	2021	1	0.54	0.76	0.01		
Upstream of Xayaburi c. 110 km upstream of da	WQ1	January 13, 2021	2021	1	0.54	1.50	0.02	1.87	1.24
Within Xayaburi Impoundment, 1 km above da	WQ2	January 13, 2021	2021	1	0.47		0.01	1.60	1.31
Xayaburi downstream around 1-2 km from dam	WQ3	January 13, 2021	2021	1	0.52		0.02	1.74	1.16
Xayaburi downstream around 4 km from dam	WQ4	January 13, 2021	2021	1	0.55	0.94	0.02	1.90	1.13
Pakhoung Village, 10-km downstream of dam	WQ5	January 13, 2021	2021	1	0.85		0.02	1.61	1.27
Vientiane	H011901	January 15, 2021	2021	1	0.32	0.41	0.01		
Luang Prabang	H011200	February 15, 2021	2021	2	0.36	0.96	0.01		
Upstream of Xayaburi c. 110 km upstream of da	WQ1	February 15, 2021	2021	2	0.43	1.01	0.01	1.54	0.00
Within Xayaburi Impoundment, 1 km above da	WQ2	February 13, 2021	2021	2	0.44		0.01	1.36	0.01
Xayaburi downstream around 1-2 km from dam	WQ3	February 13, 2021	2021	2	0.38		0.01	0.46	0.00
Xayaburi downstream around 4 km from dam	WQ4	February 13, 2021	2021	2	0.43	0.88	0.01	0.44	0.04
Pakhoung Village, 10-km downstream of dam	WQ5	February 13, 2021	2021	2	0.33		0.01	0.81	0.00
Vientiane	H011901	February 18, 2021	2021	2	0.19	0.78	0.02		
Luang Prabang	H011200	March 18, 2021	2021	3	0.55	0.68	0.02		
Upstream of Xayaburi c. 110 km upstream of da	WQ1	March 13, 2021	2021	3	0.66	1.42	0.07	3.16	0.03
Within Xayaburi Impoundment, 1 km above da	WQ2	March 14, 2021	2021	3	1.69		0.07	3.21	0.03
Xayaburi downstream around 1-2 km from dam	WQ3	March 14, 2021	2021	3	1.54		0.05	1.11	0.00
Xayaburi downstream around 4 km from dam	WQ4	March 14, 2021	2021	3	0.84	1.21	0.03	1.47	0.01
Pakhoung Village, 10-km downstream of dam	WQ5	March 14, 2021	2021	3	1.89		0.06	1.56	0.00
Vientiane	H011901	March 19, 2021	2021	3	0.34	0.41	0.01		
Luang Prabang	H011200	April	2021	4					
Upstream of Xayaburi c. 110 km upstream of da	WQ1	April 6, 2021	2021	4	0.29	0.35	0.01	1.40	0.30
Within Xayaburi Impoundment, 1 km above da	WQ2	April 7, 2021	2021	4	0.25		0.02	2.20	0.60
Xayaburi downstream around 1-2 km from dam	WQ3	April 7, 2021	2021	4	0.37		0.03	0.77	0.00
Xayaburi downstream around 4 km from dam	WQ4	April 7, 2021	2021	4	0.17	0.33	0.01	0.54	0.03
Pakhoung Village, 10-km downstream of dam	WQ5	April 7, 2021	2021	4	0.30		0.01	0.40	0.00
Vientiane	H011901	April	2021	4					
Luang Prabang	H011200	May 18, 2021	2021	5	0.31	0.34	0.02		
Upstream of Xayaburi c. 110 km upstream of da	WQ1	May	2021	5					
Within Xayaburi Impoundment, 1 km above da	WQ2	May	2021	5					
Xayaburi downstream around 1-2 km from dam	WQ3	May	2021	5					
Xayaburi downstream around 4 km from dam	WQ4	May	2021	5					
Pakhoung Village, 10-km downstream of dam	WQ5	May	2021	5					
Vientiane	H011901	May 20, 2021	2021	5	0.37	0.42	0.02		
Luang Prabang	H011200	June 15, 2021	2021	6	0.29	0.50	0.02		
Upstream of Xayaburi c. 110 km upstream of da	WQ1	June 21, 2021	2021	6	0.31	0.52	0.09	1.08	0.11
Within Xayaburi Impoundment, 1 km above da	WQ2	June 22, 2021	2021	6	0.28		0.05	1.53	0.01
Xayaburi downstream around 1-2 km from dam	WQ3	June 22, 2021	2021	6	0.29		0.05	0.96	0.03
Xayaburi downstream around 4 km from dam	WQ4	June 22, 2021	2021	6	0.24	0.55	0.04	0.84	0.01
Pakhoung Village, 10-km downstream of dam	WQ5	June 22, 2021	2021	6	0.33		0.03	0.60	0.00
Vientiane	H011901	June 11, 2021	2021	6	0.25	0.36	0.03		

Table 0-4: Xayaburi JEM Pilot Results for pollutants, Ammonium, COD and Faecal coliforms, October 2020 to June 2021

Station Name	STATID	DATE	Year	Month	NH4N_mg/L	CODMN_mg/L	FC _MPN/100ml
Water Quality Guideline threshold (Human Health)					**0.50**	**5.0**	**1000 cells/100ml**
Water Quality Guideline threshold (Aquatic Life)					**0.10**	-	-
Luang Prabang	H011200	October 20, 2020	2020	10	0.06	1.35	40
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	October 15, 2020	2020	10	0.07	1.54	130
Within Xayaburi Impoundment, 1 km above dam	WQ2	October 18, 2020	2020	10			
Xayaburi downstream around 1-2 km from dam	WQ3	October 14, 2020	2020	10			
Xayaburi downstream around 4 km from dam	WQ4	October 18, 2020	2020	10	0.45	0.77	110
Pakhoung Village, 10-km downstream of dam	WQ5	October 16, 2020	2020	10			
Vientiane	H011901	October 16, 2020	2020	10	0.03	9.30	27
Luang Prabang	H011200	November 25, 2020	2020	11	0.03	1.93	40
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	November 14, 2020	2020	11	0.05	2.70	45
Within Xayaburi Impoundment, 1 km above dam	WQ2	November 15, 2020	2020	11			
Xayaburi downstream around 1-2 km from dam	WQ3	November 11, 2020	2020	11			
Xayaburi downstream around 4 km from dam	WQ4	November 19, 2020	2020	11	0.04	0.96	40
Pakhoung Village, 10-km downstream of dam	WQ5	November 15, 2020	2020	11			
Vientiane	H011901	November 16, 2020	2020	11	0.05	1.35	40
Luang Prabang	H011200	December 18, 2020	2020	12	0.01	0.76	78
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	December 14, 2020	2020	12	0.02	0.35	45
Within Xayaburi Impoundment, 1 km above dam	WQ2	December 18, 2020	2020	12			
Xayaburi downstream around 1-2 km from dam	WQ3	December 15, 2020	2020	12			
Xayaburi downstream around 4 km from dam	WQ4	December 16, 2020	2020	12	0.01	0.40	110
Pakhoung Village, 10-km downstream of dam	WQ5	December 15, 2020	2020	12			
Vientiane	H011901	December 11, 2020	2020	12	0.01	0.88	20
Luang Prabang	H011200	January 14, 2021	2021	1	0.01	4.93	220
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	January 13, 2021	2021	1	0.05	3.49	110
Within Xayaburi Impoundment, 1 km above dam	WQ2	January 13, 2021	2021	1			
Xayaburi downstream around 1-2 km from dam	WQ3	January 13, 2021	2021	1			
Xayaburi downstream around 4 km from dam	WQ4	January 13, 2021	2021	1	0.07	1.82	45
Pakhoung Village, 10-km downstream of dam	WQ5	January 13, 2021	2021	1			
Vientiane	H011901	January 15, 2021	2021	1	0.04	1.21	110
Luang Prabang	H011200	February 15, 2021	2021	2	0.01	0.60	<18
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	February 15, 2021	2021	2	0.01	8.11	130
Within Xayaburi Impoundment, 1 km above dam	WQ2	February 13, 2021	2021	2			
Xayaburi downstream around 1-2 km from dam	WQ3	February 13, 2021	2021	2			
Xayaburi downstream around 4 km from dam	WQ4	February 13, 2021	2021	2	0.01	1.57	<18
Pakhoung Village, 10-km downstream of dam	WQ5	February 13, 2021	2021	2			
Vientiane	H011901	February 18, 2021	2021	2	0.01	1.18	91
Luang Prabang	H011200	March 18, 2021	2021	3	0.03	1.17	<18
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	March 13, 2021	2021	3	0.01	0.40	110
Within Xayaburi Impoundment, 1 km above dam	WQ2	March 14, 2021	2021	3			
Xayaburi downstream around 1-2 km from dam	WQ3	March 14, 2021	2021	3			
Xayaburi downstream around 4 km from dam	WQ4	March 14, 2021	2021	3	0.01	0.80	<18
Pakhoung Village, 10-km downstream of dam	WQ5	March 14, 2021	2021	3			
Vientiane	H011901	March 19, 2021	2021	3	0.01	1.15	78
Luang Prabang	H011200	April	2021	4			
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	April 6, 2021	2021	4	0.02	1.54	180
Within Xayaburi Impoundment, 1 km above dam	WQ2	April 7, 2021	2021	4			
Xayaburi downstream around 1-2 km from dam	WQ3	April 7, 2021	2021	4			
Xayaburi downstream around 4 km from dam	WQ4	April 7, 2021	2021	4	0.02	2.70	45
Pakhoung Village, 10-km downstream of dam	WQ5	April 7, 2021	2021	4			
Vientiane	H011901	April	2021	4			
Luang Prabang	H011200	May 18, 2021	2021	5	0.01	1.37	<18
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	May	2021	5			
Within Xayaburi Impoundment, 1 km above dam	WQ2	May	2021	5			
Xayaburi downstream around 1-2 km from dam	WQ3	May	2021	5			
Xayaburi downstream around 4 km from dam	WQ4	May	2021	5			
Pakhoung Village, 10-km downstream of dam	WQ5	May	2021	5			
Vientiane	H011901	May 20, 2021	2021	5	0.01	1.20	<18
Luang Prabang	H011200	June 15, 2021	2021	6	0.01	0.10	45
Upstream of Xayaburi c. 110 km upstream of dam	WQ1	June 21, 2021	2021	6	0.04	2.24	110
Within Xayaburi Impoundment, 1 km above dam	WQ2	June 22, 2021	2021	6			
Xayaburi downstream around 1-2 km from dam	WQ3	June 22, 2021	2021	6			
Xayaburi downstream around 4 km from dam	WQ4	June 22, 2021	2021	6	0.01	3.20	68
Pakhoung Village, 10-km downstream of dam	WQ5	June 22, 2021	2021	6			
Vientiane	H011901	June 11, 2021	2021	6	0.01	0.44	78

Annex 3 : Monthly Water Quality results for Don Sahong

Table 0-5: Don Sahong JEM Pilot Results for Temperature, pH, Conductivity, Dissolved Oxygen, Total Suspended Solids and Turbidity, October 2020 to June 2021

Station Name	STATID	DATE	Year	Month	TEMP_°C	pH	COND_mS/m	DO_mg/L	TSS_mg/L	Turbidity_FTU
Water Quality Guideline threshold (Human Health)					**Natural**	**6 - 9**	**70 - 150**	**>4**	**-**	**-**
Water Quality Guideline threshold (Aquatic Life)					**Natural**	**6 - 9**	**>150**	**>5**	**-**	**-**
Pakse	H013900	October 14, 2020	2020	10	25.70	7.16	18.50	7.12	195.25	
Upstream of Don Sahong impoundment	WQ6	October 18, 2020	2020	10	25.60	7.33	10.70	7.31	186.60	241.00
Within the impoundment c. 600 m upstream of dam wall	WQ7	October 14, 2020	2020	10	25.60	7.09	10.20	5.96		253.00
Downstream of Don Sahong c. 250 m downstream of dam	WQ8	October 18, 2020	2020	10	25.70	7.63	10.60	7.83		156.00
Downstream of Don Sahong c. 700 m downstream of dam	WQ9	October 18, 2020	2020	10	25.60	7.31	10.70	6.57	193.75	159.00
Stung Treng	H014501	October 25, 2020	2020	10	29	6.6	13.2	8.2	244.0	
Pakse	H013900	November 25, 2020	2020	11	26.30	7.20	20.60	6.99	18.33	
Upstream of Don Sahong impoundment	WQ6	November 15, 2020	2020	11	27.42	5.87	21.10	7.04	31.50	27.00
Within the impoundment c. 600 m upstream of dam wall	WQ7	November 11, 2020	2020	11	27.28	5.94	21.00	7.83		27.21
Downstream of Don Sahong c. 250 m downstream of dam	WQ8	November 19, 2020	2020	11	27.45	6.67	20.80	8.43		26.80
Downstream of Don Sahong c. 700 m downstream of dam	WQ9	November 19, 2020	2020	11	27.46	7.98	21.00	9.17	4.33	28.10
Stung Treng	H014501	November 22, 2020	2020	11	30	7.8	22.8	7.40	38.2	
Pakse	H013900	December 21, 2020	2020	12	28.90	6.57	21.10	6.02	21.30	
Upstream of Don Sahong impoundment	WQ6	December 18, 2020	2020	12	26.40	8.42	24.90	7.81	8.70	7.60
Within the impoundment c. 600 m upstream of dam wall	WQ7	December 15, 2020	2020	12	26.33	8.40	24.80	7.26		8.13
Downstream of Don Sahong c. 250 m downstream of dam	WQ8	December 16, 2020	2020	12	26.66	8.46	24.90	7.91		8.30
Downstream of Don Sahong c. 700 m downstream of dam	WQ9	December 16, 2020	2020	12	26.70	8.46	24.90	8.00	6.75	8.60
Stung Treng	H014501	December 19, 2020	2020	12	29	7.8	24.3	8.1	50.7	
Pakse	H013900	January 14, 2021	2021	1	22.8	7.99	26.6	7.94	7.10	
Upstream of Don Sahong impoundment	WQ6	January 15, 2021	2021	1	22.70	8.54	264.00	8.92	4.55	5.40
Within the impoundment c. 600 m upstream of dam wall	WQ7	January 15, 2021	2021	1	23.00	8.55	265.00	8.52		7.04
Downstream of Don Sahong c. 250 m downstream of dam	WQ8	January 15, 2021	2021	1	22.70	8.64	264.00	8.66		9.00
Downstream of Don Sahong c. 700 m downstream of dam	WQ9	January 15, 2021	2021	1	22.90	8.61	264.00	8.83	4.00	5.80
Stung Treng	H014501	January 22, 2021	2021	1	29.50	7.4	28.5	6.29	3.4	
Pakse	H013900	February 13, 2021	2021	2	25.2	8.25	25.7	6.29	14.14	
Upstream of Don Sahong impoundment	WQ6	February 17, 2021	2021	2	26.23	8.58	26.30	8.04	7.40	6.41
Within the impoundment c. 600 m upstream of dam wall	WQ7	February 17, 2021	2021	2	26.24	8.49	26.23	7.83		7.29
Downstream of Don Sahong c. 250 m downstream of dam	WQ8	February 17, 2021	2021	2	26.33	8.56	26.33	8.25		7.36
Downstream of Don Sahong c. 700 m downstream of dam	WQ9	February 17, 2021	2021	2	26.33	8.59	26.30	8.20	9.80	7.47
Stung Treng	H014501	February 19, 2021	2021	2	29.30	7.3	24.7	7.50	4.4	
Pakse	H013900	March 13, 2021	2021	3	28.00	7.49	26.40	7.87	5.50	
Upstream of Don Sahong impoundment	WQ6	March 15, 2021	2021	3	28.55	8.11	26.95	7.84	4.30	4.59
Within the impoundment c. 600 m upstream of dam wall	WQ7	March 15, 2021	2021	3	28.74	8.22	27.00	7.83		5.09
Downstream of Don Sahong c. 250 m downstream of dam	WQ8	March 15, 2021	2021	3	28.77	8.26	26.93	8.03		5.04
Downstream of Don Sahong c. 700 m downstream of dam	WQ9	March 15, 2021	2021	3	28.74	8.28	26.90	7.97	4.40	5.14
Stung Treng	H014502	March 20, 2021	2021	3	30.40	7.5	24.2	7.65	4.9	
Pakse	H013900	N/M	2021	4						
Upstream of Don Sahong impoundment	WQ6	April 9, 2021	2021	4	28.72	7.85	23.90	7.33	5.00	5.30
Within the impoundment c. 600 m upstream of dam wall	WQ7	April 9, 2021	2021	4	28.85	8.00	23.94	7.06		6.60
Downstream of Don Sahong c. 250 m downstream of dam	WQ8	April 9, 2021	2021	4	28.87	8.08	23.94	7.33		6.13
Downstream of Don Sahong c. 700 m downstream of dam	WQ9	April 9, 2021	2021	4	28.86	8.09	23.90	7.31	6.00	5.99
Stung Treng	H014501	April 21, 2021	2021	4	29.40	7.6	23.6	7.40	6.9	
Pakse	H013900	May 15, 2121	2021	5	27.4	8.15	25.10	7.84	21.20	
Upstream of Don Sahong impoundment	WQ6	N/M	2021	5						
Within the impoundment c. 600 m upstream of dam wall	WQ7	N/M	2021	5						
Downstream of Don Sahong c. 250 m downstream of dam	WQ8	N/M	2021	5						
Downstream of Don Sahong c. 700 m downstream of dam	WQ9	N/M	2021	5						
Stung Treng	H014501	May 23, 2121	2021	5	31.00	7.8	24.3	7.13	11.1	
Pakse	H013900	June 13, 2021	2021	6	28.80	6.83	16.88	6.56	59.20	
Upstream of Don Sahong impoundment	WQ6	June 24, 2021	2021	6	28.86	7.53	27.45	7.52	11.20	5.45
Within the impoundment c. 600 m upstream of dam wall	WQ7	June 24, 2021	2021	6	29.16	7.74	29.41	7.11		5.73
Downstream of Don Sahong c. 250 m downstream of dam	WQ8	June 24, 2021	2021	6	29.50	8.04	26.17	7.50		6.67
Downstream of Don Sahong c. 700 m downstream of dam	WQ9	June 24, 2021	2021	6	29.85	8.31	25.80	7.52	16.00	6.19
Stung Treng	H014501	June 22, 2021	2021	6	30.60	7.9	24.7	7.28	56.9	

Table 0-6: Don Sahong JEM Pilot Results for Nutrients and Phytoplankton, October 2020 to June 2021

Station Name	STATID	DATE	Year	Month	NO32_mg/L	TOTN_mg/L	TOTP_mg/L	Chlorophyll A_ug/L	Cyanobacteria_ug/L
Water Quality Guideline threshold (Human Health)					**5.00**	**-**	**-**	**> 50 micrograms/l**	**Predominance**
Water Quality Guideline threshold (Aquatic Life)					**0.50**	**-**	**0.13**	**-**	**-**
Pakse	H013900	October 14, 2020	2020	10	0.03	0.42	0.04		
Upstream of Don Sahong impoundment	WQ6	October 18, 2020	2020	10	0.58	0.99	0.05	0.00	0.00
Within the impoundment c. 600 m upstream o	WQ7	October 14, 2020	2020	10	0.75		0.06	0.00	0.00
Downstream of Don Sahong c. 250 m downstre	WQ8	October 18, 2020	2020	10	0.72		0.04	0.00	0.00
Downstream of Don Sahong c. 700 m downstre	WQ9	October 18, 2020	2020	10	0.54	1.29	0.04	0.00	0.00
Stung Treng	H014501	25-Oct-20	2020	10	0.037	0.505	0.04		
Pakse	H013900	November 25, 2020	2020	11	0.10	1.75	0.03		
Upstream of Don Sahong impoundment	WQ6	November 15, 2020	2020	11	0.57	1.85	0.07	0.06	0.00
Within the impoundment c. 600 m upstream o	WQ7	November 11, 2020	2020	11	0.64		0.02	0.20	0.00
Downstream of Don Sahong c. 250 m downstre	WQ8	November 19, 2020	2020	11	0.32		0.25	0.10	0.00
Downstream of Don Sahong c. 700 m downstre	WQ9	November 19, 2020	2020	11	0.76	2.22	0.60	0.10	0.00
Stung Treng	H014501	22-Nov-20	2020	11	0.229	0.377	0.02		
Pakse	H013900	December 21, 2020	2020	12	0.04	0.57	0.06		
Upstream of Don Sahong impoundment	WQ6	December 18, 2020	2020	12	0.53	1.04	0.04	0.30	0.00
Within the impoundment c. 600 m upstream o	WQ7	December 15, 2020	2020	12	0.47		4.60	0.20	0.00
Downstream of Don Sahong c. 250 m downstre	WQ8	December 16, 2020	2020	12	0.51		0.02	0.50	0.05
Downstream of Don Sahong c. 700 m downstre	WQ9	December 16, 2020	2020	12	0.57	0.86	8.20	0.33	0.14
Stung Treng	H014501	19-Dec-20	2020	12	0.397	0.466	0.08		
Pakse	H013900	January 14, 2021	2021	1	0.35	0.89	0.02		
Upstream of Don Sahong impoundment	WQ6	January 15, 2021	2021	1	0.38	0.68	0.01	0.87	0.17
Within the impoundment c. 600 m upstream o	WQ7	January 15, 2021	2021	1	0.43		0.02	0.40	0.10
Downstream of Don Sahong c. 250 m downstre	WQ8	January 15, 2021	2021	1	0.26		0.01	1.40	0.15
Downstream of Don Sahong c. 700 m downstre	WQ9	January 15, 2021	2021	1	0.40	0.61	0.02	1.13	0.17
Stung Treng	H014501	22 January 2021	2021	1	0.042	0.096	0.033		
Pakse	H013900	February 13, 2021	2021	2	0.04	0.41	0.01		
Upstream of Don Sahong impoundment	WQ6	February 17, 2021	2021	2	0.08	0.32	0.01	1.07	0.44
Within the impoundment c. 600 m upstream o	WQ7	February 17, 2021	2021	2	0.06		0.01	1.49	0.57
Downstream of Don Sahong c. 250 m downstre	WQ8	February 17, 2021	2021	2	0.10		0.01	1.09	0.44
Downstream of Don Sahong c. 700 m downstre	WQ9	February 17, 2021	2021	2	0.06	0.25	0.01	1.37	0.43
Stung Treng	H014501	19 February 2021	2021	2	0.054	0.096	0.042		
Pakse	H013900	March 13, 2021	2021	3	0.29	0.48	0.02		
Upstream of Don Sahong impoundment	WQ6	March 15, 2021	2021	3	0.54	0.98	0.04	0.00	0.00
Within the impoundment c. 600 m upstream o	WQ7	March 15, 2021	2021	3	0.41		0.03	0.07	0.00
Downstream of Don Sahong c. 250 m downstre	WQ8	March 15, 2021	2021	3	0.34		0.02	0.10	0.03
Downstream of Don Sahong c. 700 m downstre	WQ9	March 15, 2021	2021	3	0.58	1.02	0.06	0.10	0.00
Stung Treng	H014502	20 March 2021	2021	3	0.031	0.077	0.044		
Pakse	H013900	April	2021	4					
Upstream of Don Sahong impoundment	WQ6	April 9, 2021	2021	4	0.23	0.42	0.02	0.31	0.00
Within the impoundment c. 600 m upstream o	WQ7	April 9, 2021	2021	4	0.12		0.01	0.33	0.10
Downstream of Don Sahong c. 250 m downstre	WQ8	April 9, 2021	2021	4	0.29		0.01	0.23	0.06
Downstream of Don Sahong c. 700 m downstre	WQ9	April 9, 2021	2021	4	0.24	0.52	0.01	0.27	0.01
Stung Treng	H014501	21 April 2021	2021	4	0.027	0.075	0.027		
Pakse	H013900	May 15, 2121	2021	5	0.28	0.39	0.02		
Upstream of Don Sahong impoundment	WQ6	May	2021	5					
Within the impoundment c. 600 m upstream o	WQ7	May	2021	5					
Downstream of Don Sahong c. 250 m downstre	WQ8	May	2021	5					
Downstream of Don Sahong c. 700 m downstre	WQ9	May	2021	5					
Stung Treng	H014501	23 May 2021	2021	5	0.036	0.097	0.025		
Pakse	H013900	June 13, 2021	2021	6	0.33	0.56	0.03		
Upstream of Don Sahong impoundment	WQ6	June 24, 2021	2021	6	0.25	0.48	0.06	0.13	0.01
Within the impoundment c. 600 m upstream o	WQ7	June 24, 2021	2021	6	0.20		0.03	0.34	0.06
Downstream of Don Sahong c. 250 m downstre	WQ8	June 24, 2021	2021	6	0.35		0.03	0.36	0.01
Downstream of Don Sahong c. 700 m downstre	WQ9	June 24, 2021	2021	6	0.33	0.41	0.03	0.31	0.00
Stung Treng	H014501	22 June 2021	2021	6	0.054	0.143	0.054		

Table 0-7: Don Sahong JEM Pilot Results for pollutants, Ammonium, COD and Faecal coliforms, October 2020 to June 2021

Station Name	STATID	DATE	Year	Month	NH4N_mg/L	CODMN_mg/L	FC _MPN/100ml
Water Quality Guideline threshold (Human Health)					**0.50**	**5.0**	**1000 cells/100ml**
Water Quality Guideline threshold (Aquatic Life)					**0.10**	**-**	**-**
Pakse	H013900	October 14, 2020	2020	10	0.02	10.60	110
Upstream of Don Sahong impoundment	WQ6	October 18, 2020	2020	10	0.02	3.28	45
Within the impoundment c. 600 m upstream of d	WQ7	October 14, 2020	2020	10			
Downstream of Don Sahong c. 250 m downstrear	WQ8	October 18, 2020	2020	10			
Downstream of Don Sahong c. 700 m downstrear	WQ9	October 18, 2020	2020	10	0.04	2.51	28
Stung Treng	H014501	25-Oct-20	2020	10	0.110	1.7	
Pakse	H013900	November 25, 2020	2020	11	0.02	1.73	230
Upstream of Don Sahong impoundment	WQ6	November 15, 2020	2020	11	0.04	2.89	45
Within the impoundment c. 600 m upstream of d	WQ7	November 11, 2020	2020	11			
Downstream of Don Sahong c. 250 m downstrear	WQ8	November 19, 2020	2020	11			
Downstream of Don Sahong c. 700 m downstrear	WQ9	November 19, 2020	2020	11	0.03	3.86	<18
Stung Treng	H014501	22-Nov-20	2020	11	0.120	2.7	
Pakse	H013900	December 21, 2020	2020	12	0.04	0.80	78
Upstream of Don Sahong impoundment	WQ6	December 18, 2020	2020	12	0.05	2.11	93
Within the impoundment c. 600 m upstream of d	WQ7	December 15, 2020	2020	12			
Downstream of Don Sahong c. 250 m downstrear	WQ8	December 16, 2020	2020	12			
Downstream of Don Sahong c. 700 m downstrear	WQ9	December 16, 2020	2020	12	0.03	1.58	<18
Stung Treng	H014501	19-Dec-20	2020	12	0.060	1.0	
Pakse	H013900	January 14, 2021	2021	1	0.06	1.42	130
Upstream of Don Sahong impoundment	WQ6	January 15, 2021	2021	1	0.04	1.21	<18
Within the impoundment c. 600 m upstream of d	WQ7	January 15, 2021	2021	1			
Downstream of Don Sahong c. 250 m downstrear	WQ8	January 15, 2021	2021	1			
Downstream of Don Sahong c. 700 m downstrear	WQ9	January 15, 2021	2021	1	0.03	1.21	45
Stung Treng	H014501	22 January 2021	2021	1	0.021	0.55	
Pakse	H013900	February 13, 2021	2021	2	0.02	1.68	78
Upstream of Don Sahong impoundment	WQ6	February 17, 2021	2021	2	0.01	0.24	<18
Within the impoundment c. 600 m upstream of d	WQ7	February 17, 2021	2021	2			
Downstream of Don Sahong c. 250 m downstrear	WQ8	February 17, 2021	2021	2			
Downstream of Don Sahong c. 700 m downstrear	WQ9	February 17, 2021	2021	2	0.01	1.44	<18
Stung Treng	H014501	19 February 2021	2021	2	0.019	0.96	
Pakse	H013900	March 13, 2021	2021	3	0.02	4.05	210
Upstream of Don Sahong impoundment	WQ6	March 15, 2021	2021	3	0.01	0.80	45
Within the impoundment c. 600 m upstream of d	WQ7	March 15, 2021	2021	3			
Downstream of Don Sahong c. 250 m downstrear	WQ8	March 15, 2021	2021	3			
Downstream of Don Sahong c. 700 m downstrear	WQ9	March 15, 2021	2021	3	0.01	1.60	45
Stung Treng	H014502	20 March 2021	2021	3	0.021	0.94	
Pakse	H013900	April	2021	4			
Upstream of Don Sahong impoundment	WQ6	April 9, 2021	2021	4	0.02	1.02	110
Within the impoundment c. 600 m upstream of d	WQ7	April 9, 2021	2021	4			
Downstream of Don Sahong c. 250 m downstrear	WQ8	April 9, 2021	2021	4			
Downstream of Don Sahong c. 700 m downstrear	WQ9	April 9, 2021	2021	4	0.01	1.65	45
Stung Treng	H014501	21 April 2021	2021	4	0.045	1.43	
Pakse	H013900	May 15, 2121	2021	5	0.05	0.86	20
Upstream of Don Sahong impoundment	WQ6	May	2021	5			
Within the impoundment c. 600 m upstream of d	WQ7	May	2021	5			
Downstream of Don Sahong c. 250 m downstrear	WQ8	May	2021	5			
Downstream of Don Sahong c. 700 m downstrear	WQ9	May	2021	5			
Stung Treng	H014501	23 May 2021	2021	5	0.034	1.54	
Pakse	H013900	June 13, 2021	2021	6	0.05	1.80	220
Upstream of Don Sahong impoundment	WQ6	June 24, 2021	2021	6	0.01	2.50	68
Within the impoundment c. 600 m upstream of d	WQ7	June 24, 2021	2021	6			
Downstream of Don Sahong c. 250 m downstrear	WQ8	June 24, 2021	2021	6			
Downstream of Don Sahong c. 700 m downstrear	WQ9	June 24, 2021	2021	6	0.03	2.11	130
Stung Treng	H014501	22 June 2021	2021	6	0.045	0.84	

Annex 4: Statistical analysis of Water Quality data at Xayaburi

$p < 0.05$ is considered a significant difference

Table 0-8: 1 vs 2

	October	November	December	January	February	March	April	June
Temperature	<0.0001 2↑	<0.0001 2↑	<0.0001 2↑	<0.0001 2↑	<0.0001 2↑	<0.0001 2↑	<0.0001 2↑	<0.0001 1↑
Conductivity	0.08	<0.0001 2↑	0.002 2↑	<0.0001 2↑	0.40	<0.0001 1↑	<0.0001 1↑	<0.0001 2↑
% Dissolved O_2	0.004 2↑	0.46	0.002 2↑	0.006 1↑	<0.0001 2↑	<0.0001 2↑	0.0002 2↑	0.004 1↑
Turbidity	<0.0001 1↑	<0.0001 1↑	<0.0001 1↑	<0.0001 2↑	<0.0001 1↑	<0.0001 1↑	<0.0001 1↑	<0.0001 1↑
pH	<0.0001 2↑	<0.0001 2↑	<0.0001 2↑	0.016 2↑	0.319	0.069	0.02 2↑	<0.0001 2↑
Chlorophyll a	0.009 2↑	<0.0001 2↑	0.0005 2↑	0.002 1↑	0.09	019	<0.0001 2↑	<0.0001 2↑
Cyanobacterial chlorophyll	0.01 2↑	0.008 2↑	ND	0.16	ND	0.5	<0.0001 2↑	0.022 1↑

Table 0-9: 2 vs 3

	October	November	December	January	February	March	April	June
Temperature	<0.0001 2↑	<0.0001 2↑	<0.0001 2↑	0.0006 3↑	0.001 2↑	0.0003 2↑	<0.0001 2↑	0.006 3↑
Conductivity	0.27	0.001 2↑	0.022 3↑	ND	ND	0.08	0.24	<0.0001 3↑
% Dissolved O_2	<0.0001 2↑	<0.0001 2↑	0.073	0.001 3↑	0.0001 2↑	<0.0001 3↑	0.46	<0.0001 3↑
Turbidity	<0.0001 3↑	0.0134	0.10	<0.0001 3↑	0.0001 3↑	0.32	0.004 3↑	<0.0001 2↑
pH	<0.0001 2↑	0.002 2↑	0.0005 2↑	0.27	0.41	0.294	0.18	<0.0001 3↑
Chlorophyll a	0.009 2↑	0.011 2↑	0.40	0.177	<0.0001 2↑	<0.0001 2↑	<0.0001 2↑	<0.0001 2↑
Cyanobacterial chlorophyll	0.014 2↑	0.008 2↑	ND	0.027 2↑	ND	0.074	<0.0001 2↑	0.043 3↑

Table 0-10: 3 vs 4

	October	November	December	January	February	March	April	June
Temperature	ND	0.37	ND	<0.0001 4↑	0004 3↑	0.074	0.098	0.32
Conductivity	0.32	ND	0.04 3↑	ND	ND	ND	0.16	<0.0001 4↑
% Dissolved O_2	<0.0001 4↑	0.03 3↑	0.064	0.260	0.09	0.31	0.36	0.0094 4↑
Turbidity	0.12	0.5	0.005 3↑	<0.001 3↑	0.013 3↑	0.143	0.290	0.19
pH	0.26	0.44	0.101	0.044 4↑	0.18	0.054	0.13	<0.0001 3↑
Chlorophyll a	ND	0.002 3↑	0.08	0.099	0.35	<0.0001 3↑	0.006 3↑	<0.0001 3↑
Cyanobacterial chlorophyll	ND	ND	ND	0.251	ND	0.162	0.35	0.008 3↑

Table 0-11: 4 vs 5

4 vs 5	October	November	December	January	February	March	April	June
Temperature	ND	0.145	0.047 4↑	?	0.0008 5↑	0.001 5↑	0.014 4↑	<0.0001 5↑
Conductivity	0.29	0.21	0.158	?	ND	ND	0.074	ND
% Dissolved O_2	<0.0001 4↑	<0.0001 5↑	0.024 5↑	0.006 5↑	0.0002 5↑	0.002 5↑	0.15	<0.0001 4↑
Turbidity	0.26	0.27	0.010 4↑	?	0.010 4↑	0.37	0.28	0.11
pH	0.008 4↑	0.03 4↑	0.002 4↑	?	0.015 4↑	0.27	0.001 4↑	0.23
Chlorophyll a	ND	0.34	0.07	0.016 4↑	<0.0001 5↑	0.13	0.074	<0.0001 4↑
Cyanobacterial chlorophyll	ND	ND	ND	0.017 5↑	ND	017	0.074	0.158

Annex 5: Information requested from the hydropower developers of Xayaburi and Don Sahong

Hydrology

1. Water level and flow (if available) on an hourly basis for the following sites for 1 Jan 2019 - present. This data will be used to understand water level fluctuations in the river as a function of flow changes. The upstream water level results will assist in understanding water level changes associated with the operation of other HPPs and natural inflows:
    a. Xayaburi:
        i. Upstream of Luang Prabang (Ban Hat Nga, Ban Sibounom)
        ii. Discharge from the Xayaburi HPP separated into flow through the turbines and releases through the gates
        iii. Downstream of Xayaburi
    b. Don Sahong
        i. Upstream of Hou Sahong site GB01 in hydrology reports, or equivalent location
        ii. Discharge from DSHPP, separated into flow through the turbines and releases through the gates
        iii. Downstream of Hou Sahong - Don the Khone Yuak – site AR03 in hydrology reports, or equivalent location
        iv. Don Sahong: discharge and flow velocity data in Khone Falls areas, from the feasibility studies (2009?) until now, for fish passage analysis

2. A description of any issues which have affected or altered hydropower operations during 2019 – 2021. An example is DSHPP operating more in the dry season than planned. Another example would be outages of one or more turbines.

Sediment

1. Suspended sediment results collected upstream and downstream of the impoundment from 2019 – present. These will be used to compare with the JEM monitoring results, and to extend / fill-in the JEM time-series to provide a more complete understanding.
2. Bedload transport information – physical measurements or ADCP loop test results along with ADCP discharge file(s) if available
3. Any repeat surveyed cross-section upstream, within the impoundment or downstream of the HPP site.

Water Quality

1. Water quality monitoring/sampling locations carried out by the hydropower operator, with coordinates, frequency of sampling and parameters measured – both upstream, within the impoundment and downstream and depth profiles in the impoundment
2. All water quality monitoring results for the period October 2020 to June 2021.
3. Details of plant operation on the following dates, e.g. numbers of turbines working and capacity, or estimated flows released, or spillway/bottom outlets open, to coincide with the JEM sampling missions (if the extended time-series cannot be provided).

Table 0-12: Information on operation status requested from Xayaburi HPP

Date	Times	Xayaburi Plant operation status	Spillway gates open?
02/11/2020	06:00 to 18:00		
16/11/2020	06:00 to 18:00		
11/12/2020	06:00 to 18:00		
13/01/2021	06:00 to 18:00		
14/02/2021	06:00 to 18:00		
14/03/2021	06:00 to 18:00		
07/04/2021	06:00 to 18:00		

Table 0-13: Information on operation status requested from Xayaburi HPP

Date	Times	Don Sahong Plant operation status	Spillway gates open?
27/10/2020	06:00 to 18:00		
13/11/2020	06:00 to 18:00		
14/12/2020	06:00 to 18:00		
15/01/2021	06:00 to 18:00		
17/02/2021	06:00 to 18:00		
15/03/2021	06:00 to 18:00		
09/04/2021	06:00 to 18:00		

The purpose of the request is to compare and validate the JEM Water quality sampling and analysis, and to understand if there is any variation in water quality with different operational modes of the HPP.

Ecological Health Monitoring

1. Does the HPP carry out any ecological health monitoring within the impoundment or downstream of the dam?
2. Describe locations of sampling, frequency of sampling and parameters investigated – e.g. Benthic diatoms, zooplankton, littoral and benthic macroinvertebrates, phytoplankton and Cyanobacteria.
3. The results for the most recent sampling occasions

The purpose of the request is to compare and validate the JEM Ecological health sampling and analysis.

Fisheries

- Xayaburi:
    a. Analysis reports of the early fish passage success experiments (2012-2015 by FishTek, and subsequent studies)

    b. Analysis reports of the PIT tagging experiments (CSU)

- Don Sahong:
    a. Data and analysis reports of the 2013 spaghetti tagging experiment
    b. Data and analysis reports of the fish monitoring with fishers undertaken from the beginning (impact assessment studies) until now
    c. Data and analysis reports of the fish larvae and juveniles monitoring undertaken from the beginning until now.

Annex 6: Calculations of EH Index for all mainstream sites and JEM EHM sites

Table 0-14: Calculations of EH Index for all mainstream sites between Xieng Kok and Luang Prabang between 2011 to 2019

Site							LMX						TCS						LPB		
Year					2011	2013	2015	2017	2019		2011	2013	2015	2017	2019		2011	2013	2015	2017	2019
Site Disturbance Score SDS					2.18	2.08	2.25	2.06	2.31		2.30	2.24	2.34	2.34	2.21		1.66	1.70	1.65	2.02	2.76
Average Abundance																					
	Benthic diatoms				25.70	79.50	22.40	42.10	164.40		457.80	887.50	1,912.74	-	131.00		298.60	60.00	227.80	196.90	254.40
	Zooplankton				94.00	35.00	173.00	291.00	N/D		-	5.33	4.00	-	10.33		127.00	27.00	271.00	291.00	272.00
	Littoral macroinvertebrates				7.90	49.00	46.00	90.90	22.70		93.00	1.60	6.80	68.20	8.70		47.70	19.70	45.30	187.00	22.50
	Benthic macroinvertebrates				3.50	17.78	7.83	11.50	26.75		106.92	1.92	16.25	0.25	2.42		6.92	5.00	12.08	40.92	28.50
Richness	Benthic diatoms				5.40	17.20	5.80	11.80	18.00		3.40	4.00	3.80	-	9.70		12.00	7.80	18.10	19.30	18.20
	Zooplankton				14.00	7.33	19.67	26.67	N/D		-	1.67	2.67	-	5.00		17.67	7.00	25.33	28.00	25.00
	Littoral macroinvertebrates				4.50	4.50	4.90	4.30	3.60		93.00	1.60	6.80	68.20	8.70		7.30	5.50	7.00	12.40	7.40
	Benthic macroinvertebrates				0.67	5.22	2.92	4.42	3.58		2.33	1.00	1.58	0.25	0.50		2.50	2.56	3.83	5.25	5.83
ATPST	Benthic diatoms				20.97	44.37	42.82	43.94	42.67		44.00	42.00	42.80	48.70	49.40		19.81	41.95	41.26	43.50	42.81
	Zooplankton				47.36	45.24	46.92	45.93	50.77		ND	39.00	42.20	ND	43.10		39.36	40.43	40.35	43.22	52.30
	Littoral macroinvertebrates				45.58	45.04	50.07	46.52	53.52		35.00	32.00	43.20	41.70	33.00		39.22	39.43	39.26	45.51	57.25
	Benthic macroinvertebrates				17.99	44.40	40.81	45.47	54.62		25.00	28.00	43.40	40.40	40.40		29.14	41.49	39.70	45.71	59.40
Ecosystem Health index Calculations		10th	90th	Threshold																	
		percentile	percentile	Guideline																	
Abundance	Benthic diatoms	136.22	376.34	>136.22	FALSE	FALSE	FALSE	FALSE	1		1	1	1	FALSE	FALSE		1	FALSE	1	1	1
	Zooplankton	22.33	174.07	>22.33	1	1	1	1	1		FALSE	FALSE	FALSE	FALSE	FALSE		1	1	1	1	1
	Littoral macroinvertebrates	46.68	328.56	>46.48	FALSE	1	FALSE	1	FALSE		1	FALSE	FALSE	1	FALSE		1	FALSE	FALSE	1	FALSE
	Benthic macroinvertebrates	5.37	56.34	>5.37	FALSE	1	1	1	1		1	FALSE	1	FALSE	FALSE		1	FALSE	1	1	1
Richness	Benthic diatoms	6.54	11.78	>6.54	FALSE	1	FALSE	1	1		FALSE	FALSE	FALSE	FALSE	1		1	1	1	1	1
	Zooplankton	9.8	20.2	>9.8	1	FALSE	1	1	1		FALSE	FALSE	FALSE	FALSE	FALSE		1	FALSE	1	1	1
	Littoral macroinvertebrates	5.37	18.48	>5.37	FALSE	FALSE	FALSE	FALSE	FALSE		1	FALSE	1	1	1		1	1	1	1	1
	Benthic macroinvertebrates	1.87	7.88	>1.87	FALSE	1	1	1	1		1	FALSE	FALSE	FALSE	FALSE		1	1	1	1	1
ATPST	Benthic diatoms	30.85	38.38	<38.38	1	FALSE	FALSE	FALSE	FALSE		FALSE	FALSE	FALSE	FALSE	FALSE		1	FALSE	FALSE	FALSE	FALSE
	Zooplankton	34.83	41.8	<41.8	FALSE	FALSE	FALSE	FALSE	FALSE		FALSE	1	FALSE	FALSE	FALSE		1	1	1	FALSE	FALSE
	Littoral macroinvertebrates	27.8	33.58	<33.58	FALSE	FALSE	FALSE	FALSE	FALSE		FALSE	1	FALSE	FALSE	1		FALSE	FALSE	FALSE	FALSE	FALSE
	Benthic macroinvertebrates	31.57	37.74	<37.74	1	FALSE	FALSE	FALSE	FALSE		1	1	FALSE	FALSE	FALSE		1	FALSE	FALSE	FALSE	FALSE
	Total number of parameters meeting threshold				4	5	4	6	6		6	4	3	2	3		11	5	8	8	7
	Classification	Score			C	C	C	C	C		C	C	D	D	D		A	C	B	B	B
Excellent	A	>10															11				
Good	B	>7																	8	8	7
Moderate	C	>4			4	5	4	6	6		6	4						5			
Poor	D	<4											3	2	3						

Table 0-15: Calculations of EH Index for all mainstream sites between Luang Prabang and Vientiane, including the JEM Pilot at Xayaburi HPP

Site					LPB						EHM1	EHM2	EHM3	EHM4	EHM5	EHM6		LVT				
Year					**2011**	**2013**	**2015**	**2017**	**2019**		**2021**	**2021**	**2021**	**2021**	**2021**	**2021**		**2011**	**2013**	**2015**	**2017**	**2019**
Site Disturbance Score SDS					1.66	1.70	1.65	2.02	2.76		1.46	1.41	2	1.92	1.5	1.46		1.84	1.85	1.86	2.04	2.23
Average Abundance																						
	Benthic diatoms				298.60	60.00	227.80	196.90	254.40		667.50	1,954.00	1,026.60	982.60	1,283.80	1,479.20		257.50	25.00	153.50	37.50	955.50
	Zooplankton				127.00	27.00	271.00	291.00	272.00		25.33	39.60	32.00	26.33	15.00	12.60		86.00	24.00	452.00	341.00	315.00
	Littoral macroinvertebrates				47.70	19.70	45.30	187.00	22.50		160.80	9.10	4.20	7.70	148.90	39.00		103.10	13.00	22.40	115.80	53.20
	Benthic macroinvertebrates				6.92	5.00	12.08	40.92	28.50		2.75	3.08	2.25	1.25	2.58	3.16		0.58	2.44	9.58	13.42	27.83
Richness	Benthic diatoms				12.00	7.80	18.10	19.30	18.20		13.60	2.70	26.60	26.60	28.00	30.50		8.10	4.60	11.80	4.00	29.20
	Zooplankton				17.67	7.00	25.33	28.00	25.00		8.66	5.66	10.33	7.33	7.00	5.66		16.33	5.67	25.67	23.33	21.67
	Littoral macroinvertebrates				7.30	5.50	7.00	12.40	7.40		6.30	1.40	1.50	2.00	5.20	6.70		11.10	3.00	5.40	7.80	9.80
	Benthic macroinvertebrates				2.50	2.56	3.83	5.25	5.83		1.66	1.58	1.16	1.00	1.58	1.25		0.58	1.11	3.50	4.92	3.67
ATPST	Benthic diatoms				19.81	41.95	41.26	43.50	42.81		39.00	39.00	42.00	40.00	39.00	38.00		28.53	38.82	42.31	44.03	42.84
	Zooplankton				39.36	40.43	40.35	43.22	52.30		33.00	30.00	42.00	37.00	32.00	31.00		41.83	41.89	42.86	44.47	49.55
	Littoral macroinvertebrates				39.22	39.43	39.26	45.51	57.25		31.00	31.00	32.00	28.00	30.00	33.00		41.57	41.91	42.25	45.38	51.90
	Benthic macroinvertebrates				29.14	41.49	39.70	45.71	59.40		34.54	31.85	33.66	28.15	29.44	21.34		17.27	28.60	39.74	45.74	50.98
Ecosystem Health index Calculations		10th percentile	90th percentile	Threshold Guideline																		
Abundance	Benthic diatoms	136.22	376.34	>136.22	1	FALSE	1	1	1		1	1	1	1	1	1		1	FALSE	1	FALSE	1
	Zooplankton	22.33	174.07	>22.33	1	1	1	1	1		1	1	1	1	FALSE	FALSE		1	1	1	1	1
	Littoral macroinvertebrates	46.68	328.56	>46.48	1	FALSE	FALSE	1	FALSE		1	FALSE	FALSE	FALSE	1	FALSE		1	FALSE	FALSE	1	1
	Benthic macroinvertebrates	5.37	56.34	>5.37	1	FALSE	1	1	1		FALSE	FALSE	FALSE	FALSE	FALSE	FALSE		FALSE	FALSE	1	1	1
Richness	Benthic diatoms	6.54	11.78	>6.54	1	1	1	1	1		1	FALSE	1	1	1	1		1	FALSE	1	FALSE	1
	Zooplankton	9.8	20.2	>9.8	1	FALSE	1	1	1		FALSE	FALSE	1	FALSE	FALSE	FALSE		1	FALSE	1	1	1
	Littoral macroinvertebrates	5.37	18.48	>5.37	1	1	1	1	1		1	FALSE	FALSE	FALSE	FALSE	1		1	FALSE	1	1	1
	Benthic macroinvertebrates	1.87	7.88	>1.87	1	1	1	1	1		FALSE	FALSE	FALSE	FALSE	FALSE	FALSE		FALSE	FALSE	1	1	1
ATPST	Benthic diatoms	30.85	38.38	<38.38	1	FALSE	FALSE	FALSE	FALSE		FALSE	FALSE	FALSE	FALSE	FALSE	1		1	FALSE	FALSE	FALSE	FALSE
	Zooplankton	34.83	41.8	<41.8	1	1	1	FALSE	FALSE		1	1	FALSE	1	1	1		FALSE	FALSE	FALSE	FALSE	FALSE
	Littoral macroinvertebrates	27.8	33.58	<33.58	FALSE	FALSE	FALSE	FALSE	FALSE		1	1	1	1	1	1		FALSE	FALSE	FALSE	FALSE	FALSE
	Benthic macroinvertebrates	31.57	37.74	<37.74	1	FALSE	FALSE	FALSE	FALSE		1	1	1	1	1	1		1	1	FALSE	FALSE	FALSE
	Total number of parameters meeting threshold				11	5	8	8	7		8	5	6	6	6	7		8	2	7	6	8
	Classification	**Score**			A	C	B	B	B		B	C	C	C	C	B		B	D	B	C	B
Excellent	A	>10			11																	
Good	B	>7					8	8	7		8					7		8		7		8
Moderate	C	>4				5						5	6	6	6						6	
Poor	D	<4																	2			

Table 0-16: Calculations of EH Index for all mainstream sites between Vientiane and Khong Chiam between 2011 to 2019

Site					LVT						TNP						TKC				
Year					2011	2013	2015	2017	2019		2011	2013	2015	2017	2019		2011	2013	2015	2017	2019
Site Disturbance Score SDS					1.84	1.85	1.86	2.04	2.23		1.90	1.87	1.94	2.14	1.97		1.90	1.95	2.06	2.22	2.09
Average Abundance																					
	Benthic diatoms				257.50	25.00	153.50	37.50	955.50		131.65	200.20	1,518.00	322.00	582.05		147.10	2,980.50	1,324.80	79.40	161.50
	Zooplankton				86.00	24.00	452.00	341.00	315.00		1.00	110.00	8.67	-	39.33		0.33	116.00	3.00	0.67	27.33
	Littoral macroinvertebrates				103.10	13.00	22.40	115.80	53.20		209.20	120.50	96.20	N/D	N/D		521.30	23.40	77.80	19.00	29.90
	Benthic macroinvertebrates				0.58	2.44	9.58	13.42	27.83		45.50	61.17	136.17	37.67	43.83		17.08	5.83	28.83	10.00	22.58
Richness	Benthic diatoms				8.10	4.60	11.80	4.00	29.20		2.50	2.90	4.70	17.40	15.00		3.90	3.10	5.50	12.30	9.20
	Zooplankton				16.33	5.67	25.67	23.33	21.67		0.33	9.67	2.33	-	5.00		0.33	9.67	1.67	0.67	7.33
	Littoral macroinvertebrates				11.10	3.00	5.40	7.80	9.80		209.20	120.50	96.20	N/D	N/D		5.80	1.00	3.70	2.90	4.00
	Benthic macroinvertebrates				0.58	1.11	3.50	4.92	3.67		1.83	1.75	2.75	1.83	1.67		1.92	0.75	1.58	0.67	0.92
ATPST	Benthic diatoms				28.53	38.82	42.31	44.03	42.84		41.00	39.00	44.90	47.10	45.40		38.00	39.00	41.70	46.90	46.80
	Zooplankton				41.83	41.89	42.86	44.47	49.55		50.00	38.00	40.50	ND	43.20		33.00	38.00	41.80	40.60	43.70
	Littoral macroinvertebrates				41.57	41.91	42.25	45.38	51.90		32.00	37.00	40.30	44.20	39.80		34.00	38.00	40.20	44.10	44.20
	Benthic macroinvertebrates				17.27	28.60	39.74	45.74	50.98		26.00	24.00	40.40	48.00	47.20		27.00	37.00	40.80	49.00	49.00
Ecosystem Health index Calculations		10th	90th	Threshold																	
		percentile	percentile	Guideline																	
Abundance	Benthic diatoms	136.22	376.34	>136.22	1	FALSE	1	FALSE	1		FALSE	1	1	1	1		1	1	1	FALSE	1
	Zooplankton	22.33	174.07	>22.33	1	1	1	1	1		FALSE	1	FALSE	FALSE	1		FALSE	1	FALSE	FALSE	1
	Littoral macroinvertebrates	46.68	328.56	>46.48	1	FALSE	FALSE	1	1		1	1	1	1	1		1	FALSE	1	FALSE	FALSE
	Benthic macroinvertebrates	5.37	56.34	>5.37	FALSE	FALSE	1	1	1		1	1	1	1	1		1	1	1	1	1
Richness	Benthic diatoms	6.54	11.78	>6.54	1	FALSE	1	FALSE	1		FALSE	FALSE	FALSE	1	1		FALSE	FALSE	FALSE	1	1
	Zooplankton	9.8	20.2	>9.8	1	FALSE	1	1	1		FALSE	FALSE	FALSE	FALSE	FALSE		FALSE	FALSE	FALSE	FALSE	FALSE
	Littoral macroinvertebrates	5.37	18.48	>5.37	1	FALSE	1	1	1		1	1	1	1	1		1	FALSE	FALSE	FALSE	FALSE
	Benthic macroinvertebrates	1.87	7.88	>1.87	FALSE	FALSE	1	1	1		FALSE	FALSE	1	FALSE	FALSE		1	FALSE	FALSE	FALSE	FALSE
ATPST	Benthic diatoms	30.85	38.38	<38.38	1	FALSE	FALSE	FALSE	FALSE		FALSE	FALSE	FALSE	FALSE	FALSE		1	FALSE	FALSE	FALSE	FALSE
	Zooplankton	34.83	41.8	<41.8	FALSE	FALSE	FALSE	FALSE	FALSE		FALSE	1	1	FALSE	FALSE		1	1	FALSE	1	FALSE
	Littoral macroinvertebrates	27.8	33.58	<33.58	FALSE	FALSE	FALSE	FALSE	FALSE		1	FALSE	FALSE	FALSE	FALSE		FALSE	FALSE	FALSE	FALSE	FALSE
	Benthic macroinvertebrates	31.57	37.74	<37.74	1	1	FALSE	FALSE	FALSE		1	1	FALSE	FALSE	FALSE		1	1	FALSE	FALSE	FALSE
	Total number of parameters meeting threshold				8	2	7	6	8		5	7	6	5	6		8	5	3	3	4
	Classification	Score			B	D	B	C	B		C	B	C	C	C		B	C	D	D	C
Excellent	A	>10																			
Good	B	>7			8		7		8			7					8				
Moderate	C	>4						6			5		6	5	6			5			4
Poor	D	<4				2													3	3	

Table 0-17: Calculations of EH Index for all mainstream sites between Don Ngiew and Kratie, with JEM sites at Don Sahong in 2021

Site					LDN						EHM7	EHM8	EHM9	EHM10		CKM						CKT						CMR				
Year					2011	2013	2015	2017	2019		2021	2021	2021	2021		2011	2013	2015	2017	2019		2011	2013	2015	2017	2019		2011	2013	2015	2017	2019
Site Disturbance Score SDS					1.66	1.74	1.96	1.66	1.81		1.33	2.1	2.25	2.13		2.00	1.90	1.60	1.53	1.52778		1.00	1.46	1.74	1.71	1.71		1.00	2.05	1.65	1.52	1.52
Average Abundance																																
	Benthic diatoms				223.90	32.10	15.60	59.10	914.10		1162	6238.4	1264.5	3653.4		N/D	159.70	294.10	318.30	28.60		N/D	135.50	232.10	272.60	34.00		N/D	133.20	218.40	245.60	39.80
	Zooplankton				436.00	42.00	686.00	560.00	457.00		14.00	22.66	16.00	17.00		N/D	7.33	269.33	150.11	160.11		N/D	69.33	19.78	65.00	30.44		N/D	15.78	27.44	17.78	32.67
	Littoral macroinvertebrates				401.60	32.10	54.80	46.40	65.80		77.3	134.2	96.3	66.0		N/D	12.30	39.90	85.70	46.40		N/D	26.40	58.80	497.40	1,418.90		N/D	372.80	65.20	396.60	222.50
	Benthic macroinvertebrates				18.83	8.78	13.33	13.83	30.42		5.16	7	12.25	10.58		N/D	2.42	0.67	22.75	13.17		N/D	8.67	13.00	15.17	10.00		N/D	4.17	16.50	33.58	28.70
Richness	Benthic diatoms				20.60	3.10	6.50	14.10	29.10		15	4.1	25	36.2		N/D	15.30	15.30	14.80	6.50		N/D	21.20	21.20	16.40	9.70		N/D	11.70	11.70	9.40	8.40
	Zooplankton				29.00	9.33	53.33	52.67	40.00		6.33	5	6.00	5.66		N/D	2.00	20.22	21.56	160.11		N/D	8.00	11.00	15.22	8.33		N/D	8.00	10.00	15.22	2.22
	Littoral macroinvertebrates				12.50	3.40	10.90	6.50	9.90		17.5	3	9.3	12.6		N/D	6.20	9.20	16.00	13.17		N/D	5.30	10.40	16.70	82.40		N/D	5.30	13.80	24.00	15.70
	Benthic macroinvertebrates				4.25	2.44	4.25	5.25	5.50		2.41	1.91	3.90	5.16		N/D	1.50	0.58	5.92	6.50		N/D	2.08	2.33	4.33	1.33		N/D	2.33	3.25	5.25	1.42
ATPST	Benthic diatoms				34.34	41.30	38.26	42.46	42.80		37	47	46	47		31.00	34.97	37.04	41.37	38.00		29.00	32.96	36.97	40.74	38.00		31.00	36.40	37.93	44.62	39.00
	Zooplankton				37.89	41.52	43.74	42.23	46.38		28	47	47	47		45.00	20.18	39.57	39.14	36.00		43.00	35.17	37.93	38.23	39.00		41.00	39.90	38.81	38.42	37.00
	Littoral macroinvertebrates				39.47	37.71	43.01	41.78	48.19		29	42	45	42		34.00	30.08	36.30	33.86	35.00		30.00	30.08	35.85	34.69	34.00		26.00	40.43	36.43	34.80	37.00
	Benthic macroinvertebrates				34.65	35.62	44.12	44.25	49.61		36.6	48.7	47.8	49.9		37.00	24.26	11.42	36.49	36.00		23.00	13.16	27.31	38.30	36.00		20.00	22.70	31.40	26.46	35.00
Ecosystem Health index Calculations		**Percentile**		**Threshold**																												
		10th	**90th**	**Guideline**																												
Abundance	Benthic diatoms	136.22	376.34	>136.22	1	FALSE	FALSE	FALSE	1		1	1	1	1			1	1	1	FALSE			FALSE	1	1	FALSE			FALSE	1	1	FALSE
	Zooplankton	22.33	174.07	>22.33	1	1	1	1	1		FALSE	1	FALSE	FALSE			FALSE	1	1	1			1	FALSE	1	1			FALSE	1	FALSE	1
	Littoral macroinvertebrates	46.68	328.56	>46.48	1	FALSE	1	FALSE	1		1	1	1	1			FALSE	FALSE	1	FALSE			FALSE	1	1	1			1	1	1	1
	Benthic macroinvertebrates	5.37	56.34	>5.37	1	1	1	1	1		FALSE	1	1	1			FALSE	FALSE	1	1			1	1	1	1			FALSE	1	1	1
Richness	Benthic diatoms	6.54	11.78	>6.54	1	FALSE	FALSE	1	1		1	FALSE	1	1			1	1	1	FALSE			1	1	1	1			1	1	1	1
	Zooplankton	9.8	20.2	>9.8	1	FALSE	1	1	1		FALSE	FALSE	FALSE	FALSE			FALSE	1	1	1			FALSE	1	1	FALSE			FALSE	1	1	FALSE
	Littoral macroinvertebrates	5.37	18.48	>5.37	1	FALSE	1	1	1		1	FALSE	1	1			1	1	1	1			FALSE	1	1	1			FALSE	1	1	1
	Benthic macroinvertebrates	1.87	7.88	>1.87	1	1	1	1	1		1	1	1	1			FALSE	FALSE	1	1			1	1	1	FALSE			1	1	1	FALSE
ATPST	Benthic diatoms	30.85	38.38	<38.38	1	FALSE	1	FALSE	FALSE		1	FALSE	FALSE	FALSE			1	1	FALSE	1			1	1	FALSE	1			1	1	FALSE	FALSE
	Zooplankton	34.83	41.8	<41.8	1	1	FALSE	FALSE	FALSE		1	FALSE	FALSE	FALSE			1	1	1	1			1	1	1	1			1	1	1	1
	Littoral macroinvertebrates	27.8	33.58	<33.58	FALSE	FALSE	FALSE	FALSE	FALSE		1	FALSE	FALSE	FALSE			1	FALSE	FALSE	FALSE			1	FALSE	FALSE	FALSE			FALSE	FALSE	FALSE	FALSE
	Benthic macroinvertebrates	31.57	37.74	<37.74	1	1	FALSE	FALSE	FALSE		1	FALSE	FALSE	FALSE			1	1	1	1			1	1	FALSE	1			1	1	1	1
	Total number of parameters meeting threshold				11	5	7	6	8		9	5	6	6			7	8	10	8			8	10	9	8			6	11	9	7
	Classification	**Score**			A	C	B	C	B		B	C	C	C		N/D	B	B	A	B		N/D	B	A	B	B		N/D	C	A	B	B
	A	>10			11														10											A		
	B	>7					7		8		9						7	8		8			8		8	B					B	B
	C	>4				5		6				5	6	6															C			
	D	<4																														

Figure 0-15: Variation in Abundance, Species Richness and ATSPT in all mainstream EHM sites in 2019 between Xieng Kok and Kratie, in comparison with JEM pilot sites in 2021

Annex 5: Recent Fish Migrations in Khone Falls (Lao PDR) according to Local Ecological Knowledge

Mekong River Commission

RECENT FISH MIGRATIONS IN KHONE FALLS (LAO PDR) ACCORDING TO LOCAL ECOLOGICAL KNOWLEDGE

Piloting a Joint Environmental Monitoring (JEM) Programme on Two Mekong Mainstream Dams: The Don Sahong and Xayaburi Hydropower Projects

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ABBREVIATIONS AND ACRONYMS

AMFC	Assessment of Mekong Fisheries Component project
DSHP	Don Sahong Hydropower Project
DSPC	Don Sahong Power Company
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GPS	Global Positioning System
ICEM	International Centre for Environmental Management
MRC/MRCS	Mekong River Commission / Mekong River Commission Secretariat
PDR	People Democratic Republic
USD	US Dollar

EXECUTIVE SUMMARY

This local ecological knowledge survey at the Khone Falls area near the Don Sahong Hydropower Project (HPP) forms part of the fisheries component for the pilot project of the Joint Environmental Monitoring (JEM) Programme for Mekong Mainstream Hydropower Projects. The JEM Programme is implemented by the Mekong River Commission (MRC) and Member Countries (MCs) and was designed to provide independent information about linkages between water resources and environmental conditions and how these change under hydropower developments. The local ecological knowledge survey specifically aims to complement and inform the design of an upcoming study monitoring migration and fish passage through the area using fish tags.

Khone Falls are comprised of more than 31 large islands, 25 large waterfalls or waterfall areas, and at least 52 individually identified channels. These features create a large number of corridors and dead ends through which fish attempt to migrate. Systematically gathering of fishers' local ecological knowledge for the purposes of assess ecological patterns among fish species is a rapid, detailed, cost-effective and reliable research approach. The Mekong region has generated extensive local ecological knowledge including several previous studies on the Khone Falls fish bioecology. The recent changes in the area, in particular the construction of the Don Sahong Dam and extensive dam development in the Lower Mekong Basin mean that a fresh update of information is much needed. This survey responds to that need whilst informing inform design guidance for fish passage channels, and identify the factors needed for optimal mitigation of dam impacts.

Methodology: Based on the initial Mekong protocol of Poulsen and Valbo-Jørgensen (1999; 2000), the 16 villages of Khone Falls were categorised into three zones (upstream, middle areas and downstream) and surveyed between 10 March and 30 March 2021 to collect information regarding the following questions:

- how do migratory fish arrive to Khone Falls from downstream and from upstream?
- which channels are targeted by species for initial passage?
- which channels ultimately allow species to pass the falls?
- what are the channel specificities that allow passage or not?
- in the middle section of the falls, what passage improvements could be conducted?
- are there areas of the falls of special importance in terms of passage or ecology?

These questions targeted ten species (Table 1) that were selected for the survey as representative of the larger groups of species that migrate through Khone Falls. The survey design aimed to provide an informative, manageable survey (10 species x 35 question = 350 questions per interview) to document the main passage strategies and capabilities of the target species through focus group discussions.

Results: Detailed photographs and characteristics were collected for each of the nine channels targeted by fish passage improvement measures by the Don Sahong Power Company, being:

- Hoo Som Yai (where MRC monitored a *Lee* trap fishery for 20 years);
- Hoo Som Pordan[1] next to Khone Phapheng waterfall;

[1] Som Pordan, the name used by the Don Sahong Power Company (DSPC), is also locally pronounced as Som Pa Lan.

- Hoo Sadam between Don Sadam and Don Papeng;
- Hoo Xang Peuak Noy, Nyoi Koong, Koum Tao Hang, Hoo Wai and Luong Pi Teng between Don Ee Som and Don Sahong; and
- Hoo Don Lai next to Lee Pee waterfall.

The following observations for the ten target species were reported by fishers during the survey:

- ***Hypsibarbus malcolmi*** and its group migrate upstream later than reported in Baird (2001) and Baran (2005) (now mainly January - February); the species is not caught in Hoo Sadam anymore. It migrates downstream in June-August via the Khone Fang area.
- ***Gymnostomus siamensis*** and ***Gymnostomus lobatus*** (Cyprinidae)*:* These results underline the quasi-disappearance of species that used to be the most abundant ones, and their upstream migrations now limited to a few days a year - in particular in relation to reduced water levels in former key passages such as Khone Pa Soi.
- ***Scaphognathops bandanensis*** *(*Cyprinidae)*:* Patterns are unclear for *S. bandanensis* and the group of early dry season medium-sized cyprinids, suggesting a permanent residence in some sites, in particular upstream of Khone Falls (e.g. Don Tholathi). Migrations are identified mainly in January-February (upstream) and July-August (downstream)- without being common to all sites. All channels seem to be used for movements.
- ***Cirrhinus microlepis*** and ***Cyclocheilos enoplos*** *(*Cyprinidae)*:* "Dry- to early wet season large cyprinids" seem to be vanishing from catches in the falls and upstream of them, and the remaining individuals caught are not sufficient to characterize migrations and further.
- ***Helicophagus leptorhynchus*** and ***Pangasius macronema*** *(*Pangasiidae). Like "Dry- to early wet season large cyprinids", fishers report the progressive disappearance of "Early wet season small Pangasiids", and the remaining individuals are not enough in sufficient numbers to clearly characterize migrations any further.
- ***Pangasius krempfi**, **Pangasius conchophilus*** (Pangasiidae). The beginning of the migration is never reported in May but spans mainly in June-August. Strong loss of abundance (50 to 0% remain) and, like in other groups, some permanent presence in very low abundance and without clear migration pattern is noted in several sites. Downstream migration is never reported.

Target migratory species caught in the zones surveyed: In the upstream zone, Ban Don Tan Tok and Ban Don Tan Oke village fishers report the lowest number (6-7 species) of target fish caught during the past 3 years. Within the mid-falls zone, the lowest catch of species surveyed and the lowest abundance are reported in Ban Houa Sadam and Ban Khone Nuea villages. Downstream zones villages report a high diversity of species surveyed.

Species passing the falls: In the past three years, only five among the ten target species have been identified as migrating through the falls. These five are *Cirrhinus microlepis, Gymnostomus lobatus, Gymnostomus siamensis, Scaphognathops bandanensis* and *Hypsibarbus malcolmi*.

Which way do migratory fish arrive to Khone Falls? While results are biased by sampling only on the Lao PDR side and not on the Cambodian side, most responses indicate that fish from the downstream areas pass up to the falls through the comparably deeper eastern Mekong channel between Koh Chheu Teal Thom and the east bank.

Which channels are initially then successively targeted by species for initial passage? Which channels are ultimately used by species to successfully pass the falls? Three species (*Gymnostomus lobatus, Gymnostomus siamensis* and *Pangasius macronema*) attempt to pass upstream through the following channels in the dry season:

- Hoo Kogma and Hoo Khone Souang (Khone Fang area, passable);
- Hoo Somphamit (impassable);
- Hoo Xang Peuak, Hoo Khone Lan and Hoo Wai (central zone); and
- Hoo Sadam.

In recent years, fish stay in Hoo Phapheng downstream of the falls without attempting migration through Hoo Sadam. At the beginning of the rainy season, fish target Hoo Nok Gasoom, Hoo Xang Peuak and Hoo Sadam but they are not accessible before June. Hoo Phapheng is still very attractive to fish despite reduced discharge following the Don Sahong Dam flow diversion, but passage is impossible at Khone Phapheng and at the lateral channels since they are now dry for most of the year due to the same reason. In the wet season, June water levels are insufficient for fish to pass the water falls in the Khone Fang area. Fish can therefore only pass through Hoo Xang Pheuak, Hoo Sadam and Hoo Phapheng.

What are the channel specificities that allow passage? Fishers identified factors that attract fish and allow passage to be the following: adequate discharge, channel width and depth, presence of multiple resting pools or habitat complexity, and characteristics of higher head, higher dissolved oxygen and lower water temperate Due to the attractiveness of the Don Sahong Dam site, it was observed that fish tend to stay in the outflow area and many do not attempt to go further upstream towards Hoo Xang Pheuak or Khone Lan as they previously did. Fish passage has also been compromised by the increasing pressure of fishing gear in these past years.

What are the passage improvements that could be further conducted?

In the Khonefang area, Hoo Khone Xouang is a potential new candidate for fish pass improvement together with the micro channel Hoo Khone Xuangnoi that provides optional clearance for a deeper channel to have more water supply all year round.

At the Liphi waterfalls, it is not possible for fish migration to occur upstream from Hoo KhoneKhouang to the Khone Khoum waterfalls areas in either the dry season or the early wet season from May to July because of the very high waterfall, the high slope angle and the strong water flow. However, Hoo Pataep is a potential candidate micro channel since it has water all year round, and it is located at the opposite site of Don Lai Channel. Hoo Pataep is a hub of several micro channels- Hoo Khonekor, Hoo Khone Koum, Hainoi and Hai Nyai.

1. INTRODUCTION

The Joint Environmental Monitoring (JEM) Programme for Mekong Mainstream Hydropower Projects is implemented by the Mekong River Commission (MRC) and Member Countries (MCs) to provide independent information about linkages between water resources and environmental conditions and how these change under hydropower developments. The JEM Programme monitors across five disciplines: Hydrology and Sediment, Water Quality, Ecological Health and Fisheries. Results are intended to provide a common basis for constructive discussions by communities and MCs on the implications of hydropower development.

At the end of 2019 the International Center for Environmental Management (ICEM) was the commissioned by the MRC and Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH (GIZ) to conduct pilot projects for the JEM programme at two sites, the Don Sahong and Xayaburi hydropower projects, across 2020 and 2021. This is henceforth referred to as the JEM Pilot project.

For the fisheries component, the JEM Pilot project both implements monitoring of fish abundance and diversity and develops new methods to assess the effectiveness and efficiency of mitigation measures aimed at allowing fish migration. These new methods focus particularly on monitoring the Don Sahong HPP site and include piloting the use of fish tagging.

To complement this upcoming migration and passage study based on monitoring using fish tagging, the MRC and the JEM Pilot project conducted a survey of local ecological knowledge between 10th and 30th March 2021 to both a) document how fish pass through the Khone Falls, and b) to inform improvements to fish passage. This report presents the results of this survey.

Khone Falls is an area of the Mekong Basin where local ecological knowledge (LEK[2]) is strongly developed as recognized by many years of documentation through more than 15 publications. The first of these was the seminal work of the MRC in 1999 for the *Assessment of Mekong Fisheries Component (AMFC): Fish Migrations and Spawning and the Impact of Water Management Project*. Previous studies based on local knowledge, and confirmed by fisheries data, have particularly focused on documentation of which species pass at different times of the year (Baird, 2001; Baran *et al.,* 2005; Baran, 2006).

The results of this new survey study contribute knowledge, inform design guidance for fish passage channels, and identify the factors needed for optimal mitigation of dam impacts. More specifically, the study was designed to generate information on the following:

- when and how fish arrive to Khone Falls from downstream (their preferred initial migration channels);
- which channels are the most important for successful fish passage (depending on species and timing);
- physical and hydrological qualitative descriptors of channels that allow fish passage;
- recommended fish passage improvements from the perspectives of local residents; and

---

[2] *Local ecological knowledge* is information obtained from natural resource users, those who depend on species and ecosystems for their physical and cultural survival. This information has also been named *"fishers' knowledge"*, "*indigenous technical knowledge*" or "*traditional ecological knowledge*". The relevance of this knowledge to scientific ecology and resource management has been underlined since the 90's, in particular within the Pacific (works of Bob Johannes). Such work in the Mekong was initiated around 2000 (*Assessment of Mekong Fisheries: Fish Migrations and Spawning and the Impact of Water Management Project* at MRC).

- other channels or falls that could be further managed for improved fish passage.

1.1. Geographic context

Khone Falls are comprised of more than 31 large islands, 25 large waterfalls or waterfall areas, and at least 52 individually identified channels. These features create a large number of corridors and dead ends through which fish attempt to migrate. During their migrations they are targeted by highly skilled fishers from 16 villages, as listed in Figure 1-1.

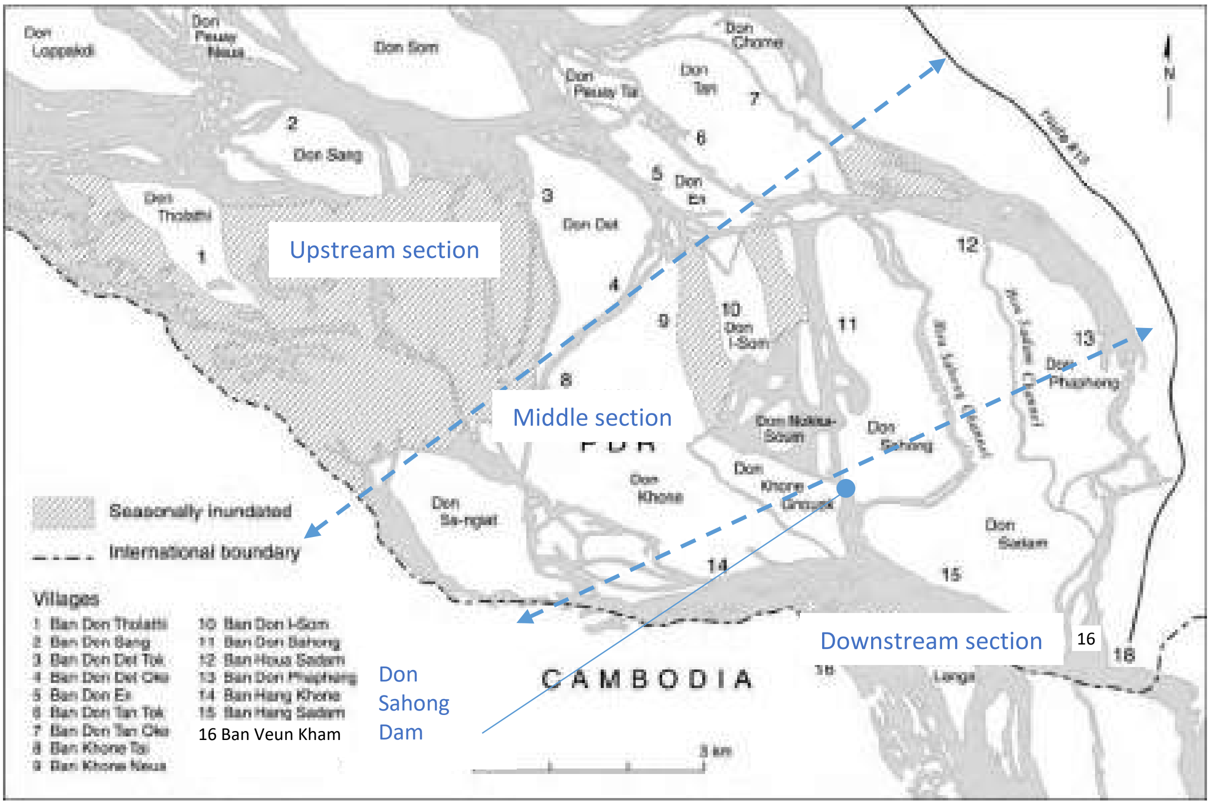


Figure 1-1. Map of Khone Falls main islands, channels and villages

The Khone Falls areas can be divided into three main zones from south to north:

i) **downstream of the falls,** between the Mekong mainstream at the border with Cambodia and the main waterfalls;

ii) **the middle section**, corresponding to the fault line and its multiple falls and channels around 8 main islands; and

iii) **the upstream area**, north of the fault line, where the system of islands and channels continues but without falls.

The head difference between upstream and downstream areas reaches 10 meters. Surveys were conducted in 16 villages, categorized by zone, as identified in Table 1-1.

Table 1-1. Khone Falls area villages surveyed

	Villages
Upstream area	#1 Ban Don Tholathi , #2 Ban Don Sang, #3 Ban Don Det Tok, #4 Ban Don Det Oke, #5 Ban Don En, #6 Ban Don Tan Tok, #7 Ban Don Tan Oke
Middle area	#8 Ban Khone Tai, #9 Ban Khone Neua, #10 Ban Don I Som, #11 Ban Don Sahong, #12 Ban Houa Sadam, #13 Ban Don Phapheng

Downstream area	#14 Ban Hang Khone; #15 Ban Hang Sadam; #16 Ban Veun Kham

1.2. Existing information on fish migrations in Khone Falls

Khone Falls is a biological hotspot, a fisheries landmark and a migration bottleneck that has attracted much attention in past decades. Its fish resources and fisheries have been detailed in multiple publication covering specific topics as follows:

- biodiversity (Baird, 2001);
- fisheries, fish bioecology (Roberts and Baird, 1995; Baran *et al.*, 2005); and
- local ecological knowledge (Baird and Flaherty, 2005; Baird, 2006, 2007).

Migration patterns in Khone Falls derived from local ecological knowledge have been summarized in Baran (2006) (Figure 1-2).

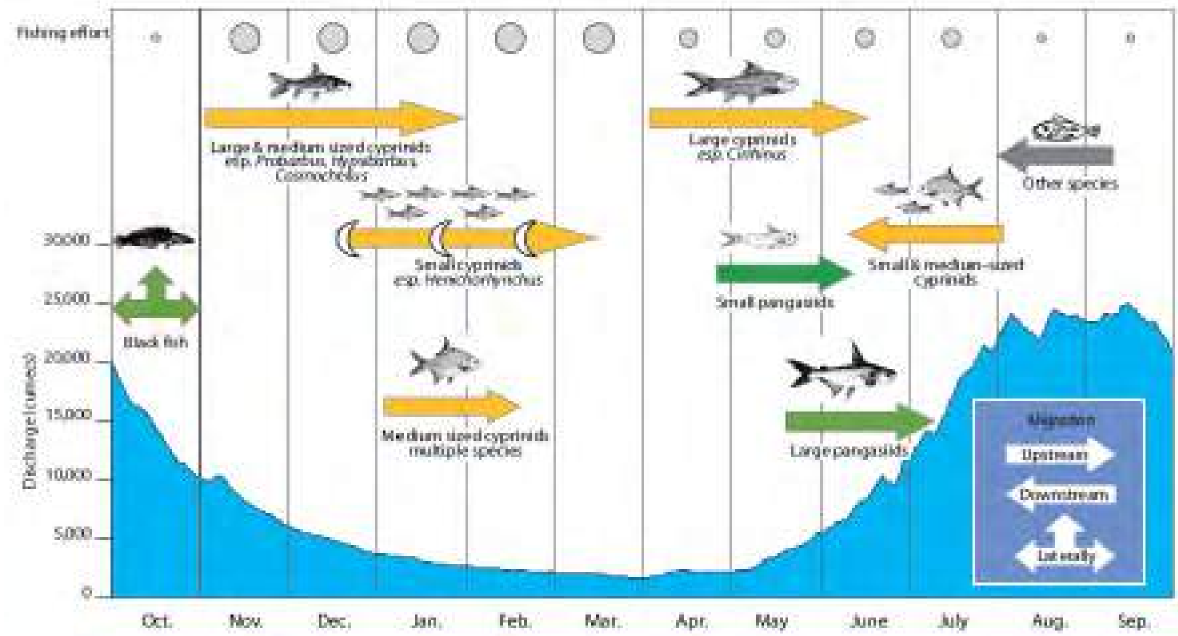


Figure 1-2: Annual fish migration patterns at Khone Falls, from Baran (2006)

Khone Falls fish bioecology is also reflected in several studies based on local ecological knowledge but developed on a larger scale (Chan Sokheng *et al.*, 1999; Poulsen and Valbo-Jørgensen, 1999; Poulsen et al., 2000; Bao et al., 2001; MFD, 2003; Poulsen, 2003).

These valuable studies of fisheries and ecological patterns describe a situation that is now between 15 to 25 years old. Given the significant changes in the area, in particular the construction of the Don Sahong Dam and extensive dam development in the Lower Mekong Basin, updated information that reflects current conditions is much needed.

2. METHODOLOGY

Systematically gathering of fishers' local ecological knowledge for the purposes of assess ecological patterns among fish species is an approach first developed in the Pacific (Johannes, 1981; 1989; and 1993). Comparisons of findings between local ecological knowledge surveys and scientific surveys conclude that gathering fishers' experience provides rapid, detailed and reliable information and is cost-effective (Poizat and Baran, 1997; Ticheler et al., 1998). As a rule of thumb, local ecological knowledge can provide 70% of the information for 10% of the cost and time. This approach was subsequently taken up and promoted (Johannes et al*.,* 2000; Rahman, 2000; Valbo-Jorgensen and Poulsen, 2000; Baird and Overton, 2001) and associated protocols were reviewed and refined (Haggan et al., 2003; 2007; Garcia-Allut et al., 2003; Moller et al., 2004; Cowie et al., 2020).

The Mekong is one region where assessments based on local ecological knowledge have been used extensively (Chhuon Kim Chhea, 2000; Dubois, 2005; Baird, 2007; Chan Sokheng et al., 2008; Baran and Seng Sopheak, 2011). The approach has also implemented in other river basins worldwide (Fishcher et al., 2015; Baran et al., 2015; Win Ko Ko et al., 2016) with most of these surveys having used - and sometimes adapted- the Mekong protocol originally described in Poulsen and Valbo-Jørgensen (1999; 2000). This protocol is also reflected in the present study.

2.1. Questionnaires

Questionnaires were developed for the 16 villages of Khone Falls based on the initial Mekong protocol, with simplifications made as suited to the Cambodian and Lao context. Gathering of information was undertaken during focus group discussion (one in each village) and using questionnaires that covered the following questions:

- how do migratory fish arrive to Khone Falls from downstream and from upstream?
- which channels are targeted by species for initial passage?
- which channels ultimately allow species to pass the falls?
- what are the channel specificities that allow passage or not?
- in the middle section of the falls, what passage improvements could be conducted?
- are there areas of the falls of special importance in terms of passage or ecology?

Since these questions correspond to different sections of the falls, the questionnaires were tailored for upstream, middle area and downstream zones. A map of the survey location is provided in Figure 2-1. The resulting survey questionnaires are detailed in Annex 1. Detailed local maps derived from Google Earth were also prepared to facilitate the discussion in each site.

Interviews were organized at each site between 10 March and 30 March 2021 by the first author and a field assistant, with guidance and support provided by the MRC Secretariat and national and local fisheries-related agencies. Each focus group discussion or meeting involved five to eight fishers, and never less than three. The group size aimed to achieve a balance between a low enough number of participants that opinions would not be collectively validated, yet a sufficiently high number of participants to avoid low group dynamics. Each fisher invited had at least 10 years of fishing experience and 5 years of residence in the site surveyed. Each focus group discussion and interview was conducted in Lao language with notetaking by a national assistant. When fishers disagreed, the answer recorded was the consensus response as agreed by most participants. In total more than 80 fishers were surveyed for the study. Completion of each questionnaire required between two to three hours and was followed by data entry on the same day (i.e. 1 village surveyed per day).

Figure 2-1. **Location map, with main islands (yellow), main waterfalls (blue) and the 9 channels improved by DSPC (orange)**

2.2. Target species

The survey was designed to cover abundance, size, timing, migration behaviour, passage routes and spawning. This corresponded to 30-35 questions by species. This survey design acknowledges that it is not possible to survey ecological knowledge about every migratory species in a place characterized by 201 fish species in 39 families, including 110 species harvested by fishers. Furthermore, our survey aimed at documenting not individual species but rather the main passage strategies and capabilities. A final design consideration for the survey was that the questionnaire should potentially be usable as a JEM routine in future and therefore fit within the time available with fishers (a few hours for each interview) and the time available for analysis. Ten target species were therefore selected for the survey as being representative of large groups of other species that migrate through Khone Falls. Limiting the number of species to ten provides an informative, manageable survey (10 species x 35 question = 350 questions per interview).

Criteria for the species selection are detailed below:

- Species migrating through Khone Falls, with broad migration patterns already mapped (MRC Mekong Fish Database);
- Species already identified by the MRC for transboundary management (10 Priority Species identified at MRC Joint Workshop on transboundary species management in May 2016; 5 species identified and chosen in 2017 as 5 Priority Fish Species for Transboundary Management);
- Species comprising a significant percentage of catches in Khone Falls fisheries (based on 6 years of monitoring as presented in Baran (2005));
- Clear migration patterns, to simplify the discussion with fishers;
- Migration at different times of the year, in different water levels (important for flows in fish passage and the selection of tagging methods;
- Species sensitive to discharge and flow velocity, i.e. to the conditions at fish passes (Baran, 2006); and
- Species belonging to different size groups (important in relation to the selection of swimming ability, and to tag options.

The full species selection process is detailed in Annex 2. The resulting ten species selected for this survey are listed in Table 2-1.

Table 2-1. List of migratory fish species selected for local ecological knowledge survey

Cirrhinus microlepis (paphone mak kok)	*Hypsibarbus malcolmi* (papak nouat/pa pak kom/pa pak)
Cyclocheilos enoplos (pa chok)	*Pangasius conchophilus* (pa pho/pa ke)
Gymnostomus lobatus (pa soi houa lem)	*Pangasius krempfi* (pa souay hang leuang)
Gymnostomus siamensis (pa soi houa po)	*Pangasius macronema* (pa gnone siap)
Helicophagus leptorhynchus	*Scaphognathops bandanensis* (pa pian)

Each of these selected species migrates through Khone Falls. They migrate at different times of the year and in different water levels (important considerations when assessing flows for fish passage and the selection of tagging methods). The selected species belong to different size groups which is an important factor in relation to the selection of swimming ability, and to tag options. They also exhibit clear migration patterns, detailed in particular in Baird (2001) and illustrated in Baran (2006). Finally, the selected ten species include representatives of the 6 main groups of species that migrate through Khone Falls as shown in Figure 2-2.

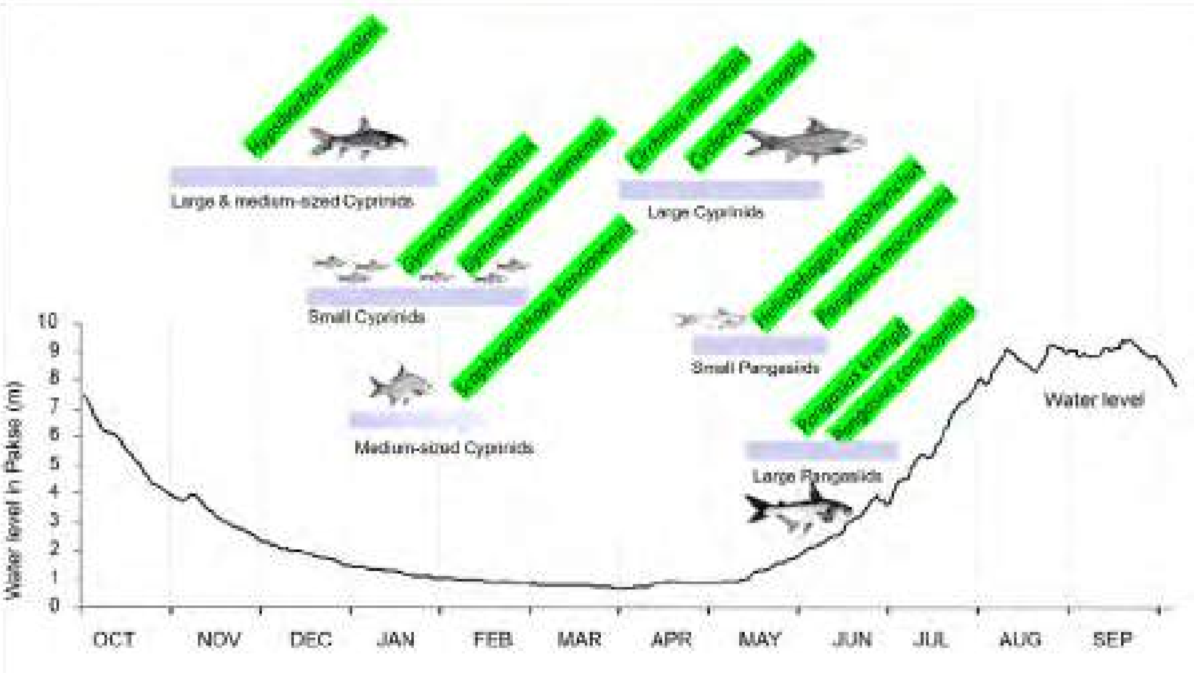


Figure 2-2. Illustration of the species selected

3. RESULTS

3.1. Information on species

The following sections present the new information gathered during this survey for each of the ten target species representing a group of migratory fish.

3.1.1. End of rainy season large- and medium-size cyprinids (*Hypsibarbus malcolmi*)

Basic information about the species is provided in Table 3-1 and Figure 3-1.

Table 3-1 Basic information about *Hypsibarbus malcolmi (sourced from FishBase.org, MFD [2003])*

Name	*Hypsibarbus malcolmi* (Cyprinidae)
Invalid synonym	*Poropuntius malcolmi*
Biology	Max. standard length (cm): 50; Length at maturity (cm): 29
Reproduction	Pelagic mainstream spawner that breeds in the late wet-or early dry season
Ecology	Found in large rivers in the dry season and moves to medium-size rivers in the wet seasons

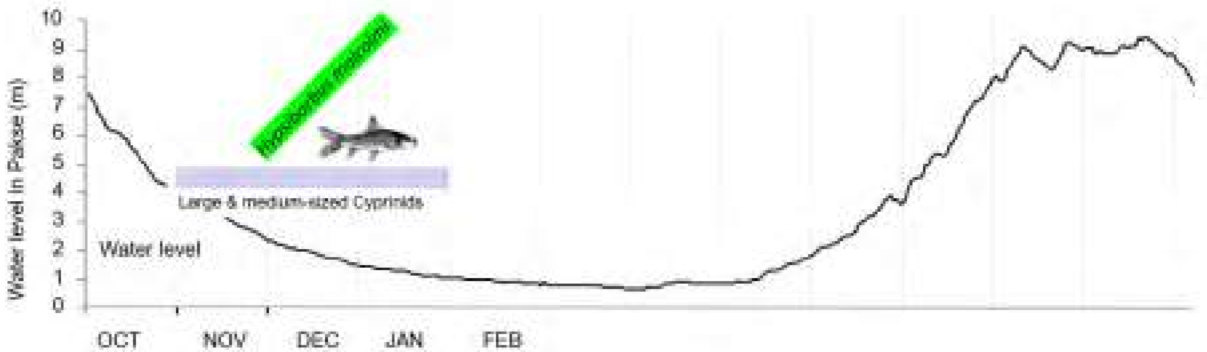


Figure 3-1. Migration of "end of rainy season large- and medium-size cyprinids" in the literature

The survey results indicated the following recent trends about *Hypsibarbus malcolmi* and its group, with migration patterns as shown in Figure 3-2 and Figure 3-3:

- Schools migrating all day. Downstream migrations are unknown.
- Downstream: the species migrates upstream in December- January - February (25-30 cm long fish with eggs) but is found in the area in the following months without migrating. Upstream migration channels sought are Hoo Phapheng, Li Phi and Khone Fang area.
- Mid-falls: fish are now never caught in Hua Sadam (Don Sadam Island), and *never caught in Hoo Sadam*. Migration channels are Hoo Phapheng, Hoo Don Wai, Hoo Xang Pheuak and Hoo Khone Lan.
- Upstream: Species absent from around Don Tan Island (unsuitable shallow environment, slow water current, water considered too warm). Species are migrating upstream in January at Don En. Downstream migration between June and August via the Khone Fang area (Khone Fang, Khone Souang, Khone Somhong).

<u>Conclusion</u>: Hypsibarbus malcolmi and its group migrate upstream later than reported in Baird (2001) and Baran (2005) (now mainly January - February); the species is not caught in Hoo Sadam anymore. It migrates downstream in June-August via the Khone Fang area.

Figure 3-2. Temporal migration of "end of rainy season large- and medium-size cyprinids" according to our survey (in blue) compared to 2001 information (in grey)

Figure 3-3. Spatial migration of Hypsibarbus malcolmi (end of rainy season large- and medium-size cyprinids) through (mainly) Hoo Xang Pheuak and close channels.

3.1.2. Early dry season small cyprinids (*Gymnostomus. siamensis* and *G. lobatus*)

Basic information about the species is provided in Table 3-7, Table 3-1 and Figure 3-2.

Table 3-2 Basic information about *Gymnostomus siamensis* and *Gymnostomus lobatus* (Cyprinidae). *Sources: FishBase.org, MFD 2003.*

Name	*Gymnostomus siamensis* and *Gymnostomus lobatus* (Cyprinidae)
Invalid synonym	*Cirrihinus siamensis / Henicorhynchus siamensis* and *Cirrihinus lobatus / Henicorhynchus lobatus*

Biology	Max. standard length (cm): 20 for *G. siamensis*; 15 for *G. lobatus*
Reproduction	April to July for *G. siamensis* (peak in May-June), June - July for *G. lobatus*
Ecology	Among the most abundant Mekong species, found from the Mekong Delta up to Chiang Khong. Migrates from Xayaburi to Chiang Khong. Migrates through Khone Falls between December and February and downstream in May-July. Discharge variation is a migration trigger.

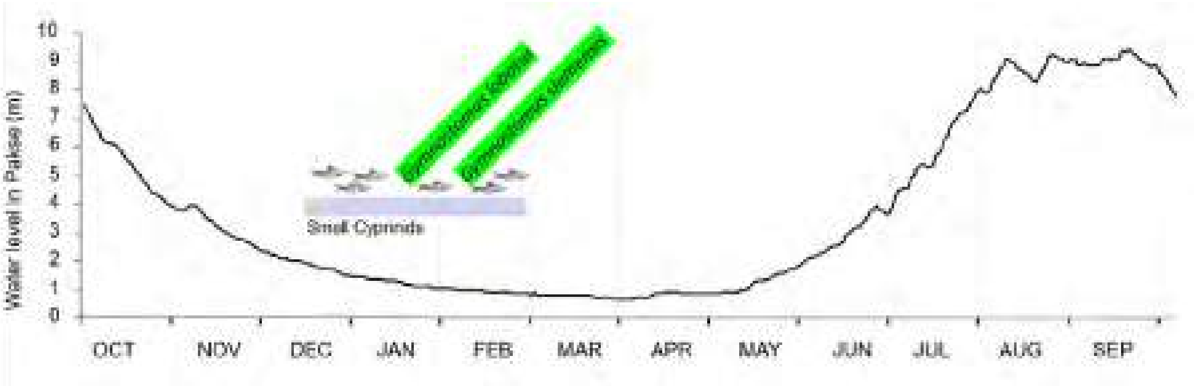


Figure 3-4. Temporal migration of "early dry season small cyprinids" in the literature

The survey results reported the following recent trends about *G. siamensis* and *G. lobatus* and their group, with migration patterns as shown in Figure 3-5 and Figure 3-6:

- <u>Downstream</u>: upstream migration in January-February, by small individuals (5-10 cm). However, the catch is quite minimal, to the point that fishers in Veunkham cannot identify a migration pattern any longer for *G. siamensis.* Migration mainly through Hoo Sadam, Hoo Xang Peuak and Hoo Don Dai, but almost not through Hoo Phapheng and not any more through Khone Pa Soi, as water diversion in Hoo Sahong for Don Sahong Dam leaves too little water for attraction and passability of Khone Pa Soi - whose name meaning "*Gymnostomus* water fall" highlights its former central role for the migrations of these species
- <u>Mid-falls</u>: Several villages report the quasi-total disappearance of upstream migrations of early dry season small cyprinids; this includes Ban Don Phapheng (east of the falls) and Ban Khone Neua (north of Don Khone). Several other villages report abundance reduced by 90% and migration pulses lasting a few days only, mainly in February, by schools of immature individuals and in the daytime. Downstream migrations remain observed in July-August, with schools of larger individuals bearing eggs and making noise; the migration uses all central and eastern channels, in particular the Khone Lan area, Hoo Sadam and Hoo Phapheng
- <u>Upstream</u>: similar patterns are observed in upstream villages, except that downstream migration is observed earlier (June-July)

<u>Conclusions</u>: These results underline the quasi-disappearance of species that used to be the most abundant ones, and their upstream migrations now limited to a few days a year - in particular in relation to reduced water levels in former key passages such as Khone Pa Soi.

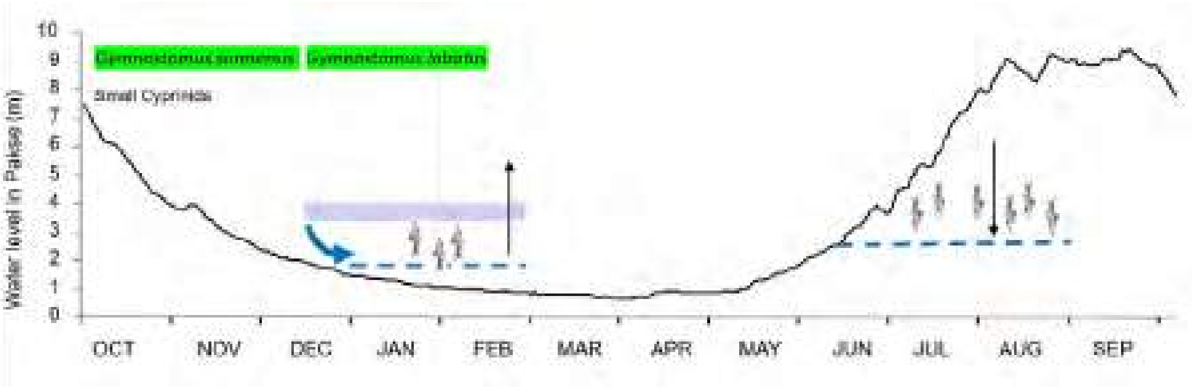


Figure 3-5. Temporal migration of "early dry season small cyprinids" according to our survey

Figure 3-6. Migration patterns of "early dry season small cyprinids" through (mainly) Hoo Phapheng, Hoo Sadam, Hoo Xang Pheuak and close channels.

3.1.3. Early dry season medium-sized cyprinids (*Scaphognathops bandanensis)*

Basic information about the species is provided in Table 3-3 and Figure 3-7.

Table 3-3 Basic information about *Scaphognathops bandanensis* (Cyprinidae). *Sources: FishBase.org, MFD 2003.*

Name	*Scaphognathops bandanensis (*Cyprinidae)
Reproduction	Breeds in July-August in floodplains and streams and at the end of the rainy season in receding waters areas. Juveniles appear in catches in April.
Ecology	Found in the Middle Mekong (Xe Bangfai, Sekong, Sesan and Srepok basins). The fish migrates up from Cambodia to Lao PDR in January-February, into smaller

	streams and floodplains in June-July, and returns to the mainstream in November-December.

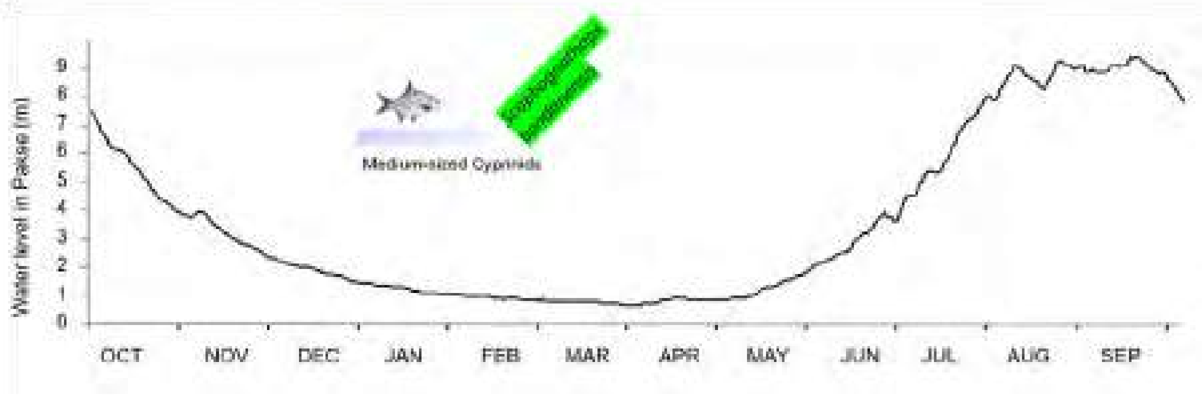


Figure 3-7: Temporal migration of "medium-sized cyprinids" in the literature

The survey results reported the following recent trends about *Scaphognathops bandanensis* and their group, with migration patterns as shown in Figure 3-8 and Figure 3-9:

- Overall, the pattern is unclear for that species.
- Downstream: the species appears in February and the upstream migration is more intense in March-April, up to June. Individuals at that time are 15-20 cm long and do not bear eggs. One site (Ban Hang Khone) mentions a downstream migration in July. The species moves upwards towards all channels, in particular Hoo Sadam and Hoo Phapheng
- Mid-falls: the pattern is very different from site to site, with some villages mentioning upstream migrations early in the year or in June-July. In the latter case, the direction of migration is unclear. Some sites (Ban Hua Sadam, Ban Don Phapheng) mention a quasi-permanent presence of the species in the area during which migrations are not clearly identified- while others (Ban Don Xom, Ban Khone Neua) claim a quasi-permanent absence. During upstream migrations, most channels seem to be used (which seems in contradiction with the case of *Gymnostomus* whose channel options are said to be limited as too shallow: Scaphognathops undertakes its migration at the same period as *Gymnostomus*, and its body-size is larger).
- Upstream: In upstream sites patterns are also unclear: *S. bandanensis* is said to be almost permanently present (Ban Don Tan OK, Ban Don Tan Tok, Ban Don Tholathi) or almost permanently absent (Ban Don Xang). The only common feature in all villages is a downstream migration around July - but villagers do not agree about egg presence. Most channels seems to be used for movements, in particular Hoo Sadam and the Khone Lan area.

Conclusions: Patterns are unclear for S. bandanensis and the group of early dry season medium-sized cyprinids, suggesting a permanent residence in some sites, in particular upstream of Khone Falls (e.g. Don Tholathi). Migrations are identified mainly in January-February (upstream) and July-August (downstream)- without being common to all sites. All channels seem to be used for movements.

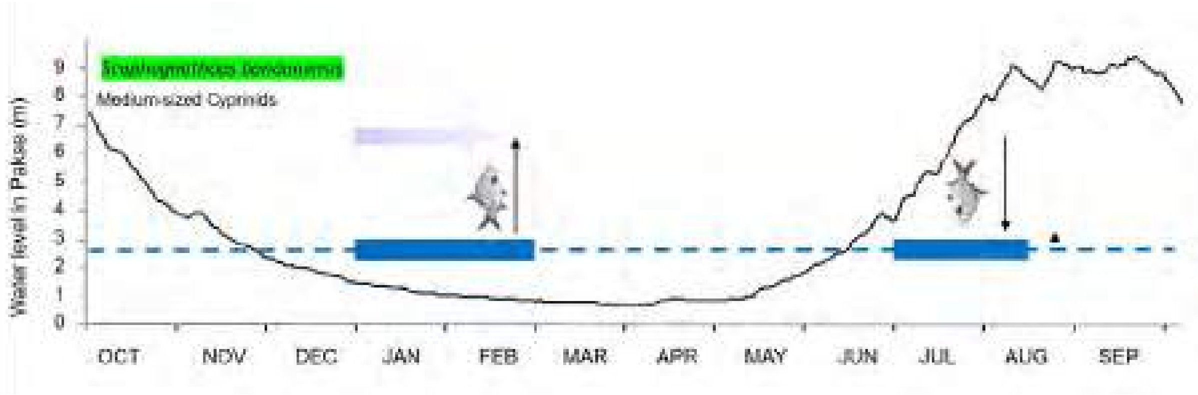


Figure 3-8. Temporal migration of Scaphognathops bandanensis *and its group according to our survey*

Figure 3-9. Migration patterns of "early dry season small cyprinids" through Hoo Phapheng (a little), Hoo Sadam, and Hoo Xang Pheuak.

3.1.4. Dry- to early wet season large cyprinids (*Cirrhinus microlepis* and *Cyclocheilos enoplos)*

Basic information about the species is provided in Table 3-4 and Figure 3-10.

Table 3-4 Basic information about *Cirrhinus microlepis* and *Cyclocheilos enoplos* (Cyprinidae). *Sources: FishBase.org, MFD 2003.*

Name	*Cirrhinus microlepis* and *Cyclocheilos enoplos (*Cyprinidae)
Biology	Max. standard length (cm): 74; length at maturity: 41.1 (*Cyclocheilos enoplos);* Max. standard length: 65; length at maturity: 36.6 (*Cirrhinus microlepis).* The latter is a fast swimmer and a nervous "jumper".

Reproduction	Start spawning in the early flood season, July-August (*Cyclocheilos enoplos) or* May-August (*Cirrhinus microlepis*). Eggs and larvae are pelagic, and drift downstream.
Ecology	Both are found from the Mekong Delta to Bokeo or Chiang Saen. *C. enoplos* migrates upstream as a response to the first rainfalls and downstream in October - December. *Cirrhinus microlepis* seems to feature several populations.

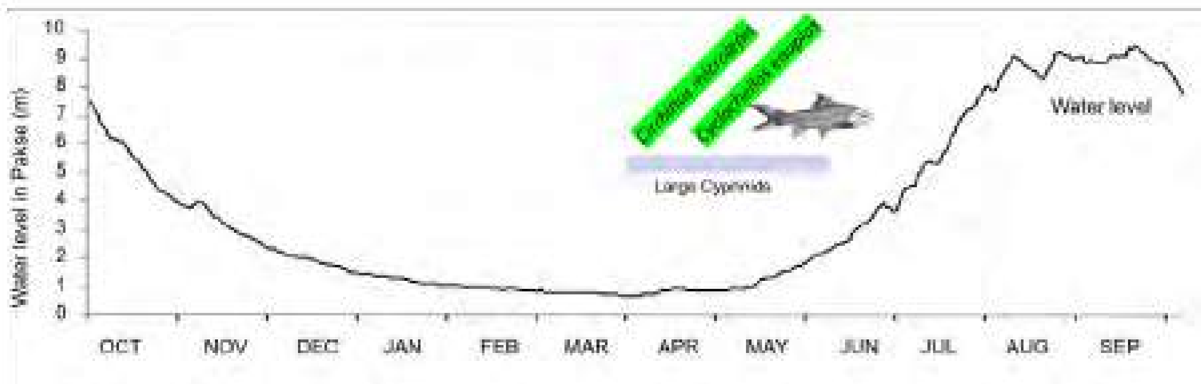


Figure 3-10: Temporal migration of "Dry- to early wet season large cyprinids" in the literature

The survey results reported the following recent trends about *Cirrhinus microlepis*, *Cyclocheilos enoplos* and their group, with migration patterns as shown in Figure 3-11:

- Downstream: Patterns are contradictory depending on species, with villages reporting upstream migrations (without eggs) for *C. microlepis* in February-March, and December for *C. enoplos*, but all agree about downstream migrations (with eggs) in June-July for *C. microlepis*, and limited or no downstream migration pattern for *C. enoplos*. Interestingly, fishers also identified a *Cirrhinus microlepis* breeding area on the east bank of Don Det.
- Mid-falls: All sites report a species collapse of catches, with now 10% to 0% of previous catches (no more catches of *C. enoplos* in Ban Hua Sadam, Ban Don Sahong or Ban Don Xom). Among villages with remaining catches of *C. microlepis*, the only common pattern is downstream migrations of 50-60 cm long individuals bearing eggs, between July and September - but with peaks lasting 1 to 3 days only. Among villages still catching *C. enoplos*, patterns are contradictory and also limited to 2-3 days a year.
- In this context, it is difficult to confirm the various upstream migration channels identified by fishers - among which Hoo Sadam and the Khone Lan area are mentioned a few times.
- Upstream: half of upstream villages report the total absence of *C. microlepis* and *C. enoplos* year round, in particular around Don Tan; other villages still report some migrations, but patterns are contradictory (e.g. upstream in June-July-August and downstream in July-September, with eggs or without for *C. microlepis*, and no more clear migrations, together with a tiny catch, for *C. enoplos*.

Conclusions: "Dry- to early wet season large cyprinids" seem to be vanishing from catches in the falls and upstream of them, and the remaining individuals caught are not sufficient to characterize migrations and further.

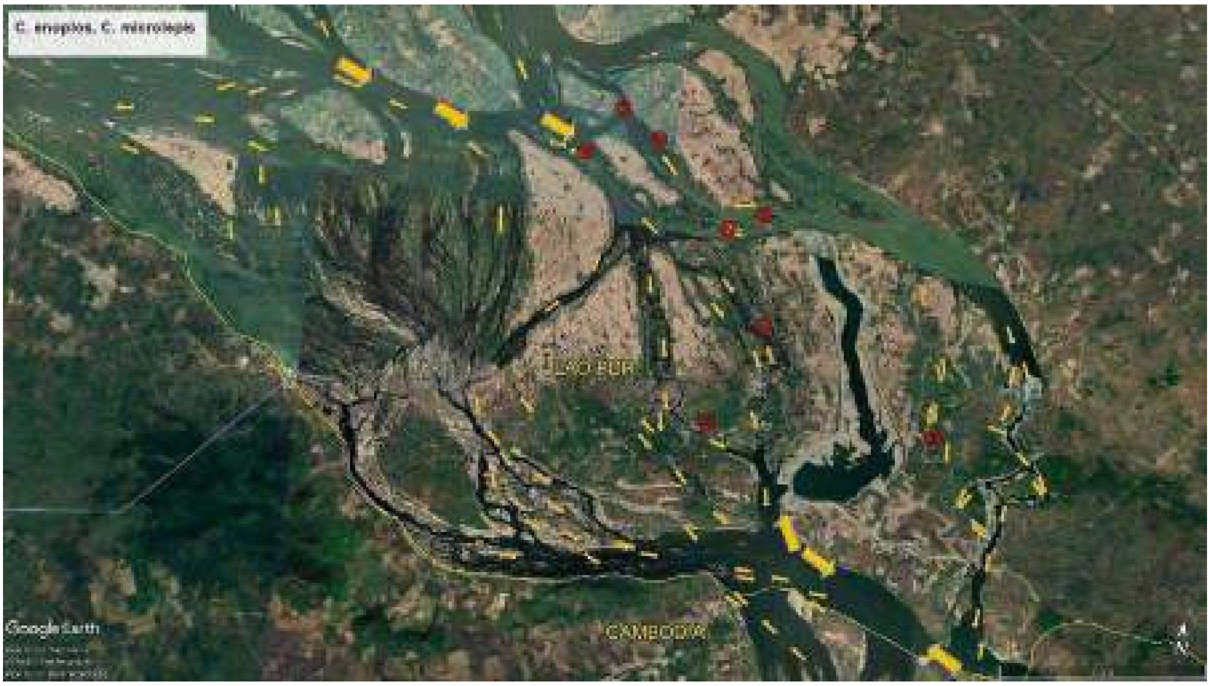


Figure 3-11. Migration patterns of **Cirrhinus microlepis and Cyclocheilos enoplos, mainly through Hoo Phapheng and Hoo Sadam.** *Red marks indicate claims of total absence of species year round*

3.1.5. Early wet season small Pangasiids (*Helicophagus leptorhynchus* and *Pangasius macronema*)

Basic information about the species is provided in Table 3-5 and Figure 3-12.

Table 3-5 Basic information about *Helicophagus leptorhynchus* and *Pangasius macronema* (Pangasiidae) ***Sources: FishBase.org, MFD 2003.***

Name	*Helicophagus leptorhynchus* and *Pangasius macronema (*Pangasiidae)
Invalid synonym	*Helicophagus waandersii* (a species from Sumatra and Malaysia only)
Biology	Max. total length (cm): 70; length at maturity (cm): 39.1 (*Helicophagus leptorhynchus);* Biology: Max. total length (cm): 30; length at maturity (cm): 18.5 (*Pangasius macronema).*
Reproduction	Eggs are observed from March to July with a peak in May-June (*Helicophagus leptorhynchus)*, or year round, but most often between April and June (*Pangasius macronema),* with some variability in both cases.
Ecology	Found basinwide. Migrates upstream at the beginning of the flood season and downstream at the end of the flood season.

Figure 3-12: Temporal migration of "Early wet season small Pangasiids" in the literature

The survey results reported the following recent trends about *Helicophagus leptorhynchus*, *Pangasius macronema* and their group, with migration patterns as shown in Figure 3-13:

- Downstream: Some downstream villages that *H. leptorhynchus* is now present from January to July without migrating, the upstream migration happening in November-December, while others report an upstream migration (with no eggs) in July-August. The migration of *P. macronema* is only reported upwards, but timing diverges (March-May or March-July, with eggs in case of later months).
- Mid-falls: Several villages report the absence, now, of *P. macronema* year round (Ban Don Phapheng, Ban Hua Sadam) while in others the upstream migration is reported any time between March and August (very brief 2-day peaks, usually individuals with no eggs). A same low-intensity stretched pattern is reported for H. leptorhynchus, with an upstream migration spanning between June and October, but with very low peaks or even anecdotal presence during these months without migration. In all cases abundance is now extremely low, representing 30% to 0% of the former abundance.
- Upstream: villages report the presence of these species, in very low abundance, either year round without any migration pattern, or a slight upstream migration pattern in June-July.

Conclusions: Like "Dry- to early wet season large cyprinids", fishers report the progressive disappearance of "Early wet season small Pangasiids", and the remaining individuals are not enough in sufficient numbers to clearly characterize migrations any further.

Figure 3-13. Migration patterns of **Helicophagus leptorhynchus** *and* **Pangasius macronema through all channels.** *Red marks indicate claims of total absence of the species year round*

3.1.6. Early wet season large Pangasiids (*Pangasius krempfi*, *P. conchophilus*)

Basic information about the species is provided in Table 3-6 and Figure 3-14.

Table 3-6 Basic information about *Pangasius krempfi* and *Pangasius conchophilus* (Pangasiidae). ***Sources: FishBase.org, MFD 2003.***

Name	*Pangasius krempfi, Pangasius conchophilus* (Pangasiidae)
Biology	Max. standard length (cm): 120 (both species).
Reproduction	Sexually mature fish migrate upstream from May to September, with peaks lasting 3-5 days (*Pangasius krempfi);* spawn at various times of the year but dominantly at the beginning of the flood season until October (*Pangasius conchophilus)*.
Ecology	Anadromous species caught from the coasts of Vietnam up to Chiang Saen (*P. krempfi)* or from the Delta also up to Chiang Saen *(P. conchophilus).* Populations start migrating upstream in May until August-September. Downstream migrations in October. Water level variation is a migration trigger.

Figure 3-14: Temporal migration of "wet season large Pangasiids" in the literature

The survey results reported the following recent trends about *Pangasius krempfi, Pangasius conchophilus* and their group, with migration patterns as shown in Figure 3-15 and Figure 3-16.

- Downstream: Upstream migrations in June-August; contradictory information about September - October (either migrating up, or down).
- Mid-falls: upstream migration reported between June and August, with variability depending on sites. Eggs are visible during the flood period, but not at the beginning. Movements unanimously described as in schools, at night. Abundance reduced to 50%- 0% in all sites.
- Upstream: same patterns and trends as mid-fall villages. Permanent very low abundance presence in some sites.

Conclusions: the beginning of the migration is never reported in May but spans mainly in June-August. Strong loss of abundance (50 to 0% remain) and, like in other groups, some permanent presence in very low abundance and without clear migration pattern is noted in several sites. Downstream migration is never reported.

*Figure 3-15. Temporal migration of "*Pangasius krempfi *and* Pangasius conchophilus*" according to our survey*

Figure 3-16. Migration patterns of "wet season large Pangasiids", mainly through Hoo Sadam, Hoo Xang Pheuak and the Khone Pa Soi area

3.2. Information on channels

The local knowledge survey was also used to gather recent information about the channels used by fish for their migrations. These findings provide an update that reflects the hydrological changes across the past few years in a context of basin-wide dam development and climate change. Since it is impossible to detail all channels of the falls, nine channels identified over the years as important to fish migrations were selected for reporting of environmental conditions. These nine channels have also been the target of activities by the Don Sahong Power Company to improve fish passage. Listed from east to west, these nine channels are the following:

- Hoo Som Yai (where MRC monitored a *Lee* trap fishery for 20 years);
- Hoo Som Pordan[3] next to Khone Phapheng waterfall;
- Hoo Sadam between Don Sadam and Don Papeng;
- Hoo Xang Peuak Noy, Nyoi Koong, Koum Tao Hang, Hoo Wai and Luong Pi Teng between Don Ee Som and Don Sahong; and
- Hoo Don Lai next to Lee Pee waterfall.

Coordinates for these channels are shown in Table 3-7. The environmental terminology contained within their names is described in Box 1.

[3] Som Pordan, the name used by the Don Sahong Power Company (DSPC), is also locally pronounced as Som Pa Lan.

Table 3-7: Fish passage channels improved by Don Sahong Power Company and their location

	Lao name (Latin script)	Lao name (Lao script)	Latitude	Longitude
1	Hoo Som Yai	ໂສມໃຫຍ່	13°57'32.64"N	105°58'57.94"E
2	Som Pordan	ໂສມປໍດານ	13°57'46.10"N	105°58'54.24"E
3	Hoo Sadam	ຮູສະດຳ	13°58'22.51"N	105°58'10.03"E
4	Xang Peuak Noy	ຮູຊ້າງເຜືອກນ້ອຍ	13°57'27.50"N	105°57'23.13"E
5	Nyoi Koong	ຍ່ອຍກຸ່ງ	13°57'4.49"N	105°57'14.79"E
6	Khoum Tao Hang	ຂຸ່ມເຕົ່າຮ່າງ	13°57'6.15"N	105°57'9.22"E
7	Luang Phi Teng	ຮູລ່ອງຜີແຕ່ງ	13°57'24.29"N	105°57'1.33"E
8	Hoo Wai	ຮູຫວາຍ	13°57'31.77"N	105°56'58.34"E
9	Hoo Don Lai	ຮູດອນໄລ່	13°57'14.40"N	105°54'59.28"E

Khone: small to medium-size waterfall

Haew: high waterfall too high for fish to pass

Hoo: channel

Yai : large/ *Noi:* small

Don: island

Ban: village

Box 1. Environmental terminology in Lao language

3.2.1. End of Hoo Som Yai channel near Khone Phapheng

An aerial view and photograph of this channel is provided in Figure 3-17, with characteristics provided in Table 3-8.

Figure 3-17: Hoo Som Yai channel near Khone Phapheng, in March 2020 (left) and October 2014 (right)

Table 3-8: Hoo Som Yai channel characteristics

	Width	
Width in dry season	6 - 10 m	
Width in wet season	6 +- 15 m	
	Min. depth in dry season	**Max. depth in wet season**
Now	Dry	2 m
These past 2 years, months with no water	Nov. to June	
10 years ago	80 cm	2 m
10 years ago, months with no water	Water year round	

3.2.2. Hoo Som Pordan channel near Khone Phapheng

An aerial view and photo of this channel is provided in Figure 3-18 with characteristics provided in Table 3-9.

Figure 3-18. Hoo Som Pordan (left), flowing into Hoo Som Yai, in March 2020

Table 3-9. Hoo Som Pordan channel characteristics

	Width	
Width in dry season	3 - 15 m	
Width in wet season	5- 15 m	
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	Dry	1.8 m
These past 2 years, months with no water	Dec. to early June	
10 years ago	Dry	1.8 - 2 m
10 years ago, months with no water	April to May	

3.2.3. Hoo Sadam channel

Hoo Sadam is located between Don Sadam and Don Papeng. An aerial view and photo of this channel is provided in Figure 3-19 and Figure 3-20 with characteristics provided in Table 3-10.

This narrow channel is without waterfalls and is known to be important for all migrating species across most of the year. Fishers have highlighted that this channel is special due to the presence of pools and other resting sites used by fish during their migrations. Some of these pools reach 2m depth. In this channel, fish are also caught during the downstream migration from May until July, after which the water level is too high to catch fish.

Figure 3-19. Hoo Sadam channel in March 2020

Table 3-10. Hoo Sadam channel characteristics

	Width (m)	
Width in dry season (m)	7 - 90	
Width in wet season (m)	25 - 90	
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	Water not flowing. 30-50 cm depth in some places but very shallow upstream. Standing waters and disconnected pools	3 m
These past 2 years, months with no water	Dec. to June	
10 years ago	1 m	5 m
10 years ago, months with no water	Water year round	

Figure 3-20. Hoo Sadam (left: upstream; right; downstream) in March 2014

3.2.4. Hoo Xang Peuak

Hoo Xang Peuak is a major dual pathway for fish migrating upstream, with two main channels and waterfalls (yai = large, noy = small) as shown in Figure 3-21.

Figure 3-21. Hoo Xang Peuak Yai and Noy (location map)

Here the waterfalls **Khone Xang Peuak Yai** and **Khone Xang Peuak Noy** are 3-4 m high, but not particularly wide. In May-June the migrating *Pangasius conchophilus* and *P. krempfi* pass them, while *Pangasius macronema* cannot. *Hypsibarbus spp.* can also get up these falls. In October, fish can pass these falls more easily. These channels used to be the sites of multiple traps catching small cyprinids in the months of January and February.

Hoo Xang Peuak Yai is listed here since it is one of the two components of Hoo Xang Peuak channel however it should be noted that it was not modified by Don Sahong Power Company for improved fish passage and is currently not passable by fish (being a high waterfall). An aerial view and photo of this channel is provided in Figure 3-22 with characteristics provided in Table 3-11.

Hoo Xang Peuak Noy was the first passage widened by the Don Sahong Power Company as an intended alternative to Hoo Sahong in the dry season. An aerial view and photo of this channel is provided in Figure 3-23 with characteristics provided in Table 3-12.

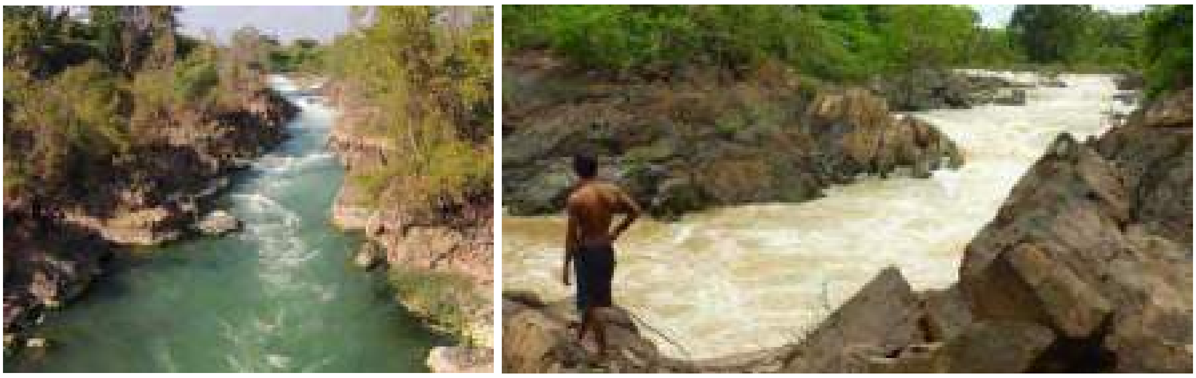


Figure 3-22. Hoo Xang Peuak Yai in January 2015 (left) and June 2015 (right)

Table 3-11: Hoo Sang Peuak Yai characteristics

	Width	
Width in dry season	4 - 25 m	
Width in wet season	10 - 40 m	
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	about 1.3m	4-5 m
These past 2 years, months with no water		
10 years ago	1.3 m	4-5 m
10 years ago, months with no water	Water year round	

Figure 3-23. Hoo Xang Peuak Noy in February 2015 (left) and October 1017 (right)

Table 3-12. Hoo Sang Peuak Noy characteristics

	Width	
Width in dry season	3 - 13 m	
Maximum width in wet season	8 - 35 m	
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	10 - 20 cm	2 m
These past 2 years, months with no water		
10 years ago	30 - 40 cm	2 m
10 years ago, months with no water	Water year round	

3.2.5. Nyoi Koong

Nyoi Koong is a channel located 700 m upstream of the Don Sahong Dam. An aerial view and photo of this channel is provided in Figure 3-24 with characteristics provided in Table 3-13.

Figure 3-24. Nyoi Koong in March 2020

Table 3-13. Nyoi Koong characteristics

	Width	
Width in dry season	4 - 40 m	
Width in wet season	10 - 70 m	
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	Dry	2.5 m

These past 2 years, months with no water	Dec to June	
10 years ago	40-50 cm	2.5 m
10 years ago, months with no water	Water year round	

3.2.6. Koum Tao Hang

Koum Tao Hang is another channel located 900 m upstream of the Don Sahong Dam. An aerial view of this channel is provided in Figure 3-25 with characteristics provided in Table 3-14.

Figure 3-25. Koum Tao Hang channel

Table 3-14. Koum Tao Hang characteristics

	Width	
Width in dry season	13 - 37 m	
Width in wet season	22 - 40 m	
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	Dry	4 m
These past 2 years, months with no water	March - May	
10 years ago	50 cm	4 m
10 years ago, months with no water	Water year round	

3.2.7. Hoo Wai channel

Hoo Way is a major channel allowing fish to swim around the very challenging Khone Lan. It has been the subject of extensive earthworks by the Don Sahong Company, with blocks of rocks put in place to provide shelter and break up the current.

The channel is wide and moderately deep with several steps where PIT antennas can be set. It is currently unclear whether its entrance in the reverse direction is comparable to the main flow from Khone Lan as an attractive option for fish. An aerial view and photo of this channel is provided in Figure 3-26 and Figure 3-27, with characteristics provided in Table 3-15.

Figure 3-26. Hoo Wai channel (location map)

Figure 3-27. Hoo Wai channel in November 2019

Table 3-15. Koum Hoo Wai characteristics

	Width	
Width in dry season	9 - 22 m	
Width in wet season	23 - 52 m	
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	50 cm	10 m
These past 2 years, months with no water		
10 years ago	70 cm	10 m
10 years ago, months with no water	Water year round	

3.2.8. Luong Pi Teng

Luong Pi Teng, like Koum Tao Hang, is a channel intended to complement Hoo Wai in bypassing Khone Lan. It is very shallow with turbulent water most of the year. An aerial view and photo of this channel is provided in Figure 3-28 with characteristics provided in Table 3-16.

Figure 3-28. Luong Pi Teng channel

Table 3-16. Luong Pi Teng characteristics

	Width	
Width in dry season	5 - 8 m	
Width in wet season	Merged with Khone Lan	
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	Dry	2 m
These past 2 years, months with no water	March to June	
10 years ago	Dry	2 m
10 years ago, months with no water	March to April	

3.2.9. Hoo Don Lai

Hoo Don Lai channel is located next to Haew Sompamit. An aerial view and photo of this channel is provided in Figure 3-29 and Figure 3-30 with characteristics provided in Table 3-17.

This is an important channel for small cyprinids (*Cirrhinus, Paralaubuca, Crossocheilus, Labiobarbus*) but also cobitids and other species migrating in January-February. However, according to fishers it is challenging for fish to exit this channel during the dry season. Fish can only enter and swim in the lower part of this channel up to the 1.5m high step at mid-way that becomes impassable in this season. As water levels increase then more fish species can pass these falls.

Figure 3-29. Hoo Don Lai (location map)

Figure 3-30. Hoo Don Lai in January 2016 (left: downstream; middle: mid-range; right: upstream)

Table 3-17. Hoo Don Lai characteristics

	Width
Width in dry season	3 - 28 m
Width in wet season	7 - 34 m

	Min. depth in dry season	Max. depth in wet season
In 2021 dry season	40 cm- 1 m last year 50 cm (head water)	1-2 m (head water)
These past 2 years, months with no water		
10 years ago	Dry	1 m
10 years ago, months with no water	March to April	

4. OVERVIEW AND PERSPECTIVES

A series of observations and perspectives is presented based on the survey results set out in Chapter 3.

Target migratory species caught in the zones surveyed

Among seven upstream villages, fishers from Ban Don Tan Tok and Ban Don Tan Oke villages report the lowest number (6-7 species) of target fish caught during the past 3 years. They provide the following two reasons for this:

i) the local environment is shallow and not diverse, i.e. not attractive for fish, and
ii) the villages are close to the Don Sahong Dam reservoir inlet, with a strong current that does not allow fishing any longer.

Fishing has shifted towards the west (above Khone Lan) and fishers have started gathering snail to make a living.

Within the six villages of the mid-falls zone, the lowest catch of species surveyed and the lowest abundance are reported in Ban Houa Sadam and Ban Khone Nuea (6-7 species). This finding is explained by the fact that these villages have seen a restriction of their fishing zone which is now limited to Hoo Sadam. In contrast, catch by fishers from those villages having access to the Khone Pa Soi waterfalls (Ban Khone Nuea, Ban Houa Sadam, Ban Hoo Sadam) still feature a higher diversity and abundance.

Downstream villages report a high diversity of species surveyed. Fishers explain this as being a result of a favorable aquatic environment (e.g. deep pools along the east bank near Veun Kham; Tam Ee Deng deep pool near Khone Fang).

Species passing the falls

In the past three years, only five among the ten target species have been identified as migrating through the falls. These five are *Cirrhinus microlepis, Gymnostomus lobatus, Gymnostomus siamensis, Scaphognathops bandanensis* and *Hypsibarbus malcolmi*. Three species are reported as having upstream migration only through the falls (*Pangasius conchophilus, Pangasius macronema* and *Pangasius krempfi*). One species (*Helicophagus leptorhynchus*) was sometimes reported as having upstream migrations but without further clarity of trajectory noted. Similarly, in upstream villages it was reported that *Cyclocheilos enoplos* no longer features a clear pattern due to a combination of permanent presence and very low abundance yet downstream and mid-falls villages confirm that its upstream migration continues.

Which way do migratory fish arrive to Khone Falls?

This survey is biased by a sampling deficit on the west bank of the Mekong River downstream of the falls, since ideally Cambodian villages on that west bank should have been sampled too. However most responses indicate that fish from the downstream areas pass through the eastern Mekong channel between Koh Chheu Teal Thom and the east bank in order to arrive to the falls, since this channel is much deeper (5 to 30 meter deep) compared to other channels (1 to 3 m depth south of Koh Lngor/Don Langa). Fish then either move i) north towards Hoo Phapheng, ii) towards the central zone (Hoo Nok Gasoom, Hoo Dtat Wai), or iii) eastwards by following the line of deepest waters (3 to 30m deep north of Koh Lngor/Don Langa) towards Khone Fang area.

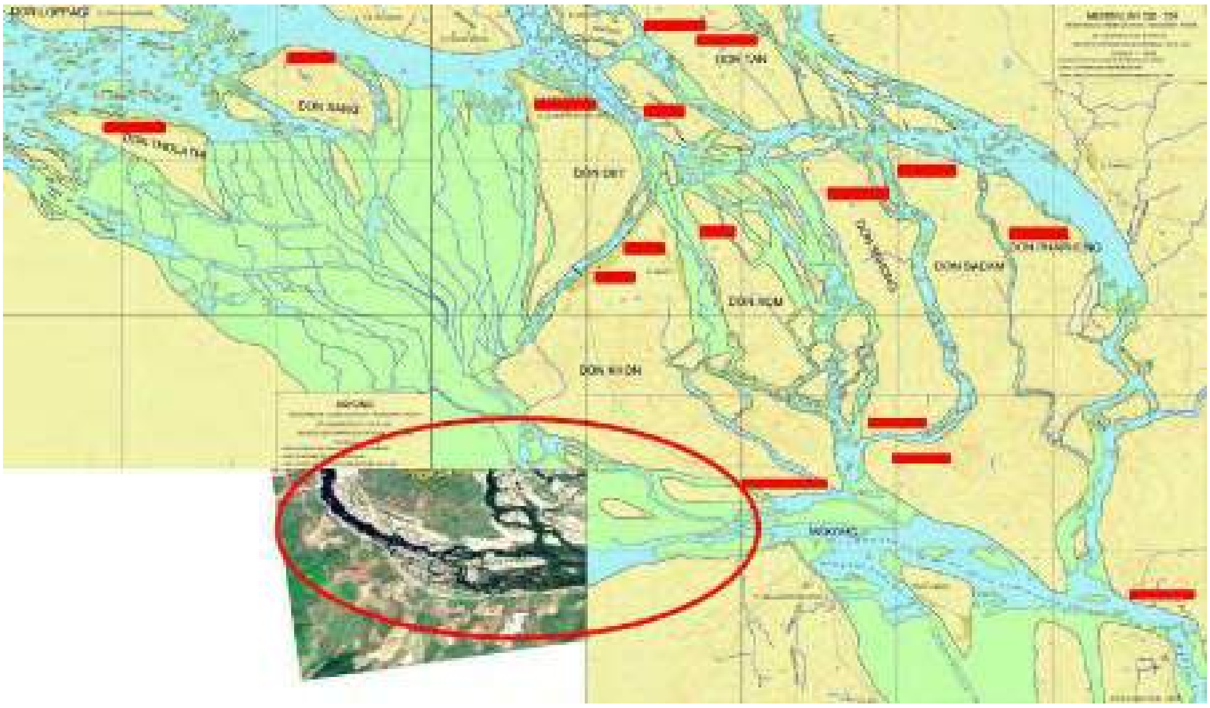


Figure 4-1. **Overview of villages surveyed (red rectangles) and of the area with no villages, limited fishing, and information deficit on migrations, channels and bathymetry (red oval)**

Which channels are initially then successively targeted by species for initial passage? Which channels are ultimately used by species to successfully pass the falls?

In the dry season**,** 3 species (*Gymnostomus lobatus, Gymnostomus siamensis* and *Pangasius macronema*) attempt to pass upstream through the following channels:

- Hoo Kogma and Hoo Khone Souang (Khone Fang area, passable);
- Hoo Somphamit (impassable);
- Hoo Xang Peuak, Hoo Khone Lan and Hoo Wai (central zone); and
- Hoo Sadam.

In recent years, **fish stay in Hoo Phapheng downstream of the falls without attempting migration through Hoo Sadam** as a result of the lower water levels and the loss of current-related migration cues.

Hoo Nok Gasoom, Hoo Xang Peuak and Hoo Sadam are channels targeted by fish at the beginning of the rainy season, but it is noted that they are not accessible before June. Fishers say that migrations start earlier in those places with deep pools or fish conservation zones (for example, because the fish spend the dry season in these places and so do not have to travel from far away). **Hoo Phapheng is still very attractive to fish despite reduced discharge following the Don Sahong Dam flow diversion**, but **passage is impossible at Khone Phapheng and at the lateral channels** (Hoo Som Yai and Hoo Som Pordan) since they are now dry for most of the year due to the same reason.

In the wet season, June water levels are insufficient for fish to pass the water falls in the Khone Fang area. **Fish can therefore only pass through Hoo Xang Pheuak, Hoo Sadam and Hoo Phapheng**. In the Khone Fang area, fish arriving earlier are reported to wait in deep pools until July (in particular, at the tip of Don Langa and at Tam Ee Deng).

What are the channel specificities that allow passage?

Fishers identify several factors that attract fish and allow passage:

i) adequate discharge, i.e. just strong enough to be attractive but still swimmable;
ii) width and depth of the channel (the more the better); and
iii) higher head producing noise, high dissolved oxygen content and lower water temperature; and
iv) presence of multiple resting pools or habitat complexity, with multiple steps allowing fish to progressively jump upstream.

Due to the high discharge with the attractive noise and oxygen levels at Don Sahong Dam site, fish tend to stay in the outflow area and many do not attempt to go further upstream towards Hoo Xang Pheuak or Khone Lan in the manner that they did a few years ago. This phenomenon is illustrated by the concentration of fishers found at the dam outflow.

Overall, fish passage across these past years has also been compromised by a) the high number of gears set to compensate for a drastically decreasing catch per unit effort, b) the increasing use of fine monofilament gillnets and c) the return of *Li* traps in several channels.

What are the passage improvements that could be further conducted?

In Khone Fang area the two main channels (Khonefang and Liphi waterfalls) show presence of the predominant fish species undertaking upstream migration in the dry season and early wet season. Therefore, this area could be considered for leveling and deepening (reduction of current water head) to improve fish passage during the dry season with detailing of locations. Following additional survey as detailed in Annex 3, the following locations are identified to have potential for future channel alteration:

Khonefang areas

i) Hoo Khone Xouang (main channel, alternative passage 1); and
ii) Hoo Khone Xouang Noi (micro channel, alternative passage 2).

Liphi waterfalls

i) Hoo Pataep (main channel, alternative passage 1); and
ii) Hoo Khonekor, Hoo Khone Koum, Hainoi and Hai Nyai (a hub of micro channels).

In the Khonefang area, **Hoo Khone Xouang is a potential new candidate for fish pass improvement together with the micro channel Hoo Khone Xuangnoi** that provides optional clearance for a deeper channel to have more water supply all year round.

At the Liphi waterfalls, it is not possible for fish migration to occur upstream from Hoo KhoneKhouang to the Khone Khoum waterfalls areas in either the dry season or the early wet season from May to July because of the very high waterfall, the high slope angle and the strong water flow. However, **Hoo Pataep is a potential candidate micro channel** since it has water all year round, and it is located at the opposite site of Don Lai Channel. **Hoo Pataep is a hub of several micro channels- Hoo Khonekor, Hoo Khone Koum, Hainoi and Hai Nyai.**

5. REFERENCES

Baird, I. G. (2001). *Aquatic biodiversity in the Siphandone wetlands.* In Daconto G. (ed.). *Siphandone wetlands* (Pp. 61-74). Publication of the project Environmental protection and community development in Siphandone wetlands. CESVI Cooperazione e Sviluppo, Bergamo, Italy. 192 pp.

Baird, I. G. (2006). Conducting rapid biology-based assessments using local ecological knowledge. *Nat. Hist. Bull. Siam. Soc.* 54 (2);167-175.

Baird, I. G. (2007). *Local ecological knowledge and small-scale freshwater fisheries management in the Mekong River in Southern Laos.* In. Haggan N., Neis B., and Baird I. G. (eds.): *Fishers' knowledge in fisheries science and management* (Pp. 227-266). Coastal Management Sourcebooks 4. United Nations

Baird, I. G., Flaherty, M. S. (2005). Environmental Assessment. Mekong River fish conservation zones in Southern Laos: assessing effectiveness using local ecological knowledge. *Environmental Management*. 36 (3);439-454.

Baird, I. G., Overton, J. L. (2001). *Local knowledge and the conservation and use of aquatic biodiversity*. In. IIRR, IDRC, FAO, NACA and ICLARM (eds.): *Utilizing different aquatic resources for livelihoods in Asia: a resource book* (Pp. 177-185.). International Institute of Rural Reconstruction, Cavite, Philippines. 416 pp.

Bao, T. Q., Bouakhamvongsa K., Chan S., Chhuon K. C., Phommavong T., Poulsen A. F., Rukawoma P, Suornratana U., Tien D. V., Tuan T. T., Tung N. T., Valbo-Jorgensen J., Viravong S., Yoorong N. (2001). *Local knowledge in the study of river fish biology: experiences from the Mekong.* Mekong Development Series No. 1. Mekong River Commission, Phnom Penh, Cambodia. 22 pp.

Baran, E. (2006). *Fish migration triggers in the Lower Mekong Basin and other tropical freshwater system*. MRC Technical Paper n° 14. Mekong River Commission, Vientiane, Lao PDR. 56 pp.

Baran, E., Baird I. G., Cans G. (2005). *Fisheries bioecology at the Khone Falls (Mekong River, Southern Laos)*. WorldFish Center, Penang, Malaysia. 84 pp.

Baran, E., Seng, S. (2011). *Fish migrations in the Sekong, Sesan and Srepok Rivers (Mekong River Basin).* Report for the project "Scenario-based assessment of the potential effects of alternative dam construction schemes on freshwater fish diversity in the Lower Mekong Basin". WorldFish Center, Phnom Penh, Cambodia. 77 pp.

Baran, E., Win, K. K., Wah, Z. Z., Estepa, N., Saray, S., Tezzo, X., Khin, M. N., Maningo, E. (2015). *Distribution, migrations and breeding of Hilsa (Tenualosa ilisha) in the Ayeyarwady system in Myanmar.* BOBLME-2015-Ecology-39. Bay of Bengal Large Marine Ecosystem project, Phuket, Thailand. 120 pp

Chan, S., Chhuon, K. C., Sintavong, V., Kongpeng, B., Ubolratana, S., Noppanum, Y., Nguyen, T. T., Tran, Q. B., Poulsen A. F., Jorgensen J. V. (1999). *Fish migrations and spawning habits in the Mekong mainstream: a survey using local knowledge (Basin-wide).* Draft. Assessment of Mekong Fisheries: Fish Migrations and Spawning and the Impact of Water Management Project (AMFC), Vientiane, Lao PDR, November 1999. 57 pp.

Chan, S., Putrea, S., Leang, S. (2008). *Using local knowledge to inventory deep pools important fish habitats in Tonlé Sap and mainstream around Great Lake in Cambodia*. In Burnhill T.J. and

Bamrunggrach P. (eds.): *Proceedings of the 8th Technical Symposium on Mekong Fisheries* (Pp. 43–63), 15th–17th November 2006. MRC Conference Series No. 7. Mekong River Commission, Vientiane, Laos. 238 pp.

Chhuon, K. C. (2000). *Fisher's knowledge about migration patterns of three important Pangasius catfish species in the Mekong mainstream*. Department of Fishery, Ministry of Agriculture, Forestry and Fisheries, Phnom Penh, Cambodia. 135-142.

Cowie, W., Al Dhaheri, S., Al Hashmi, A., Solis–Rivera, V., Baigun, C., Chang, K., Cooney, R., Kamakaʻala, S., Lindeman, K., Louwa, C., Roe, D., Walker–Painemilla, K., Al Baharna, R., Al Ameri, M., Al Hameli, S., Al Jaberi, K., Alzahlawi, N, Binkulaib, R., Al Kharusi, Y. (2020). *IUCN Guidelines for gathering of fishers' knowledge for policy development and applied use.* IUCN, Gland, Switzerland; and Environment Agency – Abu Dhabi, United Arab Emirates. 76 pp.

Dubois, M. (2005). *Integrating local ecological knowledge: tools and approaches in upland aquatic resource management*. in: NAFRI, NAFES, NUOL (eds*.) Improving livelihoods in the upland of the Lao PDR* (Pp. 120–127)*.* Volume 2: Options and opportunities. National Agriculture and Forestry Research Institute. Vientiane, Lao PDR.

Fischer, J., Jorgensen, J., Josupeit, H., Kalikoski, D., Lucas, C.M. (eds.) (2015). *Fishers' knowledge and the ecosystem approach to fisheries: applications, experiences and lessons in Latin America*. FAO Fisheries and Aquaculture Technical Paper No. 591. Rome, FAO. 278 pp.

Garcia-Allut, A., Freire, J., Barreiro, A., Losada, D. E. (2003). *Methodology for integration of fishers' ecological knowledge in fisheries biology and management using knowledge representation [artificial intelligence]*. In Haggan N., Brignall C., Wood L. (ed)s. *Putting Fisheries' Knowledge to Work* (Pp. 227-237). Conference Proceedings August 27-30, 2001. Fisheries Centre, University of British Columbia, Canada.

Haggan, N., Brignall, C., Wood, L. (eds). (2003). *Putting fishers' knowledge to work*. Proceedings of a conference held at the Fisheries Centre, University of British Columbia during August 27–30, 2001. 504 pp.

Haggan N., Neis B., and Baird I. G. (eds.) (2007). *Fishers' knowledge in fisheries science and management*. Coastal Management Sourcebooks 4. United Nations Educational, Scientific and Cultural Organization, Paris, France. 437 pp.

Johannes, R. E. (1993). *Integrating traditional ecological knowledge and management with environmental impact assessment*. In Inglis J. (ed.): *Traditional ecological knowledge: concepts and cases. International Program on Traditional Ecological Knowledge*; International Development Research Centre, Ottawa, ON, Canada. 33-39.

Johannes, R.E. (ed.). (1989). *Traditional ecological knowledge: a collection of essays*. Johannes R. E. Ed. IUCN, Gland, Switzerland and Cambridge, UK. 77pp.

Johannes, R.E. (1981). Working with fishers to improve coastal tropical fisheries and resource management. *Bulletin of Marine Science*.31 (3); 673–680.

Johannes, R.E., Freeman, M.M.R., Hamilton, R.J. (2000). Ignore fishers' knowledge and miss the boat. *Fish and fisheries*. 1; 257–271.

MFD (Mekong Fish Database). (2003). *Mekong River Commission: Mekong Fish Database*. A taxonomic fish database for the Mekong Basin. Mekong River Commission, Vientiane, Lao PDR. CD-Rom.

Moller, H., Berkes, F., Lyver, P.O, Kislalioglu, M. (2004). Combining science and traditional ecological knowledge: monitoring populations for co-management. *Ecology and Society.* 9 (3); URL: http://www.ecologyandsociety. org/vol9/iss3/art2.

MRC. (2017). *Transboundary fisheries management issues in the Mekong and Sekong Rivers*. Mekong River Commission, Vientiane, Lao PDR. 38 pp.

Poizat, G., Baran E. (1997). Fishermen's knowledge as background information in tropical fish ecology: a quantitative comparison with fish sampling results. *Environmental Biology of Fishes*. 50; 435–449.

Poulsen, A. F. (2003). *Integration of fishers' knowledge into research on a large tropical River Basin, the Mekong River in Southeast Asia*. In Haggan N., Brignall C. and Wood L. (eds). *Putting Fishers' Knowledge to Work* (Pp. 198-207). Conference proceedings, August 27-30, 2001, Fisheries Centre, University of British Columbia. 11 (1);198-207.

Poulsen, A. F., Valbo-Jørgensen, J. (1999). *Survey manual for the use of local fishers' knowledge in the study of fish migrations and spawning in the Mekong River Basin*. (Basin wide) Assessment of Mekong Fisheries - AMFP Technical Report 1/99 version 1. 0. Mekong River Commission, Vientiane, Lao PDR. 30 pp.

Poulsen, A.F., Valbo-Jørgensen, J., Chan, S., Chhuon, K. C., Sintavong, V., Kongpeng, B., Thavone, P., Ubolratana, S.a, Noppanum, Y., Nguyen, T. T., Tran, Q. B., Truong, T. T., Doan, V. T.. (2000). *Fish migrations and spawning habits in the Mekong mainstream: A survey using local knowledge (Basinwide)*. AMFC Technical Report. Mekong River Commission. February 2000, Lao PDR. 149 pp.

Rahman, A. (2000). *Development of an integrated traditional and scientific knowledge base: A mechanism for accessing, benefit-sharing and documenting traditional knowledge for sustainable socio-economic development and poverty alleviation*. United Nations Conference on Trade and Development (UNCTAD) Expert Meeting on Systems and National Experiences for Protecting Traditional Knowledge, Innovation and Practices. 30 October – 1st November 2000, Geneva, Switzerland. 15 pp.

Roberts, T. R., Baird, I. G. (1995). Traditional fisheries and fish ecology on the Mekong River at Khone Waterfalls in Southern Laos. *Nat. Hist. Bull. Siam Soc*. 43; 219-262.

Ticheler, H.J., Kolding, J., Chanda, B. (1998). Participation of local fishers in scientific fisheries data collection: a case study from the Bangweulu Swamps, Zambia. *Fisheries Management and Ecology*. 5; 81–92.

Valbo-Jorgensen, J., Poulsen, A. F. (2000). Using local knowledge as a research tool in the study of river fish biology: experiences from the Mekong. Environment, *Development and Sustainability*. 2; 253-276.

Win K. K., Wah, Z. Z., Estepa, N., Ouch, K., Saray, S., Khin, M. N., Tezzo, X. and Baran, E. (2016). *Presence, distribution, migration patterns and breeding sites of thirty fish species in the Ayeyarwady system in Myanmar.* Report for the MYFish project. Yangon, Myanmar: WorldFish and Department of Fisheries.

ANNEX 1: QUESTIONNAIRES OF THE SURVEY

5.1. Upstream questionnaire

Use this questionnaire only in villages
#1 Ban Don Tholathi
#2 Ban Don Sang
#3 Ban Don Det Tok
#4 Ban Don Det Oke
#5 Ban Don En
#6 Ban Don Tan Tok
#7 Ban Don Tan Oke

FORM A: SURVEY DETAILS

C1. Survey form # (MonthDayQuestionnaire#): 031001
C2. Date:
C3. Who led the interview?
C4. Who entered data?
C5. Village and Village number on our map

C6. Draw on the map with a pencil the specific fish habitats in the area and indicate special characteristics of the environment
Cover at least one channel beyond those bordering the island surveyed

Special features may include:
- □ deep pools
- □ fish breeding sites (indicates which species breed there, and when)
- □ fish feeding areas
- □ fish resting areas (before crossing a channel, or between two bottlenecks)
- □ areas with year-round local resident species

FORM B: MIGRATORY SPECIES PRESENT

Tick □ if the species has been caught locally at least some time in the past 5 years:

C7. □ *Cirrhinus microlepis*
C8. □ *Gymnostomus lobatus*
C9. □ *Gymnostomus siamensis*
C10. □ *Scaphognathops bandanensis*
C11. □ *Hypsibarbus malcolmi*
C12. □ *Cyclocheilos enoplos*
C13. □ *Helicophagus leptorhynchus*
C14. □ *Pangasius conchophilus*
C15. □ *Pangasius macronema*
C16. □ *Pangasius krempfi*

FORM C: ABUNDANCE, MIGRATION BEHAVIOUR BY SPECIES

Species:

Tick answers below (no question about gear nor about quantities). For Size range, use sticks

Month	C17. Abundance when fishing					C18. Size range in centimeters			C19. Peak duration (days)	C20. Remarks
	High	Low	None	Don't fish	Don't know	0 – 25	25 – 50	> 50		
A. Jan										
B. Feb										
C. Mar										
D. Apr										
E. May										
F. Jun										
G. Jul										
H. Aug										
I. Sep										
J. Oct										
K. Nov										
L. Dec										

C21. Do you consider this species to be migratory? Yes ☐ No ☐ Don't know ☐

C22. How can you tell which channel(s) the fish enter the fall and which channel(s) the fish exit the falls (no channel name yet)**?**

C23. Are periods of peak occurrence <u>predictable</u> from any (natural) event? Yes□ No□

C24. If yes, which event? . .

Species:

<u>UPSTREAM MIGRATION</u>

C25. Which month does the migration <u>start</u> going <u>upstream</u>? . . Don't know ☐

C26. Which month does the migration <u>stop</u> going <u>upstream</u>? . . Don't know ☐

C27. Any remark about the upstream migration of this species?

C28. Show on the map the main upstream migration channels?

<u>DOWNSTREAM MIGRATION</u> USE THE SPECIES MAP

C29. Which month does the migration <u>start</u> going <u>downstream</u>? . . Don't know ☐

C30. Which month does the migration <u>stop</u> going <u>downstream</u>? . . Don't know ☐

C31. Any remark about the downstream migration of this species? Name of main downstream migration channels?

C32. Show on the map the main downstream migration channels?

<u>SPAWNING</u>

C33. Does this species spawns in Khong District? Yes☐ No☐ Don't know ☐

C34. Additional information concerning the spawning of this species?

FORM E: CONCLUSIONS

C35. Number of fishers actually interviewed (recommendation: 5-6)**:**.   .

C36. Was the quality of this interview? Good☐ Average☐ Poor☐

C37. If good, contact of a person for coming back:

C38. Other remarks concerning the interview:

5.2. Mid-falls questionnaire

Use this questionnaire only in villages

#8 Ban Khone Tai

#9 Ban Khone Neua

#10 Ban Don I Som

#11 Ban Don Sahong

#12 Ban Houa Sadam

#13 Ban Don Phapheng

FORM A: SURVEY DETAILS

B1. Survey form # (MonthDayQuestionnaire#):
B2. Date:
B3. Who led the interview?
B4. Who entered data?
B5. Village and Village number on our map

B6. Draw on the map <u>with a pencil</u> the specific fish habitats in the area and indicate special characteristics of the environment
Cover at least one channel beyond those bordering the island surveyed

Special features may include:
- □ deep pools
- □ fish breeding sites (indicates which species breed there, and when)
- □ fish feeding areas
- □ fish resting areas (before crossing a channel, or between two bottlenecks)
- □ areas with year-round local resident species

FORM B: MIGRATORY SPECIES PRESENT

Tick □ if the species has been caught locally at least some time in the past 5 years

B7. □ *Cirrhinus microlepis*
B8. □ *Gymnostomus lobatus*
B9. □ *Gymnostomus siamensis*
B10. □ *Scaphognathops bandanensis*
B11. □ *Hypsibarbus malcolmi*
B12. □ *Cyclocheilos enoplos*
B13. □ *Helicophagus leptorhynchus*
B14. □ *Pangasius conchophilus*
B15. □ *Pangasius macronema*
B16. □ *Pangasius krempfi*

FORM C: ABUNDANCE, MIGRATION BEHAVIOUR BY SPECIES

Species:

Tick answers below (no question about gear nor about quantities). For Size range, use sticks

Month	B17. Abundance when fishing					B18. Size range in centimeters			B19. Peak duration (days)	B20. Remarks
	High	Low	None	Don't fish	Don't know	0 – 25	25 – 50	> 50		
A. Jan										
B. Feb										
C. Mar										
D. Apr										
E. May										
F. Jun										
G. Jul										
H. Aug										
I. Sep										
J. Oct										
K. Nov										
L. Dec										

B21. Do you consider this species to be migratory? Yes ☐ No ☐ Don't know ☐

B22. How can you tell the fish are migrating and the direction of the migration?

B23. Are periods of peak occurrence <u>predictable</u> from any (natural) event? Yes□ No□

B24. If yes, which event? . .

Species:

<u>UPSTREAM MIGRATION</u> USE THE SPECIES MAP

B25. Which month does the migration <u>start</u> going <u>upstream</u>? . . Don't know ☐

B26. Which month does the migration <u>stop</u> going <u>upstream</u>? . . Don't know ☐

B27. Any remark? Day/night swimming? Surface/bottom? New / full moon? Female/male first? Waiting phase before moving up?

B28. Towards which channels are fish attracted for initial passage upstream? (attractive channels, not necessarily passable channels)
Use the map. Number channels in blue on the map by order of preference (if any preference among fish)

<u>DOWNSTREAM MIGRATION</u> USE THE SPECIES MAP

B29. Which month does the migration <u>start</u> going <u>downstream</u>? . . Don't know ☐

B30. Which month does the migration <u>stop</u> going <u>downstream</u>? . . Don't know ☐

B31. Any remark about the downstream migration of this species? Name of main downstream migration channels?

A32. Does the species pass downstream through impoundment of Don Sahong dam?

Yes☐ No☐ Don't know ☐

<u>SPAWNING</u>

B33. Does this species spawns in Khong District? Yes☐ No☐ Don't know ☐

B34. Additional information concerning the spawning of this species?

FORM D: FISH PASSAGE

USE THE SPECIES MAP

B35. Which channels are ultimately used by this species to successfully pass the falls on the way up?

Draw a circle in green around triangle on the channels passable by the species
For each channel where fish passage is possible (red triangle) indicate minimal water depth or month

B36. Any remark?

What are the channel specificities that make passage for this species possible or impossible?

Tick answers. Open answers are possible in G., H., I. and P., Q., R.

B37 Passage possible because			**B38 Passage impossible because**
A. Limited fall height			J. Fall too hight
B. Limited flow speed			K. High flow speed
C. Multiple steps			L. No progressive steps
D. Deep water			M. Shallow water
E. Resting sites			N. No resting sites
F. Micro-channels along the main channel			O. No micro-channels
G.			P.
H.			Q.
I.			R.

B39. Any remark?

B40. In the middle section of the falls, what are the passage <u>improvements</u> (fish passes) that could be further conducted?

Name the channel of the passage for each recommendation

B41. Are there falls or channels not considered so far that could be candidates for passage facilitation (opening passage by removing obstacles)? Name:

ORM E: CONCLUSIONS

B42. Number of fishers actually interviewed (recommendation: 5-6)**:**.   .

B43. Was the quality of this interview? Good☐   Average☐   Poor☐

B44. If good, contact of a person for coming back:

B45. Other remarks concerning the interview:

5.3. Downstream questionnaire

Use this questionnaire only in villages
#14 Ban Hang Khone in Don Khone
#15 Ban Hang Sadam in Don Sadam
#16 Ban Veun Kham on the left bank

FORM A: SURVEY DETAILS

A1. Survey form # (MonthDayQuestionnaire#):
A2. Date:
A3. Who led the interview?
A4. Who entered data?
A5. Village and Village number on our map

A6. Draw on the map <u>with a pencil</u> the specific fish habitats in the area and indicate special characteristics of the environment
Special features may include:
- □ deep pools
- □ fish breeding sites (indicates which species breed there, and when)
- □ fish feeding areas
- □ fish resting areas (before crossing a channel, or between two bottlenecks)
- □ areas with year-round local resident species

FORM B: MIGRATORY SPECIES PRESENT

Tick □ if the species has been caught locally at least some time in the past 5 years

A7. □ 01 *Cirrhinus microlepis*
A8. □ 02 *Gymnostomus lobatus*
A9. □ 03 *Gymnostomus siamensis*
A10. □ 04 *Scaphognathops bandanensis*
A11. □ 05 *Hypsibarbus malcolmi*
A12. □ 06 *Cyclocheilos enoplos*
A13. □ 07 *Helicophagus leptorhynchus*
A14. □ 08 *Pangasius conchophilus*
A15. □ 09 *Pangasius macronema*
A16. □ 10 *Pangasius krempfi*

FORM C: ABUNDANCE, MIGRATION BEHAVIOUR AND SPAWNING BY SPECIES

One form per species

Species:

Tick answers below (no question about gear nor about quantities). For Size range, use sticks

Month	A17. Abundance when fishing					A18. Size range in centimeters			A19. Peak duration (days)	A20. Remarks
	High	Low	None	Don't fish	Don't know	0 – 25	25 – 50	> 50		
A. Jan										
B. Feb										
C. Mar										
D. Apr										
E. May										
F. Jun										
G. Jul										
H. Aug										
I. Sep										
J. Oct										
K. Nov										
L. Dec										

A21. Do you consider this species to be migratory? Yes ☐ No ☐ Don't know ☐

A22. How can you tell the fish are migrating and the direction of the migration?

A23. Are periods of peak occurrence <u>predictable</u> from any (natural) event? Yes□ No□

A24. If yes, which event? . .

Species:

<u>UPSTREAM MIGRATION</u> USE THE SPECIES MAP

A25. Which month does the migration <u>start</u> going <u>upstream</u>? . .

Don't know ☐

A26. Which month does the migration <u>stop</u> going <u>upstream</u>? . .

Don't know ☐

A27. Which way do fish arrive to Khone Falls from downstream? From which bank, going where, why?
Use the map. Draw patterns on the map and use 3 types of arrows:
1) Large thick arrows: most of the fish (main trajectory) if there is a large clear pattern
2) Small thin arrow: if some of the fish only

A28. Any remark? Day/night swimming? Surface/bottom? New / full moon? Female/male first? Waiting phase before moving up?

A29. Towards which channels are fish attracted for initial passage?
Use the map. Number channels in blue on the map by order of preference (if any preference among fish)

A30. Any remark? Khone Fang first? Khone Phapheng first? Progressive moves? Different fish groups have different strategies?

A31. Are there falls not considered so far that could be candidates for passage facilitation (opening passage by removing obstacles)?
Name:

Species:

<u>DOWNSTREAM MIGRATION</u> USE THE SPECIES MAP

A32. Which month does the migration <u>start</u> going <u>downstream</u>? . . Don’t know ☐

A33. Which month does the migration <u>stop</u> going <u>downstream</u>? . .Don’t know ☐

A34. Any remark about the downstream migration of this species? Name of main downstream migration channels?

A35. Does the species pass downstream through impoundment of Don Sahong dam?

Yes☐ No☐ Don’t know ☐

<u>SPAWNING</u>

A36. Does this species spawn in Khong District? Yes☐ No☐ Don’t know ☐

A37. Additional information concerning the spawning of this species?

FORM C: CONCLUSIONS

A38. Number of fishers actually interviewed (recommendation: 5-6)**:**. **.**

A39. Was the quality of this interview? Good☐ Average☐ Poor☐

A40. If good, contact of a person for coming back:

A41. Other remarks concerning the interview:

ANNEX 2: Selection of target species for the survey

Process: species reviewed, criteria used, selection and justifications

Species	Migration pattern (Baird 2001)	Migration mapped (MFD 2003)	Percentage of catches in Khone Falls fisheries over 6 years (Baran et al. 2005)	Sensitivity to discharge (Baran 2006)	One of the 10 MRC Priority Species identified in May 2016[4]	Priority Fish Species for Transboundary Management (MRC 2017)	Family and size	Conclusion
Barbonymus altus	Big migration peak in Dec-March, small one in June	No	-	Very high	X	-	Small -medium cyprinid	**Not selected**
Cirrhinus microlepis	two peaks (dry and wet season respectively)	Yes	0.6	Very high	x	x	Medium-large cyprinid	**Selected**
Cyclocheilos enoplos	Peak at the beginning of the rainy season	Yes	1.2	High	-	-	Large cyprinid	**Selected**
Gymnostomus lobatus	Two peaks, Dec-Feb upstream, June-July downstream	Yes	17.3	Low	x	-	Small Cyprinid	**Selected**
Gymnostomus siamensis	Two peaks, Dec-Feb	Yes	2.2	Low	x	-	Small Cyprinid	**Selected**

[4] MRC Joint Planning Workshop on transboundary species management, Pakse, Lao PDR, May 2016.

Species	Migration pattern (Baird 2001)	Migration mapped (MFD 2003)	Percentage of catches in Khone Falls fisheries over 6 years (Baran et al. 2005)	Sensitivity to discharge (Baran 2006)	One of the 10 MRC Priority Species identified in May 2016[4]	Priority Fish Species for Transboundary Management (MRC 2017)	Family and size	Conclusion
	upstream, June-July downstream							
Helicophagus leptorhynchus	-	No	-	-	x	x	Medium size cyprinid	**Selected**
Hemibagrus spilopterus	-	No	-	-	x	-	Medium size Bagridae	**Not selected**
Hypsibarbus malcolmi	Two peaks in December and May	No	0.9	High	x	-	Medium-large cyprinid	**Selected**
Hypsibarbus wetmorei	Two peaks in December (small) and May (large)	No	-	-	x	-	Medium-large cyprinid	**Not selected**
Labeo chrysophekhadion	Two peaks in December (small) and May (large)	No	-	Medium	X	-	Large cyprinid	**Not selected**
Labiobarbus leptocheilus	-	No	1.7	-	X	-	Medium size cyprinid	**Not selected**
Mekongina erythrospila	-	No	1.4	-	x	x	Small Cyprinid	**Selection not recommended by Dr So Nam**
Pangasius conchophilus	Peak in May-June	Yes	11.5	High	x	x	Large Pangasiid	**Selected**
Pangasius krempfi	Peak in June	Yes	14	High	-	-	Large Pangasiid	**Selected**

Species	Migration pattern (Baird 2001)	Migration mapped (MFD 2003)	Percentage of catches in Khone Falls fisheries over 6 years (Baran et al. 2005)	Sensitivity to discharge (Baran 2006)	One of the 10 MRC Priority Species identified in May 2016[4]	Priority Fish Species for Transboundary Management (MRC 2017)	Family and size	Conclusion
Pangasius larnaudii	Peak in May-June	No	0.8	High	x	x	Large Pangasiid	**Selection not recommended by Dr So Nam**
Pangasius macronema	April-July, peak in June	Yes	7.9	High	X	-	Small Pangasiid	**Selected**
Paralaubuca typus	Peak in Jan-March	-	11.4	Very high	X	-	Small Cyprinid	**Selection not recommended by Dr So Nam**
Puntioplites falcifer	Small peak in Jan-Feb, high peak in May	-	0.5	Medium	x	-	Medium size cyprinid	**Not selected**
Scaphognathops bandanensis	2 peaks in January and May	-	3.4	Very high	x	-	Medium size Cyprinid	**Selected**

Final result: 10 species selected

Cirrhinus microlepis (paphone mak kok)

Cyclocheilos enoplos (pa chok).

Gymnostomus lobatus (pa soi houa lem)

Gymnostomus siamensis (pa soi houa po)

Helicophagus leptorhynchus

Hypsibarbus malcolmi (pa pak nouat/pa pak kom)

Pangasius conchophilus (pa pho/pa ke)

Pangasius krempfi (pa souay hang leuang)

Pangasius macronema (pa gnone siap)

Scaphognathops bandanensis (pa pian)

References cited:

Baird I. G. 2001. Aquatic biodiversity in the Siphandone wetlands. Pp. 61-74 in Daconto G. (ed.). 2001 Siphandone wetlands. Publication of the project Environmental protection and community development in Siphandone wetlands. CESVI Cooperazione e Sviluppo, Bergamo, Italy. 192 pp.

Baran E. 2006. Fish migration triggers in the Lower Mekong Basin and other tropical freshwater system. MRC Technical Paper n° 14. Mekong River Commission, Vientiane, Lao PDR. 56 pp.

Baran E., I.G. Baird and G. Cans. 2005. Fisheries bioecology at the Khone Falls (Mekong River, Southern Laos). WorldFish Center. 84 p.

MFD (Mekong Fish Database) 2003. Mekong River Commission: Mekong Fish Database. A taxonomic fish database for the Mekong Basin. Mekong River Commission, Vientiane, Lao PDR. CD-Rom.

MRC 2017. Transboundary fisheries management issues in the Mekong and Sekong Rivers. Mekong River Commission, Vientiane, Lao PDR. 38 pp.

ANNEX 3: A Synopsis Report on Field Survey of Fish Migration Channels at Khone Fang areas.

Field Synopsis Report on Survey of Local Knowledge of Fish Migration in Khone Falls

Project: Piloting a Joint Environmental Monitoring Programme on two Mekong mainstream dams 'Don Sahong Hydropower Project and Xayaburi Hydropower Project'

Reported by: Mr. Sinsamout Ounboundisane, ICEM National Consultant.

Report field duration: 23-30th June 2021

Field mission: Surveys in 5 sites at Khonefang areas, Khong district, Champasack province

Background

In recent years the Mekong River Commission formulated and developed a programme for the Joint Environment Monitoring of Mekong mainstream hydropower projects (JEM). The JEM programme is meant to monitor important parameters in hydrology, sediment, water quality, aquatic ecology and fisheries, using a system independent from the project developers. The collection of robust and standardized information will inform technical designs, identification of effective and efficient mitigation measures and promotion of sustainable management and operation of Mekong mainstream dams.

At the end of 2019 the International Center for Environmental Management (ICEM) was commissioned by the MRC and GIZ for a 2020-2021 pilot of the Joint Environmental Monitoring at Don Sahong and Xayaburi hydropower project sites (JEM Pilot project).

In Fisheries, the JEM Pilot project implements monitoring of fish catches and develops new methods to assess the efficiency of fish migrations through the Khone Falls area. The JEM Pilot project is planning to use fish tagging methodologies to i) generate reliable data on trans-boundary fish species and their migration patterns, and ii) assess the effectiveness of the two natural fish passages channels (Hou Sadam and Hou Xang Pheuak).

Khone Falls is an area of the Mekong Basin where local ecological knowledge is highly developed and been documented through more than 15 publications since 1995. To complement the migration and passage study based on fish tagging, the MRC and the JEM Pilot project implemented a survey of local ecological knowledge to document how fish pass the falls and inform what can be improved or mitigated, according to fishers, to improve fish passage through the multiple channels of the Falls.

This report documents findings from a survey at the Khonefang area.

Study area

For the present study, the survey will be conducted in the 5 fish pass candidate channels in Khone Fang areas falls (see Figure 1 and Table 1).

Objectives

- to conduct the field survey on how fish pass the 5 candidate channels in Khone Fang areas falls; and
- to describe and document each channel in terms of nature (width, depth, slope, current, obstacles, photos), passability by fish (when, which species, in which water conditions), potential interventions desirable to improve passability.

Figure 1. The map of five fish pass candidate channels at Khone Fang area in Khong district

Results of the survey

The site survey of fish pass channels at Khone Fang areas in Khong district, Champasack province was completed between 23-30th June 2021 by a National Consultant for the JEM programme. The survey was divided into two zones of main river assessment:

1. Khonefang channel working together with the DoneXang and Tholathai village head and a local fisher; and
2. Liphi channel that links to the upstream Khone falls, working together with Khone village organization committee members and a local fisher.

The survey included first-day site survey planning to assess the channels that can be visited by boat, based on the list of existing fish pass channels to be validated, and potential candidate channels for fish passage in the future. This report summarizes the main key findings of this fieldwork.

Table 18 Fish species migrating in the two surveyed areas

Area/ River Channels	Khonefang channel Hoo KhoneHai, Hoo KokMa, Hoo SamHong, Hoo KhoneXouang.		Liphi channel Hoo Khone Khouang	
Small to large size of fish species in the main channels	**Upstream migration**		**Upstream migration**	
	June-July		**June-August**	**July to Aug**
	Pangasius conchophilus, labeo barbatulus, Labeo chrysophekadion, Pangasius bocourti, Pangasius larnaudii, Pangasius hypophthalmus, Bagarius yarrelli, Helicophagus leptorhynchus, Pangasius macronema, Mystus sp, *Cycolcheilichya enoplos, Cosmochilus harmandi, Scaphognathops bandanensis, Hypsibarbus sp, Poropuntius sp, Puntioplites sp, Phalacronotus* sp, *Belodontichthys truncatus, Kryptopterus* sp. *Hemibragus wyckiodes, Hemibragus spilopterus, Chitala sp.*		*Pangasius bocourti, Pangasius conchophilus, labeo barbatulus, Labeo chrysophekadion, Pangasius larnaudii, Pangasius hypophthalmus, Pangasius Krempfi, Bagana behri, Bagarius yarrelli, Helicophagus leptorhynchus, Pangasius, macronema, Mystus* sp, *Cycolcheilichya enoplos, Cosmochilus harmandi*, Catlocapio siamensis, *Scaphognathops bandanensis, Hypsibarbus sp, Poropuntius sp, Puntioplites sp, Phalacronotus* sp, *Belodontichthys truncatus, Kryptopterus* sp. *Hemibragus wyckiodes, Hemibragus spilopterus, Chitala sp.*	Pangasius *krempfi* and other large catfish species.
	Downstream migration		**Downstream migration**	
	July-Aug	**Nov-Dec**	**July-Aug**	**Nov-Dec**
	Hypsibarbus sp, Cirrhinus microlepis, Gymnostomus lobatus, Gymnostomus siamensis, Hemibragus spilopterus.	*Probarbus jullieni, Bagarius yarrelli, Phalacronotus* sp, *Hypsibarbus sp, Belodontichthys truncatus, Chitala sp and Phalacronotus* sp.	*Hypsibarbus sp, Cirrhinus microlepis, Gymnostomus lobatus, Gymnostomus siamensis, Hemibragus spilopterus.*	*Probarbus jullieni, Bagarius yarrelli, Phalacronotus* sp, *Hypsibarbus sp, Belodontichthys truncatus, Chitala sp and Phalacronotus* sp.
Small size of fish in Micro channels	**January to March**		**January to March**	
	Pungasius macronema, Gymnostomus lobatus, Gymnostomus siamensis, Parachela sp,Yasuhikotakia sp, Labiobarbus leptocheilus, Thynnichthys thynnoides.		*Pungasius macronema, Gymnostomus lobatus, Gymnostomus siamensis, Parachela sp,Yasuhikotakia sp, Labiobarbus leptocheilus, Thynnichthys thynnoides, Gyrinocheilus pennocki.*	

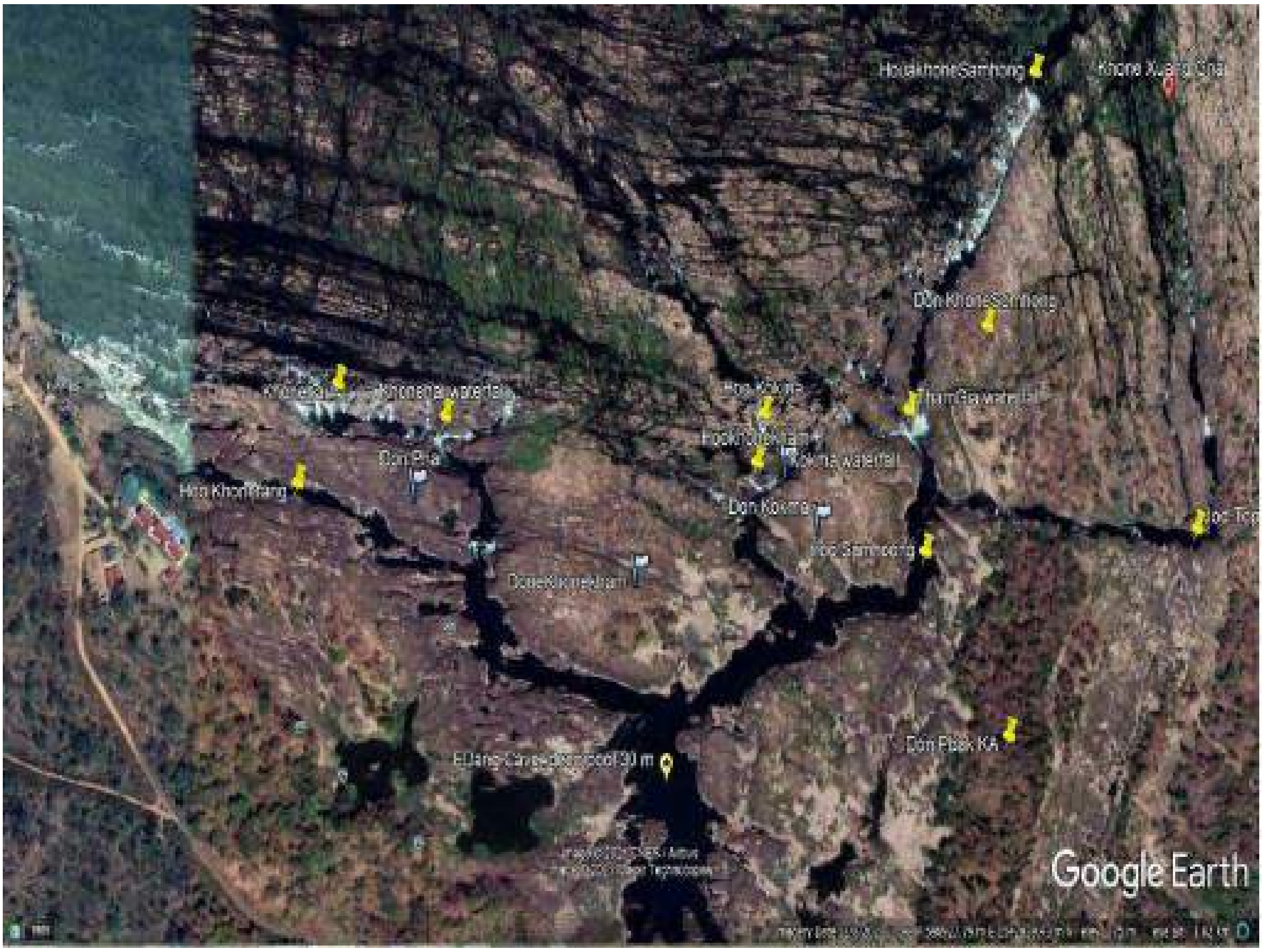


Figure 2. Overview the site assessment at Khonefang site.

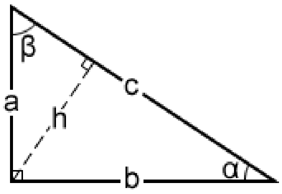
1. Hoo KhoneHai. GPS: 13.951502°N, 105.890182° E. Elevation= 69.06 m

Main channel

This area presents the waterfalls with multiple micro waterfall channels, high slope angle, deep pools beneath the falls, steep rocks and the bedrocks, presenting three steps of waterfalls (height=3 -5m) along Hoo KhoneHai with high slope angle before the water flows down to the main channel of Hoo Khonefang.

Due to the high-water level in June, the surveyor cannot reach the site due to high water flooded and strong water flow was observed during the survey, and was risky to assess the site. Moreover, there was a restriction to work near the Lao-Cambodia border.

Slope calculation[5]



Given a=10 m (Height), and
b=330 m (length),
c = 330 m
∠α = 1.736°
∠β = 88.264°
Width of channel= 15-24 m

Figure 5. The river length calculation of Hoo KhoneHai channel between Don Phai and Don KhoneKham

[5] https://www.calculator.net/right-triangle-calculator.html

Figure 6. KhoneHai waterfalls area in Khong district, Champasack province

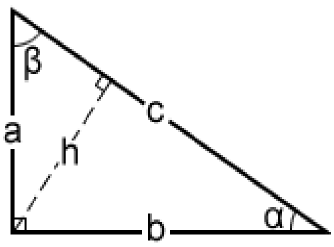
Figure 7. KhoneHai waterfalls area in Khong district, Champasack province

Figure 8. The view of KhoneHai waterfalls area in March 2021

Figure 8. The view of KhoneHai waterfalls site in June 2021

<table>
<tr><th colspan="2">2. Hoo KokMa (See photos and videos in the link)
GPS: 13.951187°N, 105.896557°E, Elevation= 64.6 m</th></tr>
<tr><th>Main channel</th><th>Micro channels</th></tr>
<tr><td>HooKokMa presents the waterfalls areas and several micro channels, high slope angle, and the flows divide the path into two channels:
• One route flow to Hoo Kokma between Don KhoneKham and Don KokMa;
• Another route flows to meet at ThamJai waterfall at Hoo Somhong.

In addition, this area presents the small deep pools beneath the falls, rocks and boulders. However, August to November each year, this area is flooded with a high-water level.

This location presents several Li traps in each channel.


Given a=8 m (height)
and b=317 m (length),
c = 301 m
∠α = 1.446°
∠β = 88.554°
Width of channel= 10-15 m
Water depth= 3-5m in the dry season
Medium to strong water flowing.</td>
<td>There is one micro channel at Don KhoneKham where it can be possible for small size fish species to migrate to the upstream. It shows water all year round and one step of waterfall on the site (Micro site A: GPS: 13.950466°N, 105.895972°E, elevation= 64.6 m), with less water in dry season (about 20 cm of water level) serving for Gymnostomus lobatus, Gymnostomus siamensis, Labiobarbus sp, Paralaubuca sp, Poropuntius sp. and other small Cyprinidae species.

Li traps were constructed to collect especially “Pasoi” Gymnostomus sp and were destroyed during a visit by government authority and then re-built by the villagers.

Micro site B (GPS: 13.950283°N, 105.895016°E, elevation= 64.6 m). Present much water in early wet season and less water in dry season in comparison to Micro site A.

Given a=8 m (height)and b=191 m (length),
c = 220 m
∠α = 2.083°
∠β = 87.917°
Width of channel= 7-12 m
Water depth= 20 cm in the dry season. Slow water flowing in the dry season.

Conclusion: It is not suitable for migration of large sizes of fish species to the upstream area during dry and early wet seasons.</td></tr>
</table>

Figure 9. The river length calculation of Hoo KokMa between Don KhoneKham and Don KokMa

Figure 10. Hoo KokMa, Hoo Somhong and Hoo Khone Xouang site

Figure 11. KokMa waterfalls in March 2021.

Figure 12. Hoo KokMa waterfalls at Hai tree in March 2021.


Figure 13. Micro channel at Don Khone Kham, Micro site A. March 2021.


Figure 14. Middle section of micro channel at Don Khone Kham, Micro site A. March 2021.


Figure 15. Waterfall site of micro channel at Don Khone Kham, Micro site A. March 2021.


Figure 16. Waterfall part of micro channel at Don Khone Kham, Micro site B. June 2021.

Figure 17. Waterfall part of micro channel at Don Khone Kham, Micro site B. June 2021.

<table>
<tr><th colspan="2">3. Hoo Somhong (See photos and videos in the link)
GPS: 13.954775 °N, 105.900572 °E, Elevation= 69.06 m</th></tr>
<tr><th>Main channel</th><th>Micro channels</th></tr>
<tr><td>Hoo Somhong presents very strong water flows , fast flowing, steep rocks, small to medium size of boulders and bedrocks, and has water all year round. There is a waterfall located in the same channel called Tham Chea's waterfall which is a main barrier (height= 7 m in dry season) to the fish migration to the upstream. This channel also receives the water volume from Kok Ma channel to the joint water in Hoo Somhong.

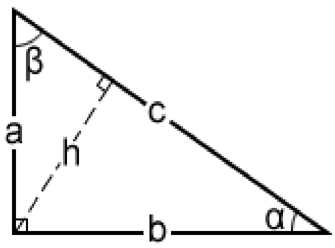
Hoo Somhong has water all year round. The main obstacle is a height of Tham Chea waterfall that indicates a challenge to the fish capacity to pass during the early wet season migration. Furthermore, there are several micro waterfalls that show medium barriers at the upper section of Hoo Samhong as well. However, in Aug to Nov each year, this area is high water flooded.

The width of head water=35m, at the end part of channel= 46m.

Water level in dry season-30m, Wet season=40m at the end part of this channel.</td><td>There are three micro channels (Hoo TamNgaee, GPS: 13.953752 °N, 105.900951 °E, Elevation= 70.24 m, Hoo TamNgaee-KhoneHai, GPS: 13.952105°N, 105.901836 °E, Elevation= 70.24 m, and Hoo KhoneXuangnoi, GPS: 13.951791°N, 105.902621°E, Elevation= 70.24 m - see photos and videos in the link) that are located in the areas of between Hoo Somhong and Hoo KhoneXuang.

At these three channels, water flows down to the main channel of Hoo KhoneXuang, but there is a lack of water supply into these channels only two months in April and May.

Fishers fished in these micro channels were to catch Gymnostomus sp,</td></tr>
</table>

 Given a=11 m (height) and b=652m (length), c = 652 m ∠α = 0.967° ∠β = 89.033° -Width of channel= 18-35 m -Water depth= 4m -Medium to strong water flowing.	*Hypsibabus sp* and *Scaphognathops bandanensis.* **Hoo TamNgaee** See photos and videos in the link Width= 6 m Length= 436 m Water flow-Slow to moderate. Steep level at the exit point. **TamNgaee-KhoneHai** See photos and videos in the link Width= 5 m Length= 246 m Water flow-Slow to moderate. Steep level at the exit point. **Hoo KhoneXuang noi** See photos and videos in the link Width= 8-13 m Length= 344 m

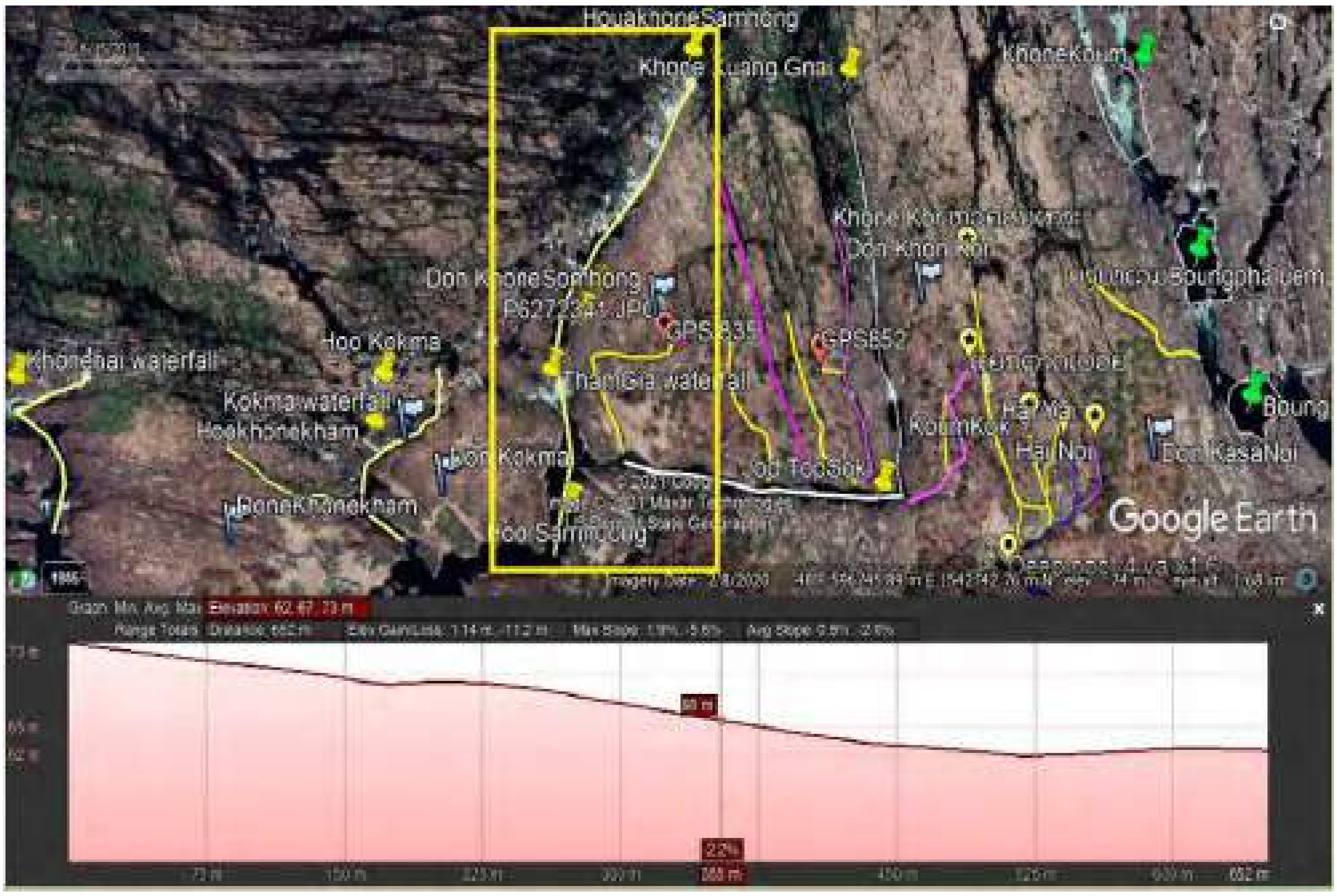


Figure 18. The elevation calculation of Hoo Somhong.


Figure 19. The view of headwater at Hoo Somhong in June 2021.


Figure 20. The view of downside at Hoo Somhong in June 2021.

Figure 21. Water channel spilt from Hoo Kokma link to Hoo Somhong in March 2021.

Figure 22. ThamJai waterfall at Hoo Somhong in June 2021

Figure 23. The end part of Hoo Somhong in June 2021.

4. **Hoo KhoneXouang** See photos and videos in the link
GPS: 13.954541°N, 105.902598°E, Elevation= 70.24 m

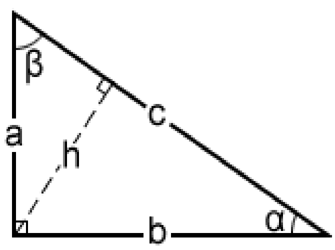
Main channel

Hoo KhoneXouang presents an important main channel for fish migration to the upstream section alternatively after Hoo Somhong. This channel presents medium slope angle, steep rock, small to medium size of boulders and bedrocks.

There are two important barriers (waterfalls height=2- 3 m, width=35m) in this channel, and has a medium to strong fast flowing and various deep pools beneath the falls.

Deep pool at the site 1: water depth in dry season- 5 m and water depth in wet season- 15m;
Deep pool at the site 2: water depth in dry season- 10 m and water depth in wet season- 35m;
Deep pool at the L-Shape: water depth in dry season- 7 m and water depth in wet season- 25 m.

Hoo KhoneXoung has water all year round and present small steps of water flowing at L-shape in the dry season (0.5 m to 1 m in the shallow areas depends on the water supply level). In addition, this areas presents steep rocks and boulders at the falls site. However, in Aug to Nov each year, this area is high water flooded including all islands nearby.



Given a=7 m (height) and b=493 m (length),
c = 493 m
∠α = 0.813°
∠β = 89.187°
-Width of channel= 8-13 m
-Water depth= 10 m.
-Medium to strong water flowing.

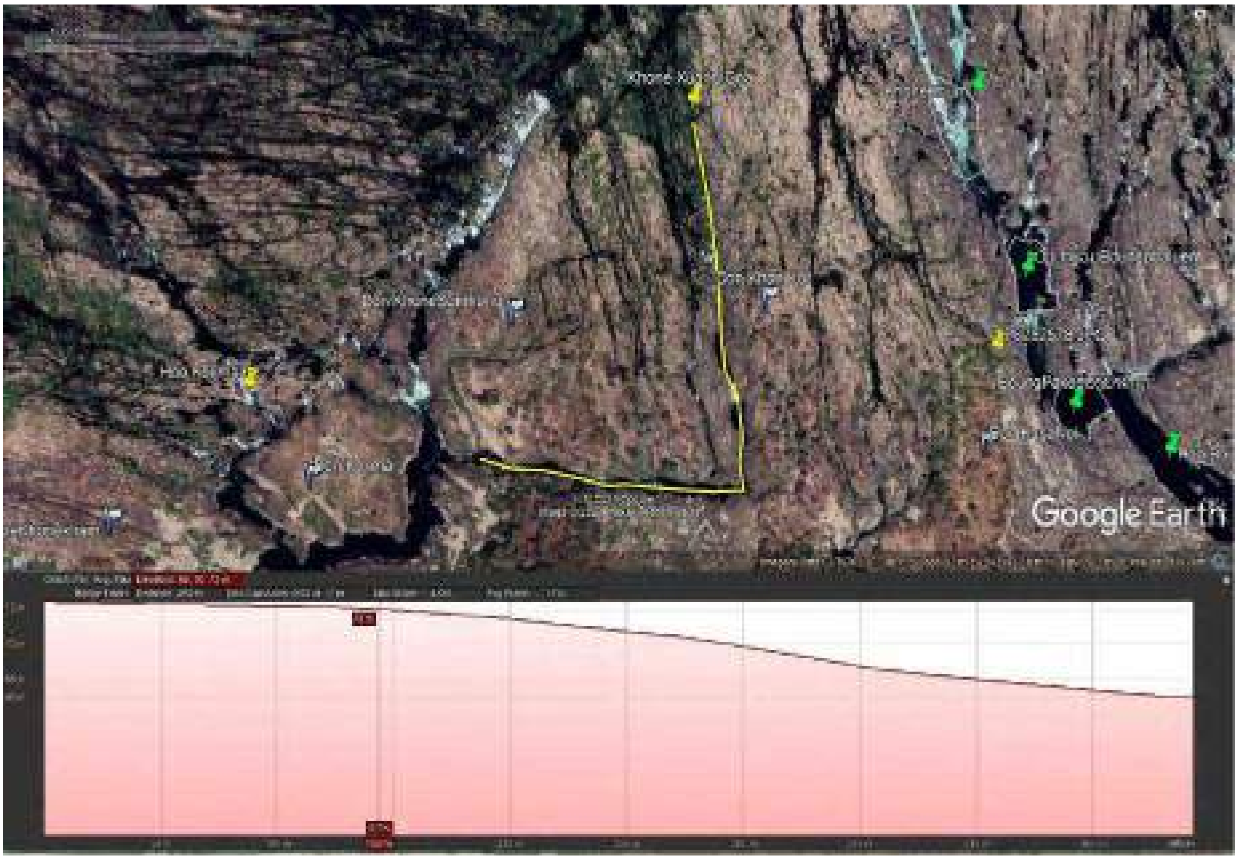


Figure 24. The elevation calculation of Hoo Khone Xouang.

Figure 25. Aerial photo of Hoo Khone Xouang.

Figure 25. Headwater of Hoo Khone Xouang.

Figure 26. Waterflow at barrier number 1 in Hoo Khone Xouang

5. **Hoo Khone Khouang (**See photos and videos in the link)
GPS: 13.950575°N, 105.908924°E, Elevation= 70.24 m

Main channel

Liphi channel presents two divided sections between Liphi (main channel on the left side of river flow) at KhoneKhouang and Hoo Khonekhouang is located on the right side of river flow. However, most fishers commonly called the name Liphi or Somphanmit channels for tourist visitors for an easy understanding and well-known to the site.

Liphi channel is an option for fish upstream migration from the west part of the Lao-Cambodia border where fish migrate from Vernkham to Khonefang areas. It is an important main channel for fish migration to the upstream section as an alternative after Hoo Somhong. This area presents steep rapids, medium to large size of boulders and bedrocks and sand bars, and an abundance of vegetation and floodplain trees. It also provides connection to feeding areas for freshwater Dolphins at Don Fai.

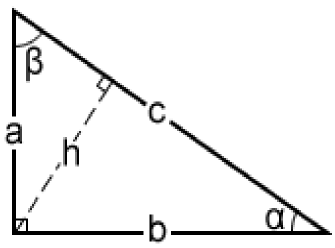
From early wet season until the peak water level in the rainy season (June to August), this main Liphi channel has reported a high number of fish catches during the early fish migration season - whether at Hoo Pataep up to Khone Kor, Koum Kok, Hainoi and Hai Nyai, similar to the areas of Boung Paked, Hoo Khantahang, Hoo khonewat, Hoo Donlai, Hoo Salapaenoi and Hoo SalapaeNyai.

Hoo Khone Khouang one of the target site assessment and is a branch channel of Liphi waterfalls. This channel presents high slope angle, steep rocks, medium to large size of boulders and bedrocks. As the result, there was not possible for fish migration to upstream either in dry season or early wet season from May to July because the waterfall is very high and high slope angle and strong water flow. However, there is a micro channel called Hoo Fonsaenha which has a water level of about 20-30cm in the dry season. This micro channel is suitable for small Cyprinidae families such as: *Gymnostomus lobatus, Gymnostomus siamensis, Parachela sp,Yasuhikotakia sp, Labiobarbus leptocheilus, Thynnichthys* thynnoides*.*

An alternative channel called Hoo Pataep, GPS: 13.946535°N, 105.908924°E, Elevation= 66.21 m (in the link) is one of the important channel that has water all year round and it is located at the opposite site of Don Lai channel. The channel presents a medium slope angle, sand bars at the exit point and dominant by small to medium size of boulders, rapids and a deep pool at L-shape channel and other areas at the upper section at KoumKok and Khonekor. Hoo Pataep has been reported for a high catch of medium to large size of fish species during the peak migration time in the early wet season from June to July when the fish was not able to pass through Hoo Khone Khouang and Liphi waterfalls while the Don Lai channel has been improved by DSH for fish passage.

Hoo Pataep is a main channel that links to several channels- Hoo Khonekor, Khone Koum, Hainoi and HaiNyai.

Calculation of Hoo Khonekhouang



Given a=12 m and b=1190 m,
c = 1,190 m
∠α = 0.578°
∠β = 89.422°
-Width of micro channel of Hoo Khone Khouang= 20-25 m
-Width of main channel at Khone Koum= 50-65 m

Water flow**-** Extremely high and fast water flowing, complex rapid and bedrocks substrates

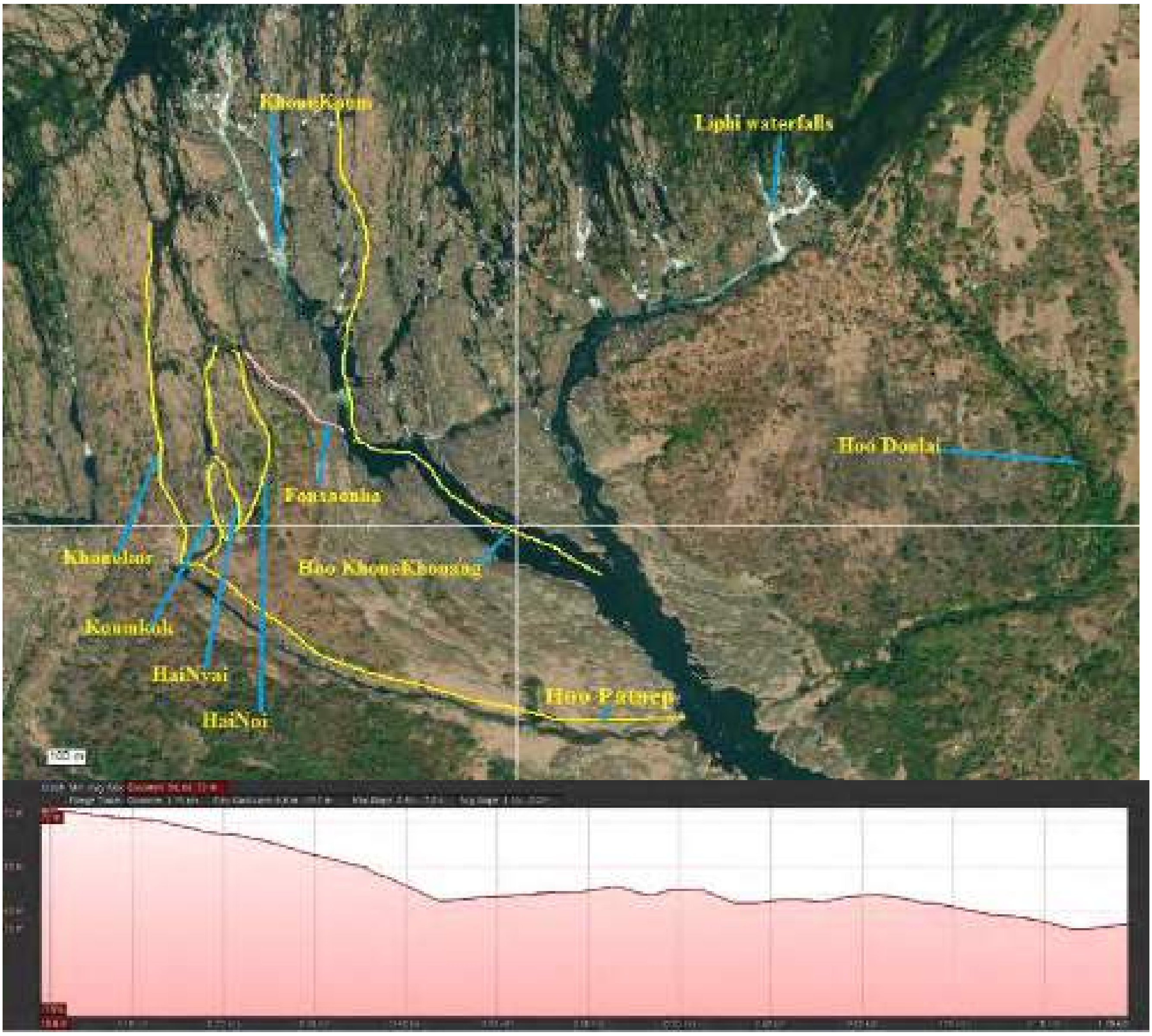


Figure 27. Main channels and micro channels at Liphi waterfalls

Figure 28. An alternative channel candidate for fish passage at Hoo Pataep-Khonekor

Calculation of Hoo Pataep
Given a=12 m and b=1190 m,
c = 1,190 m
∠α = 0.578°
∠β = 89.422°
-Width of micro channel of Hoo Khone Khouang= 20-25 m
-Width of main channel at Khone Koum= 50-65 m

Figure 28. Boung Paluem (a *Pangasius sanitwongsei* pool) at Hoo Khone Khouang

Figure 28. Boung Paked (a *Phalacronotus sp.* pool) at Hoo Khone Khouang

Figure 29. Fonsaenha micro channel (on the right-hand side of Hoo Khone Khouang)

Figure 30. Hoo Pataep at the exit point to the main Liphi channel.

Figure 30. L-shape at Hoo Pataep that links to several channel-Khonekor, Koumkok, HaiNyai and Hainoi

Conclusion

A solo survey of fish pass channel was conducted in June 2021 in Khone Fang areas falls to describe and document each channel with the aim of recommending the potential interventions to improve passability for fish. The names of islands are also documented. The results of site survey for two main channels (Khonefang and Liphi waterfalls) indicates the predominant fish species passable for fish upstream migration in the dry season and early wet season. During the wet season until early dry season (high water level), fish species could pass through every channel without obstacles, for the purposes of upstream and downstream migrations. The key findings of the site survey are recommended as below.

Khonefang areas		Conclusions
Main channels	**Brief summary**	
• Hoo KhoneHai	Presenting the same line of waterfalls and micro waterfall channels, strong water flow, steep rocks and bedrocks. There are three steps of waterfalls along Hoo KhoneHai with high slope angle and it has water all year round. Hoo KhoneHai is located near the border restriction between Laos and Cambodia.	This area is not suitable for upstream migration fish passage in the dry season and early wet season due to the presence of multiple waterfalls and the height of obstacles along the main channel. However, from July to November each year, this area is flooded with a high-water level.
• Hoo KokMa	KokMa is high slope angle, and presenting the same line of waterfalls and micro waterfall channels. The water splits the flows into two channels (Hoo KokMa and HooSamhong) and has water all year round. The channel at the head point of waterfall is narrow and then is more widen at the end part. Hoo KokMa presents a strong water flow, steep rocks and the bedrocks.	It is not suitable for medium to large sizes of fish species to migrate to the upstream during dry and early wet seasons due to the height of waterfalls in the river channels, high slope angles, and strong water flows. However, from July to November each year, this area is flooded with a high-water level.
• Hoo Samhong	Hoo Somhong presents very strong water flows, fast flowing, steep rocks, small to medium size of boulders and bedrocks, and has water all year round. One main barrier called Thamchea's waterfalls (height = 7 m in dry season) is deep beneath the falls with a high DO and strong noise. Furthermore, there are also several micro waterfalls that show medium barriers at the upper section of Hoo Samhong as well.	It is not suitable for medium to large sizes of fish species to migrate to the upstream during dry and early wet seasons due to the height of waterfalls (Thamchea) in the river channels, high slope angles, and strong water flows. Moreover, there is an additional consideration to identify more workload of the complex micro waterfalls along the same line at the head point of water. However, from July to November each year, this area is flooded with a high-water level.
• Hoo KhoneXouang	Hoo KhoneXouang presents an important main channel for fish migration to the upstream section alternatively after Hoo Somhong and presents medium slope angle. This channel presents medium slope angle,	Hoo KhouneXuang is a potential recommendation for a new candidate for fish pass improvement together with micro channel-Hoo KhoneXuangnoi- an optional clearance for a deeper channel to have more water supply all year round. Moreover, the main site of Hoo KhoneXuang has been reported for a high catch of medium to large

	steep rocks, small to medium size of boulders and bedrocks. There are two important barriers (waterfalls height=2- 3 m, width=35m) in this channel, and it has a medium to strong, fast flowing and various deep pools beneath the falls.	size of fish species during the peak migration time in early wet season from June to July when the fish was not able to pass through Hoo KokMa and Hoo Samhong sites.
Liphi channel		**Conclusions**
Main channels	**Detailed summary**	
• Hoo Khone Khouang	Hoo Khone Khouang is a branch channel of Liphi waterfalls and has water all year round. This channel presents high slope angle, steep rapids, medium to large size of boulders, bedrocks and sand bars, and an abundance of vegetation and floodplain trees. The route from Hoo KhoneKhouang to KhoneKoum presents a high waterfall (main and micro waterfalls in the same line) and strong water flow. Two big deep pools (Boung Paked and Boung Paluem) are well-known to the artisanal fishers.	It is not possible for fish migration to occur upstream from Hoo KhoneKhouang to Khone Khoum waterfalls areas either in dry season or early wet season from May to July because the waterfall is very high and there is a high slope angle and strong water flow. However, there is an optional micro channel candidate called Hoo Pataep. Hoo Pataep is one of the important channels that has water all year round, and it is located at the opposite site of Don Lai Channel. Hoo Pataep is a hub of several channels- Hoo Khonekor, Khone Koum, Hainoi and HaiNyai. Hoo Pataep has been reported for a high catch of medium to large size of fish species during the peak migration time in the early wet season from June to July when the fish was not able to pass through Hoo Khone Khouang and Liphi waterfalls while the Don Lai channel has been improved by DSH for fish passage.

Annex 6: First Pilot Site Report on Don Sahong

Mekong River Commission

FIRST PILOT SITE REPORT ON DON SAHONG

Piloting a Joint Environmental Monitoring (JEM) Programme on Two Mekong Mainstream Dams: The Don Sahong and Xayaburi Hydropower Projects

November 2021

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ABBREVIATIONS AND ACRONYMS

ADCP	Acoustic Doppler Current Profiler
ARTFISH	Approaches, Rules and Techniques for Fisheries Statistical Monitoring
ATSPT	Average Tolerance Score Per Taxon
Bed GS	Bed material grain-size analysis
COD	Chemical Oxygen Demand
CPUE	Catch per unit effort
DMH	Department of Meteorology and Hydrology
DoNRE	Department of Natural Resources and Environment (Lao PDR)
DSM	Discharge and sediment monitoring sites
DSMP	Discharge Sediment Monitoring Project
EHI	Ecological Health Index
EHM	Ecological Health Monitoring
FADM	Fish Abundance and Diversity Monitoring
FAO	Food and Agriculture Organization of the United Nations
FLDM	Fish Larvae Diversity Monitoring
FTU	Formazin Turbidity Unit
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GPS	Global Positioning System
HPP	Hydropower plant
HYCOS station	Automatic hydrological monitoring station
ICEM	International Centre for Environmental Management
IKMP	Information and Knowledge Management Programme
JEM	Joint Environmental Monitoring
LARReC	Living Aquatic Resources Research Centre
LMB	Lower Mekong Basin
LPB	Luang Prabang
MoNRE	Ministry of Natural Resources and Environment (Lao PDR)
MRC/MRCS	Mekong River Commission/Mekong River Commission Secretariat
NRESRI	Natural Resources and Environment Statistics and Research Institute
Lao PDR	Lao People's Democratic Republic
QA/QC	Quality assurance/quality control
SSC	Suspended sediment concentrations
TSS	Total suspended solids
UK	United Kingdom
WHO	World Health Organization
WQ	Water Quality
WQGA	Water Quality Guideline for the Protection of Aquatic Health
WQGH	Water Quality Guideline for the Protection of Human Health
WQMN	Water Quality Monitoring Programme

EXECUTIVE SUMMARY

The Joint Environment Monitoring (JEM) Programme for Mekong Mainstream Hydropower Projects (HPPs) is implemented by the Mekong River Commission (MRC) and Member Countries, which aims provide information about linkages between water resources and environmental conditions and how these change under hydropower developments. The JEM Programme monitors across five disciplines: Hydrology and Sediment, Water Quality, Ecological Health and Fisheries. This first progress report describes the preliminary monitoring results, analysis findings and lessons for future monitoring based on the JEM pilot project at Don Sahong HPP for the October 2020 to February 2021 period. Generally, the monitoring data collected to date are very limited and larger records are needed to strengthen interpretation. The JEM monitoring data collection and analysis are supported by the development of a comprehensive new database.

To support the pilot activities, JEM protocol training activities were conducted with the monitoring teams via online sessions and peer-to-peer training. New equipment was procured and delivered including the installation of a Hydrological Cycle Observing System (HYCOS) water level recorder at Koh Key, Cambodia in early 2021, and new Acoustic Doppler Current Profiler (ADCP) and boat for Pakse, Lao PDR. Despite COVID-19 restrictions, the project successfully completed procurement of all the originally specified non-fish tagging equipment. The initiation of fish tagging equipment procurement was delayed until January 2021 when additional expertise from Charles Sturt University was engaged to inform the design of pilot methodology. Given the complexities of procurement, future projects should plan to allow for less-than-ideal timing of delivery due to changes in project requirements, changes in equipment specifications, and other factors.

Monitoring frequency for hydrology and sediment varied between the countries with limited monitoring conducted at Pakse. At Stung Treng UP, monitoring was initiated in April 2020 atogether with nearby discharge sediment monitoring (DSM) sites. Based on the pilot monitoring activities, recommendations are to: (i) finalise the newly installed water level gauge at Koh Key; (ii) implement improved technique for measurement of discharge using the ADCP; (iii) improve processing of HYCOS data, sediment monitoring and laboratory analysis according to identified opportunities; and (iv) conduct active maintenance of equipment to ensure its longevity. The first nine months of the JEM pilot monitoring provided good results at the Stung Treng UP, Sekong Bridge (SKB) and Stung Treng site despite the delays in monitoring at Pakse. The preliminary hydrological data allow some indications of power station operations in the area. Although data are limited to one month (February 2021) at the new Koh Key water level recording site, the results show strong similarities with the flow pattern at Pakse. There is no indication that the operation of the Don Sahong HPP is altering flows in the mainstream Mekong downstream of the project. At Stung Treng, water level fluctuations have increased with a substantial change in the distribution of flow changes between 2016 and 2019 and 2020. The water level changes are, however, below the 5 cm/hour limit recommended in the Hydropower Mitigation Guidelines (MRC, 2020) and are limited to periods of relatively low flow in the river, likely reflecting power station operations at the Lower Sesan II HPP.

Discharge monitoring at the Stung Treng UP, SKB and Stung Treng sites shows a good balance, and there is good agreement between the discharge measured by ADCP in 2020 and the predicted flow based on the 2013 rating curve. More results are required to capture the entire wet season for suspended sediment concentration (SSC). Concentrations and loads were low at all sites in 2020 compared to previous years, although SSC results are only available through September. SSC loads show a fair balance across the monitoring sites, and estimates based on a discharge/SSC rating curve suggest that the annual load at Stung Treng could be in the range of 21 Mt/yr to 23 Mt/yr, which are the lowest loads recorded since monitoring began in 2011.

Water quality regular sampling missions were conducted between October 2020 and February 2021. The parameters measured are identical to the parameters used in the MRC's Water Quality Monitoring Network (WQMN), in addition to the new JEM measurements of turbidity, chlorophyll-a and cyanobacteria. Interpretation of the water quality results show that Don Sahong sampling stations were comparable to the normal seasonal patterns. There is little difference seen between sampling stations for most parameters indicating that the impoundment and dam operation is not affecting the overall water quality. There is no evidence of stratification within the water profiles of the Don Sahong impoundment. The chlorophyll-a and cyanobacteria measurements indicate no current trend towards eutrophication. Total suspended solids (TSS) showed variable patterns. October 2020 showed similar levels in TSS passing through the impoundment and downstream, while November and December 2020 results showed a marked decrease downstream compared to water flowing into the impoundment. Raised values of nitrate/nitrite and total nitrogen were observed in October, November and December 2020. Very high values of total phosphate were observed in December 2020. These findings are of great concern and need to be checked for recurrence and possible sources identified. As further results of both the routine WQMN and the JEM come in, we will be wanting to uncover whether these reflect a river basin trend as a whole or are peculiar to the pilot.

The annual 2020 ecological health field sampling was postponed due to COVID-19 restrictions on travel within Lao PDR. Analysis therefore focused on (i) consolidation and refinement of the species lists from all four countries for each of the four parameters, and (ii) reviewing historical biennial Ecological Heath Index (EHI) results from sampling sites on the Mekong mainstream to produce a 2011 to 2019 baseline using sites at the LDN (Done Ngew, Champassak) and CKT (Stung Treng Ramsar site) on either side of the Don Sahong dam. Differences found between the species recorded by the teams of the four countries indicates that each country's monitoring is not exactly comparable for analysis of changes in species mix due to impoundments and downstream flow sites. There is a need to strengthen the capacity of the bioassessment teams in all countries in the consistent identification of the species in the unified composite lists and in completion of the reporting forms. Given the complexity and time required for the EHI process, a further recommendation is to trial a simplified rapid EHI assessment based on littoral macroinvertebrates in the interest of a simplified bioassessments each year rather than every two years, and on more sites.

The fisheries Fish Abundance and Diversity Monitoring Programme (FADM) results from the Don Sahong sites in Lao PDR are not yet available. The December 2019 – March 2020 early field phase and implementation of the FADM indicated few major problems, but more time is required to complete new protocols particularly in Lao PDR. During the early field phase, concerns from the national teams led to testing of gillnets in Cambodia and Lao PDR to ensure a maximised abundance and diversity of catch. Findings show that short nets result in the highest total catch and highest number of species, with a lower catch and lowest number of species observed with the longest net. The mesh size with the highest catch is the 40 mm, with none caught in mesh sizes above 90 mm. This testing resulted in proposed changes to the protocol with regard to the arrangement and placement of nets.

Implementation of the Fish Larvae Drift Monitoring Programme (FLDM) protocol started in July 2020 in Cambodia and in August 2020 in Lao PDR, with data collected up until February 2021. Some preliminary analysis from the FLDM data in the Cambodian rainy season data shows that between 28 and 45 species belonging to 16 families were collected in each sampling site. There is a large difference in the samples collected from the different banks and sampling points, e.g. 45% more species on the right bank than on the left bank in Preah Romkel in Cambodia, confirming the relevance of sampling in a diversity of points for a given site. Findings suggest, first, that more training is required to support fishers with the use of bongo nets and anchors, second, that more support for recoding metre figures and sample bottles, and third, that the night sample timing should be shifted to 21:00 instead of midnight.

An external contract has been added to the JEM programme for Charles Sturt University to implement the fish tagging pilots. The tagging methodology to study fish passage at Khone Falls is being developed taking into consideration: (i) traditional external tags (spaghetti tags) combined with a recapture programme; (ii) PIT tags; (iii) acoustic tags; and (iv) radio tags. Due to the diversity of species and stream sizes to be monitored at Khone Falls, several types of tags and receivers must be used; a comprehensive review of fish tag types options in the Mekong is provided in a separate Technical Paper. A preliminary series of steps to designing and conducting a fish tagging study is set out with regard to management issues, possible study sites, target species and available resources. A survey of local ecological knowledge at Khone Falls was conducted in March 2021 to inform the development of this fish passage monitoring protocol, particularly design guidance on selection of channels for monitoring. Findings from this survey are described in a separate technical report.

These results and the recommendations for future monitoring protocols are preliminary, based upon a limited set of results, not yet really frequent enough for more detailed statistical analysis. However, they confirm the usefulness of the parameters and sampling stations chosen, and the experience has identified some practical modifications to the JEM protocols.

1. Introduction and scope of the report

In May 2019, the Mekong River Commission (MRC) finalised its documents for the Joint Environment Monitoring (JEM) Programme for Mekong Mainstream Hydropower Projects (HPPs), which is aimed at providing information about the availability and condition of the water resources and their linkages with environmental conditions in the Basin, and how they are changing under present and future hydropower developments. This information is intended to provide a common basis for constructive discussions by communities and Member Countries on the implications of hydropower development.

The Environmental Management Division of the MRC with the support of Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH has been developing two pilot projects to trial and refine the JEM approach and monitoring and reporting protocols based upon a two-year implementation around the Xayaburi HPP and the Don Sahong HPP. In November 2019, the International Centre for Environmental Management (ICEM Asia) was commissioned by GIZ and the MRC to undertake the two-year Environmental Monitoring Pilots project for the JEM Programme.

This is the first progress report on the monitoring that has been carried out around the **Don Sahong HPP;** the monitoring carried out around the Xayaburi HPP is provided in a separate report. It is noted that many aspects of the pilot projects – procurement of equipment, training of the monitoring teams and the actual field work by the teams – has been delayed significantly by the restrictions due to the COVID-19 pandemic. These reports had been scheduled as half-yearly pilot sites/stations progress reports submitted at six-month intervals during the first year, with reports for each pilot site/station, i.e. in September 2020 and March 2021. The September 2020 reports were replaced by more general quarterly progress reports.

The report is organized by the five disciplines – hydrology and sediment, water quality, ecological health and fisheries. For each discipline it will highlight any adjustments or evolutions in the sampling protocols that have occurred during the project to date, both in general and specifically for the Don Sahong monitoring sites. The report will document any activities that have taken place at the Don Sahong pilot and provide some preliminary monitoring results and analysis. Lessons learned or suggestions for future monitoring for each discipline will be provided.

While the *Hydrology and Sediment, and the Water Quality* sections of the report provide the results of regular sampling missions between October 2020 and February 2021 and their analysis, the *Ecological Health* section contains analysis of historic bioassessment in sites adjacent to Xayaburi on the Mekong mainstream and because the annual 2020 field sampling was cancelled due to COVID-19 restrictions. The focus of this section is therefore on progress made in preparing the database structure to accommodate the complexity of the species lists for the bioassessments. In contrast to the earlier sections, the *Fisheries* section reports on the experiences of implementing the FADM and FLDM around the Don Sahong HPP, because the fishery results are still limited, as well as the recently initiated local knowledge survey and review of the fish tagging options for fish passage monitoring. The fishery section provides suggestions for practical implementation of the fishery protocols.

The report concludes with more general progress information on the development of the database and procurement or equipment, with reference to particular aspects that relate to the **Don Sahong pilot.**

2. Hydrology and Sediment

The hydrology and sediment monitoring component of the JEM Pilot at Don Sahong includes upgrades to discharge and sediment monitoring at the existing Pakse DSM site, the establishment of a new discharge and monitoring site upstream of the confluence of the Sekong (3S catchment). The monitoring pilot also includes increasing the parameters determined at the existing Stung Treng (ST) and Sekong Bridge (SKB) site to include bedload. The monitoring sites are shown in Figure 2.1, together with the location of the Don Sahong HPP.

The Don Sahong project is located across one sub-channel of the river, has very little storage, and is not expected to alter the hydrology of the river or sediment transport at a regional level. Locally the project has substantially altered the distribution of flow through the various channels to maximise the water passing through the power station.

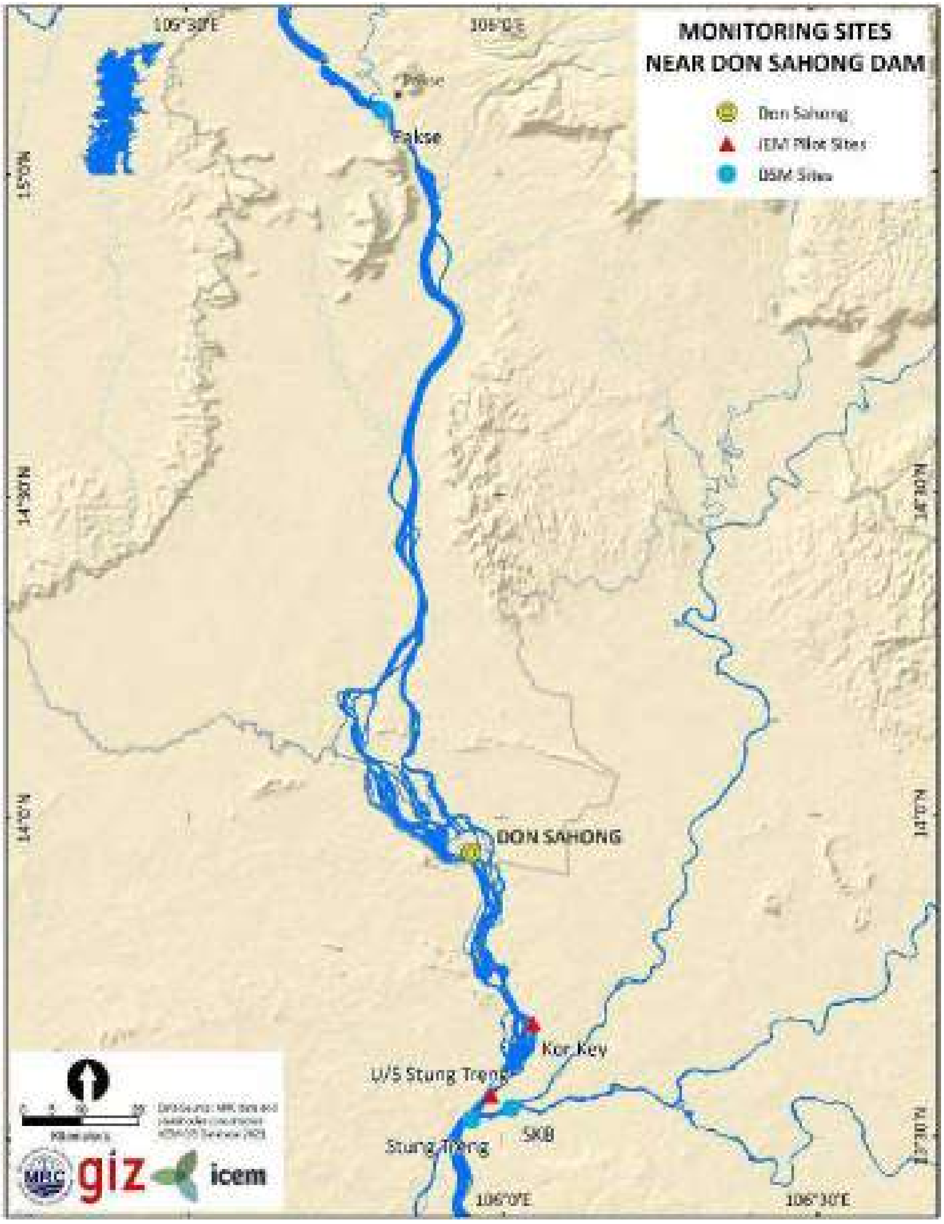

Figure 2.1. Location map showing sites included in the JEM Pilot related to the Don Sahong HPP

Note: The location of the dam and the ongoing routine discharge and sediment monitoring (DSM) sites are indicated on the map.

Although little change is expected to the hydrology or sediment transport in the river at a regional level as a direct result of the Don Sahong project, the monitoring sites included in the JEM pilot provide valuable information about the net effect of hydropower and other developments upstream on the Mekong and its tributaries, and provides a measure of the river flow and sediment load entering the Cambodian floodplain. These results are needed to understand the functioning of the floodplain, the complex hydrology of the Tonle Sap system. and ultimately, the Vietnamese delta. The monitoring sites also allow to understand what is entering from the 3S catchment, which has been widely developed for hydropower, compared to what is being delivered down the mainstream Mekong, which is a major advancement in monitoring in the Mekong.

2.1. Adjustments and evolutions

The planned hydrology and sediment activities under the Don Sahong JEM Pilot have undergone some modifications directly and indirectly due to the COVID-19 pandemic. Impacts include:

- delays in the delivery of new monitoring equipment. This applies to Pakse, where a new ADCP, boat, engine and winch system has been supplied by the JEM pilot;
- delays in installing the new water level recorder at Koh Key upstream of ST due to delays in equipment arriving and the inability of overseas experts to travel to the region;
- changes to how training was delivered, with planned training events changed to on-line courses or field training led by local experts or peers.

The monitoring location associated with the new Koh Key site has also been changed. Initially, Cambodia nominated Koh Key as the water level and monitoring site, but after installing the water level recorder, the monitoring team found that boat access is difficult in low flow due to the abundance of rocks in the channel and in high flow due to poor roads and strong currents. The Cambodian team proposed a new monitoring location located several kilometres upstream of the confluence of the 3S river system (as shown in Figure 2.1), which is called Stung Treng UP (ST-UP) to differentiate it from Stung Treng (ST). Discharge measurements from the site should still be able to be used to derive a rating curve at Koh Key since there are no tributaries entering the river between the sites.

2.2. Activities

2.2.1. Equipment delivered and/or installed

Table 2.1 summarises the equipment procured through the JEM project and delivered to Lao PDR and Cambodia for JEM, with some photos provided in Figure 2.2. All equipment has been field-tested and is functioning.

The water level recorder at Koh Key was installed in early 2021, and data have been transmitted via the HYCOS network since 1 February 2021, with an example of the results shown in Figure 2.3.

Table 2.1. Summary of equipment delivered to the indicated countries.

Country	Equipment Delivered
Lao PDR	1 Teledyne RiverRay ADCP for use at Pakse
	1 boat suitable for field monitoring
	1 85-HP Yamaha engine, fuel tanks and controller switch
	1 pipe dredge for the collection of bed material samples

Country	Equipment Delivered
	1 newly developed winch system to use with D96 depth-integrated suspended sediment sampler
Cambodia	1 new HYCOS station, with water level recorded, rain gauge, telemetry and solar panels installed at Koh Key upstream of Stung Treng
	1 pipe dredge for the collection of bed material samples
	1 all-weather digital GPS camera for the collection of repeat photos at monitoring sites
	Replacement cable for Rio Grande ADCP
	1 Dell Latitude Field Computer to use with the ADCP

Figure 2.2. Photos of equipment provided by the JEM Pilot.

Note: Equipment shown is (top left) pipe dredge for collecting bed materials (top right) Acoustic Doppler Current Profiler (ADCP) (middle right) new boat and engine for Pakse (bottom left) new winch system for Pakse (bottom right) Koh Key water level site

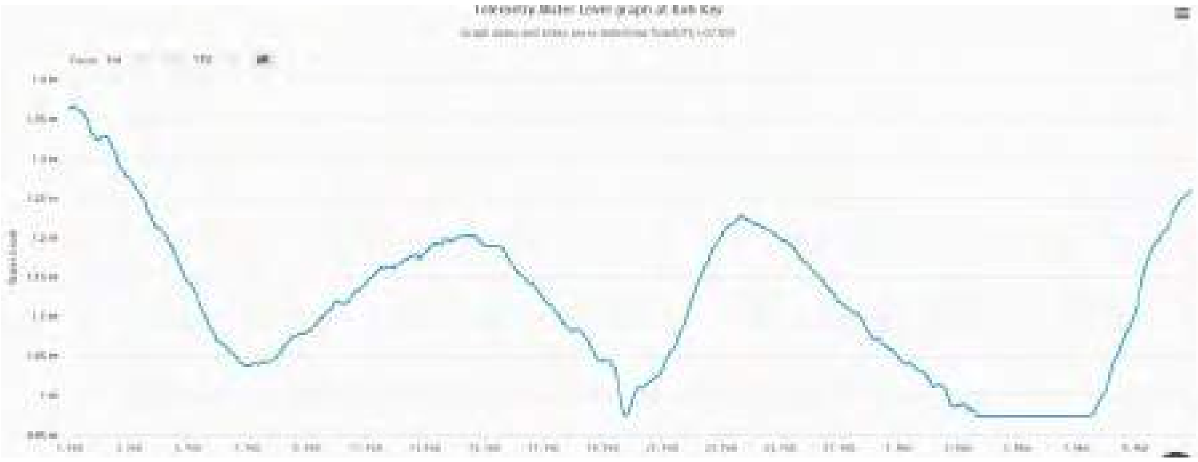

Figure 2.3. Time-series of 15 minute water level results from new JEM site at Koh Key downstream of Don Sahong.

Note: Record shows 1 February 2021 to 10 March 2021. Data from MRC data portal

Source: MRC (2021a)

2.2.2. Hydrology and sediment training completed

Training for hydrology and sediments were combined as the two disciplines are required to be monitored by the same teams on the same day. Training completed include the following:

- A 3.5-day online course delivered by Dr Lois Koehnken, with participants from 15 different locations. The training used PowerPoint presentations with English subtitles and some simultaneous translation into Lao. Topics included:
    - Theory of water level, discharge and suspended and bedload sediment monitoring
    - The operation and use of field equipment using videos and live demonstrations of software
    - The order of field monitoring to be completed, and reporting of results
    - Detailed demonstrations of the processing of Acoustic Doppler Current Profiler (ADCP) data to extract reliable discharge measurements and estimates of bedload transport
    - Question and answer sessions for each topic covered and in the final session.

Peer training for hydrographic teams who have received new equipment was provided by an experienced team in the operation of ADCPs, and D96 sediment sampler training was provided by a a less experienced team from the same country. The Lao PDR peer training involved the Luang Prabang team training the Pakse team. In Thailand, the Nong Khai team assisted the Chiang Khan team. Two peer training sessions were completed for each pair of teams, and activities included practice setting up and calibrating instruments and collecting field measurements. GIZ and MRC experts facilitated these training sessions (Figure 2.4):

- training in the use of the new boat and engine for the Pakse team;
- training for the Pakse team in the use of the winch system developed by VGS for the JEM pilot;
- ad hoc support in Lao PDR to train new staff in the completion of SSC (suspended sediment concentrations) measurements and the grain-size analysis of bed materials.

Figure 2.4. Peer training in Xayaburi, with the RiverRay ADCP included in the photo

Source: Photo by the MRC.

2.2.3. Monitoring missions

The JEM monitoring at the sites shown in Figure 1 has varied between the countries. Discharge monitoring at Pakse was reported for two occasions in 2020 due to the late arrival of equipment and the need for training. A third set of results was collected in October 2020, but was reported to the MRC. Sediment monitoring at Pakse commenced in March 2021 after the arrival of the new boat, which will allow the safe deployment of the heavy D96 SSC sampler (Table 2.2).

Table 2.2. Summary of monitoring results reported by the Lao PDR monitoring team at Pakse

Pakse – Results reported to the MRC			
Date	**Discharge**	**SSC**	**Bed materials**
October 2020	X (collected but not reported)		
12/11/2020	X		
21/12/2020	X		

Note: SSC = Suspended sediment concentration, Bed GS= Bed material grain-size analysis.

Monitoring at the JEM site at ST-UP (e.g. downstream of Koh Key) was initiated in April 2020, together with monitoring at the nearby DSM monitoring sites of ST and SKB (Table 2.3). ADCP files were received for monitoring through November 2020 and SSC results were submitted for monitoring through September 2020, but no bed material analyses were submitted.

Table 2.3. Summary of monitoring results reported by the Cambodian monitoring teams through March 9, 2021

Stung Treng UP (ST-UP)				Stung Treng (ST)				Sekong Bridge (SKB)			
Date	**Q**	**SSC**	**Bed GS**	**Date**	**Q**	**SSC**	**Bed GS**	**Date**	**Q**	**SSC**	**Bed GS**
3/04/2020	X	X		29/04/2020	X	X		29/04/2020	X	X	
16/05/2020	X	X		15/05/2020	X	X		15/05/2020	X	X	
30/05/2020	X	X		29/05/2020	X	X		29/05/2020	X	X	
6/06/2020	X	X		5/06/2020	X	X		5/06/2020	X	X	
13/06/2020	X	X		12/06/2020	X	X		12/06/2020	X	X	
19/06/2020	X	X		18/06/2020	X	X		18/06/2020	X	X	
30/06/2020	X	X		29/06/2020	X	X		29/06/2020	X	X	
5/07/2020	X	X		4/07/2020	X	X		4/07/2020	X	X	
14/07/2020	X	X		13/07/2020	X	X		13/07/2020	X	X	
23/07/2020	X	X		22/07/2020	X	X		22/07/2020	X	X	
31/07/2020	X	X		30/07/2020	X	X		30/07/2020	X	X	
7/08/2020	X	X		6/08/2020	X	X		6/08/2020	X	X	
16/08/2020	X	X		15/08/2020	X	X		15/08/2020	X	X	
23/08/2020	X	X		22/08/2020	X	X		22/08/2020	X	X	
29/08/2020	X	X		28/08/2020	X	X		28/08/2020	X	X	
6/09/2020	X	X		5/09/2020	X	X		5/09/2020	X	X	
11/09/2020	X	X		10/09/2020	X	X		10/09/2020	X	X	
23/09/2020	X	X		24/09/2020	X	X		24/09/2020	X	X	
30/09/2020	X			29/09/2020	X			29/09/2020	X		
11/10/2020	X			10/10/2020	X			10/10/2020	X		
20/10/2020	X			19/10/2020	X			19/10/2020	X		
27/10/2020	X			27/10/2020	X			27/10/2020	X		
13/11/2020	X			31/10/2020	X			31/10/2020	X		
				13/11/2020	X			13/11/2020	X		
				28/11/2020	X			28/11/2020	X		

Note: Q=discharge, SSC = Suspended sediment concentration, Bed GS= Bed material grain-size analysis.

2.3. Hydrology – Preliminary results and data analysis

2.3.1. Water level at sites

Water level recorded at Pakse and ST from July 2020 to March 2021 (Figure 2.5) show similar flow patterns. The sharper 'peaks' recorded at ST compared to Pakse likely reflect high inflows from the 3S catchments as the water level site is immediately below the confluence. The water level at Koh Key is available from February 2021 and shows similar flow patterns to Pakse. Beginning in late 2020 and extending into March 2021, the ST results show small magnitude, high-frequency fluctuations that are not present at Pakse or Koh Key. These are likely attributable to operations at the Lower Sesan II hydropower project, which is located about 36 river km upstream of the confluence with the Mekong.

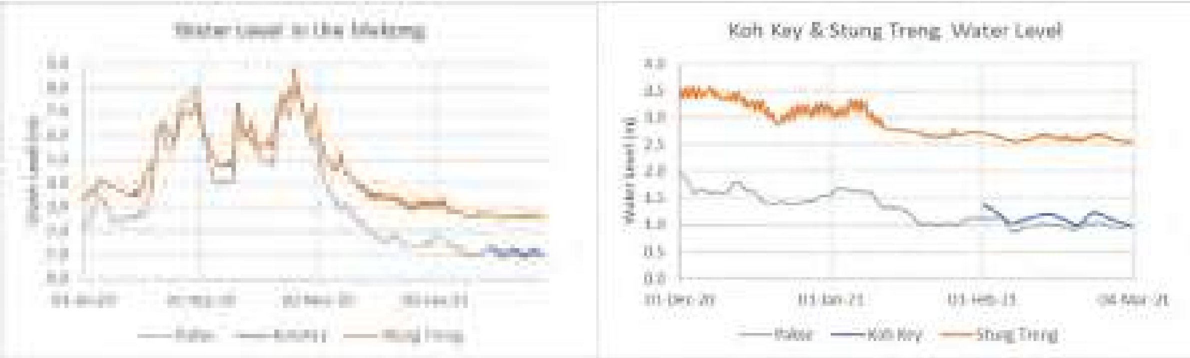

Figure 2.5. Water level at Pakse, Koh Key and Stung Treng from (left) July 2020 to March 2021 and (right) in February 2021

Sources: Water level data from Pakse are based on manual readings aggregated to a daily time-step. Koh Key and Stung Treng are based on 15 minute automatic readings. Data sourced from MRC (2021a).

A comparison of water level changes at ST in December 2016 (prior to commissioning of Lower Sesan II) with those recorded in December 2019 and December 2020 shows that there has been a substantial increase in water level changes greater than -0.002 or +0.002 m/15 minutes (Figure 2.6). In 2016, <5% of water level decreases were greater than -0.002 m/15 minutes, whereas in 2019 and 2020, this value was 34% and 32%, respectively. Water level increases greater than 0.002 m/15 minute occurred < 3% of the time in December2016, whereas in December2019 and 2020, they occurred 31% and 34% of the time, respectively.

The MRC Hydropower Mitigation Guidelines (MRC, 2020) recommend that rates of water level change remain < 50 mm/hr to maintain the ecological health of the river and reduce riverbank erosion. This rate is equivalent to 0.0125 mm/15 minutes. In 2019, there were no water level decreases that exceeded this threshold and only three increases that were greater than 0.0125 mm/15 minutes. In 2020, no water level increases or decreases were recorded at ST that exceeded the recommended threshold. This analysis suggests that although there has been a substantial change to water level fluctuations during low flows at ST, they likely pose a low risk to the aquatic ecosystem or stability of the riverbanks by the time the flow reaches ST. Rates and magnitude of change, and hence potential impacts, are likely to be higher closer to the dam site.

Figure 2.6. Histogram and cumulative percent of water level changes at Stung Treng in December 2016, 2019 and 2020

Note: This is based on 15-minute water level data.

2.3.2. Discharge measurement

Discharge measurements are collected from ST-UP, SKB and ST over a two-day period, providing a snapshot of flow conditions across the 3S confluence. ADCP profiles of each of the monitoring locations show the bathymetry of the site and distribution of flow in the river during high flow in September 2020 (*Figures 2.7 to 2.9*). The cross-sections show that flow in the Mekong at ST-UP and at ST is centred in the middle of the channel, with a strong jet of water occurring mid-stream. The cross-sectional area of the ST site is considerably greater (19,000 m^2) than that of ST-UP (14,600 m^2), which can account for the reduction in maximum and average velocities at the site. The SKB site shows more heterogeneity of flow, which may be caused by the mixing of the Sekong and Sesan Rivers and potential backwater from the Mekong.

However, ADCP moving bed tests have not been successfully completed during the monitoring runs at any of the sites, so the ADCP discharge results are uncorrected and are potentially too low. At high flow, this correction can be up to 10%, which is substantial. The uncorrected ADCP discharge results have been used in the following analysis. This issue is discussed in more detail in Section 1.4.1.

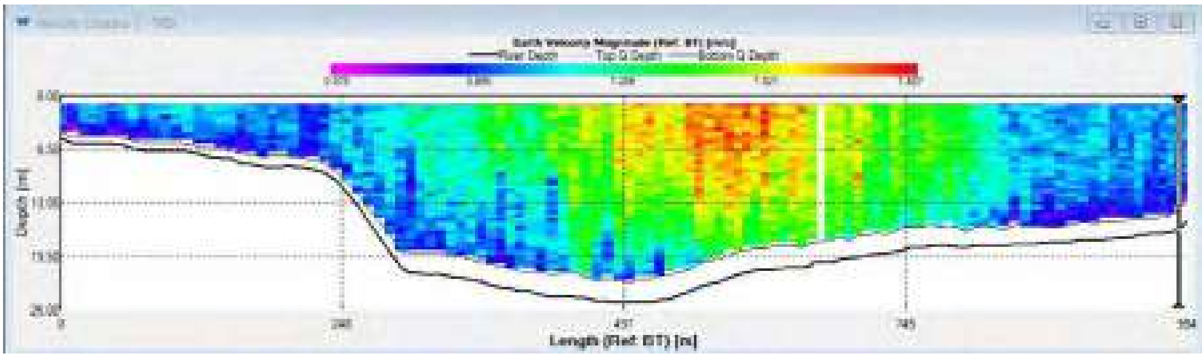

Figure 2.7. ADCP profile of Stung Treng UP on 6 September 2020

Notes: View is facing downstream. Velocity scale is shown at top of profile

Source: Data collected by DHRW, Cambodia.

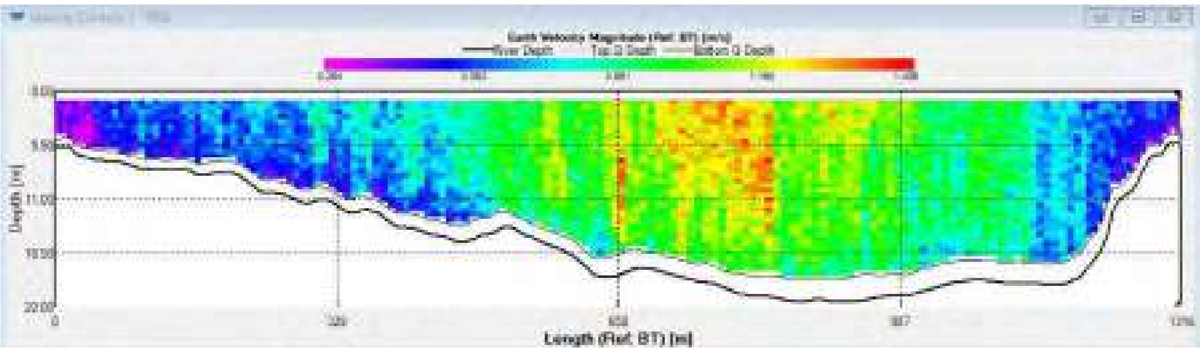

Figure 2.8. ADCP profile of Stung Treng 5 September 2020.

Notes: View is facing downstream. Velocity scale is shown at top of profile

Source: Data collected by DHRW, Cambodia.

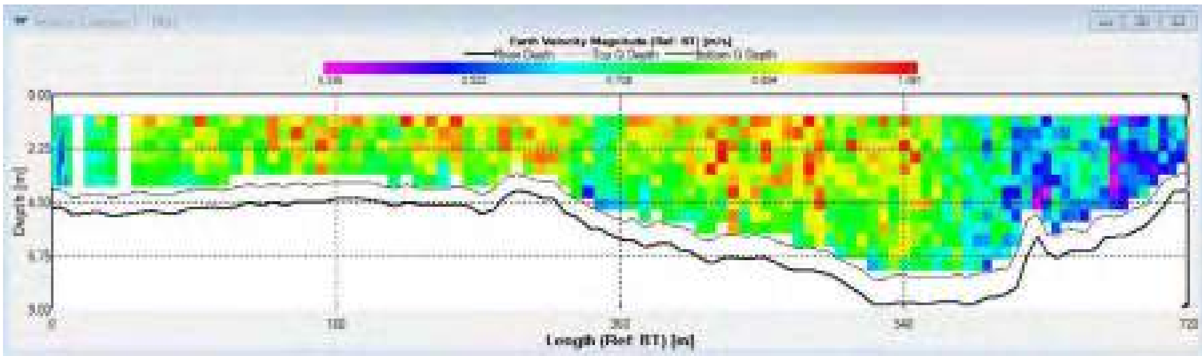

Figure 2.9. ADCP profile of Sekong Bridge on 5 September 2020

Notes: View is facing downstream. Velocity scale is shown at top of profile.

Source: Data collected by DHRW, Cambodia.

The time-series of the ADCP discharge measurements collected at each site shows the seasonality of flow in the Mekong, with the onset of the wet season occurring in late July and August (Figure 2.10). In October, there is a second flow peak at all sites. The maximum measured flow at ST was ~32,000 m^3/s in October 2020, which coincided with the highest water level recorded during the year.

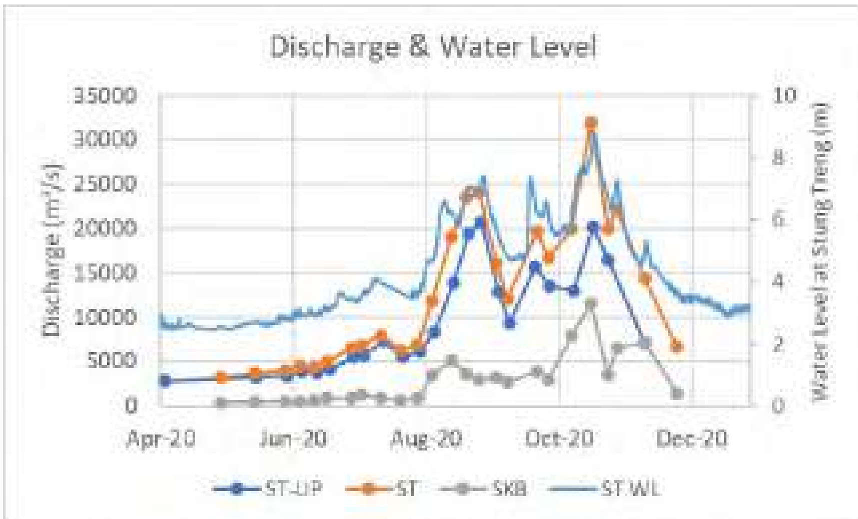

Figure 2.110. Time-series of discharge measured at each site from April 2020 to December 2020

Source: Data collected by DHRW, Cambodia.

The discharge results from each site for each monitoring period were used to construct a flow balance across the 3S confluence. For each monitoring period, the flows recorded at ST-UP and the SKB were added together (stacked) and compared to the flow recorded at ST (Figure 2.11). The results show an excellent balance between the sites throughout the monitoring period.

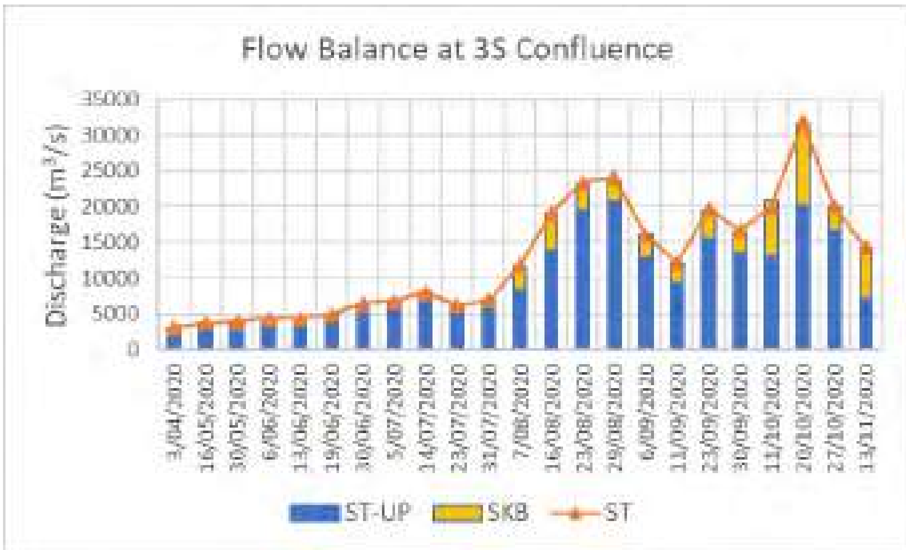

Figure 2.11. Flow balance of the 3S confluence.

Notes: Stacked bars show flow in the Mekong at ST-UP and at Sekong Bridge. The Orange line shows the measured flow at Stung Treng

Source: Data collected by DHRW, Cambodia.

The results also provide insights into the relative contribution of flow from the Mekong and the 3S catchments to the lower Mekong floodplain. The percent contribution from ST-UP and SKB varies throughout the year, with the 3S providing a large proportion of flow late in the wet season and into the beginning of the dry season (Figure 2.12). In October, up to 40% of the flow is derived from the 3S, and in November, this value increases to 50%.

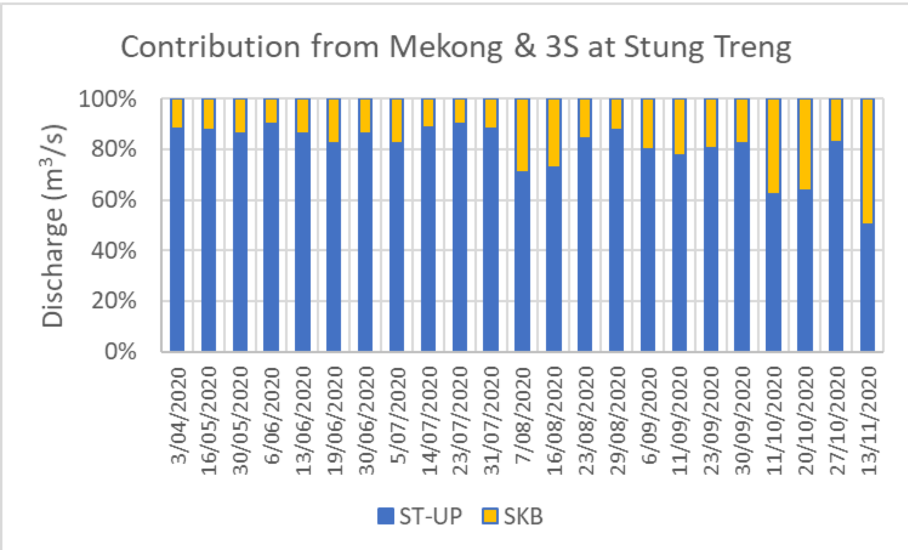

Figure 2.12. Relative contribution from the Mekong and Sekong Rivers to flow at Stung Treng

Source: Data collected by DHRW, Cambodia.

2.3.3. Rating curve at Stung Treng

The measured discharge at ST and water level at the time of monitoring are plotted in Figure 2.13, together with the MRC rating curve derived by Someth (2013) based on discharge and water level measurements collected in 2009–2012. The recent measurements show good agreement with the rating curve.

Although this shows that there has been little change since the equation was derived, there is a high risk that both the ADCP results and rating curve calculations are too low at high flow rates because neither the 2009–2012 nor the 2020 results were corrected for a moving riverbed. If the sediment on the bed of the river is being transported downstream, then the discharge recorded by the ADCP will be lower than the actual discharge because the ADCP assumes that the bed is stationary. Under conditions of high flow, a moving bed may result in a discharge measurement that is up to 10% too low.

However, moving bed tests are routinely conducted at the ST site, but the results of the tests are not valid due to the ADCP compass not being calibrated. These errors have persisted for many years, and correcting them should be a priority in the remaining JEM monitoring.

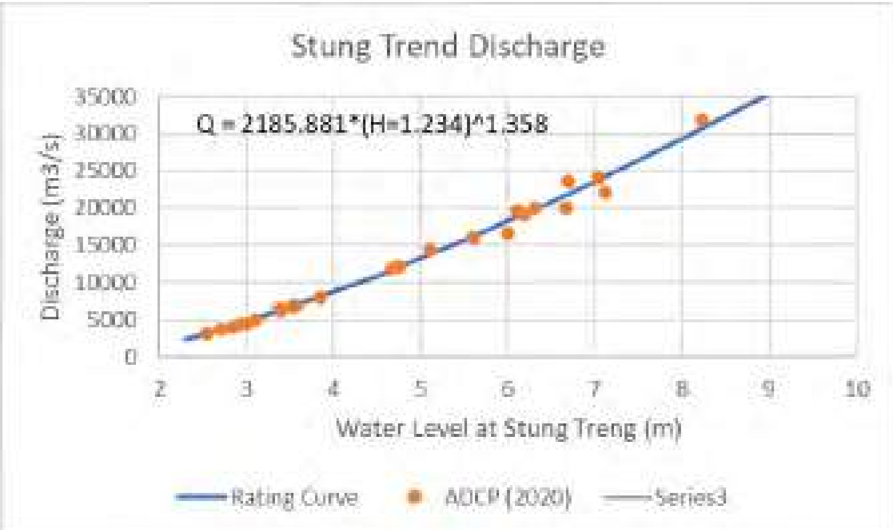

Figure 2.13. Discharge measurements and recorded water level during monitoring in April to December 2020 compared to the existing rating curve for Stung Treng

Source: Someth (2013)

2.4. Procedure for the Maintenance of Flow at Stung Treng

The Procedure for the Maintenance of Flow (PMFM) provides a framework to ensure that a mutually acceptable hydrological flow regime on the mainstream is maintained to optimize the multiple uses and mutual benefits of all riparian countries and to minimize the harmful effects under the 1995 Mekong Agreement - Article 6: Maintenance of Flows on the Mainstream (MRC, 1995). ST is one of the hydrological stations selected for implementation of the PMFM, and flows at the site are compared to the PMFM targets for the dry and wet seasons in the following sections.

2.4.1. Dry season

The dry season PMFM thresholds for ST are compared to the average daily flow in Figure 2.14. The graph shows that flow at ST was below the long-term average for part of December 2020, but remained in Zone 1. Zone 1 indicates that flow is above the 1:5 annual return interval (ARI) and is considered within normal hydrologic bounds. In April 2021, flow at ST exceeds historic maximum levels. This will be discussed in the Annual JEM report.

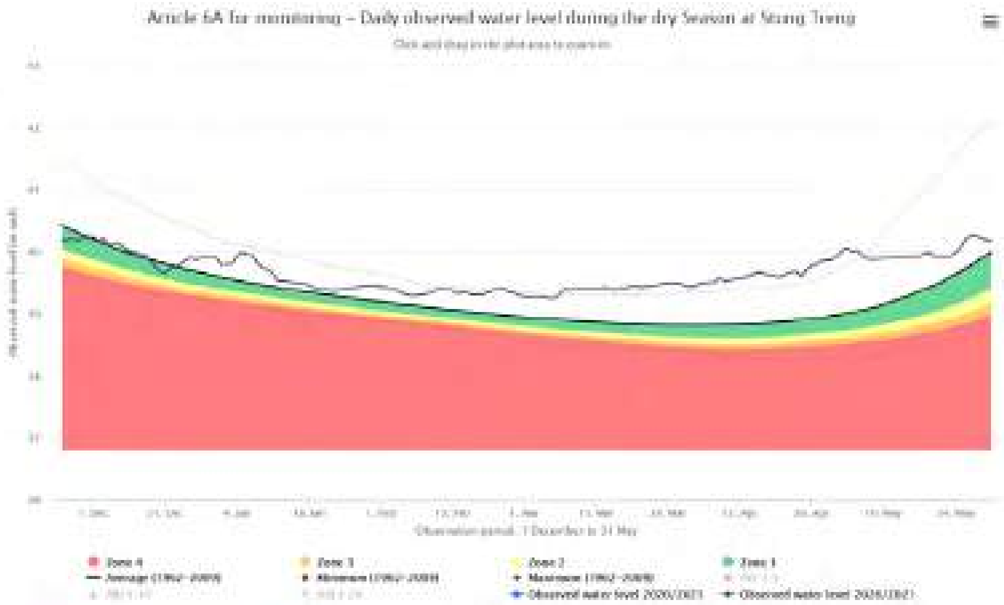

Figure 2.14. Daily water level at Stung Treng during the 2020–2021 dry season compared to the PMFM monitoring thresholds for the site.

Source: Figure from MRC (2021b)

2.4.2. Wet season

The PMFM objective in the wet season is to prevent average daily peak flows greater than what naturally occur on the average during the flood season. The 2020 wet season flow results all fall within zone 1, which is defined as below the ARI 1:2, and considered to be normal hydrologic conditions.

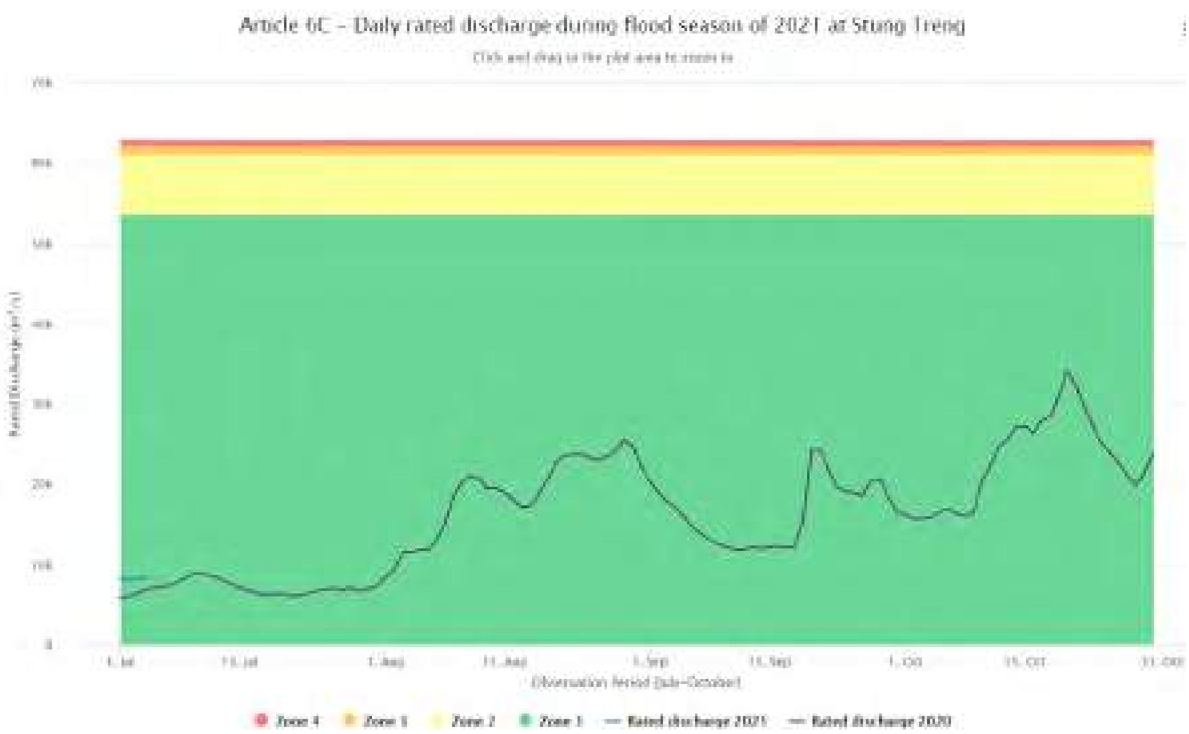

Figure 2.15. Average daily flow at Stung Treng July 2020 – October 2020, and beginning of July 2021 compared to the PMFM wet season thresholds

Source: Figure from MRC (2021c)

2.5. Sediment results

SSC results were reported for ST-UP, SKB and ST through September 2020. No SSC results were reported for Pakse, and no bed material results were reported for any of the sites.

2.5.1. SSC at 3S confluence

Time series of SSC at ST-UP, SKB and ST show that concentrations ranged from <10 mg/L to around 175 at ST-UP and ST. The inflow from the 3S had peak SSC concentrations of about 225 mg/L, but in general, were lower than in the Mekong during the wet season.

Figure 2.16. SSC results for Stung Treng UP, Sekong Bridge and Stung Treng for April to September 2020

Source: Data collected by DHRW, Cambodia.

Sediment loads based on the SSC results and measured discharge show that the 3S contributed a low sediment load compared to what is being transported in the Mekong during the wet season. Peak sediment loads exceeded 300,000 tonnes/day at ST in August 2020, with the minimum load being about 1,000 tonnes/day in April 2020.

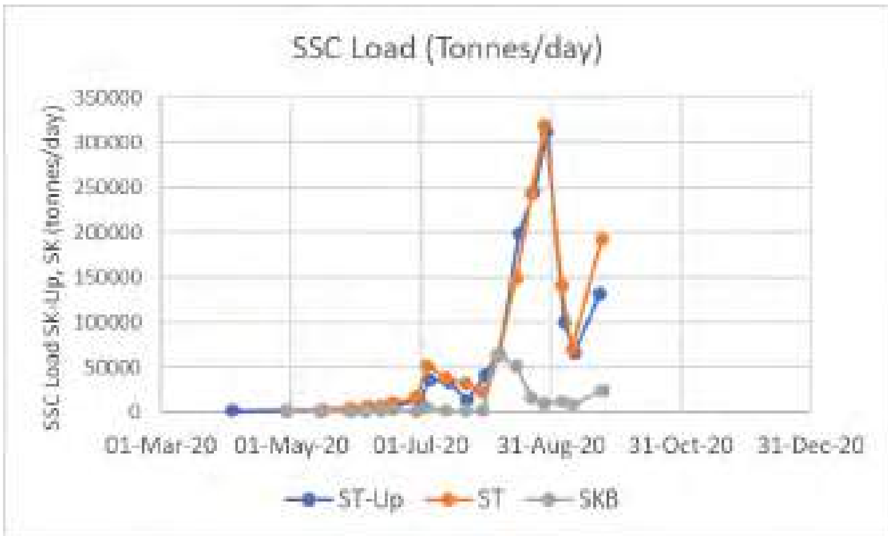

Figure 2.17. Time-series of SSC load at Stung Treng UP, Sekong Bridge and Stung Treng based on SSC concentrations and measured discharge from April to September 2020

Source: Data collected by DHRW, Cambodia.

An SSC load balance has been constructed similar to the previously presented flow balance (Figure 2.16). The agreement between the sites for SSC load is not as good as for the flow, with the combined loads of Stung Treng UP and SKB exceeding those measured at ST at the beginning of the wet season, and the loads at ST exceeding the inputs at the end of the wet season.

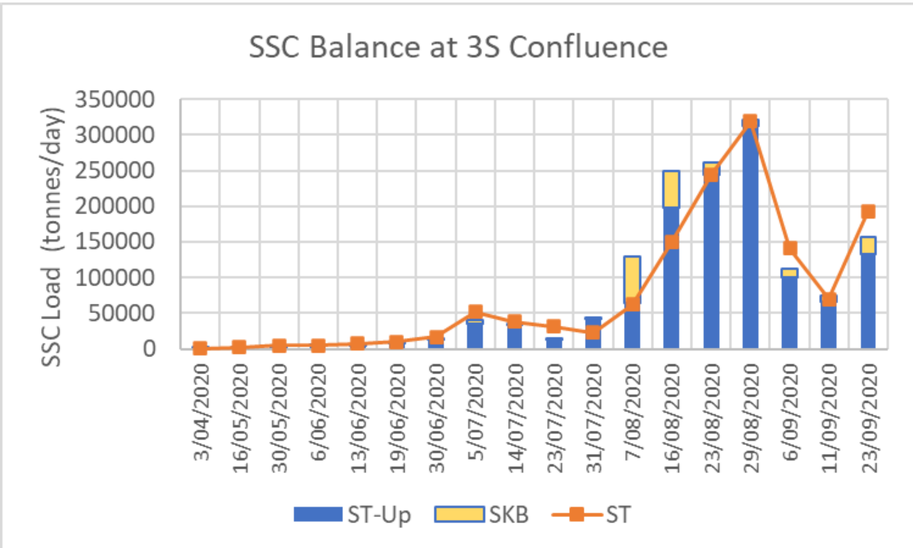

Figure 2.18. SSC load balance at the 3S confluence

Notes: Stacked bars show flow in the Mekong at Stung Treng UP and at Sekong Bridge**.**The orange line shows the SSC load at Stung Treng.

Source: Data collected by DHRW, Cambodia.

The reason for the discrepancy is likely due to the location of the monitoring sites in the Sekong and at ST. As shown in Figure 2.17, the rivers are not uniform with respect to sediment concentration near the monitoring sites. At the ST-UP site, the Mekong is well mixed since it has emerged from a turbulent section of the river, and there are no major tributary inputs for many kilometres upstream. In contrast, the Sekong River shows high variability across the channel with respect to sediment due to the different sediment loads being transported by the Sesan and Sekong Rivers. These inflows do not mix across the channel before the Sekong joins the Mekong. At the ST monitoring site, the inflow from the Sekong is not uniformly mixed with the Mekong by the time the river arrives at the ST monitoring site. If rivers are not uniformly mixed, then sampling sediment evenly across the section (at each 20% of the flow) will not produce an accurate sediment load.

Based on this, the results from ST-UP are considered accurate, so results at ST that are less than this value are likely to be underestimated. Sediment loads will also be affected by the local deposition and erosion of sediment deposits, which vary over time. Although the three sites' measurements were completed within two days, the flow shows a good balance, so the natural variability of the sediment load may be contributing to the differences.

Figure 2.19. Google Earth image from 20 October 2019 showing 3S confluence and difference in sediment content in the Sesan, Sekong and Mekong Rivers.

Note: Monitoring locations indicated.

Viewing the results as the proportion of sediment derived from the Mekong and from the 3S catchment (Figure 2.18) shows that, except for one large influx of sediment in August 2020, the 3S contributes relatively low loads. The 3S input ranged from 2% to 50% of the combined Mekong and 3S load, with an average of 14%.

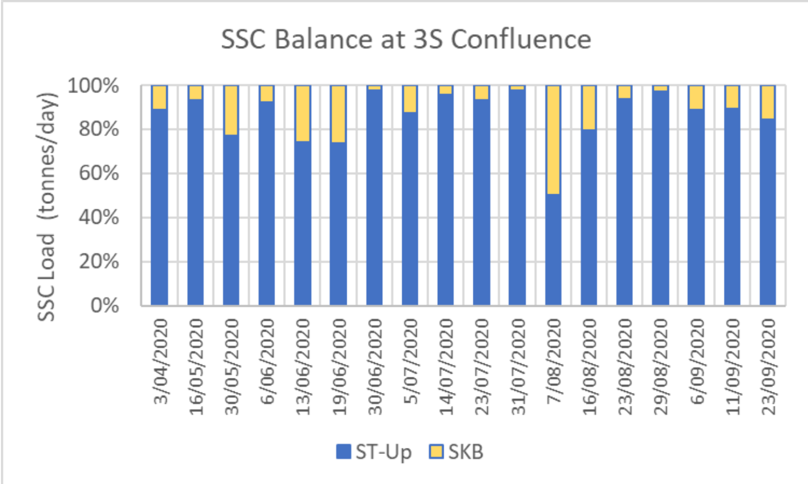

Figure 2.20. Proportion of sediment derived from the Mekong (ST-UP) and from the 3S catchment (SKB) during each of the monitoring runs

Source: Data collected by DHRW, Cambodia.

2.5.2. Estimate of annual sediment load at Stung Treng

The SSC loads derived from the 2020 monitoring results are compared to historical values in Figure 2.19. Although the 2020 monitoring captured the highest flow recorded for the year, the SSC loads are the lowest recorded since monitoring began in 2011 due to the very low concentrations of suspended sediment recorded. Note the very high load in 2018 occurred immediately following a dam break in Lao PDR. The 3S was also the source of the high peak in 2019 when greater than 3 g/L of sediment was present in some of the sub-samples at Sekong Bridge. At ST, the average concentration was 500 mg/L. Whether this large influx is related to sediment flushing, a large landslip or other process is unknown.

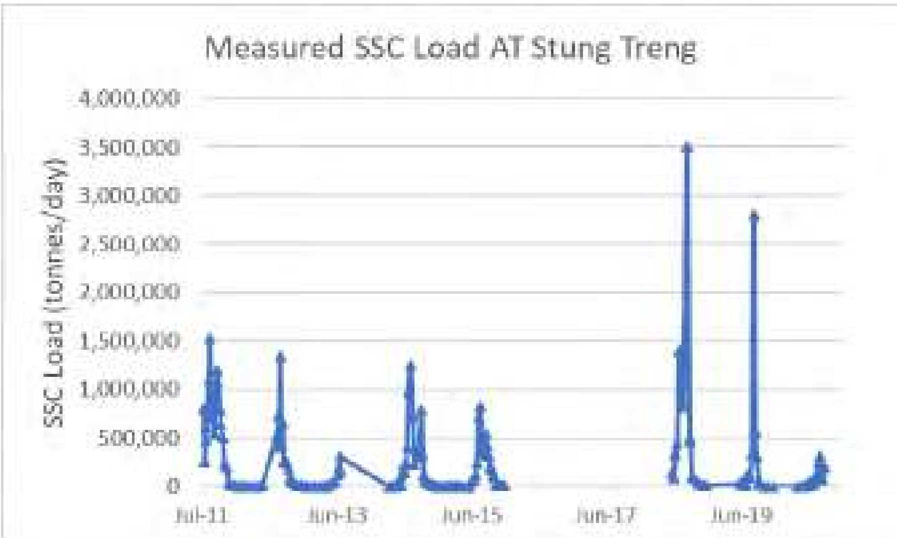

Figure 2.21. Time-series of measured SSC loads at Stung Treng, 2011–2020

Source: Based on data collected through DSM by DHRW, Cambodia.

The discharge and SSC results from ST in 2020 show a reasonable relationship (Figure 2.20) which has been used to estimate the annual sediment load at ST. The derived discharge SSC relationship equation has been applied to the average daily flow at the site, using the water level recorded at the site and the discharge rating equation discussed in Section 2.4.1. For January to December 2020, the estimated sediment load at ST was 21 Mt/yr. Using a linear equation based resulted in an estimated load of 23 Mt/yr. These estimates are low compared to recent SSC annual loads, which have ranged from 28 Mt/yr to 99 Mt/yr (Figure 2.21) in recent years, and exceedingly low based on historical estimates of up to 160 Mt/yr. The estimate for 2020 is based on data collected from the first half of the wet season only. Until the analysis is updated using SSC results for the entire wet season, these results should be considered preliminary.

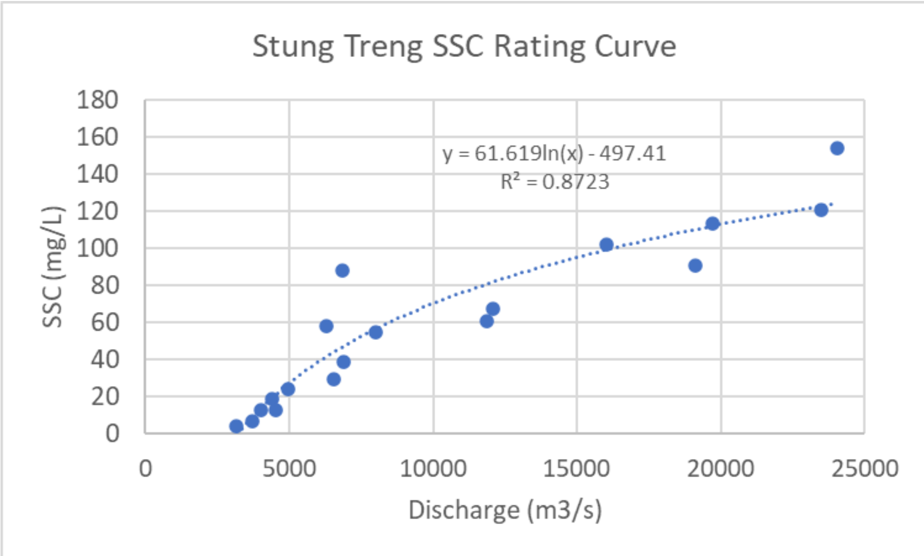

Figure 2.22. SSC rating curve for Stung Treng based on 2020 discharge and SSC results

Figure 2.21 shows that there is some correspondence between flow and SSC loads; however, lower sediment loads are being recorded during wet years, such as in 2018, than during earlier wet years. A large decrease in sediment output due to sediment trapping in tributary and mainstream dams has been predicted by numerous studies and investigations, including the MRC Council Study. These results are broadly consistent with the predictions.

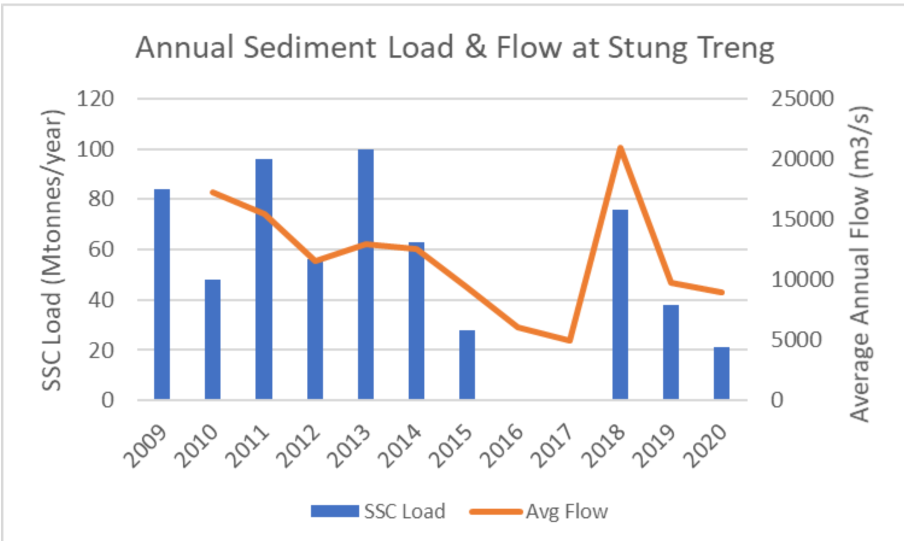

Figure 2.23. Estimated annual sediment loads and average annual flow at Stung Treng, 2009–2020

Source: 2009–2013 results from Koehnken (2015); other years based on MRC unpublished DSM monitoring results.

2.5.3. Bedload transport

No estimates of bedload transport can be made because the moving bed tests required to measure the rate of bedload movement have not been accurately completed, and no grain-size material of bedload has been submitted.

2.6. Lessons learned and recommendations

The first nine months of the JEM pilot monitoring has provided good results at the ST-UP, SKB and ST site. Monitoring at Pakse has been hampered by a number of factors, mainly related to COVID-19, which prevented in-person training, resulted in the slow delivery of equipment, and hindered field access for the monitoring teams.

Despite these challenges, the information being generated by the JEM Pilot in southern Lao PDR and northern Cambodia is showing the following characteristics related to the Don Sahong and other power station operations. This assessment should be considered preliminary until more data are available:

- Data are limited to one-month (February 2021) at the new Koh Key water level recording site, but the results show strong similarities with the flow pattern at Pakse. There is no indication that the operation of the Don Sahong HPP is altering flows in the mainstream Mekong downstream of the project.
- Water level fluctuations have increased at the ST water level recording site, with a substantial change in the distribution of flow changes between 2016 and 2019, and 2020. These changes must be associated with inflows from the Sekong River and likely reflect power station operations at the Lower Sesan II hydropower project. Although the range and frequency of fluctuations have increased relative to 2016, the water level changes are below the 5 cm/hour limit recommended in the MRC Hydropower Mitigation Guidelines (MRC, 2020). The fluctuations are limited to periods of relatively low flow in the river, as would be expected.
- Discharge monitoring at the ST-UP, SKB and ST sites shows a good balance, with the ST flow equivalent to the sum of discharge at the two upstream stations. There is good agreement between the discharge measured by ADCP in 2020 and the predicted flow based on the 2013 rating curve, but it is likely that the flows are underestimated due to the measurements not being corrected for the moving bed of the river.
- SSC concentrations and loads were low at all sites in 2020 compared to previous years, although SSC results are only available through September, and more results are required to capture the entire wet season.
- SSC loads show a fair balance across the monitoring sites, with differences likely attributable to the heterogeneity of sediment transport in the Sekong, and incomplete mixing in the Mekong at ST. An uneven distribution of sediment in the cross-section will prevent the collection of representative SSC samples.
- Estimated SSC loads based on a discharge/SSC rating curve suggest that the annual load at ST could be in the range of 21 to 23 Mt/yr, which are the lowest loads recorded since monitoring began in 2011. The previous range has been from 28 Mt/yr in 2015 (MRC unpublished results) to 99 Mt/yr in 2013 (Koehnken, 2015).

2.6.1. Recommendations

Recommendations arising from the first year of the JEM pilots are provided below.

1. Hydrology

The newly installed water level gauges at Koh Key require finalisation, as follows:

- A survey of the site is required to link the site into the local datum and to establish a base level for water level measurements.
- Twice daily manual water level readings need to be recorded and reported to the MRC.
- For the measurement of discharge using the ADCP, the following actions need to be completed at each site:
  - Calibrate the ADCP compass prior to starting discharge measurements at each site.
  - Check the moving bed test results in the field to ensure that the test is valid, and if not, complete an additional test.
  - Ensure that the internal GPS is used when completing the discharge measurement and moving bed test.
  - Read and record the water level gauge at the beginning and end of each discharge measurement with the level recorded on the JEM revised Q2 form. At Koh Key, the reading of the gauge should coincide with the time of discharge measurement if possible.
  - Countries should ensure that there are numerous staff trained in the collection of accurate ADCP measurements, so that there are no gaps if one staff member leaves or is not available to complete the work.
- Processing of HYCOS data at the MRC
  - The quality of the incoming data should be routinely checked, with machine spikes and poor data removed from the database.
  - Rating curves derived in 2013 based on 2009-2012 discharge measurements should be reviewed and updated.

2. Sediment monitoring and laboratory analysis

- The laboratory teams should review the method for determining SSC and ensure that all filters (blank and containing sediment) are dried prior to weighing and the volume of the sample filtered is accurately recorded on the datasheet.
- Countries should ensure that there are numerous staff trained in the required field and laboratory procedures to ensure continuity of monitoring when staff leave or retire.

3. Maintenance of equipment

The JEM Pilot project has made a substantial investment in new equipment to enable discharge and sediment monitoring. It is critical that this equipment be stored and maintained appropriately to ensure that it remains in a suitable condition. Recommendations include:

- Boats should be removed from the river whenever possible to minimise damage caused by sediment and freshwater organisms on the hull of the boats.
- Boats should be thoroughly cleaned on a regular basis, and any damage to the fiberglass on the boats should promptly be fixed.
- Good quality engine oil should be used in the engines to ensure smooth operation and prolong the life of the engine.
- A spare prop or blades for the engine should be carried at all times as a safety precaution. The supplier of the new boat at Pakse has recommended Piranha props, which are made of plastic

and allow individual blades to be replaced, rather than the entire prop making them easy to fix and more economical.

Figure 2.24. Components of a Piranha prop

Note: Blades can be easily changed if damaged without having to purchase an entire new prop.

- All wires and lines used for the deployment of the D96 depth-integrated suspended sediment sampler should be routinely inspected for wear and tear and replaced when required to prevent loss of equipment.

3. Water Quality

3.1. Adjustments to monitoring protocols

3.1.1. Monitoring stations

Four monitoring stations for the monthly water quality sampling was selected for the Don Sahong pilot site, one above Khone Falls at the head of the impoundment, one in the impoundment about 600 m from the dam wall, and two downstream of the dam at 250 m and 1 km downstream (see Table 3.1 and Figure 3.1).

There have been no changes in the locations of the sampling stations, and the water quality team has not indicated any access or sampling difficulties at these stations.

Table 3.1. Water quality sampling stations for Don Sahong JEM Pilot projects

Code	Station	River	Latitude	Longitude
WQ6	Upstream of Don Sahong Dam, at the impoundment inlet point	Mekong	13°58'41.8"N	105°57'16.2"E
WQ7	Within the impoundment (around 1.2 km upstream of the dam wall)	Mekong	13°56'38.8"N	105°57'42.5"E
WQ8	Downstream of Don Sahong (around 250 m downstream of the dam)	Mekong	13°56'31.7"N	105°57'15.8"E
WQ9	Downstream Monitoring #2 of Don Sahong (around 1-km downstream of the dam).	Mekong	13°56'14.7"N	105°57'25.7"E

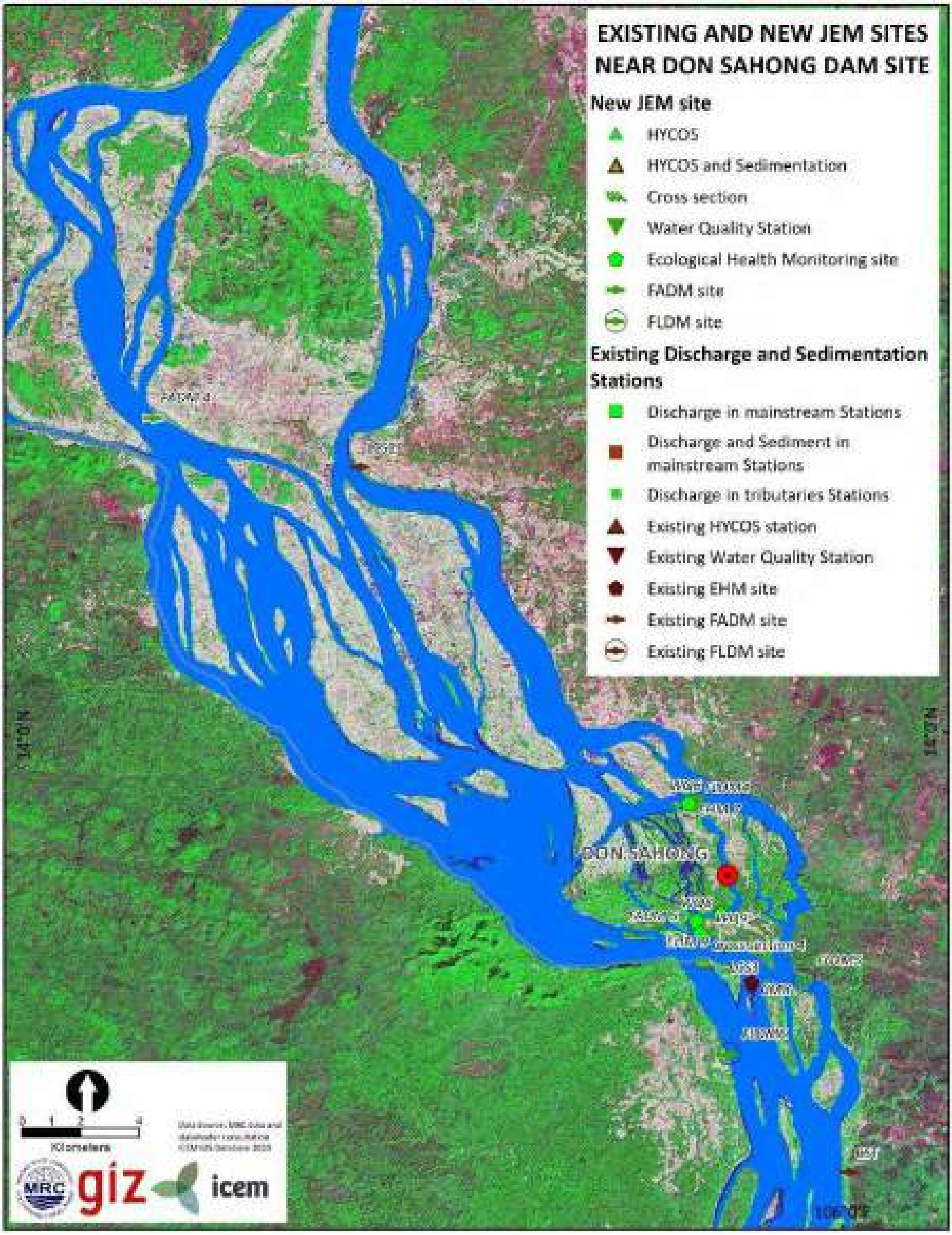

Figure 3.1. Water quality sampling stations downstream of the Don Sahong dam

3.1.2. Monitored parameters

The sampling stations are scheduled to be visited by the Lao water quality team on a monthly basis and carry out measurements using both water quality probes and taking samples for analysis in the laboratory at each site. The parameters measured are identical to the parameters used in the MRC's routine water quality monitoring programme (WQMN). The new parameters of turbidity, chlorophyll-a and cyanobacteria measurements are carried out using the AlgaeTorch, procured by the pilot project, or by taking water samples for spectrophotometric analysis once the training in the spectrophotometer has been delivered. Table 3.2 shows the parameters measured at each site, some with the full complement of parameters measured and others with a more restricted set. In addition, at the impoundment site, a depth profile using the water quality probe and AlgaeTorch lowered at 1-m intervals to 20 m and 10 m, respectively. There have been no changes to these parameters and analyses, and no constraints identified by the Lao water quality monitoring team.

Table 3.2. Water quality monitoring parameters measured at each of the Don Sahong monitoring stations

Parameter	Unit	Frequency	Probe	Lab	H013900	WQ6	WQ7	WQ7	WQ8	WQ9	H014501
					Pakse	Upstream of DSH Dam, at impoundment inlet point	Within the impoundment (c. 600 m upstream of the dam wall)		Downstream of DSH (around 250 m downstream of the dam)	Downstream Monitoring #2 of DSH (c 1-km downstream of the dam)	Stung Treng
					Mekong	Mekong	Mekong	Depth profile	Mekong	Mekong	Mekong
					15.1206	13°58'41.8"N	13°56'38.8"N		13°56'31.7"N	13°56'14.7"N	13.545
					105.7837	105°57'16.2"E	105°57'42.5"E		105°57'15.8"E	105°57'25.7"E	106.0164
Temperature	TEMP_°C	Monthly	x		x	x	x	x	x	x	x
pH	pH	Monthly	x		x	x	x	x	x	x	x
Conductivity (Salinity)	COND_mS/m	Monthly	x		x	x	x	x	x	x	x
Alkalinity/Acidity	ALK_meq/L	Monthly		x	x	x				x	x
Dissolved Oxygen (DO)	DO_mg/L	Monthly	x		x	x	x	x	x	x	x
Total phosphorous (TP)	TOTP_mg/L	Monthly		x	x	x	x		x	x	x
Total Nitrogen (TN)	TOTN_mg/L	Monthly		x	x	x				x	x
Ammonium (NH_4+-N)	NH4N_mg/L	Monthly		x	x	x				x	x
Nitrite+Nitrate (NO_2+$_3$-N)	NO32_mg/L	Monthly		x	x	x	x		x	x	x
Fecal Coliforms	FC_MPN/100ml	Monthly		x	x	x				x	x
Total Suspended Solids (TSS)	TSS_mg/L	Monthly		x	x	x				x	x
Chemical Oxygen Demand (COD)	CODMN_mg/L	Monthly		x	x	x				x	x
Calcium (Ca)	Ca_meq/L	Monthly for 7 months		x	x	x				x	x
Magnesium (Mg)	Mg_meq/L	Monthly for 7 months		x	x	x				x	x
Sodium (Na)	Na_meq/L	Monthly for 7 months		x	x	x				x	x
Potassium (K)	K_meq/L	Monthly for 7 months		x	x	x				x	x
Sulphate (SO42-)	SO4_meq/L	Monthly for 7 months		x	x	x				x	x
Chloride (Cl^-)	Cl_meq/L	Monthly for 7 months		x	x	x				x	x
Turbidity	FTU	Monthly	x								
Chlorophyll *a*	micrograms/l	Monthly	x	x		x	x	x	x	x	
	cell count/l										
Cyanobacteria	micrograms/l	Monthly	x								
	cell count/l										

Note: Blue = routine WQ monitoring, Green = measurement in the laboratory, Yellow = measurement in the field by probe.

3.2. Activities

3.2.1. Water quality training sessions

On-line water quality training sessions were held on 16, 17 and 19 June 2020, attended principally by the Lao water quality team and representatives from the teams from other Member Countries. These training sessions emphasized the purpose of the JEM monitoring, the sampling stations, as well as the parameters and methods to be used. It outlined the water quality monitoring protocols and field data sheets. In particular, information on the new equipment – the AlgaeTorch and Horizontal Van Dorn sampling bottle –was provided.

A lab-based training is yet to be provided for the analysis of chlorophyll-a using spectrophotometric techniques, which will be provided when COVID-19 restrictions allow.

A follow-up meeting with the Lao water quality team was held on 2 February 2021 to discuss any issues and challenges faced by the team in carrying out the water quality monitoring in order to consider the initial monitoring results and report preparation.

3.2.2. Monitoring missions

The Lao water quality monitoring team provided by NRESRI, MoNRE (Vanhna Phanpongsa, Mr. Xayphavanh Pengkhamhuck); DoNRE of Champasak (Sitthideth Phannavong) visited the Xayaburi sampling stations on the following occasions:

Table 3.3. Dates of sampling visits to Xayaburi pilot sampling stations

Sampling stations	2020			2021	
Month	10	11	12	1	2
WQ6	27.10.2020	13.11.2020	14.12.2020	15.01.2021	17.2.2021
WQ7	27.10.2020	13.11.2020	14.12.2020	15.01.2021	17.2.2021
WQ8	27.10.2020	13.11.2020	14.12.2020	15.01.2021	17.2.2021
WQ9	27.10.2020	13.11.2020	14.12.2020	15.01.2021	17.2.2021

3.3. Preliminary results and initial analysis

3.3.1. Surface water results

The monitoring results of the first five months of sampling of the JEM pilot sites at Don Sahong are shown in Table 3.5. In comparison, the monthly average WQMN results for the Pakse (131 km above Don Sahong) and ST (50 km below Don Sahong) sites are shown in *Table 3.6***.** The probe reading results are first compared on a monthly basis for all stations (*Figure 3.2*). The average monthly results for the routine monitoring and nutrient levels at Pakse and ST are shown in *Figures 3.3 and 3.4*, respectively.

The JEM results are consistent with the similar monthly averages in the reference sites of Pakse and ST. The only parameter that is different is pH, with the JEM sites being consistently more alkaline (mostly above pH 8) than Pakse (pH7.3–7.7) and ST (pH 7.1–7.6) sites, although it is the same for all the pilot sites, indicating little difference due to the HPP. Conductivity results are slightly higher (generally in mid-20s mS/m) for the time of year for this stretch of river between Pakse and ST, and dissolved oxygen is consistently above 6 mg/l for all sites (varying between 6.8 mg/l and 9.2 mg/l), which is consistent with the reference sites. COD levels in the JEM sites area similar to the readings at Pakse (between 2 mg/l and 3 mg/l), but higher than those at Stung Treng (between 0.5 mg/l and 1.8 mg/l) and faecal coliforms are at consistently fairly low levels, below those of Pakse.

Table 3.4 shows a comparison of water quality data for the Mekong River sites from the 2017 LMB Water Quality Report for comparison. While most of the results from the JEM sites lie within the usual ranges shown for both 1985–2016 and for 2017, there are some readings for both total nitrogen and phosphate which are abnormally high, well above the mean of 0.6 mg/l for total nitrogen and exceeding the maximum values recorded for total phosphate of 4.9 mg/l in December. These are marked on Table 3.5, with yellow highlighting. Nitrate figures in the JEM pilot sites are generally higher (ranging between 0.5 and 0.75 mg/l) than the mean values for 1985–2016 and 2017 (0.2 mg/l). The higher nitrate values are the same across all the JEM pilot sampling stations, but the December high phosphate values show a marked increase within the impoundment and downstream.

Table 3.4. Comparison of water quality data in the Mekong River, between 1985–2016 and 2017

Parameter	Unit	Water Quality Guidelines		1985-2016				2017			
		Protection of									
		Human Health (WQGH)	Aquatic Life (WQGA)	Max	Mean	Min	Stdev	Max	Mean	Min	Stdev
Temp	°C	Natural	Natural	38.0	27.1	13.0	3.1	32.3	28.1	18.0	2.6
pH		6-9	6-9	9.9	7.5	3.8	0.5	8.4	7.3	6.1	0.5
TSS	mg/L	-	-	5,716.0	148.7	0.1	260.3	422.1	103.1	3.4	86.5
EC	mS/m	70 - 150	<150	841.0	20.7	1.2	27.7	41.4	19.0	7.6	5.3
NO3-2	mg/L	5	0.5	1.4	0.2	-	0.2	0.9	0.3	-	0.2
NH4N	mg/L	0.5	0.1	3.0	-	-	0.1	0.5	0.1	-	0.1
TOTN	mg/L	-	-	4.9	0.6	-	0.4	2.6	0.7	0.1	0.4
TOTP	EC	-	0.13	2.2	0.1	-	0.1	0.3	0.1	-	0.1
DO	mg/L	≥ 4	> 5	13.9	7.2	2.3	1.1	9.8	6.9	4.6	1.2
COD	mg/L	5	-	65.0	2.2	-	2.0	9.4	2.4	0.1	1.5

Source: MRC 2017. Lower Mekong Regional Water Quality Monitoring Report.

The longitudinal (WQ6 – WQ9) results of JEM monitoring are shown graphically for each month in order to illustrate changes with flow through the impoundment and downstream of the dam (*Figure 3.5* Month 10, *Figure 3.6* Month 11, *Figure 3.7* Month 12, *Figure 3.8* Month 1, *Figure 3.9* Month 2).

In the next section, the water quality index for both the protection of aquatic health and of human health are calculated for every site and month and compared to the monthly averages of the water quality indices for Pakse and ST during the 2013–2018 period.

Table 3.5. Don Sahong Water Quality monitoring results for months 10/11/12 in 2020 and 1 and 2 in 2021

StationID	Station name	Year	Month	TEMP	pH	TSS	COND	NO32	NH4N	TOTN	TOTP	DO	Turbidity	Chlorophyll-a	Cyanobacteria	CODMN	FC
				°C		mg/L	mS/m	mg/L	mg/L	mg/L	mg/L	mg/L	FTU			mg/L	MPN/100ml
WQ6	Inlet point	2020	10	25.60	7.33	186.60	10.57	0.58	0.02	0.99	0.05	7.17	241.14	-	-	3.28	45
WQ6	Inlet point	2020	11	27.45	6.83	31.50	21.03	0.57	0.04	1.85	0.07	7.04	27.00	0.06	-	2.89	45
WQ6	Inlet point	2020	12	26.52	8.45	8.70	24.86	0.53	0.05	1.04	0.04	7.85	7.61	0.30	-	2.11	93
WQ6	Inlet point	2021	1	22.70	8.58		26.40					8.92	5.39	0.87	0.17		
WQ6	Inlet point	2021	2	22.15	8.39		29.30					6.76	5.69	0.81	-		
WQ7	Impoundment	2020	10	25.90	7.12		10.60	0.75			0.06	6.80	259.00	-	-		
WQ7	Impoundment	2020	11	28.46	5.90		21.00	0.64			0.02	6.80	24.80	0.20	-		
WQ7	Impoundment	2020	12	26.95	8.49		24.70	0.47			4.60	7.30	8.70	0.30	-		
WQ7	Impoundment	2021	1	23.80	8.56		26.70					8.53	9.90	0.10	-		
WQ7	Impoundment	2021	2	26.24	8.49		26.23					7.83	7.29	1.49	0.57		
WQ8	#1downstream	2020	10	25.67	7.45		10.67	0.72			0.04	7.54	156.90	-	-		
WQ8	#1downstream	2020	11	27.73	6.92		21.06	0.32			0.25	8.41	26.81	0.04	-		
WQ8	#1downstream	2020	12	26.92	8.56		24.84	0.51			0.02	7.90	8.33	0.24	0.06		
WQ8	#1downstream	2021	1	22.71	8.64		26.36					8.66	8.98	1.43	0.16		
WQ8	#1downstream	2021	2	26.33	8.56		26.33					8.25	7.36	1.09	0.44		
WQ9	#2downstream	2020	10	25.64	7.38	193.75	10.71	0.54	0.04	1.29	0.04	6.77	159.17	-	-	2.51	28
WQ9	#2downstream	2020	11	27.50	8.01	4.33	21.04	0.76	0.03	2.22	0.60	9.20	28.14	0.13	-	3.86	<18
WQ9	#2downstream	2020	12	26.71	8.46	6.75	24.90	0.57	0.03	0.86	8.20	8.02	8.63	0.33	0.14	1.58	<18
WQ9	#2downstream	2021	1	22.87	8.61		26.40					8.83	5.83	1.13	0.17		
WQ9	#2downstream	2021	2	26.33	8.59		26.30					8.20	7.47	1.37	0.43		

Note: Yellow highlights indicate results that exceed routine MQMN means and ranges.

Table 3.6. Average monthly water quality results for Pakse and Stung Treng WQMN sites between 2013 and 2018

Month	TEMP	pH	TSS	COND	NO32	NH4N	TOTN	TOTP	DO	CODMN	FC
	°C		mg/l	mS/m	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	MPN/100ml
Pakse											
1	24.3	7.67	34.7	21.10	0.37	0.06	0.60	0.11	6.32	2.00	335
2	24.5	7.69	41.8	20.48	0.24	0.03	0.42	0.22	6.24	2.16	189
3	26.2	7.82	48.4	21.90	0.14	0.02	0.30	0.11	7.05	1.96	37
4	28.0	7.55	24.5	23.03	0.28	0.04	0.68	0.08	6.91	2.15	417
5	27.8	7.67	68.6	22.23	0.26	0.03	0.47	0.04	6.18	1.71	139
6	27.1	7.56	71.8	20.55	0.32	0.04	1.06	0.09	6.68	3.30	378
7	26.5	7.35	134.8	17.71	0.20	0.04	0.55	0.15	6.57	3.01	117
8	27.4	7.33	169.8	13.12	0.27	0.01	0.58	0.39	7.14	3.85	151
9	28.2	7.52	173.8	14.97	0.23	0.02	0.45	0.03	5.58	2.87	382
10	28.8	7.52	102.1	13.59	0.31	0.02	0.46	0.12	6.23	3.48	57
11	27.8	7.43	92.7	16.48	0.33	0.03	0.46	0.07	7.08	2.70	118
12	26.8	7.42	37.9	16.93	0.23	0.02	0.46	0.05	6.99	1.29	53
Stung Treng											
1	27.3	7.49	14.9	21.05	0.13	0.06	0.30	0.05	8.65	0.99	N/D
2	29.5	7.60	15.0	20.22	0.11	0.12	0.29	0.03	8.59	1.12	N/D
3	29.9	7.44	12.9	19.84	0.08	0.08	0.24	0.04	8.52	1.18	N/D
4	31.1	7.53	11.4	18.73	0.14	0.06	0.44	0.04	8.48	0.52	N/D
5	31.7	7.39	21.7	20.49	0.20	0.03	0.37	0.05	8.45	1.61	N/D
6	30.7	7.36	83.6	19.27	0.18	0.06	0.36	0.23	8.15	0.91	N/D
7	28.6	7.29	161.4	13.45	0.17	0.07	0.50	0.25	7.75	1.84	N/D
8	30.2	7.35	226.7	14.29	0.20	0.07	0.51	0.23	8.10	1.54	N/D
9	28.5	7.10	143.8	12.17	0.24	0.05	0.39	0.16	6.08	1.55	N/D
10	29.8	7.19	85.0	15.30	0.19	0.07	0.38	0.15	7.63	1.76	N/D
11	29.2	7.43	67.9	18.37	0.24	0.05	0.41	0.17	8.16	0.71	N/D
12	32.9	7.52	29.5	21.40	0.23	0.08	0.41	0.09	9.39	0.62	N/D

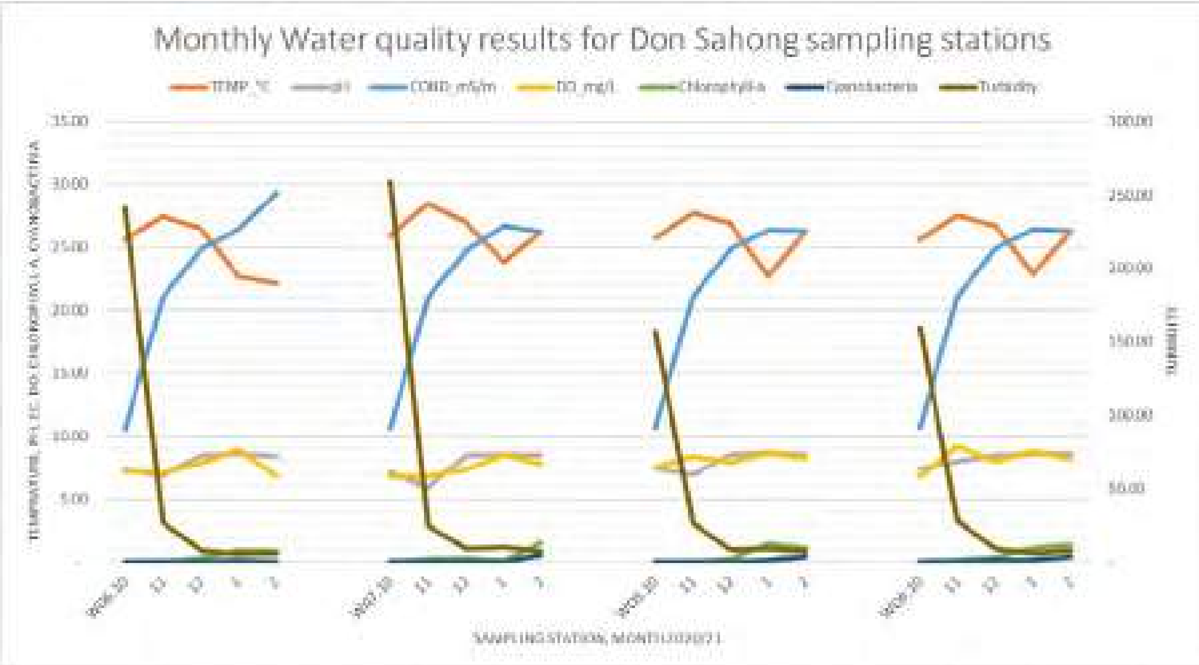

Figure 3.2. Monthly water quality probe readings for Xayaburi sampling stations, Month 10 (2020) to Month 2 (2021)

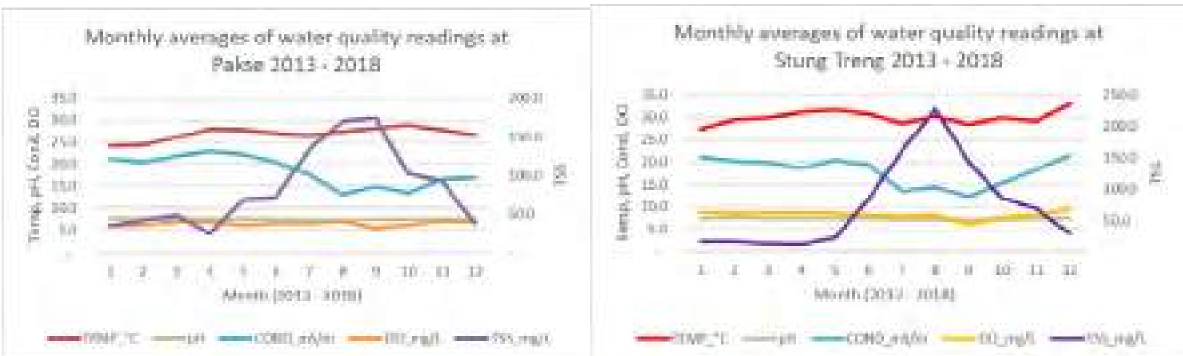

Figure 3.3. Monthly averages of water quality results for Pakse and Stung Treng, WQMN sites, 2013–2018

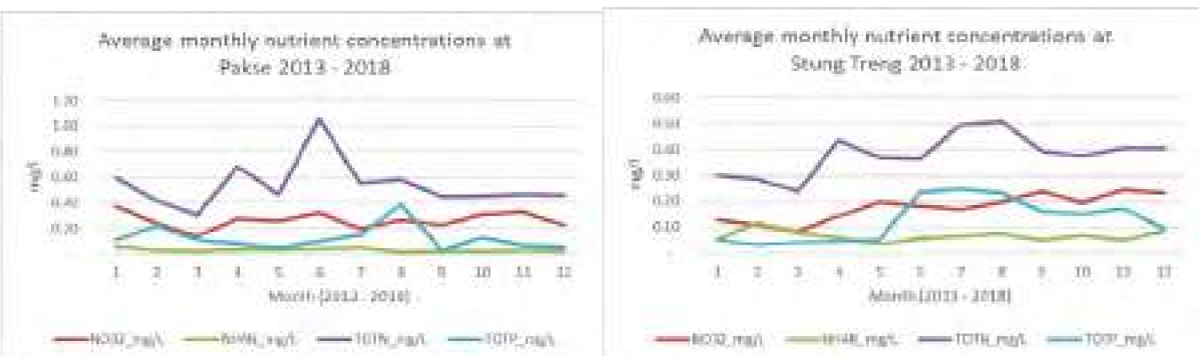

Figure 3.4. Monthly averages of nutrient levels for Pakse and Stung Treng WQMN sites, 2013–2018

When the results from the probe readings at each site are compared from October 2020 to February 2021 (Figure 3.2), there are several trends over time that can be observed at all sampling stations. Temperature shows a rise from about 26 °C to 28 °C in the last three months of 2020, but then falling below 23 °C in January, followed by a rise in the impoundment and downstream in February. This is to be expected with seasonal air temperature changes.

pH remains more or less constant at around 8 for all sites and months. Conductivity increases over the months from about 11 mS/m to 27 mS/m with a levelling off in February. This reflects the expected increased dissolved salts during lower flows. Dissolved oxygen is slightly variable between 6 and 8 mg/l with a peak in January at all stations, but all readings show good levels of dissolved oxygen. Turbidity readings show much higher levels, at WQ6 and WQ7, than at the downstream sampling stations, but all stations show a distinct fall in turbidity readings from highs in October (160–240 FTU), levelling off at very low levels (<10 FTU) in January and February 2021. This is consistent with decreasing levels of suspended solids as flows decrease seasonally.

Chlorophyll-a and cyanobacteria levels are low at all stations in October and November, and then rise slightly to between 1 and 2 micrograms/l in December, falling slightly in January and February. Cyanobacteria are always lower than chlorophyll-a and sometimes zero. These are well below WHO guideline threshold levels (50 micrograms/l of chlorophyll-a with a predominance of cyanobacteria = moderate probability of adverse health effects).

When the changes in the water quality parameters are compared at different stations downstream for each month (*Figure 3.5*, *Figure 3.6*, *Figure 3.7*, *Figure 3.8*, *Figure 3.9*), temperature and conductivity remain fairly constant with passage through the impoundment (WQ7) and downstream. There may be a very small increase in temperature within the impoundment in all months. pH and dissolved oxygen remain more or less constant with passage downstream in all months. Turbidity readings across all sites in the same month are varied with no obvious pattern (decreasing downstream in month 10, level in month 11, level in month 12, rising in the impoundment and falling downstream in month 1 2021 and increasing in the impoundment and downstream in month 2). Chlorophyll-a and cyanobacteria are at similar levels with passage downstream, reflecting the seasonal changes.

TSS results are variable – in month 10, there is very little difference above and below the dam, at high levels (<200 mg/l), but there is a significant drop between WQ6 and WQ9 in month 11 (from 32 to 4 mg/l). In month 12, the TSS levels are both low, but WQ6 is slightly higher than WQ9. The changes in turbidity at the same sample times do not reflect the changes in TSS.

Nutrient levels are generally high at this pilot site, especially of total phosphate in December. When the upstream levels are compared to the impoundment and downstream, there is little difference in oxides of nitrogen concentrations passing downstream in October, November and December. Similarly, there is little difference between the readings for total nitrogen at WQ6 and WQ9, although the levels are high (above the mean values for the Mekong, as shown in Table 3.4).

In October, total phosphate levels are very low and do not change between the sampling stations, and in November, there is a slight increase downstream (from 0.07 mg/l and 0.02 mg/l above and in the impoundment, increasing to 0.25 and 0.6 mg/l in the two downstream sites). In December, the upstream station shows 0.04 mg/l increasing to 4.6 mg/l in the impoundment, decreasing to 0.02 mg/l at WQ8 and increasing markedly to 8.2 mg/l at WQ9. These results are confusing and will need to be reconfirmed and compared with the routine WQMN sites at Pakse and ST during the same period.

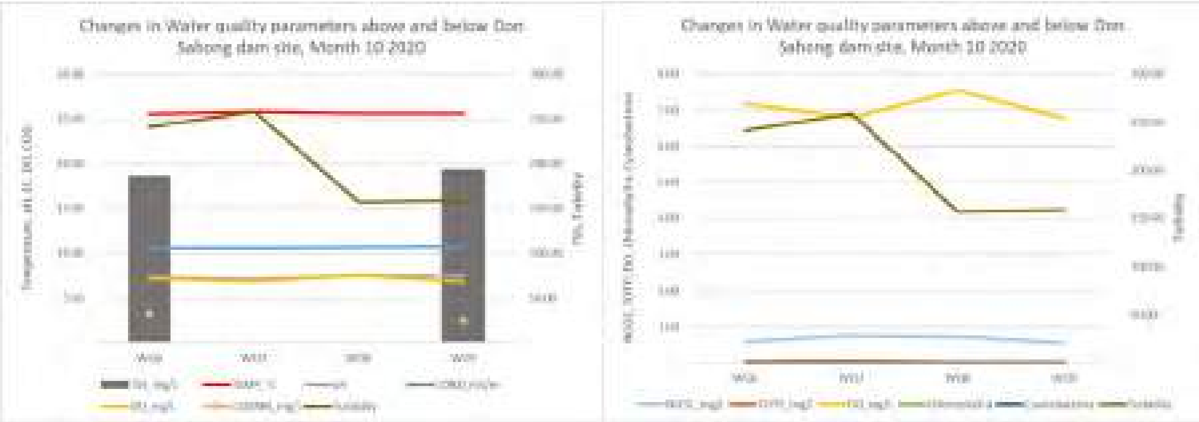

Figure 3.5. Water quality results for Don Sahong pilot sites for Month 10, 2020

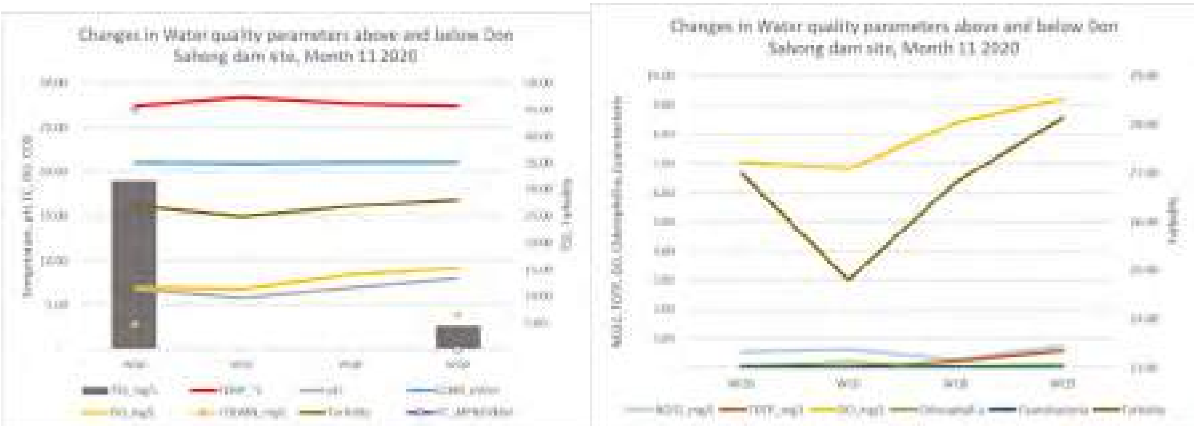

Figure 3.6. Water quality results for Don Sahong pilot sites for Month 11, 2020

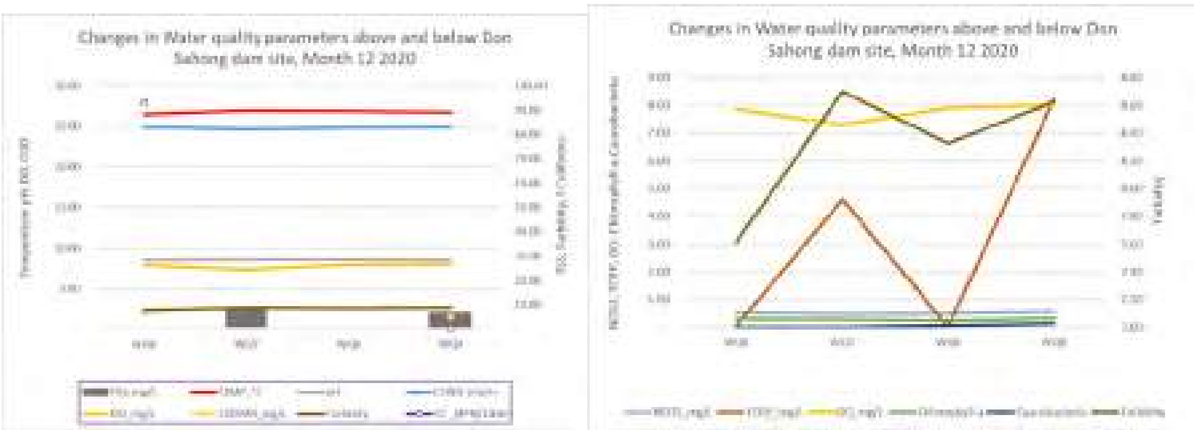

Figure 3.7. Water quality results for Don Sahong pilot sites for Month 12, 2020

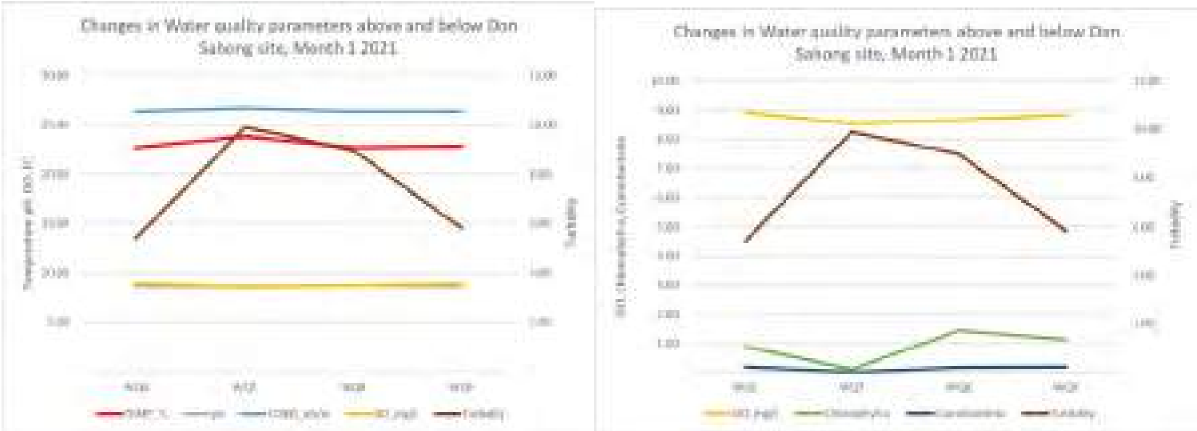

Figure 3.8. Water quality results for Don Sahong pilot sites for Month 1, 2021

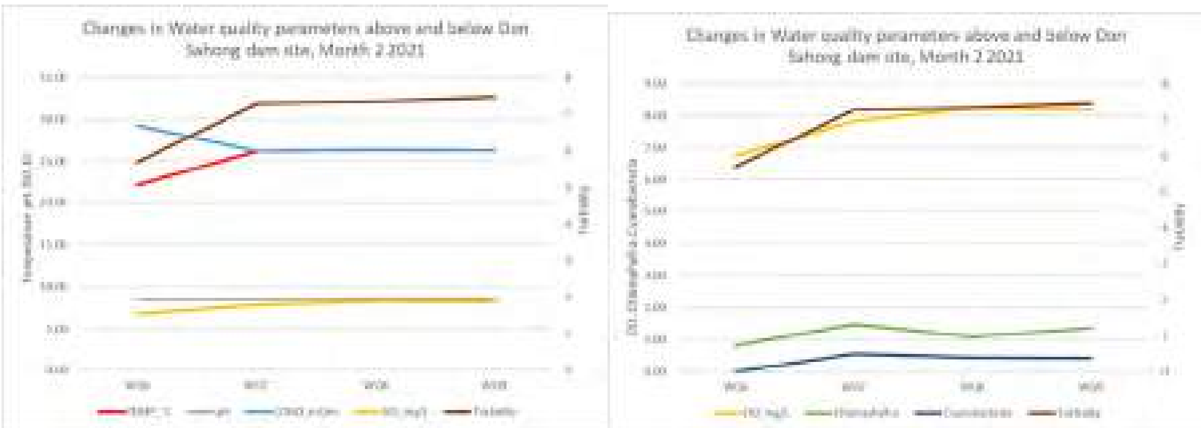

Figure 3.9. Water quality results for Don Sahong pilot sites for Month 2, 2021

3.3.2. Water quality indices

3.3.2.1. Water Quality Index for the Protection of Aquatic Health

The water quality index and classes for the protection of aquatic health and for human health have been calculated for each of the sites and sampling months by comparing the results for pH, Conductivity, oxides of nitrogen, ammonia, total phosphate and dissolved oxygen to thresholds (see Table 3.4). If the results lie within these thresholds, they are awarded 1 point, as shown in Table 3.7, and then the index calculated as a ratio of the parameters lying within the thresholds.

The Water Quality Guideline for the Protection of Aquatic Health (WQGA) Index and classes for each of the sites shows that generally the Pakse WQMN site is of (A) High Quality, except for February when the thresholds are exceeded for total phosphate and the class is downgraded to (B) Good Quality. In comparison, the inlet to the Don Sahong impoundment WQ6 is of (B) Good Quality, because the threshold values for oxides of nitrogen are exceeded. Within the impoundment at WQ7, the class is (B) Good Quality, because oxides of nitrogen are exceeded in October and November, and total phosphate exceeded in December.

In the two downstream sites, WQ8 show similar patterns of WQGA index and class (B) Good Quality, driven by exceedances in oxides of nitrogen in October and December, and by exceedance in total phosphate in November. However, WQ9 is classed as (B) Good Quality in October and (C) Moderate quality in November and December, because of the high oxides of nitrogen and total phosphate levels.

The monthly averages at ST WQMN site show (B) Good Quality in October and November due to total phosphate exceedance, upgrading to (A) High Quality in December and January, and downgrading to (B) Good Quality due to a threshold exceedance in ammonia.

Note that for all sites in months 1 and 2, 2021, there are results for only three parameters, so the WQGA class has not been estimated, and these indices will have to be recalculated when the lab analysis has been completed.

Table 3.7. Estimates of the water quality index for the protection of aquatic health

StationID	station name	Year	Month	ph	Cond	NO	NH	Tot P	DO	WQ Index	WQ Class
				meeting target guidelines							
	Pakse MQMN	2013 - 2018	10	1	1	1	1	1	1	10.00	A
	Monthly averages		11	1	1	1	1	1	1	10.00	A
			12	1	1	1	1	1	1	10.00	A
			1	1	1	1	1	1	1	10.00	A
			2	1	1	1	1	0	1	8.33	B
WQ6	Inlet point of Donsahong Impoundment	2020	10	1	1	0	1	1	1	8.33	B
WQ6	Inlet point of Donsahong Impoundment	2020	11	1	1	0	1	1	1	8.33	B
WQ6	Inlet point of Donsahong Impoundment	2020	12	1	1	0	1	1	1	8.33	B
WQ6	Inlet point of Donsahong Impoundment	2021	1	1	1				1	10.00	
WQ6	Inlet point of Donsahong Impoundment	2021	2	1	1				1	10.00	
WQ7	Impoundment area of Donsahong Dam	2020	10	1	1	0	1	1	1	8.33	B
WQ7	Impoundment area of Donsahong Dam	2020	11	1	1	0	1	1	1	8.33	B
WQ7	Impoundment area of Donsahong Dam	2020	12	1	1	1	1	0	1	8.33	B
WQ7	Impoundment area of Donsahong Dam	2021	1	1	1				1	10.00	
WQ7	Impoundment area of Donsahong Dam	2021	2	1	1				1	10.00	
WQ8	Downstream #1 of Donsahong Dam	2020	10	1	1	0	1	1	1	8.33	B
WQ8	Downstream #1 of Donsahong Dam	2020	11	1	1	1	1	0	1	8.33	B
WQ8	Downstream #1 of Donsahong Dam	2020	12	1	1	0	1	1	1	8.33	B
WQ8	Downstream #1 of Donsahong Dam	2021	1	1	1				1	10.00	
WQ8	Downstream #1 of Donsahong Dam	2021	2	1	1				1	10.00	
WQ9	Downstream #2 of Donsahong Dam	2020	10	1	1	0	1	1	1	8.33	B
WQ9	Downstream #2 of Donsahong Dam	2020	11	1	1	0	1	0	1	6.67	C
WQ9	Downstream #2 of Donsahong Dam	2020	12	1	1	0	1	0	1	6.67	C
WQ9	Downstream #2 of Donsahong Dam	2021	1	1	1				1	10.00	
WQ9	Downstream #2 of Donsahong Dam	2021	2	1	1				1	10.00	
	Stung Treng MQMN	2013 - 2018	10	1	1	1	1	0	1	8.33	B
	Monthly averages		11	1	1	1	1	0	1	8.33	B
			12	1	1	1	1	1	1	10.00	A
			1	1	1	1	1	1	1	10.00	A
			2	1	1	1	0	1	1	8.33	B

3.3.2.2. Water quality index for the protection of human health

The water quality index and classes for the protection of human health have been calculated for each of the sites and sampling months by comparing the results for pH, conductivity, oxides of nitrogen, ammonia, COD and dissolved oxygen to thresholds (see Table 3.4). If the results lie within these thresholds, they are awarded 1 point, as shown in Table 3.8, and then the index calculated as a ratio of the parameters failing the guidelines by exceeding the thresholds. The results show that in none of the sites and months do the results exceed the thresholds, and that the Water Quality Index for the protection of Human Health WQGH class is (A) Excellent Quality, which is compared with the average monthly results at Pakse WQMN and ST WQMN. Note that although many of the parameters used are the same as WQGA, the thresholds used in the WQGH are higher and thus easier to comply with.

Table 3.8. Estimates of the Water Quality Index for the protection of human health

StationID	station name	Year	Month	ph	Cond	NO	NH	COD	DO	WQGH Index	WQGH class
				meeting target guidelines							
	Pakse WQMN	2013 - 2018	10	1	1	1	1	1	1	100.00	A
	averaged monthly results		11	1	1	1	1	1	1	100.00	A
			12	1	1	1	1	1	1	100.00	A
			1	1	1	1	1	1	1	100.00	A
			2	1	1	1	1	1	1	100.00	A
WQ6	Inlet point of Donsahong Impoundment	2020	10	1	1	1	1	1	1	100.00	A
WQ6	Inlet point of Donsahong Impoundment	2020	11	1	1	1	1	1	1	100.00	A
WQ6	Inlet point of Donsahong Impoundment	2020	12	1	1	1	1	1	1	100.00	A
WQ6	Inlet point of Donsahong Impoundment	2021	1	1	1				1	100.00	
WQ6	Inlet point of Donsahong Impoundment	2021	2	1	1				1	100.00	
WQ7	Impoundment area of Donsahong Dam	2020	10	1	1	1		1	1	100.00	A
WQ7	Impoundment area of Donsahong Dam	2020	11	1	1	1		1	1	100.00	A
WQ7	Impoundment area of Donsahong Dam	2020	12	1	1	1		1	1	100.00	A
WQ7	Impoundment area of Donsahong Dam	2021	1	1	1				1	100.00	
WQ7	Impoundment area of Donsahong Dam	2021	2	1	1				1	100.00	
WQ8	Downstream #1 of Donsahong Dam	2020	10	1	1	1		1	1	100.00	A
WQ8	Downstream #1 of Donsahong Dam	2020	11	1	1	1		1	1	100.00	A
WQ8	Downstream #1 of Donsahong Dam	2020	12	1	1	1		1	1	100.00	A
WQ8	Downstream #1 of Donsahong Dam	2021	1	1	1				1	100.00	
WQ8	Downstream #1 of Donsahong Dam	2021	2	1	1				1	100.00	
WQ9	Downstream #2 of Donsahong Dam	2020	10	1	1	1	1	1	1	100.00	A
WQ9	Downstream #2 of Donsahong Dam	2020	11	1	1	1	1	1	1	100.00	A
WQ9	Downstream #2 of Donsahong Dam	2020	12	1	1	1	1	1	1	100.00	A
WQ9	Downstream #2 of Donsahong Dam	2021	1	1	1				1	100.00	
WQ9	Downstream #2 of Donsahong Dam	2021	2	1	1				1	100.00	
	Stung Treng WQMN	2013 - 2018	10	1	1	1	1	1	1	100.00	A
	averaged monthly results		11	1	1	1	1	1	1	100.00	A
			12	1	1	1	1	1	1	100.00	A
			1	1	1	1	1	1	1	100.00	A
			2	1	1	1	1	1	1	100.00	A

3.3.3. Impoundment profiles

The impoundment depth profiles at different months are shown in Figure 3.10. Probes measure temperature, pH, conductivity, dissolved oxygen and turbidity at 1-m intervals down to 20 m below the surface, and the AlgaeTorch measures chlorophyll-a and cyanobacteria down to 10 m below the surface. The overall impression from the results is that there is very little change in any of the parameters with depth in any of the months, indicating that the impoundment is well mixed down to 20 m. There is an indication that dissolved oxygen is beginning to decrease, with depth after about 12 m in January. Turbidity in November shows increasing FTU with depth, especially after 13 m.

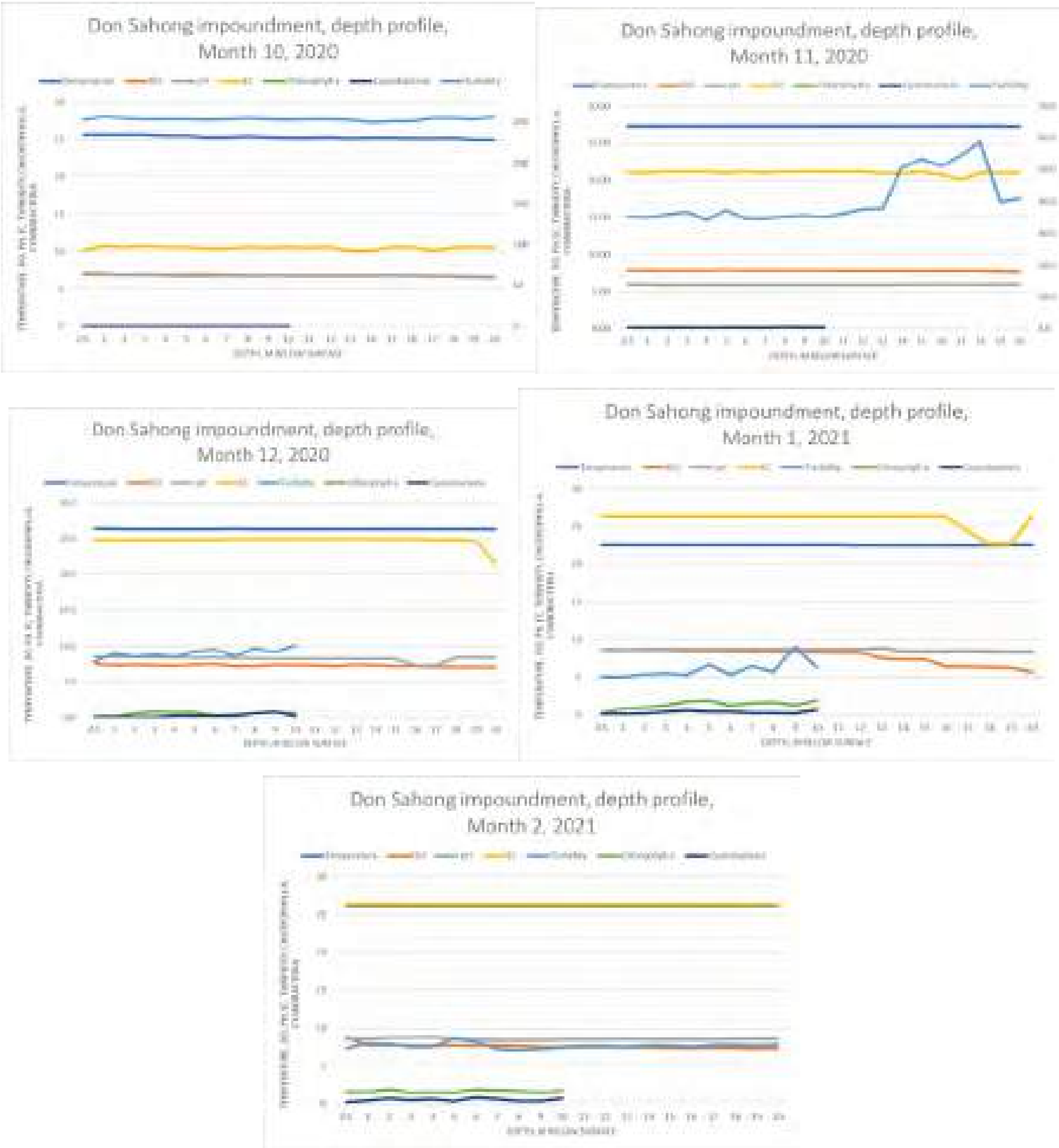

Figure 3.10. Depth profiles in the Don Sahong impoundment for months 10, 11, 12 (2020), and 1 and 2 (2021)

3.4. Lessons learned

3.4.1. Water quality sampling and analysis

The main lessons to be learned from the experience of carrying out these monthly sampling missions are as follows:

- The AlgaeTorch worked well, but since the training on the spectrophotometric analysis of chlorophyll-a has not yet been provided due to COVID-19 restrictions, it has not been possible to make a comparison of the two methods.
- Difficulties were experienced in obtaining reliable readings from the AlgaeTorch in running water. A sampling modification was suggested to take a bucketful of the flowing water and to place the probe into the water in the bucket, taking care to use the probe protector to achieve the correct distance from the bottom of the bucket.
- It was found to be useful to record field observations of flow and water level, water colour, opacity and smell, so that any unusual findings from the analysis could be related to these observations. This has been added to the field data report.
- Similarly, the field data report should contain the names of the team carrying out the sampling, so that unusual records could be cross-checked with these team members.
- Because of anomalies in turbidity and TSS readings, it is suggested that TSS should be measured in the laboratory at all sites so that an understanding of the correlation between the two parameters can be developed.
- The very high phosphate values recorded in December 2020 are of concern and need:
  (i) confirmation from routine WQMN results from the same period and future JEM monitoring, and (ii) QA/QC confirmation of the analyses for December.
- No difficulties were experienced in entering the water quality data into the JEM database.

3.4.2. Interpretation of the water quality results

- Overall, the results indicate that for many parameters there is little difference in the results between sampling stations with passage downstream in the same month. Water quality parameters such as dissolved oxygen, pH, COD and faecal coliforms show little change between upstream within the impoundment and downstream sites.
- Monthly differences followed the normal seasonal patterns in parameters such as temperature and conductivity.
- Turbidity readings do not show obvious patterns with passage downstream in different months.
- TSS results show variable patterns from similar levels in TSS passing through the impoundment and downstream (October 2020), to a marked decrease downstream compared to water flowing into the impoundment (November and December 2020). There is a recognized correlation between turbidity and TSS (Rügner et al., 2013), but these TSS results do not follow the decreasing turbidity measurements with passage through the impoundment. This needs to be investigated further, possibly by taking TSS measures in other stations and by linking with the flows and dam operations at the time of sampling.
- The raised values of nitrate/nitrite and total nitrogen in the three final months of 2020 and the very high values of total phosphate in December are of great concern and need confirmation described above, especially if they are confirmed as trends.
- Chlorophyll-a and cyanobacteria are low with little change between the different sites above and below the impoundment, indicating no trends towards eutrophication and well below the WHO thresholds for human health hazard. Depth profiles indicate that the water within the Don Sahong impoundment appear to be well mixed do not show any stratification.

4. Ecological Health Monitoring

4.1. Adjustments and evolutions

The first annual bioassessment monitoring was planned for April 2020, but this had to be cancelled because of the COVID-19 restrictions on travel within Lao PDR. It was not possible to carry out the 2020 field mission later in the year because monitoring has to be carried out when river levels are low, and the indicator groups will not have been dispersed by rising water levels and flash flows at the beginning of the wet season. The campaign for 2021, originally planned for April 2021, will be brought forward to earlier in the year to allow for the identification and reporting process to be conducted in a timely manner. However, this means that there are no results for the 2020 campaign to present in this report.

Because the 2020 campaign was cancelled, the sampling sites were not assessed for their suitability, and there is no change in the sampling sites selected that include one site above the impoundment (EHM7) in the same location as the water quality monitoring station (WQ6), one site within the impoundment (EHM8), and two sites below the dam. These are listed in Table 4.1 and illustrated in Figure 4.1.

Table 4.1. Confirmed EHM sampling sites around Don Sahong

Site no.	Name of site	River	Latitude N	Longitude E
Don Sahong				
EHM 7	Don Sahong upstream at inlet of impoundment	Mekong	13°58'42.6"N	105°57'07.4"E
EHM 8	Don Sahong impoundment	Mekong	13°56'40.1"N	105°57'43.6"E
EHM 9	Downstream Don Sahong at round 2 km	Mekong	13°56'33.0"N	105°57'15.2"E
EHM 10	Downstream Don Sahong at around 4 km	Mekong	~13°56'19.1" N	105°57'19.9"E

The focus for the EHM work reported here has been on the consolidation and refinement of the species lists of each of the four parameters – benthic diatoms, zooplankton, littoral and benthic macroinvertebrates, and the review of the historic data from the mainstream biennial bioassessment monitoring. This work was necessary for entry into the database and has involved the compilation of composite species lists from all four countries and the cleaning of the historic data.

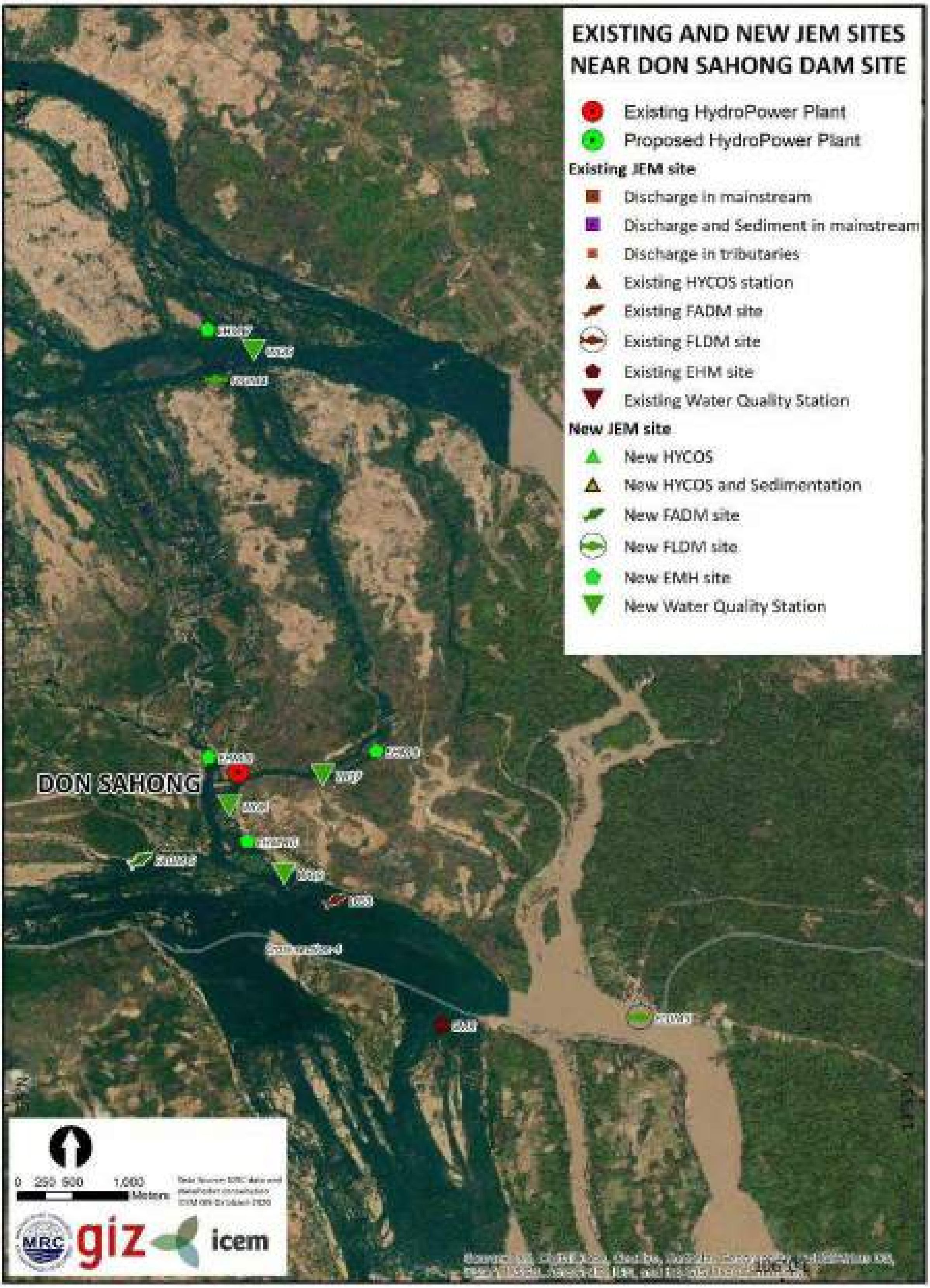

Figure 4.1. Bioassessment monitoring sites around Don Sahong HPP

4.2. Activities

4.2.1. Ecological Health Monitoring training

In July 2020, an on-line training course was provided across three half-days for the ecological health monitoring teams in each of four Mekong countries (Cambodia, Lao PDR, Thailand and Viet Nam). Technical staff from the Mekong River Commission Secretariat (MRCS), and from the Don Sahong HPP also participated.

Initially the training had been planned to be conducted in Vientiane in March 2020, but due to travel restrictions associated with the COVID-19 pandemic, face-to-face training was not possible. In place of the planned training, the basic training was conducted in an online format, with participants located in the MRC offices in Vientiane and the offices of the National Mekong Committees in the other countries.

Training modules included: (i) The Rationale for JEM Ecological Health Monitoring: Looking for impacts of hydropower; (ii) New Aspects of Ecological Health Monitoring introduced for JEM; (iii) Preparation for JEM Ecological Health Field Sampling; and (iv) Ecological Health Monitoring Data Entry and management.

4.2.2. Preparation and analysis of historic EHM results

The review of the historic biennial EHM results for the sampling sites on the Mekong mainstream has been an extremely useful exercise to develop the database structure and refine the reporting formats. This process has involved:

- consolidating all of the species lists developed by all four countries since 2011, eliminating duplicates, and correcting spelling mistakes and taxonomic errors to provide a unified species list for each of the four parameters. There are now listed 360 species of zooplankton, 435 species of benthic diatoms, 1,009 species of littoral macroinvertebrates, and 751 species of benthic macroinvertebrates recorded from the Lower Mekong Basin (LMB);
- researching and providing taxonomic details (phylum, class, order and family) for all species, which will ease identification and appropriate classification of species found in the future. It will also enable the database to be used to highlight more detailed changes in species at the monitoring sites, for example an increase in the numbers of molluscs and a decrease in flowing water species in impoundment sites;
- conducting the analyses of abundance, species richness and Average Tolerance Score Per Taxon (ATSPT) for each of the historic biennial EHM records on mainstream sites, and calculating the Ecological Health Index (EHI) for each site and year;
- designing the structure and data entry forms for the database.

4.3. Preliminary results and initial analysis

The historic biennial EHI scores from 2011 to 2019 for the LDN (Done Ngew, Champassak) and CKT (ST Ramsar site) sites were calculated as shown in Table 4.2. These are the two sites on each side of the Don Sahong dam. The LDN site lies over 100 km upstream of EHM6, and CKT lies about 50 km downstream.

The results of the historic EHI show that there has been a variability in the EHI at LDN from Class A in 2011 to Class C in 2013 and 2015, with improvement to Class B between 2015 and 2019. At ST, the EHI condition is more consistently good, with Class B in 2013, Class A in 2015, and Class B in 2017 and 2019 (no bioassessment sampling was done in 2011). The EHI reflects the changing patterns of flow and water quality throughout the year. As the closest upstream site, these changes would be reflected in the EHI at Done Ngew (LDN), but any downstream developments and conditions in the multiple channels at Khone Phapheng Falls may affect the biota and EHI at the Don Sahong sites. With the dam in place, the EHI in the impoundment is likely to change due to the changed flow and water level conditions, and in the downstream, the EHI is likely to deteriorate due to the daily fluctuations in flow rate and water level.

Table 4.2. Historic Ecological Health Index calculations for Luang Prabang and Vientiane sites (above and below Xayaburi)

Site					LDN						CKT				
Year					2011	2013	2015	2017	2019		2011	2013	2015	2017	2019
Site Disturbance Score SDS					1.66	1.74	1.96	1.66	1.81		1.00	1.46	1.74	1.71	1.71
Average Abundance															
	Benthic diatoms				223.90	32.10	15.60	59.10	914.10		N/D	135.50	232.10	272.60	34.00
	Zooplankton				436.00	42.00	686.00	560.00	457.00		N/D	69.33	19.78	65.00	30.44
	Littoral macroinvertebrates				401.60	32.10	54.80	46.40	65.80		N/D	26.40	58.80	497.40	1,418.90
	Benthic macroinvertebrates				18.83	8.78	13.33	13.83	30.42		N/D	8.67	13.00	15.17	10.00
Richness	Benthic diatoms				20.60	3.10	6.50	14.10	29.10		N/D	21.20	21.20	16.40	9.70
	Zooplankton				29.00	9.33	53.33	52.67	40.00		N/D	8.00	11.00	15.22	8.33
	Littoral macroinvertebrates				12.50	3.40	10.90	6.50	9.90		N/D	5.30	10.40	16.70	82.40
	Benthic macroinvertebrates				4.25	2.44	4.25	5.25	5.50		N/D	2.08	2.33	4.33	1.33
ATPST	Benthic diatoms				34.34	41.30	38.26	42.46	42.80		29.00	32.96	36.97	40.74	38.00
	Zooplankton				37.89	41.52	43.74	42.23	46.38		43.00	35.17	37.93	38.23	39.00
	Littoral macroinvertebrates				39.47	37.71	43.01	41.78	48.19		30.00	30.08	35.85	34.69	34.00
	Benthic macroinvertebrates				34.65	35.62	44.12	44.25	49.61		23.00	13.16	27.31	38.30	36.00
Ecosystem Health index Calculations		Percentile		Threshold											
		10th	90th	Guideline											
Abundance	Benthic diatoms	136.22	376.34	>136.22	1	FALSE	FALSE	FALSE	1			FALSE	1	1	FALSE
	Zooplankton	22.33	174.07	>22.33	1	1	1	1	1			1	FALSE	1	1
	Littoral macroinvertebrates	46.68	328.56	>46.48	1	FALSE	1	FALSE	1			FALSE	1	1	1
	Benthic macroinvertebrates	5.37	56.34	>5.37	1	1	1	1	1			1	1	1	1
Richness	Benthic diatoms	6.54	11.78	>6.54	1	FALSE	FALSE	1	1			1	1	1	1
	Zooplankton	9.8	20.2	>9.8	1	FALSE	1	1	1			FALSE	1	1	FALSE
	Littoral macroinvertebrates	5.37	18.48	>5.37	1	FALSE	1	1	1			FALSE	1	1	1
	Benthic macroinvertebrates	1.87	7.88	>1.87	1	1	1	1	1			1	1	1	FALSE
ATPST	Benthic diatoms	30.85	38.38	<38.38	1	FALSE	1	FALSE	FALSE			1	1	FALSE	1
	Zooplankton	34.83	41.8	<41.8	1	1	FALSE	FALSE	FALSE			1	1	1	1
	Littoral macroinvertebrates	27.8	33.58	<33.58	FALSE	FALSE	FALSE	FALSE	FALSE			1	FALSE	FALSE	FALSE
	Benthic macroinvertebrates	31.57	37.74	<37.74	1	1	FALSE	FALSE	FALSE			1	1	FALSE	1
	Total number of parameters meeting threshold				11	5	7	6	8			8	10	9	8
	Classification	Score			A	C	B	C	B		N/D	B	A	B	B
	A	>10													
	B	>7													
	C	>4													
	D	<4													

Note: "False" in this table means that the parameter did not meet the threshold guidance.

4.4. Lessons learned

4.4.1. Capacity strengthening in species-consistent species identification

The review of the historic bioassessment data has highlighted the differences between the species recorded by the teams of the four countries, with the implication that the findings of each country monitoring are not exactly comparable. While this may reflect the changing conditions and species mix in different parts of the Basin, it also reflects the variable capacity of the teams for consistent and accurate identification of the species. This may not be significant when the composite EHI is calculated for each site, but it will be important for analysing the changes in species mix due to impoundments and downstream flow sites.

There is a need to strengthen the capacity of the bioassessment teams in all countries in the consistent identification of the species in the unified composite lists and in completion of the reporting forms.

The capacity of teams in the identification of species is strongly dependent on the experience of the specialists, and attention should be paid to developing the capacity of younger team members to complement and eventually replace the older team members as they retire.

4.4.2. Simplified EHI assessments

The analysis of the historic data also illustrates the complexity of the EHI process, and the time and effort it requires. The JEM pilot site assessments would be an opportunity for trialling a simplified rapid EHI assessment based on littoral macroinvertebrates and comparing the EHIs for both historic and JEM pilot sites. If the EHIs are consistently similar for littoral macroinvertebrates as for the full EHI with the four parameters, then it may be possible to conduct the simplified bioassessments each year rather than every two years, and on more sites. This comparison will be trialled on the historic data.

5. Fisheries

The overall objective of fisheries monitoring in the JEM Programme is to measure indicators contributing to the interpretation of the status and trends of local, regional and basin-wide capture fisheries. The monitoring also aims at providing an effective means of monitoring and assessing the effects of water management and basin development activities, specifically hydropower development.

Specific objectives are focused on: biodiversity assessment and fish stock assessments; fish catch monitoring; ecological knowledge and the species-habitat relationship; the socio-economics of the fisheries sector; and a dam impact assessment, with specific studies at Xayaburi site.

Four protocols are considered to cover these aspects, in particular the first two under the Fish Abundance and Diversity Monitoring (FADM) Programme:

1) FADM monitoring of artisanal catch
2) FADM standardized gillnet surveys
3) Fish Larvae Drift Monitoring (FLDM) Programme
4) Development of a fish tagging programme at Don Sahong site.

As detailed in the project Inception Report, activities have focused on:

- under FADM
    - adjustments to the current fish abundance and diversity (FADM) protocol;
    - the definition of a standardized scientific monitoring based on multiple panel gillnets in the same sites.
- under FLDM
    - adjustments to the existing protocols in sites selected.
- under fish tagging
    - development of a simple methodology for fish migration study around dams;
    - feasibility of a fish passage monitoring programme using different types of tags and tagging techniques at Don Sahong site.

In agreement with parties consulted, the other sampling protocols mentioned in the draft JEM Programme (seine net sampling, electrofishing, sampling of various habitats) have not been covered. In the absence of results from Xayaburi, this section also describes the FADM and FLDM activities and preliminary results around Don Sahong to illustrate how the monitoring methods may be adapted for JEM at Xayaburi.

5.1. Adjustments and evolutions

Lessons learned during the December 2019 – March 2020 early field phase, and during implementation later on are presented in sections below while underlining the substantial disruptions resulting from the COVID-19 pandemic and subsequent restrictions to field work (national teams), in-country travel and field visits (international team) and joint activities.

5.1.1. Fish Abundance and Diversity Monitoring

5.1.1.1. Monitoring of fishers

Data are gathered by fishers (three fishers in each site). Each fisher records his/her catch daily. The procedure based on logbooks should follow instructions in standard sampling guidelines for FADM section 6.2 and JEM documents v.3 Annex 19. Data sheets are compiled weekly by a key fisher at each site, and are collected quarterly by national agency staff, then cleaned and entered in the database by IFReDI and LARReC staff.

This protocol, long established in some countries, does not pose any major problem, except for the slow processing of data in Lao PDR due to error checking and cleaning.

The main point raised by Lao teams is the need of updated photo flipcharts that better include small and new species.

5.1.1.2. Gillnet sampling

Following discussions at the end of training sessions on FADM in Luang Prabang in February (see Fisheries Annex 1) a decision was made to modify the gillnet monitoring protocol proposed in the draft JEM guidelines. Arguments for modifications and reasons underpinning final choices are detailed in Fisheries Annexes 1, 2 and 3.[1] and summarized below.

Gillnet monitoring is carried out using graded fleet of panels of various mesh sizes. A fleet of nets should be made of 14 panels. Each panel is 8-m long and 2.5-m high (stretched mesh dimension; total length: 112 m).

The necessary reliance on netting available in markets in the region imposes the use of mesh sizes following an arithmetic series (stretched mesh of 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150 mm).

In line with international standards, a randomization process on the range of 14 JEM mesh sizes produced the following series, now fixed and constant for all fleets of the JEM gillnet monitoring protocol.

110 mm
120 mm
80 mm
150 mm
70 mm
100 mm
40 mm
130 mm
20 mm
90 mm
140 mm
60 mm

[1] Fisheries Annex 1: Report on three fisheries training events and initial revision of protocols in fisheries. 20 May 2020, 125 pp.; Fisheries Annex 2: JEM Pilots technical note. Mounting of gillnets for the JEM monitoring of fishery resources 2 March 2020, 10 pp.; Fisheries Annex 3: Revised JEM methodology for fish sampling with standardized multiple panel gillnets. 28 May 2020, 5 pp.

30 mm

50 mm.

The measure used (also used by Mekong fishers) is 'stretched mesh'. Gillnets are made of nylon monofilament. There is no requirement about filament diameter (we use netting from the market in which the filament diameter is usually proportional to mesh size). The mounting ratio should be 50% (i.e. 16 m of net on 8 m of rope).

<u>Net setting</u>

Multiple panel gillnets should be set **once a week in each monitoring site, each week of the year.** In each monitoring site, **each fleet of nets should be identified by a letter (A, B, C)**. **Each panel in a fleet should have a float indicating its fleet letter and mesh size** (e.g. A20 for "fleet A mesh size 20 mm", B80 for "fleet B mesh size 80 mm", etc.). This panel ID allows a quick identification of fleets and mesh sizes for data entry.

Figure 5.1. Mounting and identification of gillnet panels

Fishers should decide in each site and season on the best place to set the nets. The nets can be set along the bank or across the flow, along rocks or between islands; it is up to fishers to decide in each location, depending on hydrological conditions, season, habitats or migrations. Fishers should not try to catch specific high value species, but only to maximize each time the abundance and diversity of fishes. **The objective of sampling should be to maximize the abundance and diversity of the catch.**

Multiple panel gillnets should be set **once a week in each monitoring site, each week of the year.** Nets should be **set in the evening (16:00–18:00) and retrieved the following morning (06:00–08:00)**.

Even when the catch is abundant, no subsampling is done. The reporting is done by panel, and then by species. Catches should be recorded using the amended forms provided. Changes include the following:

1) **Panel ID** is recorded (i.e. fleet letter and mesh size of the panel).

2) For each species, the **fish code** and/or **local fish species name** are entered.

3) the **total number of fishes for that species in that panel** is noted.

4) the **total weight of all the fishes of that species in that panel** is noted:

Weights should be expressed <u>in grams</u> (not kg). For weighting, a suspension scale is recommended (no electronic scale because of batteries and water issues).

5) the **length of the largest individual fish of that species in that panel** is noted:

The length measured should be the standard length (fork length).

A net hanging in water is looser than when it is stretched. When in water, a net with a 2.5 m stretched height and a 0.5 mounting ratio actually measures $2.5 \times \sqrt{(1 - 0.25)} = 2.5 \times 0.866 = 2.17$ m. In JEM and

FADM, calculation of catch per unit effort (CPUE) should consider that the nets in operation in water are 2.17-m high, not 2.5-m high.

The national teams thought that the amount of net fishing (20 m^2 per mesh size, 280 m^2 per net) may have been insufficient to reflect fish abundance and diversity in study sites, as fishers in Cambodia and Lao PDR commonly use several hundred metres of gillnets, sometimes as much as 1,000 m, to catch 'enough fish' for their livelihood. It was also argued that regardless of the total length used, more fish is caught when units of nets are smaller and can adapt to local river configurations (e.g. across a curve in the bank, along a crest of rocks or across a channel). Fears were also expressed in Luang Prabang that long stretches of continuous net (i.e. 100- or 150-m long) might become subject to water current and could be carried away and lost.

For these reasons, a testing protocol was proposed, which is detailed in Annex 4[2].

This testing, slightly modified due to local constraints, was implemented in Cambodia and Lao PDR, with a focus on different total lengths of net:

Figure 5.2. Dimensions of gillnet sets tested

Results, analysed by IFReDI scientists, show that:

1) the net type with the highest total catch is the short net (20 kg in these nets), and the one with the lower catch is the longest net (15 kg)

Figure 5.3. Catch (kg) by net type in the gillnet testing survey

[2] Annex 4: Testing of multiple panel gillnets lengths for fish sampling, 29 May 2020

2) the net type with the highest number of species is the short net (35 species), and the one with the lowest number of species caught is the longest net (28 species);

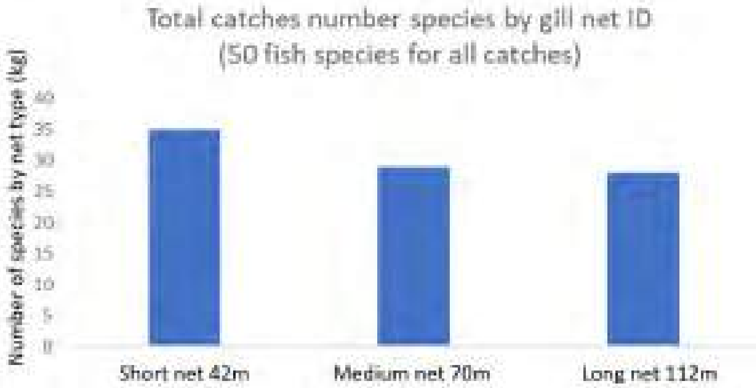

Figure 5.4. Species richness by net type in the gillnet testing survey

3) the mesh with the highest catch is the 40 mm mesh; larger mesh sizes have a decreasing catch, and there is no catch in mesh sizes above 90 mm;

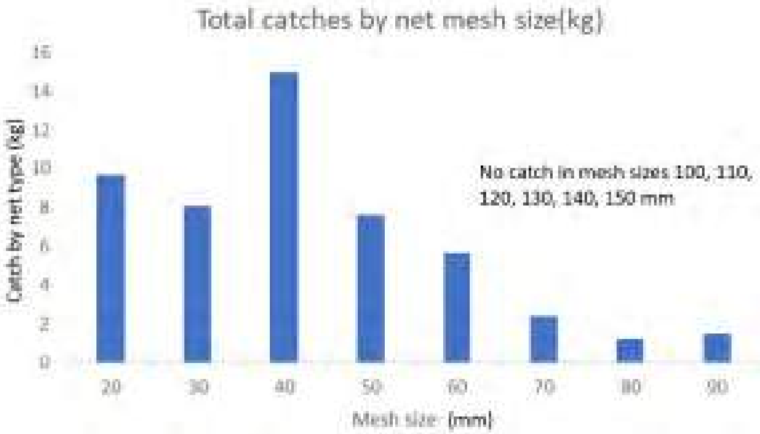

Figure 5.5. Catch (kg) by mesh size in the gillnet testing survey

4) mesh sizes catching the highest number of species are the 30 mm and 40 mm (22 and 21 species, respectively); larger mesh sizes have a decreasing catch, and no species is caught in mesh sizes above 90 mm.

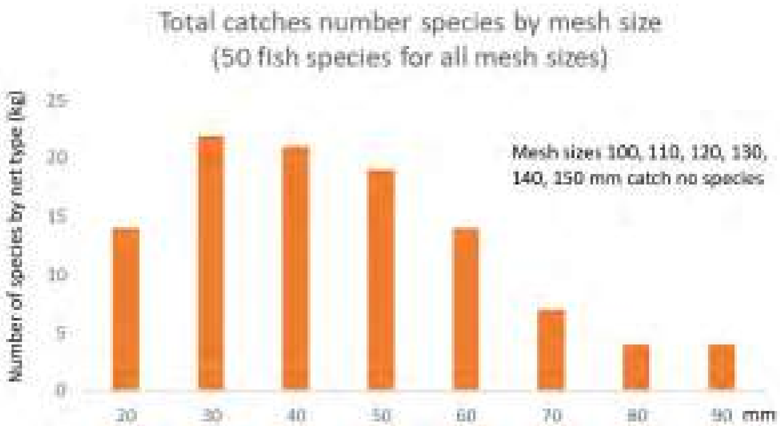

Figure 5.6. Species richness by net type in the gillnet testing survey

Scientists having tested the nets (both Lao and Cambodian teams in their February 2021 progress report) conclude that:

- the longest net length (120 m) is difficult to set up; this long length is not suitable for areas with vegetation, nor in strong water currents; few places are suitable for such length of nets.
- The need to find longer nets places with limited or no vegetation (e.g. beaches) induces a bias towards places with few fish, as abundance and diversity are found in vegetated areas. This is likely the explanation for the lower catches and lower species diversity in long nets despite their larger surface area.
- Seven months of trial show that the catch is limited to mesh sizes between 20 mm and 90 mm; larger mesh sizes remained empty. This might be explained by the fact that all gillnets were set near riverbanks to ensure a sufficient catch. Fishers usually set large mesh sizes in the middle of the river to catch large (and rare) fish swimming in deeper water, but these fish are not commonly present by the banks. Fishers who set their large-mesh nets in the middle of the river also use very high nets (5–7-m high; personal communication from IFReDI scientists). Large fish being less common, they require a large netting area, but our standard sets feature a common height (2.5 m) for all mesh sizes.

  This point requires further discussion and decision by the JEM team: If the sampling is focused on obtaining a snapshot of the fish community, then panels of the same dimension should be used for all mesh sizes. However, if the sampling is focused on monitoring in particular large species that are more exposed to threats, then an increased sampling effort should be developed towards these species, with higher nets of large mesh size panels.
- The total number of species sampled with gillnets (50 species) is small compared to the number of species in the FADM protocol collecting data from fishers; this suggests that the current sampling effort is insufficient to accurately represent the composition of the fish community. As a consequence, **it is recommended to** increase the frequency of fishing (more than once per week), or, if the budget does not allow, to use longer panels (10 m per panel or mesh size, i.e. +25%).
- **It is recommend that** nets are split into groups of three nets of close mesh sizes: 20 mm to 60 mm (5 panels) to be set near banks and the vegetation to target small fish in their habitat; 70 mm to 110 mm (5 panels) to be set in suitable locations decided by fishers; and 120 mm to 150 mm panels (4 panels) to be set in the middle of the river to target large fish in their preferred habitat.
- The combination of the two latter options – i.e. (i) 25% longer panels = 25% more fishing effort and (ii) splitting the set of 14 panels, previously 112-m long, into three units of 40–50 m length each to target and fit to different environments – is believed to address current concerns and increase the representativeness of the sampling at no cost.

At this stage, the gillnet testing led to the conclusion, as opposed to assumptions expressed during the February meeting in Luang Prabang, that:

- 112 m length is not an effective size, and gillnet sets are more effective when they are shorter (70 m or 42 m);
- The catch and species richness observed are considered insufficient to accurately represent fish presence and diversity in sites, nor provide enough specimens for biological monitoring of individual species;

- Gillnet sets should be split by groups of mesh size (20 mm to 60 mm; 70 mm to 110 mm; 120 mm to 150 mm) to allow being set in habitats and water conditions that match mesh size with species found in these habitats.

This leads to a revised recommendation for gillnet sets:

- One panel should be 10-m long (instead of 8 m) and 2.5-m high (still the same mesh sizes, i.e. 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140 and 150 mm stretched mesh), a total of 14 panels measuring 10 m x 2.5 m = 350 m^2 per gillnet set.
- Each set of 14 panels should be composed of three distinct units: one unit of 20, 30, 40, 50 and 60 mm mesh size; one unit of 70, 80, 90, 100 and 110 mm mesh size; and one unit of 120, 130, 140 and 150 mm mesh size).
- Fishers should set each unit of a given panel in the most suitable habitat to allow maximizing the catch.

5.1.2. Fish Larvae Drift Monitoring

In Lao PDR and Cambodia, the implementation of the larvae protocol started in July 2020, with data gathered until February 2021, and analysed in Cambodia for the July 2020 – October 2020 period (wet season).

Experienced gathered indicates the following:

- Fishers need more training on how to use bongo nets. In particular bongo nets are fixed by anchors (the anchor is attached to the net, not to the boat) and fishers need to learn more about how to use anchors for the bongo net to be immobile at the point decided for sampling. When anchors are set several times, the flow metre keeps running, creating a wrong measurement.
- Fishers need more training on how to record samples.
    - Flow calculation is not accurate because the metre figure used on time t for calculation is usually a copy of the last figure recorded on time t-1 during the previous sampling, which is not the reality (the flow metre usually keeps spinning while bongo nets are tentatively set with anchors).
    - At least in Cambodia, sampling locations are noted by fishers when the boat returns to the bank, which creates a possible confusion between samples (e.g. left bank pot confused with right bank pot).
- In Cambodia, there is too much current in the rainy season in the sampling point in the middle of the river (difficult to set up the bongo net). In this specific location, the point selected should be moved at a distance, away from the strong current.
- Midnight sampling is a problem in all sites. Data gathered by fishers in the absence of supervision are not credible. For their own activities, fishers normally go to bed late and wake up early; they cannot, in addition, wake up in the middle of the night to sample larvae. Thus, they most likely collect the midnight sample at some other time.

Recommendations

- Firmly set anchors in a fixed place and fix the net to the anchor instead of throwing anchor and bongo nets repeatedly to the water for each sampling session.
- Provide more training to fishers about recoding metre figures and sample bottles:

- Set the night sample at 21:00 instead of midnight. This is justified because larvae are normally active from dusk to early night (18:00 to 22:00) and become mostly immobile after that time. This modification is in line with observations of national larvae specialists and with publications detailing day and night larval activity in the Mekong on a detailed time step (Solyda, 2003; Hortle et al., 2005 and Nguyen et al., 2006). These studies show a lack of significant difference in larvae abundance/density between the different hours of the night. Preferred hours of activity/abundance seem to depend on species, and are not systematically more intense at midnight. When this fact is combined with objections about sampling at midnight (i.e. lack or reliability of "midnight" sampling by fishers), there is no reason **not** to move the night sampling at 21:00.

As a consequence, the timing of samples would evolve from:

- 6:00 – 12:00 – 18:00 – 00:00 (now)

  to

- 6:00 – 12:00 – 18:00 – 21:00.

In addition,

- The Lao team recommends buying a camera compatible with the microscope, so that samples can be identified and measured on photos (under the assumption that this remains possible and accurate).
- The Cambodian team recommend buying three new flow metres as the existing ones are old and do not operate properly.
- Some bugs are to be fixed in the larvae database, in particular automatic filling of cells when a sample is empty (entering "0" or "#NA" automatically creates a species code).

5.1.3. Fish tagging

Initial developments on fish tagging studies (see Inception Report, April 2020) led to the following conclusions:

- Four types of tags can be considered: (i) traditional external tags (spaghetti tags), combined with a recapture programme; (ii) PIT tags, as already studied in Xayaburi by Charles Sturt University; (iii) acoustic tags for large and medium-size fish; and (iv) radio tags for large fish, which are costly.
- The diversity of species and stream sizes to be monitored clearly requires the use of several kinds of tags and receivers. The lack of specification about the tags to be used in the DSHPP pilot TORs prevents starting the fish tagging study immediately.
- The study of fish passage at Khone Falls is extremely complex; the methodology is not operational and requires a substantial design and testing phase before fish passage can be assessed.

The work initially considered in the pilot project TORs and planned at Don Sahong was deeply compromised by the COVID-19-related context and the impossibility for international experts to come and work in Lao PDR as expected. Thus, a report documenting the methodological approach, to be underpinned by a field survey, was expected by October 2020, and training of national partners by

Charles Sturt University was expected around November–December 2020. None of these activities could be achieved due to the impossibility for project scientists to travel to Lao PDR from March 2020 to date.

During this period, three large lines of work were developed:

a) the development of a comprehensive review of fish tagging methodologies available for the Mekong. This review, designed to be readily published by the MRC, was required since no similar review existed in the international literature. This review is unique because, for six broad categories of tags, it covers the principles of operation, models available, insertion in fish, receptors and antennas, electric supply, operation range, software, data analysis, price range, providers and key references. This review, involving nine international specialists in fish tagging or Mekong fish, was designed as a foundational document and a precursor to the concrete recommendations needed by the JEM programme.

b) the development of a close collaboration with Lee Baumgartner's team at Charles Sturt University, as alluded to in the Pilot TORs. The activities of this collaborative initiative now co-funded by the Australian Water Partnership include:

- Activity 1: Scoping and designing a pilot programme; obtaining permits to operate; procurement. Deadline: April 2021.
- Activity 2: Training local counterparts in fish tagging (knowing the tag type and its functioning, antennas, surgical procedures, optimal fish survival; field testing. Deadline: May 2021 (now online).

Assumption of borders reopening in July 2021

- Activity 3: Building an acoustic tag database by a private company. Deadline: Aug. 2021
- Activity 4. Reviewing and analysis of initial results with ICEM and MRCS. Deadline: September 2021
- Activity 5: Testing with ICEM and MRCS fisheries specialists acoustic tagging in a Khone falls channel. Deadline: September 2021
- Activity 6. Discussing PIT tag methodology tested at Xayaburi
- Activity 7. Contributing to development of standard fish passage monitoring protocols to update the draft JEM Programme. October 2021
- Activity 8. Participating in and presenting at MRC regional environmental management expert group meetings by a member of CSU team in 2021
- Activity 9. Participating in a meeting of an advisory panel of experts.

3) the development of a study of local ecological knowledge in Khone Falls, aimed at supplying the information currently missing for the development of a detailed fish passage monitoring protocol at Don Sahong. This study, its principles and its implementation are detailed in separate sections.

5.2. Activities

5.2.1. Fish Abundance and Diversity Monitoring

Data collection has been going on from July 2020 to date in Cambodia, and from August 2020 to the time of writing in Lao PDR.

5.2.2. Fish Larvae Drift Monitoring

Data collection has been ongoing since July 2020 to the time of writing in Cambodia, and from August 2020 to date in Lao PDR.

Sampling started in July 2020, with sampling two days per week in the wet season (May to September). During this season, four samples are collected each day (6:00, 12:00, 18:00 and 24:00).

In the dry season (October to April), larvae are collected one day per week, with four samples each day as above.

Figure 5.7. Fish larvae sampling activities with partner fishers

After each sampling operation, fish larvae bottles are removed from the cod-end of the net and immediately preserved in 97% ethanol; they are later identified to the lowest taxonomic level possible at each institution's lab.

At this point, 215 samples have been collected in Cambodia.

Figure 5.8. Fish larvae collection and identification

In Cambodia, these activities filled a database detailed in the corresponding section.

5.2.3. Survey of local ecological knowledge

In order to complement the migration and passage study based on fish tagging, a survey of local ecological knowledge was being conducted to document how fish pass the falls and provide information on what can be done to improve fish passage. The activity is aimed at:

- generating information on when and how fish arrive to Khone Falls from downstream (preferred initial migration channels);
- identifying which channels are the most important for successful fish passage (depending on species and timing);
- recommending fish passage improvements from local residents' perspective, and other channels or falls that could be further managed for improved fish passage.

This information can complement the tagging of fish species in Hou Sadam and Hou Xang Peuak channels, for instance by identifying some very specific locations (setting of tag receptors), sharpening the tagging study (e.g. day vs. night release of tagged fish), or explaining tagging results (attraction or not of tagged fish towards some channels).

It will also provide a broader context to the JEM Pilot assessment focused of the role of Hou Sadam and Hou Xang Peuak channels as alternative fish ways expected to absorb all transboundary fish migrations.

Finally, it will allow testing the gathering, relevance and cost of local ecological knowledge as a possible contribution to dam impact monitoring and mitigation management.

The results of the study could therefore contribute to updating the JEM Programme by contributing knowledge and design guidance on fish passage channels and on the factors that need to be integrated for optimal mitigation of dam impacts.

The survey of local ecological knowledge in Khone Falls started on 10 March 2021.

Figure 5.9. From top left: LEK Survey Team, material for interviews and first meeting of the local knowledge survey team

The first days of work involves the production of the first maps of the migration of 10 priority species upstream and downstream of Khone Falls, data entry of the first questionnaires in the database designed for this use, and the conversion of first migration maps into Google Earth maps (see below).

Figure 5.10. Gathering local knowledge through migration maps, and corresponding data entry in a database

5.2.4. Fish tagging

As briefly mentioned in the section, *Activities and evolution*, three main activities were carried out for fish passage studies at Don Sahong and in the Mekong.

A major activity consisted in the development, until the end of March 2021, of a comprehensive review of options, technicalities, pitfalls, pros and cons of the various tagging techniques available and potentially usable in the Mekong. This review, already integrating the first MRC and GIZ comments, is proposed as a companion volume to this report.

This review results from (non-remunerated) collaborations with:

- two fish passage and fish tagging specialists from the Fish-Pass company in France (www.fish-pass.fr/uk/index.php);
- two fish tagging and Mekong fish specialists from Charles Sturt University (Australia, www.csu.edu.au/research/ilws/home), who particularly experienced in passage studies at Xayaburi site;
- one database and tag data analysis specialist from Australia (www.karltek.com.au);
- a fish tagging specialist and a Lao fish biologist from FISHBIO organization (https://fishbio.com), both experienced in Lao PDR;
- a Mekong fish specialist from the University of Nevada, experienced in tagging in Cambodia and in Thailand (http://mekongwonders.org).

In a context where a single tag company proposes as many as 92 different kinds of electronic fish tags, the inputs of these specialists allowed the Mekong experts to highlight in the review a number of technicalities to be considered and integrated for the success of a long-term tagging programme in the Mekong Basin. This is usually not detailed in scientific publications or commercial brochures, in particular, in the case of electronic tags. For instance, actual fish detection range in field condition (turbidity, water conductivity, bridges as sources of white noise or signal perturbation, etc.); power supply and battery renewal requirements; security measures to avoid theft of the equipment; etc. The review also emphasizes the requirements for the insertion of fish tags to ensure that the results of the study and the investment are not compromised in the short term by a low survival rate among fish tagged.

Thus, the review details the different dimensions of tagging illustrated below and paves the way for specific developments in these respective directions.

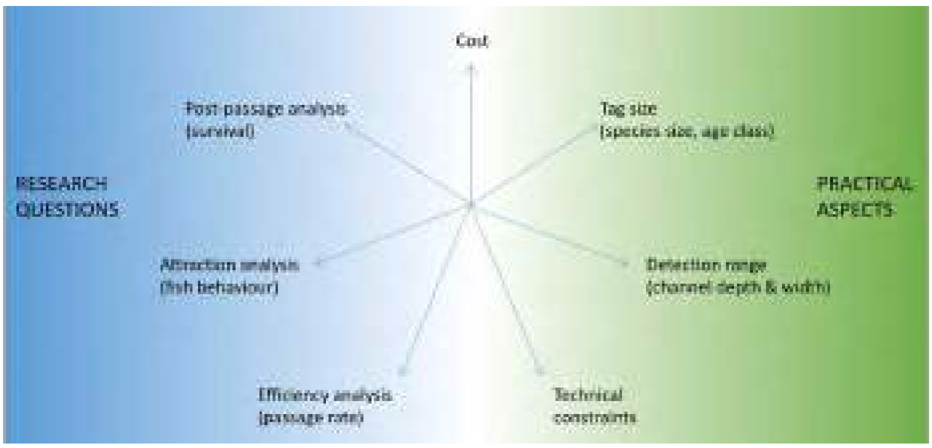

Figure 5.11. Main factors influencing a tagging approach and tag selection

These developments include a possible tagging experiment using non-electronic external 'spaghetti' tags or fish inking.

5.3. Preliminary results and initial analysis

5.3.1. Fish Abundance and Diversity Monitoring

The fishery database is based on the MRC fishery database. The current database receiving FADM data has a very simple structure that includes the following fields and relationships:

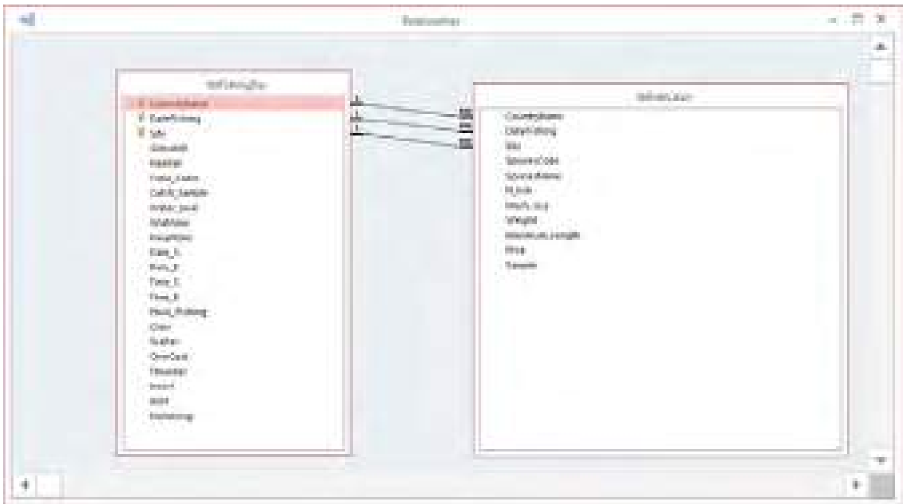

Figure 5.12. Relationships in the FADM database

This structure reflects the integration of remarks and amendments made during the project on previous redundancies or inconsistencies in the original database.

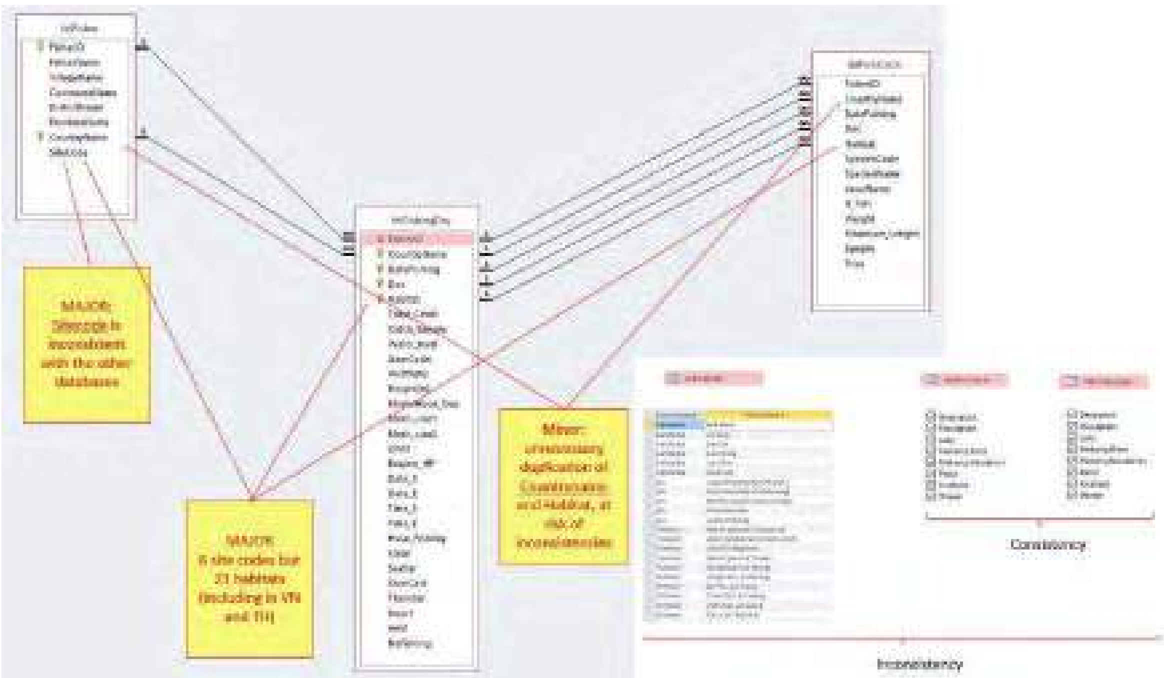

Figure 5.13. Redundancies and inconsistencies identified in the original version of the database

This structure also allows an easy data extraction for scientists unfamiliar with MS Access and willing to analyse data in MS Excel.

Once displayed, that information allows plotting information on maps (see Figure 5.14).

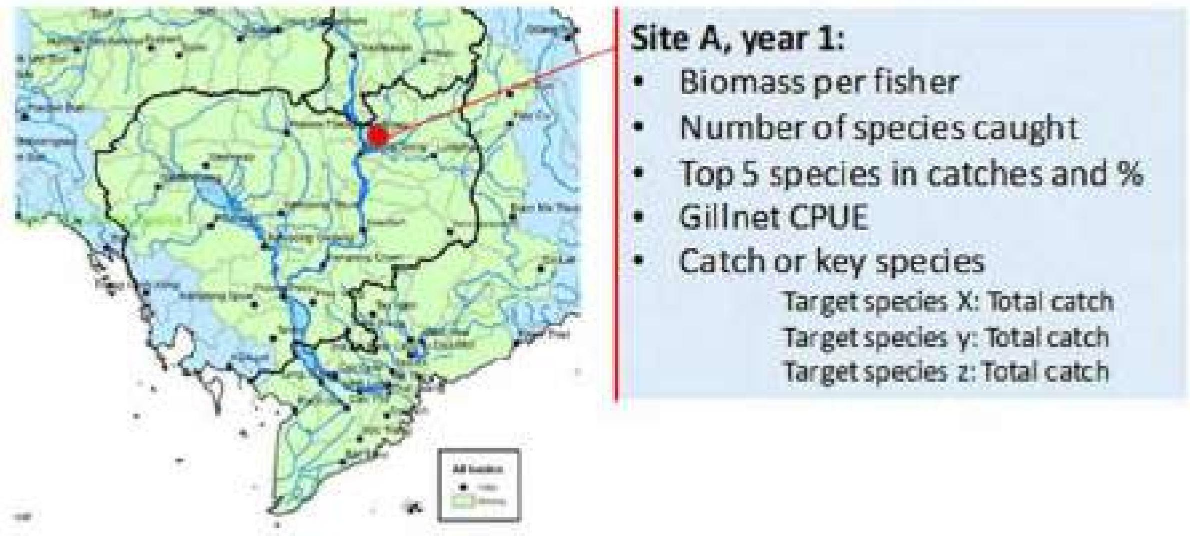

Figure 5.13. Possible plotting of information for the display

5.3.2. Fish Larvae Drift Monitoring

The database receiving FLDM data includes the following fields and relationships:

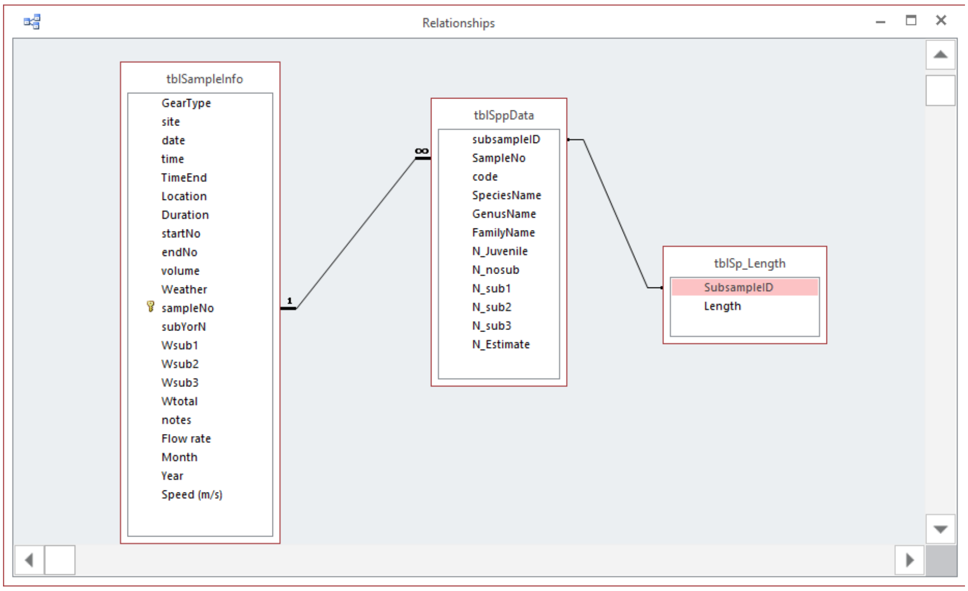

Figure 5.14. Relationships in the FLDM database

It was designed to include six locations and to date includes only data from Cambodia.

Country	Province	District	Village	Site Code	location	N	E
Cambodia	Stung Treng	Thala Borivath	Preah Romkel	CJDC	Downstream of Don Sahong Dam in Cambodia	13°54'4.63"N	105°57'52.34"E
Laos	Champasak	Khong	Sadam	LIDD	Downstream of Don Sahong Dam	13°56'3.76"N	105°57'25.32"E
Laos	Champasak	Khong	Hou Sahong	LIDU	Upstream of Don Sahong Dam	13°58'23.94"N	105°57'27.41"E
Laos	Xayabouri	Xayabouri	Pak Houng	LIXD	Downstream of Xayabouri Dam	19°18'9.72"N	101°49'2.76"E
Laos	Xayabouri	Xayabouri	Tha Deua	LIXI	Xayabouri Dam Impoundment	19°25'36.76"N	101°50'40.84"E
Laos	Luangprabang	Luangprabang	Pha O	LIXU	Upstream of Xayabouri Dam	19°50'37.40"N	102°13'12.01"E

GearType	site	date	time	TimeEn	Lc	Dura	startNo	endNo	volun	Weath	sampleNo
Bongo net	CJDD	03-Sep-20	8:00	8:30	R	30	902932	913119	215		CJDD_03-Sep-20_08:00_
Bongo net	CJDD	03-Sep-20	14:20	14:50	R	30	913119	926889	291		CJDD_03-Sep-20_14:20_
Bongo net	CJDD	08-Jul-20	10:10	10:40	R	30	484556	513265	606		CJDD_08-Jul-20_10:10_
Bongo net	CJDD	08-Jul-20	17:10	17:40	R	30	688062	860393	3637		CJDD_08-Jul-20_17:10_
Bongo net	CJDD	09-Sep-20	6:30	7:00	R	30	971157	999716	603		CJDD_09-Sep-20_06:30_
Bongo net	CJDD	09-Sep-20	8:10	8:30	R	20	135154	139867	99		CJDD_09-Sep-20_08:10_
Bongo net	CJDD	09-Sep-20	13:30	14:00	R	30	999719	628055	13262		CJDD_09-Sep-20_13:30_
Bongo net	CJDD	14-Jul-20	8:30	9:00	R	30	528021	540496	263		CJDD_14-Jul-20_08:30_
Bongo net	CJDD	14-Jul-20	14:30	15:00	R	30	540492	556120	330		CJDD_14-Jul-20_14:30_
Bongo net	CJDD	21-Aug-20	6:30	7:00	R	30	737615	738904	27		CJDD_21-Aug-20_06:30_
Bongo net	CJDD	21-Aug-20	12:10	12:40	R	30	738904	740568	35		CJDD_21-Aug-20_12:10_
Bongo net	CJDD	28-Jul-20	9:25	9:55	R	30	575624	588876	280		CJDD_28-Jul-20_09:25_
Bongo net	CJDD	28-Jul-20	10:19	10:49	R	30	588876	602365	285		CJDD_28-Jul-20_10:19_

Figure 5.15. Sampling locations and current records in the FLDM database

A preliminary analysis of Cambodian rainy season data (see *Table 5.1*) shows that:

- between 28 and 45 species belonging to 16 families were collected in each sampling site;
- families with the most species diversity are cyprinids (up to 25 species per sampling site), Pangasiidae and Bagridae (up to 4 species) and Siluridae (up to 3 species);
- the presence among larvae of taxa not common as adults (e.g. Chandidae, Gobiidae, Sisoridae, Soleidae), which confirms the relevance of the larvae monitoring for a more comprehensive assessment of the biodiversity;
- a large heterogeneity between banks and therefore sampling points (45% more species on the right bank than on the left bank in Preah Romkel in Cambodia). This confirms the relevance of sampling in a diversity of points for a given site:
    - The difference between families and species found near Don Sahong site and those that have been sampled over the years near Phnom Penh and in the Tonle Sap will require substantial time before teams have absorbed that diversity and data can be compared.

Table 5.1. Preliminary analysis of larvae data in Cambodia (Preah Romkel site, Stung Treng Province)

Family	Species on right bank of the river	Species in the middle of the river	Species on the left bank of the river
Bagridae	4		2
Chandidae		1	
Channidae	1	1	
Cichlidae	1		
Clupeidae	1		
Cobitidae	1		

Family	Species on right bank of the river	Species in the middle of the river	Species on the left bank of the river
Cyprinidae	25	17	15
Dasyatidae	1		
Gobiidae	2	1	
Mastacembelidae		2	3
Notopteridae	1		
Osphronemidae			1
Pangasiidae	3	4	3
Siluridae	3	1	2
Sisoridae	1	1	
Soleidae	1	2	2
Total	**45**	**30**	**28**

5.3.3. Survey of local ecological knowledge

In fisheries, the JEM Pilot Project implements monitoring of fish catches and develops new methods to assess the efficiency of upstream migration, in particular at Don Sahong site. For this purpose, fish tagging methodologies are planned to: (i) generate reliable data on transboundary fish species and their migration patterns; and (ii) assess the effectiveness of the two natural fish passages channels (Hou Sadam and Hou Xang Peuak).

Khone Falls are actually made of more than 31 large islands, 25 large waterfalls or waterfall areas, and at least 52 channels individually identified, creating a large number of corridors and dead ends through which fish attempt migrations. During their migration they are targeted by highly skilled fishers from 16 villages, in which local ecological knowledge is very developed, well recognized, and documented in more than 15 publications.

In order to complement the migration and passage study based on fish tagging, the JEM Programme Pilot Project proposed to conduct a survey of local ecological knowledge to document how fish pass the falls and contribute to informing what can be improved or mitigated to improve fish passage through the falls. The results of the study can contribute knowledge and guidance on fish passage channels and on the factors that need to be integrated for optimal mitigation of dam impacts.

The proposed activity is aimed at:

- generating information that can complement the tagging of fish species in these channels, for instance by identifying some very specific locations (setting of tag receptors), sharpening the tagging study (e.g. day vs. night release of tagged fish) or explaining tagging results (attraction or not of tagged fish towards some channels);
- providing a broader context to the JEM Pilot Project assessment focused on the role of Hou Sadam and Hou Xang Peuak channels as alternative fish ways expected to absorb all transboundary fish migrations;
- testing the gathering, relevance and cost of local ecological knowledge as a possible contribution to dam impact monitoring and mitigation.

For a survey aimed at *documenting main passage strategies and capabilities* in an environment characterized by 201 fish species in 39 families, it was necessary to *select 10 species representative of large groups of other species that migrate through Khone Falls.*

This selection was based on a review of species known to migrate through Khone Falls, already identified by the MRC for transboundary management (10 priority species), making a significant percentage of catches in Khone Falls fisheries, migrating at different times of the year, in different water levels and belonging to different size groups (swimming capabilities, ability to be tagged). See details in Fisheries Annex 1: “Selection of species for local knowledge survey”.

The final selection consists of:

Cirrhinus microlepis (paphone mak kok)	*Hypsibarbus malcolmi* (papak nouat/pa pak kom/pa pak)
Cyclocheilos enoplos (pa chok)	*Pangasius conchophilus* (pa pho/pa ke)
Gymnostomus lobatus (pa soi houa lem)	*Pangasius krempfi* (pa souay hang leuang)
Gymnostomus siamensis (pa soi houa po)	*Pangasius macronema* (pa gnone siap)
Helicophagus leptorhynchus	*Scaphognathops bandanensis* (pa pian)

These species are representatives of the six main groups of species that migrate through Khone Falls, as illustrated below:

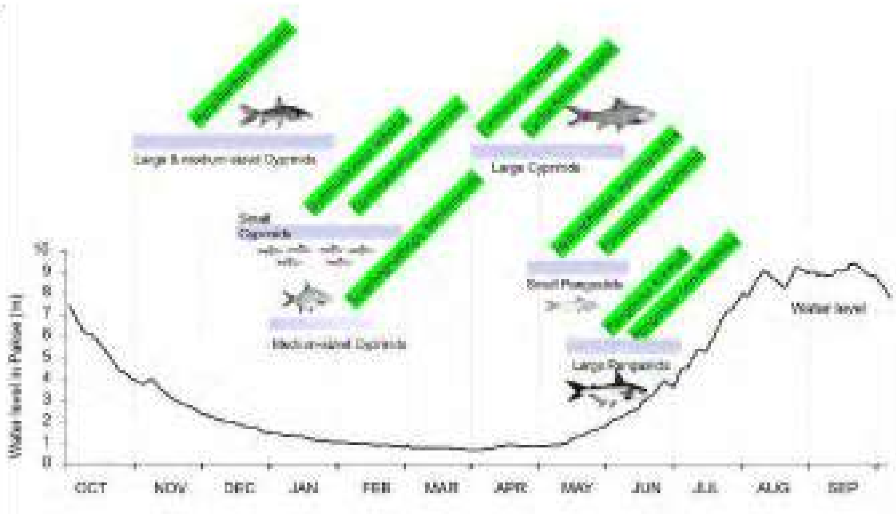

Figure 5.16. 10 species selected as priority species for collection of local ecological knowledge

Some examples of the first digital maps reflecting interviews on migrations are shown below.

Figure 5.17. Display in Google Earth of fish migrations around Don Det Tok village

Figure 5.18. Display of migration by species (here, Pangasius species) using Google Earth

5.3.4. Fish tagging

Presented below is a range of local specificities of fish passage channels in the Don Sahong area, in relation to tagging options in each location.

To date, Don Sahong Power Company has developed activities to improve fish passage in nine channels; from East to West:

- Hoo Som Yai (where the MRC monitored a Lee trap fishery for 20 years, and Hoo Som Pordan next to Khone Phapheng waterfall (Som Pordan, the name used by Don Sahong Power Company is also locally pronounced as Som Pa Lan);
- Hoo Sadam between Don Sadam and Don Papeng;
- Hoo Xang Peuak Noy, Nyoi Koong, Koum Tao Hang, Hoo Wai and Luong Pi Teng between Don Ee Som and Don Sahong;
- Hoo Don Lai next to Lee Pee waterfall.

Works at two additional channels have been planned:

- Hoo Nok Gasoom Noi between Don Ee Som and Don Nok Gasoom (dry in March 2021);
- Hoo Ta Sang next to Don Pa Soi.

Table 5.2. Fish passage channels improved by Don Sahong Power Company and their location

	Lao name (Latin script)	Lao name (Lao script)	Latitude	Longitude
1	Hoo Som Yai	ໂສມໃຫຍ່	13°57'32.64"N	105°58'57.94"E
2	Som Pordan	ໂສມປໍດານ	13°57'46.10"N	105°58'54.24"E
3	Hoo Sadam	ຮູສະດຳ	13°58'22.51"N	105°58'10.03"E
4	Xang Peuak Noy	ຮູຊ້າງເຜືອກນ້ອຍ	13°57'27.50"N	105°57'23.13"E
5	Nyoi Koong	ຍ່ອຍກຸ່ງ	13°57'4.49"N	105°57'14.79"E
6	Khoum Tao Hang	ຂຸ່ມເຕົ່າຮ່າງ	13°57'6.15"N	105°57'9.22"E
7	Luang Phi Teng	ຮູລ່ວງຜີແຕ່ງ	13°57'24.29"N	105°57'1.33"E
8	Hoo Wai	ຮູຫວາຍ	13°57'31.77"N	105°56'58.34"E
9	Hoo Don Lai	ຮູດອນໄລ່	13°57'14.40"N	105°54'59.28"E

The authors review the sites modified by Don Sahong Power Company for passage improvement, and propose a preliminary review of possible tagging methods in each site, based on the estimated width, depth and turbulence of each channel in each season, and on the size of species considered for tagging: small-sized: <25 cm; medium-sized: 25 to 50 cm; and large-size fish: >50 cm.

Descriptions below build on the work of Baird and his initial description of Khone Falls channels, and on updates from villagers gathered during the last two weeks of March 2021 by the field team implementing the local knowledge survey.

Hoo Som Yai near Khone Phapheng

Figure 5.20. Hoo Som Yai near Khone Phapheng, in March 2020 (left) and October 2014 (right)

Table 5.3. Hoo Som Yai characteristics

	Width	
Width in dry season	6–10 m	
Width in wet season	6–15 m	
	Min. depth in dry season	**Max. depth in wet season**
Now	Dry	2 m
These past 2 years, months with no water	Nov. to June	
10 years ago	80 cm	W2 m
10 years ago, months with no water	Water year round	

Table 5.4. Possible tagging options for fish at Hoo Som Yai

	Size	Wet season (high discharge)	Dry season
Species	**Small**	PIT: Unlikely (too wide)	PIT: no (dry)
	Medium to large	PIT: Unlikely (too wide)	PIT: no (dry)
		Acoustic: Usability in relation to noise level should be assessed	Acoustic: no (dry)
		Radio: yes	Radio: no (dry)

<u>**Hoo Som Pordan near Khone Phapheng**</u>

Figure 5.19. Hoo Som Pordan (left), flowing into Hoo Som Yai, in March 2020

Table 5.5. Hoo Som Pordan characteristics

	Width	
Width in dry season	3 - 15 m	
Width in wet season	5- 15 m	
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	Dry	1.8 m
These past 2 years, months with no water	Dec. to early June	
10 years ago	Dry	1.8 - 2 m
10 years ago, months with no water	April to May	

Table 5.6. Possible tagging options for fish at Hoo Som Pordan

	Size	Wet season (high discharge)	Dry season
Species	Small	PIT: yes (multiple antennas possibly required)	PIT: no (dry)
	Medium to large	PIT: yes (multiple antennas possibly required)	PIT: no (dry)
		Acoustic: usability in relation to noise level should be assessed	Acoustic: no (dry)
		Radio: yes	Radio: no (dry)

Hoo Sadam

Hoo Sadam is located between Don Sadam and Don Papeng. This narrow channel without waterfalls is known to be important for all migrating species during most of the year. Fishers have highlighted that this channel is special because of the presence of pools and other resting sites used by fish during their migrations (some pools reach 2 m in depth). In this channel, fish are also caught during the downstream migration (from May until July, after which water level is too high to catch fish).

Figure 5.20. Hoo Sadam in March 2020

Table 5.7. Hoo Sadam characteristics

	Width (m)	
Width in dry season (m)	7 - 90	
Width in wet season (m)	25 - 90	
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	Water not flowing. 30–50 cm depth in some places but very shallow upstream. Standing waters and disconnected pools	3 m
These past 2 years, months with no water	Dec. to June	
10 years ago	1 m	5 m
10 years ago, months with no water	Water year round	

Figure 5.21. Hoo Sadam (left: upstream; right; downstream) in March 2014

Table 5.8. Possible tagging options for fish at Hoo Sadam

	Size	Wet season	Dry season
Species	Small	PIT: no (too wide, too deep)	PIT: no (dry)
	Medium to large	PIT: no (too wide, too deep)	PIT: no (dry)
		Acoustic: yes	Acoustic: no (dry)
		Radio: yes	Radio: no (dry)

Hoo Xang Peuak

Hoo Xang Peuak is a major dual pathway for fish migrating upstream, with two main channels and waterfalls (Nyai = large, Noi = small). Waterfalls **Khone Xang Peuak Yai and Khone Xang Peuak Noy** are 3–4-m high, but not wide. In May–June, migrating *Pangasius conchophilus* and *P. krempfi* pass them, while *Pangasius macronema* cannot. *Hypsibarbus spp.* can also swim and jump up these waterfalls. In October, fish pass these falls more easily. These channels used to be the places of multiple traps catching small cyprinids in January – February.

Hoo Xang Peuak Noy was the first passage widened by the Don Sahong Power Company as an alternative to Hoo Sahong in the dry season.

Figure 5.22. Hoo Xang Peuak Yai and Noy (location map)

Figure 5.23. Hoo Xang Peuak Yai in January 2015 (left) and June 2015 (right)

Table 5-9. Hoo Sang Peuak Yai characteristics

	Width	
Width in dry season	4–25 m	
Width in wet season	10–40 m	
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	about 1.3m	4–5 m
These past 2 years, months with no water		
10 years ago	1.3 m	4–5 m
10 years ago, months with no water	Water year round	

Table 5.10. Possible tagging options for fish at Hoo Xang Peuak Yai

	Size	Wet season	Dry season
Species	Small	PIT: probably not (strong current, depth)	PIT: yes
	Medium to large	PIT: no (same reasons)	PIT: yes
		Acoustic: usability in relation to noise level should be assessed	Acoustic: possibly
		Radio: yes	Radio: yes

Hoo Xang Peuak Yai is listed here because it is one of the two components of Hoo Xang Peuak channel, but was not modified by Don Sahong Power Company for improved fish passage and is currently not passable by fish (high waterfall).

Figure 5.24. Hoo Xang Peuak Noy in February 2015 (left) and October 1017 (right)

Table 5.11. Hoo Sang Peuak Noy characteristics

		Width
Width in dry season		3–13 m
Maximum width in wet season		8–35 m
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	10–20 cm	2 m
These past 2 years, months with no water		
10 years ago	30–40 cm	2 m
10 years ago, months with no water	Water year round	

Table 5.12. Possible tagging options for fish at Hoo Sang Peuak Noy

	Size	Wet season	Dry season
Species	Small	PIT: yes	PIT: yes
	Medium to large	PIT: yes	PIT: yes
		Acoustic: usability in relation to noise level should be assessed	Acoustic: probably too shallow
		Radio: yes	Radio: yes

Nyoi Koong

Nyoi Koong is a channel located 700 m upstream of Don Sahong Dam.

Figure 5.25. Nuay Khoun in March 2020

Table 5.13. Nyoi Koong characteristics

	Width	
Width in dry season	4 m – 40 m	
Width in wet season	10 m – 70 m	
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	Dry	2.5 m
These past 2 years, months with no water	Dec. to June	
10 years ago	40–50 cm	2.5 m
10 years ago, months with no water	Water year round	

Table 5.14. Possible tagging options for fish at Nyoi Koong

	Size	Wet season	Dry season
Species	Small	PIT: yes	PIT: no (dry)
	Medium to large	PIT: yes	PIT: no (dry)
		Acoustic: usability in relation to noise level should be assessed	Acoustic: no (dry)
		Radio: yes	Radio: no (dry)

Koum Tao Hang

Koum Tao Hang is another channel located 900 m upstream of Don Sahong Dam

Figure 5.26. Koum Tao Hang channel

Table 5.15. Koum Tao Hang characteristics

	Width	
Width in dry season	13 - 37 m	
Width in wet season	22 - 40 m	
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	Dry	4 m
These past 2 years, months with no water	March–May	
10 years ago	50 cm	4 m
10 years ago, months with no water	Water year round	

Table 5.16. Possible tagging options for fish at Koum Tao Hang

	Size	**Wet season**	**Dry season**
Species	Small	PIT: yes	PIT: no (dry)
	Medium to large	PIT: yes	PIT: no (dry)
		Acoustic: no	Acoustic: no (dry)
		Radio: yes	Radio: no (dry)

Hoo Wai

Hoo Way is a major channel allowing fish to swim around the very challenging Khone Lan. It has been the site of extensive earthworks by Don Sahong Company, with in particular blocks of rocks put in place to provide shelter and break the current. The channel is wide, moderately deep, with several steps where PIT antennas can be set. However, it is unclear whether its entrance in reverse direction compared to the main flow from Khone Lan make it an attractive option for fish.

Figure 5.27. Hoo Wai channel (location map)

Figure 5.28. Hoo Wai channel in November 2019

Table 5.17. Koum Hoo Wai characteristics

	Width	
Width in dry season	9–22 m	
Width in wet season	23–52 m	
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	50 cm	10 m
These past 2 years, months with no water		
10 years ago	70 cm	10 m
10 years ago, months with no water	Water year round	

Table 5.18: Possible tagging options for fish at Hoo Wai

	Size	Wet season	Dry season
Species	Small	PIT: no	PIT: yes
	Medium to large	PIT: no (too wide)	PIT: yes
		Acoustic: possibly too noisy	Acoustic: no (too shallow)
		Radio: yes	Radio: yes, if large fish can pass

Luong Pi Teng

Luong Pi Teng is, like Koum Tao Hang, a channel meant to complement Hoo Wai in bypassing Khone Lan. It is very shallow, with turbulent water most of the year.

Figure 5.29. Luong Pi Teng channel

Table 5.17. Luong Pi Teng characteristics

	Width	
Width in dry season	5–8 m	
Width in wet season	Merged with Khone Lan	
	Min. depth in dry season	**Max. depth in wet season**
In 2021 dry season	Dry	2 m
These past 2 years, months with no water	March–June	
10 years ago	Dry	2 m
10 years ago, months with no water	March–April	

Table 5.18. Possible tagging options for fish at Luong Pi Teng

	Size	Wet season	Dry season (if not dry)
Species	Small	PIT: yes, if the channel bed is well identified	PIT: no (dry)
	Medium to large	PIT: yes, if the channel bed is well identified	PIT: no (dry)
		Acoustic: usability in relation to noise level should be assessed	Acoustic: no (dry)
		Radio: possibly	Radio: no (dry)

Hoo Don Lai

Hoo Don Lai channel is located next to Haew Sompamit. This is an important channel for small cyprinids (*Cirrhinus, Paralaubuca, Crossocheilus, Labiobarbus*), but also cobitids and other species migrating in January–February; however, exiting the channel is challenging in the dry season. Fishers indicate that fish can only enter and swim in the lower part of this channel in the dry season, up to the waterfalls at mid-way. As water levels gets higher, more fish species can pass these falls.

Figure 5.30. Hoo Don Lai (location map)

Figure 5.31. Hoo Don Lai in January 2016 (left: downstream; middle: mid-range; right: upstream)

Table 5.19. Hoo Don Lai characteristics

	Width
Width in dry season	3–28 m
Width in wet season	7–34 m

	Min. depth in dry season	Max. depth in wet season
In 2021 dry season	40 cm – 1 m last year 50 cm (head water)	1–2 m (head water)
These past 2 years, months with no water		
10 years ago	Dry	1 m
10 years ago, months with no water	March to April	

Table 5.20. Possible tagging options for fish at Hoo Don Lai

Size	Wet season	Dry season

Species	Small	PIT: yes (with multiple antennas)	PIT: yes
	Medium to large	PIT: yes (with multiple antennas)	PIT: yes
		Acoustic: usability in relation to noise level should be assessed	Acoustic: no (too shallow)
		Radio: yes	Radio: yes

5.4. Lessons learned and findings

5.4.1. Lessons learned in FADM and FLDM

Field implementation of the FADM protocol focused on the catch of fishers does not pose any major problem. Data gathering and data entry in Lao PDR requires more time than in Cambodia, and a catch database could not be examined yet for Don Sahong site.

It is recommended that MRC supervisors or colleague scientists from another partner country undertake in the coming months a round of data gathering and data entry together with Lao colleagues. This will secure the quality and standardization of implementation at the village level (timing of fishing, species identification, accuracy of recording, etc.) and strengthen the training of national scientists supervising the protocol and entering data.

Field implementation of the FLDM protocol is more challenging because a rigorous larvae collection protocol is now in the hands of fishers. This requires a close assistance to and supervision of these fishers, with also a visit in the months to come to the partner fishers.

The midnight sampling unit is challenging in all stations and may lose credibility in the long term; it is therefore recommended to move it to 21:00, (21:00 being the night sample replacing the midnight sampling).

5.4.2. Lessons learned in fish tagging

The review of channels, their depth and width in different seasons, and the types of tags that can be used in them are summarized in Table 5.22 using the following codes:

#NA: impossible X: unlikely XX: worth trying XXX: priority candidate site

Table 5.21. Overview of candidate channels and their suitability of tagging experiments

Channel	Wet season	Dry season
Hoo Som Yai	X	#NA
Hoo Som Pordan	XXX	#NA
Hoo Sadam	X	#NA
Hoo Xang Peuak Yai	XX	XXX
Hoo Xang Peuak Noy	XXX	XXX
Nyoi Koong	XXX	#NA
Koum Tao Hang	XX	#NA
Hoo Wai	X	XX
Luong Pi Teng	XX	#NA
Hoo Don Lai	XXX	XX

This analysis reveals that:

- priority sites for wet season tagging are Hoo Som Pordan, Hoo Xang Peuak Noy, Nyoi Koong and Hoo Don Lai;
- priority sites for dry season tagging are Hoo Xang Peuak Noy, Hoo Wai and Hoo Don Lai;
- Hoo Xang Peuak Yai is listed here in case of attractiveness studies, but was not modified by DSCP and is not passable by fish;
- Hoo Xang Peuak Noy stands out as the only site suitable in all seasons, the second-best site being Hoo Don Lai.

5.5. Detailed strategy for a tagging approach

Designing and conducting a fish tagging study requires several steps. The following sections describe the key considerations, questions and decisions required at each.

5.5.1. Defining objectives

a. Definition of research objectives, of management questions

Defining objectives, i.e. the exact scope of tagging, is the most important step because it conditions the whole tagging approach (choice of target species, of a tagging method, budget, logistics, duration, etc.).

At the moment, two management questions are explicitly considered by the JEM programme:

- Are mitigation measures taken to facilitate fish migration locally effective?
- Do they ensure that the sustainability of fish populations?

These broad questions actually correspond, at the site level, to three more specific and more technical questions:

- Do fish find the passage (i.e. improved channel or fish ladder)?
- Do fish pass through the channel or fish ladder?
- Do fish keep living after the passage (survival and breeding)?

These questions focused on upstream migrations through channels can also be complemented by questions about downstream fish migrations.

At the moment the exact scope of tagging is not clearly defined in the JEM programme, and remains as a priority for Member Countries to determine.

At Khone Falls (Figure 5.34), these questions must be considered in context, i.e. fish arriving from Cambodia in a wide and deep river (400-1,500 m wide, 10–30 m deep), trying to pass through narrow and shallow channels (3–30 m wide, 0.2–10 m deep) and continuing their journey upstream in a wide and moderately deep river (500-2,000 m wide, 1–6 m depth).

Figure 5.32. View of Khone Falls and river characteristics downstream, at mid-falls and upstream

Do fish find the passage?

The tagging design can be driven by the following questions:

- *Do fish coming from downstream or upstream locate the fishway entrance?*
- *Do fish enter the fishway or improved fish channel?*

Do fish coming from downstream or upstream locate the fishway entrance? The objective of the study here is to assess whether the location of the passage and the flow conditions in the passage are suitable to attract fish. If not, the passage exists but fish do not find it and do not use it. To answer such question, both tagging and detection devices must be set in the downstream environment, i.e. a wide and deep river, which conditions the type of equipment to be used The least costly electronic tagging method for large deep rivers is acoustic tagging. It is only possible for medium- to large-size fish (or small fish > 9 cm if specific JSATS tags are used)

"*Do fish enter the fishway or improved fish channel"* is a question that can be considered at two scales:

- large-scale, by a mere assessment of the number of fish swimming at the entrance of the fishway. To carry out this assessment, and given the small dimensions of a fishway, both PIT tagging and radio tagging are suitable (acoustic signal detection requires larger spaces). PIT tagging can be applied to small, medium and large species, but radio tagging is limited to large species; or
- fine-scale, by a study of the behaviour of fish in front of the passage entrance (which allows refining or retrofitting the design of the fish pass to be more attractive). Both acoustic and radio tagging allow such level of study, but acoustic tagging is largely superior in terms of 3D location, at the cost of complex data analysis.

Do fish pass the obstacle? This is a question about the configuration of channels and fish ladders (depth, width, discharge, current speed, etc.), and the ability of fish to pass these obstacles once they have found them. The tagging equipment required here corresponds to narrow and shallow channels This allows using PIT tagging whose detection range is limited to 1 m (even though dimensions >1 m are constrained to a complex combination of multiple antennas). PIT tagging can be applied to almost all species sizes. The use of acoustic tags is limited by the limited volume of the environment often noisy, but radio tagging on large fish can also be used here.

Do fish survive the passage?

This question concerns the survival of fish after passing the obstacle, and therefore the sustainability of the population. In some cases, fishes are too exhausted or damaged by the passage to be able to continue their migration and breed upstream.

- *Do fish continue their migratory journey after the fishway (and the impoundment)?*
- *Are fish populations sustained despite the dam or thanks to fish passage improvement?*

Here again the question is to be considered in the upstream environment (large river, impoundment) and the equipment to be used needs to be selected accordingly. Here again, both acoustic and radio tags are suitable, the former being less costly, but none of these methods is suitable for small species.

Downstream fish migrations

Little or also no studies on downstream fish passage in relation to hydropower and irrigation barriers/dams and their fishways have been conducted in small and large rivers throughout the world. Questions on downstream migrations are of different nature, and tend to focus around on the reservoir and the dam:

- *Do migratory fish settle in a dam reservoir or impoundment?*
- *What is the fish behaviour in relation to diversion barriers and screens?*
- *Do fish pass through turbines or spillways; what proportion survives?*

Determining whether fish settle in the dam reservoir does not require a tagging study; working with fishers makes it possible to answer this question. Determining fish behaviour at diversion barriers and screens is a question about fish behaviour in space, which requires acoustic tagging. Assessing the proportion of fish surviving passage through turbines or spillways can be addressed by radio tagging (PIT tags with very short detection range and acoustic tags sensitive to noise are excluded).

In conclusion, no single method can answer all the above questions. Addressing the entire set of questions requires, if budget and human resources allow, a combination of different fish tagging methods, and even a combination of electronic tags with other tagging methods requiring recapture (spaghetti tagging, inking, etc.). Covering the whole range of questions around sustainability of migratory fish populations confronted to passage at dam site (Figure 5.35) requires the whole range of available tagging technologies, for a cost, integrating human resources, logistics and data analysis-reaching a million US dollar.

The main features and constraints of each electronic method are detailed in *Table* ***5.23***.

Table 5.22. Main conditions of use for the different electronic tagging methods

	Radio tagging	Acoustic tagging	PIT tagging
Possible water depth (m)	0-5	1.5–100	< 1
Usable with small fish	Moderately	Moderately (new small-size tags)	Yes
Reception range (m)	20–5,000	20–300	0.1 to 1–2
Lifespan of the tag	20 days – 2 years	10 days – 1 year or more	No limit
Long-term studies (> 1 y)	Medium to large fish	Medium to large fish only	All fish sizes
3D-tracking	Limited, complex (requires multidirectional array and depth loggers)	Yes	No
Cost of one tag (USD) Cost of one receiver (USD)	> 200 1,000 –5,000 (40k for depth loggers) x 4 units minimum	> 300 1,500–2,000 x 6 units minimum (up to 70 for 36,000 ha)	1–4 > 5,000

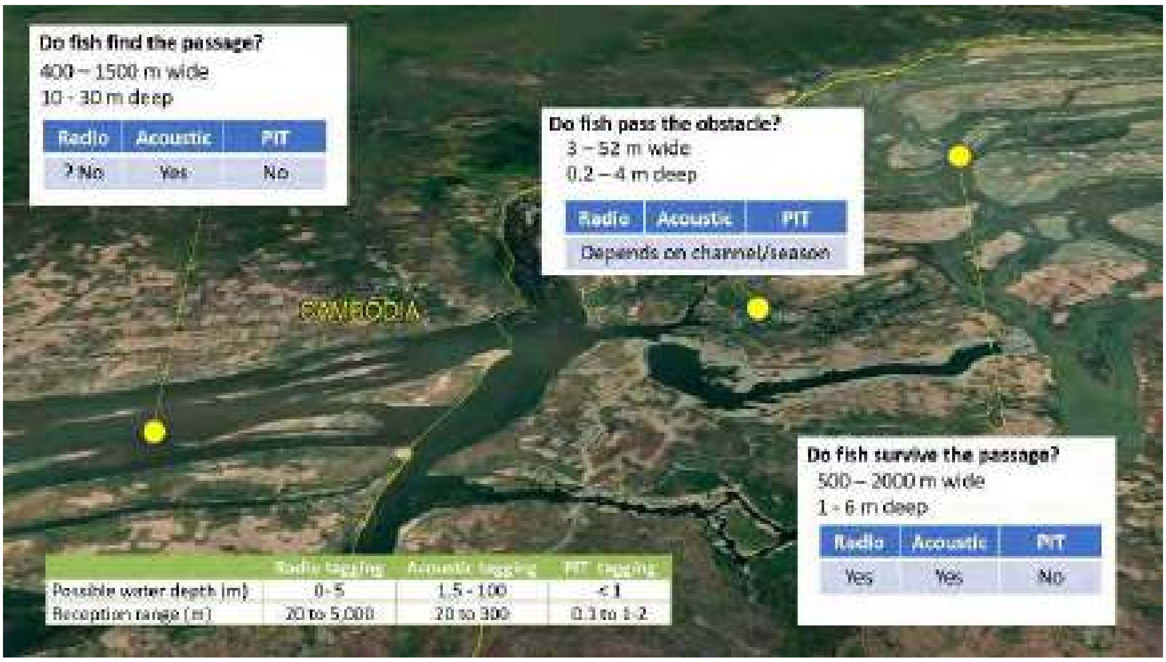

Figure 5.33. Electronic tagging methods useable in the various Khone Falls environments, in relation to management questions asked

When considered in the context of Khone Falls:

- acoustic tagging is usable in the downstream environment, and is therefore the method to be considered a priority to answer management questions about fish finding the passage. Radio tagging could be used whereas PIT tagging cannot be used;

- when dealing with questions about fish passing the obstacle or not, the fish tagging method to be used depends on the channel considered and on the season (i.e. water depth, width of the channel);
- questions about fish surviving the passage or not are also set in a context where both radio and acoustic tagging are usable.

b. Review of possible study sites, target species, tagging methods, study dates

This report reviews possible study sites. The companion publication , "Fish tagging options for the study of river fish migrations – a review with particular focus on the Mekong", reviews tagging methods. The report, "Recent fish migrations in Khone Falls (Lao PDR) according to local ecological knowledge", reviews the best target species.

These studies show that the development of a tagging programme depends on layers of information that must be gathered before any tagging is undertaken.

c. Review of statistical requirements, i.e. how many fish should be tagged

The number of fish to be tagged (and therefore the cost of the study) depends on the question asked and the dimensions of the corresponding environment (Figure 5.36).

Do fish coming from downstream or upstream locate the fishway entrance?

This corresponds to a large-scale question in a vast environment. To credibly answer this question, several hundred fish need to be tagged.

Do fish enter the fishway or improved fish channel?

Three sub-questions can be considered here:

- *What is the proportion of downstream fish entering the channel?* This is, again, a large-scale question requiring large-scale tagging (several hundred fish).
- *What is the amount of fish entering the channel?* This question can be answered with a limited number of tagged fish (e.g. 30 per species) released just downstream of the passage required, but the answer would then be limited to the immediate surroundings of the passage.
- *What is the behaviour of target species in front of the entrance?* (e.g. surface or bottom swimming depending on flow speed). This question is important, in particular for the design and positioning of a fish ladder. Since it deals with fish movements in three dimensions, observing the behavior of a limited number of fish needed (5–10 per species) already allows getting a good idea of their behaviour.

Do fish pass the obstacle?

Two sub-questions can be considered here:

- *Can fish cope with flow conditions in the fishway?* The answer can be positive if 20–50 tagged fish can pass it.
- *Is the passage effective for population sustainability*? Answering this question implies assessing the significance of the number of tagged fish passing the obstacle compared to the number of fish initially tagged (what proportion of all fish reaches the fishway exit? which species or size classes reach the fishway exit?). Answering the latter question requires tagging a large number of fish to ensure that statistical power reaches 0.8 (1,000 fish tagged or more).

Do fish survive the passage?

Two sub-questions can be considered here:

- *Do fish continue their migratory journey after the fishway (and the impoundment)?*
- *Are fish populations sustained despite the dam or thanks to fish passage improvement?*

These are large-scale questions in a vast environment; it is necessary to tag a large number of fish (>1,000) to realistically answer these questions.

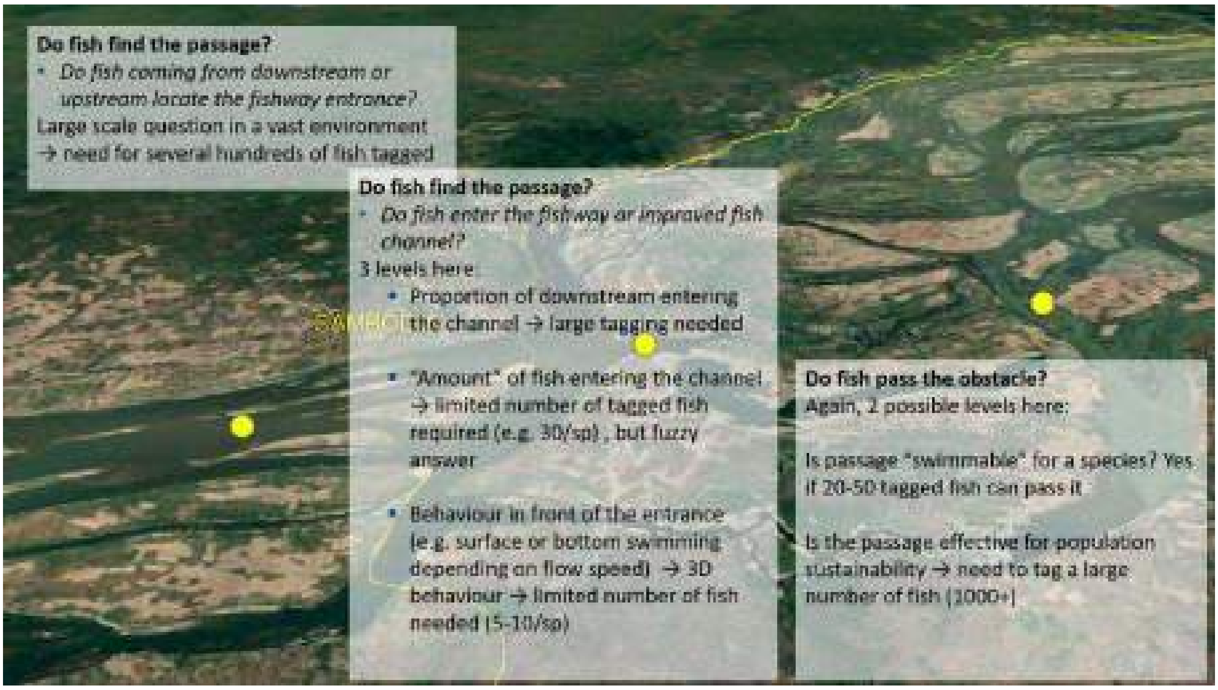

Figure 5.34. Amount of fish to be tagged depending on the management questions asked

d. Costing of options and adjustments

Finally, the design of a tagging programme requires the costing of options and of logistics involved (procurement, power supply, maintenance, etc.)

5.5.2. Making choices

Thus, it is technically impossible to determine *what are the best methods for a given site*, *how many fish should be tagged* or *what methods are financially feasible* without starting with an identification of the management question(s) to be tackled as a priority from the perspective of MRC countries. It is only once the priority objectives of the study have been clearly identified by the management body commissioning the study that choices can be made:

- Selection of study sites, target species, tagging methods and study dates
- Review of logistical requirements (what, how, where, by whom)
- Detailed budgeting, practical adjustments.

The approach for JEM might be to identify budget hypotheses according to which some tagging experiments can be developed. In any case, tagging is an approach that will allow to answer specific questions (e.g. use of a fishway) for specific target fish species, but should not be expected to answer generic questions about fish populations' sustainability. These fish tagging methods are recommended primarily in the Mekong for HPP developers to monitor the effectiveness and efficiency of their fishways and adaptive management of the operation of dam projects and their fishways.

5.5.3. Securing fish supply

Securing the supply of the fish that will be tagged is an important part of the entire tagging process. In order to ensure that the supply of non-damaged fresh fish that will survive the tagging and have a good chance of passing the obstacle, the procedure implies identifying the least damaging live fish capture method among those locally available. This in turn might influence the selection of the target species (a species that should be abundant and catchable by non-damaging gears). Gillnets usually wound fish by damaging their scales, so electrofishing or traps should be preferred.

More generally, securing the entire live fish supply chain (who, where, when?) is a key requirement.

The last point to be considered is stocking live fish before tagging (where, how, how long?).

5.5.4. Testing methodologies

Since tagging is always site-, device- and species-specific, testing methodologies are essential before recapture rates can be considered an accurate reflection of the biological reality, and not the result of a tagging bias. Testing includes:

- Preliminary study of live fish survival (before being tagged)
- Preliminary study of fish survival to tagging
- Lab testing of antenna design and performance
- Field testing of antenna performance.

5.5.5. Tagging

Tagging can be a logistically heavy process, which implies defining the conditions of this activity:

- When, where, how long, by whom and logistical, sanitary and staffing aspects.
- Post-tagging fish keeping for recovery: where can fish be kept while they recover from the surgery?

5.5.6. Releasing tagged fish

Tagging is usually done in a safe environment with water supply, tanks, electricity, and proper sanitary conditions. As a consequence, the protocol must also consider how fish will be transported back to the river after tagging and the recovery period.

5.5.7. Monitoring tags

Monitoring tags implies defining when these tags will be monitored (seasonal or permanent monitoring), where (selection of sites, see above), for how long (short-term experiment, seasonal study of migration pulses, or multi-annual study [survival of tagged fish over the years, return to breeding sites, etc.]). Monitoring also implies defining who will monitor fish, or at least collect the monitoring data from receptors and recorders, and ensure the maintenance of this equipment.

5.5.8. Analysing data

Analysing data is a key element of the chain of activities in tagging. This implies clarifying at the beginning of the study how tag signals will be processed, how tag data will be converted into computer data, and more generally, how data will be cleaned and mapped or analysed to produce statistically valid conclusions.

5.5.9. Reporting

The end point of the above chain of activities is reporting, i.e. answering the questions initially asked – and often identifying knowledge gaps and requirements for further studies.

Finally, this review also underlines the relevance of initiating, in complement to electronic tagging, a tagging experiment based on traditional external spaghetti tags. After a testing phase about survival, this tagging could involve a few hundred fishes of species selected among the 10 species identified during the local knowledge survey (see section 5.3.3), the collaboration of the fishers who are already partners of the FADM monitoring, as well as a larger-scale awareness programme about tags and rewards for other fishers of the Khone Falls area.

6. Database

6.1. Hydrology and sediment monitoring database

The hydrology and sediment component of the JEM database has been developed to include the following parameters:

- Hydrology and hydraulics: Channel width, channel area, total discharge, average flow velocity
- Sediments: Average suspended sediment concentrations (SSC), moving bed velocity (from moving bed test), bed material grain-size and grain-size distribution of suspended sediment

The database will also contain links to the original ADCP and data submission forms to allow review and interrogation of all results.

The database manager has requested that all of the historic (2009–2019) results, and the first year of JEM results be entered into a compatible spreadsheet prior to the data being uploaded to the database. To date, the historic (2009–2018) results have been input to the database for most of the JEM sites. Much of the 2019 data have been reviewed and put through a QA/QC process and have been entered. Together with some of the 2018 results, this work is time-intensive and ongoing.

All JEM results reported through 10 March 2021 have been incorporated into the worksheets along with the historic results, and this worksheet has been used as the basis for analysis for the information contained in this report. When the outstanding monitoring results for 2020 are received, the worksheets will be finalised, and the data uploaded into the JEM database.

6.2. Water quality monitoring database

The water quality monitoring database has been structured to include the following parameters:

- ID; StationID; station name; CollectedBy; CollectedDate; Year; Month; Time start
- TEMP_°C ; pH; TSS_mg/L; COND_mS/m; Ca_meq/L; Mg_meq/L; Na_meq/L; K_meq/L;
- ALK_meq/L; Cl_meq/L; SO4_meq/L; NO2_mg/L; NO32_mg/L; NH4N_mg/L; TOTN_mg/L; PO4P_mg/L; TOTP_mg/L
- Turbidity; chlorophyll-a; cyanobacteria;
- DO_mg/L; CODMN_mg/L; BOD; FC _MPN/100ml
- Al_mg/L; ACID_meq/L; LinkForm;
- Remarks – weather and river conditions

A second form covers the probe measurements for depth profiles within the impoundments for:

- TEMP_°C ; pH; COND_mS/m; DO_mg/L; (down to 20 m);
- Turbidity; chlorophyll-a; cyanobacteria; (down to 10 m).

Data entry from field report forms include the field probe readings for the surface waters and impoundment profiles, and the notes on weather and river conditions. When the laboratory analysis results come in every quarter, they are copied into the data entry form and entered into the database.

The unified site codes for the Don Sahong WQ monitoring sites have been allocated, and the details are shown in Table 6.1. together with notes showing correlation with sampling stations from other disciplines.

The data from five monthly sampling occasions (October 2020 to February 2021) has been entered into the database.

In addition, the historic data from selected routine WQMN stations on the Mekong mainstream between 2010 to 2019 has been entered into the database. These routine WQMN sites are shown in Table 6.2.

6.3. EHM database

The structure of the EHM database has recently been completed, following the review of the EHM species lists and historic data from the biennial bioassessment monitoring. The EHM structure consists of two data entry forms:

- **Level 1** – This contains the consolidated data on presence of species in each sampling station from each year – StationID; Station Name; Species_ID; Species Name; SamplingDate; Year; SurveyBy; A (Ave. No. Individuals counted per sample); B (No. of +ve samples per site).
- **Level 2** – This contains the calculated analysis from the species list raw data and environment parameters – StationID; Station Name; Year; Country; Altitude; Width; Depth; Secchi; Temp; DO; pH; Cond; SDS (Site Disturbance Score)
- For each of the four parameters (benthic diatoms, zooplankton, littoral and benthic macroinvertebrates): sample occasions (no. of samples taken at site); Average Abundance; Average Richness; ATSPT; 10th Percentile and 90th Percentile threshold guideline; Abundance Index; Richness Index; and ATSPT Index (numbers of times the threshold guideline is exceeded).
- From the last three parameters, the database will estimate the EH Index for each site.

The unified site codes for the Don Sahong EHM monitoring sites were allocated, and the details are shown in *Table 6.1*, together with notes showing correlation with sampling stations from other disciplines.

No data have yet been entered into the database, because this structure has only recently been agreed. The historic data from the routine biennial EHM sites on the Mekong mainstream (Table 6.3) will be entered in the near future.

Table 6.1. Unified monitoring station codes for water quality and EHM stations for Don Sahong pilot

SiteCode	LocationID_Short	LocationID_Long	AQTS	SiteName	River	UTM_N	UTM_E	Lat	Lon	Notes
013306	LA_013306	LA_013306_[JEM_WQ6]	LA_013306_[Don Sahong_Thakho]	Upstream of Don Sahong Dam, at the impoundment inlet point	Mekong	13°58'41.8"	105°57'16.2"	13.97827778	105.9545	Shared the same code to the LIDU and Shared WQ and EHM code
013306	LA_013306	LA_013306_[JEM_EHM7]	LA_013306_[Don Sahong_Thakho]	Upstream of Don Sahong Dam, at the impoundment inlet point	Mekong	13°58'42.6"	105°57'07.4"	13.9785	105.9520556	
013307	LA_013307	LA_013307_[JEM_WQ7]	LA_013307_[Don Sahong_Impoundment]	Within the impoundment (around 600 m upstream of the dam wall)	Mekong	13°56'38.8"	105°57'42.5"	13.94411111	105.9618056	This one will have two separate water quality readings a) surface water and b) depth profile down to 20 m
013307	LA_013307	LA_013307_[JEM_EHM8]	LA_013307_[Don Sahong _Impoundment]	Within the impoundment (around 600 m upstream of the dam wall)	Mekong	13°56'40.1"	105°57'43.6"	13.94447222	105.9621111	Shared with WQ code
013308	LA_013308	LA_013308_[JEM_WQ8]	LA_013308_[Don Sahong_DonSadam]	Downstream of Don Sahong (around 250 m downstream of the dam)	Mekong	13°56'31.7"	105°57'15.8"	13.94213889	105.9543889	Shared the same code to the HFWQM at the downstream of DSHPP
013308	LA_013308	LA_013308_[JEM_EHM9]	LA_013308_[Don Sahong_DonSadam]	Downstream of Don Sahong (around 250 m downstream of the dam)	Mekong	13°56'33.0"	105°57'15.2"	13.9425	105.9542222	Shared the same code to the HFWQM at the downstream of DSHPP
013309	LA_013309	LA_013309_[JEM_WQ9]	LA_013309_[Don Sahong_DonSadam2]	Downstream Monitoring #2 of Don Sahong (around 700 m downstream of the dam)	Mekong	13°56'14.7"	105°57'25.7"	13.93741667	105.9571389	Shared the same code to the JEM's FADM and FLDM sites
013309	LA_013309	LA_013309_[JEM_EHM10]	LA_013309_[Don Sahong_DonSadam2]	Downstream Monitoring #2 of Don Sahong (around 700 m downstream of the dam)	Mekong	13°56'19.1"	105°57'19.9"	13.93863889	105.9555278	Shared the same code to the JEM's FADM and FLDM sites

Table 6.2. Routine WQMN sites on Mekong mainstream

CCode	StationID	LocationCode	Location ID	Location Name	River	Lat	Lon
LA	010500	LA_010500	LA_010500_[Houa Khong]	Houa Khong	Mekong	21.55	101.16
TH	010501	TH_010501	TH_010501_[Chiang Saen]	Chiang Saen	Mekong	20.27	100.09
LA	011200	LA_011200	LA_011200_[Luang Prabang]	Luang Prabang	Mekong	19.9	102
LA	011901	LA_011901	LA_011901_[Vientiane KM4]	Vientiane KM4	Mekong	17.93	102.62
TH	013101	TH_013101	TH_013101_[Nakhon Phanom]	Nakhon Phanom	Mekong	17.43	104.77
LA	013401	LA_013401	LA_013401_[Savannakhet]	Savannakhet	Mekong	16.56	105.74
TH	013801	TH_013801	TH_013801_[Khong Chiam]	Khong Chiam	Mekong	15.32	105.49
LA	013900	LA_013900	LA_013900_[Pakse]	Pakse	Mekong	15.12	105.78

CCode	StationID	LocationCode	Location ID	Location Name	River	Lat	Lon
KH	014501	KH_014501	KH_014501_[Stung Treng]	Stung Treng	Mekong	13.53	105.95
KH	014901	KH_014901	KH_014901_[Kratie]	Kratie	Mekong	12.48	106.02

Table 6.3. Routine EHM sampling sites on Mekong mainstream most relevant to the JEM pilot sites

CCode	SiteCode	LocationID_Short	LocationID_Long	SiteName	River	UTM_N	UTM_E	UTMZone	Lat	Lon
LA	010402	LA_010402_[LMX]	LA_010402_[LMX_Ban Xiengkok_Luangnamtha]	Ban Xiengkok, Luangnamtha	Mekong	2311778	670860	47Q	20.89810652	100.6385659
TH	010502	TH_010502_[TCS]	TH_010502_[TCS_Chiang Saen]	Chiang Saen	Mekong	614706	2240577	47N	5.358335802	114.5191676
LA	010702	LA_010702_[LPB]	LA_010702_[LPB_Done Chor_Luang Prabang]	Done Chor, Luang Prabang	Mekong	2206957	206113	48Q	19.93691586	102.1924987
LA	011905	LA_011905_[LVT]	LA_011905_[LVT_Ban Huayhome_Vientiane]	Ban Huayhome, Vientiane	Mekong	1988731	239871	48Q	17.9712965	102.5437788
TH	013103	TH_013103_[TNP]	TH_013103_[TNP_Nakorn Phanom]	Nakorn Phanom	Mekong	476351	1926537	48N	4.202870674	117.7482043
LA	013902	LA_013902_[LDN]	LA_013902_[LDN_Done Ngew_Champasak]	Done Ngew, Champasak	Mekong	1657517	596193	48P	14.99092917	105.894687
KH	014702	KH_014702_[CKT]	KH_014702_[CKT_Stung Treng_Ramsar Site]	Stung Treng Ramsar Site	Mekong	618663	1504098	48N	5.527686616	114.0283106
KH	014001	KH_014001_[CMR]	KH_014001_[CMR_Kampi Pool_Kratie]	Kampi Pool, Kratie	Mekong	610914	1393502	48N	5.472601657	113.0399921

Note: LA 013902 (LPB) and KH 014702 (CKT) are the two routine MQMN sites closest upstream and downstream of Don Sahong HPP, respectively.

6.4. Fisheries database

The database is designed for the current stations:

FADM-IEM

Site ID	Country	Province	District	Village	Site Code	location	N	E
CJDC1	Cambodia	Stung Treng	Thala Borivath	O'Svay Village	CJDC	Downstream o	13°54'4.63"N	105°57'52.34"E
CJDC2	Cambodia	Stung Treng	Thala Borivath	O'Svay Village	CJDC	Downstream o	13°54'4.63"N	105°57'52.34"E
CJDC3	Cambodia	Stung Treng	Thala Borivath	O'Svay Village	CJDC	Downstream o	13°54'4.63"N	105°57'52.34"E
LJDD1	Laos	Lhampasak	Khong	Hang Khone	LJDD	Downstream o	13°56'15.59"N	105°56'54.32"E
LJDD2	Laos	Lhampasak	Khong	Hang Khone	LJDD	Downstream o	13°56'15.59"N	105°56'54.32"E
LJDD3	Laos	Lhampasak	Khong	Hang Khone	LJDD	Downstream o	13°56'15.59"N	105°56'54.32"E
LJDU1	Laos	Lhampasak	Khong	Saen Nue	LJDU	Upstream of D	14° 5'51.11"N	105°47'2.18"E
LJDU2	Laos	Lhampasak	Khong	Saen Nue	LJDU	Upstream of D	14° 5'51.11"N	105°47'2.18"E
LJDU3	Laos	Lhampasak	Khong	Saen Nue	LJDU	Upstream of D	14° 5'51.11"N	105°47'2.18"E

Figure 6.1. Sampling stations pre-identified in the FADM database

In its current state dated 8 January 2021, the database contains 69 records corresponding to 69 fishing operations, all from Cambodia. For each fishing operation, the catch is detailed by species, with subsequent details (305 individual records). This sampling harvested 50 species among 1,316 individuals.

CountryNam	DateFishing	Site	GillnetID	Habitat	Total_Catch	Catch_Samp	Water_level	Width(m)	Height(r
Cambodia	07-Nov-20	CJDC3	3	Mekong	0.06		Rising	42	

SpeciesCode	SpeciesName	N_fish	Mesh_size	Weight	Maximum_L	Price	Sample
62	Henicorhynchus siamensis	10	20	0.03	9	3000	No
149	Hypsibarbus wetmorei	2	40	0.02	8	3000	No
44	Hypsibarbus malcolmi	1	40	0.01	8	3000	No
0		0	0	0	0	0	

CountryNam	DateFishing	Site	GillnetID	Habitat	Total_Catch	Catch_Samp	Water_level	Width(m)	Height(r
Cambodia	14-Nov-20	CJDC1	1	Mekong	0.27		Falling	112	
Cambodia	14-Nov-20	CJDC2	2	Mekong	0.25		Falling	78	
Cambodia	14-Nov-20	CJDC3	3	Mekong	0.66		Rising	42	
Cambodia	21-Nov-20	CJDC1	1	Mekong	0.4		Falling	112	
Cambodia	21-Nov-20	CJDC3	3	Mekong	0.34		Rising	42	

SpeciesCode	SpeciesName	N_fish	Mesh_size	Weight	Maximum_L	Price	Sample
55	Puntioplites falcifer	1	30	0.1	7	3500	No
62	Henicorhynchus lobatus	13	20	0.12	9	3500	No
44	Hypsibarbus malcolmi	1	40	0.12	9	2500	No
0		0	0	0	0	0	

CountryNam	DateFishing	Site	GillnetID	Habitat	Total_Catch	Catch_Samp	Water_level	Width(m)	Height(r
Cambodia	28-Nov-20	CJDC1	1	Mekong	0.73		Falling	112	
Cambodia	28-Nov-20	CJDC2	2	Mekong	0.73		Falling	78	
Cambodia	28-Nov-20	CJDC3	3	Mekong	0.31		Rising	42	
Cambodia	03-Dec-20	CJDC3	3	Mekong	0.5		Rising	42	

Figure 6.2. Example of records in the FADM database

The team recommends having the species list of the database updated to reflect recent changes in the taxonomy, particularly for major species such as the former *Henicorhynchus*. The current reference manuals for species in Cambodia and Lao PDR are So et al. (2018), Praxaysombath et al. (2020) and Tran et al. (2013). The latest publications should also be considered, particularly Ciccotto and Page (2020).

7. Procurement

The equipment for the project was procured across three countries, with the equipment in general (but not always) targeting the two pilot sites being used to test the JEM guidelines.

7.1. Adjustments

Since the beginning of the JEM project, there have been several adjustments to the procurement. Table 7.1 shows the original procurement scope for equipment related to the Don Sahong pilot site, compared with the current status of procurement, including removals, changes and additions to the procurement.

Table 7.1. Routine equipment procurement for JEM Pilot projects

Original equipment list	Pilot site	Revised equipment list	Notes
HYCOS Station, Cambodia	Don Sahong	✓	Installed
	Don Sahong	Added – Bed material sampler-Cambodia	Delivered
Camera (x1), Cambodia.	Don Sahong	✓	Delivered
Flow meter (x1), Cambodia	Don Sahong	Adjusted to 2 metres	Delivered
	Don Sahong	Added – ADCP cable	Delivered
	Don Sahong	Added – a computer (laptop)-Cambodia	Delivered
D-96 (Lao PDR)	Don Sahong	Removed	-
	Don Sahong	Added – high-frequency water logger,[3] water level monitor and rain gauge –Lao PDR	Procurement underway
	Don Sahong	Added – bed material sampler – Lao PDR	Delivered
ADCP, Lao PDR	Don Sahong	For Pakse DSM Team	Delivered
Boat and engine, Lao PDR	Don Sahong	✓	In LPB, awaiting delivery to Pakse
Bongo Net (x1) Cambodia	Don Sahong	Removed	-
Conical Larvae net (x1) Cambodia	Don Sahong	Removed	-
Fish tags (x1,200) Lao PDR	Don Sahong	Revised equipment requirements	
Fish tag receivers (x30) Lao PDR	Don Sahong	Revised equipment requirements	
Fish trapping equipment for fish tagging – Lao PDR	Don Sahong		

[3] The original project TOR included a high frequency water quality logger (HFWQL) to be installed downstream of Xayaburi. This HFWQL was removed from the project because there was no suitable location for installing it. The HFWQL+ that has been added for the Don Sahong site replaces the HFWQL that was reported as removed in the Xayaburi site report.

Original equipment list	Pilot site	Revised equipment list	Notes
	Don Sahong	Added – Acoustic transmitters, V7 & V13 (x 60)	Procurement process commenced
	Don Sahong	Added – VR2W acoustic receivers (x14)	Procurement process commenced
	Don Sahong	Added – dummy acoustic transmitters (for training, x 100)	Procurement process commenced
	Don Sahong	Acoustic tag accessories and tools	Procurement process commenced
	Don Sahong	PIT tags, receivers, training dummies, tools and accessories	Details for procurement being prepared
	Don Sahong	Surgical and lab equipment	Details for procurement being prepared

Table 7.1 shows that there has been substantial variation in the procurement from the original project procurement plan, with three items removed, three items added, and three items whose quantities and specifications have been revised. The three main reasons for adjustments to procurement of Don Sahong-related equipment are as follows:

a) Changes in project requirements led to additional equipment procurement (e.g. outboard motor for LPB monitoring boat, high frequency water quality logger, and rain gauge and water level monitor, ADCP cable).

b) Due to difficulties in defining equipment requirements, some equipment was not procured under the project (e.g. Bongo Net, conical net).

c) There were requests from national monitoring teams for equipment to support their monitoring activities (e.g. ADCP cable).

7.2. Achievements

Despite the restrictions imposed due to COVID-19 and the adjustments to procurement based on the three key factors outlined above, the project successfully completed the procurement of all the originally specified non-fish tagging equipment.[4] The fish tagging component of the project is being completed by a consortium led by Charles Sturt University, with funding from Australia's Department of Foreign Affairs and Trade. The fish tagging procurement process through ICEM began in January 2021 and is expected to be complete by June 2021.

7.3. Lessons learned

Procurement is time-consuming. The original project workplan indicated that it would begin in December 2019 and be complete in time for a procurement report to be delivered in March 2020. Given the complexities of procurement, this timeline was unrealistic even without the impact of

[4] All the original non-fish tagging equipment that has not been removed from the procurement list.

COVID-19. In addition to the changes in procurement during the project, the following three factors also affected procurement:

a) COVID-19 impacts delayed procurement and shipping processes.

b) The decision to add an external contract for Charles Sturt University meant that fish tag procurement did not begin until January 2021;

c) There was different understanding and management of tax exemption processes across the three target countries.

The lesson learned from this is that future projects should allow for changes in project requirements, changes in equipment specifications, and other factors to impact on procurement timelines. Project planning should take these into account and plan for less-than-ideal delivery of equipment.

8. Conclusion

This first report on the monitoring of the JEM pilot sites around the Don Sahong HPP presents the results of the period between October 2020 and February 2021. Monitoring missions, which had been anticipated to start in the second quarter of 2020, were delayed due to COVID-19 restrictions.

The first nine months of the JEM pilot project monitoring provided good results at the ST-UP, SKB and ST site, although monitoring at Pakse was delayed to some extent. However, the preliminary hydrological data from the JEM pilot project in southern Lao PDR and northern Cambodia allow some indications of the Don Sahong and other power station operations. Although data are limited to one month (February 2021) at the new Koh Key water level recording site, the results show strong similarities with the flow pattern at Pakse. There is no indication that the operation of the Don Sahong HPP is altering flows in the mainstream Mekong downstream of the project.

Water level fluctuations have increased at the ST water level recording site, with a substantial change in the distribution of flow changes between 2016 and 2019 and in 2020. These changes must be associated with inflows from the Sekong River, and likely reflect power station operations at the Lower Sesan II HPP. Although the range and frequency of fluctuations has increased relative to 2016, the water level changes are below the 5 cm/hour limit recommended in the MRC Hydropower Mitigation Guidelines (MRC, 2020). The fluctuations are limited to periods of relatively low flow in the river, as would be expected.

Discharge monitoring at the ST-UP, SKB and ST sites shows a good balance, with the ST flow equivalent to the sum of discharge at the two upstream stations. There is good agreement between the discharge measured by ADCP in 2020 and the predicted flow based on the 2013 rating curve, but it is likely that the flows are underestimated due to the measurements not being corrected for the moving bed of the river.

SSC concentrations and loads were low at all sites in 2020 compared to previous years, although SSC results are only available through September, and more results are required to capture the entire wet season. SSC loads show a fair balance across the monitoring sites, with differences likely attributable to the heterogeneity of sediment transport in the Sekong, and incomplete mixing in the Mekong at ST. An uneven distribution of sediment in the cross-section will prevent the collection of representative SSC samples. Estimated SSC loads based on a discharge/SSC rating curve suggest that the annual load at ST could be in the range of 21 to 23 Mt/yr, which are the lowest loads recorded since monitoring began in 2011. The previous range was from 28 Mt/yr in 2015 to 99 Mt/yr in 2013.

The water quality measurements at the Don Sahong sampling stations appeared to be comparable to the normal seasonal patterns, with temperature following decreasing air temperatures and increasing conductivity as flows fall. When the water quality results between the stations above in the impoundment and downstream are compared each month, there is little difference in parameters such as dissolved oxygen, pH, COD, and faecal coliforms, which indicates that the Don Sahong impoundment and operation are not affecting water quality. However, turbidity and TSS do not show obvious patterns with passage downstream in different months. TSS results show variable patterns from similar levels in TSS passing through the impoundment and downstream (October 2020), to a marked decrease downstream compared to water flowing into the impoundment (November and December 2020). There is a recognized correlation between turbidity and TSS, but these TSS results do not follow the decreasing turbidity measurements with passage through the impoundment. An attempt was made to link the TSS and turbidity readings with flows passing through the two dams at the times of sampling, but water level and flow data were not available for those times and days. This needs to be investigated further, with more comparisons of the two readings over time, and by taking measurements of TSS at all JEM sites rather than at selected sites under the present regime.

There should also be a correlation between suspended solids concentration (SSC) and TSS, but because of differences in sampling and analytical methods, the correlation is not as strong as might be expected. TSS, which was developed for wastewater analysis, tends to underestimate the sediment being transported, especially the larger sand particles, while SSC is considered to be more reflective of all the sediments being transported (Gray et al. 2000).With the limited results to date, it is difficult to make any comparisons between the two sets of data being collected at similar sites and dates, but as more data are collected, this will be an area for comparative assessments.

The nutrient analysis at the Don Sahong site is an area for concern as oxides of nitrogen and total nitrogen tend to be higher than the mean levels recorded for the Mekong as a whole, albeit with little change between upstream, in the impoundment and downstream sites. As further results of both the routine WQMN and the JEM come in, it will be necessary to discern whether this is a river basin trend as a whole or peculiar to the two hydropower pilots. Similarly, the very high levels of total phosphate recorded in December at both pilot sites will need to be checked for recurrence and possible sources identified.

Chlorophyll-a and cyanobacteria are low, with little change between the different sites above and below the impoundment, indicating no trends towards eutrophication and well below the WHO thresholds for human health hazard. Depth profiles indicate that the water within the Don Sahong impoundment appear to be well mixed and do not show any stratification.

The 2020 annual bioassessment monitoring at the sites around Don Sahong had to be cancelled due to COVID-19, and the 2021 bioassessment campaign has not yet started. The historic biennial Ecological Health Index scores from 2011 to 2019 for the LDN (Done Ngew, Champassak) and CKT (ST Ramsar site) sites were calculated. These are the two sites on each side of the Don Sahong dam. The LDN site lies over 100 km upstream of EHM6, and the CKT lies about 50 km downstream.

The results of the historic EHI show that there has been a variability in the EHI at LDN from Class A in 2011 to Class C in 2013 and 2015, with improvement to Class B between 2015 and 2019. At ST the EHI condition is more consistently good, with Class B in 2013, Class A in 2015, and Class B in 2017 and 2019. It would be expected that without the dam, the EHI for the Don Sahong sites would reflect or improve upon the EHI condition for LDN, depending on developments and flow changes between LDN and Don Sahong. With the dam in place, the EHI in the impoundment is likely to change due to the changed flow and water level conditions, and in the downstream the EHI is likely to deteriorate due to the daily fluctuations in flow rate and water level.

The fisheries FADM results from the Don Sahong sites in Lao PDR are not yet available, and some preliminary analysis from the FLDM data in the Cambodian rainy season data shows that between 28 and 45 species belonging to 16 families were collected in each sampling site. The families with the most species diversity are cyprinids (up to 25 species per sampling site), Pangasiidae and Bagridae (up to 4 species) and Siluridae (up to 3 species). The presence among larvae of taxa not common as adults (e.g. Chandidae, Gobiidae, Sisoridae, Soleidae) confirms the relevance of the larvae monitoring for a more comprehensive assessment of the biodiversity. There is a large difference in the samples collected from the different banks and sampling points, e.g. 45% more species on the right bank than on the left bank in Preah Romkel in Cambodia. This confirms the relevance of sampling in a diversity of points for a given site. The difference between families and species found near Don Sahong site and those that have been sampled over the years near Phnom Penh and in the Tonle Sap will require substantial time before teams have absorbed that diversity and data can be compared. An analysis of the local geomorphology and flow conditions at larvae sampling sites may be useful for understanding these differences, although this information will probably not be available from the specific JEM hydrological and sediment monitoring sites.

The local knowledge survey of fishers to investigate the movements of 10 selected species through the different channels at Don Sahong has just started but has already provided some preliminary indications of the important channels for fish migration. This will complement the review of fish tagging options to allow the selection of the appropriate methods for fish passage monitoring to answer fisheries management questions, both through the channels of Don Sahong and for more conventional fish passage around other dams.

The aim of the JEM database is to facilitate comparisons and correlations between the findings of the five disciplines at different sampling stations and times. As the database becomes populated with more data than are currently available, future study and reports will explore the possibilities of these linkages.

9. References

Ciccotto, P.J., and Page, L.M. (2020). Revision of the Genus Henicorhynchus, with a revised diagnosis of Gymnostomus (*Cyprinidae: Labeoninae). Copeia*, 108(3), 485–502. https://doi.org/10.1643/CI-19-304

Gray, J. R., Glysson, G. D., Turcios, L. M., & Schwarz, G. E. (2000). *Comparability of suspended-sediment concentration and total suspended solids data*. USGS Water-Resources Investigations Report 00-4191.

Hortle, K. G., Chea, T., Bun, R., Em, S., Thac, P. (2006). *Drift of fish juveniles and larvae and invertebrates over 24-hour periods in the Mekong River at Phnom Penh, Cambodia*. In T.J. Burnhill and M.M. Hewitt (Eds.). *Proceedings of the 6th Technical Symposium on the Mekong Fisheries, 26th-28th November 2006* (Pp. 19-33). MRC Conference Series No. 5. Mekong River Commission, Vientiane, Lao PDR.

Koehnken, L. (2015). *Discharge Sediment Monitoring Project (DSMP) 2009–2013 Summary & Analysis of Results*. Final Report. Report for the MRC Secretariat.

Mekong River Commission [MRC]. (1995). *1995 Mekong Agreement and Procedures*. Mekong River Commission.

MRC. (2018). The Council Study. *Modelling the impacts of climate change and development infrastructure on Mekong flow, sediment regimes and water quality.* Modelling Volume 1 Summary report. Retrieved 24 February 2021, from https://www.mrcmekong.org/assets/Publications/Council-Study/Modelling-the-impacts-of-climate-change_Council-Study.pdf

MRC. (2020). The MRC Hydropower Mitigation Guidelines. *Guidelines for hydropower environmental impact mitigation and risk management in the Lower Mekong mainstream and tributaries*. Vol. 3, Vientiane, MRC Secretariat.

MRC. (2021a). Mekong River Commission Data Portal. *Time-series Inventory*. Retrieved 15 February, 2021, from https://portal.mrcmekong.org/time-series/water-level

MRC. (2021b). *Procedures for the Maintenance of Flows on the Mainstream.* Stung Treng – 6A for monitoring purposes. Rated discharge. Retrieved 15 February 2021, from https://pmfm.mrcmekong.org/monitoring/6a/stung-treng/

MRC (2021c). *Procedures for the Maintenance of Flows on the Mainstream*. Stung Treng – 6C for monitoring purposes. Rated discharge. Retrieved 15 February, 2021, from https://pmfm.mrcmekong.org/monitoring/6c/stung-treng/

Nguyen, T.T., Nguyen, N. D., Vu, V. A., Truong, T. T. (2006). *Monitoring of fish larvae during the annual flood of the Mekong and Bassac Rivers, Mekong Delta, Viet Nam*. In T.J. Burnhill and T.J. Warren. (Eds). *The proceedings of the 7th Technical Symposium Mekong Fisheries, 15–17 November 2005* (pp. 71-87). MRC Conference Series No. 6. Mekong River Commission, Vientiane, Lao PDR.

Praxaysombath, B., Utsugi, K., Phongsa, K., Nammanivong, M., Vannachak, V., Phommacanh, K., Phommavong, T., Phoutthana, V., Duangthasy, V., Latsamy, S. (2020). *Fishes of the Mekong Basin of Lao PDR*. Biology Department, Faculty of Natural Sciences, National University of Lao PDR, Vientiane, Lao PDR.

Putrea, S. (2003). *Distribution of fish larvae and juveniles in Lungvek canal, Kandal Province, Cambodia*. In A. Poulsen, (Ed.). *Proceedings of the 5th Technical Symposium on the Mekong Fisheries, 11–12 December 2002* (pp. 43–56). MRC Conference Series No. 4. Mekong River Commission, Phnom Penh, Cambodia.

Rügner, H., Schwientek, M., Beckingham, B. et al. (2013). Turbidity as a proxy for total suspended solids (TSS) and particle facilitated pollutant transport in catchments. *Environ Earth Sci*, 69, 373–380. https://doi.org/10.1007/s12665-013-2307-1

So, N., K. Utsugi, K. Shibukawa, P. Thach, S. Chhuoy, S. Kim, D. Chin, P. Nen. and P. Chheng. (2018). *Fishes of Cambodian Freshwater Bodies*. Inland Fisheries Research and Development Institute, Fisheries Administration, Phnom Penh, Cambodia.

Someth, P., Seebacher, F., Khem, S., Kong, S., Preap, S. (2013). *Preliminary analysis – Rating curves for mainstream and tributaries of the Mekong River*. Information and Knowledge Management Programme (IKMP), Mekong River Commission Secretariat (MRCS).

Tran, D.D., Shibukawa, K., Nguyen, P.T., Ha, H.P., Tran, L.X., Mai, H.V., Utsugi, K. (2013). *Fisheries of the Mekong Delta, Vietnam.* Can Tho University Publishing House, Can Tho, Vietnam.

10. Annexes

10.1. ANNEX 1 on Fisheries: Report on three fisheries training events and initial revision of protocols in fisheries

MRC. (2020). Mekong River Commission - Piloting a Joint Environmental Monitoring (JEM) Programme on Two Mekong Mainstream Dams: The Don Sahong Hydropower Project and the Xayaburi Hydropower Project: Report on three fisheries training events (February – March 2020). Vientiane, Lao PDR.

10.2. ANNEX 2 on Fisheries: JEM Pilots technical note. Mounting of gillnets for the JEM monitoring of fishery resources (29/03/2020)

10.2.1. Introduction

The FADM guidelines (Cowx et al., 2019) and the JEM programme noted that existing monitoring throughout the region does not use standardized gears, methodologies or systematic sampling strategy for assessment of status and trends in fish stocks. This resulted in the decision to implement a standardized, multi-panel, multi-mesh gillnets set in a systematic spatial and temporal framework.

The draft JEM guidelines (MRC, 2019) recommend the use of a graded fleet of panels of mesh sizes connected at random,[5] ranging from 12 mm to 150 mm (12, 16, 22, 35, 45, 57, 73, 93, 115, 118, 150 mm), each gillnet panel being 5-m long, 2–3-m deep, mounted at a hanging ratio of 50%.

The inception report of the ICEM JEM pilots study (MRC 2020) notes that the mesh sizes recommended in the JEM guidelines include sizes that are not found on markets (e.g. 12, 57, 73 or 93 mm) and recommends a revised and updated list of mesh sizes.[6]

A meeting with project partners on 27 February 2020 in Luang Prabang resulted in the collegial decisions to:

- better distribute mesh sizes;
- use common mesh sizes only;
- increase number of panels to 14;
- use the following mesh sizes: 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150 mm (stretched mesh dimensions)
- set the width of each panel to 8 m (14 nets x 8 m = 112 m);
- keep other parameters unchanged (i.e. 2.5 m height, 50% mounting ratio).

One last question left open was the distribution of mesh sizes in each net (arrangement of nets in the fleet sequence): Should panels be connected together by order of sizes, randomly, or with a certain pattern among mesh sizes?

[5] There seems to be a contradiction between the terms ‘graded’ (i.e. arranged gradually, sorted or classified) and “connected at random”.

[6] The set of nets prepared in Cambodia was 25, 35, 45, 70, 90, 115, 120,145, 160, 185 and 200 mm, i.e. 11 x 10 m-long nets, with 2.5-m high.

The literature review below aims, after a brief overview of sampling with gillnets, at answering this question.

10.2.2. Background information on gillnets

10.2.2.1. Terminology

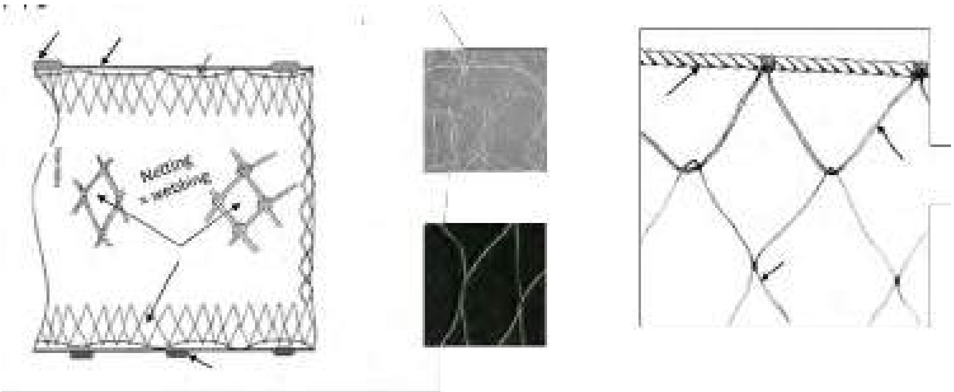

Figure 10-1: Main terms used in gillnet making (1/2)

In JEM and FADM, gillnets are made of nylon monofilament.

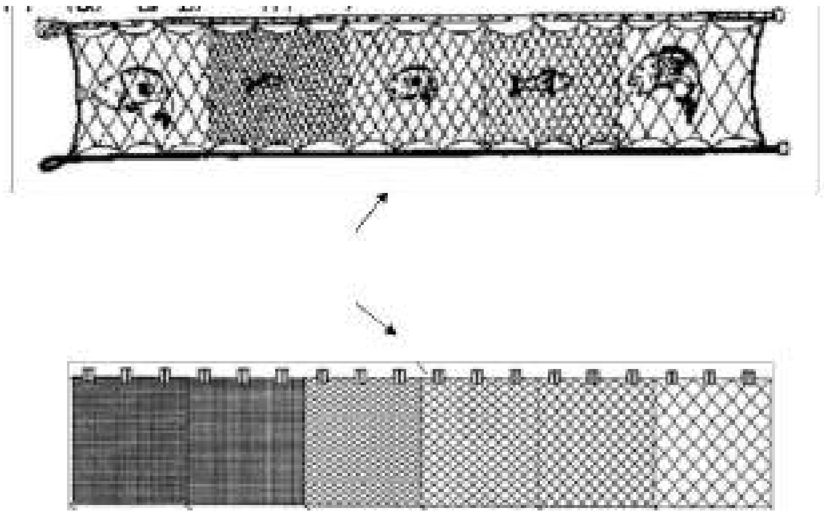

Figure 10.2. Main terms used in gillnet making (2/2)

In JEM and FADM, the fleets are made of 14 panels. Each panel is 8-m long and 2.5-m high (total length: 112 m).

10.2.2.2. Measuring mesh sizes

There are two ways to measure mesh sizes: 'knot to knot' (= bar mesh = mesh side), or 'stretched mesh'. Both are commonly used. The measurement of a stretched mesh is twice that of the mesh side (stretched mesh = 2 bar mesh). It is therefore important to always specify the measure standard used.

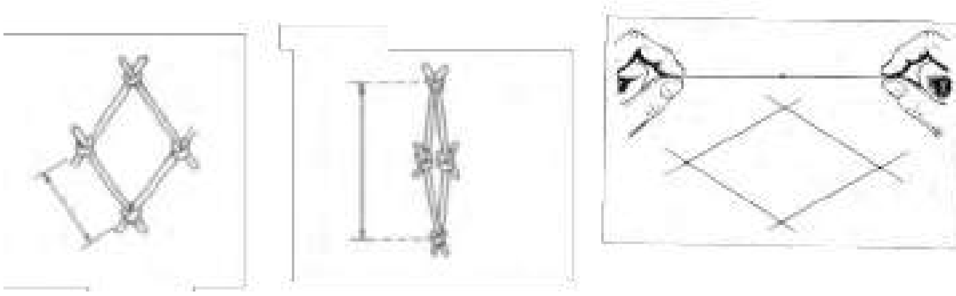

Figure 10.3. Measuring gillnet mesh size

In JEM and FADM, the measure used (also used by Mekong fishers) is 'stretched mesh'.

10.2.2.3. Mounting ratio

The mounting ratio is the ratio between the length of stretched net and the length of rope it is mounted on (E = rope length/net length). This defines the looseness of the net.

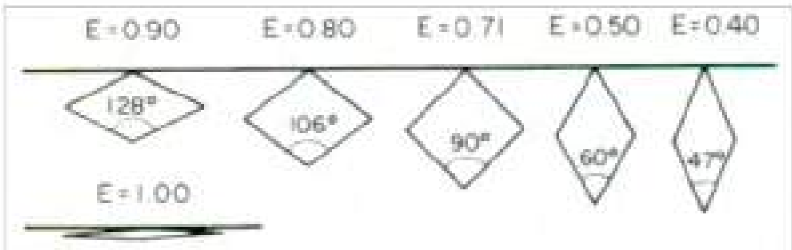

Figure 10.4. Gillnet mounting ratios = hanging ratios

The most common mounting ratio E is 50%. If E < 50%, the net will be loose and will catch a higher diversity of species (e.g. bottom nets); if E > 50%, the net will be more stretched and more selective (e.g. drift nets).[7]

In the JEM Programme and FADM, the mounting ratio is 50% (i.e. 16 m of net on 8 m of rope).

[7] In stretched nets, fishes are mainly gilled (i.e. caught by the gills) or wedged (caught by the largest part of the body), whereas in loose nets they can also be snagged (caught by the mouth, teeth or jaw bones) or entangled (caught by head, spines or fins).

10.2.2.4. Relationship between filament diameter and mesh size

Large meshes require a thicker filament (= yarn) than small meshes. In principle, the ratio between filament diameter and mesh size should be 0.005 to 0.01. This ratio varies between 0.0025 (nets used in quiet waters) and 0.02 (drift nets, bottom nets).

In JEM and FADM, there is no requirement about filament diameter (we use netting from the market in which filament diameter is usually proportional to mesh size).

10.2.2.5. Height of a gillnet in water and CPUE calculation

A net hanging in water is looser than when it is stretched. The formula relating hanging height to stretched height is:

Hanging height in water = height of stretched meshes x square root of [1 - (mounting ratio)^2].

Thus, if a net as a stretched height of 2.5 m and its mounting ratio is 0.5, its height in water (i.e. when fishing) is: 2.5 x √ (1 - 0.25) = 2.5 x 0.866 = 2.17 m.

The looseness of a gillnet in operation is to be integrated to the calculation of CPUE, as the unit effort is a square area of net <u>fishing</u>.

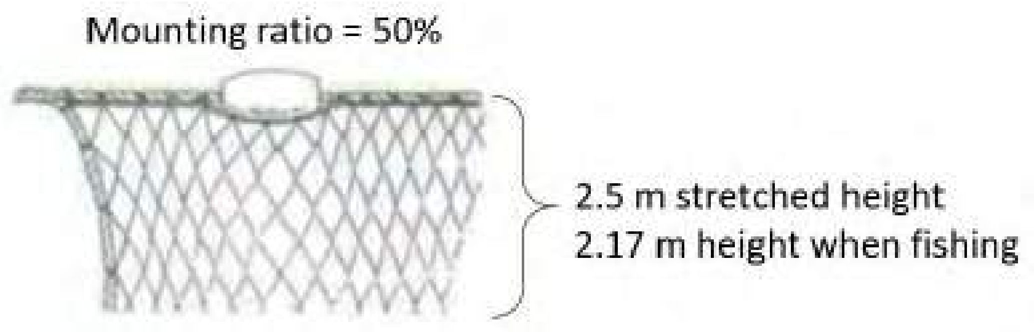

Figure 10.5. Height of a gillnet in operation

In JEM and FADM, calculation of CPUE should consider that the nets in operation in water are 2.17-m high, not 2.5-m high.

10.2.2.6. Mesh size and size of fish caught

The Fridman formula indicates the relationship between mesh size and size of fish caught:

Length of the fish (mm) = K x stretched mesh size (mm)

L = K.m

where K is a coefficient depending on the species shape:

- long narrow fish: K = 5
- average fish: K = 3,5
- high or wide fish: K = 2,5

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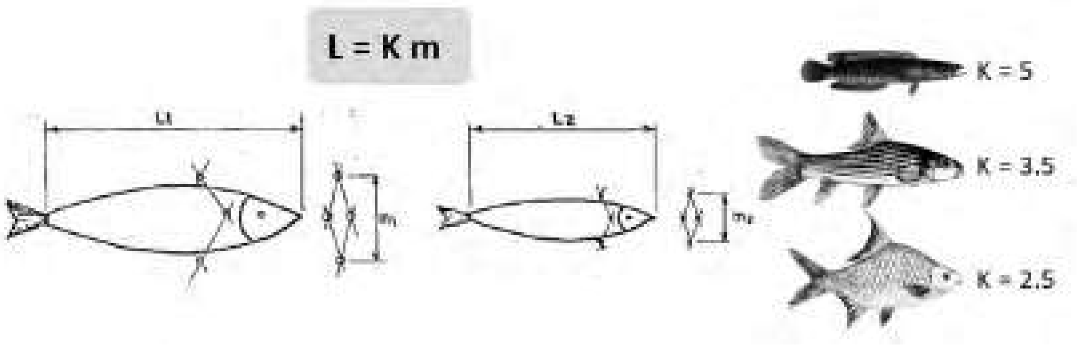

Figure 10.6. Mesh sizes and size of fish caught, depending on their body shape

Sources: Prado and Dremière (1988); Thomas (2008).

10.2.2.7. Factors affecting gillnet selectivity

An overview of the 20 factors or more affecting gillnet selectivity is proposed by Holst et al. (1998):

Table 10.1. Parameters affecting gillnet selectivity

Gear parameters	Fishing parameters	Fish parameters
• Gang and net dimensions • Mesh size • Twine/filament diameter • Hanging ratio • Floatation • Soaking time • *Arrangement of nets in the fleet sequence*	• Handling techniques • Water current • Bottom type • Depth • Environmental parameters (turbidity, vegetation, bank shape, etc.) • Debris • Light level	• Fish behaviour towards the net • Fish size • Fish shape (girth) • Presence of predators • Net saturation

Gear parameters can be standardized, but the diversity of fishing parameters (and of fish parameters in distant sites) makes a strict standardization of fishing operations impossible.

In JEM and FADM, the impossibility of standardizing fishing parameters led to the decision to allow fishers to set standardized nets according to their preference, under the assumption that they always try to maximize fish catch.

10.2.2.8. Selection of mesh sizes for scientific sampling

Several authors noted that the variance in fish length selectivity curves increases with mesh size (large mesh sizes can sometimes catch small fish, but small mesh sizes cannot catch large fish; see Hamley [1980]).

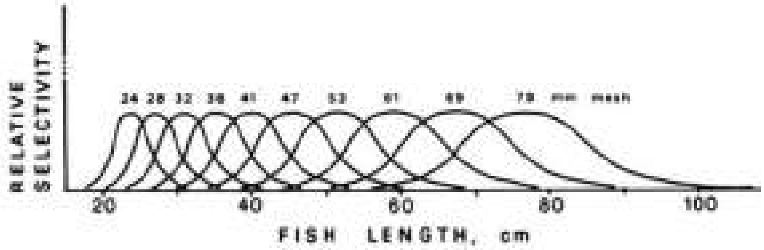

Figure 10.7. Fish length selectivity curves for different mesh sizes

Source: Hamley 1980.

Šmejkal et al. (2015) show actual distribution curves of mesh-specific length frequency distributions for reservoir fish.

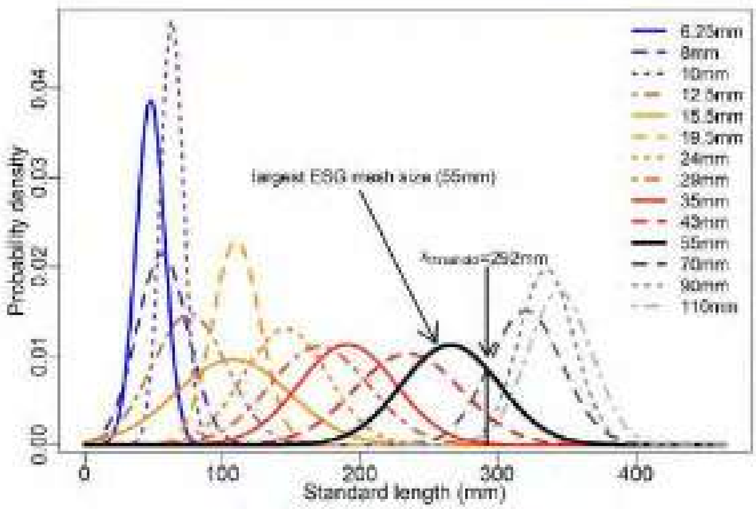

Figure 10.8. Fish length selectivity curves for different mesh sizes

Source: Šmejkal et al. 2015.

For this reason, optimal sampling requires that mesh sizes in a gang of panels increase following a geometric series (e.g. 5, 6.25, 8, 10, 12.5, 15.5, 19.5, 24, 29, 35, 43, 55, with a factor of 1.25 between meshes; see Appelberg et al. [1995]). This set of mesh sizes is now the norm for fish monitoring in Europe (CEN, 2005), although Šmejkal et al. (op. cit.) recommend adding larger mesh sizes to this set (70, 90, 110 and 135 mm knot-to-knot).

In practice, Holst et al. (1998) note that the commercial availability of the different mesh sizes often leads to the use of arithmetic series (e.g. 10, 20, 30, 40, 50 mm). The latter arithmetic progression was also commonly used in large-scale monitoring studies anterior to the CEN 2005 norm (e.g. Lévêque et al. [1988]).

In JEM and FADM, the reliance on netting available in markets in the region imposes the use of mesh sizes following an arithmetic series (20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150 mm stretched mesh).

The use of 120, 130, 140 and 150 mm stretched meshes (= 60, 65, 70 and 75 mm knot-to-knot) meets the recommendation to extend the range of mesh sizes defined by CEN (2005).

10.2.3. Order of mesh sizes in a multi-mesh net

Scientific sampling with gillnets and the selectivity of these nets have generated hundreds of publications. However, the arrangement of nets in the fleet sequence is mentioned in very few publications, and when it is, it can be either ascending, mixed (i.e. repeated sets of ascending mesh sizes in one fleet), or random. Examples are provided in Table 10-1.

Table 10.1. Distribution of gillnet mesh sizes in different studies

Authors	Mesh sizes	Panel dimensions (i.e. per mesh size)	Total net size	Order of sizes	Location
Lévêque et al. 1977	15, 20, 25, 30, and 40 mm	Sets of 5 mesh sizes (1 m length each) repeated 5 times per fleet. 5 m length per mesh size, 2 m height	25 m	Mixed sets, ascending in a set	West African rivers
Barbier 1985	10, 14, 22, 26, 30, 34, 37, 40, 44, 50 and 55 mm	Sets of 11 mesh sizes (2.5 m length each) repeated 4 times per fleet. 10 m length per mesh size, 2 m height	110 m	Mixed sets, ascending in a set	Switzerland
Lamberts 2001	10, 20, 30, 40, 50, 60, 70, 80 and 100 mm knot to knot	10 m length, 2 m height	90 m	Ascending	Tonle Sap (Cambodia)
Tejerina-Garro and de Merona 2001	15, 20, 25, 30, 35, 40, 50, 60 and 70 mm knot to knot	25 m length, 2 m height.	225 m	Ascending	Sinnamary River (South America)
Appelberg 2000, CEN 2005	5, 6.25, 8, 10, 12.5, 15.5, 19.5, 24, 29, 35, 43, and 55 mm knot to knot	2.5 m length, 1.5 m height	30 m	Random	Europe
Argent and Kimmel 2005	38, 64, 89, 114, 140 mm bar mesh	7.62 m length, 2.4 m height	38 m	Ascending	Ohio (USA)
Næsje et al. 2007	10, 12, 16, 20, 25, 32, 39, 48, 58, 70, 86, 110 mm stretch mesh	2.5 m length, 1.5 m height	30 m	Random	Orange River (Namibia)
Pengal et al. 2013	42, 20, 6.5, 10, 55, 12, 24, 16, 35, 30 mm.	20 m length, 2.5 m and/or 5 m height	200 m	Random	Adriatic Sea (Slovenia)

Overall, the CEN (2005) European standard, based on the NORDIC model (Appelberg, 2000) and using a randomized distribution of panels, is underpinned by extensive testing. However, the reason for randomization of mesh sizes is not given. Even reviews of fish behaviour in relation to gillnets (e.g. Potter and Pawson, [1991]) do not address the order of mesh sizes in scientific sampling. Fishers usually do not use multi-mesh gillnets, because they prefer to target specific species with one mesh size; their experience offers little insights in this case.

Barbier (1985) hypothesizes that the juxtaposition of large and small mesh sizes reduces the catch potential of small mesh sizes when a large fish is caught in large meshes, but this hypothesis is not tested. He also recommends splitting each fleet of nets into two sub-fleets: one of small mesh sizes, and one of large mesh sizes.

10.2.4. Conclusions

In absence of any clear-cut conclusion in the bibliography analysed about the arrangement of nets in the fleet sequence, we recommend following the norm for gillnet fish monitoring in Europe (CEN, 2005), i.e. random distribution of panels in the fleet.

A randomization process on the range of 14 JEM mesh sizes[8] produced the following series:

110	120	80	150	70	100	40	130	20	90	140	60	30	50

It is therefore recommended to mount all JEM multi-mesh gillnets in the following order:

110 mm

120 mm

80 mm

150 mm

70 mm

100 mm

40 mm

130 mm

20 mm

90 mm

140 mm

60 mm

30 mm

50 mm.

This order of mesh sizes is now fixed and should remain constant for all fleets of the JEM gillnet monitoring protocol.

[8] Generation of 14 random numbers using MS Excel, and rearrangement of JEM mesh sizes based on this series.

10.2.5. References

Appelberg, M. (2000). *Swedish standard methods for sampling freshwater fish with multi-mesh gillnets*. Fiskeriverket Information 2000:1. Institute of Freshwater Research, Drottningholm, Sweden.

Appelberg, M., Berger, H.M., Hesthagen, T., Kleiven, E., Kurkilahti, M., Raitaniemi, J. & Rask, M. (1995). Development and intercalibration of methods in Nordic freshwater fish monitoring. *Water air and soil pollution.* 85(2), 401–406.

Argent, D. G. & Kimmel, W.G. (2005). Efficiency and selectivity of gillnets for assessing fish community composition of large rivers. *North American Journal of Fisheries Management.* 25. 1315–1320.

Barbier, B. (1985) *Les techniques de capture*. Engins passifs: les filets maillants. In D. Gerdeaux & R. Billard (Eds.) *Gestion piscicole des lacs et retenyes artificielles* (pp. 81–90). Institut National de Recherche Agronomique, Paris.

CEN (Comite Européen de Normalisation), (2005). *Water quality - sampling of fish with multi-mesh gillnets.* European standard EN-14757. European Committee for Standardization, Brussels, Belgium.

Cowx, I.G., Nuon, V. & So, N. (2019). *Standard Sampling Guidelines for Fish Abundance and Diversity Monitoring in the Lower Mekong Basin*. Mekong River Commission, Vientiane.

Hamley, J.M. (1980). *Sampling with gillnets*. Chapter 4 in Backiel T. and Welcomme R. L. (eds). *Guidelines for sampling fish in inland waters*. EIFAC Tech. Pap. n° 33.

Holst, R., Madsen, N., Fonseca, P., Moth-Poulsen, T. & Campos, A. (1998). *Manual for gillnet selectivity*. European Commission and ConStat, The North Sea Centre, Hirtshals, Denmark.

Lamberts, D. (2001). *Tonle Sap fisheries: a case study on floodplain gillnet fisheries in Siem Reap, Cambodia.* FAO Regional Office for Asia and the Pacific, Bangkok, Thailand. RAP Publication 2001/11

Lévêque, C., Fairhurst, C.P., Abban, K., Paugy, D., Curtis, M.S. & Traore, K. (1988). Onchocerciasis control programme in West Africa: ten years monitoring of fish populations. *Chemosphere*, 17(2), 421-440

Lévêque, C., Odei, M. & Pugh, T. M. (1977). *The Onchocerciasis Control Programme and the monitoring of its effect on the riverine biology of the Volta River Basin*. In F.H. Perring & K. Mellanby (Eds). *Ecological effects of pesticides* (pp. 133–143). Academic Press, London, UK.

MRC. (2019). Joint Environment Monitoring of Mekong mainstream hydropower projects (draft version 3.0 – April 2019). Environmental Management Division, Mekong River Commission, Vientiane.

MRC. (2020). Mekong River Commission - Piloting a Joint Environmental Monitoring (JEM) System on Two Mekong Mainstream Dams: The Don Sahong Hydropower Project and the Xayaburi Hydropower Project. Inception Report. Vientiane, Lao PDR.

Næsje, T.F., Hay, C.J., Nickanor, N., Koekemoer, J., Strand, R. & Thorstad, E.B. (2007). *Fish populations, gillnet catches and gillnet selectivity in the Orange River, Namibia, from 1995 to 2001*. NINA report n°231. Norwegian Institute for Nature Research, Trondheim, Norway.

Pengal, P., Jenič, A., Pajk, N. & Toman, M. J. (2013). A new design of multi-mesh survey gillnets to sample fish community in the Adriatic Sea. *Acta Adriat*., 54(2). 169 - 182.

Potter, E.C.E. & Pawson, M.G. (1991). *Gillnetting*. Laboratory leaflet n° 69. Directorate of Fisheries Research, Lowesoft, UK.

Prado, J. & Dremière, P.Y. (1988). *Guide pratique du marin pêcheur.* Division des industries de la pêche, FAO. Techn. & Documentation – Lavoisier. Paris.

Šmejkal, M., Ricard, D., Prchalová, M., Říha, M., Muška, M., Blabolil, P., et al. (2015). Biomass and Abundance Biases in European Standard Gillnet Sampling. *PLoS ONE*. 10(3). DOI: 10.1371/journal.pone.0122437

Tejerina-Garro, F.L., & de Merona B. (2001). *Gill-net sampling standardisation in large rivers of French Guiana (South America)*. [Bulletin] Francais de la Peche et de la Pisciculture, 227–240.

Thomas, S.N. (2008). *Gillnets and their operation*. In Training manual on design and operation of responsible fishing gear (pp 129–144). Central Institute of Fisheries Technology, Cochin, India.

10.3. ANNEX 3 on Fisheries: Revised JEM methodology for fish sampling with standardized multiple panel gillnets (28 May 2020)

10.3.1. Terminology

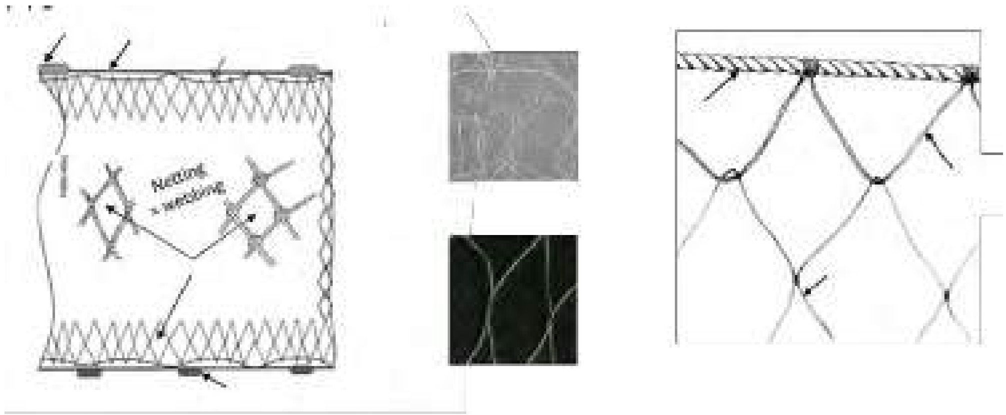

Figure 10.9. Terminology used in gillnet fishing and sampling

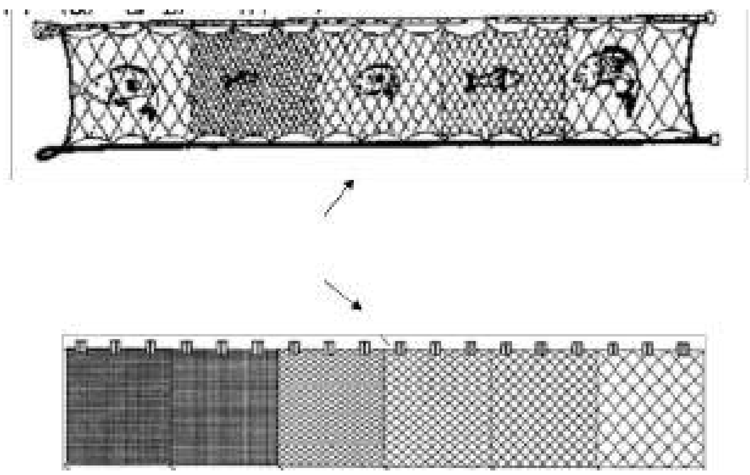

Figure 10.10. Terminology used for multi-mesh gillnets

In JEM and FADM the measure of the mesh size (also used by Mekong fishers) is ‘stretched mesh’.

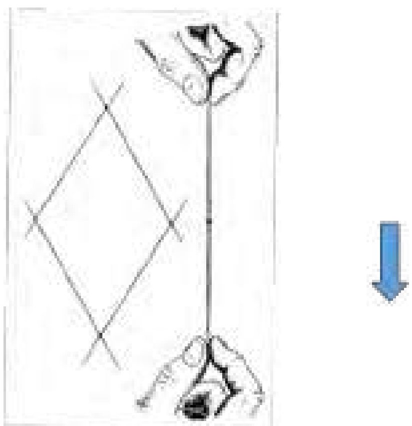

Figure 10.11. Measuring mesh size

10.3.2. Nets used

The multiple panel gillnets protocol consists in sampling fish using a standardized set of 14 panels of different mesh sizes.

The mesh sizes are 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120; 130, 140, and 150 mm (stretched mesh).

JEM follows the norm for gillnet fish monitoring in Europe (CEN 2005), i.e. **randomized fixed distribution of panels in the fleet**. Thus, all the nets of the series should be distributed as follows:

110 mm	**120 mm**	**80 mm**	**150 mm**	**70 mm**	**100 mm**	**40 mm**	**130 mm**	**20 mm**	**90 mm**	**140 mm**	**60 mm**	**30 mm**	**50 mm**

The net mounting ratio should be 50%.

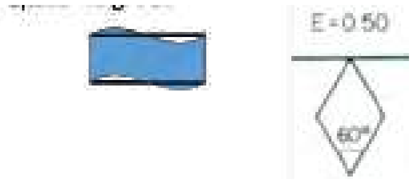

Figure 10.12. Principle of 50% mounting ratio

In each monitoring site, each panel of each fleet should be given a **Panel ID= letter + mesh size**. Example: A20, A30, A40, B20, B30, B40, C20, etc.

Identification of nets (Panel ID)

In each monitoring site, **each fleet of nets should be identified by a letter (A, B, C)**. **Each panel in a fleet should have a float indicating its fleet letter and mesh size** (e.g. A20 for “fleet A mesh size 20 mm”, B80 for “fleet B mesh size 80 mm”, etc.). This panel ID allows the quick identification of fleets and mesh sizes for data entry.

Figure 10.13. Identification of net fleets and panels

10.3.3. Monitoring sites

Xayaburi

Upstream: Pha O

In the impoundment: Tha Deua

Downstream: Pak Houng

Don Sahong

Upstream: Muang Saen Nua in Lao PDR

Downstream: Ban Hang Khone in Lao PDR

Plus

Upstream: Ban Hat and Ban Hang Sadam in Lao PDR

Downstream: Ou Run in Cambodia

10.3.4. Where to set the nets in a monitoring site

Fishers should decide in each site and season what is the best place to set the nets. The nets can be set along the bank or across the flow, along rocks or between islands: it is up to fishers to decide in each place, depending on hydrological conditions, season, habitats or migrations. Fishers should not try to catch specific high value species, but only to maximise each time the abundance and diversity of fishes. **The objective of sampling should be to maximise the abundance and diversity of the catch.**

10.3.5. When to set the nets in a monitoring site

Multiple panel gillnets should be set **three times a week in each monitoring site, each week of the year.** Nets should be **set in the evening (16:00–18:00) and retrieved the following morning (06:00-08:00)**.

10.3.6. Catch recording

No subsampling is done.

The reporting is prepared by panel, and then by species.

Catches should be recorded using the form below.

1) **panel ID** is recorded (i.e. fleet letter and mesh size of the panel);
2) for each species. the **fish code** and/or **local fish species name** are entered;
3) the **total number of fish for that species in that panel** is noted;
4) the **total weight of all the fish of that species in that panel** is noted.

   Weights should be expressed in grams (not kg). For weighting, a suspension scale is recommended and not a electronic scale because of batteries and water issues;
5) the **length of the largest individual fish of that species in that panel** is noted.

   The length measured should be the standard length (fork length).

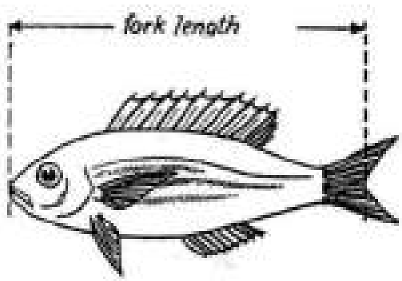

Figure 10.13. Weighting and measuring fish

STANDARD GILLNET MONITORING FORM

Village name: [ ]

Fisher name: [ ]

Date (dd/mm/yy)

Date of net setting:	Date of net checking:

Time

Time of net setting:	Time of net checking:

Habitat:

Floodplain	Lake	Mekong River	Mekong tributary	Pond	Rice field	Stream

Total catch (grams): [ ]

Water level:

○ Rising
○ Static
○ Falling

Weather:

○ ○ ○ ○

CATCH BY PANEL

Panel ID	Fish code	Fish local name	Number of fish	Weight of all fish (grams)	Standard length (cm) of the largest fish by species by panel

Additional sheets:

Village name:

Fisher name:

Date (dd/mm/yy) Date of net setting:

CATCH BY PANEL

Panel ID	Fish code	Fish local name	Number of fish	Weight of all fish (grams)	Standard length (cm) of the largest fish by species by panel

ANNEX 4 onFisheries: Testing of multiple panel gillnet lengths for fish sampling (29 May 2020)

10.3.7. Introduction

The "Standard sampling procedures for fish abundance and diversity monitoring in the Lower Mekong Basin" (Cowx et al., 2019) states in section 6.5.2. (*Standardised gillnet surveys*[9]) that:

1. multi-panel, multi-mesh size gillnets will consist of a graded fleet of 11 panels connected at random;
2. each gillnet panel will be 2–3 m deep and 5 m long;
3. each panel will be repeated at least once for each mesh size;
4. the result will be a multi-panel gillnet of approximately 110 m.
5. the different mesh panels should be joined so that there is no gap between panels.

Point 1 (each net is made of 11 panels) and #2 (each panel is 5-m long, i.e. 11 x 5=55 m for the whole net) apparently contradict point 4 (a resulting multi-panel gillnet of approximately 110 m), unless point 3 is integrated (each panel is repeated at least once). However, integrating point 3 (each 5-m panel for a given mesh size is present twice) implies that the total net is made of 22 panels, which contradicts point 1.

This leaves three possibilities for a standard fleet of 11 mesh sizes:

- 11 panels of 5m for a total length of 55 m;
- 11 panels of 10 m for a total length of 110 m;
- 22 panels of 5m, distributed at random, for a total length of 110 m.

Interactions with MRC staff in early 2020 indicated that the length of panels should be 10 m, not 5 m, while their height should be 2.5 m. Further interaction (see JEM technical note – Mounting gillnets) led to the decision to include 14 mesh sizes rather than 11, i.e. **14 panels and mesh sizes, not 11**.

During training on FADM sampling in Luang Prabang in February 2020, the desirable length of nets was discussed. Several arguments were confronted by the participants:

1) 'Enough net' needs to be used to catch 'enough fish' to accurately represent the fish community in the area surveyed (mainly species diversity and relative abundance per species, the sampling bias due to using gillnets being acknowledged).
2) How much 'enough fish' is remains unclear, but can be approached through exhaustive fishing, i.e. fishing as much as possible during one test survey and comparing with the catch of a more limited fishing effort or lower length of net.
3) Fishers in Cambodia and Lao PDR commonly use several hundred metres of gillnets, sometimes as much as 1,000 m, to catch "enough fish" for their livelihood.

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[9] *"Thus, standard, multi-panel, multi-mesh size gillnets will be used on all occasions. Each of these will follow a basic design consisting of a graded fleet of panels of mesh sizes ranging from 12 mm - 150 mm (12, 16, 22, 35, 45, 57, 73, 93, 115, 118, 150 mm) connected at random. Nets larger than 200 mm mesh are not used in order to avoid the capture of large individuals of rare species, such as the larger catfishes, which are important for maintaining stocks. Each gillnet panel will be 2–3 m deep and 5 m long and will be mounted at a hanging ratio of 50% and repeated at least once for each mesh size, thus creating a multi-panel gillnet of approximately 110 m. Filament diameter should be 0.28 mm–0.4 mm diameter from larger to small meshes although this may be revised based on detailed design and manufacturers' data. The different mesh panels should be connected prior to deployment from the boat and where possible should be joined so there is no gap between panels."*

4) Regardless of the total length used, more fish is caught when units of nets are smaller and can adapt to local river configurations (e.g. across a curve in the bank, along a crest of rocks or across a channel).

5) Experience shows that long stretches of continuous net (i.e. 100- or 150-m long) become subject to water current and can be carried away and lost.

The latter reason led to the recommendation to limit the total size of the 14 panels to 14 x 8 m = 112 m maximum, instead of 14 x 10 m = 140 m.

However, some debate remained about the optimal total length of net to be used, and it was decided to undertake a test study with different lengths.

10.3.8. Testing gillnet length

Mesh sizes (mm) and order of panels:

110 120 80 150 70 100 40 130 20 90 140 60 30 50

as previously decided. In all cases, panels should be tied together, in order to constitute one single netting, with **no gap between panels**, as rightly recommended in Cowx et al. (2019).

Length of nets

Several options are possible. Depending on budget, it is recommended to **test at least three of the options below**, classified by order of preference:

1) One 112-m long multiple panel gillnet consisting of 14 panels (8 m each)
    - this is the default option.
2) **Two** 56-m long multiple panel gillnets consisting of 14 panels (4 m each);
    - in this case, the sampling unit remains 112 m of multiple panel gillnet, but for fishing, the total length is split in two in order to avoid water current problems, and possibly maximize the catch.
3) One 112-m long multiple panel gillnet made of **28 panels** (4 m each with *each mesh size represented by two panels,* as recommended in Cowx et al. [2019]).
4) One 70-m long multiple panel gillnet consisting of 14 panels (5 m each).
5) One 42-m long multiple panel gillnet consisting of 14 panels (3 m each).
    - This total length is expected to be too short for a sufficient catch, but can be tested.

For testing accuracy, it is important to test:

- these **3 or more options together during the same night,**
- **during 3 consecutive nights.**

The lumped catch of all gears together will constitute the 'exhaustive fishing', representing the maximum fishing effort possible (i.e. 3, 4 or 5 sets of multiple panel gillnets). The catch of each option (species diversity and abundance per species) can then be related to the maximum fishing effort possible, and thus provide an estimate of the representativeness of the catch of each option. This will allow in particular to distinguish:

- the efficiency of 2 sets of 56 m (as one sampling unit) vs. 1 set of 112 m;
- the efficiency of 1 set of 28 panels vs. 1 set of 14 panels.

Testing during three consecutive nights -while **changing the order of nets in the different locations**- will allow minimizing the aleatory high or low catch of any given fishing session, and the location effect (some sites being better fishing places, with more fish around).

10.4. ANNEX 5 on Fisheries: Report on three fisheries training events and initial revision of protocols in fisheries

10.4.1. Number of species selected

In a place characterized by 201 fish species in 39 families, including 110 species harvested by fishers, it is not possible to survey ecological knowledge about all migratory species. Furthermore, the survey aims at documenting not individual species but the main passage strategies and capabilities. As such, it covers abundance, size, timing, migration behaviour, passage routes and spawning. This corresponds to 30–35 questions by species. The time spent with fishers (a few hours for each interview), the time available for analysis, and the need to design a questionnaire, and the potential usability as a JEM routine later on all led to limiting the number of species to 10 (10 species x 35 question = 350 questions per interview). These 10 species are representative of large groups of other species that migrate through Khone Falls.

10.4.2. Criteria for species selection

- species migrating through Khone Falls, with broad migration patterns already mapped (MRC Mekong Fish Database);
- species already identified by the MRC for transboundary management (10 priority fish species identified at MRC Joint Workshop on transboundary species management in May 2016; 5 species identified and choses in 2017 as five priority fish species for Transboundary Management);
- species making a significant percentage of catches in Khone Falls fisheries (based on 6 years of monitoring, Baran (2005);
- clear migration patterns, to simplify the discussion with fishers;
- migration at different times of the year, in different water levels (important for flows in fish passage and the selection of tagging methods;
- species sensitive to discharge and flow velocity, i.e. to the conditions at fish passes (Baran 2006);
- species belonging to different size groups (important in relation to the selection of swimming ability, and to tag options.

10.4.3. Final result: 10 species selected

Cirrhinus microlepis (paphone mak kok)	*Hypsibarbus malcolmi* (papak nouat/pa pak kom/pa pak)
Cyclocheilos enoplos (pa chok).	*Pangasius conchophilus* (pa pho/pa ke)
Gymnostomus lobatus (pa soi houa lem)	*Pangasius krempfi* (pa souay hang leuang)
Gymnostomus siamensis (pa soi houa po)	*Pangasius macronema* (pa gnone siap)
Helicophagus leptorhynchus	*Scaphognathops bandanensis* (pa pian)

10.4.4. Conclusion

The species selected all migrate through Khone Falls. They migrate at different times of the year, in different water levels (important for flows in fish passage and the selection of tagging methods. They belong to different size groups (important in relation to the selection of swimming ability, and to tag options). They exhibit clear migration patterns for most species.

These species are representative of the six main groups of species that migrate through Khone Falls.

10.4.5. References

Baird I. G. (2001). *Aquatic biodiversity in the Siphandone wetlands*. pp. 61–74. In Daconto, G. (Ed.) (2001). *Siphandone wetlands*. Publication of the project Environmental protection and community development in Siphandone wetlands. CESVI Cooperazione e Sviluppo, Bergamo, Italy.

Baran, E. (2006). *Fish migration triggers in the Lower Mekong Basin and other tropical freshwater system*. MRC Technical Paper n° 14. Mekong River Commission, Vientiane, Lao PDR.

Baran, E., Baird, I.G. & Cans, G. (2005). *Fisheries bioecology at the Khone Falls (Mekong River, Southern Lao PDR).* WorldFish Center.

MFD (Mekong Fish Database). (2003). Mekong River Commission: Mekong Fish Database. A taxonomic fish database for the Mekong Basin. Mekong River Commission, Vientiane, Lao PDR. CD-Rom.

MRC. (2017). *Transboundary fisheries management issues in the Mekong and Sekong Rivers.* Mekong River Commission, Vientiane, Lao PDR.

Table 10.2. Process: species reviewed, criteria used, selection and justifications

Species	Priority Fish Species for Transboundary Management (MRC 2017)	One of the 10 MRC Priority Species identified in May 2016	Percentage of catches in Khone Falls fisheries over 6 years	Family and size	Migration mapped	Migration pattern	Sensitivity to discharge	Conclusion
Barbonymus altus	-	X	-	Small - medium cyprinid	No	Big migration peak in Dec-March, small one in June	Very high	Not selected
Cirrhinus microlepis	x	x	0.6	Medium-large cyprinid	Yes	two peaks (one for dry and one for wet season)	Very high	Selected
Cyclocheilos enoplos	-	-	1.2	Large cyprinid	Yes	Peak at the beginning of the rainy season	High	Selected
Gymnostomus lobatus	-	x	17.3	Small cyprinid	Yes	Two peaks, Dec.–Feb. upstream, June-July downstream	Low	Selected
Gymnostomus siamensis	-	x	2.2	Small cyprinid	Yes	Two peaks, Dec.-Feb. upstream, June–July downstream	Low	Selected
Helicophagus leptorhynchus	x	x	-	Medium size cyprinid	No	-	-	Selected

Species	Priority Fish Species for Transboundary Management (MRC 2017)	One of the 10 MRC Priority Species identified in May 2016	Percentage of catches in Khone Falls fisheries over 6 years	Family and size	Migration mapped	Migration pattern	Sensitivity to discharge	Conclusion
Hemibagrus spilopterus	-	x	-	Medium size Bagridae	No	-	-	Not selected
Hypsibarbus malcolmi	-	x	0.9	Medium-large cyprinid	No	Two peaks, in December and May	High	Selected
Hypsibarbus wetmorei	-	x	-	Medium-large cyprinid	No	Two peaks, in December (small) and May (large)	-	Not selected
Labeo chrysophekhadion	-	X	-	Large cyprinid	No	Two peaks, in December (small) and May (large)	Medium	Not selected
Labiobarbus leptocheilus	-	X	1.7	Medium size cyprinid	No	-	-	Not selected
Mekongina erythrospila	x	x	1.4	Small Cyprinid	No	-	-	Selection not recommended by Dr So Nam
Pangasius conchophilus	x	x	11.5	Large Pangasiid	Yes	Peak in May–June	High	Selected
Pangasius krempfi	-	-	14.0	Large Pangasiid	Yes	Peak in June	High	Selected

Species	Priority Fish Species for Transboundary Management (MRC 2017)	One of the 10 MRC Priority Species identified in May 2016	Percentage of catches in Khone Falls fisheries over 6 years	Family and size	Migration mapped	Migration pattern	Sensitivity to discharge	Conclusion
Pangasius larnaudii	x	x	0.8	Large Pangasiid	No	Peak in May–June	High	Selection not recommended by Dr So Nam
Pangasius macronema	-	X	7.9	Small Pangasiid	Yes	April–July, peak in June	High	Selected
Paralaubuca typus	-	X	11.4	Small cyprinid	-	Peak in Jan.–March	Very high	Selection not recommended by Dr So Nam
Puntioplites falcifer	-	x	0.5	Medium size cyprinid	-	Small peak in Jan.–Feb., high peak in May	Medium	Not selected
Scaphognathops bandanensis	-	x	3.4	Medium size cyprinid	-	2 peaks in January and May	Very high	Selected

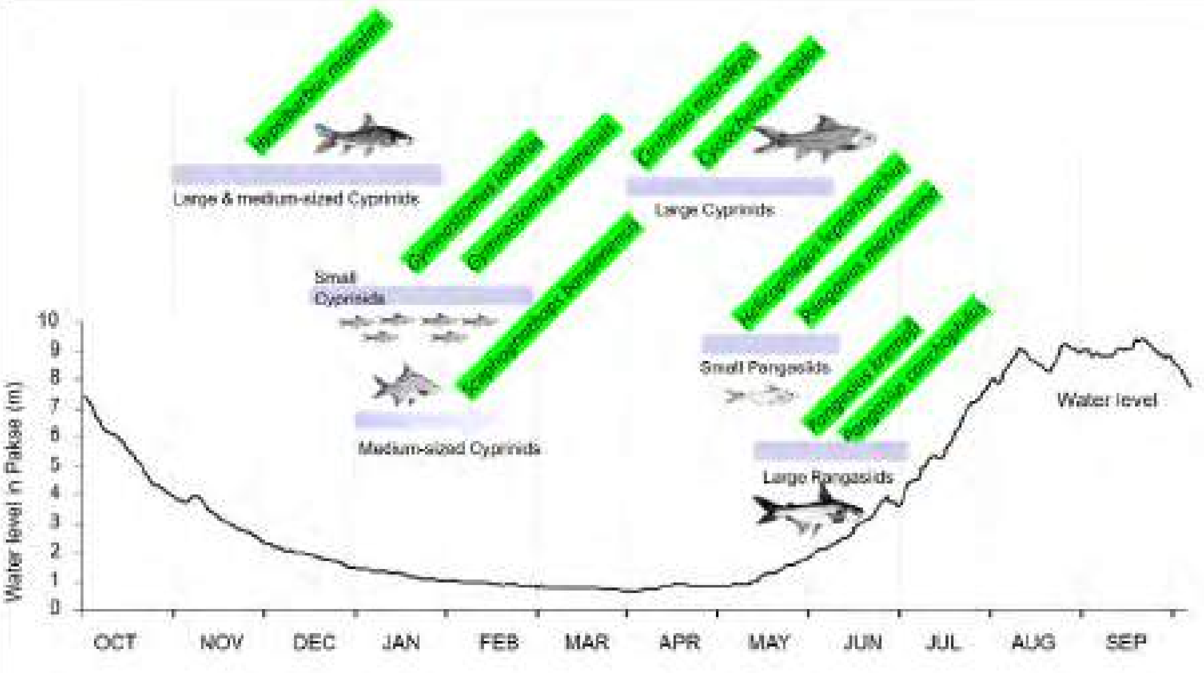


Figure 10.14. Illustration of the species selected

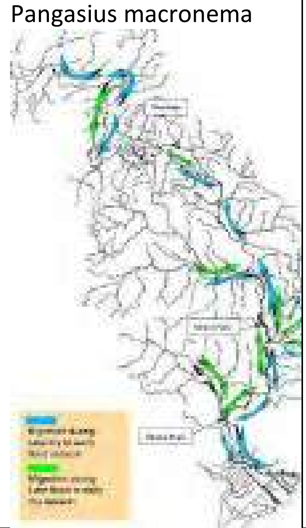
Cirrhinus microlepis 	*Cyclocheilos enoplos* 	*Pangasius conchophilus* 	*Pangasius krempfi* 
Gymnostomus lobatus 	*Gymnostomus siamensis* 	Pangasius macronema 	
Helicophagus leptorhynchus	*Hypsibarbus malcolmi*	*Scaphognathops bandanensis*	

Figure 10.15. Migration maps

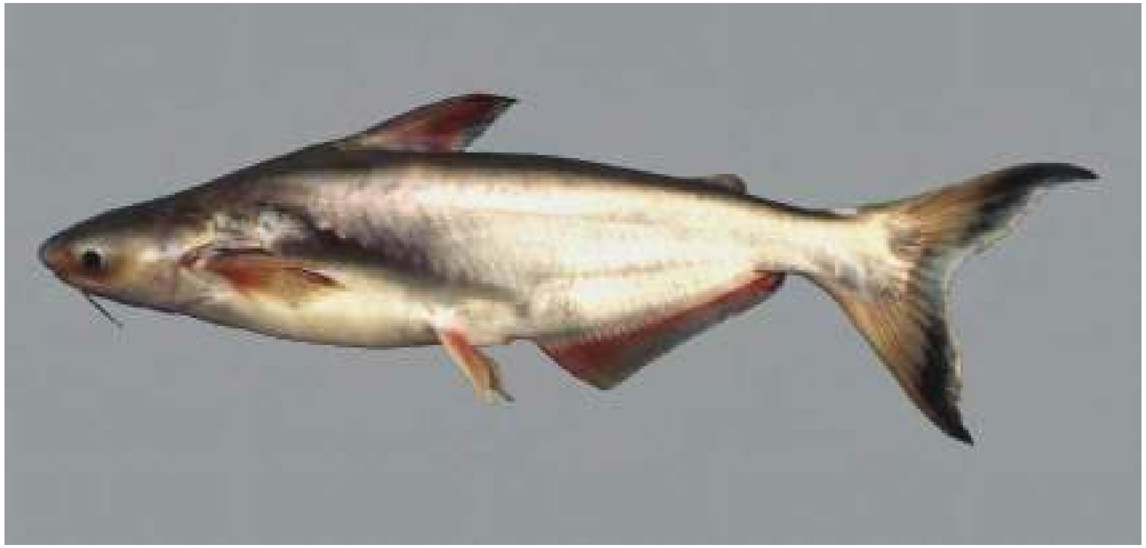
10.5. ANNEX 6 on Fisheries: Flipchart of 10 priority species for the survey of fish migrations through local knowledge

Gymnostomus siamensis

Pa soi houa po

Gymnostomus lobatus
Pa soi houa lem/Pa soi hang leuang

Pangasius conchophilus
Pa pho/Pa ke



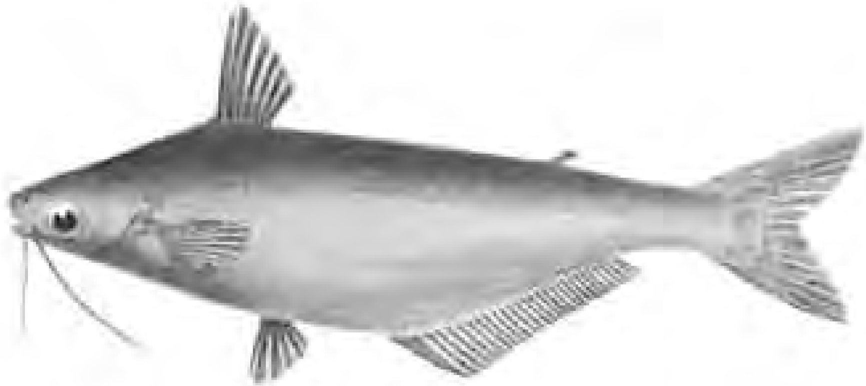
Helicophagus leptorhynchus

Hypsibarbus malcolmi
(papak nouat/pa pak kom/pa pak)

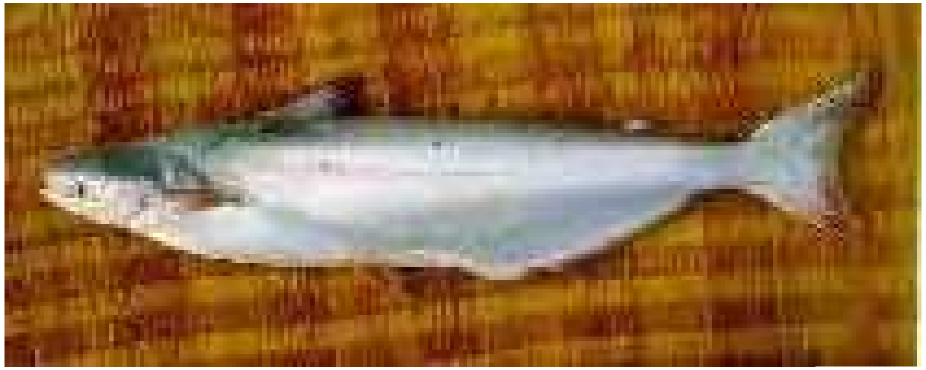
Cyclocheilichthys enoplos
Pa chok

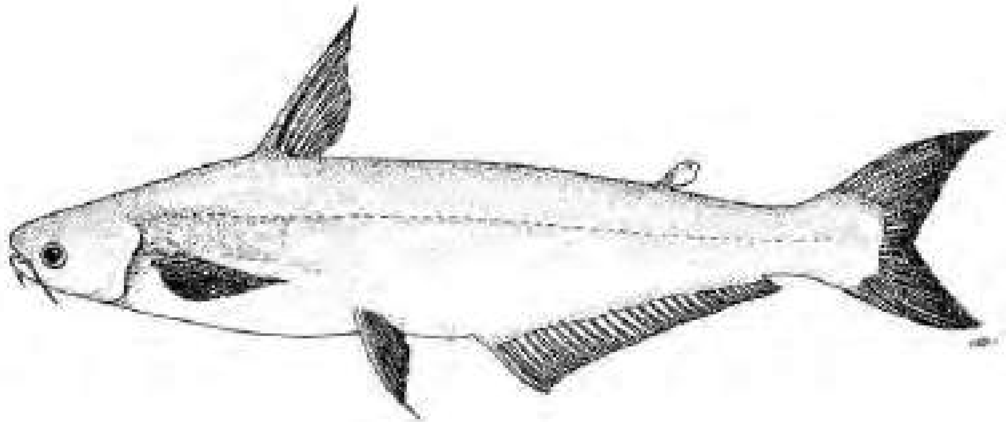
Pangasius macronema

Pa gnone siap

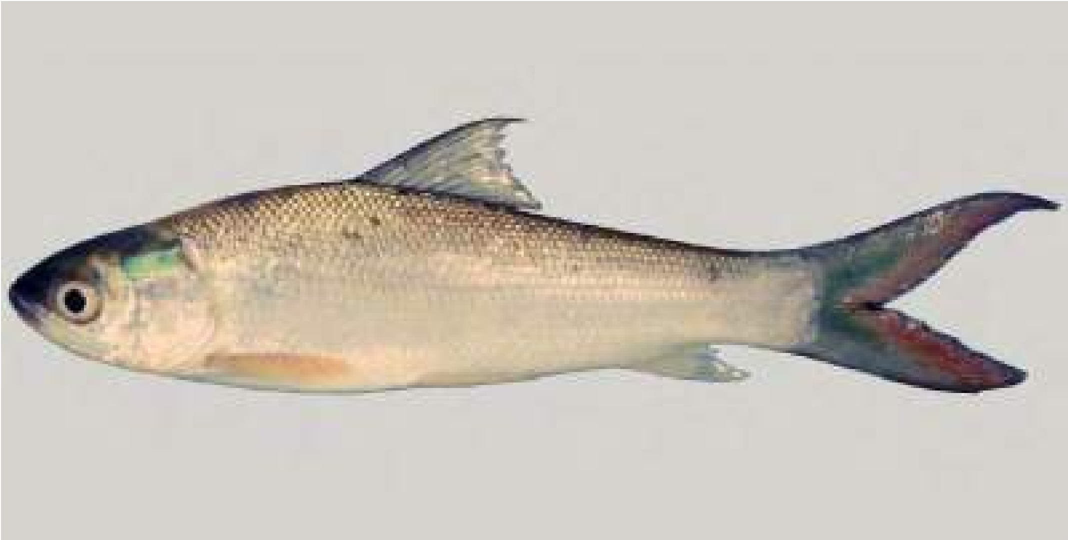


Pangasius krempfi
Pa souay hang leuang



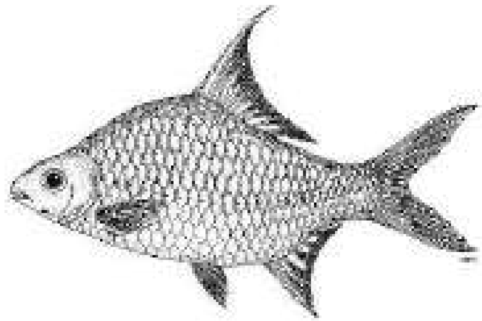


Cirrhinus microlepis
Pa phone mak kok



Scaphognathops bandanensis

Pa pian/Pa pien



10.6. ANNEX 7 on Fisheries: Information sheets on the 10 species surveyed

Baran E., So Nam 2010. Information on migrant fish species dominant in Mekong fisheries. Report for the project "Scenario-based assessment of the potential effects of alternative dam construction schemes on freshwater fish diversity in the Lower Mekong Basin". WorldFish, Phnom Penh, Cambodia. 62 pp.

10.6.1. Gymnostomus siamensis

- Family: Cyprinidae
- Remark: Formerly *Cirrihinus siamensis, Henicorhynchus siamensis*
- Name in Lao: Pa soi houa po
- Name in English: Siamese mud carp.

BIOLOGY:

- Max. total length (cm): 25 Max. standard length (cm): 20
- Length at maturity (cm): 12.9
- Status: native Resilience: medium

REPRODUCTION:

Spawning: Mature eggs are reported from April to July with a strong peak during May–June. Spawns in the rainy season

- Spawns in rivers (% respondents): 100
- Nurses in floodplain (% respondents): 100.

FEEDING:

Feeds on algae, periphyton and phytoplankton (Rainboth, 1996); Filamentous chlorophytes.

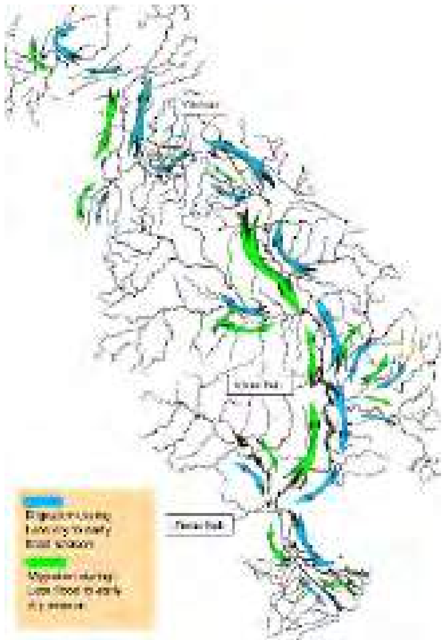
- Feed in floodplain (% respondents): 100.

ECOLOGY:

- Habitat: Benthopelagic. Distribution: occurs from the Mekong Delta all the way along the Mekong mainstream to Chiang Khong; also recorded from the Xe Bangfai Basin.

Migration: From Xayaburi to Chiang Khong, the fish migrate upstream from March to July, first the juveniles, later followed by the adults. At Khone Falls, medium sized fish migrate downstream, while large individuals migrate upstream during the wet season. These migrations are for reproductive purposes, and during the migration, the fish feeds very little, relying on fat deposits around the viscera. From Khone Falls, the fish migrate downstream from May to July, towards the large floodplains located north and south of Phnom Penh and all the way to the Mekong Delta. Here, the fish migrate out of the Mekong into canals and flooded areas during August-September. When the water recedes, it enters the Tonle Sap from the flooded areas along the river and the Great Lake. Once in the Tonle Sap, they migrate down to the Mekong and from October to February continue their journey upstream the Mekong, at least until they reach Khone Falls.

- Discharge as migration trigger: Discharge variation is a migration trigger.
- Water level as migration trigger: No information.



10.6.2. Gymnostomus lobatus

IDENTIFICATION:

- Family: Cyprinidae
- Remark: Formerly known as *Cirrihinus lobatus and Henicorhynchus lobatus*
- Name in Lao: Pa soi houa lem or Pa soi hang leuang

BIOLOGY:

- Max. standard length (cm): 15
- Status: Native
- Habitat: Benthopelagic.

REPRODUCTION:

It is a protogynous hermaphrodite, which spawns in June and July in the main channel and in floodplains. Spawning migration from December to February from the Tonle Sap Lake floodplains to Mekong River through Tonle Sap River.

- Nurses in floodplain (% respondents): 100.

FEEDING

Feeds on small water plant and algae B; aquatic chlorophytes and plant material.

- Feeds in floodplain (% respondents): 100.

ECOLOGY

This migratory herbivorous species plays a key role in the food chain. Seasonally, one of the most abundant species in the major migrations that occur in the mainstream of the Mekong River below Khone Falls every December-February and May–July, where there is an important artisanal fishery. In Cambodia, this migration starts from December to February from the Tonle Sap Lake floodplains to Mekong River through Tonle Sap River. This is a spawning migration. It is probably the single most important forage or prey species for many piscivore fish species present there and may also be heavily preyed upon by the local dolphin, *Orcaella brevirostris*. It is one of the lead species in the massive migrations of cyprinid fishes moving up the Mekong mainstream in the Khone Falls area. During the dry season, its refuge is deep pools of the mainstream and large tributaries.

- Discharge as migration trigger: Discharge variation is a migration trigger.
- Water level as migration trigger: no information.
- Migration type: Displays longitudinal as well as lateral migrations.

10.6.3. Pangasius conchophilus

Pangasius conchophilus (IFReDI collection)

Pangasius conchophilus (Rainboth, W.)

- Family: Pangasiidae
- Name in Lao: pa pho/pa ke

BIOLOGY:

- Max. standard length (cm): 120
- Length at maturity (cm): 62.9
- Status: Native
- Habitat: Benthopelagic.

FEEDING

It feeds on molluscs primarily gastropods (but also some bivalves, insects; crabs, and algae, filamentous green algae, leaves; forest fruits). Juveniles feed on prawns and insects; and sub-adults and adults on prawns, insects and particularly molluscs, which are more predominant in stomach contents than in any other Pangasius species, and also small fish and crabs; and adults feed mainly on shellfish, crab, and fruit seeds. Snails are an especially important source of food in the low-water season between January and May. Dense green algae are an important source of food between January and March, when algae floats down the Mekong River in abundance. Leaves and forest fruits are the dominant food sources for this catfish between late April and September.

REPRODUCTION:

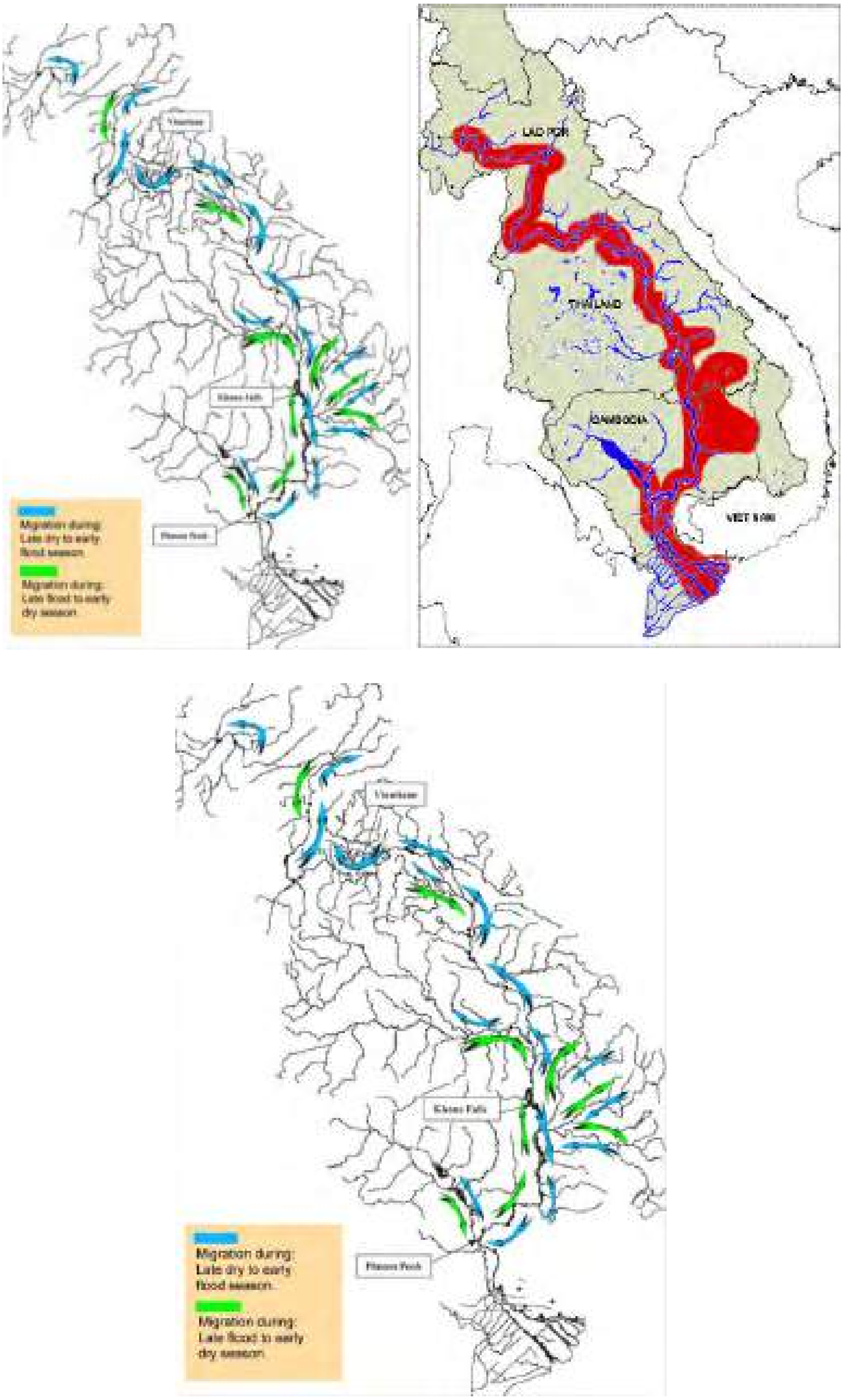
Spawning: Based on egg reports from March to August with a strong peak in May–July and the presence of females in spawning condition in March, June and August (Baird and Phylavanh, 1999); and juveniles of 6 to 7 cm by late June; it seems likely that the species spawn at various times of the year, although it probably mainly reproduces early in the flood season; the spawning period may extend to October. An important spawning ground is in the Mekong mainstream between Kompong Cham and Khone Falls; and in rapids and riffles of the Mun River. It breeds in reservoirs: There is no information on breeding in reservoirs.

ECOLOGY:

Distribution: The distribution range is from the Mekong Delta all the way along the Mekong to Chiang Saen. In the Mekong Delta in Viet Nam, mainly juveniles less than 30 cm are reported. There seem to be one population below Khone Falls and one (to several) above the Falls. Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang.

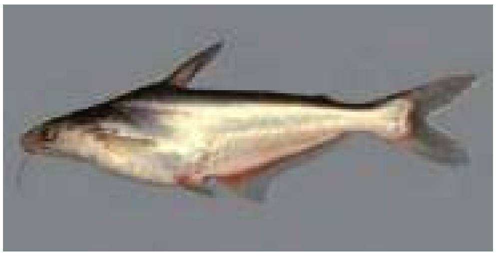
Migration: It is migratory and mainly moves at night. It is a very important species in the fishery and is caught with nets, traps, and hooks. It migrates upstream from just upstream Khone Falls to Chiang Saen when the Mekong River rises quickly with the beginning of the monsoon season around May, it mainly moves in large schools at night; and the migration continues until August; however, this migration of 40– 90 cm sexually mature fish seem to be preceded by a migration of 10 to 40 cm sub-adults in the March to May period. It migrates up the Mun River to spawn in the rainy season.

- Discharge as migration trigger: no information.
- Water level as migration trigger: Water level variation is a migration trigger.



Records, distribution (in red) and migrations of Pangasius conchophilus

10.6.4. Helicophagus leptorhynchus



Helicophagus leptorhynchus (Rainboth, W.)

Helicophagus leptorhynchus (Warren T.)

IDENTIFICATION:

- Family: Pangasiidae
- Name in Lao:

A number of studies mention *H. waandersii* as a Mekong *Helicophagus*. However, hee we refer to Ng and Kottelat (2000), who showed that among the fish formerly identified as *H. waandersii*, two species had to be distinguished: *H. waandersii* found in Sumatra and peninsular Malaysia *only*, and *H. leptorhynchus*, a new species with distinct characteristics found in the Mekong and Chao Phraya Basins. Therefore, all specimens formerly named *H. waandersii* found in the Mekong Basin are actually *H. leptorhynchus*.

Helicophagus leptorhynchus differs from *Helicophagus waandersii* by having:

- a longer anal fin (34.5–38.2% of standard length for *H. leptorhynchus* vs. 31.9–34.3% for *H. wandersii*);
- a longer head (20.8–22.8% of standard length for *H. leptorhynchus* vs. 18.9–20.3% for *H. wandersii*);
- bigger eyes (16.1–21.2% of head length for *H. leptorhynchus* vs. 14.1–15.9% for *H. waandersii).*

Furthermore, *Helicophagus leptorhynchus* is characterized by premaxillary tooth plates separate at midline, and large palatine tooth plates

BIOLOGY:

- Max. total length (cm): 70
- Length at maturity (cm): 39.1
- Status: Native
- Habitat: Demersal.

FEEDING:

Molluscivorous: Feeds almost exclusively on bivalve molluscs. The stomach content of the specimens examined generally consisted of molluscs, usually bivalves.

REPRODUCTION:

Spawning: Eggs occur from March to July, peaking in May–June, likely the main spawning season; however, to season may extend to September – October; However the species has also been reported to spawn in January to April. In addition, 2–4 cm juveniles have been reported both below (downstream to Can Tho and Dong Thap) and above Khone Falls (upstream to Nong Khai Province).

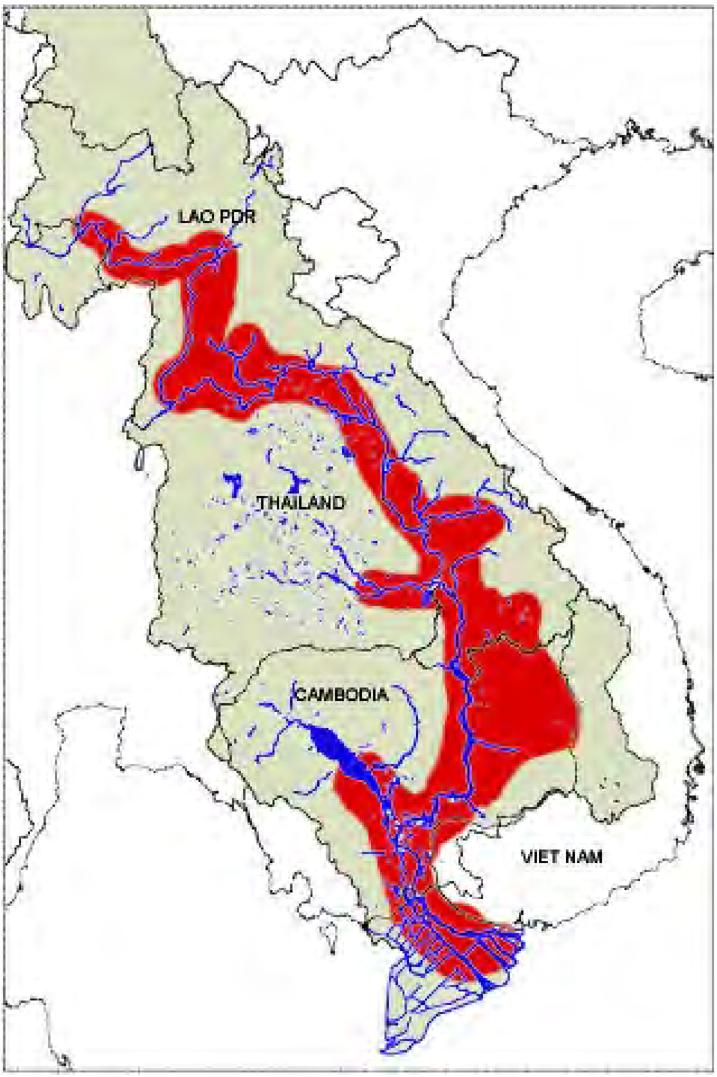
No information on breeding in reservoirs.

ECOLOGY:

Distribution: They are found basin wide in the mainstream of the Mekong. They occur in medium- to large-sized rivers and are marketed fresh.

Migration: They migrate upstream when water levels begin to rise at the beginning of the flood season and moves downstream as water clears at the end of the flood season. Above the Khone Falls they migrate upstream during the late dry season and/or the early flood season; these migrations are relatively short, and the purpose seems to be spawning, although they may also involve migrations for dispersal and feeding by sub-adults. The fish move downstream as water clears at the end of the flood season. Below the Falls, the pattern is the opposite, with a downstream migration at the onset of the flood season and an upstream migration from the during the dry season. Some populations migrate into major tributaries (e.g. Nam Ngum River and Songkhram River. In Mun River, the species migrate upstream from the beginning of the rainy season to the end of August and move back downstream from late September to November.

- Migration type: Displays longitudinal as well as lateral migrations.
- Discharge as migration trigger: No information
- Water level as migration trigger: Water level variation is a possible trigger (So Nam, pers. comm., 2007).



Records and distribution (in red) of *Helicophagus leptorhynchus* (no map of migrations)

10.6.5. Hypsibarbus malcolmi

Hypsibarbus malcolmi (Warren, T.)

Hypsibarbus malcolmi (Chavalit Vidthayanon)

IDENTIFICATION

- Family: Cyprinidae
- Remark: Formerly known as *Poropuntius malcolmi*
- Name in Lao: papak nouat/pa pak kom/pa pak
- Name in English: Goldfin tinfoil barb

BIOLOGY:

- Max. standard length (cm): 50
- Length at maturity (cm): 29
- Status: Native
- Habitat: Benthopelagic
- Resilience: Low

REPRODUCTION:

Pelagic mainstream spawner that breeds in the late wet season or early dry season, young of the years 2 cm length appear in February to March.

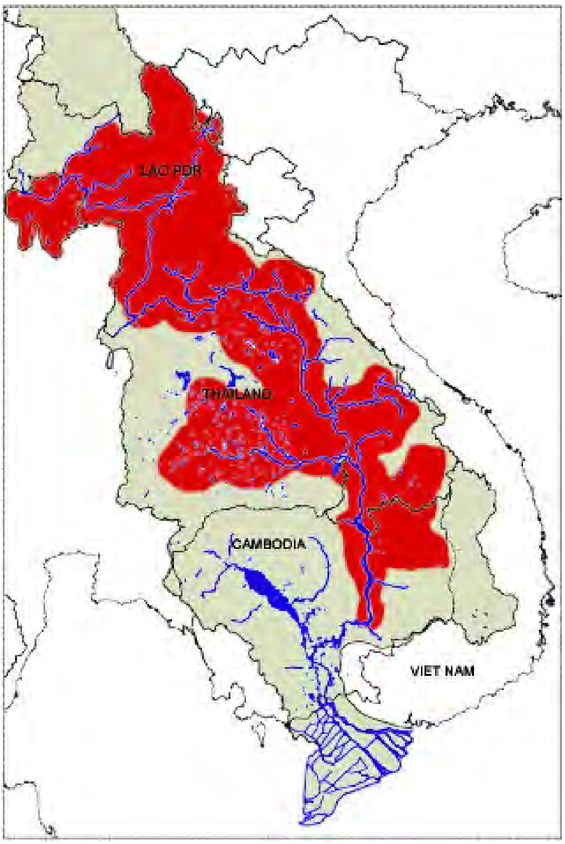
- Breed in reservoir: No information on breeding in reservoirs.

FEEDING: Zoobenthos

ECOLOGY:

They occur in midwater to bottom depths in large and medium-sized rivers. They are found in large rivers in the dry season and move to medium-sized rivers in the wet seasons. They are usually found over coarse substrate and marketed fresh; they also seen in the aquarium trade (Rainboth, 1996).

- Migration type: Displays longitudinal as well as lateral migrations.



Records and distribution (in red) of *Hypsibarbus malcolmi* (no migration map)

10.6.6. Cyclocheilichthys enoplos

Cyclocheilichthys enoplos (Baird, I.G.)

Cyclocheilichthys enoplos (Roberts, T.R.)

- Family: Cyprinidae
- Name in Lao: pa chok.

BIOLOGY:

- Max. total length (cm): 91 - Max. standard length (cm): 74
- Length at maturity (cm): 41.1
- Status: Native - Habitat: Benthopelagic

FEEDING

They feeds on snails, fine algae, earthworms, detritus, roots, insect larvae, crustaceans, and fish, bivalves, and green algae; the young feed on zooplankton.

- Feeds in floodplain (% respondents): 100.

REPRODUCTION:

Spawning: They probably spawn in the early flood season, July–August. Females reach sexual maturity at a length of 10.3cm, while males reach this stage at 9.7 cm, the average fecundity in 150 mm fish is 3,943 eggs. They are a total spawner, spwaning on floodplains, inundated riparian forests or in the main river channel. Eggs and larvae are pelagic, and drift from the spawning ground onto flooded areas or stagnant, shallow segments of the mainstream.

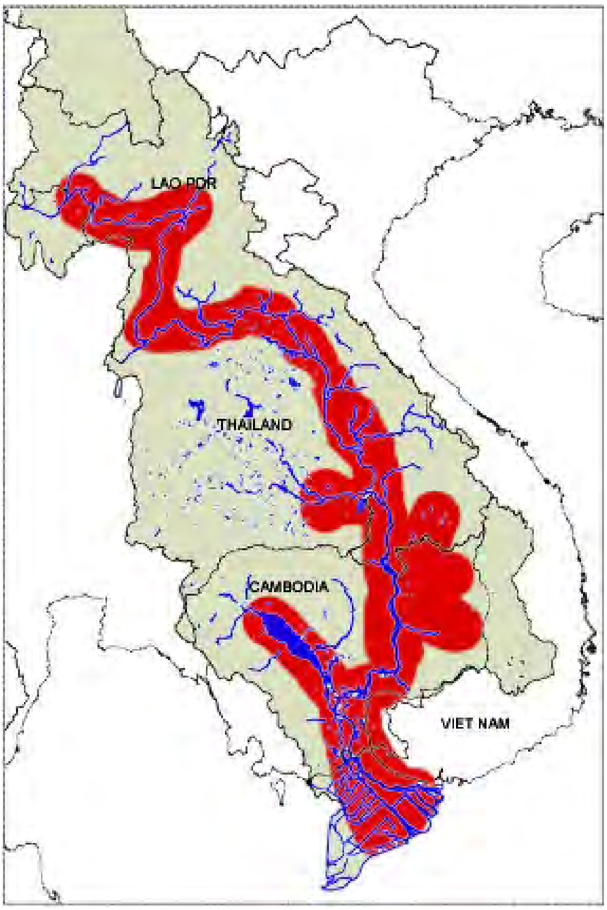
- Breed in reservoirs: No information on breeding in reservoirs
- Nurse in floodplains (% respondents): 100

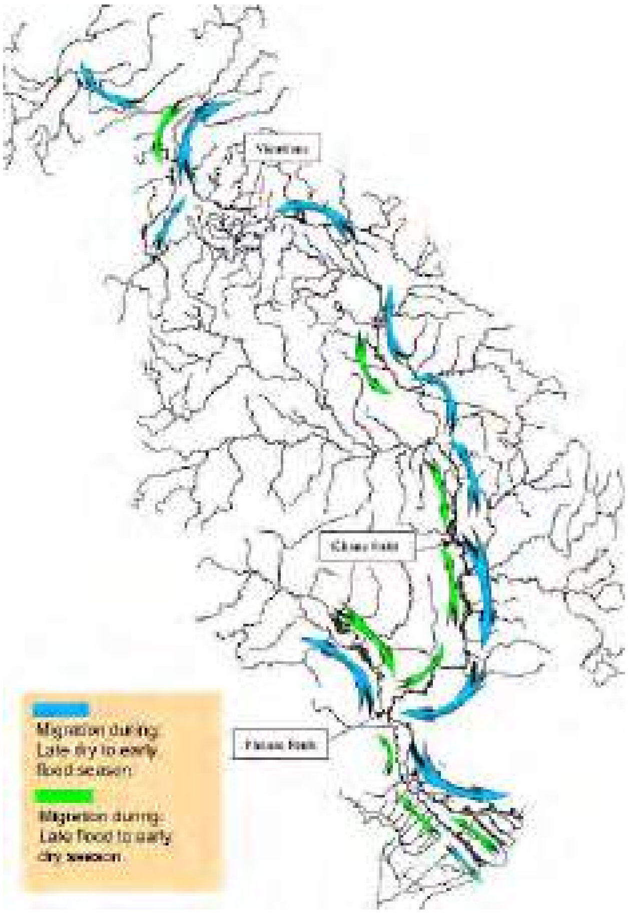
ECOLOGY:

Distribution: Common in the Mekong, which is found basin-wide in the mainstream; from Bokeo in the north to the Mekong Delta in the south; larvae/juveniles have been recorded from the drift in the Mekong and Bassac Rivers in An Giang.

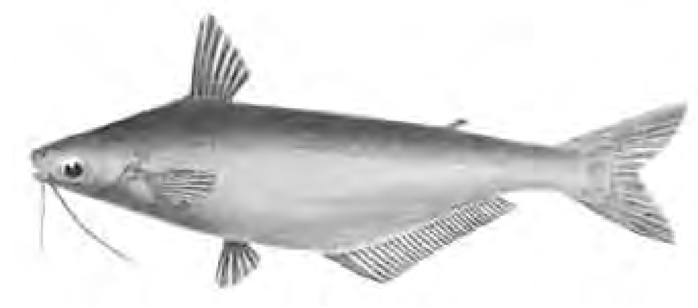
Migration: They migrate upstream as a response to the first rainfall at the end of the dry season as well as rising water levels and higher turbidity; it returns to the rivers from October to December.

- Migration type: Display longitudinal as well as lateral migrations.
- Discharge as migration trigger: No information.
- Water level variation is a migration trigger.





10.6.7. Pangasius macronema



Pangasius macronema (Fowler 1935)

Pangasius macronema (Chavalit Vidthayanon)

- Family: Pangasiidae
- Name in Lao: pa gnone siap

BIOLOGY:

- Max. total length (cm): 30
- Max. standard length (cm):
- Length at maturity (cm): 18.5
- Status: native

FEEDING:

They feed on aquatic insect larvae, insects, earthworms, miscellaneous fruits, leaves, pulverised wood, mushrooms, detritus, mud, plant fragments, and plant seeds, and also scavenge.

REPRODUCTION:

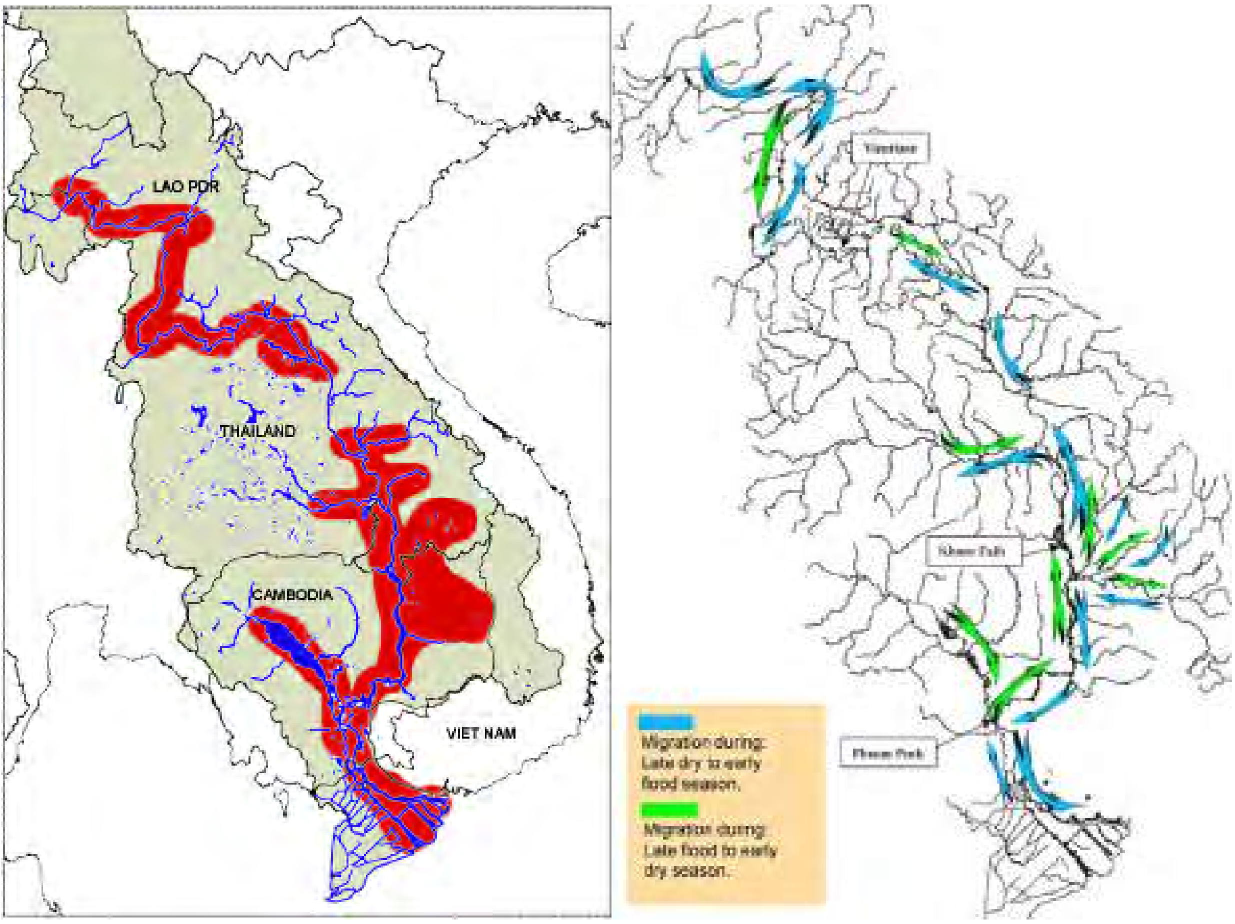
Eggs have been observed in the abdomen of this fish all year round except for February, but most often reported from April to June. A female with ripe eggs has been found in September. The species spawns from February to April; in rapids in the beginning of the rainy season; and in June in Cambodia where larvae are present in July. In Viet Nam, it was reported to spawn in August to September in the main river. Females are sexually mature at 13 cm and 25 g.

ECOLOGY:

Distribution: It is found basin wide in the mainstream of the Mekong except for a short stretch from Nakhon Phanom and Mukdaharn Provinces; it is rarely caught at Hoo Som Yai at the Khone Falls. It is found in many reservoirs in Thailand, and often in large schools.

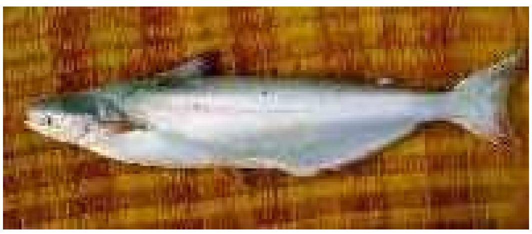
Migration: A white fish species, it migrates upstream to spawn in the beginning of the rainy season. Many fishers correlate the occurrence of this species with the emergence of insects, especially dragonflies. From Boulikhamxay Province and northwards the species mainly migrates upstream in May to June. In Cambodia, there is an upstream migration from November until January/February. The fish go downstream in May–June, and migrate upstream in May–June. In 1994, migratory activity was concentrated around early- to mid-June when water flow volume was increasing rapidly. In 1996, migratory activity was concentrated over two periods: late May/early June and again towards the end of June. There are some specimens with moderate fat deposits during the time of migration. Migration is for dispersal and feeding; they pass the Khone Falls in April-May. During the period from late April to early May, its numbers increase substantially by migrants coming from downstream. As the water transparency decreases, it moves into tributary streams and flooded forests together with many species of cyprinids and other species of visually oriented catfishes such as *P. pleurotaenia*.

- Migration type: displays longitudinal as well as lateral migrations.
- Discharge as migration trigger: Yes

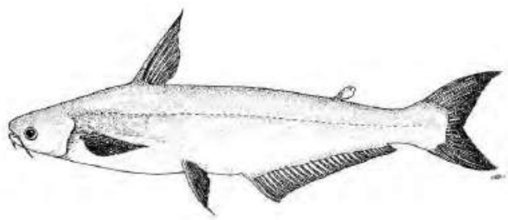


Records, distribution (in red) and migrations of *Pangasius macronema*

10.6.8. Pangasius krempfi



Pangasius krempfi (Roberts, T.R.)



Pangasius krempfi
(E. D' Antoni, after Chaux and Fang, 1949 (in Rainboth, 1996)

- Family: Pangasiidae
- Name in Lao: pa souay hang leuang

BIOLOGY:

- Max. Standard length (cm): 120.0
- Food: Mainly plants
- Status: Native
- Habitat: Benthopelagic.

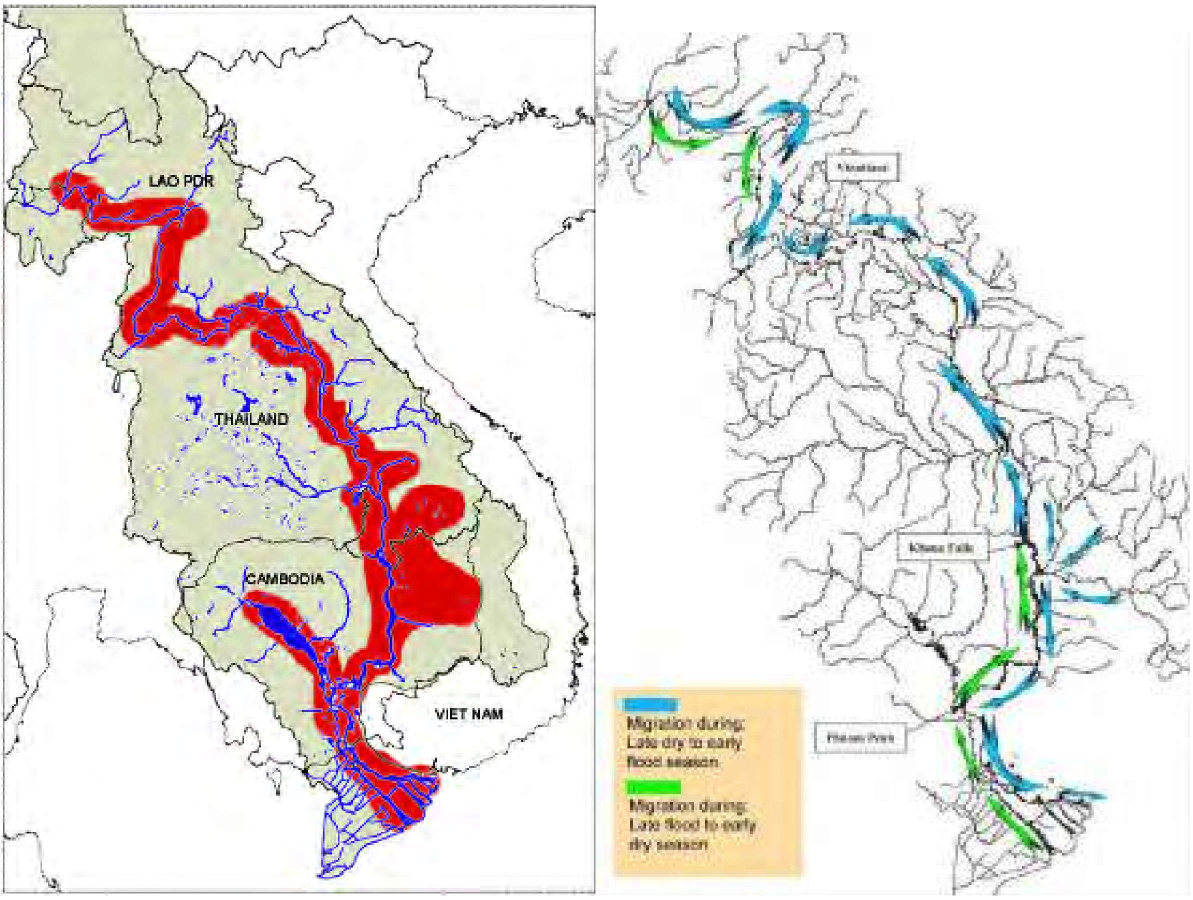
FEEDING: An omnivorous species

ECOLOGY:

Distribution: It occurs in the mainstream from the Mekong Delta all the way to Chiang Saen; it is also caught in the estuary and sometimes at sea. Often parasitized. Stays in deep pools within the mainstream during the dry season. Locally important in the fisheries where it is caught with nets, hooks and traps. It is marketed fresh.

Migrations: The species is anadromous and undertakes long-distance migrations from the Mekong Delta and open ocean in Viet Nam up the Mekong River to Cambodia, Lao PDR and Thailand. It is found in the freshwater tidal zone as juveniles, moving to brackish water as sub-adults, and finally as adults to river mouths and inshore areas. Sexually mature fish migrate far upstream to spawn and migration is triggered by rising water levels in the Mekong from May to September. It is only occasionally caught at Ban Hang Khone between July and November, and has never been reported from Lao PDR between December and April. The upstream migrations occur in peaks of 3–5 days, several times during the migration period. While many specimens are seen at Ban Hang Khone during May and June each year, specimens weighing less than approximately 1.5 kg and over about 20 kg have never been found in catches there. It was hypothesized that at least two populations in the Mekong undertake migration: one population migrates during May-September from just south of Khone Falls upstream to spawning grounds along the mainstream Mekong all the way to Chiang Khong near the Lao-Thai-Myanmar border; and the other population migrates downstream from around ST to unknown spawning grounds between ST and Kompong Cham in Cambodia during the spawning season between May and August. When water level starts to fall in October, the fish moves back to the main river to initiate an upstream dispersal migration, reaching the stretch just below Khone Falls.

- Migration type: Display longitudinal as well as lateral migrations.
- Discharge as migration trigger: No information.
- Water level as migration trigger: Water level variation is a migration trigger.



Records, distribution (in red) and migrations of Pangasius krempfi

10.6.9. Cirrhinus microlepis

(Rainboth, W.)

Cirrhinus microlepis (Roberts, T.R.)

- Family: Cyprinidae
- Name in Lao: *paphone mak kok*
- Name in English: Small-scale mud carp

BIOLOGY:

- Max. total length (cm): 80
- Max. standard length (cm): 65
- Length at maturity (cm): 36.6
- Status: Native
- Habitat: Benthopelagic

- Notes: It is a long-lived, benthopelagic, riverine species, which is not known to persist in impoundments. It is a fast swimmer, and a nervous and lively fish, which will jump many feet into the air in order to clear obstacles. The fish schools appear in certain definite periods and are captured in large amounts in only a few locations. There are reports that this fish shows four year cycles of abundance.

FEEDING:

Feeds on phytoplankton, plant fragments and detritus; it grazes on filamentous algae especially during the clear water dry season. With the flood it moves into the flooded forest where it feeds on leaves wood and lichens. Although it is mainly a herbivorous fish, it also feeds on zooplankton and insects.

- Feeds in floodplain (% respondents): 100

REPRODUCTION:

Spawning: It spawns in the Mekong mainstream; for example, in the rapids between Sambor and Khone Falls, and at Phatomphone, 48 km south of Pakse, where it is caught in considerable numbers in full spawning condition It spawns during the wet-season, in May–June; June to August; or June to July. It is a pelagic spawner, and the eggs are buoyant or semi-buoyant and drift downstream and out onto flooded areas. It is sexually mature when 17-cm long; females of 47–65 cm total length and weighing 1.8–2.9 kg may bear 131,290–271,040 eggs (the diameter of the egg is about 2 mm).

- Breeds in reservoirs: No information on breeding in reservoirs
- Spawns in rivers (% of respondents): 30
- Nurses in floodplain (% of respondents): 100
- Fecundity: 80,000 eggs/kg.

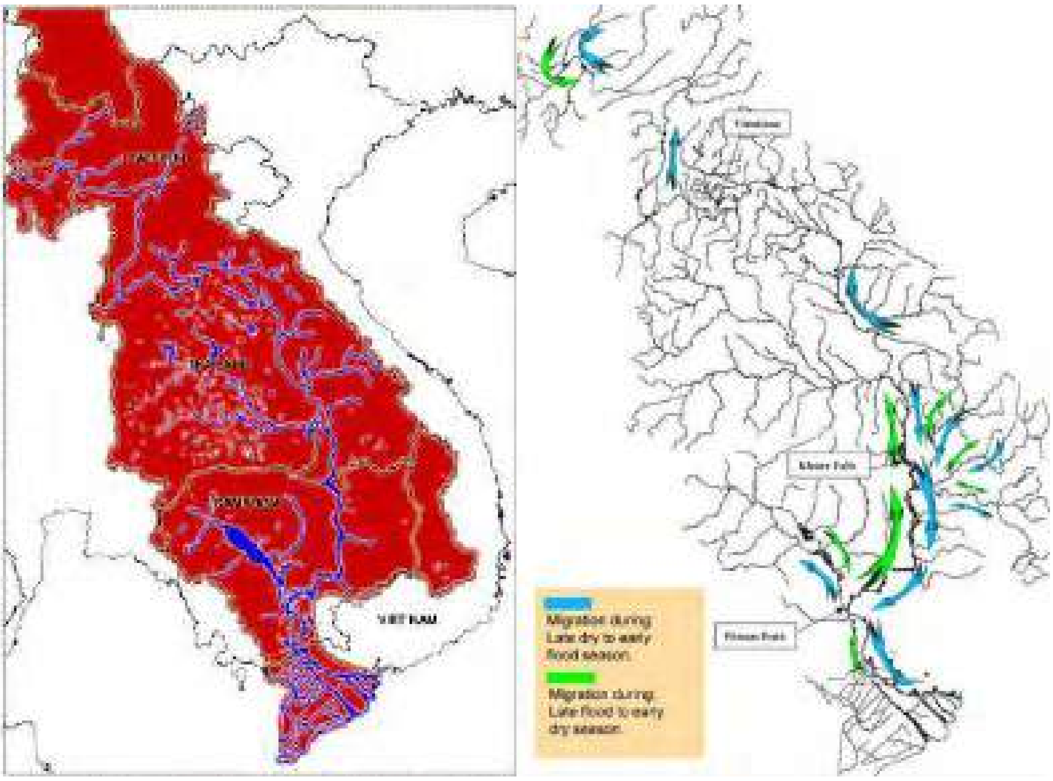
ECOLOGY:

Distribution: Found basin-wide in the mainstream of the Lower Mekong; from the Delta to Chiang Saen; also reported from the Xe Bangfai, Mun, Se Kong, Xe Pian, Xe Kamanh, and Xe Sou. Larvae/juveniles have been recorded from the drift in both the Mekong and Bassac Rivers in An Giang. There seem to be at least two populations: one population from Loei to Chiang Saen, and another from Boulikhamxay in the North to the Mekong Delta (Poulsen and Valbo-Jørgensen, 2000).

Migration: Above Khone Falls, it migrates downstream in June or July and August to spawn at a site 48–52 km south of Pakse, possibly from as far upstream as Khammuan. After spawning, adults and juveniles move downstream and out onto floodplains where they stay during the flood season, when the water begins to recede at the end of the flood season. The fish move back into rivers. In Cambodia, the fish move into the Tonle Sap when the water level increases in order to feed in the rich feeding grounds of the inundated forests. At the descent of the waters, they leave the Great Lake (and the Tonle Sap regions in waves, and migrate up the Mekong. Like all Cambodian migrating fishes, this coincides with the waxing moon, i.e. it occurs between the 5th and the 15th day of the Vietnamese calendar. During late December or early January, large individuals (2–3 kg), and some smaller individuals begin arriving in the Mekong mainstream of southern Lao PDR on their upstream dry-season migration. They congregate over shallow, rocky ground where they graze on areas of filamentous algae developing on rock surfaces. Towards the middle of the dry season, and particularly around the time of the new moon phase of the first and second lunar cycles after the winter solstice, large numbers of small individuals begin appearing in fish landings. The exact purpose of this upstream, dry-season movement is unknown, but likely involves dispersal and feeding.

- Migration type: Displays longitudinal as well as lateral migrations.
- Discharge as migration trigger: no information

- Water level as migration trigger: no information



Records, distribution (in red) and migrations of *Cirrhinus microlepis*

10.6.10. Scaphognathops bandanensis

Scaphognathops bandanensis
Fish #88 in Baird et al. 1999

IDENTIFICATION:

- Family: Cyprinidae
- Name in Lao: pa pian/Pa pien

Has 9 branched dorsal rays; 5 branched anal rays; a wide mouth with broad and massive lower jaw (width 22–26% in head length); rudimentary lower lips; and pale yellow to grey caudal fin in life.

REPRODUCTION

Breeds at the end of the rainy season as water levels fall, or after the end of the rainy season when water levels in upland areas have already declined; however, Baird et al. maintains that it spawns in July–August in floodplains and streams. The young of the year reach a2-cm length by late February, and juveniles start appearing in catches during April.

FEEDING:

It feeds on detritus, periphyton, worms, and insects; fish, shrimps, snails, small molluscs, worms, flowers, grass, and fruits.

ECOLOGY:

An endemic, omnivorous species, which occurs in the mainstream of the Middle Mekong Basin during the dry season and migrates into smaller streams and floodplains during the flood season; caught with nets and traps; marketed fresh.

Found in the Middle Mekong; recorded in the Xe Bangfai Basin; Sekong, Sesan and Srepok.

Occurs in the mainstream, tributaries, and small streams; it lives in the mainstream during the dry season.

The fish migrate up from Cambodia to Lao PDR in January–February, and to smaller streams and floodplains during the rainy season in June–July. The fish returns to the Mekong in November–December.

10.7. ANNEX 8 on Fisheries: Questionnaires of the fish knowledge survey

10.7.1. UPSTREAM QUESTIONNAIRE (C)

Use this questionnaire only in villages
#1 Ban Don Tholathi
#2 Ban Don Sang
#3 Ban Don Det Tok
#4 Ban Don Det Oke
#5 Ban Don En
#6 Ban Don Tan Tok
#7 Ban Don Tan Oke

FORM A: SURVEY DETAILS

C1. Survey form # (MonthDayQuestionnaire#): 031001
C2. Date:
C3. Who led the interview?
C4. Who entered data?
C5. Village and Village number on our map

C6. Draw on the map with a pencil the specific fish habitats in the area and indicate the special characteristics of the environment.
Cover at least one channel beyond those bordering the island surveyed.

Special features may include:

- □ deep pools
- □ fish breeding sites (indicates which species breed there, and when)
- □ fish feeding areas
- □ fish resting areas (before crossing a channel, or between two bottlenecks)
- □ areas with year-round, local resident species

FORM B: MIGRATORY SPECIES PRESENT

Tick □ if the species has been caught locally at least some time in the past 5 years:

C7. □ *Cirrhinus microlepis*
C8. □ *Gymnostomus lobatus*
C9. □ *Gymnostomus siamensis*
C10. □ *Scaphognathops bandanensis*
C11. □ *Hypsibarbus malcolmi*
C12. □ *Cyclocheilos enoplos*
C13. □ *Helicophagus leptorhynchus*
C14. □ *Pangasius conchophilus*
C15. □ *Pangasius macronema*
C16. □ *Pangasius krempfi*

FORM C: ABUNDANCE, MIGRATION BEHAVIOUR BY SPECIES

Species:

Tick answers below (no question about gear nor about quantities). For size range, use sticks.

Month	**C17. Abundance when fishing**					**C18. Size range (cm)**			**C19. Peak duration (days)**	
	High	Low	None	Don't fish	Don't know	0–25	25–50	> 50		
A. Jan.										
B. Feb.										
C. Mar.										
D. Apr.										
E. May										
F. June										
G. July										
H. Aug.										
I. Sep.										
J. Oct.										
K. Nov.										
L. Dec.										

C21. Do you consider this species to be migratory? Yes ☐ No ☐

Don't know ☐

C22. How can you tell the channel(s) from which the fish enter the falls and the channel(s) from which the fish exit the falls (no channel name yet)**?**

C23. Are periods of peak occurrence <u>predictable</u> from any (natural) event? Yes□ No□

C24. If yes, which event?

Species:

<u>UPSTREAM MIGRATION</u>

C25. Which month does the migration <u>start</u> going <u>upstream</u>? . .

Don't know ☐

C26. Which month does the migration <u>stop</u> going <u>upstream</u>? . .

Don't know ☐

C27. Have you any remarks about the upstream migration of this species?

C28. Show on the map the main upstream migration channels.

<u>DOWNSTREAM MIGRATION</u> USE THE SPECIES MAP

C29. Which month does the migration <u>start</u> going <u>downstream</u>? .

Don't know ☐

C30. Which month does the migration <u>stop</u> going <u>downstream</u>? .

Don't know ☐

C31. Have you any remarks about the downstream migration of this species? Name of main downstream migration channels?

C32. Show on the map the main downstream migration channels.

<u>SPAWNING</u>

C33. Does this species spawn in Khong District? Yes☐ No☐ Don't know ☐

C34. Have you any additional information concerning the spawning of this species?

FORM E: CONCLUSIONS

C35. Number of fishers actually interviewed (recommendation: 5.6)**:**. .

C36. What was the quality of this interview? Good☐ Average☐ Poor☐

C37. If good, contact of a person for coming back:

C38. Other remarks concerning the interview:

10.7.2. MID-FALLS QUESTIONNAIRE (B)

Use this questionnaire only in villages
#8 Ban Khone Tai
#9 Ban Khone Neua
#10 Ban Don I Som
#11 Ban Don Sahong
#12 Ban Houa Sadam
#13 Ban Don Phapheng

FORM A: SURVEY DETAILS

B1. Survey form # (MonthDayQuestionnaire#):
B2. Date:
B3. Who led the interview?
B4. Who entered the data?
B5. Village and village number on our map.

B6. Draw on the map with a pencil the specific fish habitats in the area and indicate special characteristics of the environment.
Cover at least one channel beyond those bordering the island surveyed.

Special features may include:
- □ deep pools
- □ fish breeding sites (indicates which species breed there, and when)
- □ fish feeding areas
- □ fish resting areas (before crossing a channel, or between two bottlenecks)
- □ areas with year-round, local resident species.

FORM B: MIGRATORY SPECIES PRESENT

Tick □ if the species has been caught locally at least some time in the past 5 years

B7. □ *Cirrhinus microlepis*
B8. □ *Gymnostomus lobatus*
B9. □ *Gymnostomus siamensis*
B10. □ *Scaphognathops bandanensis*
B11. □ *Hypsibarbus malcolmi*
B12. □ *Cyclocheilos enoplos*
B13. □ *Helicophagus leptorhynchus*
B14. □ *Pangasius conchophilus*
B15. □ *Pangasius macronema*
B16. □ *Pangasius krempfi*

Survey form #(MonthDayQuestionnaire#): ....

FORM C: ABUNDANCE, MIGRATION BEHAVIOUR BY SPECIES

Species:

Tick answers below (no question about gear or about quantities). For size range, use sticks.

Month	**B17. Abundance when fishing**					**B18. Size range (cm)**			**B19. Peak duration (days)**	**B20. Remarks**
	High	Low	None	Don't fish	Don't know	0–25	25–50	> 50		
A. Jan.										
B. Feb.										
C. Mar.										
D. Apr.										
E. May										
F. Jun										
G. July										
H. Aug.										
I. Sep.										
J. Oct.										
K. Nov.										
L. Dec.										

B21. Do you consider this species to be migratory? Yes ☐ No ☐ Don't know ☐

Survey form #(MonthDayQuestionnaire#): ………………………………………

B22. How can you tell the fish are migrating and the direction of the migration?

B23. Are periods of peak occurrence <u>predictable</u> from any (natural) event? Yes□ No□

B24. If yes, which event? . .

Species:

<u>UPSTREAM MIGRATION</u> USE THE SPECIES MAP

B25. Which month does the migration <u>start</u> going <u>upstream</u>? . . Don't know ☐

B26. Which month does the migration <u>stop</u> going <u>upstream</u>? . . Don't know ☐

B27. Have you any remarks? Day/night swimming? Surface/bottom? New/full moon? Female/male first? Waiting phase before moving up?

B28. Which channels are fish attracted to for initial upstream passage? (attractive channels, not necessarily passable channels)
Use the map. Number channels in blue on the map by order of preference (if any preference among fish).

<u>DOWNSTREAM MIGRATION</u> USE THE SPECIES MAP

B29. Which month does the migration <u>start</u> going <u>downstream</u>? . . Don't know ☐

Survey form #(MonthDayQuestionnaire#): ……………………………………

B30. Which month does the migration stop going downstream? . . Don't know ☐

B31. Have you any remarks about the downstream migration of this species? Name of main downstream migration channels.

A32. Does the species pass downstream through the Don Sahong dam impoundment?

Yes☐ No☐ Don't know ☐

SPAWNING

B33. Does this species spawn in Khong District? Yes ☐ No ☐ Don't know ☐

B34. Have you any additional information concerning the spawning of this species?

Survey form #(MonthDayQuestionnaire#): ……………………………………….

FORM D: FISH PASSAGE

USE THE SPECIES MAP

B35. Which channels are ultimately used by this species to successfully pass the falls on the way up?
Draw a circle in green around triangle on the channels passable by the species.
For each channel where fish passage is possible (red triangle), indicate minimal water depth or month.

B36. Have you any remarks?

What are the channel specificities that make passage for this species possible or impossible?
Tick answers. Open answers are possible in G., H., I. and P., Q., R.

B37 Passage possible because			**B38 Passage impossible because**	
A. Limited fall height			J. Fall too hight	
B. Limited flow speed			K. High flow speed	
C. Multiple steps			L. No progressive steps	
D. Deep water			M. Shallow water	
E. Resting sites			N. No resting sites	
F. Micro-channels along the main channel			O. No micro-channels	

Survey form #(MonthDayQuestionnaire#): ………………………………………

G.			P.	
H.			Q.	
I.			R.	

B39. Have you any remarks?

B40. In the middle section of the falls, what are the passage <u>improvements</u> (fish passes) that could be further conducted?
Name the channel of the passage for each recommendation.

B41. Are there falls or channels not yet considered that could be candidates for passage facilitation (opening passage by removing obstacles)?
Name:

FORM E: CONCLUSIONS

B42. Number of fishers actually interviewed (recommendation: 5.6)**:** .

B43. Was the quality of this interview? Good ☐ Average ☐ Poor ☐

B44. If good, contact of a person for coming back:

B45. Other remarks concerning the interview:

10.7.3. DOWNSTREAM QUESTIONNAIRE (A)

Use this questionnaire only in villages
#14 Ban Hang Khone in Don Khone
#15 Ban Hang Sadam in Don Sadam
#16 Ban Veun Kham on the left bank

FORM A: SURVEY DETAILS

A1. Survey form # (MonthDayQuestionnaire#):
A2. Date:
A3. Who led the interview?
A4. Who entered data?
A5. Village and village number on our map

A6. Draw on the map <u>with a pencil</u> the specific fish habitats in the area and indicate special characteristics of the environment Special features may include: □ deep pools □ fish breeding sites (indicates which species breed there, and when) □ fish feeding areas □ fish resting areas (before crossing a channel, or between two bottlenecks) □ areas with year-round local resident species

FORM B: MIGRATORY SPECIES PRESENT

Tick □ if the species has been caught locally in the past 5 years.

A7. □ 01 *Cirrhinus microlepis*
A8. □ 02 *Gymnostomus lobatus*
A9. □ 03 *Gymnostomus siamensis*
A10. □ 04 *Scaphognathops bandanensis*
A11. □ 05 *Hypsibarbus malcolmi*
A12. □ 06 *Cyclocheilos enoplos*
A13. □ 07 *Helicophagus leptorhynchus*
A14. □ 08 *Pangasius conchophilus*
A15. □ 09 *Pangasius macronema*
A16. □ 10 *Pangasius krempfi*

FORM C: ABUNDANCE, MIGRATION BEHAVIOUR AND SPAWNING BY SPECIES

One form per species

Species:

Tick answers below (no question about gear nor about quantities). For size range, use sticks.

Month	A17. Abundance when fishing					A18. Size range (cm)			A19. Peak duration (days)	A20. Remarks
	Hight	Low	None	Don't fish	Don't know	0–25	25–50	> 50		
A. Jan.										
B. Feb.										
C. Mar.										
D. Apr.										
E. May										
F. June										
G. July										
H. Aug.										
I. Sep.										
J. Oct.										
K. Nov.										
L. Dec.										

A21. Do you consider this species to be migratory? Yes ☐ No ☐ Don't know ☐

A22. How can you tell that the fish are migrating and the direction of the migration?

A23. Are periods of peak occurrence <u>predictable</u> from any (natural) event? Yes☐ No☐

A24. If yes, which event? . .

Species:

UPSTREAM MIGRATION USE THE SPECIES MAP

A25. Which month does the migration start going upstream? . .

Don't know ☐

A26. Which month does the migration stop going upstream? . .

Don't know ☐

A27. Which way do fish arrive to Khone Falls from downstream? From which bank, going where, why?
Use the map. Draw patterns on the map and use 3 types of arrows:
1) Large thick arrows: most of the fish (main trajectory) if there is a large clear pattern
2) Small thin arrow: if only some of the fish

A28. Have you any remarks? Day/night swimming? Surface/bottom? New/full moon? Female/male first? Waiting phase before moving up?

A29. Towards which channels are fish attracted for initial passage?
Use the map. Number channels in blue on the map by order of preference (if any preference among fish)

A30. Have you any remarks? Khone Fang first? Khone Phapheng first? Progressive moves? Different fish groups have different strategies?

A31. Are there falls not yet considered that could be candidates for passage facilitation (opening passage by removing obstacles)?
Name:

Species:

<u>DOWNSTREAM MIGRATION </u>USE THE SPECIES MAP

A32. Which month does the migration <u>start</u> going <u>downstream</u>? .

Don't know ☐

A33. Which month does the migration <u>stop</u> going <u>downstream</u>?

Don't know ☐

A34. Have you any remarks about the downstream migration of this species? Name of main downstream migration channels?

A35. Does the species pass downstream through Don Sahong dam impoundment?

Yes☐ No☐ Don't know ☐

<u>SPAWNING</u>

A36. Does this species spawn in Khong District? Yes☐ No☐ Don't know ☐

A37. Have you any additional information concerning the spawning of this species?

FORM C: CONCLUSIONS

A38. Number of fishers actually interviewed (recommendation: 5–6)**:**

A39. Was the quality of this interview? Good☐ Average☐ Poor☐

A40. If good, contact of a person for coming back:

A41. Other remarks concerning the interview:

Annex 7: First Pilot Site Report on Xayaburi

Mekong River Commission

FIRST PILOT SITE REPORT ON XAYABURI

Piloting a Joint Environmental Monitoring (JEM) Programme on Two Mekong Mainstream Dams 'Don Sahong and Xayaburi Hydropower Projects'

November 2021

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ABBREVIATIONS AND ACRONYMS

ADCP	Acoustic Doppler Current Profiler
ATSPT	Average Tolerance Score Per Taxon
COD	Chemical oxygen demand
DMH	Department of Meteorology and Hydrology
DSM	Discharge and sediment monitoring sites
EHM	Ecological health monitoring
EHI	Ecological Health Index
FADM	Fish abundance and diversity monitoring
FLDM	Fish larvae diversity monitoring
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GPS	Global Positioning System
HPP	Hydropower plant
HYCOS station	Automatic hydrological monitoring station
ICEM	International Centre for Environmental Management
JEM	Joint Environmental Monitoring
Lao PDR	Lao People's Democratic Republic
LMB	Lower Mekong Basin
LPB	Luang Prabang
MC	Member Country
MRC/MRCS	Mekong River Commission/Mekong River Commission Secretariat
ONWR	Office of National Water Resources (Thailand)
PMFM	Procedures for the Maintenance of Flows on the Mainstream
SSC	Suspended sediment concentrations
TSS	Total suspended solids
UK	United Kingdom
WQ	Water Quality
WQGA	Water Quality Guideline for Protection of Aquatic Health
WQMN	Water quality monitoring network

EXECUTIVE SUMMARY

The Joint Environment Monitoring (JEM) Programme for Mekong Mainstream Hydropower Projects is implemented by the Mekong River Commission (MRC) and Member Countries to provide information about linkages between water resources and environmental conditions and how these change under hydropower developments. The JEM Programme monitors across five disciplines: Hydrology and Sediment, Water Quality, Ecological Health and Fisheries. This first progress report describes the preliminary monitoring results, analysis findings and lessons for future monitoring based on the JEM pilot project at Xayaburi Hydropower Project (HPP) for the period between October 2020 and February 2021. Generally, the monitoring data collected to-date is very limited and larger records are needed to strengthen interpretation. The JEM monitoring data collection and analysis is supported by development of a comprehensive new database. Thus far, the database incorporates all monitoring results received through to early March 2021 along with historic results.

To support the pilot activities, JEM protocol training activities were conducted with the monitoring teams via online sessions and peer-to-peer training. New equipment was procured and delivered including installation of the automatic hydrological monitoring station (HYCOS station) at Ban Pakhoung (Lao PDR) downstream of Xayaburi, depth extension for the water level probe at Ban Pakhoung, and installation of a manual water level gauging site upstream of Luang Prabang at Ban Xanghai. Despite COVID-19 restrictions the project has successfully completed procurement of the all the originally specified equipment relating to the Xayaburi pilot site, except for the delayed D-96 suspended sediment sampler for Thailand. Given the complexities of procurement, future projects should plan to allow for less-ideal timing of delivery due to changes in project requirements, changes in equipment specifications, and other factors.

Regular sampling missions were conducted for piloting of the hydrology and sediment monitoring between October 2020 and February 2021. Discharge and sediment sampling including Suspended sediment (SSC) and bed material monitoring was initiated in Luang Prabang, Lao PDR in October 2020 and at Ban Pakhuong in December 2020. Manual water level monitoring at Ban Xanghai was initiated in February 2021. In Chiang Khan, monitoring of discharge and SSC was initiated in July 2020. Based on the pilot monitoring activities, recommendations are to: (i) finalise the newly installed water level gauges at Ban Xanghai and Ban Pakhoung; (ii) implement improved technique for measurement of discharge using the Acoustic Doppler Current Profiler (ADCP); (iii) improve processing of HYCOS data, sediment monitoring and laboratory analysis according to identified opportunities, and (iv) conduct active maintenance of equipment to ensure its longevity.

Preliminary analysis shows no evidence that the operation of the hydropower project has altered water flows on a seasonal basis. Potential impacts that may be associated with Xayaburi HPP operation were observed to be: (i) water level fluctuations at Ban Pakhoung, downstream of the dam, reflecting the operation of the turbines when inflow is less than the flow required to run all turbines; (ii) increased rate of water level fluctuations during the dry season at Chiang Khan; (iii) potential reduction of water level fluctuations during the months leading into the wet months, consistent with the storage being used to modulate inflows to produce a more uniform flow rate for hydropower generation; (iv) low suspended sediment concentrations at all of the sites, consistent with sediment trapping in Xayaburi and likely other upstream HPPs that have come online in 2019 and 2020; and (v) considerable bedload transport is considerable at Ban Xanghai and Ban Pakhoung where water velocities are high even during conditions of low flow.

Water quality regular sampling missions were conducted between October 2020 and February 2021. The parametres measured are identical to the parameters used in the MRC's Water Quality Monitoring Network (WQMN), except for the new JEM measurements of turbidity, chlorophyll-a and cyanobacteria. Lessons learned from the pilot monitoring activities identify opportunities to improve the monitoring practices and analysis of field samples. Interpretation of the water quality results indicates little difference between sampling stations for most parameters indicating that the impoundment and dam operation is not affecting the overall water quality. The exceptions to this were turbidity and total suspended solids (TSS) although this needs to be investigated further – possibly by taking TSS measures in other stations, and by linking with the flows and dam operations at the time of sampling. There is no evidence of stratification within the water profiles of the Xayaburi impoundment. The chlorophyll-a and cyanobacteria measurements linked with the nutrient analysis indicate no current trend towards eutrophication. Raised values of total nitrogen were observed in November and very high values of total phosphate in December, which are of great concern; further results are needed to confirm and explain this anomaly and trend.

The annual 2020 Ecological Health field sampling was postponed to March 2021 due to COVID-19 restrictions and ecological needs (i.e. sampling needs to take place during the dry season). Analysis therefore focused on developing a baseline using historic bioassessment from 2011 to 2019 at sites adjacent to Xayaburi on the Mekong mainstream. The review of the historic bioassessment data highlighted the differences between the species recorded by the teams of the four countries with implications that the findings of each country monitoring are not exactly comparable. This will affect the analysis of changes in species mix due to impoundments and downstream flow sites. There is a need to strengthen the capacity of the bioassessment teams in all countries in the consistent identification of the species in the unified composite lists and in completion of the reporting forms. Given the complexity and time required for the Ecological Health Index (EHI) process, a further recommendation is to trial a simplified rapid EHI assessment based on littoral macroinvertebrates in the interest of a simplified bioassessments each year rather than every two years, and on more sites.

No results are available yet for the fisheries monitoring. The December 2019 – March 2020 early field phase and implementation of the fish abundance and diversity monitoring (FADM) Programme indicates few major problems but more time is required to complete new protocols. Implementation of the Fish Larvae Drift Monitoring (FLDM) Programme protocol started in July 2020 and suggests, first, that more training is required to support fishers with recoding metre figures and sample bottles, and second, that the night sample timing should be shifted to 21:00 instead of midnight.

These results and the recommendations for future monitoring protocols are preliminary, based upon a limited set of results, not yet really frequent enough for more detailed statistical analysis. However, they appear to confirm the usefulness of the parameters and sampling stations chosen, and the experience has identified some practical modifications to the JEM protocols.

1. Introduction and scope

In May 2019, the Mekong River Commission (MRC) finalised its documents for Joint Environment Monitoring (JEM) Programme for Mekong Mainstream Hydropower Projects, which is aimed at providing information about the availability and condition of the water resources and their linkages with environmental conditions in the basin and how these are changing under present and future hydropower developments. This information is intended to provide a common basis for constructive discussions by communities and Member Countries (MCs) on the implications of hydropower development.

The Environmental Management Division of the MRC with the support of Germany has been developing two pilot projects to trial and refine the JEM approach and monitoring and reporting protocols based upon a two-year implementation around the Xayaburi hydropower project (XHPP) and the Don Sahong hydropower project (DSHPP). In November 2019, the International Centre for Environmental Management (ICEM Asia) was commissioned by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and the MRC to support the implementation of the two-year Environmental Monitoring Pilots project for the Joint Environmental Monitoring (JEM) Programme.

This is the first progress report on the monitoring that has been carried out around the **Xayaburi Hydropower Project.** The monitoring conducted around the Don Sahong HPP is provided in a separate report. It is noted that many aspects of the pilot projects – procurement of equipment, training of the monitoring teams and the actual field work by the teams – has been delayed significantly by the restrictions due to the COVID-19 pandemic. These reports had been scheduled as half-yearly pilot sites/stations progress reports submitted at six monthly intervals during the first year, with reports for each pilot site/station i.e. in September 2020 and March 2021. The September 2020 reports has been postponed to March 2021 and two more general interim progress reports had been prepared in September and December 2020.

The report is organised by the five disciplines – Hydrology and Sediment, Water quality, Ecological Health and Fisheries. For each discipline it will highlight any adjustments or evolutions in the sampling protocols that have occurred during the project so far, both in general and specifically for the Xayaburi monitoring sites. The report will document any activities that have taken place at the Xayaburi pilot and provide some preliminary monitoring results and analysis. Lessons or suggestions for future monitoring for each discipline will be provided.

While the Hydrology and Sediment and Water quality sections of the report provide the results of regular sampling missions between October 2020 and February 2021 and their analysis, the Ecological Health section contains analysis of historic bioassessment in sites adjacent to Xayaburi on the Mekong mainstream and because the annual 2020 field sampling was postponed to March 2021 due to COVID-19 restrictions and ecological needs (i.e. sampling needs to take place during the dry season). The focus of this section is therefore about progress in preparing the database structure to accommodate the complexity of the species lists for the bioassessments. In contrast to the earlier sections, the fisheries section reports upon the experiences of implementing the FADM and FLDM around the Xayaburi HPP[1], because the fishery results are still limited. The fishery section provides suggestions for practical implementation of the fishery protocols.

[1] Some fishery monitoring results from the Don Sahong pilot have also been provided here where these contribute to fishery monitoring protocols.

The report concludes with more general progress information on the development of the database and procurement or equipment, with reference to particular aspects which relate to the **Xayaburi pilot.**

2. Hydrology and sediment

2.1. Adjustments and evolutions

The planned hydrology and sediment activities under JEM have undergone some modifications, directly and indirectly, due to the COVID-19 pandemic. Impacts have included:

- Delays in the delivery of monitoring equipment;
- Delays in the initiation of monitoring due to restrictions preventing teams from going to sites within their countries;
- Some joint Lao – Thai activities have not been able to be completed due to COVID-19. This includes the surveying of cross-sections in the Nong Khai/Vientiane area as proposed under JEM (Figure 2.1);
- Changes to how training was delivered, with planned training events, changed to on-line courses or field training led by local experts or peers;
- Delays in installing water level monitoring sites due to delays in equipment arriving and the inability of overseas experts to travel to the region.

Figure 2.1 Locations of surveyed cross-sections to be collected collaboratively by Lao PDR and Thailand

Note:

Due to COVID-19, this work could not be completed.

2.2. Activities

2.2.1. Equipment delivered/installed

The hydrology and sediment monitoring associated with Xayaburi includes monitoring at 3 sites:

Table 2.1 summarises the equipment related to hydrology and sediment monitoring that has been delivered to Lao PDR and Thailand during the JEM downstream of the Xayaburi pilot. Photos of some of the equipment are shown in Figure 2.3 and Figure 2.4. All equipment has been field-tested and is functioning.

The HYCOS station at Ban Pakhoung (Lao PDR) downstream of Xayaburi has been installed and integrated into the HYCOS system, with live results available on the MRC monitoring website (Figure 2.2). The depth of the water level probe at Ban Pakhoung was extended in January 2021 to increase the range over which water levels at the site are able to be recorded.

A manual water level gauging site has been installed upstream of Luang Prabang at Ban Xanghai. This site is required as the existing Luang Prabang water level site is now affected by backwater from the Xayaburi dam. A manual site was selected for implementation as it is suspected that back water effects associated with Xayaburi can extend upstream to the confluence with Nam Ou under some conditions, and the JEM team did not think it was a good use of resources to install an automatic HYCOS station until the water level results from the site had been evaluated. Initial inspection of the Ban Xanghai site identified issues with the painting of the water level gauge, which was scheduled to be corrected. However, delays have occurred due to the availability of personnel.

One piece of equipment is yet to be delivered, a D96 depth-integrated suspended sediment sampler, which has been substantially delayed due to COVID-19. The manufacturer has not provided the delivery date for the sampler. Once delivered, the sampler will be deployed to Chiang Khan.

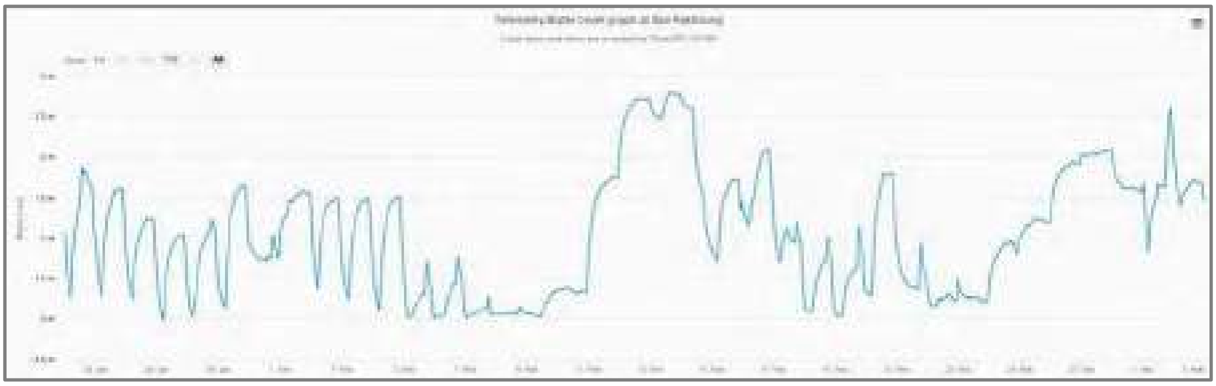

Figure 2.2. Time-series of water level in the Mekong River at Ban Pakhoung HYCOS site

Source: Data from MRC (2021a)

Note:

The water level fluctuations are associated with the turning on and off of turbines in response to inflows to the impoundment.

Table 2.1. Summary of equipment delivered to the indicated countries

Country	Equipment Delivered
Lao PDR	1 new HYCOS station, with water level recorded, rain gauge, telemetry and solar panels installed at Ban Pakhoung
	2 Pipe dredges for the collection of bed material samples, one for Luang Prabang and one for Pakse Team
	1 all-weather digital GPS camera for the collection of repeat photos at monitoring sites
	1 85 HP Yamaha engine, fuel tanks and controller switch
	1 trailer for transporting the boat based at Luang Prabang downstream to measure the downstream of Xayaburi site
	1 Nissan pickup tow bar for Luang Prabang DSM Team
Thailand	1 Teledyne RiverRay ADCP
	1 newly developed winch system to use with D96 depth-integrated suspended sediment sampler
	1 Pipe dredge for the collection of bed material samples
	1 All-weather digital GPS camera for the collection of repeat photos at monitoring sites




Figure 2.3. Equipment delivered to Lao PDR and Thailand.

Note: (top left) RiverRay ADCP for Chiang Khan, (top right) pipe dredge for collecting bed material samples, (middle left) bespoke trailer for transporting the MRC boat, (bottom right) HYCOS site at Ban Pakhoung downstream of Xayaburi, (bottom left) winch system deployed on the new boat.

Source: All photos except ADCP provided by P. Simcock of VGS.

Figure 2.4. Photos of equipment delivered to Lao PDR and Thailand.

Note: (left) Camera with GPS, (right) Tow bar.

2.2.2. Hydrology and sediment training completed

Training for hydrology and sediments were combined as the two disciplines are required to be monitored by the same teams on the same day. Training completed include the following:

- An online course delivered by Dr Lois Koehnken on 22, 23, 24, and 26 June 2020, 08:30–12:30, with participants joining from 15 different locations. The training used PowerPoint presentations with English subtitles and some simultaneous translation into Lao. Topics included:
  - Theory of water level, discharge and suspended and bedload sediment monitoring.
  - The operation and use of field equipment using videos and live demonstrations of software.
  - The order of field monitoring to be completed, and reporting of results.
  - Detailed demonstrations of the processing of Acoustic Doppler Current Profiler (ADCP) data to extract reliable discharge measurements and estimates of bedload transport.
  - Answer and question sessions for each topic covered and in the final session.
- Peer training for hydrographic teams receiving new equipment. The training was based on a team with experience in the operation of ADCPs and D96 sediment sampler training a less experienced team from the same country. The Lao PDR peer trainings involved the Luang Prabang team training the Pakse team. In Thailand, the Nong Khai team assisted the Chiang Khan team. Two peer training sessions were completed for each pair of teams, and activities included practice setting up and calibrating instruments and collecting field measurements. GIZ and MRC experts facilitated these training sessions.
- Training in the loading and unloading of the boat on Xayaburi's boat trailer for transport through the Xayaburi dam site.
- Training in the use of the new boat procured for Pakse, and a new winch system developed by VGS for the JEM pilot programme.
- Ad-hoc support in Lao PDR to train new staff in completing SSC (suspended sediment concentrations) measurements and the grain size analysis of bed materials.

Figure 2.5. Peer training in Xayaburi, with the RiverRay ADCP (photo by MRC)

Figure 2.6. New boat and winch system for Lao PDR

2.2.3. Monitoring missions

Figure 2.7 shows the discharge and sediment monitoring sites in the upper Lower Mekong Basin (LMB) and the newly established JEM monitoring sites associated with the JEM Xayaburi pilot project.

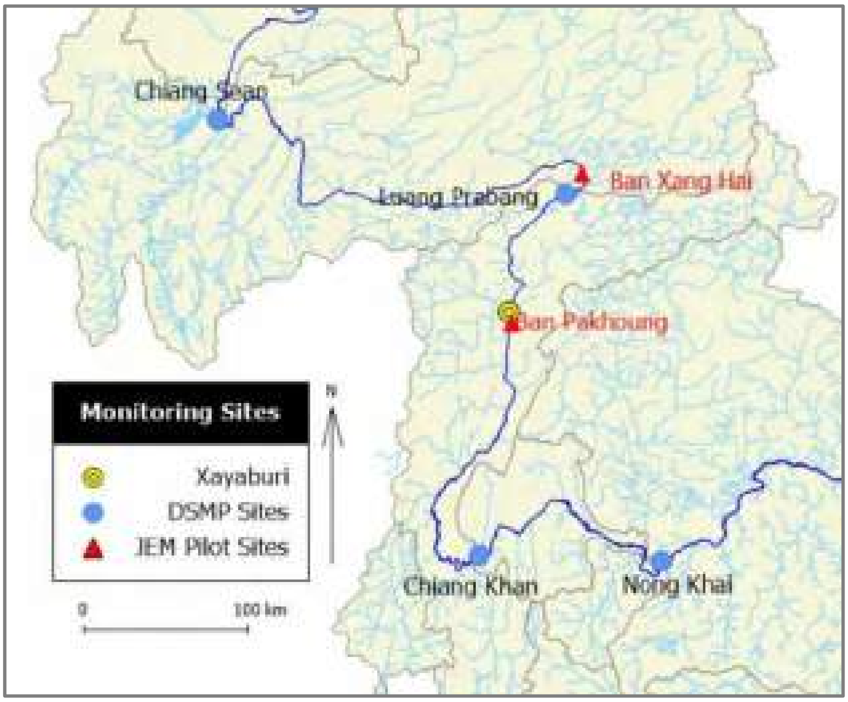

Figure 2.7. JEM and ongoing discharge and sediment monitoring sites (DSM)

In Lao PDR, monitoring was delayed due to the delayed delivery of equipment and issues with the existing equipment. The Lao team in Luang Prabang initiated discharge and sediment sampling in October 2020, coinciding with the Peer training sessions. The Pakse team initiated discharge monitoring in November 2020, after returning from the training session in Luang Prabang. SSC and bed material monitoring began in Pakse in March 2021 when the new boat became available for use as it was previously stationed in Luang Prabang. A summary of the results reported to date from Lao PDR is summarised in Table 2.2.

Table 2.2. Summary of monitoring results reported by the monitoring teams to 5 March 2021

Xanghai				Ban Pakhoung			
Date	**Discharge**	**SSC**	**Bed Material**	**Date**	**Discharge**	**SSC**	**Bed Material**
28/10/2020	X	X	X	28/10/2020	X		
30/10/2020	X	X	X	29/10/2020	2X		
31/10/2020	X	X	X	28/11/2020	X		
21/11/2020	X	X	X	15/12/2020	X		X (2)
16/12/2020	X	X	X	15/01/2021	X	X	
26/01/2021	X	X	X	28/01/2021	X		X
8/02/2021	X	X	X	7/02/2021	X	X	X

Source: Data collected by the DMH, Lao PDR.

The Chiang Khan team initiated monitoring in July 2020, and the results listed in Table 2.3 have been reported. These and the Lao PDR results are summarised in the 'Results and Analysis' sections.

Table 2.3. Summary of monitoring results reported by the monitoring teams through 5 March 2021

Chiang Khan (Thailand)			
Date	**Discharge**	**SSC**	**Bed Materials**
8/07/2020	X	X	
15/07/2020	X	X	
22/07/2020	X	X	
29/07/2020	X	X	
5/08/2020	X	X	
13/08/2020	X	X	
19/08/2020	X	X	
26/08/2020	X	X	
9/09/2020	X		
23/09/2020	X		
21/10/2020	X		
11/11/2020	X		
25/11/2020	X		
9/12/2020	X		
23/12/2020	X		

Source: Data collected by Office of National Water Resources (ONWR), Thailand.

2.3. Hydrology – preliminary results and data analysis

2.3.1. Water level at sites

A preliminary analysis of water level changes at Ban Pakhoung, Chiang Khan and Nong Khai has been completed to investigate how the operations of Xayaburi are altering the downstream river. Unfortunately, there are no water level stations upstream of the Xayaburi impoundment's backwater to provide an accurate understanding of the behaviour of the river upstream of Xayaburi. The existing Luang Prabang probe is now affected by the impoundment's backwater, so no longer indicative of flow in the river. In 2021 the new station upstream of Xayaburi at Ban Xanghai should become operational and provide more insights into changes in the upper river.

Time-series of the water level at Chiang Khan and Nong Khai for 2015 and 2020 are shown in Figure 2.8. The 2015 results reflect river conditions prior to the commissioning of Xayaburi in late 2018, and the 2020 results show results after commissioning. In the 2015 results, the two water level records are similar, and the increase in water level in the dry season due to the Lancang Cascade operation is evident at both sites. In 2020, the water level records also showed similarities, but the Chiang Khan site shows more short-term fluctuations, some of which are also evident in the Nong Khai data.

Figure 2.8. Water level at Chiang Khan and Nong Khai in 2015 and 2020 based on 15-minute recordings at HYCOS sites.

Source: Data from MRC (2021a)

The Ban Pakhoung HYCOS site was commissioned in November 2020, and the available record through February 2021 is presented in Figure 2.9. The site shows a large number of short-term water level fluctuations, presumably associated with the operation of the turbines in the power station. The corresponding water level traces at Chiang Khan and Nong Khai show similar overall flow trends but do not have the same magnitude of water level fluctuations.

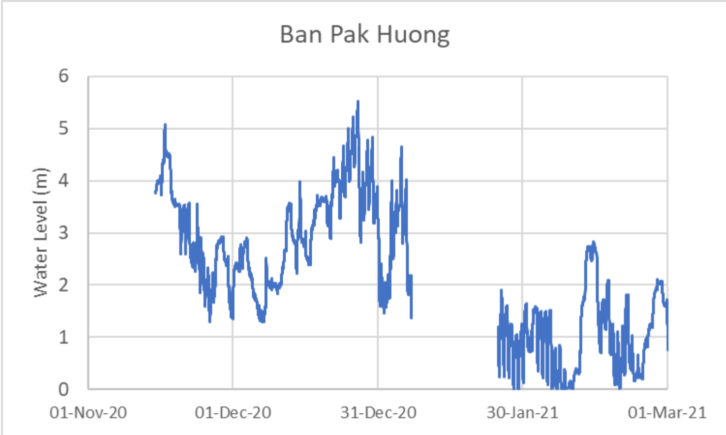

Figure 2.9. Water level at Ban Pakhoung located 5 km downstream of Xayaburi based on 15-minute recordings at HYCOS site

Source: Data from MRC (2021a)

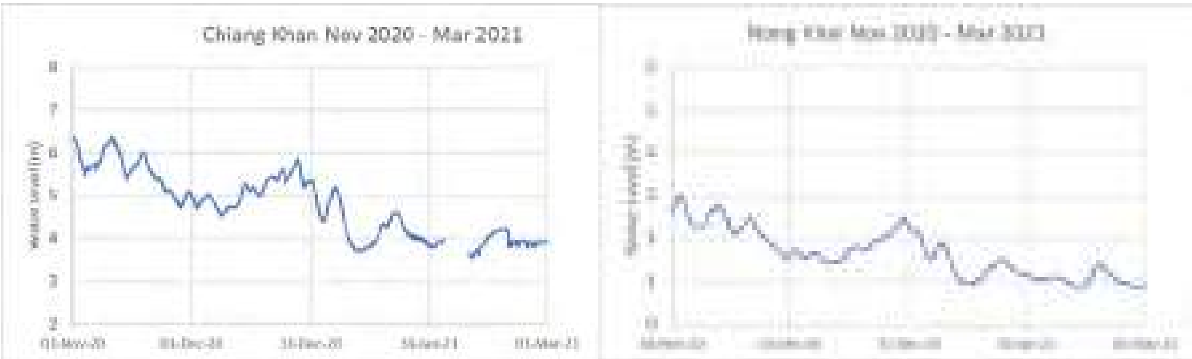

Figure 2.10. Water level at Chiang Khan in 2020 based on 15-minute recordings at HYCOS sites

Source: Data from MRC (2021a).

The 15-minute results were analysed by month (Nov 2020 to Feb 2021) for water level change (m/15-min). The average positive (water level increase/15 min) and negative (water level decrease/15-min) and the range of water level changes are summarised in Figure 2.10 and show that Jan 2020 has had the largest average water level changes (~+0.04 and -0.04 m/15-min). All months have had maximum changes of between 0.25 and 0.35 m/15 minutes. Maximum water level decreases are relatively smaller, ranging from -0.15 to -0.25 m/15 minutes. This difference reflects the recession of the river following a decrease in power station output.

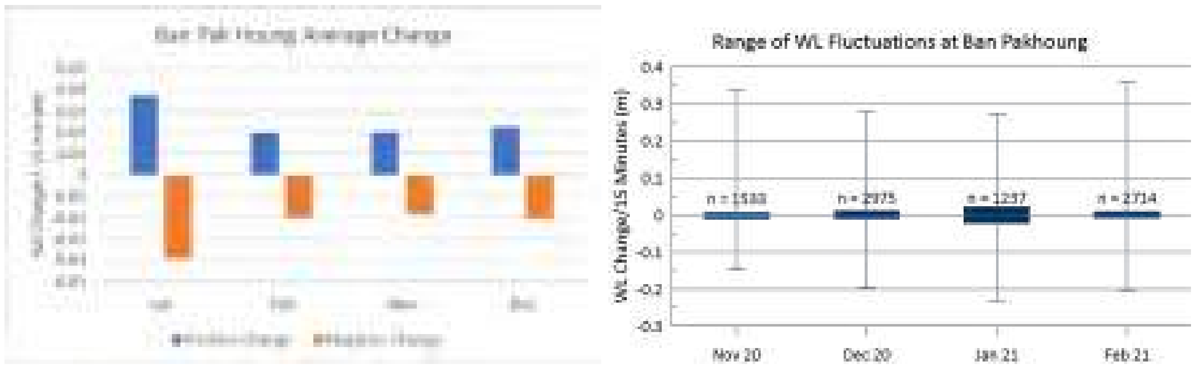

Figure 2.11 (left) Average water level increases and decreases in 15-minutes by month at Ban Pakhoung (right) Range of water level fluctuations at Ban Pakhoung

Note: The box encompasses 25th to 75th percentile values and lines show minimum and maximum values.

A similar analysis of average and maximum water level fluctuations has been compiled for Chiang Khan for the periods 2012.2016 (pre-Xayaburi) and 2018-March 2021 (post-Xayaburi). Prior to the analysis, poor quality data (spikes or unrealistic changes) were removed from the data set. Average change results at Chiang Khan suggest that the average range of water level change hasn't been altered too much due to operations at Xayaburi. However, the seasonal pattern of changes is different between the before and after data sets. Post-Xayaburi average water level changes are slightly higher in the dry season but lower in March to May. It is possible that during these periods, the operators of Xayaburi have some ability to manage the storage and modulate flows; however, a more in-depth analysis of the flows entering the impoundment would be required to substantiate this.

Figure 2.12. Water level changes at Chiang Khan during the period of 2012–2016

Note: The 2012–2016 data set for each month ranged from n = 5,882 for December to n = 11,512 for June depending on the number of years when sufficient results were available for the analysis. For the 2018–2021 analysis n ranged from n = 5,593 (April) to 8,928 (April).

Maximum and minimum flow changes at Chiang Khan pre- and post- Xayaburi (Figure 2.13) show an increase in eight of the twelve months, with some of the differences substantial. A similar trend is present for the maximum decrease in flow rates, with nine months post-Xayaburi registering larger decreases. It should be stressed that these are the maximum values, and a more in-depth analysis looking at different percentiles is required to quantify the changes better.

A similar analysis for Nong Khai is not able to be completed, due to the water level gauge only recording to 2 decimal places from October 2016 until the present, rather than 3 as was previously the case. Prior to 2016, monthly average water level changes were <0.01m/15-min. Due to the data's coarseness, the post-2016 data can only detect changes >0.01 m/15-minute, making the two datasets incompatible for comparison. Water level fluctuations at other sites will be included in the Annual Jem report.

Figure 2.13. Comparison of maximum water level change at Chiang Khan for the periods 2012–2016 and January 2018 –March 2021

Note: Based on 15-minute water level results recorded at the HYCOS monitoring site.

2.3.2. Discharge measurements

Discharge measurements using ADCP have been completed in Lao PDR upstream of Luang Prabang at Ban Xanghai, downstream of Xayaburi at Ban Pakhoung and at the existing DSM site of Chiang Khan in Thailand (locations shown in Figure 2.7). The measurements collected at each site are summarised in the following section.

2.3.2.1. Ban Xanghai

Discharge measurements at Ban Xanghai began in October 2020, with 7 results collected to date. The cross-section at the monitoring site is characterised by a deep channel on the left bank, shallowing to the right bank (Figure 2.14 and Figure 2.15). The ADCP velocity profile shows that the fastest flow is concentrated on the deepest channel's right side. The cross-section also shows uneven bathymetry and turbulence at the deepest part of the channel, which may indicate bedrock exposure in the bed. All discharge monitoring has been completed at low flow, with discharge ranging from 1,400 to 2,600 m^3/s (Figure 2.16). Average flow velocities are high at the site, even at these low flow rates, with average water velocities ranging from 0.89 to 0.94 m/s. It is not possible to assess whether the site is affected by the Xayaburi backwater because water level results are not available.

Figure 2.14. Google Earth image of Ban Xanghai monitoring site

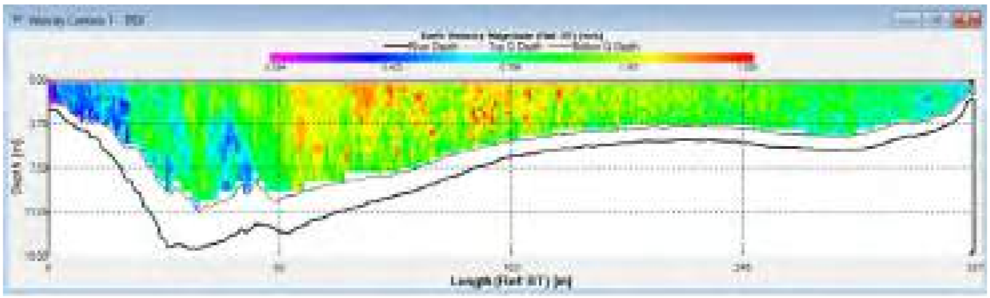

Figure 2.15. ADCP cross-section of Ban Xanghai on 20 November 2020 showing channel morphology and distribution of flow across the section

Notes: Velocity scale (m/s) is shown at the top of the figure. View is facing downstream.

Source: Profile collected by the DMH, Lao PDR.

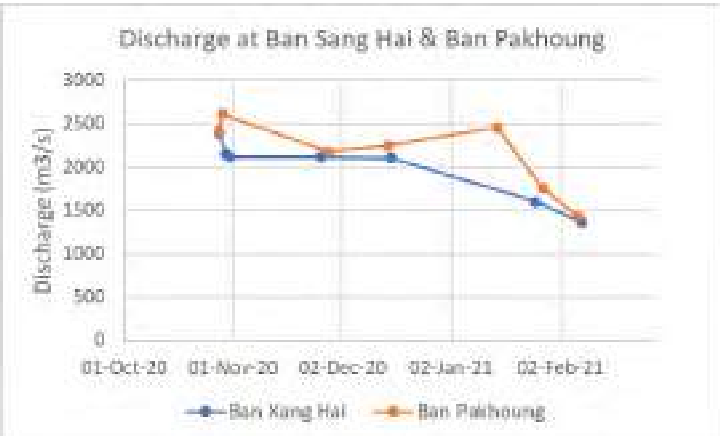

Figure 2.16. Discharge at the new monitoring sites of Ban Xang Hai upstream of Luang Prabang and Ban Pakhoung downstream of Xayaburi

Source: Data collected by the DMH Laom PDR.

2.3.2.2. *Ban Pakhoung*

Ban Pakhoung, located 5 km downstream of Xayaburi in a straight, bedrock-controlled channel, has a symmetrical cross-section with flow concentrated in the middle of the channel (Figure 2.17, Figure 2.18). Discharge during the four flow measurements completed in October to December 2020 ranged from 2175 to 2600 m^3/s, similar to the rates recorded at Ban Xang Hai. Flow velocity in the channel is slightly lower than at Ban Xang Hai, but still high, with average flow rates ranging from 0.54 to 0.74 m/s.

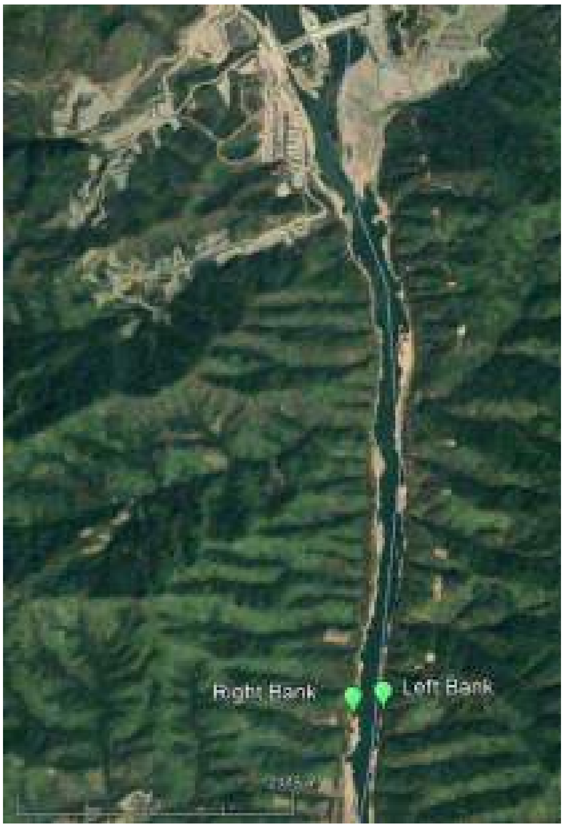

Figure 2.17. Google Earth image of Ban Pakhoung monitoring site, with Xayaburi hydropower project upstream

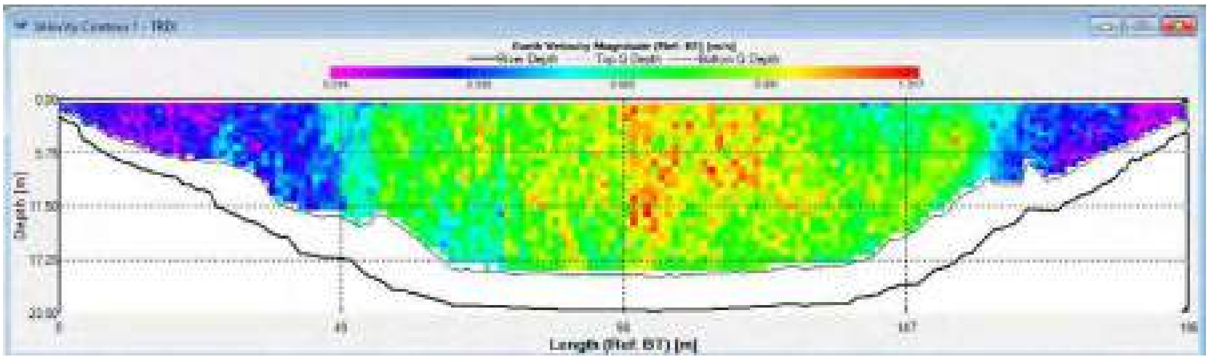

Figure 2-18. ADCP cross-section of Ban Pakhoung on 28 November 2020, showing the distribution of flow across the channel

Note: Flow velocity (m/s) is shown on the scale at the top of the cross-section. View is facing downstream. Source: Profile collected by the DMH, Lao PDR.

Chiang Khan

Monitoring initiated in July 2020 at Chiang Khan, with discharge results through December 2020 submitted to the MRC. The monitoring site's location and a cross-section of the channel are shown in Figure 2.19 and Figure 2.20, respectively. The Google Earth (GE) image shows the channel at low flow, with numerous sand bars and shoals exposed. The channel has two deeper sections, divided by a shallower mid-stream bar.

The measured discharge at Chiang Khan ranged from about 2,000 m^3/s to 8,000 m^3/s between July and December 2020. Flow in 2020 was higher than recorded in 2019 but lower than all other previous years (Figure 2.21).

Figure 2.19. Google Earth image from 2018 showing location of monitoring cross-section at Chiang Khan

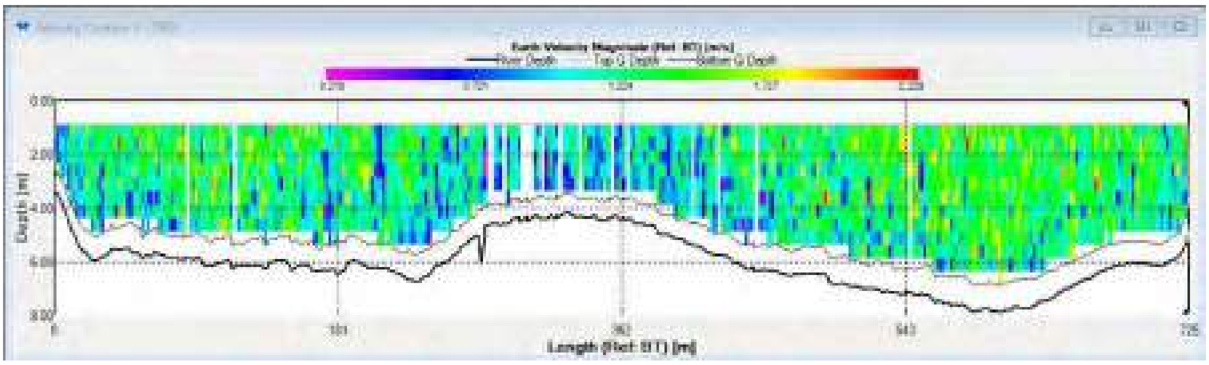

Figure 2.20. ADCP cross-section at Chiang Khan from September 2020 showing the distribution of flow across the channel.

Notes: Flow velocity (m/s) is shown on the scale at the top of the cross-section. The view is facing downstream.

Source: Profile collected by ONWR, Thailand.

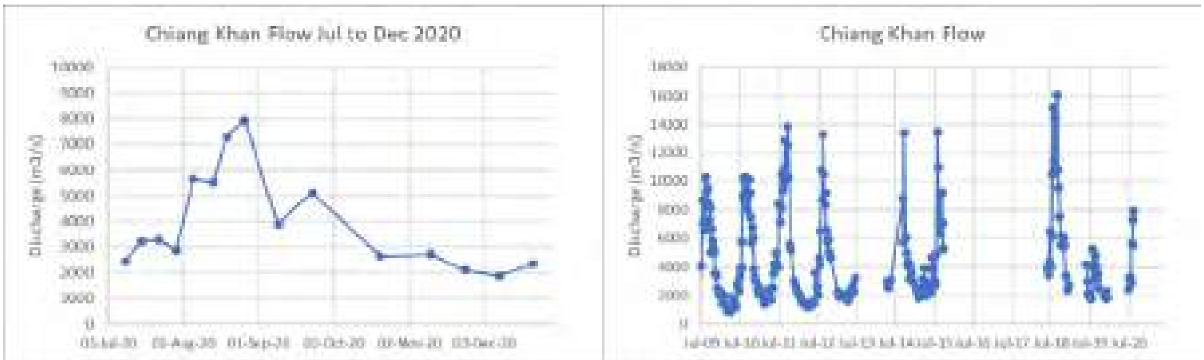

Figure 2.21. (left) Discharge measurement results at Chiang Khan, July to December 2020; (right) Discharge measurement results at Chiang Khan, July 2009 to December 2020;

Note: The method and equipment used are different: (left) use of ADCP at Chiang Khan, July to December 2020; (right) use of both current metre and later ADCP at Chiang Khan, from 2009 to December 2020

Source: Data collected by ONWR, Thailand.

2.3.3. Water level discharge relationship at Chiang Khan

Water level sites are installed and managed to convert the continuous water level readings to discharge using a rating curve (stage-discharge equation). Ensuring rating curves are accurate is critical to ensure that the calculated water discharge is accurate. Rating curves for the HYCOS sites were derived by Someth et al. (2013) for the HYCOS sites in the LMB based on discharge monitoring results collected in 2009–2012.

The measured discharge at Chiang Khan is compared to the water level at the HYCOS site in Figure 2.22. A power fit to the data shows excellent correlation, with an R^2 of 0.99 indicating the water level is a good indicator of channel discharge (e.g. the channel is not changing with discharge). In the same graph, the measured results are compared to calculated discharge values based on the established rating equation for Chiang Khan (Someth et al., 2013). The comparison shows that the measured discharge values are considerably lower than the calculated values for water levels greater than ~6 m. Using the rating equation, a gauge height of 10 m equates to a discharge of about 8,000 m^3/s, whereas the measurements indicate it is closer to 6,000 m^3/s.

In the second graph in Figure 2.21, all discharge measurements reported by Thailand from Chiang Khan since 2014 are compared to the predicted discharge values based on the rating equation. These data show that the rating curve has a good fit at both low and high water levels, at intermediate levels, the equation over-estimates discharge. This may indicate that the channel is mobile and changes shape under different flow regimes.

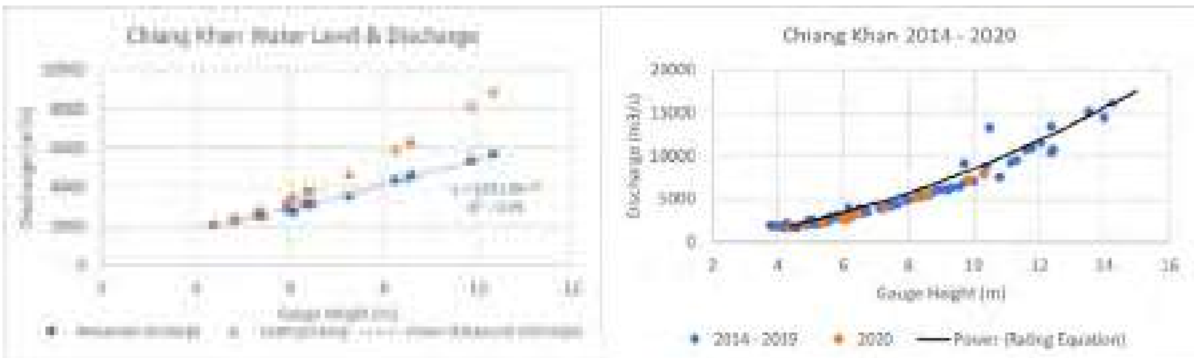

Figure 2.22. Comparison of actual and predicted discharge and water level measurements at Chiang Khan from July 2009 to December 2020

Note: (left) Measured discharge and water level from Chiang Khan Jul to Dec 2020 compared to predicted discharge using existing rating equation for Chiang Khan (right) discharge measurements from 2014–2019 and 2020 compared to rating equation over full flow range.

To test this hypothesis, bathymetric profiles extracted from ADCP measurements completed at Chiang Khan in August and December 2019 and 2020 have been compared (Figure 2.23). The profiles show that the morphology of the channel's left side varies considerably between the surveys, consistent with the GE image of the channel showing widespread sand deposits (Figure 2.18). Changes to the bed morphology can affect the relationship between water level and discharge. Based on these observations, it is recommended that the rating curve for Chiang Khan and other HYCOS sites be reviewed.

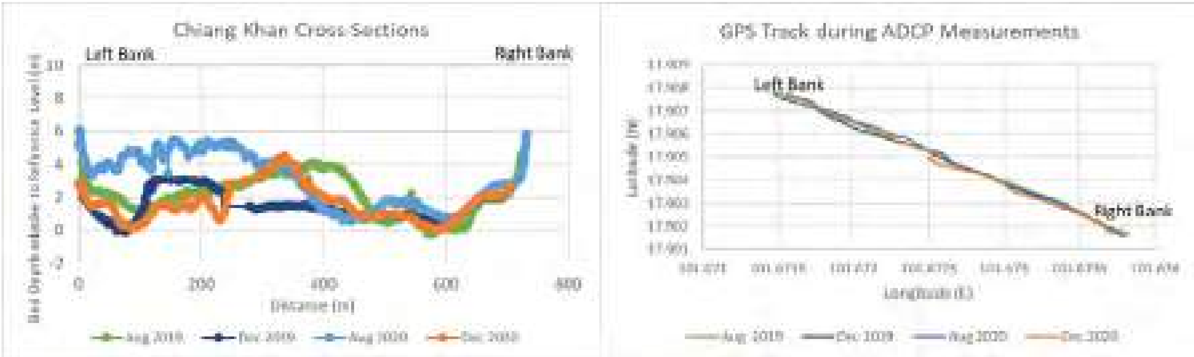

Figure 2.23. (left) Bathymetric profiles at Chiang Khan based on ADCP results (right) GPS track of boat while collecting ADCP profiles showing results collected from the same transect

Note: Profiles collected by ONWR, Thailand.

2.3.4. Procedures for the Maintenance of Flows on the Mainstream at Vientiane

The Procedures for the Maintenance of Flows on the Mainstream at Vientiane (PMFM) provides a framework to ensure that a mutually acceptable hydrological flow regime on the mainstream is maintained to optimize the multiple uses and mutual benefits of all riparian countries and to minimize the harmful effects (MRC, 1995). The closest downstream PMFM site to Xayaburi is Vientiane.

2.4.1.1. Dry season

The average daily dry season flow at Vientiane is compared to the PMFM thresholds in Figure 2.24. The figure shows that flow was in zones 2, 3 and 4 during the year. Flows in Zone 4 are considered 'severe' with flow below the Annual Recurrence Interval (ARI) 1:20, and management actions should be considered. Based on the PFMF website, 80% of the time flow was in the Zone 1, and 14% of the time in Zone 4. The results also show that in April, flows exceeded the long-term 1962–2009 maximum flow rates.

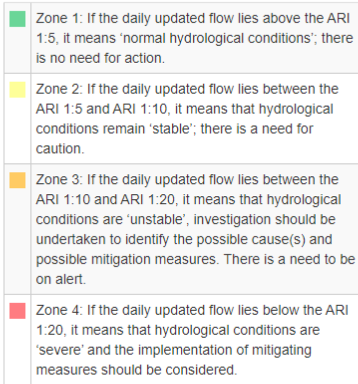

Figure 2.24. Comparison of average daily flow at Vientiane December 2020 to May 2021 with the PMFM thresholds, and threshold definitions

Note: Figures from MRC (2021b)

The PMFM dry season results for Chiang Saen (Figure 2.25) show that flow at the site was only in Zone 4 for a short period in early December 2020, but was otherwise above the long-term average for the site. This suggests that the very low flows recorded at Vientiane are due to low tributary inflows between Chiang Saen and Vientiane. This could be due to low rainfall, and/or water management strategies associated with hydropower operations.

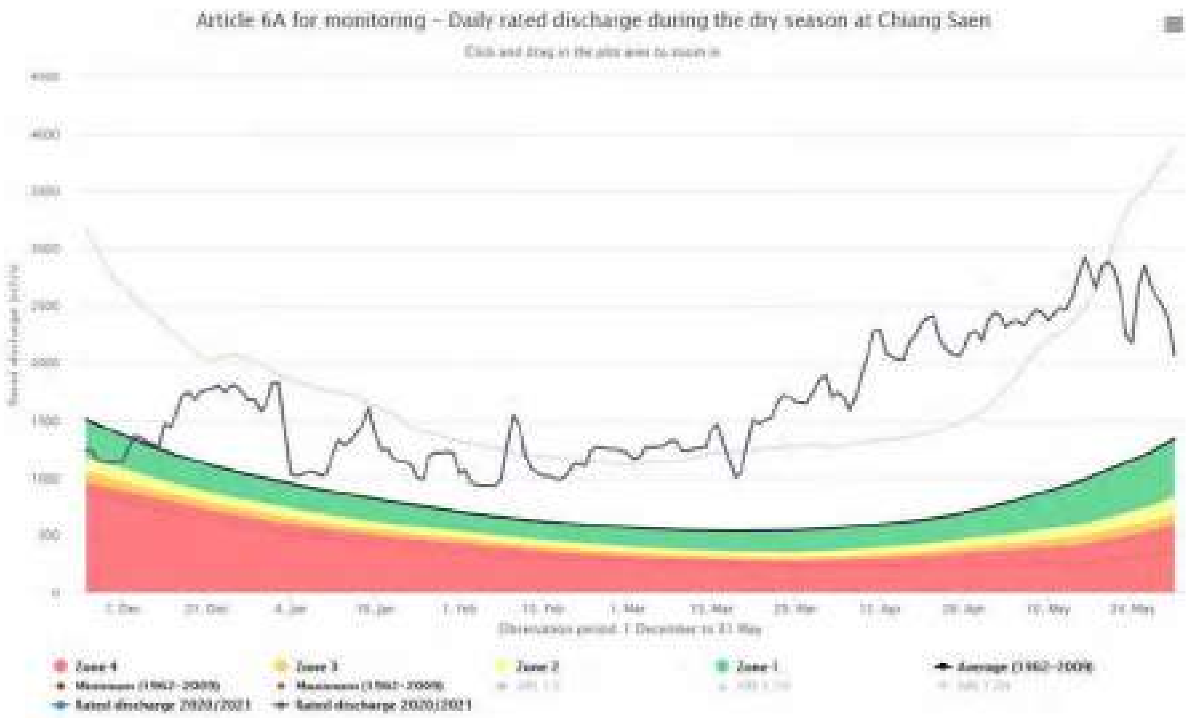

Figure 2.25. Comparison of average daily flow at Chiang Saen December 2020 to May 2021 with the PMFM thresholds

Notes: Figures from MRC (2021c)

Water level at Chiang Saen, Ban Pakhoung, Chiang Khan and Vientiane over the 2020–2021 dry season show similar patterns at all sites, consistent with low tributary inflows. The results also show that the water level fluctuations associated with operation of Xayaburi are substantially reduced at Chiang

Khan, so cannot be the responsible for the rapid water level fluctuations recorded at Vientiane. The Vientiane results are likely due to measurement error. A more in-depth analysis of flow fluctuation at Vientiane will be completed for the JEM Annual report.

Figure 2.26. Water level at Chiang Saen, Ban Pakhoung, Chiang Khan and Vientiane km 4 station during the 2020–2021 dry season (December 2020 – April 2021)

2.4.1.1. Wet season

The PMFM objective in the wet season (July – October 2020) is to prevent average daily peak flows greater than what naturally occur on the average during the flood season. The 2020 wet season flow results at Vientiane fall within PMFM Zone 1, which is defined as below the ARI 1:2 and considered normal hydrologic conditions (Figure 2.27).

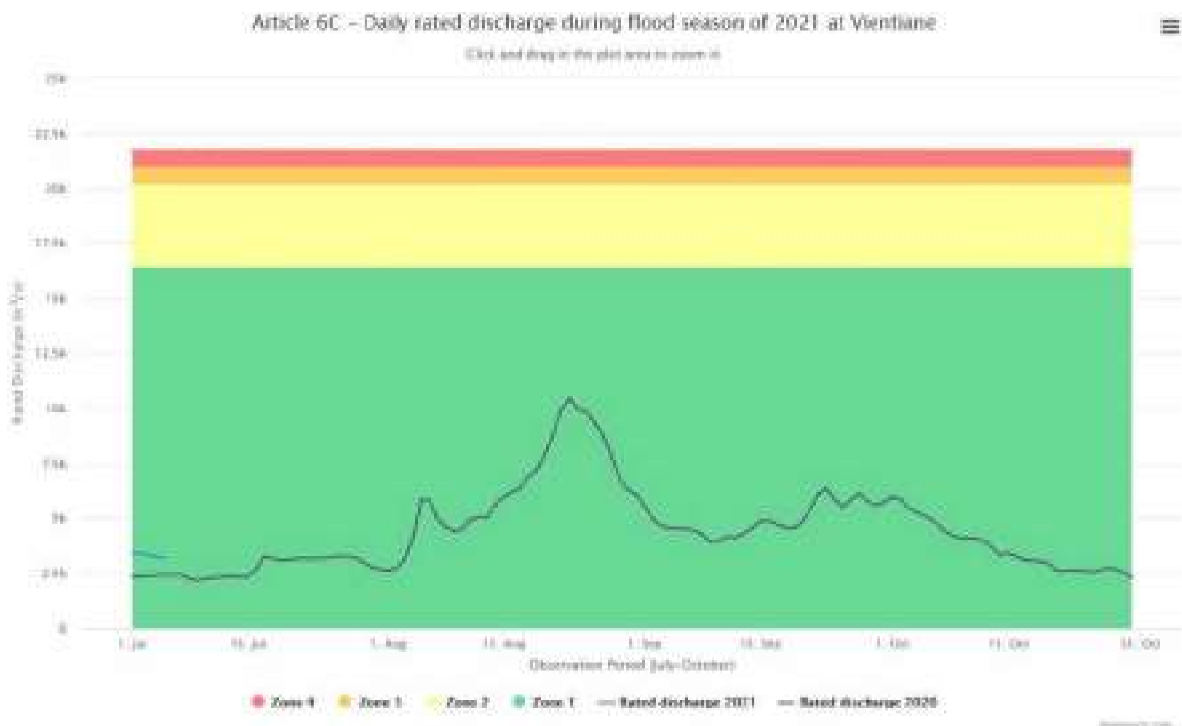

Figure 2.27. Wet season average daily discharge at Vientiane compared to PMFM thresholds

2.4. Sediment results

Three sediment parametres are included in the JEM pilot – suspended sediment (SSC), bed material grain size, and bedload movement estimates based on ADCP measurements and bed material size. The available results are discussed in the following sections.

2.4.1. Suspended sediment concentrations

2.4.1.2. Ban Xanghai and Ban Pakhoung

SSC results are determined by filtering the depth-integrated water samples through pre-weighed filters to determine the mass of sediment in each sample. However, the SSC results collected from October 2020 to February 2020 at Ban Xanghai and Pakhoung are compromised due to the weight of the empty filters not being recorded prior to filtration of the sample. To correct for this, the average weight of 20 dry filters was used as a proxy for the initial filter weight. Using this value resulted in many of the SSC results being negative, due to the very low quantities of sediment present in the samples. Table 2.4 summarizes the results, which should be considered rough estimates only. The results show low concentrations of SSC (<100 mg/L) at both sites. Until more accurate results are collected under a wider range of flow rates, it is impossible to determine the impact of Xayaburi on SSC. The water quality results show a reduction in turbidity, which would be expected to be reflected in the SSC results. This issue is discussed further in the following section (Chiang Khan).

Table 2.4. Summary of SSC results at Ban Xanghai and Ban Pakhoung monitoring sites

Ban Xanghai			Ban Pakhoung		
Date	Number of samples (n=)	SSC (mg/L)	Date	Number of samples (n=)	SSC (mg/L)
28/10/2020	5	58			
30/10/2020 (2 samples collected)	3 2	23 38			
31/10/2020	5	90			
26/11/2020	3	10			
16/12/2020	2	8			
26/1/2021	4	46	15/01/2021	1	24
8/2/2021	3	20	7/02/2021	3	20

Notes: Number of samples is the number of depth-integrated samples from the site where the final filter weight was greater than the average weight of an empty filter. Results are considered rough estimates only. Data DMH, Lao PDR.

2.4.1.3. Chiang Khan

SSC results from Chiang Khan are available for July to December 2020 and are shown together with the measured discharge results collected on the same day in Figure 2.24. The SSC concentrations range from 22 mg/L to 125 mg/L, with the highest concentration coinciding with the initial rise in flow at the start of the wet season, which is common in rivers. The concentrations decrease through August, before increasing in September and then decrease in October, and remain low for the rest of the year.

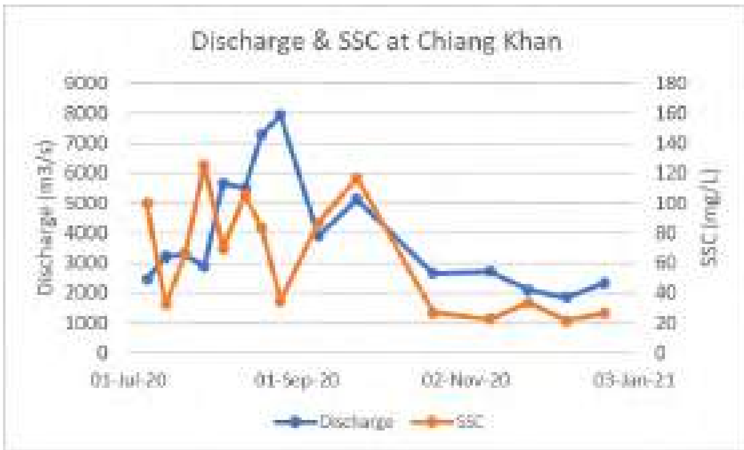

Figure 2.28. Discharge and SSC at Chiang Khan July 2020 – December 2020

Source: Data collected by ONWR, Thailand.

The flow and SSC results have been used to calculate the SSC load (tonnes/day). The daily SSC load on monitoring days ranged from 9,000 tonnes/day to 53,000 tonnes/day (Figure 2.25). Comparing the 2020 results to historical discharge and SSC load results from Chiang Khan shows that the 2019 and 2020 results have the lowest discharge and SSC loads of any year since monitoring began (Figure 2.26). The average SSC concentration in the long-term data set used for the analysis is 98 mg/L (n=131), whereas, in the 2018 to 2020 series, it is 54 mg/L (n=34).

To investigate whether sediment concentrations have decreased relative to flow rates since the construction of Xayaburi, the relationship between flow and SSC concentrations was statistically compared for the periods 2009 to 2018, and 2019 to 2020 using an ANCOVA analysis. The analysis was restricted to data collected when the flow was in the range of 1,700–8,000 m^3/s, equivalent to the flow range captured in the 2019 to 2020 data set. The analysis found that the relationship between flow and sediment in the 2019–2020 results is statistically different from the historic results ($p<0.01$), suggesting a reduction in sediment transport relative to flow since the end of 2018.

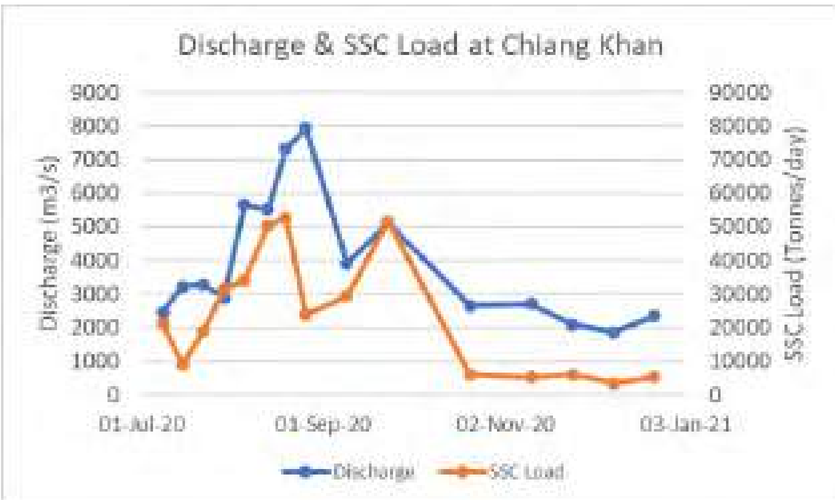

Figure 2.29. Discharge and SSC load at Chiang Khan, July to December 2020

Source: Data collected by ONWR, Thailand.

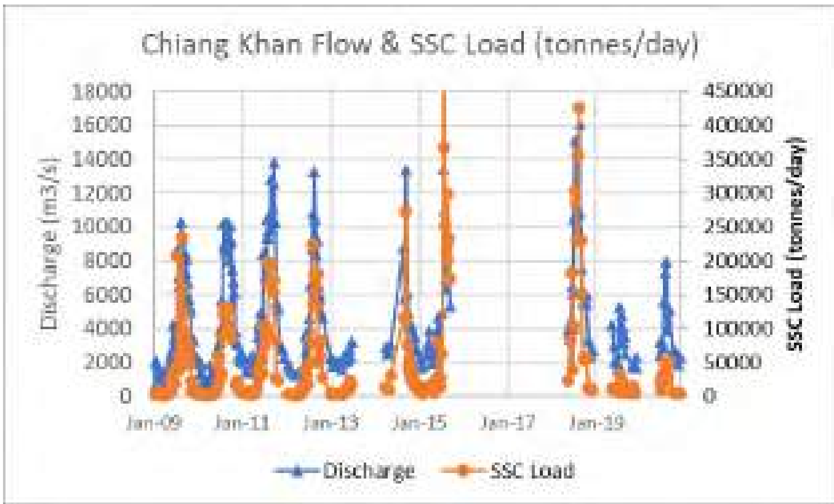

Figure 2.30. Discharge and SSC load at Chiang Khan from 2009 to the present

Note: The value of the August 2015 reading that extends off the graph is 637,740 tonnes/day

Source: Data collected by ONWR, Thailand.

The distribution of SSC results for the two time periods (Figure 2.27) shows that the median values are 80 and 45 mg/L, respectively. Long-term monitoring at this site is important for confirming and understanding the observed changes into the future.

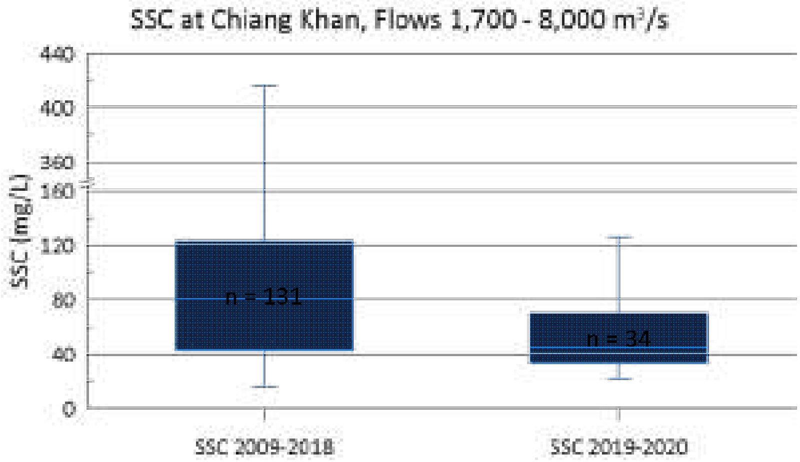

Figure 2.31. Box and whisker plot of SSC at Chiang Khan for flows between 1,700 and 8,000 for 2009–2018 and 2019–2020.

Note: The box encompasses the 25th to 75th percentile SSC values, with the lines extending to the minimum and maximum values. The median is indicated by the line in the box.

2.4.2. Bed material grain size distribution

Bed materials are collected from the same five locations across the cross-section as where the SSC samples are collected, with each point representing approximately 20% of the flow regime. Bed material results are available from Ban Xanghai and Ban Pakhoung, with no results reported for Chiang Khan.

The average grain size distribution for the samples collected from Ban Xanghai is shown in Figure 2.28. Only samples for which more than 10 g of material were collected are included in the averages. The first three results were collected within four days, and the differences between the samples is a good indication of sampling variability. The results show that medium sand (0.25–0.05 mm, light blue in the pie chart) is the most common grain size for most of the sampling dates. Finer material, in the range of 0.125 – 0.25 mm, is abundant in the October samples but decreases in abundance, with coarser material becoming more common in the November 2020 to February 2021 results. In the February 2021 sample, material coarser than 4.75 mm (pebbles) comprises about 20% of the average for the site, with most of this material present in one of the sub-samples. The trend of decreasing fine material and increasing coarse may reflect the transport of fine material being transported out of the section, resulting in the exposure of underlying coarser material.

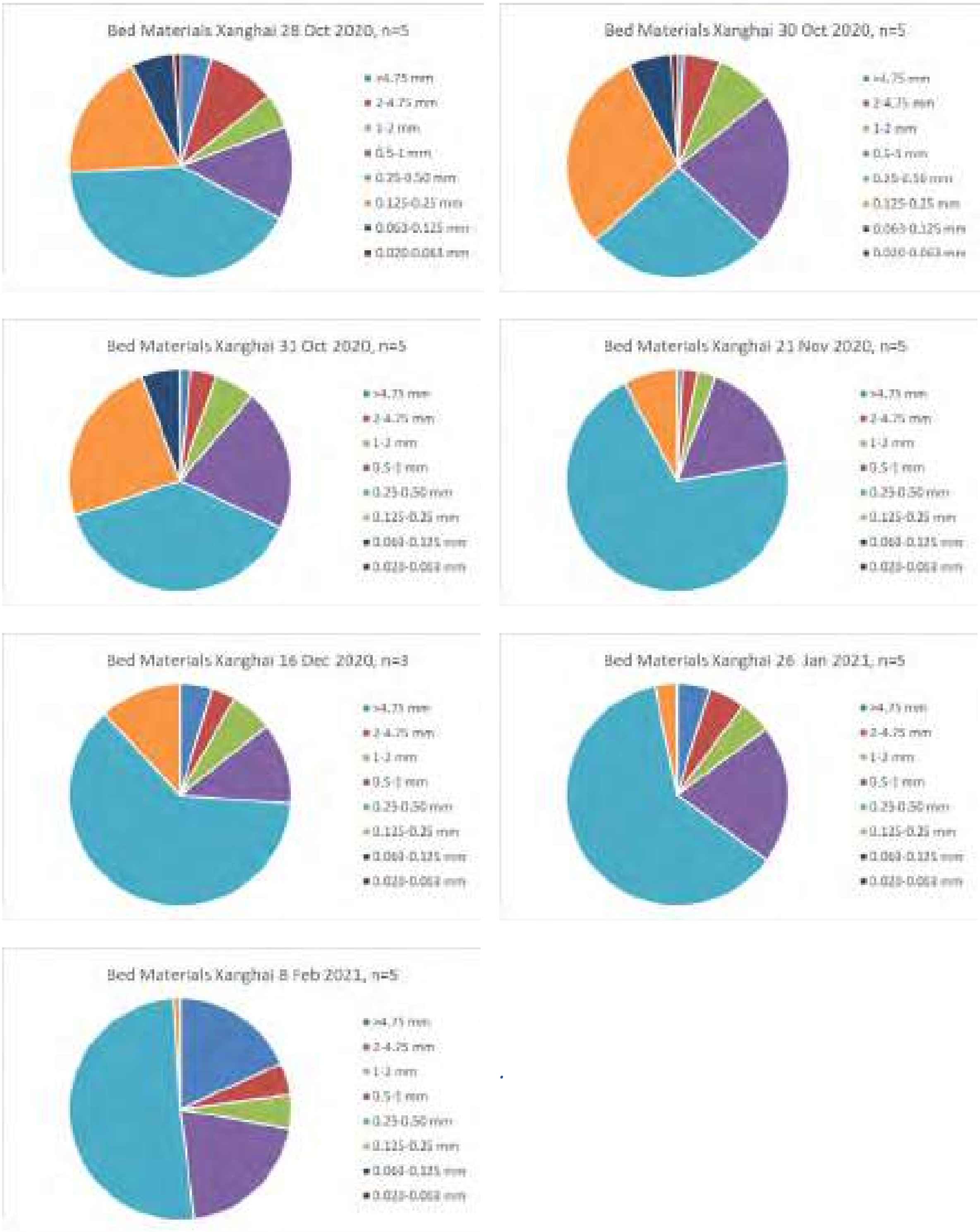

Figure 2.32. Grain size distribution of bed materials from Ban Xanghai

Note: n = number of samples collected from the cross-section where the mass was >10 g. Results from the DMH, Lao PDR.

The average grain size distribution for the samples collected from Ban Pakhoung is shown in Figure 2.29. Similar to the Ban Xanghai results, the most common grain-size class at Pakhoung is medium sand (0.25 – 0.05 mm, light blue in the pie chart), with coarse sand (0.5 – 1.0 mm, purple in the pie chart) being the next most common size. The samples collected in Jan and Feb 2021 show an increase in coarse material, similar to Ban Xanghai.

Based on the MRC model of the northern Lao PDR cascade, medium sand and coarser size fractions are unlikely to be transported through an impoundment, suggesting that the sediment in the channel downstream of Xayaburi is derived from inputs prior to the closing of the dam. Dam construction also generates large amounts of sediment, so a pulse of material associated with construction could also be moving through the river.

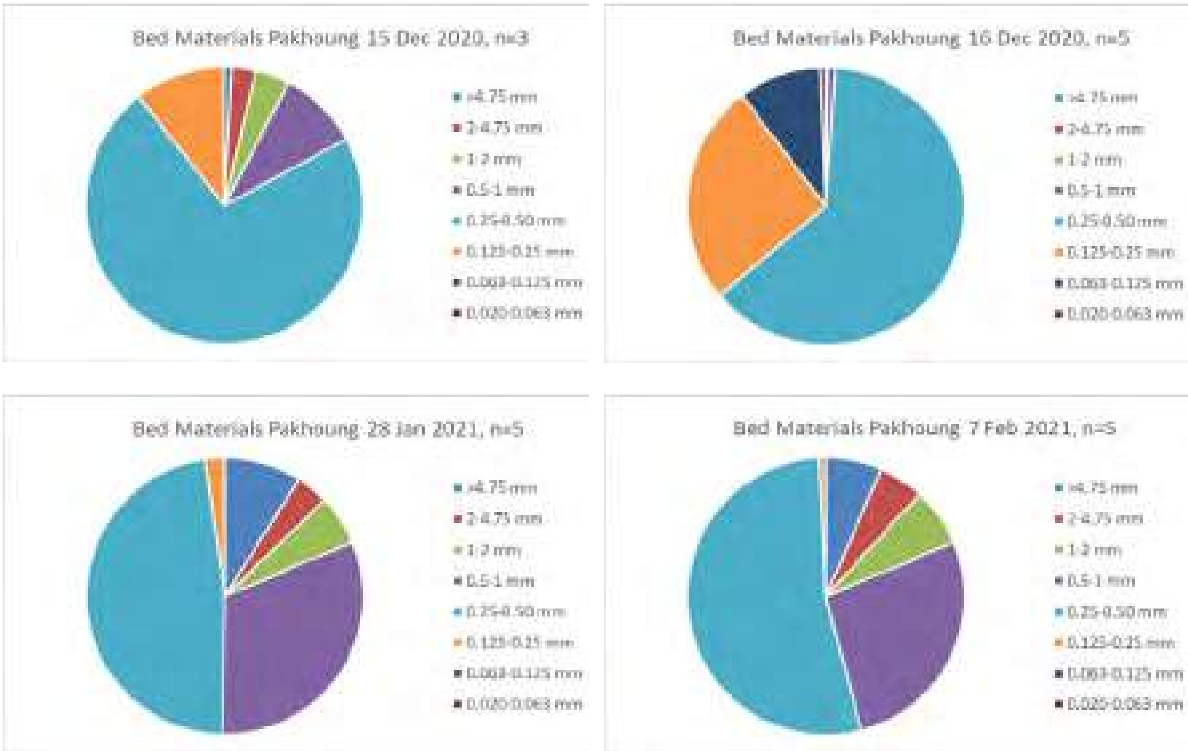

Figure 2.33. Grain size distribution of bed materials from Ban Pakhoung

Note: n = number of samples collected from the cross-section where the mass was >10 g. Results from the DMH, Lao PDR.

2.4.3. Bedload transport

2.4.3.1. Ban Xanghai and Ban Pakhoung

To estimate bedload transport, the moving bed velocity and width of the channel from the ADCP measurement are combined with the median grain size of bed material. A median grain size of 0.375 mm, based on the mid-point of the 0.25–0.50 mm grain-size class, has been used to estimate transport.

At Ban Xanghai, the estimated bedload transport ranges from 4% to 45% of the SSC load, with an average of 25%. This is very high, as bedload typically comprises <10% of transport, and is likely attributable to the high water velocity at the site, even during periods of low flow, and to the SSC being low due to upstream trapping in the Lancang and Nam Ou cascades and other tributary dams. More measurements over a wider range of flow rates are required to understand bedload transport and its relation to SSC transport.

Figure 2.34. Comparison of SSC load and estimated bedload transport at Ban Xanghai, October 2020 – February 2021

Note: The figure is in log scale.

At Ban Pakhoung, the estimates of bedload transport range from 1,000 to 2,000 tonnes/day (n=4). There are insufficient SSC results to make an estimate of the relative inputs from each source. The detection of bedload movement at Pakhoung is important, as it demonstrates that sediment in the channel 5 km downstream of Xayaburi has not yet been scoured out.

2.4.3.2. Chiang Khan

Since there are no bed material grain size analysis results available for Chiang Khan, 0.375 mm has been estimated as the median grain size of the bed material. The estimated bedload transport (Figure 2.31) ranged from <500 tonnes/ day to 4,000 tonnes/day, and was equivalent to between 3% and 17% of the SSC load, with an average of 7% (n=9).

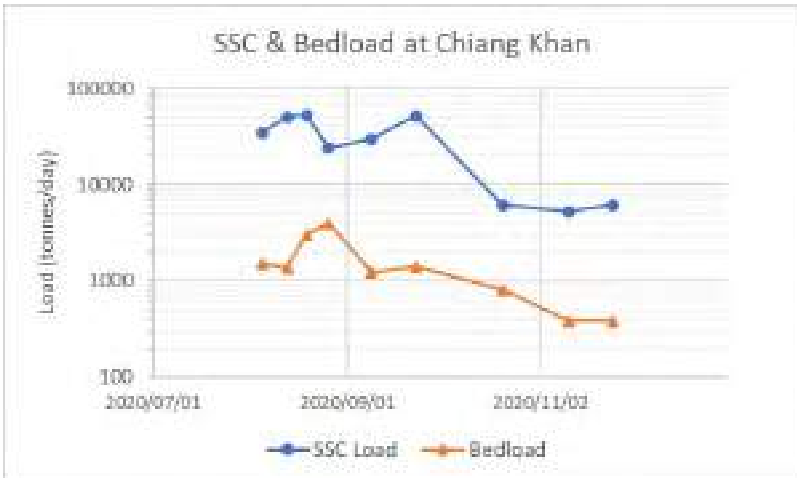

Figure 2.35. Comparison of SSC load and estimated bedload transport at Chiang Khan July 2020 – December 2020.

Note: The figure is in log scale.

2.5. Lessons learned and recommendations

The first six months of the JEM pilot monitoring provided some initial results. However, monitoring was hampered by a number of factors, mainly related to COVID-19, which prevented in-person training, resulting in the slow delivery of equipment and hindered field access for the monitoring teams.

Despite these challenges, the information being generated by the JEM Pilot at Xayaburi is showing the following impacts (potentially) associated with the operation of the hydropower project. This assessment should be considered preliminary until more data is available from a range of flow conditions:

- There are large and frequent water level fluctuations at Ban Pakhoung, around 5 km downstream of the dam, reflecting the operation of the turbines when inflow is less than the flow required to run all turbines. There are no historical results from the same site showing pre-dam conditions, but the magnitude and frequency of water level fluctuations are well beyond those shown at historic HYCOS sites.
- There is strong evidence that the operation of the project has increased the rate of water level fluctuations during the dry season at Chiang Khan.
- Compared to previous years, the power station may be reducing water level fluctuations during the months leading into the wet months at Chiang Khan. This would be consistent with the storage being used to modulate inflows to produce a more uniform flow rate for hydropower generation.
- There is no evidence that the operation of the station has altered water flows on a seasonal basis.
- Suspended sediment concentrations have been low at all of the sites, although the number of measurements completed at Ban Xanghai and Ban Pakhoung is very limited. At Chiang Khan, the 2019–2020 SSC results are statistically lower than the SSC results collected in 2009–2018 under similar flow rates (1,700–8,000 m^3/s). This decrease is consistent with sediment trapping in Xayaburi and likely other upstream HPPs that have come online in 2019 and 2020.
- Bedload transport information is very limited but suggests that bedload transport is considerable at Ban Xanghai and Ban Pakhoung, where water velocities are high even during conditions of low flow. At Chiang Khan, the bedload component is estimated to be on average, about 7% of the SSC load.

2.5.1. Recommendations

Recommendations arising from the first year of the JEM pilots include:

2.5.1.1. Hydrology

The newly installed water level gauges at Ban Xanghai and Ban Pakhoung require finalisation, as follows:

- At Ban Xanghai
    - The gauge needs to be adjusted such that the water level gauge is accurately recording water level changes.
    - A survey of the site is required to link the site into the local datum and to establish a base level for water level measurements.
    - Twice daily water level readings need to be recorded and reported to the DMH.

- At Ban Pakhoung
    - The survey of the site needs to be finalised and submitted to the MRC, with the information clearly indicating which local benchmarks have been used to reference the site to the local datum, and the elevations of different points at the site.
- For the measurement of discharge using the ADCP, the following actions should be completed at each of the sites:
    - Ensure that the internal GPS is used when completing the discharge measurement and moving bed test.
    - Calibrate the compass in the ADCP prior to every monitoring run
    - Check the moving bed test results in the field to ensure that the test is valid, and if not, complete an additional test.
    - The water level of the river should be read and at the beginning and end each discharge measurement and recorded on the JEM revised Q2 form.
    - Countries should ensure there are numerous staff trained in collecting accurate ADCP measurements, so there are no gaps if one staff member leaves or is not available to complete the work.
- Processing of HYCOS data at the MRC:
    - The quality of the incoming data should be routinely checked, with machine spikes and poor data removed from the database.
    - Rating curves derived in 2013 based on 2009–2012 discharge measurements should be reviewed and updated.

2.5.1.2. Sediment monitoring and laboratory analysis

- The laboratory teams should review the method for determining SSC and ensure that all filters (blank and containing sediment) are dried prior to weighing, that pre-weighted filters are distributed to the field teams, and that the volume of the sample filtered is accurately recorded on the datasheet.
- Countries should ensure that there are numerous staff trained in the required laboratory procedures, so there are no gaps when staff leave or retire.

2.5.1.3. Maintenance of equipment

The JEM Pilot project has made a substantial investment in new equipment to enable discharge and sediment monitoring. It is critical that this equipment be stored and maintained appropriately to ensure that it remains in a suitable condition. Recommendations include:

- Boats should be removed from the river whenever possible to minimise damage caused by sediment and freshwater organisms on the hull of the boats.
- Boats should be thoroughly cleaned on a regular basis, and any damage to the fiberglass on the boats should promptly be fixed.
- Good quality engine oil should be used in the engines to ensure smooth operation and prolong the life of the engine.
- All wires and lines used for the deployment of the D96 depth-integrated suspended sediment sampler should be routinely inspected for wear and tear, and replaced when required to prevent loss of equipment.

3. Water quality

3.1. Adjustments to monitoring protocols

3.1.1. Monitoring stations

Five monitoring stations for the monthly water quality sampling were selected for the Xayaburi pilot site, one above Luang Prabang at the head of the impoundment, one in the impoundment above the Tha Deua bridge, and three downstream of the dam 1.5 km, 5 km and 10 km downstream. These are indicated in Table 3.1 and shown in Figure 3.1, and in greater detail for the downstream sites in Figure 3.2.

There have been no changes in the locations of the sampling stations, and the water quality monitoring team has not indicated any access or sampling difficulties at these stations.

Table 3.1. Water quality sampling stations for Xayaburi JEM Pilot

Code	Station	River	Latitude	Longitude
WQ1	Upstream of Xayaburi around 110 km upstream of the dam.	Mekong	~20°00'07.2"N	102°14'06.7"E
WQ2	Within the Xayaburi Impoundment (at Ban Talan, 1 km above the dam wall)	Mekong	19°15'16.1"N	101°48'45.5"E
WQ3	Around 4–5 km downstream of the dam	Mekong	19°13'49.5"N	101°49'17.1"E
WQ4	Around 4–5 km downstream of the dam	Mekong	19°12'58.3"N	101°49'25.5"E
WQ5	Downstream at Pakhoung Village, around 10 km downstream of the dam	Mekong	19°09'28.0"N	101°48'50.6"E

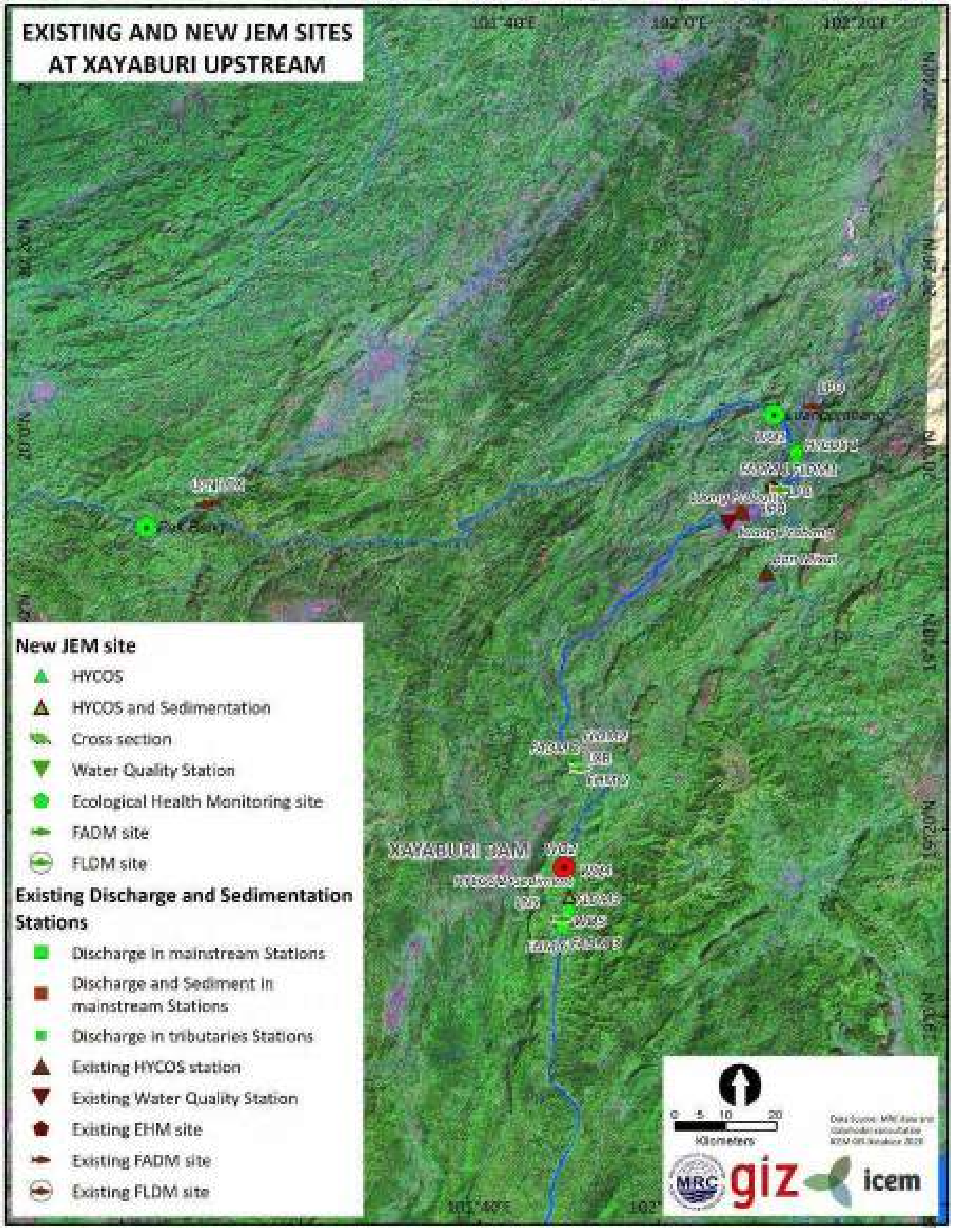

Figure 3.1. Locations of the sampling stations around Xayaburi HPP, including upstream stations

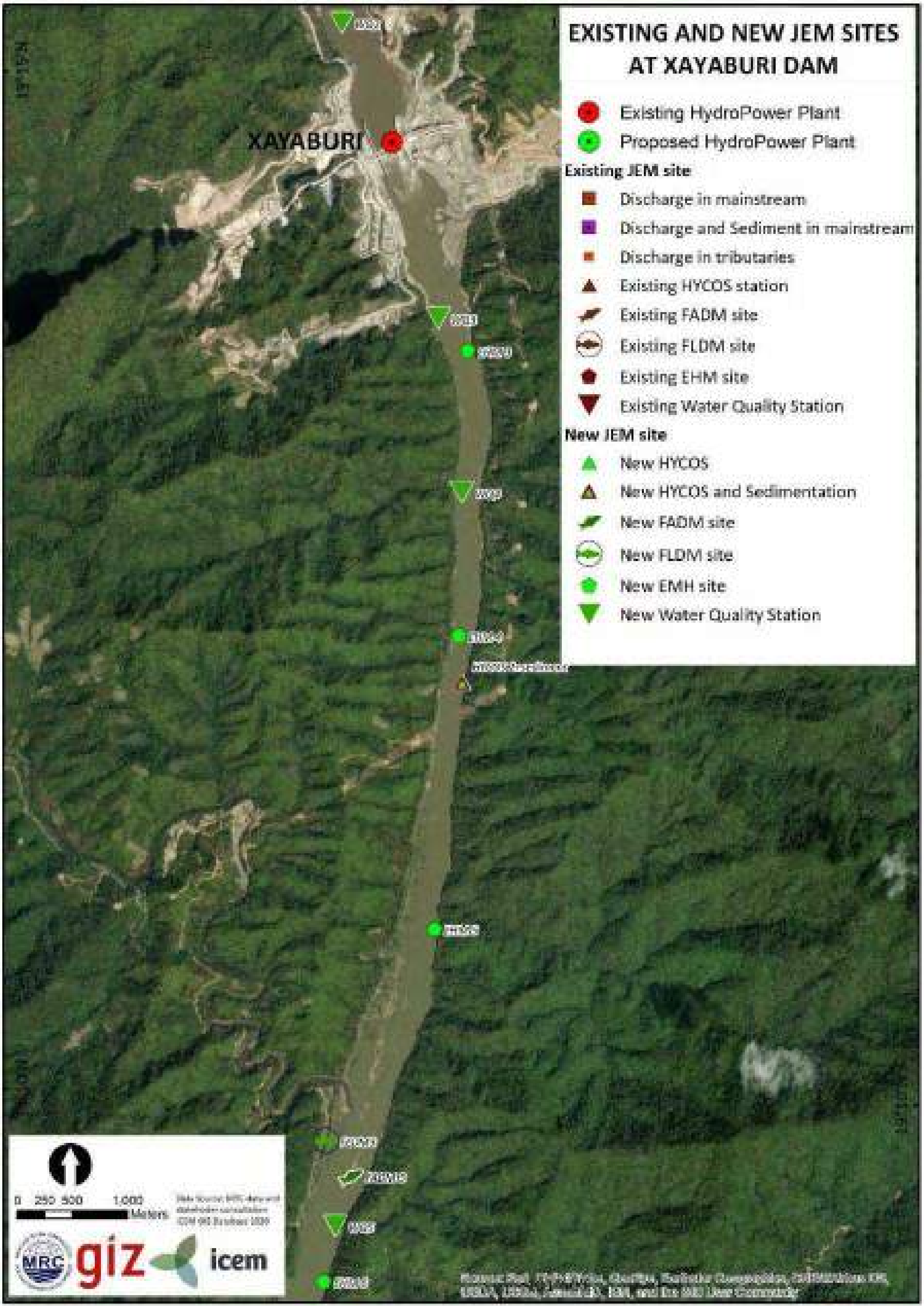

Figure 3.2. Water Quality Sampling stations downstream of the Xayaburi dam

3.1.2. Monitored parameters

The sampling stations are scheduled to be visited by the Lao water quality monitoring team on a monthly basis and carry out measurements using both water quality probes and taking samples for analysis in the laboratory at each site. The parameters measured are identical to the parameters used in the MRC's Water Quality Monitoring Network (WQMN), except for the new JEM measurements of turbidity, chlorophyll-a and cyanobacteria, which are carried out using the AlgaeTorch, procured by the pilot project. Table 3.2 shows the parameters measured at each site, some with the full complement of parameters measured, and others with a more restricted set. In addition, at the impoundment site, a depth profile using the water quality probe and AlgaeTorch lowered at 1 m intervals to 20 m and 10 m, respectively. There have been no changes to these parameters and analyses, and no constraints identified by the Lao water quality monitoring team.

Table 3.2. Water quality monitoring parameters measured at each of the Xayaburi monitoring stations

Parameter	Frequency	Probe	Lab	H011200	WQ1	WQ2	WQ2	WQ3	WQ4	WQ5	H011901
Sampling Type				WQMN	JEM Full	JEM IMP	IMP Prof	JEM short	JEM Full	JEM Short	MWQMN
				Luang Prabang	Upstream of XBR around 110-km upstream of the dam.	Within the XBR Impoundment (at Ban Talan,1-km above the dam wall)		Around 1.5km downstream of the dam)	Around 4-5 km downstream of the dam	Downstream at Pakhoung Village, around 10km downstream of the dam	Vientiane
				Mekong	Mekong	Mekong	Depth profile	Mekong	Mekong	Mekong	Mekong
				19.9	~20°00'07.2" N	19°15'16.1" N		19°13'49.5" N	19°12'58.3" N	19°09'28.0" N	17.9281
				102	102°14'06.7" E	101°48'45.5" E		101°49'17.1" E	101°49'25.5" E	101°48'50.6" E	102.62
Temperature	Monthly	x		x	x	x	x	x	x	x	x
pH	Monthly	x		x	x	x	x	x	x	x	x
Conductivity (Salinity)	Monthly	x		x	x	x	x	x	x	x	x
Dissolved Oxygen (DO)	Monthly	x		x	x	x	x	x	x	x	x
Alkalinity/ Acidity	Monthly		x	x	x				x		x
Total phosphorous (TP)	Monthly		x	x	x	x		x	x	x	x
Total Nitrogen (TN)	Monthly		x	x	x				x		x
Ammonium (NH_{4+}-N)	Monthly		x	x	x				x		x
Nitrite +Nitrate (NO_2+$_3$-N)	Monthly		x	x	x	x		x	x	x	x
Fecal Coliforms	Monthly		x	x	x				x		x
Total Suspended Solids (TSS)	Monthly		x	x	x				x		x
Chemical Oxygen Demand (COD)	Monthly		x	x	x				x		x
Calcium (Ca)	Monthly for 7 months		x	x	x				x		x
Magnesium (Mg)	Monthly for 7 months		x	x	x				x		x
Sodium (Na)	Monthly for 7 months		x	x	x				x		x
Potassium (K)	Monthly for 7 months		x	x	x				x		x
Sulphate (SO42-)	Monthly for 7 months		x	x	x				x		x
Chloride (Cl^-)	Monthly for 7 months		x	x	x				x		x
Turbidity	Monthly	x			x	x	x	x	x	x	
Chlorophyll *a*	Monthly	x	x		x	x	x	x	x	x	
Cyanobacteria	Monthly	x			x	x	x	x	x	x	

Note: Blue = routine WQ monitoring, Green = measurement in the laboratory, Yellow = measurement in the field by probe.

3.2. Activities

3.2.1. Water quality training sessions

On-line water quality training sessions were held on 16, 17 and 19 June 2020, attended principally by the Laos water quality monitoring team and representatives from the teams from other MCs. These training sessions emphasized the purpose of the JEM monitoring, the sampling stations, and the parameters and methods to be used. They outlined the water quality monitoring protocols and field data sheets. In particular, information on the new equipment was provided – the AlgaeTorch and horizontal van Dorn sampling bottle.

A lab-based training is yet to be provided for the analysis of chlorophyll-a using spectrophotometric techniques, which will be conducted when COVID-19 restrictions allow. A follow-up meeting with the Laos water quality monitoring team was held on 2 February 2021 to discuss any issues and challenges faced by the team in carrying out the water quality monitoring in order to consider the initial monitoring results and report preparation.

3.2.2. Monitoring missions

The Lao water quality monitoring team provided by the Natural Resources and Environment Statistics and Research Institute (NRESRI), the Ministry of Natural Resources and Environment (MoNRE) (Mr Sounthaly Mountha; Ms Soulisay Xayachak; Mr Sengtong Bounsavath), and the Department of Natural Resources and Environment of Luang Prabang (Mr Vueyang Yangxengyang) visited the Xayaburi sampling stations on the following occasions:

Table 3.3. Dates of sampling visits to Xayaburi pilot sampling stations

Sampling stations	2020			2021	
Month	10	11	12	1	2
WQ1	1.11.2020	15.11.2020	11.12.2020	13.01.2021	15.2.2021
WQ2	2.11.2020	16.11.2020	11.12.2020	13.01.2021	14.2.2021
WQ3	2.11.2020	16.11.2020	11.12.2020	13.01.2021	14.2.2021
WQ4	2.11.2020	16.11.2020	11.12.2020	13.01.2021	14.2.2021
WQ5	2.11.2020	16.11.2020	11.12.2020	13.01.2021	14.2.2021

3.3. Preliminary results and initial analysis

3.3.1. Surface water results

The monitoring results of the first five months of water quality sampling of the JEM pilot sites at Xayaburi are shown in *Table 3.5*. In comparison, the monthly average WQMN results between 2013 and 2018 for the Luang Prabang (113 km above Xayaburi) and Vientiane (365 km below Xayaburi) sites are shown in *Table 3.6*. The probe reading results are first compared on a monthly basis for all stations (*Figure 3.3*). The average monthly results for the routine monitoring and nutrient levels at Luang Prabang and Vientiane are shown in *Figure 3.4* and *Figure 3.5*, respectively.

Table 3.4 shows a comparison of water quality data for the Mekong River sites from the 2017 LMB Water Quality Report. While most of the results from the JEM sites lie within the usual ranges shown for both 1985–2016 and for 2017, there are some readings for both total nitrogen and phosphate that are abnormally high; these are marked on *Table 3.5* with yellow highlighting. Nitrate figures in the JEM pilot sites are generally higher than the mean values for 1985–2016 and 2017.

The JEM results for other parametres appear to be consistent with the similar monthly averages in the reference sites of Luang Prabang and Vientiane. The only parameter that appears to be different is pH, with the JEM sites being consistently more alkaline (mostly above pH 8) than in Luang Prabang (pH7.05–7.6), although more similar to Vientiane (pH 7.6–9.2). conductivity results are very similar for this stretch of river between Luang Prabang and Vientiane, and dissolved oxygen is consistently above 6 mg/l for all sites. Chemical oxygen demand (COD) levels in the JEM sites appear to be lower than in the two reference sites, and faecal coliforms are at consistently fairly low levels.

Table 3.4. Comparison of water quality data in the Mekong River in 1985–2016 and 2017

Parameter	Unit	Water Quality Guidelines Protection of		1985-2016				2017			
		Human Health (WQGH)	Aquatic Life (WQGA)	Max	Mean	Min	Stdev	Max	Mean	Min	Stdev
Temp	◦C	Natural	Natural	38.0	27.1	13.0	3.1	32.3	28.1	18.0	2.6
pH		6-9	6-9	9.9	7.5	3.8	0.5	8.4	7.3	6.1	0.5
TSS	mg/L	-	-	5,716.0	148.7	0.1	260.3	422.1	103.1	3.4	86.5
EC	mS/m	70 - 150	<150	841.0	20.7	1.2	27.7	41.4	19.0	7.6	5.3
NO3-2	mg/L	5	0.5	1.4	0.2	-	0.2	0.9	0.3	-	0.2
NH4N	mg/L	0.5	0.1	3.0	-	-	0.1	0.5	0.1	-	0.1
TOTN	mg/L	-	-	4.9	0.6	-	0.4	2.6	0.7	0.1	0.4
TOTP	EC	-	0.13	2.2	0.1	-	0.1	0.3	0.1	-	0.1
DO	mg/L	≥ 4	> 5	13.9	7.2	2.3	1.1	9.8	6.9	4.6	1.2
COD	mg/L	5	-	65.0	2.2	-	2.0	9.4	2.4	0.1	1.5

Source: MRC (2017)

The longitudinal (WQ1 – WQ5) results of JEM monitoring are shown graphically for each month in order to illustrate changes with flow through the impoundment and downstream of the dam (*Figure 3.6* Month 10, *Figure 3.7* Month 11, *Figure 3.8* Month 12, *Figure 3.9* Month 1, *Figure 3.10* Month 2).

In the next section, the water quality index for both the protection of aquatic health and of human health are calculated for every site and month and compared to the monthly averages of the water quality indices for Luang Prabang and Vientiane during the 2013–2018 period.

Table 3.5. Water Quality monitoring results for months 10/11/12 in 2020 and 1 and 2 in 2021

Station ID	Station name	Year	Month	TEMP	pH	TSS	COND	NO32	NH4N	TOTN	TOTP	DO	Turbidity	Chlorophyll-a	Cyanobacteria	CODMN	FC
				°C		mg/L	mS/m	mg/L	mg/L	mg/L	mg/L	mg/L	FTU			mg/L	MPN/100ml
WQ1	Ban.Xanghai	2020	10	25.44	8.06	41.83	22.49	0.40	0.07	1.10	0.08	6.35	32.20	-	-	1.54	130
WQ1	Ban.Xanghai	2020	11	24.29	8.16	50.20	24.84	0.44	0.05	**4.18**	0.04	6.51	31.66	-	-	2.7	45
WQ1	Ban.Xanghai	2020	12	22.12	8.36	20.90	26.74	0.58	0.02	1.22	**4.65**	8.38	18.94	-	-	0.35	45
WQ1	Ban.Xanghai	2021	1	21.14	8.29		28.50					6.90	20.00	1.87	1.24		
WQ1	Ban Xanghai	2021	2	21.88	8.34		29.31					6.18	11.03	1.54	0.00		
WQ2	Ban.Talan	2020	10	26.38	8.45		22.90	0.72			0.02	7.12	8.10	0.20	0.10		
WQ2	Ban.Talan	2020	11	25.62	8.53		25.40	0.55			0.03	6.47	7.20	0.20	0.10		
WQ2	Ban.Talan	2020	12	23.38	8.62		26.90	0.38			**6.50**	8.88	7.50	0.70	-		
WQ2	Ban.Talan	2021	1	21.32	8.45		29.70					6.35	6.40	1.50	1.20		
WQ2	Ban Talan	2021	2	22.19	7.96		29.30					6.84	5.57	1.36	0.01		
WQ3	#1 Xayaburi	2020	10	25.30	8.15		22.71	0.90			0.04	6.12	9.81	-	-		
WQ3	#1 Xayaburi	2020	11	24.83	8.31		25.30	0.56			0.04	6.11	8.43	0.23	-		

Station ID	Station name	Year	Month	TEMP	pH	TSS	COND	NO32	NH4N	TOTN	TOTP	DO	Turbidity	Chlorophyll-a	Cyanobacteria	CODMN	FC
WQ3	#1 Xayaburi	2020	12	22.86	8.43		27.10	0.30			**4.20**	8.92	7.34	0.41	-		
WQ3	#1 Xayaburi	2021	1	21.33	8.37		29.70					6.35	7.17	1.74	1.16		
WQ3	#1 Xayaburi	2021	2	22.06	8.41		29.30					6.48	6.14	0.46	0.00		
WQ4	#2 Xayaburi	2020	10	25.30	8.17	7.50	22.76	0.49	0.45	1.01	0.04	6.68	9.66	-	-	0.77	110
WQ4	#2 Xayaburi	2020	11	24.83	8.31	111.00	25.30	0.67	0.04	**3.44**	0.02	6.08	8.43	0.11	-	0.96	40
WQ4	#2 Xayaburi	2020	12	22.91	8.46	90.11	27.04	0.15	0.01	1.03	0.10	8.81	7.03	0.56	-	0.40	110
WQ4	#2 Xayaburi	2021	1	21.36	8.41		29.70					6.38	6.76	1.90	1.13		
WQ4	#2 Xayaburi	2021	2	22.07	8.42		29.30					6.54	5.90	0.44	0.04		
WQ5	#3 Xayaburi	2020	10	25.30	8.03		22.73	0.80			0.26	6.27	9.39	-	-		
WQ5	#3 Xayaburi	2020	11	24.81	8.26		25.20	0.52			0.25	6.24	8.23	0.10	0.01		
WQ5	#3 Xayaburi	2020	12	22.86	8.37		27.07	0.58			**1.04**	8.97	6.56	0.39	0.01		
WQ5	#3 Xayaburi	2021	1	21.34	8.38		29.70					6.49	6.93	1.61	1.27		
WQ5	#3 Xayaburi	2021	2	22.15	8.39		29.30					6.76	5.69	0.81	0.00		

Note: Yellow highlights indicate results that exceed routine MQMN ranges.

Table 3.6. Average monthly water quality results for Luang Prabang and Vientiane WQMN sites between 2013 and 2018

Month	TEMP °C	pH	TSS mg/l	COND mS/m	NO32 mg/l	NH4N mg/l	TOTN mg/l	TOTP mg/l	DO mg/l	CODMN mg/l	FC MPN/100ml
Luang Prabang											
1	22.4	7.58	76.3	24.82	0.31	0.02	0.56	0.20	6.42	1.73	64
2	23.7	7.23	40.9	27.20	0.26	0.03	0.39	0.06	6.17	2.25	48
3	24.6	7.11	37.5	27.50	0.29	0.02	0.50	0.15	6.33	1.59	38
4	25.0	7.15	39.9	28.22	0.46	0.02	0.68	0.08	6.75	1.77	229
5	26.2	7.21	32.9	28.82	0.32	0.02	0.61	0.04	6.41	1.01	1,516
6	26.4	6.87	47.2	26.32	0.38	0.03	0.74	0.06	5.97	2.69	77
7	26.0	6.87	134.6	22.87	0.31	0.03	0.70	0.26	5.96	4.87	149
8	25.8	6.86	309.1	18.48	0.41	0.02	0.67	0.10	6.15	4.78	592
9	26.8	7.12	197.0	16.88	0.40	0.03	0.58	0.12	6.16	3.40	48
10	26.2	7.29	83.8	19.82	0.45	0.02	0.67	0.05	6.41	2.37	77
11	24.6	7.16	43.2	24.00	0.44	0.02	0.62	0.08	6.42	2.40	57
12	22.6	7.05	50.6	23.83	0.54	0.02	0.71	0.11	7.10	1.95	81
Vientiane											
1	23.1	7.99	47.8	24.65	0.18	0.02	0.57	0.09	7.39	1.52	62
2	23.8	7.81	46.5	26.17	0.27	0.02	0.78	0.07	6.61	1.57	172
3	25.2	8.02	44.4	24.07	0.22	0.02	0.71	0.13	6.43	1.65	262
4	25.8	8.10	39.7	30.35	0.31	0.02	0.88	0.05	7.15	1.35	248
5	28.6	8.01	55.2	31.30	0.23	0.02	0.32	0.29	6.37	1.87	445
6	28.9	7.79	105.2	32.38	0.34	0.02	0.72	0.05	6.28	3.07	58
7	23.1	6.34	392.3	22.83	0.34	0.01	0.52	0.09	6.32	8.02	208
8	28.2	7.56	364.1	18.30	0.33	0.02	0.55	0.05	7.51	4.19	266

Month	TEMP °C	pH	TSS mg/l	COND mS/m	NO32 mg/l	NH4N mg/l	TOTN mg/l	TOTP mg/l	DO mg/l	CODMN mg/l	FC MPN/100ml
9	28.1	7.55	425.3	17.57	0.36	0.01	1.00	0.10	6.66	6.02	144
10	27.9	7.64	163.8	18.39	0.26	0.01	0.55	0.05	6.36	3.37	248
11	26.8	8.13	72.3	30.50	0.32	0.02	0.50	0.08	6.99	2.40	57
12	28.1	9.16	143.1	24.69	0.38	0.01	0.44	0.21	6.93	3.19	31

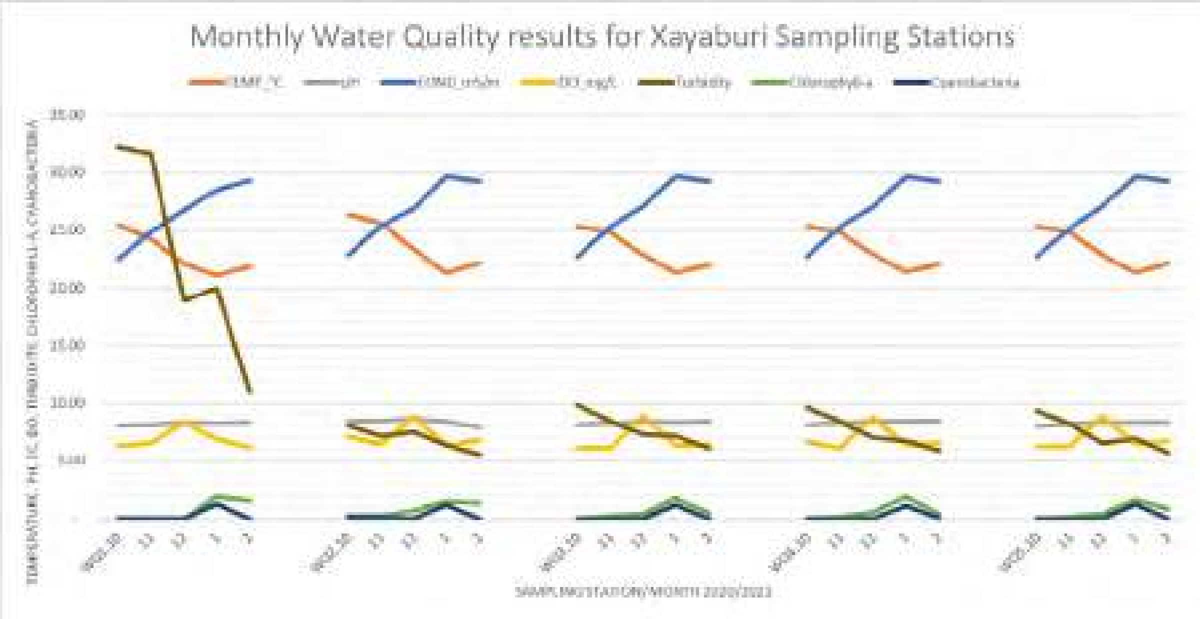

Figure 3.3. Monthly water quality probe readings for Xayaburi sampling stations. Months 10 (2020) to Month 2 (2021)

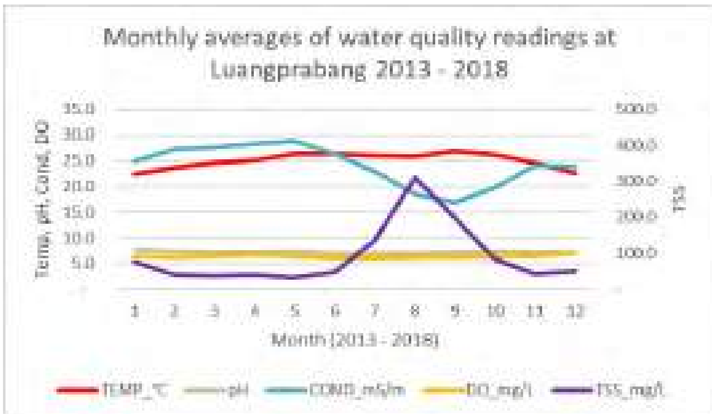

Figure 3.4. Monthly averages of water quality results in 2013–2018 for Luang Prabang and Vientiane WQMN sites

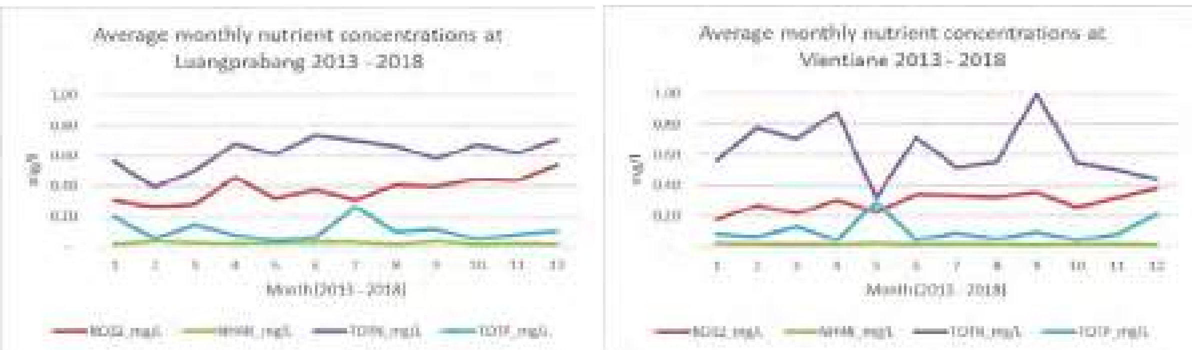

Figure 3.5. Monthly averages of nutrient levels in 2013–2018 for Luang Prabang and Vientiane WQMN sites

When the results from the probe readings at each site are compared for the months of October 2020 through to February 2021 (Figure 3.3), there are several trends over time that can be observed at all sampling stations. Temperature shows a consistent fall from about 25 ^oC to 21 ^oC to January, followed by a rise in February. This is to be expected with seasonal air temperature changes.

pH remains more or less constant at around 8 for all sites and months. conductivity increases over the months, from about 22 to 30 mS/m with a slight decrease in February. This is consistent with the readings for conductivity at Luang Prabang and Vientiane, and reflects the increased dissolved salts during lower flows. Dissolved oxygen is slightly variable, between 6 and 8 mg/l, with a peak in December at all stations, but all readings show good levels of dissolved oxygen. turbidity readings show much higher levels at WQ1 than the other sampling stations further downstream, but all stations are showing a distinct fall in turbidity readings over the period. This is consistent with decreasing levels of suspended solids as flows decrease seasonally.

chlorophyll-a and cyanobacteria levels are low at all stations in October and November and then rise slightly to between 1 mcg/l and 2 mcg/l in December, falling slightly in January and February. cyanobacteria are always lower than chlorophyll-a and sometimes zero. These are well below World Health Organization guideline threshold levels (50 mcg/l of chlorophyll-a, with a predominance of cyanobacteria = moderate probability of adverse health effects).

When the changes in the water quality parameters are compared at different stations downstream in each month (Figures 3.6, 3.7, 3.8, 3.9, 3.10), temperature and conductivity remain fairly constant, with passage through the impoundment (WQ2) and downstream. There is perhaps a very small increase in temperature within the impoundment in all months. pH and dissolved oxygen remain relatively constant with passage downstream in all months. turbidity consistently shows higher readings at WQ1 with lower readings in the impoundment and downstream, e.g. in November 2020, the WQ1 had an FTU reading of 32, compared to 8 in the impoundment – a decrease of 75%. The impoundment consistently has slightly lower FTU compared to the downstream sites. This is to be expected in a hydropower impoundment, but more results are required to confirm this trend.

However, the TSS show variable results, in October there was a significant

decrease between WQ1 and WQ4, which was reversed in November and December. This is curious but may reflect discharges downstream of the dam, depending on the flows at the time of sampling. There is a recognized correlation between TSS and turbidity that is not reflected in these results; these are parameters that need watching, with measurements being made at all sites rather than just two, and linked to flow data at the moment of sampling.

COD readings show slight reduction between WQ1 and WQ4 downstream of the dam, perhaps indicating a slight purification through the impoundment and faecal coliforms show similar levels at both stations, between 45 and 130 MPN/100 ml, i.e. little purification effects of the impoundment.

When the nutrient levels and chlorophyll-a and cyanobacteria are compared, nitrate/nitrite readings are higher than the mean values for the Mekong shown in Table 3.4 (0.2 mg/l for 198 –2016), but do not show a trend with passage downstream. Total nitrogen readings in November at WQ1 and WQ4 were also high. Total phosphate readings may show a slight decrease with passage through the impoundment and dam. In December 2020, total phosphate readings were much higher than the means and maxima shown in Table 3.4 (mean of 0.1 mg/l with maximum of 2.2 mg/l), but further results are needed to confirm and explain this anomaly and trend, which may be of significant concern. chlorophyll-a and cyanobacteria are at low levels throughout and do not show a definite pattern of change with passage through the impoundment and dam.

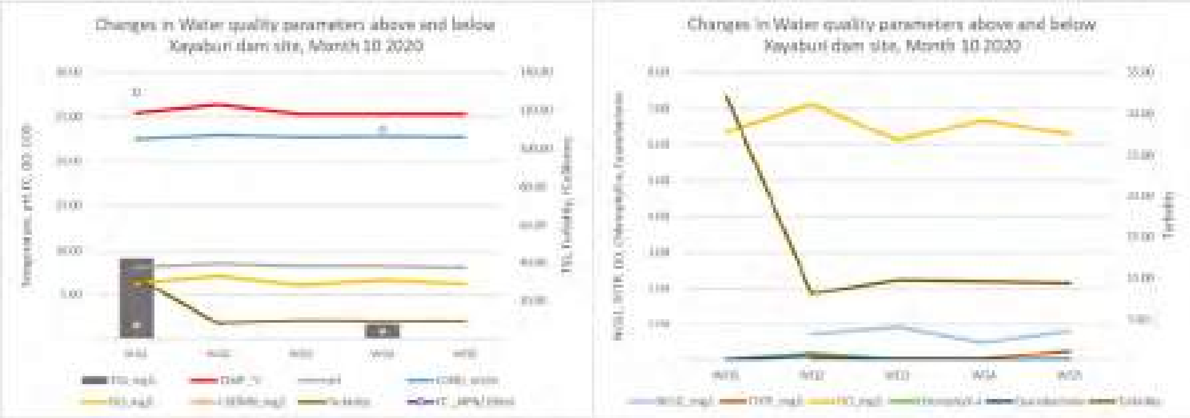

Figure 3.6. Water quality results for Xayaburi pilot sites for Month 10, 2020

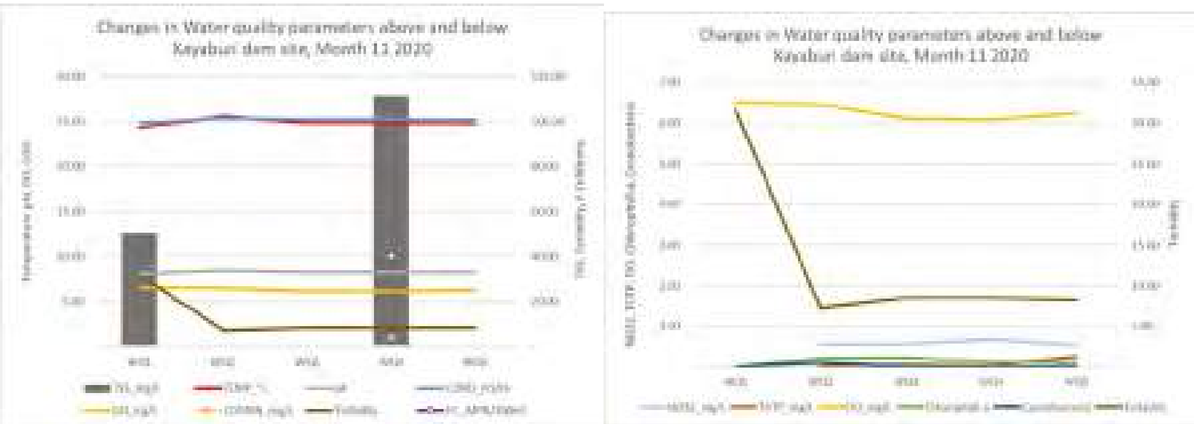

Figure 3.7. Water quality results for Xayaburi pilot sites for Month 11, 2020

Figure 3.8. Water quality results for Xayaburi pilot sites for Month 12, 2020

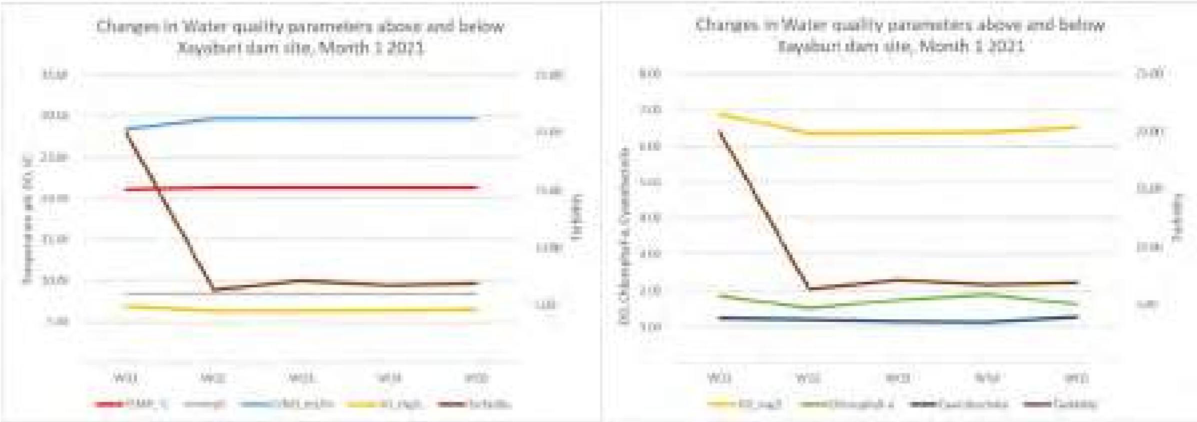

Figure 3.9. Water quality results for Xayaburi pilot sites for Month 1, 2021

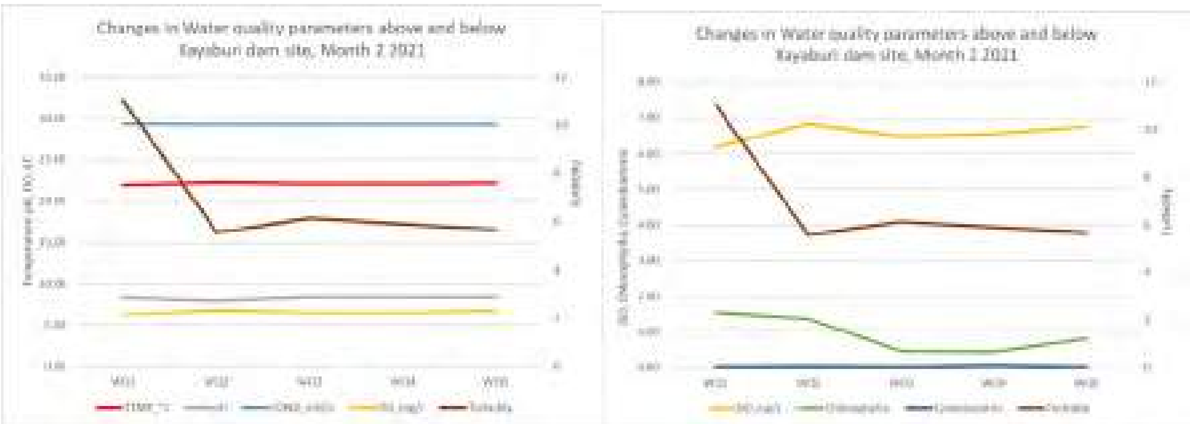

Figure 3.10. Water quality results for Xayaburi pilot sites for Month 2, 2021

3.3.2. Water quality indices

3.3.2.1. Water Quality Index for the protection of aquatic health

The water quality (WQ) index and classes for the protection of aquatic health and for human health have been calculated for each of the sites and sampling months by comparing the results for pH, conductivity, oxides of nitrogen, ammonia, total phosphate and dissolved oxygen to thresholds (shown in Table 3.4). If the results lie within these thresholds, they are awarded 1 point, as shown in Table 3.7, and then the Index is calculated as a ratio of the parameters lying within the thresholds.

The WQ index and classes for each of the sites shows that generally WQ1 is of (A) High quality, except for December when the thresholds are exceeded for oxides of nitrogen and total phosphate, and the class is downgraded to (C) Moderate quality. This trend in December is mirrored with the average figures for the Luang Prabang site.

Within the impoundment (WQ2), the Water Quality Guideline for the protection of aquatic health (WQGA) index and class shows (B) Good Quality reduced by the raised nitrogen oxides in October and November and by the very high total phosphate in December.

Downstream sites WQ3 and WQ4 show the patterns of WQGA index and class (B) good quality, but WQ5 is classed as (C) moderate quality in all of the first three months because of the high oxides of nitrogen and total phosphate levels. The comparison with the Vientiane site shows a very similar pattern to Luang Prabang and WQ1 with depressed classes in December because of exceedance of pH and total phosphate.

Note that for all sites in months 1 and 2, 2021 there are results for only three parameters, so the WQ class has not been estimated, and these indices will have to be recalculated when the lab analysis has been completed.

Table 3.7. Estimates of WQ Index for protection of Aquatic Health

StationID	station name	Year	Month	ph	Cond	NO	NH	Tot P	DO	WQ Index	WQ Class
				meeting target guidelines							
WQ1	Ban.Xanghai	2020	10	1	1	1	1	1	1	10.00	A
WQ1	Ban.Xanghai	2020	11	1	1	1	1	1	1	10.00	A
WQ1	Ban.Xanghai	2020	12	1	1	0	1	0	1	6.67	C
WQ1	Ban.Xanghai	2021	1	1	1				1	10.00	
WQ1	Ban Xanghai	2021	2	1	1				1	10.00	
	Average for site									9.17	B
	Luangprabang		10	1	1	1	1	1	1	10.00	A
			11	1	1	1	1	1	1	10.00	A
		2013 - 2018	12	1	1	0	1	1	1	8.33	B
			1	1	1	1	1	0	1	8.33	
			2	1	1	1	1	1	1	10.00	
	Average for site									9.33	B
WQ2	Ban.Talan	2020	10	1	1	0		1	1	8.00	B
WQ2	Ban.Talan	2020	11	1	1	0		1	1	8.00	B
WQ2	Ban.Talan	2020	12	1	1	1		0	1	8.00	B
WQ2	Ban.Talan	2021	1	1	1				1	10.00	
WQ2	Ban Talan	2021	2	1	1				1	10.00	
	Average for site									8.75	B
WQ3	#1 of Xayabouri HPP	2020	10	1	1	0		1	1	8.00	B
WQ3	#1 of Xayabouri HPP	2020	11	1	1	0		1	1	8.00	B
WQ3	#1 of Xayabouri HPP	2020	12	1	1	1		0	1	8.00	B
WQ3	#1 of Xayabouri HPP	2021	1	1	1				1	10.00	
WQ3	#1 of Xayabouri HPP	2021	2	1	1				1	10.00	
	Average for site									8.75	B
WQ4	#2 of Xayabouri HPP	2020	10	1	1	1	0	1	1	8.33	B
WQ4	#2 of Xayabouri HPP	2020	11	1	1	0	1	1	1	8.33	B
WQ4	#2 of Xayabouri HPP	2020	12	1	1	1	1	1	1	10.00	A
WQ4	#2 of Xayabouri HPP	2021	1	1	1				1	10.00	
WQ4	#2 of Xayabouri HPP	2021	2	1	1				1	10.00	
	Average for site									9.17	B
WQ5	#3 of Xayabouri HPP	2020	10	1	1	0		0	1	6.00	C
WQ5	#3 of Xayabouri HPP	2020	11	1	1	0		0	1	6.00	C
WQ5	#3 of Xayabouri HPP	2020	12	1	1	0		0	1	6.00	C
WQ5	#3 of Xayabouri HPP	2021	1	1	1				1	10.00	
WQ5	#3 of Xayabouri HPP	2021	2	1	1				1	10.00	
	Average for site									7.50	C
	Vientiane		10	1	1	1	1	1	1	10.00	A
	Monthly averages		11	1	1	1	1	1	1	10.00	A
		2013 - 2018	12	0	1	1	1	0	1	6.67	C
			1	1	1	1	1	1	1	10.00	
			2	1	1	1	1	1	1	10.00	
	Average for the site									9.33	B

3.3.2.2. Water Quality Index for the Protection of Human Health

The water quality index and classes for the protection of human health have been calculated for each of the sites and sampling months by comparing the results for pH, conductivity, oxides of nitrogen, ammonia, COD and dissolved oxygen to thresholds (shown in Table 3.4). If the results lie within these thresholds, they are awarded 1 point as shown in Table 3.8 and then the Index calculated as a ratio of the parameters failing the guidelines by exceeding the thresholds. The results show that in none of the sites and months do the results exceed the thresholds, and the Water Quality Guideline for the Protection of Human Health (WQGH) class is (A) Excellent quality, which is compared with the average monthly results at Luang Prabang and Vientiane. Note that although many of the parameters used are the same as WQGA, the thresholds used in the WQGH are higher and thus easier to comply with.

Table 3.8. Estimates of the Water Quality Index for the protection of human health

StationID	station name	Year	Month	ph	Cond	NO	NH	COD	DO	WQGH Index	WQGH class
				meeting target guidelines							
WQ1	Ban.Xanghai	2020	10	1	1	1	1	1	1	100.00	A
WQ1	Ban.Xanghai	2020	11	1	1	1	1	1	1	100.00	A
WQ1	Ban.Xanghai	2020	12	1	1	1	1	1	1	100.00	A
WQ1	Ban.Xanghai	2021	1	1	1				1	100.00	
WQ1	Ban Xanghai	2021	2	1	1				1	100.00	
	Luangprabang	2013 - 2018	10	1	1	1	1	1	1	100.00	A
	averaged monthly results		11	1	1	1	1	1	1	100.00	A
			12	1	1	1	1	1	1	100.00	A
			1	1	1	1	1	1	1	100.00	A
			2	1	1	1	1	1	1	100.00	A
WQ2	Ban.Talan	2020	10	1	1	1		1	1	100.00	A
WQ2	Ban.Talan	2020	11	1	1	1		1	1	100.00	A
WQ2	Ban.Talan	2020	12	1	1	1		1	1	100.00	A
WQ2	Ban.Talan	2021	1	1	1				1	100.00	
WQ2	Ban Talan	2021	2	1	1				1	100.00	
WQ3	#1 of Xayabouri HP	2020	10	1	1	1		1	1	100.00	A
WQ3	#1 of Xayabouri HP	2020	11	1	1	1		1	1	100.00	A
WQ3	#1 of Xayabouri HP	2020	12	1	1	1		1	1	100.00	A
WQ3	#1 of Xayabouri HP	2021	1	1	1				1	100.00	
WQ3	#1 of Xayabouri HPF	2021	2	1	1				1	100.00	
WQ4	#2 of Xayabouri HP	2020	10	1	1	1	1	1	1	100.00	A
WQ4	#2 of Xayabouri HP	2020	11	1	1	1	1	1	1	100.00	A
WQ4	#2 of Xayabouri HP	2020	12	1	1	1	1	1	1	100.00	A
WQ4	#2 of Xayabouri HP	2021	1	1	1				1	100.00	
WQ4	#2 of Xayabouri HPF	2021	2	1	1				1	100.00	
WQ5	#3 of Xayabouri HP	2020	10	1	1	1		1	1	100.00	A
WQ5	#3 of Xayabouri HP	2020	11	1	1	1		1	1	100.00	A
WQ5	#3 of Xayabouri HP	2020	12	1	1	1		1	1	100.00	A
WQ5	#3 of Xayabouri HP	2021	1	1	1				1	100.00	
WQ5	#3 of Xayabouri HPF	2021	2	1	1				1	100.00	
	Vientiane	2013 - 2018	10	1	1	1	1	1	1	100.00	A
	averaged monthly results		11	1	1	1	1	1	1	100.00	A
			12	1	1	1	1	1	1	100.00	A
			1	1	1	1	1	1	1	100.00	A
			2	1	1	1	1	1	1	100.00	A

3.3.3. Impoundment profiles

The impoundment depth profiles at different months are shown in Figure 3.10. Probes measuring temperature, pH, conductivity, dissolved oxygen and turbidity at 1-m intervals down to 20 m below the surface, and the AlgaeTorch measuring chlorophyll-a and cyanobacteria down to 10 m below the surface. The overall impression from the results is that there is very little change in any of the parameters with depth in any of the months, indicating that the impoundment is well mixed down to 20 m. There is an indication that water temperature is beginning to decrease with depth after about 10 m in December and after about 16 m in January.

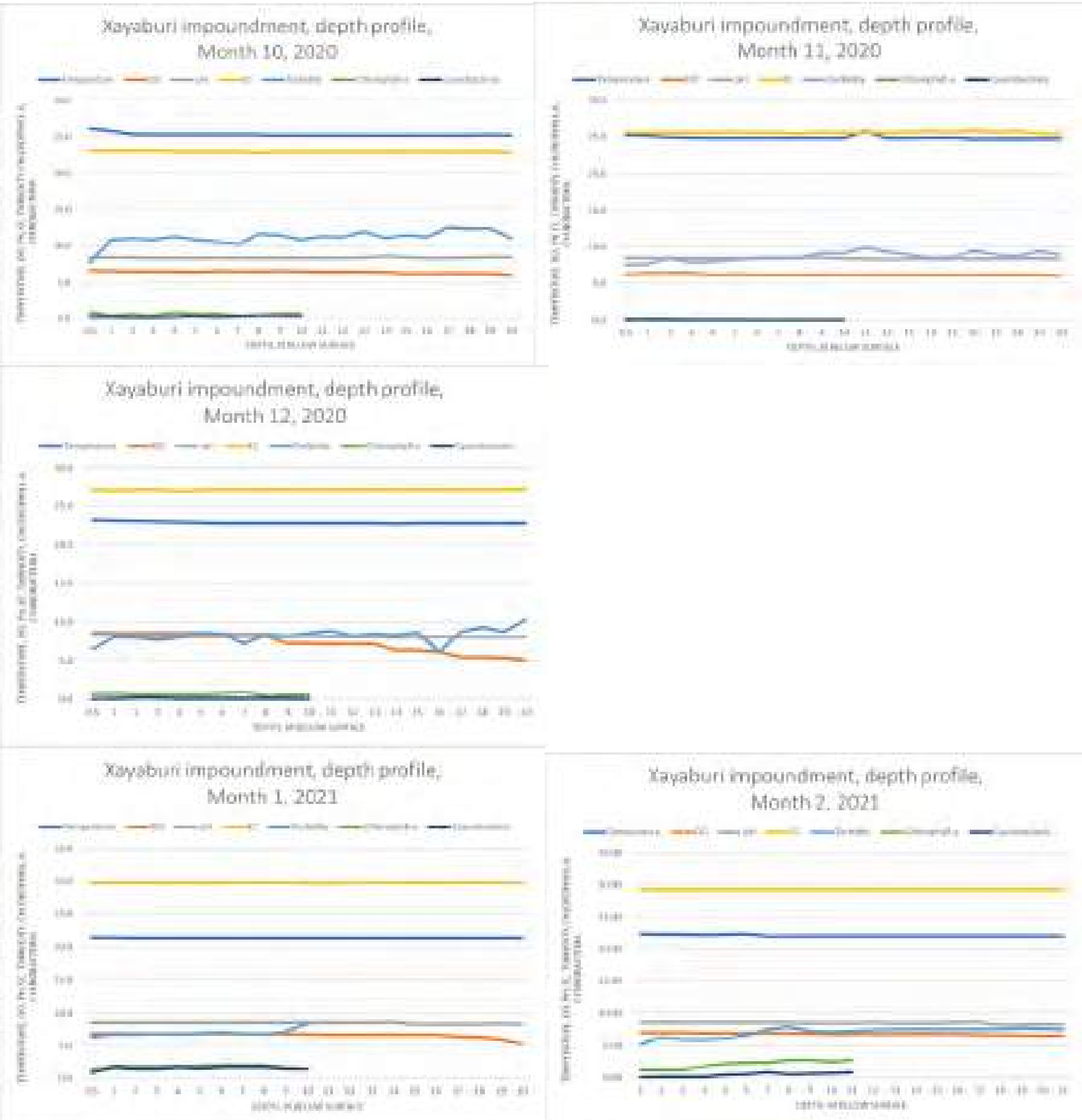

Figure 3.11. Depth profiles in the Xayaburi impoundment for months 10, 11, 12 (2020), and 1 and 2 (2021)

3.4. Lessons learned

3.4.1. Water quality sampling and analysis

The main lessons to be learned from the experience of carrying out these monthly sampling missions include:

- The AlgaeTorch appeared to work well, but since the training on the spectrophotometric analysis of chlorophyll-a has not yet been provided due to COVID-19 restrictions, it has not been possible to make a comparison of the two methods.
- Difficulties were experienced in obtaining reliable readings from the AlgaeTorch in running water. A sampling modification was suggested to take a bucketful of the flowing water and to place the probe into the water in the bucket, taking care to use the probe protector to achieve the correct distance from the bottom of the bucket.
- It was useful to record field observations of flow and water level, water colour, opacity and smell, so that any unusual findings from the analysis could be related to such observations. This has been added to the field data report.
- Similarly, the field data report should contain the names of the team members carrying out the sampling, so that unusual records could be cross-checked with them.
- Because of anomalies in turbidity and TSS readings it is suggested that TSS should be measured in the laboratory at all sites so that an understanding of the correlation between the two parameters can be developed.
- The very high phosphate values recorded in December 2020 are concerning and need confirmation from (i) routine WQMN results from the same period and future JEM monitoring, and (ii) Quality Assurance / Quality Control (QA/QC) confirmation of the analyses for December.
- No difficulties were experienced in entering the water quality data into the database.

3.4.2. Interpretation of the water quality results

- Overall, the results indicate that, for many parameters, there is little difference in the results between sampling stations with passage downstream in the same month.
- Monthly differences appeared to follow the normal seasonal patterns in parameters such as temperature and conductivity.
- The main parameters that appeared to change the most from upstream through the impoundment and downstream was turbidity, which decreased by up to 75% in the impoundment compared to the station above the impoundment.
- TSS results show variable patterns, from a decrease in TSS passing through the impoundment and downstream (October 2020), to an increase downstream compared to water flowing into the impoundment (November and December 2020). There is a recognized correlation between turbidity and TSS (Rügner et al., 2013), but these TSS results do not follow the decreasing turbidity measurements with passage through the impoundment. This needs to be investigated further, possibly by taking TSS measures in other stations and by linking with the flows and dam operations at the time of sampling.
- The water profiles within the Xayaburi impoundment show that the waters are well mixed down to 20 m in all months and there is no evidence of stratification.
- The raised values of total nitrogen in November and the very high values of total phosphate in December are of great concern and need confirmation described above, especially if they are confirmed as trends.

- The chlorophyll-a and cyanobacteria measurements linked with the nutrient analysis indicate that there is no current trend towards eutrophication and that levels are well below threshold levels for human health hazard.

4. Ecological health monitoring

4.1. Adjustments and evolutions

The first annual bioassessment monitoring was planned for April 2020, but this had to be cancelled because of the COVID-19 restrictions on travel within Lao PDR. It was not possible to carry out the 2020 field mission later in the year because monitoring has to be carried out when river levels are low, and the indicator groups will not have been dispersed by rising water levels and flash flows at the beginning of the wet season. The campaign for 2021, originally planned for April 2021, will be brought forward to earlier in the year to allow for the identification and reporting process to be conducted in a timely manner. Hence, there are no results for the 2020 campaign to present in this report.

Because the 2020 campaign was cancelled, the sampling sites have not been assessed for their suitability, and there is no change in the sampling sites selected, which include one site above the impoundment (EHM1), in the same location as the water quality monitoring station (WQ1), one site within the impoundment (EHM2), and four sites below the dam; these are listed in Table 4.1 illustrated on Figure 4.1.

Table 4.1. Confirmed sites for JEM bioassessment at Xayaburi

Site no.	Name of site	River	Latitude N	Longitude E
Xayaburi				
EHM1	Right upstream of Xayaburi Impoundment	Mekong	20°00'07.2"N	102°14'06.7"E
EHM 2	Within the impoundment	Mekong	~19°26'05.1"N	101°50'05.1"E
EHM 3	Xayaburi downstream around 2 km	Mekong	19°13'49.6"N	101°49'27.4"E
EHM 4	Xayaburi downstream around 5 km	Mekong	19°12'07.7"N	101°49'28.0"E
EHM 5	Xayaburi downstream around 8 km	Mekong	19°10'49.5"N	101°49'19.5"E
EHM 6	Xayaburi downstream around 12 km	Mekong	19°09'05.0"N	101°48'47.2"E

The ecological health monitoring (EHM) work reported here has focused on the consolidation and refinement of the species lists of each of the four parameters – benthic diatoms, zooplankton, littoral, and benthic macroinvertebrates, and the review of the historic data from the mainstream biennial bioassessment monitoring. This work was necessary for entry into the database and has involved the compilation of composite species lists from all four countries and cleaning of the historic data.

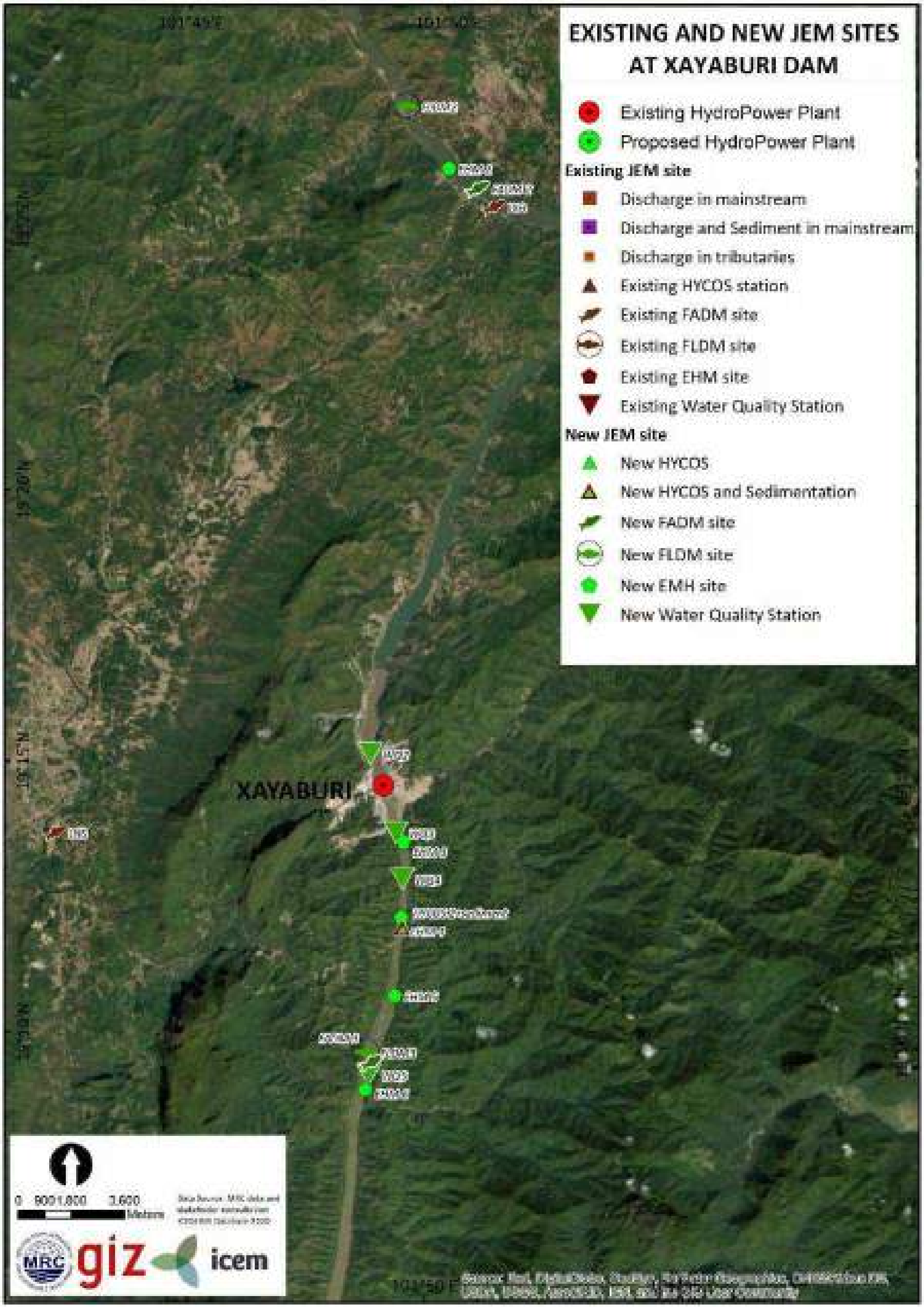

Figure 4.1. Bioassessment monitoring sites around Xayaburi HPP

4.2 Activities

4.2.1 Ecological health monitoring training

In July 2020, an on-line training course was provided across three half-days for the ecological health monitoring teams in each of four Mekong countries (Cambodia, Lao PDR, Thailand and Viet Nam). Technical staff from the Mekong River Commission Secretariat (MRCS) and from Don Sahong hydropower project also participated.

Initially, the training had been planned to be conducted in Vientiane in March 2020, but due to travel restrictions associated with the COVID-19 pandemic, face-to-face training was not possible. In place of the planned training, the basic training was conducted in an online format, with participants located in the MRC offices in Vientiane and the offices of the National Mekong Committees in the other countries.

Training modules included: (i) The Rationale for JEM Ecological Health Monitoring – Looking for impacts of hydropower; (ii) New Aspects of Ecological Health Monitoring introduced for JEM; (iii) Preparation for JEM Ecological Health Field Sampling; and (iv) Ecological Health Monitoring Data Entry and Management.

4.1.1. Preparation and analysis of historic ecological health monitoring results

The review of the historic biennial ecological health monitoring results for the sampling sites on the Mekong mainstream has been an extremely useful exercise to develop the database structure and refine the reporting formats. This process has involved:

- consolidating all of the species lists developed by all four countries since 2011, eliminating duplicates, correcting spelling mistakes and taxonomic errors to provide a unified species list for each of the four parameters. There are now listed 360 species of zooplankton, 435 species of benthic diatoms, 1,009 species of littoral macroinvertebrates, and 751 species of benthic macroinvertebrates recorded from the LMB;
- researching and providing taxonomic details (phylum, class, order and family) for all species, which will ease identification and appropriate classification of species found in the future. It will also enable the database to be used to highlight more detailed changes in species at the monitoring sites, for example, an increase in the numbers of molluscs and decrease in flowing water species in impoundment sites;
- conducting the analyses of abundance, species richness and Average Tolerance Score Per Taxon (ATSPT) for each of the historic biennial EHM records on mainstream sites and calculating the Ecological Health Index (EHI) for each site and year
- designing the structure and data entry forms for the database.

4.2. Preliminary results and initial analysis

The historic biennial EHI scores from 2011 to 2019 for the Luang Prabang and Vientiane sites were calculated as shown in Table 4.2. These are the two sites on each side of the Xayaburi dam. The Luang Prabang site is close to EHM1, although it is probably now lying within the impoundment of Xayaburi, hence its species distribution would be expected to change to match EHM2.

The results of the historic EHI show that there has been a degradation at Luang Prabang from Class A in 2011 to Class C in 2013, with subsequent improvement to Class B between 2015 and 2019. At Vientiane, the EHI condition is overall slightly poorer, but a similar pattern of Class B in 2011, Class D in 2013, and Class B in 2015 and 2019, but Class C in 2017. It would be expected that without the dam, the EHI for the Xayaburi sites would reflect the EHI condition for Luang Prabang rather than Vientiane. With the dam in place, the EHI in the impoundment is likely to change due to the changed flow and water level conditions, and in the downstream, the EHI is likely to deteriorate due to the daily fluctuations in flow rate and water level.

4.3. Lessons learned

4.3.1. Capacity strengthening in species-consistent species identification

The review of the historic bioassessment data has highlighted the differences between the species recorded by the teams of the four countries, with implications that the findings of each country monitoring are not exactly comparable. While this may reflect the changing conditions and species mix in different parts of the Basin, it also reflects the variable capacity of the teams for consistent and accurate identification of the species.

This may not be significant when the composite EHI is calculated for each site, but it will be important for analysing the changes in species mix due to impoundments and downstream flow sites.

There is a need to strengthen the capacity of the bioassessment teams in all countries in the consistent identification of the species in the unified composite lists and in completion of the reporting forms. The capacity of the teams in identifying species is highly dependent on the experience of the specialists, and attention should be paid to developing the capacity of younger team members to complement and eventually replace the older team members as they retire.

4.3.2. Simplified EHI assessments

The analysis of the historic data also illustrates the complexity of the EHI process, and the time and effort it requires. The JEM pilot site assessments would be an opportunity for trialling a simplified rapid EHI assessment based on littoral macroinvertebrates and comparing the EHIs for both historic and JEM pilot sites. If the EHIs are consistently similar for littoral macroinvertebrates as for the full EHI with the four parameters, then it may be possible to do the simplified bioassessments each year rather than every two years, and on more sites. This comparison will be trialled on the historic data.

Table 4.2. Historic Ecological Health Index calculations for Luang Prabang and Vientiane sites (above and below Xayaburi)

Site							**LPB**					**LVT**		
Year					**2011**	**2013**	**2015**	**2017**	**2019**	**2011**	**2013**	**2015**	**2017**	**2019**
Site Disturbance Score SDS					1.66	1.70	1.65	2.02	2.76	1.84	1.85	1.86	2.04	2.23
Average Abundance														
	Benthic diatoms				298.60	60.00	227.80	196.90	254.40	257.50	25.00	153.50	37.50	955.50
	Zooplankton				127.00	27.00	271.00	291.00	272.00	86.00	24.00	452.00	341.00	315.00
	Littoral macroinvertebrates				47.70	19.70	45.30	187.00	22.50	103.10	13.00	22.40	115.80	53.20
	Benthic macroinvertebrates				6.92	5.00	12.08	40.92	28.50	0.58	2.44	9.58	13.42	27.83
Richness	Benthic diatoms				12.00	7.80	18.10	19.30	18.20	8.10	4.60	11.80	4.00	29.20
	Zooplankton				17.67	7.00	25.33	28.00	25.00	16.33	5.67	25.67	23.33	21.67
	Littoral macroinvertebrates				7.30	5.50	7.00	12.40	7.40	11.10	3.00	5.40	7.80	9.80
	Benthic macroinvertebrates				2.50	2.56	3.83	5.25	5.83	0.58	1.11	3.50	4.92	3.67
ATPST	Benthic diatoms				19.81	41.95	41.26	43.50	42.81	28.53	38.82	42.31	44.03	42.84
	Zooplankton				39.36	40.43	40.35	43.22	52.30	41.83	41.89	42.86	44.47	49.55
	Littoral macroinvertebrates				39.22	39.43	39.26	45.51	57.25	41.57	41.91	42.25	45.38	51.90
	Benthic macroinvertebrates				29.14	41.49	39.70	45.71	59.40	17.27	28.60	39.74	45.74	50.98
Ecosystem Health Index Calculations		**Percentile**		**Threshold**										
		10th	**90th**	**Guideline**										
Abundance	Benthic diatoms	136.22	376.34	>136.22	1	FALSE	1	1	1	1	FALSE	1	FALSE	1
	Zooplankton	22.33	174.07	>22.33	1	1	1	1	1	1	1	1	1	1
	Littoral macroinvertebrates	46.68	328.56	>46.48	1	FALSE	FALSE	1	FALSE	1	FALSE	FALSE	1	1
	Benthic macroinvertebrates	5.37	56.34	>5.37	1	FALSE	1	1	1	FALSE	FALSE	1	1	1
Richness	Benthic diatoms	6.54	11.78	>6.54	1	1	1	1	1	1	FALSE	1	FALSE	1
	Zooplankton	9.8	20.2	>9.8	1	FALSE	1	1	1	1	FALSE	1	1	1
	Littoral macroinvertebrates	5.37	18.48	>5.37	1	1	1	1	1	1	FALSE	1	1	1
	Benthic macroinvertebrates	1.87	7.88	>1.87	1	1	1	1	1	FALSE	FALSE	1	1	1
ATPST	Benthic diatoms	30.85	38.38	<38.38	1	FALSE	FALSE	FALSE	FALSE	1	FALSE	FALSE	FALSE	FALSE
	Zooplankton	34.83	41.8	<41.8	1	1	1	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
	Littoral macroinvertebrates	27.8	33.58	<33.58	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
	Benthic macroinvertebrates	31.57	37.74	<37.74	1	FALSE	FALSE	FALSE	FALSE	1	1	FALSE	FALSE	FALSE
	Total number of parameters meeting threshold				**11**	**5**	**8**	**8**	**7**	**8**	**2**	**7**	**6**	**8**
	Classification	**Score**			A	C	B	B	B	B	D	B	C	B
	A	>10												
	B	>7												
	C	>4												
	D	<4												

Note that the term "False" in this table means that the parameter did not meet the threshold guidance.

5. Fisheries

The overall objective of fisheries monitoring in the JEM Programme is to measure indicators contributing to the interpretation of the status and trends of local, regional and basin-wide capture fisheries. The monitoring also aims at providing an effective means of monitoring and assessing the effects of water management and basin development activities, specifically hydropower development.

Specific objectives are focused on biodiversity assessment and fish stock assessments; fish catch monitoring; ecological knowledge and the species-habitat relationship; socioeconomics of the fisheries sector; and a dam impact assessment, with specific studies at Xayaburi site.

Three protocols are considered to cover these aspects, in particular the first two, under the Fish Abundance and Diversity Monitoring Programme (FADM):

1) FADM monitoring of artisanal catch;
2) FADM standardized gillnet surveys;
3) Fish Larvae Drift Monitoring Programme (FLDM).

As detailed in the project Inception Report, activities have focused on:

- under FADM
  - adjustments to the current fish abundance and diversity (FADM) protocol;
  - defining a standardized scientific monitoring based on multiple panel gillnets in the same sites;
- under FLDM
  - adjustments to the existing protocols in sites selected.

Since most of these modifications to the FADM protocol are methodological and have been tested in Cambodia, they are detailed them in the Don Sahong report. The sections below give a brief overview of activities at Xayaburi site.

5.1. Adjustments and evolutions

Lessons learned during the December 2019 – March 2020 early field phase and during implementation later are presented in the sections below. It should be underlined that there were substantial disruptions due to the COVID-19 pandemic and subsequent restrictions to field work (national teams), in-country travel, and field visits (international team), and joint activities.

5.1.1. Fish abundance and diversity monitoring

5.1.1.1. Monitoring of fishers

Data are gathered by fishers (three fishers in each site). Each fisher records his catch daily. The procedure based on logbooks should follow instructions in the standard sampling guidelines for FADM section 6.2 and JEM documents v.3 Annex 19. Data sheets are compiled weekly by a key fisher at each site, are collected quarterly by national agency staff, and then are cleaned and entered in the database by Living Aquatic Resources Research Centre staff.

This protocol does not pose any major problem except for the slow processing of data in Lao PDR due to error checking and cleaning.

The main point raised by the Lao team is the need for updated photo flipcharts that better include small and new species.

5.1.2. Fish larvae drift monitoring

The implementation of the larvae protocol started in July 2020, with data gathered until now.

Experience gathered indicates that:

- fishers need more training about how to record samples;
- midnight sampling is a problem in all sites. Data gathered by fishers in absence of supervision are not credible. For their own activities, fishers normally go to bed late and wake up early; it cannot be expected of them to wake up in the middle of the night to sample larvae. Thus, they most likely collect the midnight sample at some other time.

Recommendations are:

- To provide more training to fishers about recoding metre figures and sample bottles:

to set the night sample at 21:00 instead of midnight. This is justified by the fact that larvae are normally active from dusk to early night (18:00 to 22:00) and subsequently become mostly immobile. This modification is in line with observations of national larvae specialists and with publications detailing day and night larval activity in the Mekong on a detailed time step (Putrea Solyda, 2003; Hortle et al., 2005; Nguyen et al, 2006). As a consequence, the timing of samples would evolve from:

- 6:00 (dawn) – 12:00 noon – 18:00 (dusk) – 00:00 night (now)
  to
- 6:00 (dawn) – 12:00 noon – 18:00 (dusk) – 21:00 night.

In addition,

- The Lao team recommends buying a camera compatible with the microscope, so that samples can be identified and measured on photos (under the assumption that this remains possible and accurate).
- Some bugs are to be fixed in the larvae database, in particular, automatic filling of cells when a sample is empty (entering “0” or “#NA” automatically creates a species code).

5.2. Activities

5.2.1. Fish abundance and diversity monitoring

Data collection has been going on from August 2020 until now in Lao PDR.

5.2.2. Fish larvae drift monitoring

Data collection has been going on from August 2020 to now in Lao PDR.

Sampling started in July 2020, with sampling two days per week in the wet season (May to September). During that season, four samples are collected each day (6:00, 12:00, 18:00 and 24:00).

In the dry season (October to April), larvae are collected one day per week, with four samples each day as above.

5.3. Preliminary results and initial analysis

5.3.1. Fish abundance and diversity monitoring

The fishery database is based on the existing MRC fishery database. The current database receiving FADM data has a very simple structure that includes the fields and relationships shown in Figure 5.1.

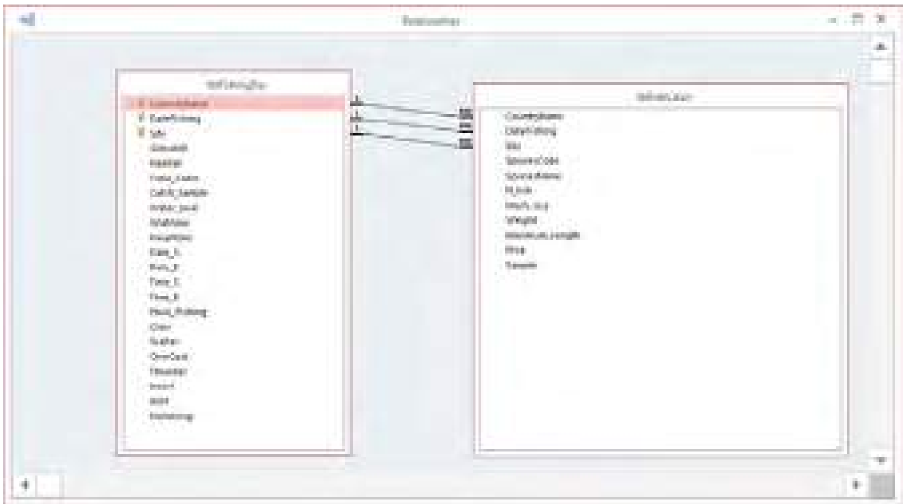

Figure 5.1. Relationships in the FADM database

5.3.2. Fish larvae drift monitoring

The database receiving FLDM data includes the fields and relationships shown in Figure 5.2.

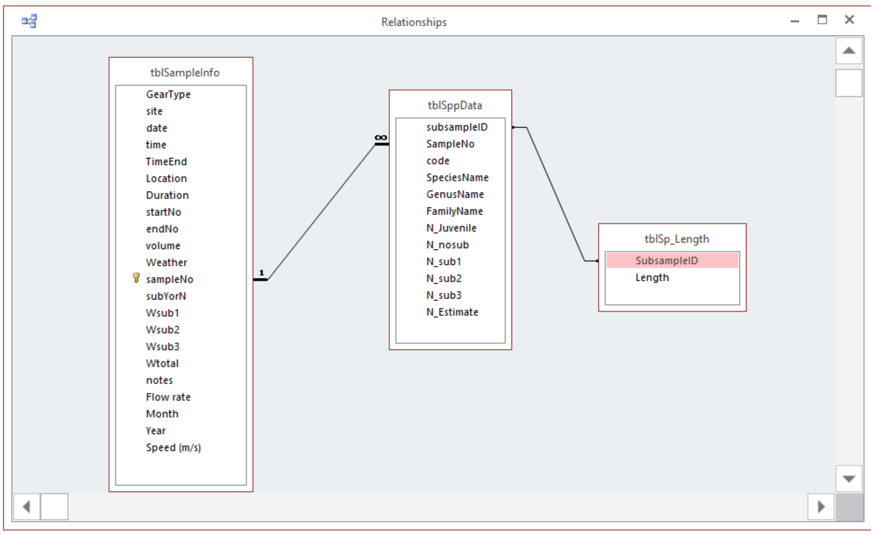

Figure 5.2. Relationships in the FLDM database

It was designed to include six locations, as shown in Figure 5.3, and to date includes only data from Cambodia.

Country	Province	District	Village	Site Code	location	N	E
Cambodia	Stung Treng	Thala Borivath	Preah Romkel	CIDC	Downstream of Don Sahong Dam in Cambodia	13°54'4.63"N	105°57'52.34"E
Laos	Champasak	Khong	Sadam	LIDD	Downstream of Don Sahong Dam	13°54'9.70"N	105°57'25.32"E
Laos	Champasak	Khong	Hau Sahong	LIDU	Upstream of Don Sahong Dam	13°58'23.94"N	105°57'27.41"E
Laos	Xayabouri	Xayabouri	Pak Houng	LIXD	Downstream of Xayabouri Dam	19°18'8.72"N	101°49'2.76"E
Laos	Xayabouri	Xayabouri	Tha Deua	LIXI	Xayabouri Dam Impoundment	19°25'36.76"N	101°50'40.84"E
Laos	Luangprabang	Luangprabang	Pha O	LIXU	Upstream of Xayabouri Dam	19°56'37.40"N	102°13'12.01"E

Figure 5.3. Sampling locations and current records in the FLDM database

5.4. Lessons learned and findings

Field implementation of the FADM protocol focused on the catch of fishers does not pose any major problem.

Data gathering and data entry in Lao PDR is requiring more time, and a catch database could not be examined yet for Xayaburi site.

For the same reasons, it is recommended that MRC supervisors or colleague scientists from another partner country undertake a round of data gathering and data entry together with Lao colleagues in the coming months. This will secure the quality and standardization of implementation at the village level (timing of fishing, species identification, accuracy of recording, etc.) and strengthen the training of national scientists supervising the protocol and entering data.

Field implementation of the FLDM protocol is more challenging because a rigorous larvae collection protocol is now in the hands of fishers. This requires a close assistance to, and supervision of, these fishers, with a visit to the partner fishers in the months to come.

The midnight sampling unit is challenging in all stations and may lose credibility in the long term; it is therefore recommended to move the sampling time to 21:00 (21:00 being the night sample replacing the midnight sampling).

6. Database

6.1. Hydrology and sediment monitoring database

The hydrology and sediment component of the JEM database has been developed to include the following parameters:

- Hydrology and hydraulics: Channel width, channel area, total discharge, average flow velocity
- Sediments: Average suspended sediment concentrations (SSC), moving bed velocity (from moving bed test), bed material grain size and grain size distribution of suspended sediment.

The database will also contain links to the original ADCP and data submission forms to allow review and interrogation of all results.

The database manager has requested that all of the historic (2009–2019) results, and the first year of JEM results be entered into a compatible spreadsheet prior to the data being uploaded to the database. To date, the historic (2009–2018) results have been input to the database for most of the JEM sites. Much of the 2019 data has been reviewed and put through a Quality Assurance/Quality Control (QA/QC) process and has been entered. Together with some of the 2018 results, this work is time-intensive and ongoing.

All JEM results reported through 10 March 2021 have been incorporated into the worksheets together with the historic results, and the worksheets have been used as the basis for analysis for the information contained in this report. When the outstanding monitoring results for 2020 are received, the worksheets will be finalized and the data uploaded into the JEM database.

6.2. Water quality monitoring database

The water quality monitoring database has been structured to include the following parametres:

- ID; StationID; station name; CollectedBy; CollectedDate; Year; Month; Time start
- TEMP_°C ; pH; TSS_mg/L; COND_mS/m; Ca_meq/L; Mg_meq/L; Na_meq/L; K_meq/L;
- ALK_meq/L; Cl_meq/L; SO4_meq/L; NO2_mg/L; NO32_mg/L; NH4N_mg/L; TOTN_mg/L; PO4P_mg/L; TOTP_mg/L
- Turbidity; Chlorophyll-a; Cyanobacteria;
- DO_mg/L; CODMN_mg/L; BOD; FC _MPN/100ml
- Al_mg/L; ACID_meq/L; LinkForm;
- Remarks – weather and river conditions

A second form covers the probe measurements for depth profiles within the impoundments for:

- TEMP_°C; pH; COND_mS/m; DO_mg/L; (down to 20 m)
- turbidity; chlorophyll-a; cyanobacteria (down to 10 m).

Data entry from field report forms, which includes the field probe readings for the surface waters and impoundment profiles, and the notes on weather and river conditions. When the laboratory analysis results arrive every quarter, they are copied into the data entry form and entered into the database.

The unified site codes for the Xayaburi WQ monitoring sites have been allocated, and the details are shown in Table 6.1, together with notes showing correlation with sampling stations from other disciplines.

The data from five monthly sampling occasions (October 2020 to February 2021) have been entered into the database.

In addition, the historic data from selected routine WQMN stations on the Mekong mainstream between 2010 and 2019 have been entered into the database. These routine WQMN stations are shown in Table 6.2.

6.3. EHM database

The structure of the EHM database has recently been completed, following the review of the EHM species lists and historic data from the biennial bioassessment monitoring. The EHM structure consists of two data entry forms:

- **Level 1** – This contains the consolidated data on presence of species in each sampling station from each year – StationID; Station Name; Species_ID; Species Name; SamplingDate; Year; SurveyBy; A (Ave. No. Individuals counted per sample); B (No. of +ve samples per site).
- **Level 2** – This contains the calculated analysis from the species list raw data and environment parametres – StationID; Station Name; Year; Country; Altitude; Width; Depth; Secchi; Temp; DO; pH; Cond; SDS (Site Disturbance Score).
- For each of the four parametres (benthic diatoms, zooplankton, littoral and benthic macroinvertebrates) Sample Occasions (no. of samples taken at site); Average Abundance; Average Richness; ATSPT; 10^{th} Percentile and 90^{th} Percentile Threshold Guideline; Abundance Index; Richness Index; ATSPT Index (numbers of times the threshold guideline is exceeded).
- From the last three, the database will estimate the EH Index for each site.

The unified site codes for the Xayaburi EHM monitoring sites have been allocated, and the details are shown in Table 6.1 together with notes showing correlation with sampling stations from other disciplines.

No data have yet been entered into the database, because this structure has only recently been agreed on. The historic data from the routine biennial EHM sites on the Mekong mainstream (Table 6-3) will be entered in the near future.

Table 6.1. Unified monitoring station codes for water quality and EHM stations for Xayaburi pilot

SiteCode	LocationID_Short	LocationID_Long	AQTS	SiteName	River	UTM_N	UTM_E	Lat	Lon	Notes
010701	LA_010701	LA_010701_[JEM_WQ1]	LA_010701_[Xayaburi_BanXangHa]	Upstream of Xayaburi around 110 km upstream of the dam	Mekong	20°00'07.2"	102°14'06.7"	20.002	102.2351944	Shared WQ and EHM code
010701	LA_010701	LA_010701_[JEM_EHM1]	LA_010701_[Xayaburi_BanXangHa]	Upstream of Xayaburi around 110 km upstream of the dam	Mekong	20°00'07.2"	102°14'06.7"	20.002	102.2351944	
011302	LA_011302	LA_011302_[JEM_EHM2]	LA_011302_[Xayaburi_BanThaDeua]	Within the impoundment, 1-2 km upstream of Tha Deua Bridge	Mekong	19°26'05.1"	101°50'05.1"	19.43475	101.83475	Shared the same code to the JEM's FADM site
011501	LA_011501	LA_011501_[JEM_EHM4]	LA_011501_[Xayaburi_Ban Pakhoung]	Xayaburi downstream around 5 km	Mekong	19°12'07.7"	101°49'28.0"	19.20213889	101.8244444	Already in AQTS, shared with HYCOS site
011502	LA_011502	LA_011502_[JEM_WQ2]	LA_011502_[Xayaburi_Ban Talan]	Within the Xayaburi Impoundment (at Ban Talan, 1 km above the dam wall)	Mekong	19°15'16.1"	101°48'45.5"	19.25447222	101.8126389	This one will have two separate water quality readings a) surface water and b) depth profile down to 20 m
011503	LA_011503	LA_011503_[JEM_WQ3]	LA_011503_[Xayaburi_Dam+2]	Xayaburi downstream around 1-2 km from dam	Mekong	19°13'49.5"	101°49'17.1"	19.23041667	101.8214167	Shared WQ and EHM code
011503	LA_011503	LA_011503_[JEM_EHM3]	LA_011503_[Xayaburi_Dam+2]	Xayaburi downstream around 1-2 km from dam	Mekong	19°13'49.6"	101°49'27.4"	19.23044444	101.8242778	
011504	LA_011504	LA_011504_[JEM_WQ4]	LA_011504_[Xayaburi_Dam+4]	Xayaburi downstream around 4 km from dam	Mekong	19°12'58.3"	101°49'25.5"	19.21619444	101.82375	
011505	LA_011505	LA_011505_[JEM_EHM5]	LA_011505_[Xayaburi_BanPakhoung+2.5]	Xayaburi downstream around 8 km from dam	Mekong	19°10'49.5"	101°49'19.5"	19.18041667	101.8220833	
011506	LA_011506	LA_011506_[JEM_WQ5]	LA_011506_[Xayaburi_BanPakhoung+5]	Downstream at Pakhoung Village, around 10-km downstream of the dam	Mekong	19°09'28.0"	101°48'50.6"	19.15777778	101.8140556	Shared the same code to the JEM's FADM and FLDM sites.
011506	LA_011506	LA_011506_[JEM_EHM6]	LA_011506_[Xayaburi_BanPakhoung+5]	Downstream at Pakhoung Village, around 10-km downstream of the dam	Mekong	19°09'05.0"	101°48'47.2"	19.15138889	101.8131111	

Table 6.2. Routine WQMN sites on Mekong mainstream

Code	Station ID	Location Code	Location ID	Location name	River	Lat	Lon
LA	010500	LA_010500	LA_010500_[Houa Khong]	Houa Khong	Mekong	21.55	101.16
TH	010501	TH_010501	TH_010501_[Chiang Saen]	Chiang Saen	Mekong	20.27	100.09
LA	011200	LA_011200	LA_011200_[Luang Prabang]	Luang Prabang	Mekong	19.9	102
LA	011901	LA_011901	LA_011901_[Vientiane KM4]	Vientiane KM4	Mekong	17.93	102.62
TH	013101	TH_013101	TH_013101_[Nakhon Phanom]	Nakhon Phanom	Mekong	17.43	104.77
LA	013401	LA_013401	LA_013401_[Savannakhet]	Savannakhet	Mekong	16.56	105.74
TH	013801	TH_013801	TH_013801_[Khong Chiam]	Khong Chiam	Mekong	15.32	105.49
LA	013900	LA_013900	LA_013900_[Pakse]	Pakse	Mekong	15.12	105.78
KH	014501	KH_014501	KH_014501_[Stung Treng]	Stung Treng	Mekong	13.53	105.95
KH	014901	KH_014901	KH_014901_[Kratie]	Kratie	Mekong	12.48	106.02

Table 6.3. Routine EHM sampling sites on Mekong mainstream that are most relevant to the JEM pilot sites

CCode	SiteCode	LocationID_Short	LocationID_Long	SiteName	River	UTM_N	UTM_E	UTMZone	Lat	Lon
LA	010402	LA_010402_[LMK]	LA_010402_[LMK_Ban Xiengkok_Luangnamtha]	Ban Xiengkok, Luangnamtha	Mekong	2311778	670860	47Q	20.89810652	100.6385659
TH	010502	TH_010502_[TCS]	TH_010502_[TCS_Chiang Saen]	Chiang Saen	Mekong	614706	2240577	47N	5.358335802	114.5191676
LA	010702	LA_010702_[LPB]	LA_010702_[LPB_Done Chor_Luang Prabang]	Done Chor, Luang Prabang	Mekong	2206957	206113	48Q	19.93691586	102.1924987
LA	011905	LA_011905_[LVT]	LA_011905_[LVT_Ban Huayhome_Vientiane]	Ban Huayhome, Vientiane	Mekong	1988731	239871	48Q	17.9712965	102.5437788
TH	013103	TH_013103_[TNP]	TH_013103_[TNP_Nakorn Phanom]	Nakorn Phanom	Mekong	476351	1926537	48N	4.202870674	117.7482043
LA	013902	LA_013902_[LDN]	LA_013902_[LDN_Done Ngew_Champasak]	Done Ngew, Champasak	Mekong	1657517	596193	48P	14.99092917	105.894687
KH	014702	KH_014702_[CKT]	KH_014702_[CKT_Stung Treng_Ramsar Site]	Stung Treng Ramsar Site	Mekong	618663	1504098	48N	5.527686616	114.0283106
KH	014001	KH_014001_[CMR]	KH_014001_[CMR_Kampi Pool_Kratie]	Kampi Pool, Kratie	Mekong	610914	1393502	48N	5.472601657	113.0399921

Note: LA 010702 (LPB) and LA 011905 (LVT) are the two routine MQMN sites closest upstream and downstream of Xayaburi HPP, respectively.

6.4. Fisheries database

The database is designed for the current stations:

FADM-IEM

Site ID	Country	Province	District	Village	Site Code	location	N	E
CJDC1	Cambodia	Stung Treng	Thala Borivath	O'Svay Village	CJDC	Downstream o	13°54'4.63"N	105°57'52.34"E
CJDC2	Cambodia	Stung Treng	Thala Borivath	O'Svay Village	CJDC	Downstream o	13°54'4.63"N	105°57'52.34"E
CJDC3	Cambodia	Stung Treng	Thala Borivath	O'Svay Village	CJDC	Downstream o	13°54'4.63"N	105°57'52.34"E
LJDD1	Laos	Lhampasak	Khong	Hang Khone	LJDD	Downstream o	13°56'15.59"N	105°56'54.32"E
LJDD2	Laos	Lhampasak	Khong	Hang Khone	LJDD	Downstream o	13°56'15.59"N	105°56'54.32"E
LJDD3	Laos	Lhampasak	Khong	Hang Khone	LJDD	Downstream o	13°56'15.59"N	105°56'54.32"E
LJDU1	Laos	Lhampasak	Khong	Saen Nue	LJDU	Upstream of Di	14° 5'51.11"N	105°47'2.18"E
LJDU2	Laos	Lhampasak	Khong	Saen Nue	LJDU	Upstream of Di	14° 5'51.11"N	105°47'2.18"E
LJDU3	Laos	Lhampasak	Khong	Saen Nue	LJDU	Upstream of Di	14° 5'51.11"N	105°47'2.18"E
LJXD1	Laos	Xayabouri	Xayabouri	Pak Houng	LJXD	Downstream o	19°09'46.6"N	101°48'46.9"E
LJXD2	Laos	Xayabouri	Xayabouri	Pak Houng	LJXD	Downstream o	19°09'46.6"N	101°48'46.9"E
LJXD3	Laos	Xayabouri	Xayabouri	Pak Houng	LJXD	Downstream o	19°09'46.6"N	101°48'46.9"E
LJXI1	Laos	Xayabouri	Xayabouri	Tha Deua	LJXI	Xayabouri Dam	19°27'12.80"N	101°49'14.38"E
LJXI2	Laos	Xayabouri	Xayabouri	Tha Deua	LJXI	Xayabouri Dam	19°27'12.80"N	101°49'14.38"E
LJXI3	Laos	Xayabouri	Xayabouri	Tha Deua	LJXI	Xayabouri Dam	19°27'12.80"N	101°49'14.38"E
LJXU1	Laos	Luangprabang	Pak Ou	Pha O	LJXU	Upstream of X	19°56'4.39"N	102°12'21.97"E
LJXU2	Laos	Luangprabang	Pak Ou	Pha O	LJXU	Upstream of X	19°56'4.39"N	102°12'21.97"E
LJXU3	Laos	Luangprabang	Pak Ou	Pha O	LJXU	Upstream of X	19°56'4.39"N	102°12'21.97"E

Figure 6.1. Sampling stations pre-identified in the FADM database

In its current state dated 8 January 2021, the database contains 69 records corresponding to 69 fishing operations, all from Cambodia. For each fishing operations, the catch is detailed by species, with subsequent details (305 individual records). This sampling harvested 50 species among 1,316 individuals.

CountryNam	DateFishing	Site	GillnetID	Habitat	Total_Catch	Catch_Samp	Water_level	Width(m)	Height(r
Cambodia	07-Nov-20	CJDC3	3	Mekong	0.06		Rising	42	

SpeciesCode	SpeciesName	N_fish	Mesh_size	Weight	Maximum_L	Price	Sample
62	Henicorhynchus siamensis	10	20	0.03	9	3000	No
149	Hypsibarbus wetmorei	2	40	0.02	8	3000	No
44	Hypsibarbus malcolmi	1	40	0.01	8	3000	No
* 0		0	0	0	0	0	

CountryNam	DateFishing	Site	GillnetID	Habitat	Total_Catch	Catch_Samp	Water_level	Width(m)	Height(r
Cambodia	14-Nov-20	CJDC1	1	Mekong	0.27		Falling	112	
Cambodia	14-Nov-20	CJDC2	2	Mekong	0.25		Falling	78	
Cambodia	14-Nov-20	CJDC3	3	Mekong	0.66		Rising	42	
Cambodia	21-Nov-20	CJDC1	1	Mekong	0.4		Falling	112	
Cambodia	21-Nov-20	CJDC3	3	Mekong	0.34		Rising	42	

SpeciesCode	SpeciesName	N_fish	Mesh_size	Weight	Maximum_L	Price	Sample
35	Puntioplites falcifer	1	30	0.1	7	3500	No
62	Henicorhynchus lobatus	13	20	0.12	9	3500	No
44	Hypsibarbus malcolmi	1	40	0.12	9	3500	No
* 0		0	0	0	0	0	

CountryNam	DateFishing	Site	GillnetID	Habitat	Total_Catch	Catch_Samp	Water_level	Width(m)	Height(r
Cambodia	28-Nov-20	CJDC1	1	Mekong	0.73		Falling	112	
Cambodia	28-Nov-20	CJDC2	2	Mekong	0.73		Falling	78	
Cambodia	28-Nov-20	CJDC3	3	Mekong	0.31		Rising	42	

Figure 6.2. Example of records in the FADM database

7. Procurement

The equipment for the project was procured across three countries, in general (but not always) targeting the two pilot sites being used to test the JEM guidelines.

7.1. Adjustments

Since the beginning of the JEM project, there have been several adjustments to the procurement. Table 7-1 shows the original procurement scope for equipment related to the Xayaburi pilot site, compared with the current status of procurement, including removals, changes and additions to the procurement.

Table 7.1. Routine Equipment procurement for JEM Pilot projects

Original equipment list	Pilot site	Revised equipment list	Notes
HYCOS station Lao PDR	Xayaburi	✓	Installed
Camera (x1) Lao PDR	Xayaburi	✓	Delivered
	Xayaburi	Added- a Camera (x1) - Lao PDR	Delivered
		✓	ADCP for Lao PDR - moved to Don Sahong Equipment list
ADCP Thailand	Xayaburi	✓	Delivered
D-96 - Thailand	Xayaburi	✓	Waiting confirmation from supplier on delivery
Winch Thailand	Xayaburi	✓	Delivered
Bed material sampler – Lao PDR	Xayaburi	Adjusted to 2 samplers	Delivered
	Xayaburi	Added – bed material sampler–Thailand	Delivered
	Xayaburi	Added – outboard motor for LPB monitoring vessel	Installed
	Xayaburi	Added – boat trailer for LPB vessel	Delivered
GPS – Lao PDR	Xayaburi	✓	Delivered
BBE Flouroprobe – Lao PDR	**Xayaburi**	**Removed**	**-**
	Xayaburi	Added – AlgaeTorch	Delivered

Original equipment list	Pilot site	Revised equipment list	Notes
High frequency water quality logger	**Xayaburi**	**Removed**	
Microscope – Lao PDR	Xayaburi	✓	Delivered
Bongo Net (x 5) Lao PDR	**Xayaburi**	**Removed**	**-**
Conical larvae net (x 5) Lao PDR	**Xayaburi**	**Removed**	**-**
Flow metre (x 5) Lao PDR	Xayaburi	Adjusted to 7 metres	Delivered

Table 7-1 shows that there has been substantial variation in the procurement from the original project procurement plan, with four items removed, three items added, and two items having quantities revised. The four main reasons for adjustments to procurement of Xayaburi related equipment are:

(i) The expense of some items led to changes in equipment procured (e.g. BBE fluoroprobe was swapped for an AlgaeTorch).

(ii) Due to the lack of suitable siting location, some equipment was not procured (e.g. high frequency water Logger for Xayaburi downstream).

(iii) Due to difficulties in defining equipment requirements, some equipment was not procured under the project (e.g. Bongo Net, conical net);

(iv) Due to difficulties with some manufacturers, an order of D-96 from 4 March 2020 is still awaiting delivery on 10 March 2021.

7.2. Achievements

Despite the restrictions imposed due to COVID-19 and the adjustments to procurement based on the four factors outlined above, the project successfully completed procurement of all the originally specified equipment relating to the Xayaburi pilot site, with the exception of the D-96 suspended sediment sampler for Thailand. The D-96 is being procured from Ricklys via a supplier based in Vientiane. The international hydrologist has advised us that Ricklys is notoriously slow on delivery. The procurement team approached an alternate manufacturer in December 2020; however, the latter stated that a D-96 would not be available until January 2022.

7.3. Lessons learned

Procurement is time-consuming. The original project workplan indicated that procurement would begin in December 2019, and be complete in time for a procurement report to be delivered in March 2020. Given the complexities of procurement, this timeline was unrealistic even without the impact of COVID-19. In addition to the changes in procurement during the project, the following factors also affected procurement.

a) COVID-19 impacts, which delayed procurement and shipping processes;

b) understanding and management of tax exemption processes across the three target countries.

The lesson drawn from this is that future projects should allow for changes in project requirements, changes in equipment specifications, and other factors to impact on procurement timelines. Project planning should take these into account and plan for less than ideal delivery of equipment.

Procurement depends on a good understanding of the current situation. For example, the procurement of the outboard motor for the LPB monitoring vessel was compromised when the supplier found they were unable to install the motor on the vessel. This issue required significant time and input from GIZ and ICEM personnel, as well as additional cost to resolve and find an alternate installer.

Procurement often relies on existing infrastructure and equipment for its value. For example, when the outboard motor was installed on the LPB monitoring vessel, it became clear that appropriate maintenance had not been carried out on the vessel; the fibreglass is deteriorating. This is an issue that requires action in the near future to address in order to ensure that the vessel remains in a condition allowing the monitoring team to undertake necessary monitoring tasks.

8. Conclusion

This first report on the monitoring of the JEM pilot sites around the Xayaburi HPP presents the results of the period between October 2020 and February 2021. Monitoring missions, which had been anticipated to start in the second quarter of 2020, were delayed due to COVID-19 restrictions.

The results of the hydrology and sediment monitoring around Xayaburi HPP indicate that there are large and frequent water level fluctuations downstream of the dam, reflecting the operation of the turbines when inflow is less than the flow required to run all turbines. The magnitude and frequency of water level fluctuations is well beyond those shown at historic HYCOS sites, for example, dry season fluctuations in water level at Chiang Khan.

The power station may likely be reducing water level fluctuations during the months leading into the wet months at Chiang Khan. This would be consistent with the storage being used to modulate inflows to produce a more uniform flow rate for hydropower generation, but there is no evidence that the operation of the station has altered water flows on a seasonal basis.

Suspended sediment concentrations were low at all of the sites, although the number of measurements completed at Ban Xanghai and Pakhoung is very limited. At Chiang Khan, the 2019 - 2020 SSC results are statistically lower than the SSC results collected in 2009–2018 under similar flow rates (1,700–8,000 m^3/s). This decrease is consistent with sediment trapping in Xayaburi, and likely other upstream HPPs that have come online in 2019 and 2020.

Bedload transport information is very limited but suggests that bedload transport is considerable at Ban Xanghai and Ban Pakhoung where water velocities are high even during conditions of low flow. At Chiang Khan, the bedload component is estimated to be on average about 7% of the SSC load.

Generally, the water quality measurements appears to be was well within the usual ranges recorded for the routine monitoring at mainstream Mekong sites at Luang Prabang and Vientiane, with the exception of raised levels of total nitrogen and total phosphate in November and December, respectively. Monthly differences followed the normal seasonal patterns in parameters such as temperature and conductivity. In comparing the results with passage downstream, many parameters show little difference between sampling stations in the same month, indicating that the impoundment and dam operation is not affecting the overall water quality, except in terms of turbidity and TSS.

Turbidity decreased by up to 75% in the impoundment compared to the station above the impoundment (Bang Xanghai), but TSS results showed variable patterns, from a decrease in TSS passing through the impoundment and downstream (October 2020), to an increase downstream compared to water flowing into the impoundment (November and December 2020). There is a recognized correlation between turbidity and TSS, but these TSS results do not follow the decreasing turbidity measurements with passage through the impoundment. These changes in TSS should be mirrored by the SSC results with trapping of sediment in the impoundment. While turbidity decreases in the impoundment and downstream follow SSC measurements, the TSS results are varied and need to be investigated further. An attempt was made to match the time of WQ sampling with water levels and flows, to see if the dam was operating at the time, but the information was not available for the time of sampling.

Chlorophyll-a and cyanobacteria concentrations and nutrient levels measured in the impoundment and downstream were all low, showing no evidence of eutrophication trends, and well below threshold levels for risk to human health. The water quality profiles within the Xayaburi impoundment showed no sign of stratification, and the water appeared to be well mixed even down to depths of 20m.

The annual bioassessment at the six sites around Xayaburi had to be cancelled, and the next assessment will take place during early 2021. The historic biennial Ecological Health Index scores from

2011 to 2019 for the Luang Prabang and Vientiane sites were calculated to provide a baseline from the two sites on each side of the Xayaburi dam. The results of the historic EHI show that there has been a degradation in the EHI at Luang Prabang from Class A in 2011 to Class C in 2013, with subsequent improvement to Class B between 2015 and 2019. At Vientiane, the EHI condition is overall slightly poorer, but a similar pattern of Class B in 2011, Class D in 2013, and Class B in 2015 and 2019, but Class C in 2017. Without the dam, it is likely the EHI for the Xayaburi sites would reflect the EHI condition for Luang Prabang rather than Vientiane. With the dam in place, the EHI in the impoundment is likely to change due to the changed flow and water level conditions, and in the downstream sites, the EHI is likely to deteriorate due to the daily fluctuations in flow rate and water level recorded by the Hydrology team.

For fisheries monitoring around Xayaburi, no results for the FADM and FLDM are available yet to compare with the flow and water quality results. The field implementation of the FADM protocol focused on the catch of fishers does not pose any major problem, but since the Lao team is new to the exercise, data gathering and data entry in Lao PDR is requiring more time than in Cambodia and a catch database could not be examined yet for Xayaburi and Don Sahong sites.

Field implementation of the FLDM protocol is more challenging, because a rigorous larvae collection protocol is now in the hands of villagers previously not exposed to such practices. This requires close assistance and supervision of these fishers, with also a visit in the months to come to the partner fishers. The midnight sampling unit is challenging in all stations and may lose credibility in the long term; it is therefore recommended to move it to 21:00 at night, replacing the midnight sampling.

In the future correlation of the results from sediment, water quality, ecological health and fisheries at the different sites will be important and linked to operation timings of the Xayaburi HPP. Sediment trapping in the impoundment and the associated requirement for sediment flushing at dam sites shows how multidisciplinary data from JEM monitoring can contribute to integrated management. Sediment flushing has an impact on downstream aquatic life and fish resources, and long-term management of both the reservoir and the fish resource requires close coordination. It results in three main categories of impacts on fish:

a) physical impacts (fish gill clogging, changes in riverine habitats and changes in downstream river temperature);

b) chemical impacts (decreased dissolved oxygen levels, chemical contamination);

c) biological impacts (changes in migration or spawning triggers, reduced ability to feed, reduced food abundance, impact on egg development, and increased vulnerability to diseases).

These results and the recommendations for future monitoring protocols are preliminary, based upon a limited set of results, not yet really frequent enough for more detailed statistical analysis. However, they appear to confirm the usefulness of the parameters and sampling stations chosen, and the experience has identified some practical modifications to the JEM protocols.

9. References

Hortle, K. G., Chea, T., Bun, R., Em, S., Thac, P. (2006). *Drift of fish juveniles and larvae and invertebrates over 24-hour periods in the Mekong River at Phnom Penh, Cambodia*. In T.J. Burnhill and M.M. Hewitt (Eds.). *Proceedings of the 6th Technical Symposium on the Mekong Fisheries, 26th-28th November 2006* (Pp. 19-33). MRC Conference Series No. 5. Mekong River Commission, Vientiane, Lao PDR.

Koehnken, L. (2015). *Discharge Sediment Monitoring Project (DSMP) 2009–2013 Summary & Analysis of Results*. Final Report. Report for the MRC Secretariat.

Mekong River Commission [MRC]. (1995). *1995 Mekong Agreement and Procedures*. Mekong River Commission.

MRC. (2019). *2017 Lower Mekong Regional Water Quality Monitoring Report*. MRC Secretariat. Vientiane, Lao PDR.

MRC. (2020). *The MRC Hydropower Mitigation Guidelines: Guidelines for hydropower environmental impact mitigation and risk management in the Lower Mekong mainstream and tributaries (vol. 3)*. MRC Secretariat. Vientiane, Lao PDR.

MRC. (2021a). *Mekong River Commission Data Portal.* Time-series Inventory. Retrieved 15 February, 2021, from https://portal.mrcmekong.org/time-series/water-level

MRC (2021b). *Procedures for the Maintenance of Flows on the Mainstream*. Vientiane – 6C for monitoring purposes. Rated discharge. Retrieved 15 February, 2021, from https://pmfm.mrcmekong.org/monitoring/6c/vientiane

MRC (2021c). *Procedures for the Maintenance of Flows on the Mainstream*. Stung Treng – 6A for monitoring purposes. Rated discharge. Retrieved 15 February, 2021, from https://pmfm.mrcmekong.org/monitoring/6a/stung-treng/

MRC (2021d). *Procedures for the Maintenance of Flows on the Mainstream*. Stung Treng – 6C for monitoring purposes. Rated discharge. Retrieved 15 February, 2021, from https://pmfm.mrcmekong.org/monitoring/6c/stung-treng/

Nguyen T.T., Nguyen N. D., Vu V. A. & Truong T. T. (2006). Monitoring of fish larvae during the annual flood of the Mekong and Bassac Rivers, Mekong Delta, Viet Nam. In T.J. Burnhill & T.J. Warren (Eds.): *Proceedings of the 7th Technical Symposium Mekong Fisheries* (pp. 71–87), 15–17 November 2005. MRC Conference Series No. 6. Vientiane: MRC Secretariat.

Putrea, S. (2003). Distribution of fish larvae and juveniles in Lungvek canal, Kandal Province, Cambodia. In A. Poulsen (Ed.) *Proceedings of the 5th Technical Symposium on the Mekong Fisheries* (pp. 43–56), 11–12 December 2002, MRC Conference Series No. 4. Phnom Penh: MRC Secretariat.

Rügner, H., Schwientek, M., Beckingham, B. et al. (2013). Turbidity as a proxy for total suspended solids (TSS) and particle facilitated pollutant transport in catchments. *Environ Earth Sci,* 69, 373–380. https://doi.org/10.1007/s12665-013-2307-1

Someth, P., Seebacher, F., Khem, S., Kong, S. & Preap, S. (2013). *Preliminary analysis – Rating curves for mainstream and tributaries of the Mekong River*. MRC Secretariat.

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