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Joint Environment Monitoring of Mekong Mainstream Hydropower Projects

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Acronyms

ADCP	Acoustic Doppler Current Profiler
COD	Chemical Oxygen Demand
DG	Design Guidance
DGPS	Differential GPS
DRIFT	Downstream Response to Imposed Flow Transformations (the ecological systems analysis tool used in the MRC Council Study)
DSM	Discharge Sediment Monitoring
EHM	Ecological Health Monitoring
EIA	Environmental Impact Assessment
FADM	Fish Abundance and Diversity Monitoring Program
HYCOS	Hydrological Cycle Observation System
IHA	Indicators of Hydrologic Alteration
ISH	Initiative on Sustainable Hydropower
JEM	Joint Environment Monitoring
LMB	Lower Mekong Basin
MC	Member Countries
MRC	Mekong River Commission
MRCS	Mekong River Commission Secretariat
NMCS	National Mekong Committee Secretariat
OAAs	Other Aquatic Animals
PDG	Preliminary Design Guidance
PNPCA	Procedures for Notification, Prior Consultation and Agreement
PAR	Photosynthetically Active Radiation
PWQ	Procedures for Water Quality
PWUM	Procedures for Water Use Monitoring
RIS	River Information System
SIMVA	Social Impact Monitoring and Vulnerability Assessment
SSC	Suspended Solid Concentration
SGSA	Suspended Grain Size Analysis
TGPWQ	Technical Guidelines for Procedures on Water Quality
TPH	Total Petroleum Hydrocarbons
USGS	United States Geological Survey
WL	Water level
WQMN	Water Quality Monitoring Network

Executive summary

This report:

- Summarises the initial development of the Joint Environmental Monitoring of Mekong Mainstream Hydropower Projects carried out under the GIZ funded Pilot studies at Don Sahong and Xayaburi
- Provides an overview of the outcomes from the pilot monitoring at each of the hydropower projects at Xayaburi and Don Sahong
- Updates the JEM monitoring strategy and protocols based on recommendations from the pilot phase where warranted, and
- Provides recommendations for implementing JEM monitoring at existing and other planned hydropower projects.

Importantly, this report will also serve as an input into the Core River Monitoring Network (CRMN), which is being developed as a long-term, ongoing monitoring network to meet the objectives of the MRC. Although JEM focusses specifically on hydropower, many of the outcomes are relevant to basin wide monitoring.

Rationale

The Lower Mekong River and surrounding basin are under pressure from rapid development, with hydropower a significant growth area. From a basin-scale perspective, information is needed about the availability and condition of the water resources and their linkages with environmental conditions in the basin, how these are changing over time, and how they may change under present and future hydropower developments. These inputs can be used to inform hydropower project siting and design, prediction of changes relating to the project operation, and development, application and evaluation of mitigation and management measures. This information will provide a common basis for constructive discussions by communities and MRC Member Countries on the implications of hydropower development.

To support this need, monitoring procedures identifying what and how to collect the appropriate standardized information (e.g. hydrology and hydraulics, sediment, water quality, aquatic ecology and fisheries) to make robust decisions about hydropower development and impact assessment is needed. This document provides a framework for preparing this Joint Environment Monitoring programme.

Strategy

The main purposes of the Joint Environment Monitoring of Mainstream Hydropower Projects (JEM) are to

i. have a common, standardised, 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;

ii. support mainstream hydropower project proponents to collect sufficient and robust scientific environmental data and information for project planning and design, construction and operation of sustainable hydropower projects;

iii. support MCs to monitor and report on the transboundary environmental impacts of Mekong mainstream hydropower projects during construction and operation to inform mitigation and management measures;

iv. after the completion of the six-month Prior consultation (PC) process to support the MRC Member Countries to establish formal coordination mechanisms to work with project proponents to collect and share fisheries and environmental data and enable adaptive management of the operation of hydropower projects.

In 2019, the JEM monitoring strategy was developed for five disciplines (hydrology sediment transport, water quality, ecological health and fisheries) and pilot studies based on the strategies were implemented at the hydropower projects at Xayaburi and Don Sahong in 2020-2021. The outcomes of the pilots included preliminary findings with respect to impacts from hydropower operations, and recommendations for improving the JEM strategy and monitoring at future hydropower projects, which have now been incorporated into the JEM Programme. The findings and recommendations for each of the disciplines include:

Hydrology

The JEM pilot established new hydrologic sites upstream (Ban Xang Hai) and downstream (Ban Pakhoung)of Xayaburi and downstream of Don Sahong at the tailrace and at Koh Key. These sites allowed the identification of water level changes associated with hydropower operations. Monitoring demonstrated that the operation of Xayaburi results in frequent, rapid and at times large (>1 m) water level changes over short periods of time, associated with the operation of turbines. The fluctuations locally exceed the 5 cm/hour guideline in the MRC Hydropower Mitigation Guidelines (MRC, 2020) but do not persist at Chiang Khan. The operation of Don Sahong can locally affect water level in the tailrace during periods of low flow but the water level fluctuations at the next downstream site (Koh Key) are infrequent and small (<5 cm). Overall, the JEM approach and methodology was suitable for understanding water level changes associated with the target hydropower projects, and also for detecting water level changes in the mainstream Mekong due to the operation of hydropower projects located on tributaries.

Future JEM monitoring at new hydropower projects should commence at the beginning of the PNPCA process and continue throughout the life-cycle of the project. The existing DSM sites are suitable for providing a regional context for future HPP sites, but additional sites have been identified that will need to be established near some of the proposed projects to allow monitoring of the near-field hydrologic changes. With respect to future DSM and the development of the CRMN, recommendations arising from the JEM Pilots include ongoing capacity building in field methodologies and data QA/QC, reviewing rating curves, updating flow monitoring equipment at all DSM sites to ADCP technology, and updating the data reporting system between the MCs and

MRCS. Future collaboration with the operators of Don Sahong and fish tagging investigations to measure flow rates through individual channels in the Si Phan Don region is recommended to better understand the hydrology of the complex area and to assist with the management of fish passage around Don Sahong.

Sediment transport and geomorphology

The findings from the JEM trials demonstrate that the existing JEM methodology is appropriate for detecting sediment transport changes associated with hydropower operations when implemented over a suitable time-frame. Sediment monitoring provided a preliminary understanding of sediment transport into and out of the Xayaburi impoundment during the dry season. However, due to covid restrictions and delays insufficient sediment (SSC) monitoring was completed during the flood season to quantify sediment trapping in the impoundment. Bedload monitoring and repeat cross-sections demonstrated that sand is actively moving through the river at upstream and downstream of Xayaburi, and at Chiang Khan.

At Don Sahong, comparison of sediment monitoring results between sites upstream (Pakse) and downstream (Koh Key) was inconclusive due to a lack of results at the upstream site. Repeat cross-sections at Preah Romkil (Dolphin Pools) showed changes to the bathymetry consistent with the movement of sandy bedload through the section. Monitoring upstream and downstream of the 3S confluence demonstrated that a large flush of sediment entered the Mekong from the 3S over a short period in 2020, which may reflect sediment flushing at impoundments in the 3S basin or a large land disturbance. Overall, the basin wide sediment results show an ongoing decline in sediment transport, likely related to a combination of drought conditions and sediment trapping in impoundments. Longer time series of monitoring results are required to understand the impact on sediment transport from the mainstream hydropower projects in the LMB.

The updated JEM Programme recommends continued monitoring at the DSM sites established during the pilot (Ban Xanghai, Ban Pakhoung, Koh Key, Don Sahong) for at least an additional 12 months to provide results over a full hydrologic year, and to confirm the preliminary sediment transport and geomorphic results, and to implement geomorphic photo monitoring. Recommendations for the future ongoing DSM and development of the CRMN include investigation of implementing in situ laser based technology for the monitoring of sediment concentration and grain size in the field, adopting lab-based automatic grain-size analysis technology in all MCs, and capacity building in field and laboratory techniques, and data reporting, management and analysis.

Water quality

The JEM water quality component is intended to complement and extend the activities of the Water Quality Monitoring Network (WQMN) coordinated by the Mekong River Commission. The WQMN primarily samples mainstream sites in the Lower Mekong basin monthly to allow an assessment of basin wide long-term changes in water quality. Monitoring proposed under the JEM is intended to provide a more localised assessment of the intensity and temporal and spatial extent of water quality changes resulting from hydropower projects.

The JEM water quality component is designed around the principles of BACI (Before After Control Impact) and statistical replication. The selection of monitoring parameters, and the arrangement of sampling locations and frequencies for each, is intended to ensure the detection of potential impacts over the temporal and spatial ranges that they may occur.

The design incorporated three campaigns, of which one is the present MRC WQMN. The other two campaigns consist of a high frequency campaign, with sampling at the time scale of hours, to detect short term potential acutely toxic events which could occur immediately downstream of each reservoir, and a lower frequency campaign, with sampling approximately monthly, to detect medium term impacts. The lower frequency campaign would include sampling at a control site upstream, a site within the pondage and several sites downstream of the impoundment. Key parameters for the high frequency campaign would be temperature, dissolved oxygen, pH, turbidity and conductivity. For the medium-term campaign within the pondage a profile for temperature, pH, dissolved oxygen and light should be measured, while at the upstream and downstream sites dissolved oxygen, pH, conductivity, turbidity, temperature, light, chlorophyll, total phosphorus and NO_x should be measured.

Water quality findings from JEM pilots

The parameters measured during the JEM pilot include some measured in the field and some measured by laboratory analysis of samples collected in the field. Temperature, pH, dissolved oxygen, conductivity, and turbidity were all measured using a water quality meter and probes, while chlorophyll-*a* and cyanobacterial chlorophyll were measured using a field fluorimeter. For the field parameters five measurements were taken at each site on each occasion and results were analysed statistically month by month.

Laboratory analyses were conducted on single samples so it was not possible to conduct any statistical analyses for these parameters on a month by month basis. The JEM method specified multiple samples (at least three) specifically to allow statistical analysis of the results. Some laboratory parameters: TSS, nutrients, COD and coliforms were limited to a reduced suite of sampling locations to reduce cost, which limited conclusions about impacts at sites where they were not analysed.

There were quality assurance issues apparent with some of the data and it will be important that training for field teams emphasises the need to calibrate probes frequently, the need to pay attention to the results as they are collected and recorded, and to note unusual results at the time of measurement and take additional readings where necessary. If multiple samples are taken for laboratory analyses that will provide QA on laboratory analyses, because there will be several measurements at each time x location for which similar results would be expected.

The cables obtained for the WQ meter probes were not sufficiently long to assess the full vertical profile of the impoundments, but it appears likely that there was stratification occurring in Xayaburi pondage in December and possibly January. It will be important to ensure that cables that are sufficiently long are obtained in future

The Algae Torch proved to be a useful monitoring tool providing rapid field-based results for both total chlorophyll-*a* and cyanobacterial chlorophyll. Difficulties were encountered using the Torch in fast flowing water due to air bubbles being reported forming on the surfaces. One suggestion was to collect a water sample in a bucket and then take a torch measurement in the still water in the bucket, and that possibility should be explored. Confirming algae torch results against laboratory absorbance methods for chlorophyll is not necessary, as the two measure different things.

High frequency monitoring of turbidity, pH, temperature, conductivity and dissolved oxygen immediately downstream of each impoundment was not able to be implemented, but was considered worth pursuing. A high frequency WQ monitoring probe system is being constructed under the JEM at Don Sahong which could be a model for a similar system at Xayaburi.

The JEM WQ specification of a single site upstream, a single site within the impoundment, and multiple sites downstream was a suitable design. However, this design was reduced at Don Sahong due to the high diluting capacity of the Mekong River through the other parallel channels, with only two downstream monitoring sites both within 1.5 km of the Don Sahong dam site. In comparison, the monitoring of downstream water quality at Xayaburi was carried out at 3 sites at distances of 1, 5 and 12 km downstream of the dam site, for WQ3, WQ4, and WQ5, respectively.

Construction impact should be considered for all mainstream hydropower projects with water quality monitoring and sampling commence at least one year prior to construction to establish baseline conditions. Precise location of sampling sites depends mainly on ease of access and safety for the samplers and allowing sampling of the flowing component of the river, and not a backwater area.

The monitoring design, of an upstream control and several downstream impact sites will not be able to be implemented in dam cascades and an alternative approach will be required. One possibility will be to monitor each cascade as a whole rather than the individual dams within it.

Equipment and sampling and analysis methods for water quality within the MRC water quality monitoring network are standardised and it is important to maintain and follow those standards. There may need to be additional training in, and standardization of, equipment calibration. There may also be a need for additional round-robin testing to ensure comparability between results of national laboratories. Such cross-calibration should occur at least once every three years. It should not be assumed, that monitoring by dam operators will be adequate in the absence of additional requirements, and enforcement, being implemented by regulators.

Ecological health

The JEM aquatic ecology component is designed to supplement the existing bioassessment activities coordinated through the Mekong River Commission. The MRC is currently conducting monitoring at 41 locations basin wide sampling each location every 2 years, to monitor long term changes in the ecological condition of the river using four indicator groups (littoral invertebrates, benthic invertebrates, zooplankton and attached diatoms), and Mekong-specific river health indices as a means of analysing the data.

The JEM suggested supplementing the MRC work by adding add either chlorophyll or phytoplankton as an indicator, running regional taxonomic workshops to improve quality assurance in the monitoring, adding additional monitoring sites upstream and downstream of each HPP, to be monitored annually, and collecting multiple samples from sites near HPPs, to allow statistical comparison between potentially impacted and control sites.

The JEM aquatic ecology component is designed around the principles of BACI (Before After Control Impact) and statistical replication. It recommends sampling one site upstream of a reservoir pondage, and at several sites downstream, extending as far as the next substantial downstream tributary. Three samples are recommended to be collected at each sampling site, with samples to be collected annually in the dry season (between March and May). The existing MRC sampling protocols should be utilised, and the existing MRC indices used as one means of comparing site results, but it is suggested that multivariate statistical analyses could also be used to compare results between sites and between sampling events.

Ecological Health findings from JEM pilot

The Ecological Health monitoring proved to be sensitive to the influence of dams with ecological assemblages apparently showing recovery from disturbance downstream.

Field measurements undertaken at the time of sampling were: the Site Disturbance Score (SDS), which at present does not include impoundments as a disturbance, but it would now be appropriate to revisit that and include information on impoundments; and a Substrate Suitability Score (SSS). This assesses the suitability of the stream bed at the site of sampling for a range of aquatic organisms.

The sampling methods and the indicator suite are specifically designed for the river and should be reviewed for impoundment sites. A distinct system for assessing reservoirs may be required. The MRC needs to consider whether the status of reservoirs is important in an MRC context beyond their impact on the river downstream.

For most of the indicator groups sampling can only be undertaken when river flows are low. It would be possible to add a second annual sampling run in the dry season, but it is not clear what the benefit would be. Only approximate locations for sampling can be specified in advance, and sampling teams must find suitable locations allowing for the appropriate substrate, access etc.

Statistical analysis was limited because only single samples were taken at each site. As a result, the range of statistical tests that could be applied was limited. It should be noted that the biota responds to a wide range of factors, and biological indicators will not correlate well with water quality indices, fisheries results or substrate conditions.

Recommendations Applicable to the Routine EHM and CRMN

The sensitivity of the EHM method makes it a very suitable monitoring tool for the Mekong basin, and the JEM pilots locations complement the routine biennial EHM campaigns.

Monitoring locations may need consideration and adjustment where previous sites are now within impoundments (such as the routine EHM site at Luang Prabang), or to allow for the future locations of dams and impoundments. They do not need to be co-located with WQMN sites or hydrological monitoring sites.

Maintaining the consistency of identifications of the invertebrates used as indicators is always an issue, and the implementation of annual invertebrate identification workshops run by regional specialists would be most helpful in capacity building across the region.

There are detailed standard procedures that have been developed and promulgated by the MRC, but it is important that adherence to them is emphasized. A freshwater invertebrate identification key has been produced by the MRC for identification of littoral invertebrates, but supplementing that with a photographic guide, possibly hosted online, would assist in achieving consistency of identification.

Fisheries and fish passage

The JEM fisheries monitoring programme is designed to provide information about how the development and operation of hydropower schemes in the LMB affect fisheries and other aquatic organisms over time and spatial scales. JEM complements the existing MRC Fish Abundance and Diversity Monitoring Programme (FADM) and Fish Larval Diversity Monitoring (FLDM) programmes in the LMB and adopts the same strategies. The JEM Programme recommend additional monitoring sites on the mainstream Mekong in the locality of each proposed HPP development using the same methods as FADM, but at greater frequency and using more fishers to monitor catches. In addition, market and household surveys should be conducted in the region of the proposed HPP to understand dependence of the local communities on the fisheries, and further fisheries independent surveys (larval drift studies, standard multi-mesh gillnetting and seine netting operating procedures) should be carried out at sites downstream of the dam, in the reservoir area and upstream of the reservoir.

In addition to fisheries monitoring data and analysis, emphasis is also put on assessing fish passage and the efficacy of fish passage mitigation measures. A range of methods using acoustic and PIT tagging telemetry are proposed to determine fish passage efficiency and fish behaviour in the fish passes, whilst DIDSON/ARIS and traditional sampling methods are recommended to evaluate abundance and biomass of fish moving upstream. Methods for assessing downstream fish mortality through turbines and disruptions to downstream drifting of larval life stages are also proposed.

The JEM pilots implemented the FADM and FLDM monitoring protocols at Don Sahong and Xayaburi. This included addition sites up and downstream of the dam to support existing monitoring sites and inclusion of larval drift monitoring sites. Improvements are suggested to strengthen the consistency and quality of monitoring. For fisheries gillnet monitoring, a number of recommendations were made based on the testing of different configurations during the JEM Pilots. This includes altering the original random distribution of mesh sizes in the standardized gillnets and replacing them with three sets of nets with five multi-mesh panels of 10 x 2.5 m each.

This recommendation changes the objectives of the sampling using standardising gill netting to compare catch statistics against nets used by fishers and determine exploitation patterns. The new procedure samples different habitat types and targets specific sized species associated with these habitats. This then becomes a fisheries independent sampling method to catch representative samples of the biodiversity, and especially small sized fish that are not caught by fisher gill nets.

For FLDM, the pilot monitoring confirmed the most useful months for sampling and to include sampling locations on both banks and one in the mainstream. However, instead of sampling at midnight, the timing should be brought forward to 21:00, although sampling only once per day is becoming the procedure recommended in the updated FLDM.

A review of fish tagging procedures was carried out during the JEM pilots and reinforced the costs and constraints of different methods raised in the JEM Programme. The study concluded that non-electronic external tags are comparatively cheaper and feasible for application to a high number of fish, whilst electronic tags are more expensive and suited to smaller numbers of target fish. Studies using external tags, however, fail to provide quantitative information on fish passage around barriers and only indicate that some (unknown number) fish can bypass obstructions and need considerable investment in a recapture and reporting programme

As yet acoustic tagging has not been installed at Xayaburi or Don Sahong because of logistic constraints. As a consequence, it was not possible to update the JEM Programme on tagging and tracking until such time as the pilot studies at Don Sahong and independent studies at Xayaburi have been established and run for several years. It is recommended the current acoustic tracking and PIT tagging studies being carried out by Charles Sturt University should be given all the necessary financial and logistical support to complete as defined in the JEM Pilot proposals. In addition, a pilot study to determine efficacy of external (spaghetti tags) tagging systems could be carried out, but the objectives of the study in relation to understanding migratory pathways the effectiveness of fish passes needs to be established.

Recommendations for future JEM projects

For future HPP developments it is recommended to implement the JEM at the start of the PNPCA process to allow sufficient time to establish baseline conditions prior to construction and operation of the hydropower project, and to continue monitoring throughout the life-cycle of the project. It is recommended that long-term MRC monitoring sites (e.g. future CRMN sites) be complimented by additional, local monitoring locations upstream, within and downstream of the proposed impoundment and dam. Significant tributaries are recommended for inclusion where they exert a major impact on the flow and ecological conditions in the Mekong mainstream near the hydropower project. Ongoing collaboration and cooperation with hydropower developers and operators should remain an important aim of JEM, but MRC managed monitoring should be sufficient in isolation to provide the required information for understanding hydropower impacts and the efficacy of mitigation measures.

1 BACKGROUND

The Lower Mekong River and surrounding basins are undergoing rapid development, with hydropower a significant growth area. The Mekong River Commission (MRC) plays an important role in coordination of environmental and ecological monitoring in the LMB, completing quality control checks and making information available that can support hydropower information needs, and subsequently enhance cooperation in development of the Mekong resources.

From a basin-scale perspective, information is needed about the availability and condition of the water resources and their linkages with environmental conditions in the basin, how these are changing over time, and how they may change under present and future hydropower developments. These inputs can potentially inform hydropower project siting and design, prediction of changes relating to the project operation, and development, application and evaluation of mitigation and management measures to ensure sustainable hydropower development. This information will provide a common basis for constructive discussions by communities and Member Countries on the implications of hydropower development.

Robust environmental information (e.g. hydrology and hydraulics, sediment, water quality, aquatic ecology and fisheries) is needed to: (1) document conditions before construction of hydropower and other water resource developments; (2) be used as reference to assess potential and actual changes associated with these developments during their construction and operational phases; (3) capture the current rate of change in the river, and highlight the existing and changing wider pressures on and variability within the basin's natural resources; (4) provide alerts of sudden changes, and enable clarity should a rapid management response be required; (5) allow more informed, effective and economic mitigation measures (e.g. fish passage, sediment flushing, environmental flows; offsetting, alternative livelihoods); and (6) facilitate accurate and objective debate on the opportunities and impacts of any infrastructure development.

Currently, the MRC's Environment Monitoring is one of its Core River Basin Management Functions (CRBMF) and central to the success of its operation. MRC has been implementing five basin-wide routine environment monitoring activities: (1) hydro-meteorological monitoring/ near real-time rainfall and water levels monitoring, (2) sediment monitoring and discharge measurement, (3) water quality monitoring, (4) ecological health monitoring, and (5) fisheries monitoring. The overall objectives of these activities are to monitor fisheries and environment indicators in the LMB contributing to the interpretation of the status and trends of basin-wide fisheries and environment as well as providing a more effective means of basin-wide monitoring and assessing the effects of water management and basin development activities.

In recent years, the MRC has carried out numerous Prior Notifications assessments (PNPCA) for mainstream hydropower developments, viz Xayaburi HPP (2011), Don Sahong HPP (2015) and Pak Beng HPP (2017), Pak Lay HPP (2018) with a fifth nearing completion (Sanakham, 2021) and sixth underway (Phou Ngoy). The MRC Technical Review Reports (TRRs) of these mainstream hydropower projects consistently provided similar recommendations regarding the need to design and implement a detailed scientific robust environmental monitoring programme, with sufficient budget, to assess fully the impacts of the developments on hydrology and hydraulics, river geomorphology (sediment), water quality, aquatic ecology and fisheries, and to guide the design or re-design of effective impact mitigation measures for the protection of fisheries, environment and river ecology in the LMB.

To support this need, the MRC's Initiative Sustainable Hydropower programme developed a tool entitled "Guiding considerations on transboundary monitoring for LMB hydropower planning and management" (i.e. monitoring of hydrology, sediments, water quality, aquatic ecology, fisheries and socio-economics) to assist hydropower decision-making and management. The five main elements of this hydropower-monitoring framework address: (1) locations, (2) parameters, (3) timing, (4) information management, and (5) information use. This framework was developed to support the MRC's Indicator Framework, but there is a need to develop robust monitoring procedures on what and how to collect the appropriate standardized information to make robust decisions about hydropower development and impact assessment.

This document provides a framework to standardise monitoring in the Mekong to support both assessment of hydropower development, but also to determine the status and trends in resources. The main purposes of this project, viz. Joint Environment Monitoring of Mainstream Hydropower (JEM), are to:

i. provide a common, standardised or 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;

ii. support mainstream hydropower project proponents to collect sufficient and robust scientific environment data and information for project planning and design, construction and operation of sustainable hydropower projects (i.e. effective mitigation measures).

iii. support MCs to monitor and report the transboundary environmental impacts of Mekong mainstream hydropower projects during construction and operation to inform mitigation and management measures;

iv. after the completion of the six-month Prior consultation (PC) process to support the Joint Action Plan (JAP) process and establish formal coordination mechanisms to work with project proponents to collect and share fisheries and environment data and information for making final technical designs and enable adaptive management of the operation of hydropower projects to avoid, minimize or mitigate both local/national and transboundary impacts.

2 STRATEGIC APPROACH TO MONITORING

2.1 Background

As indicated above, the Mekong basin is subject to considerable development pressures, especially from hydropower. To ensure the river continues to deliver the multiple service is provides to millions of people, many of whom are rural poor, it is essential environmental conditions and ecosystem processes in the river are maintained and protected. To achieve this there is a necessity to understand the baseline conditions of the river in terms of hydrology and hydraulics, sediment, water quality, aquatic ecology and fisheries, which are fundamental drivers of, and services delivered by, the ecosystem (Figure 2-1), together with follow-up monitoring to inform adaptive management activities to demonstrate the effectiveness of avoidance, minimisation and mitigation measures. For monitoring to be informative, it must have well defined objectives measured against agreed indicators to check the progress or quality of a development or activity over a period of time. The current JEM document provides guidance to help Member Countries consider whether harmful effects are arising, and if there are concerns, to build confidence about any proposals to implement revised management approaches (i.e. adaptive management).

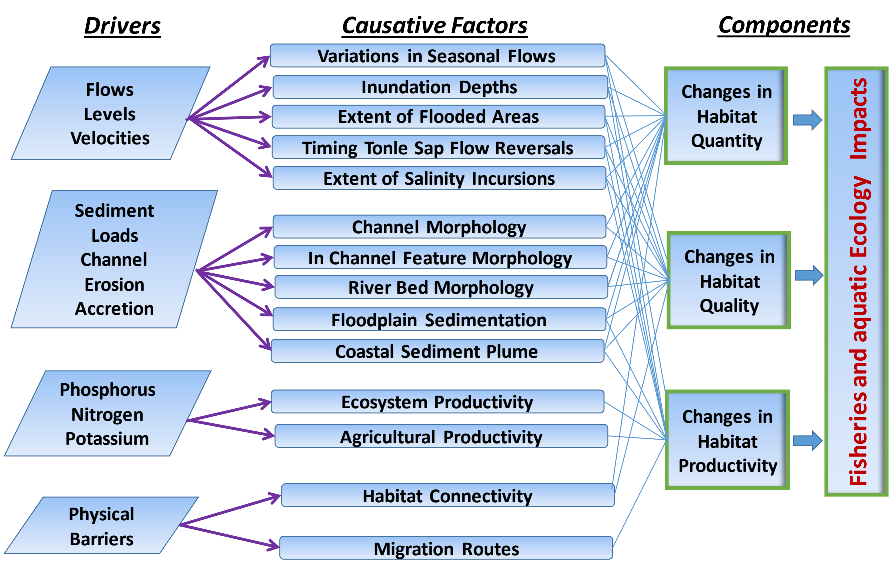

Figure 2-1. Linkages between drivers (flow-hydraulics-sediment) and impacts (water, quality, aquatic ecology and fisheries).

As in any large and complex ecosystem, relationships between environmental drivers and resources are complex, dynamic, and include multiple feedback loops (Figure 2-1). For example, hydrology is linked to physical changes to habitats (river geomorphology) and variations in sediment dynamics and water quality arise due to flow changes, and have significant influences on aquatic ecology. Fish and fisheries are dependent on conditions and processes relating to flow, habitat, water quality and aquatic ecology. Socio-economics are strongly influenced by all of these factors, and in particular where livelihoods are dependent on the river environment.

Construction and operation of hydropower dams could alter four important physical characteristics of the Mekong River within the impact area, namely hydrology, sediment, water quality, and connectivity. Connectivity includes the physical barriers to upstream/downstream movement caused by the presence of the dams as well as changes to overbank flows impacting connections between the river and floodplain wetlands. For example, the natural physical and biological systems would respond to changes caused by dams in complex ways that ultimately affect, among other environmental factors, water quality, riverbank erosion/accretion rates, formation of fish habitat, and terrestrial and aquatic biodiversity. Those physical changes would cause, or drive, effects on people and resources in the immediate area of the dam and further afield (transboundary effects). These impact drivers could cause numerous changes to the physical and biological systems in the LMB, which could directly and indirectly affect the natural environment and ecosystem function with implications for aquatic ecology, including OAAs, fisheries and biodiversity (Figure 2-1). Changes to these resources could then impact economic conditions in the impacted area and the livelihoods of local residents.

Assessing the impact of change usually involves several major steps (see Section 2.3), including the following:

1. Baseline conditions for selected key indicators of river system flows and velocities, sediment loading and transport, and water quality,
2. Baseline conditions for key indicators of aquatic ecology fisheries, OAAs and biodiversity,
3. Changes likely to occur in the key indicators of river flows and velocities, sediment loading and transport, and water quality caused by construction and operation of the mainstream dams by comparison with corresponding baseline (reference) conditions,
4. Changes likely to occur in key ecological indicators as a result of the projected changes in impact drivers.

To undertake this assessment requires considerable information on the key ecosystem elements of hydrology and hydraulics, sediment, water quality, aquatic ecology and fisheries. This document provides guidance monitoring procedures to collect and analyse robust data to support reliable EIA studies and underpin the PNPCA procedures.

2.2 Linkages to MRC Agreements, previous projects and ongoing monitoring

The JEM is consistent with and builds upon previous projects and ongoing monitoring and information gathering initiatives related to water use, and environmental and ecological assessment, in the LMB. Monitoring of water resources within the basin underpins the 1995 Mekong River Agreement for the reasonable and equitable use of water resources, and is one of the Core River Basin Management functions (CRBMF) of the MRC. Collaborative monitoring and data sharing between the Member Countries underpins the Procedures for Water Use Monitoring, and Procedure for Water Quality and is recognised as essential for the effective management of water resources in the basin.

Similarly, the MRC Fisheries Programme, and latterly the Environment Division, has been supporting fisheries monitoring programmes to track the status and trends of fisheries in the Lower Mekong Basin (LMB) since 1994. The programme is broken down into several components: (1) *Fish Abundance and Diversity Monitoring Programme (FADM)*, (2) *Fish Larvae Density Monitoring Program (FLDM), (3) Dai Fishery Monitoring Programme*; (4) *Lee Trap Monitoring Programme* but implementation has been fragmented and not fully compliant to support impact assessment and decision-making related to major infrastructural developments in the LMB. The *Fish Abundance and Diversity Monitoring Programme* is the only programme common across all countries and based on standard operating procedures (MRC 2022). Other MC programmes recognise the need for monitoring but do not provide strategic guidance. These programmes, however, provide substantial background information on which to baseline conditions in the LMB.

The MRC Initiative for Sustainable Hydropower has also addressed 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*. Some of the linkages between the JEM and these projects are described in the following sections.

These sections only provide a very high-level review of important components of these projects as related to the JEM, and the full project reports should be consulted for a more in-depth understanding of monitoring in relation to hydropower issues, and how accurate information is needed to design, implement and manage hydropower sustainably in the Mekong.

2.2.1 ISH11 – Improved baseline information for hydropower planning[1]

The ISH11 project identified information needs to support hydropower planning in the LMB, recognising that different information is required to address the issues that arise on a range of spatial and temporal scales over the project life-cycle. An example of the level and time scale of data needs for hydrology is shown in Figure 2-2, ranging from short-term information to inform generation and local water needs to large scale, long term information to understand water resource development and climate change. ISH11 developed a guiding framework for the collection of relevant information with respect to monitoring locations, parameters / indicators, timing of data collection, and information management and uses, based on the projected locations of hydropower projects and ongoing MRC monitoring programmes and networks (Figure 2-3).

ISH11 recommended a range of approaches and identified advantages for collaborative monitoring at a range of scales, which are listed below. The approach of the JEM is consistent with these concepts.

[1] http://www.mrcmekong.org/about-mrc/completion-of-strategic-cycle-2011-2015/initiative-on-sustainable-hydropower/improved-environmental-and-socio-economic-baseline-information-for-hydropower-planning-ish11/

- Countries and projects can use the same parameters and methods for more detailed information collection
- Results of more detailed information collection can be fit into the larger picture for interpretation purposes;
- Results of more detailed information collection can be verified against quality assured basin information;
- Information sharing, comparison and transboundary evaluation is facilitated;
- Good information at all levels supports good decisions

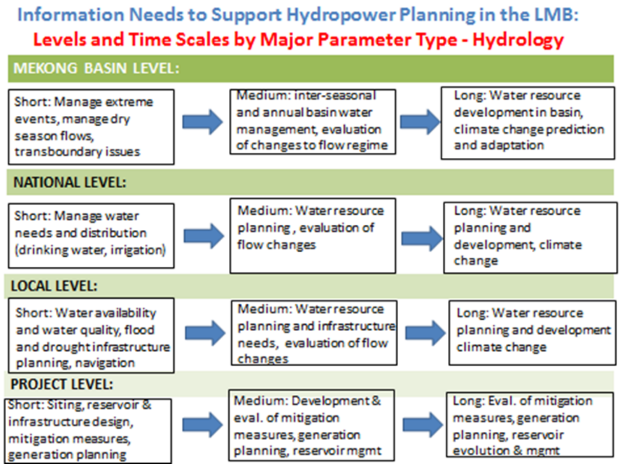

Figure 2-2. Example of hydrologic data needs over a range of spatial scales and timeframes (source ISH 11)

Guiding Framework for Basin-Scale Information for Hydropower Planning and Management

1. **Locations of Data Collection**:
   a) Cover all Mekong River hydro ecological zones
   b) Near proposed or operational hydropower project or group of projects
   c) Enable understanding of mainstream processes
   d) Facilitate understanding of changes occurring across national boundaries
2. **Parameters Monitored**:
   a) Provide inputs to indicators related to hydropower planning and management
   b) Able to be replicated across the basin
   c) Able to be measured and analysed at a low cost
   d) Able to help predict as well as explain cause and effect of changes
3. **Timing of Data Collection**:
   a) Length of record covers the cycles of natural variability (seasonal, annual, decadal)
   b) Frequency captures natural or operational system changes and migratory cycles
4. **Information Management**:
   a) Quality management systems are in place to ensure consistency across countries
   b) Systems allow information to be centrally archived and shared
5. **Information Use**:
   a) Information is readily available for users (e.g. Member Countries, developers, NMCs, Line Agencies)
   b) Links to tools are available for decision-support and analysis

Figure 2-3. Summary of ISH11 Guiding Framework for Basin-Scale Information for Hydropower Planning and Management

Recommendations arising from ISH11 with respect to monitoring locations, parameters, monitoring timing and information management and uses are summarised in Figure 2-3.

2.2.2 ISH0306 Hydropower Guidelines and Mitigation Measures[2]

The development of hydropower guidelines for the LMB was based on the identification of potential risks associated with hydropower development, and approaches and mitigation measures to address those risks. The guidelines link hydrologic, hydraulic and physical changes typically associated with hydropower development to ecosystem risks (Table 2-1). The guidelines are consistent with the hierarchy of avoidance, minimisation and mitigation and the adoption of adaptive management to address ongoing environmental issues that may arise over the life-cycle of a hydropower operation.

The collection of relevant information at appropriate spatial and temporal scales is required to guide the siting and design of a sustainable hydropower projects, with operations guided by adaptive management based on ongoing monitoring. The guidelines developed by the MRC are consistent with the monitoring requirements identified in the ISH11 project.

[2] http://www.mrcmekong.org/about-mrc/completion-of-strategic-cycle-2011-2015/initiative-on-sustainable-hydropower/guidelines-for-hydropower-environmental-impact-mitigation-and-risk-management-in-the-lower-mekong-mainstream-and-tributaries-ish0306/

Table 2-1. Examples of risks associated with flow changes arising from hydropower development. Not all risks are associated with all developments.

Hydrologic Change: Annual/Inter Annual Changes to Flow	
Theme	**Risks**
Hydrology and downstream flows	• Change of timing & duration of floods and low flows • Peaks in flood and low flow change, smoother hydrograph • Changes in Tonle Sap flows and salt intrusion in the delta
Geomorphology and Sediments	• Water logging & loss of vegetation leading to increased bank erosion • Increased erosion due to increased scour • Winnowing of smaller sediment leading to bed armouring & reduction in downstream sediment supply • Channel narrowing through encroachment of vegetation • Decoupling of tributary & mainstream flows. • Erosion and / or deposition due to tributary rejuvenation • Backwater sedimentation causing increased flood-levels upstream
Water quality	• Changes in seasonal temperature patterns downstream if reservoir stratifies • Increased water clarity increasing water temperature and risk of algal growth
Fisheries and Aquatic Ecology	• Loss of migration/ spawning triggers; • Reduced flood pulse and related productivity loss • Habitat loss due to morphological alterations
Biodiversity, Natural Resources and Ecosystem Services	• Changes in wetland functions and dynamics due to shifts in timing of sediment and nutrient delivery • Loss of wetland/floodplain habitats
Hydrologic change: Short-term flow fluctuations / Hydro-peaking	
Hydrology and downstream flows	• Short term flow fluctuations • Safety and navigability
Geomorphology and Sediments	• Rapid wetting and drying of banks • Increase in shear stress on river channel
Water quality	• Fluctuating temperature and water quality • Altered concentrations of downstream WQ parameters
Fisheries and Aquatic Ecology	• Degradation of riparian and instream habitats • Thermo-peaking • Increased fish/ macroinvertebrate drift and stranding • Offset of migration triggers • Loss of food sources
Biodiversity, Natural Resources and Ecosystem Services	• Degradation of function, dynamics and ecosystem services of wetland and riparian habitats

Physical Change: Loss of river connectivity	
Geomorphology and Sediments	• Sediment availability not timed with periods of recession • Loss of sediment 'pulse'
Water quality	• Trapping of nutrients within impoundments (change in nutrient delivery downstream)
Fisheries and Aquatic Ecology	• Blocked spawning/ feeding migrations • Habitat/ population fragmentation3) Habitat loss due to morphological alterations • fish damage/ kills due to turbine/ spill flow passage
Biodiversity, Natural Resources and Ecosystem Services	• Changes in wetland functions, dynamics and ecosystem services, due to decrease in sediment and nutrient transfer
Hydrologic and hydraulic change: Impoundments	
Geomorphology and Sediments	• Reduction in sediment availability downstream of dam leading to increased erosion • Changes to the grain size distribution of sediment downstream contributing to channel armouring and alteration of habitats • Lake bank erosion, increased risk of landslips • Loss of volume of active storage
Water Quality	• Lake stratification • Increased water clarity • Temperature change in lake and discharge • Low DO or high gas supersaturation • Changes in nutrient loads
Fisheries and Aquatic Ecology	• Changes from fluvial to lake habitats (habitat & species loss) • Habitat loss due to sedimentation (upstream) and sediment deficit (downstream) • Deposition/ delay of drifting eggs/ larvae • loss of orientation • stranding due to water level fluctuations • Reservoir flushing leading to fish damage and kills and alteration of habitats
Biodiversity, Natural Resources and Ecosystem Services	• Change to / loss of riparian- ecosystems, habitats and biodiversity
Diversions or Intra-basin Transfers	
Hydrology and downstream flows	• Change of magnitude & dynamics of flows
Geomorphology and Sediments	• Channel narrowing due to vegetation encroachment • Armouring of beds and bars • Increased bank erosion and bed incision
Water quality	• Change in nutrient and other water quality parameters in both donor and receiving catchments

Fisheries and Aquatic Ecology	• Reduced productivity due to reduced river dimension (flow, depth, width) and flow dynamics • Reduced connectivity • Stress due to water quality changes • Habitat loss due to morphological alterations • Possible loss of large species (due to river size reduction)
Biodiversity, Natural Resources and Ecosystem Services	• Flow changes to wetland and floodplain areas (decrease or increase) leading to changes in ecosystem- functions, dynamics and services as well as biodiversity

2.3 Environmental impact design strategy

The purpose of an environmental impact assessment is to evaluate whether or not a stressor (in this case a hydropower dam) has changed the environment, to determine which components are adversely affected, and to estimate the magnitude of the effects. Evaluating change in environmental conditions is often difficult, due to several factors, principally attributing any impact to one specific stressor where multiple developments are taking place. It is also often not clear which environmental component will be affected by the stressor, what type of change will occur and what the exposure will be. Choices must be made about where and when the potential effect will occur (i.e. define the spatial and temporal extent), what organisms will be affected (aquatic organisms, fish), what the exposure will be (magnitude, duration), what any mitigating factors could be (what affects distribution of exposure) and how may these factors alter exposure and effect. Change in the environment is natural and variation due to natural effects may be great. The impact assessment needs to account for such naturally occurring changes and avoid them being added to the development impacts that are being measured.

To understand any impact, decisions need to be made about which environmental parameters will be modified by the development and which organisms (fish and aquatic biota) to measure, and how the organisms will be affected. If fish are selected, their abundance may be limited by reductions in survival, loss of recruitment or displacement from the affected area. Fish abundance may be increased due to compositional changes in predators and competing fish or increased prey (tolerant species might increase while intolerants decrease). Thus, the definition of impact may be difficult, but is generally considered any change that has occurred following the start of some new human activity that directly or indirectly affects the environmental characteristics, ecological functioning and services that the ecosystem delivers for society.

The purpose of an environmental impact assessment is to provide statistically robust evidence that a meaningful change has occurred. Early approaches to impact assessment focused on empirical approaches for evaluating impact (Swartzman et al. 1977). One area of application involved the effect of nuclear power plants on fish and other organisms. As part of plant operation, a large amount of water is removed from rivers or other water bodies to cool the plant. Fish may be harmed when passing through the cooling system and the warm water that is released from the plant may affect the area near where it is released. In the late 1970s, emphasis shifted to using computer simulation models to predict the impact (Thomas et al. 1978). Decisions were then made based on the soundness of those predictions (Mapstone 1995). Although the data used to interpret effects are quite varied, the methods for analysis are often similar and involve comparison of impact areas with control areas or when information is available prior to the potential impact, comparison of status before and after intervention. In many cases these approaches have been combined to increase the robustness of the predictions or impacts. This design is commonly termed the Before-After-Control-Impact (BACI) design.

In this design, measurements are taken at the treatment (impacted) site and at a control site both before and after the impact occurs. This design is preferred over a simple Before-After comparison as a change in the response may occur independently of any impact because of temporal effects. For example, precipitation levels may change between the before and after periods and the response may be related to precipitation rather than the impact. By establishing a control site (where presumably no effect of the impact will be felt), the temporal change that occurs in the absence of the impact can be measured. The differential change in the difference over time is evidence of an environmental impact.

A key assumption of BACI designs is that the system is in equilibrium before and after the impact. Schematically (Figure 2-4), it is assumed that the overall mean before and after the impact is stable and that the change is relatively quick and sustained, i.e. there is a step change in the parameter following the intervention. The advantage of this design is that trends in environmental data are common and may or may not be due to human activity. The use of control sites allows the detection (and elimination) of changes that may be widespread and due to causes other than the activity. Normally for a BACI design, a minimum of three years data are required prior to onset of any development or construction works. These represent the baseline data against which natural variability can be tested, although longer data series are probably required for hydrological and hydro-geomorphological processes. It is against these baseline conditions that changes in the ecosystem functioning and ecological characteristics are measured.

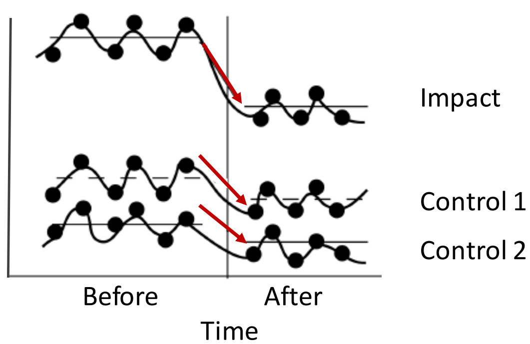

Figure 2-4. Schematic of principle of before after impact assessment.

It is proposed that a BACI-type design is adopted as the underlying procedure for assessing the impact of hydropower (and any other) development of the environmental and ecological characteristics of the Mekong both in the immediate vicinity of the development but also in terms of regional and transboundary impacts. In the case of JEM, it will be problematic to define a true control site because a lot of changes have already occurred and the river is in a state of flux, preventing collection of a fixed 'Baseline'. This highlights the need for ongoing, compatible monitoring to document how the river is continuing to change, allowing these changes to be linked to the different catchment activities. Under this scenario, the before (baseline) and after sites relate to the conditions before and after the HEP has been constructed, and control sites are established upstream of the impacted area (i.e. above the impoundment headwater or in an adjacent tributary) and the impact sites are those within the impoundment or immediately downstream of the dam. These localities allow comparisons of the change in status of the environmental parameters and aquatic ecology and fisheries during and after the construction of the HEP.

Critical to this strategy is the collection of robust, standardised monitoring data for all environmental and ecological parameters both before (baseline), and during construction and operation of the dam (impacted). These procedures are described in detail in Sections 3 to 7.

2.4 JEM Monitoring strategy

The initial concept of JEM was to integrate monitoring completed by the MRC with monitoring results collected by the hydropower developers / operators using the same standard protocol. This would produce compatible data sets that would allow meaningful comparison and integration of information. This remains the aim of JEM, even though the initial pilot projects were largely limited to monitoring results collected by the MRC. For future JEM monitoring, it is envisaged that a final monitoring plan for each hydropower project considered under the PNPCA process will be developed and implemented as part of the JAP process, with monitoring locations agreed between the developer, MC where the project is located, and the MRC. The implementation of the monitoring will be considered on a case by case basis. The future CRMN monitoring sites should provide the large scale regional context for the different disciplines, with additional sites added to capture the local impacts as required. Some of these local impacts may be captured by existing MRC monitoring sites, or may necessitate the establishment of new sites. The funding arrangements for future JEM monitoring will also be considered on a project by project basis, with the aim being to work collaboratively with the developers, and to optimise the use of available resources. Potential funding models may include, but are not limited to: the developer makes a contribution to the MRC with the MRC implementing the monitoring strategy, the develop conducts monitoring at JEM sites using the JEM protocol and shares the information with the MRC, or the MRC contributes basket funds to support some or all of the additional monitoring.

During the JEM pilot study, the hydropower developers voluntarily provided useful information at various points in the study period, which enhanced the understanding and usefulness of the MRC JEM results. Future collaboration with hydropower developers should continue to be a primary objective of JEM, with the JAP process developing into a long-term cooperative arrangement between the developers, the MCs and the MRC.

Based on the JEM Pilot experience and literature review, the following approach is recommended for implementation for future JEM monitoring, and is shown schematically in Figure 2-5. This strategy reflects the information needs at various points of the hydropower development cycle, and is linked to the PNPCA and subsequent JAP processes. Note that not all projects would warrant the establishment of all of the sites included in the conceptual diagram, and that Figure 2-5 is an idealised conceptual model for establishing monitoring locations The monitoring strategy for each hydropower project will need to be developed independently, and reflect the site-specific characteristics of the site, and consider the social and environmental conditions both upstream and downstream of the site. The idealised conceptual strategy includes the following components:

- **Monitoring at long-term ongoing sites (Pre-proposal in** Figure 2-5**)**: These sites are part of the existing MRC ongoing monitoring networks, based on established HYCOS, DSM, WQMN, EHM and fisheries monitoring locations. It is envisaged that in the future, these sites will form part of the CRMN. The monitoring results from these long-term sites will provide the basin wide and regional context for JEM monitoring conducted near hydropower projects. The identification and / or establishment of long-term sites that will not be affected by future hydropower developments is required to provide this large scale understanding of how the Mekong is responding to hydropower and other water management and land use change developments. This recommendation is included in the recommendations made by JEM to the CRMN. The same locations are not required for each discipline, but groups of monitoring sites covering specific reaches of the Mekong should allow for the integration of results. Preliminary groupings of existing sites into regional clusters that may be useful for integrated analysis were identified during the JEM pilot studies and are presented and discussed in Section 9.1.1
- **Monitoring implemented at start of PNPCA process or following the PNPCA during the JAP (PNPCA in** Figure 2-5**):** Once the exact location of the HPP and the extent of the associated impoundment (which is related to the height of the dam), then additional local monitoring sites can be identified. Monitoring sites associated with this local scale will vary depending on the discipline (e.g. not all disciplines will need to be monitored at the same location) but it is recommended that monitoring will include sites upstream, within and downstream of the proposed impoundment at locations that are suitable to capture potential changes due to construction and operation of the HPP. . Significant tributaries that are not part of the ongoing MRC monitoring network (or future CRMN network) may also be considered for inclusion with agreement from the MCs. Ideally this additional monitoring will extend and complement monitoring implemented by the hydropower developer prior to the PNPCA process. These sites will provide a local baseline for the river prior to construction of the development, and provide information about impacts during the construction phase of the project. Monitoring and implementation strategies for hydropower projects that have already completed the PNPCA process should be included in the ongoing JAP process.
- **Monitoring during construction (Construction in** Figure 2-5**):** The established monitoring locations should be monitored throughout the construction phase of the project, to provide a local baseline and to identify impacts associated with construction, and initiate responses to mitigate problems.
- **Monitoring during operations (Operation in** Figure 2-5**):** Continued monitoring at the established sites will provide information about changes associated with the commissioning and operation of the hydropower project. The monitoring needs to cover the life of the HPP, including the decommissioning period, to be able to identify changes associated with hydropower from the natural variability of the river system and provide the evidence of designing and interrogating appropriate mitigation measures.

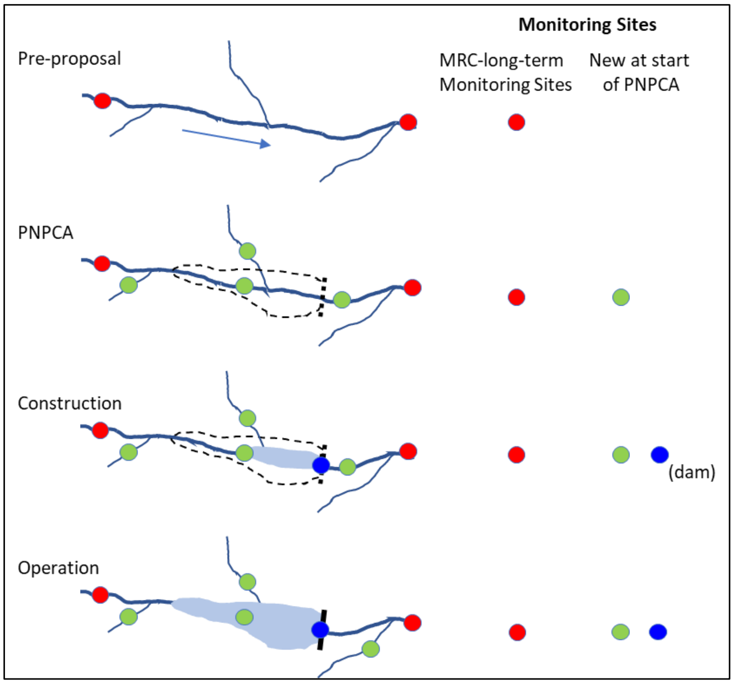

Figure 2-5. Idealised conceptual diagram of sampling sites for monitoring during the stages in project development. Red represents existing (or future) long-term MRC monitoring sites, green proposed sites to be implemented once the PNPCA process has been initiated.

3 Data Acquisition and Sharing Mechanisms

3.1 Rationale

Key elements of monitoring programmes are data management procedures: acquisition, input pathways, quality control, storage, interrogation procedures and access management (Figure 3-1). Consequently, a fundamental dimension for the successful implementation of JEM is mechanisms for storage and sharing of data for use by all stakeholders. This includes not only strategies to ensure appropriate collection and analysis of robust, defensible data (Sections 4 to 8), but also mechanisms for proper data flow and sharing for all involved in the planning, development and management of the environment and associated aquatic resources.

This section provides a framework for data acquisition, storage and sharing to meet the needs for robust integrated analysis of environmental and ecological data and support management decisions to mitigate any potential impact of hydropower or other developments in the LMB. These concepts are being built upon in the development of the CRMN.

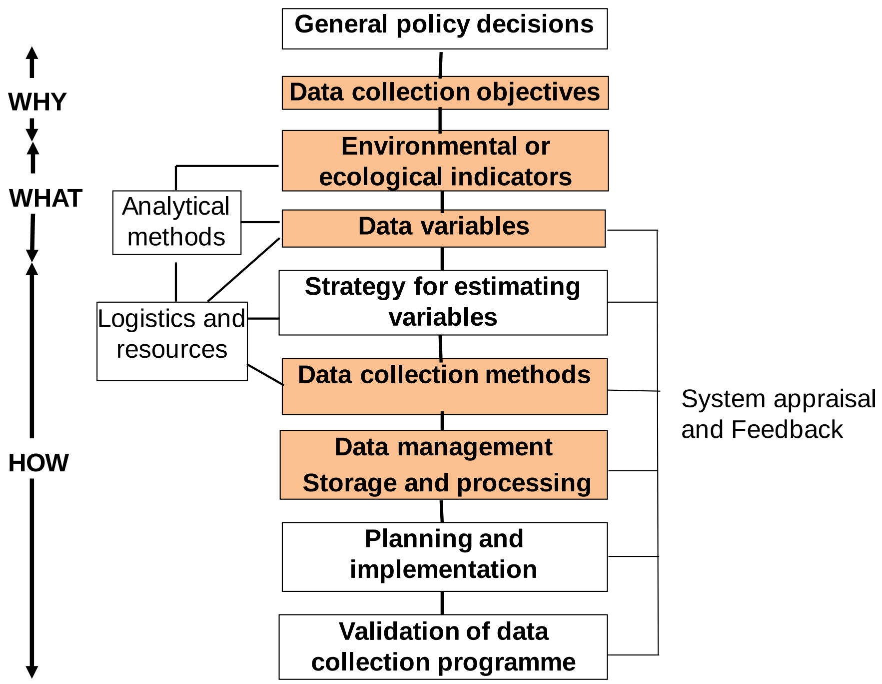

Figure 3-1. Flow chart of data collection and management system applicable to JEM.

3.2 Data collection pathways-advancements during JEM Pilots

Much of the environmental and ecological data relating to the Mekong are dispersed, fragmented and lacking continuity. Data are collected independently by the line agencies (in some cases on behalf of the MRC), NGOs, universities and developers but there is no mechanism to collate and hold such data centrally for sharing. To underpin robust environmental impact assessment, it is imperative that a strategic approach to data management is implemented. Such an approach should build on existing data management systems under each monitoring programme but integrate through a central system that can capture data from external sources, especially from the developers and other ongoing studies, where such data are available and collected in a robust and standardised manner. The following paragraphs summarise the existing data pathways for each of the monitoring disciplines.

The water level and rainfall data recorded at the HYCOS sites are transmitted to the MRC's Aquarius database, with time-series results available on the MRC website. During the JEM pilot phase, water level, and river flow results relevant to the JEM sites were extracted from the Aquarius database, and a new hydrology data base was created. This database includes queries that allow the easy extraction of time-series results from any site, as well as composite indicators such as average monthly flow, and average annual flow based on the past 20 years of data.

The present data management system for discharge and sediment monitoring (DSM) requires the countries to perform initial QA/QC. The Standard Reporting forms include control charts to assist the MCs with interpreting results and identifying potential errors. These forms are submitted electronically to the MRC, and the organisation completes a second round of QA/QC. In 2011 and 2015 this included integration and interpretation of the data set to quantify flows and loads, identify trends and investigate unusual or spurious results. In the past, this analysis has been compiled as a report, and the integrated data set has been collated in Excel files.

During the JEM pilot phase, the available discharge and sediment measurements from sites relevant to the JEM pilots were compiled into an Access database. Parameters include measured discharge, SSC, hydraulic parameters (average water velocity, water level, channel width), SSC loads and estimated bedload

Annual data from the water quality monitoring network are forwarded to MRCS by the national laboratories each year. The data are entered into the MRC water quality database, and Excel spreadsheets, which have a number of checks, such as an ion balance test, to evaluate the reliability of the data. Access to the data may be obtained through the MRCS, which has also permitted, and in some cases commissioned, analyses of the data that have been made publicly available.

Biomonitoring data were initially collated by the MRCS from the various specialists responsible for work on particular indicators. The results were interpreted by the team, and the interpretations, and raw data, were published by the MRC. However, in recent years, with the monitoring being conducted by national teams, the system has no longer been functioning as efficiently, and fewer reports have been released and delays in publishing have grown longer. Here again data are collated centrally by MRCS and reports drafted.

Data collection for fisheries largely falls under the FADM programme and supplementary larval drift studies, although considerable data are collected in individual countries as part of routine agency activities. The procedures for data collection by individual fishers, collation of data and data storage are well described by MRC (2018b). The procedures described are standard methodologies and well suited to the JEM programme, as confirmed by the pilot studies. Perhaps where the procedure falls short is collection of individual fish ecological parameters (other than length), such as maturity (linked to reproductive strategies – migration and breeding cycles) and health status (parasite, disease and general condition of the fish), which are important parameters for understanding population wellbeing, but this was not considered during the JEM pilots. Simple methodologies are available to assess these characteristics and it is recommended that mechanisms to include these parameters in the data collection (and analysis) procedures are explored, recognizing the additional cost of inclusion of such activities. Each country provides an overview of the results and trends in data, and MRCS compiles a consolidated report. Data are stored centrally in the MRC fisheries database.

There is little attempt to interpret the data in the wider context of what is happening in the LMB in terms of exploitation pressures on fisheries in each region or other external development activities. Much more can be made of the data, but this is very much constrained by the sampling protocol, limited resources to collect robust data, reporting structure and perhaps skills to analyse outputs in relation to environmental data available from MRC or government agencies. There is a clear need to make greater use of the data and information collected through robust statistical procedures where the fisheries and ecological data are related to drivers of change, especially environmental variables and anthropogenic modification of the ecosystem functioning.

After all sample processing is completed two types of checks are carried out. An expert taxonomist checks a summary of species at each location (from databases) against the photo set from the field sampling. The taxonomist signs-off on the field data sheet and in the database. The final computerised data are cross-checked against the contents of the field sheet in terms of data recorded. The data are also checked against the historical data for the location and if any major changes are evident.

3.3 Data quality assurance and quality control [QA/QC]

Data quality assurance and quality control [QA/QC] are essential components of any monitoring and evaluation programme. ISH11 suggested that the EHM data collected by MRC are largely appropriately stored but there is limited quality control. This is particularly true for Water Quality, Aquatic Ecology and Fisheries.

QA/QC of hydrological instruments is mostly covered by the Standard Operation Procedures, which provide in routine checks and update of the sensors and readings (Vol 2, Annex 1-4), and the HYCOS database system has integrated Quality Control procedures. The biggest problem arises because there are currently no standards for data exchange formats for hydrological data, and there is need to upgrade data management procedures to overcome this issue.

The QA/QC system developed for the sediment monitoring programme (DSMP) includes a review and verification of the collected monitoring results by each MC, before the results are reported to the MRC on standardised forms. QA/QC of data thereafter has been limited to a periodic review by an external consultant.

Water Quality Data Collection and Management currently requires the national laboratories to forward data collected for the WQN to MRCS annually, where it is added to the MRCS water quality database, and later made available to the member countries and to other organisations or individuals on request. The MRCS database has also been used by the MRCS to produce periodic reports on water quality trends in the basin, and to contribute to State of the Basin reports. The system appears to be functioning satisfactorily and should be continued. Data collected though the JEM should be added to the MRCS database. The spreadsheets used to tabulate the data include quality assurance functions, such as ion balances, to check that data are reliable. It would be appropriate to include data collected through JEM procedures in the MRC database.

There has been concern about consistency in the taxonomic identification of the invertebrates collected for ecological health monitoring. Initially a regional expert for each indicator group did the identifications from all four countries, but that is now conducted in each country separately. It has been suggested that MRC could initiate annual workshops for each indicator group to ensure consistency. ISH11 suggested that the ecological health monitoring data collected by MRC are largely appropriately stored but there is limited quality control. Data are stored using EXCEL spreadsheets and there is currently a project under way to update the format to make it more user friendly for those who may want to undertake analysis. There is some concern about lack of consistency in use of taxonomic names within the database and that data such as river condition and water quality data collected at the same time as the biological sampling is not incorporated into the database. It should also be possible to structure the database so that the indices, such as the ATSPT, are automatically calculated, but this is not the case at present. There is also some concern that indices may not necessarily be being calculated identically between the four national programmes. It is recommended to have an appropriate consultant work with the database managers to upgrade the system, and automate index calculation as far as possible. Data availability is adequate, data can be accessed without charge as long as those making the request obtain a Data License Agreement from MRC. Data collected through the JEM should be added to this MRCS system.

QA/QC procedures for fisheries are largely undertaken by cleaning data submitted to the MRC by MCs under the FADM protocols. QC procedures using involve checking for errors in species abundance records but this is not automated in the MRC fisheries database, which should be upgraded to improve these procedures, an issue also raised during the JEM pilots. Concerns have been expressed over the misidentification of species and problems of changing taxonomic nomenclature, again an issue also raised during the JEM pilots. It is recommended that all users access and make use of the MRC fish species database, which also holds considerable information on the basic ecology of the species and their guild categorisation. Improved procedures for QA/QC are required for fisheries data, if information is to be collated from diverse monitoring programmes, and consequently investment is required in the development of the MRC Fisheries Database.

As part of the process for preparing and enhancing the quality data for users, it is important to install a Quality Management System (QMS): an overarching set of operating procedures that control the data production process to ensure the data are of consistent and known quality, which includes the following components (ISH11).

- A set of established standards for data collection such that results are reliable, reproducible and allow results obtained by different groups or agencies to be integrated or compared;
- A data management system incorporating QA/QC measures such that reliable results can be provided to data users within an appropriate time frame;
- A long-term reliable storage and retrieval system such that the information can be maintained for ongoing or future use; and
- A validation system that ensures data being produced and distributed are serving the needs of end users.

In the context of the LMB, this Quality Management System needs to ensure that accurate results are available at 'real time' for flood forecasting, water use and navigation needs or in a timely manner for ecological and fisheries data. The system also needs to allow the storage and retrieval of long-term results including relevant meta-data.

In general it can be said that Information management should be driven by the needs of information users and QA/QC requirements. Systems and processes should ensure timely and complete data availability for the identified uses, with relevant meta-data included, such that the data set can be located and used well into the future.

The following considerations are important for information management when thinking about LMB hydropower-related or development-related information:

1. Data storage and retrieval of data sets relevant to water resource issues should be centralised and readily accessible;
2. Quality Assurance and Quality Control (QA/QC) procedures should be applied at multiple steps to ensure confidence in all data, including field and laboratory audits, capacity-building events, and inter-lab comparisons;
3. Implementation responsibilities for data collection, storage and management should be clear amongst all parties and documented, such as through the development of Standard Operating Procedures (SOP) and Work Instructions (WI);
4. International or regionally-accepted standards are useful to ensure common understanding of expectations (e.g. for specific sampling methods, and for quality management systems), and can be incorporated into SOPs or WIs; and
5. Monitoring programmes should be periodically reviewed to ensure efficiencies, valuable and significant contribution to objectives.

To facilitate the QA/QC procedures, capacity building workshops are required to ensure each MC is able to implement the established and accepted methods.

During the JEM pilots, the implementation of monitoring was delayed due to Covid constraints, and many monitoring results were not submitted to the MRC until the final month or two of the pilots. During the final consultations, the results were presented and discussed, and the countries had an opportunity to interrogate and analyse the results, but there remained insufficient time to conduct discipline specific workshops in data analysis and QA/QC.

3.4 Data sharing

For the JEM to be a success as a regional monitoring programme, the quality of information from the MRC and stakeholders must be reliable, continuous and available in a timely manner. The development of a robust and reliable MRC data management system should be a high priority for the organisation, as it is critical to the development of joint monitoring, and for understanding the changes that are rapidly occurring in this river basin.

To achieve this, all stakeholders should both provide and have access to data sources, but at the same time recognise the confidentiality of some financial information. Critical to successful implementation of data management systems are standardised sampling procedures, and transparent data sharing protocols. MRC has a central role in compiling data submitted by national partners and synchronise them into a regional database for regional sharing. Each institution participating in the monitoring programme should agreed to share their data by uploading through a centralised system by a specific time each year, nominally October.

To aid this procedure requires a robust and centralised data storage and manipulation system. The MRC is currently developing such a system (Figure 3-2) and it is recommended that collaborative agreements and protocols for sharing and accessing data be established to facilitate data management procedures.

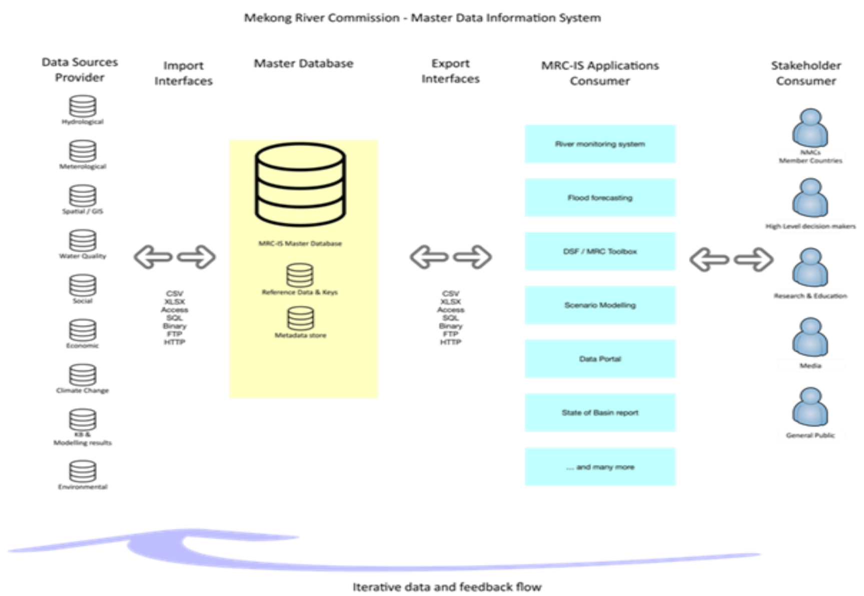

Figure 3-2. Data flow for centralized database of MRCS

Throughout the EIA process, data are collected by different stakeholders at different stages of the development (including the design, pre-construction, construction and post construction phases) and assessment period (Figure 3-3). Initially, MRC and agency monitoring, and developer and agency targeted study, data should form the basis of assessment. These data must be adequate to inform the EIA, and thus must be collected to international standards. Critical at this stage is the developer supplementing existing MRC and line agency data to fill gaps in understanding of the environmental as well as ecological parameters. These data will establish the baseline conditions and inform project design and evaluation (PNPCA procedure & DG2018), thus surveys to be carried out by the developer should be appropriate to inform the EIA process. Data should continue to be collected throughout the project feasibility and design periods and during the construction and operational phases following the standardised procedures for each discipline. This collection is in line with the DG2018 procedures, such that these data should be at both the basin scale (mostly by MRC) and more locally by the developer / operator and should be used to support identification of appropriate mitigation measures and adaptive management processes should problems arise.

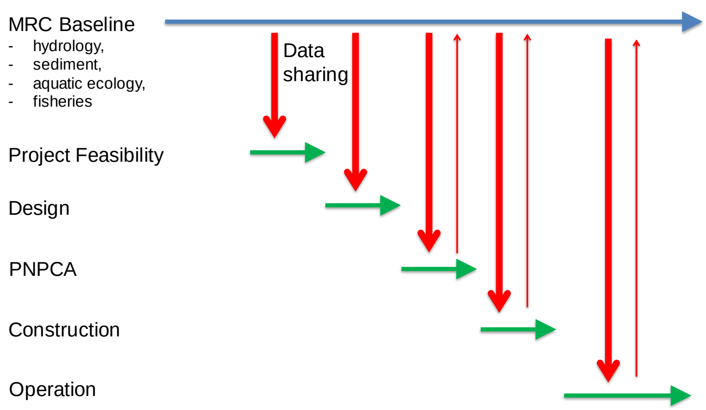

Figure 3-3. Data sharing timeline. Green arrows show the different development phases and thick red arrows show the flow of information from the MRC to the development. Thin red lines show the flow of information from the developer back to the MRC and MCs.

Critical to this procedure is sharing of monitoring data to benefit all those involved in the hydropower development, from regulators to developers and reviewers, to reduce risks arising from weak and inadequate information. Mechanisms should be put into place to enable sharing of monitoring and assessment data in a transparent and mutually beneficial manner. Currently data are collected by the different agencies and developers and there is no mechanism of drawing all the data together in one centralised data storage system. As suggested above MRC, should act as the central repository of the data and the focal point for open access to such data.

MRC's role in data management should not be simply a data centre but also include data cleaning, implementation of QA/QC procedures and provision of summary reporting. The development of a robust and reliable MRC data management system should be a high priority for the organisation, as it is critical to the development of joint monitoring, and for understanding the changes that are rapidly occurring in this river basin.

Considerable investment will be required to achieve this endpoint both for database development but also to provide suitable QA/QC procedures as well as reporting outputs. It should be noted that as data will be compiled from public and privately funded sources, no restrictions should be placed on access to such information unless it is commercially sensitive. Consequently, access should be through an open portal with no restrictions on usage other than acknowledgement of the source, and perhaps approval of the final outputs. It is, however, recommended that a user validation and registration are implemented to ensure security of information and correct use. These issues are being considered in the development of the CRMN.

Further, it is recommended that a high-level forum of developers, line agencies and experts is convened on an annual basis to discuss and review the data collected and interpretation of the outputs. In addition, any improvements in the monitoring procedures can be discussed and adopted as appropriate. The forum should facilitate transfer of information and allow the opportunity of interactive discussion of outputs to reduce ambiguity of interpretation and enable exchange of knowledge and skills. It is recommended that this annual workshop is facilitated by an external international coordinator to allow impartiality and produce reports adopted by all parties.

4 HYDROLOGY AND HYDRAULICS

4.1 Introduction and background

The development of hydrologic monitoring for JEM was based on a review of the existing monitoring systems (HYCOS, DSM) and identification of information gaps that needed to be addressed to provide an understanding of how operations at Xayaburi and Don Sahong have affected river flow. The hydrologic monitoring design was consistent with the overall JEM design. Existing HYCOS and DSM sites were identified that provided the larger scale, regional context for the project, with additional sites added to provide more local information about impacts to the flow regime. The potential impacts identified through the ISH11 and Mekong Hydropower Mitigation Guideline projects were used to refine the monitoring strategy, with the focus on changes to the frequency, rate and range of water level changes. Details of the initial monitoring design are presented in the PILOT proposals, and details of the findings are summarised in MRC 2021a and MRC 2021b. The following sub-sections provide a brief summary of the monitoring completed at each site, the findings, and the recommendations arising from the Pilot Projects.

4.1.1 JEM monitoring at Xayaburi

New hydrologic monitoring sites were established in the Mekong mainstream upstream and downstream of Xayaburi (Figure 4-1). Upstream of the impoundment, a new manual hydrology site was constructed a Ban Xang Hai, where the water level was recorded twice per day, providing general information about water level changes prior to the water entering the impoundment. It was established as a manual site as there was concern that the site might be affected by backwater from the Xayaburi impoundment. Four km downstream of the Xayaburi dam, a new HYCOS site was established at Ban Pakhoung with continuous monitoring of water level and rainfall. At both sites, discharge was measured using ADCP at a frequency of weekly (wet season) to monthly (dry season), however, the monitoring frequency was affected by Covid restrictions, and few wet season measurements were able to be completed. The long-term results from the DSM and HYCOS sites of Chiang Saen (upstream) and Chiang Khan (downstream) were used to provide a regional context for the monitoring results collected at the new sites.

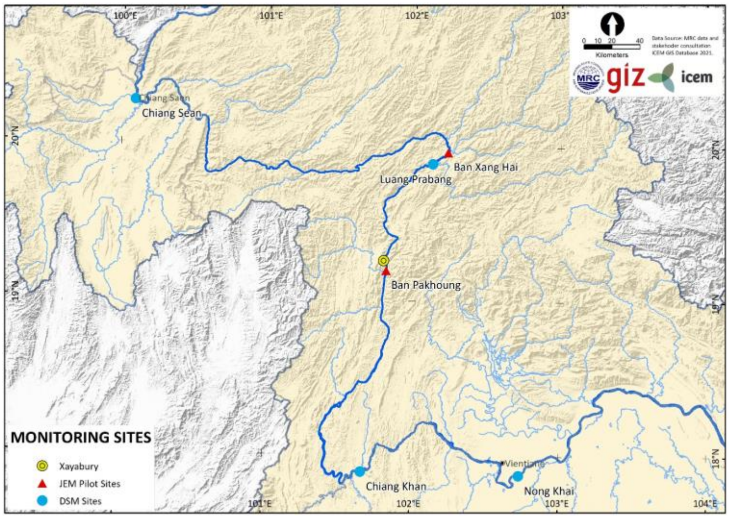

Figure 4-1. Monitoring sites included in the JEM Pilot at Xayaburi.

4.1.2 JEM monitoring at Don Sahong

Hydrologic monitoring at Don Sahong could not be implemented at sites immediately upstream and downstream of the Don Sahong hydropower project due to the river flowing through multiple channels in the region creating a highly complex flow regime. Instead, large scale hydrologic impacts were monitored through comparison of flow at the long-term site of Pakse, and a new downstream site at Koh Key in Cambodia (Figure 4-2). The Koh Key site provides information about flow in the Mekong River upstream of the confluence with the large 3S catchment. When results from Koh Key are compared with information from the existing HYCOS monitoring site downstream of the confluence at Stung Treng, the results also provided insights about flow patterns in the 3S system, which are also affected by hydropower. In the last few months of the JEM pilot, a combined water level and water quality station was installed near the Don Sahong tailrace, that provided additional detail about the impact of hydropower operations on the water level within one channel of the river. The operators of Don Sahong also provided information about flow rates through the project, and water level and flow in several of the channels in the area.

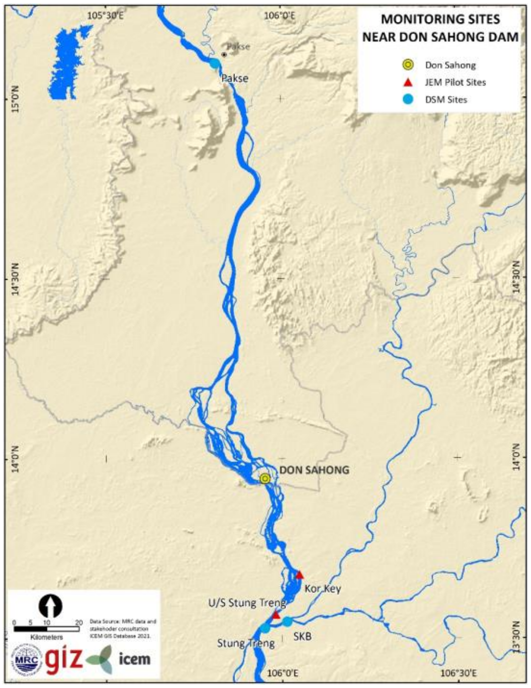

Figure 4-2. Monitoring sites included in the Don Sahong JEM Pilot.

4.2 JEM Pilots' key findings and recommendations

Hydrologic monitoring during the JEM pilot at Xayaburi found the following:

- Water level fluctuations in the river upstream of the impoundment generally paralleled that at Chiang Saen, however on occasion, there were additional flow peaks attributable to tributary inputs, most notably inflow from the Nam Ou, which is also managed for hydropower production.
- The backwater from the Xayaburi impoundment generally extends to Luang Prabang, resulting in an increase in dry season water levels of approximately 5 m compared to historical results.
- Downstream of Xayaburi, rapid and frequent water level changes regularly occurred under a wide range of flow rates, with flow changes commonly exceeding the MRC Hydropower Mitigation Guideline of 0.05m/hr (MRC 2021). The fluctuations were recorded at Ban Pakhoung, 4 km downstream of the impoundment, but not at the Thai border at Chiang Khan, approximately 200 km downstream (Figure 4-3). The observed water level changes are consistent with the fluctuating hourly flow data provided by the Xayaburi operator. The water level fluctuations have been qualitatively linked to changes in the macro invertebrate composition of the Mekong downstream of the dam.

Figure 4-3. Water level at Ban Pakhoung (blue) and Chiang Khan (green). Both sites are based on 15-minute HYCOS results. Data from MRC data portal. (Figure from MRC 2021b)

Findings from the JEM Don Sahong Pilot found the following:

- The water level at Pakse is affected by the operation of hydropower projects in tributaries, resulting in small (generally <5 cm) and frequent (daily to sub-daily) water level fluctuations. These fluctuations would not be expected to have an impact on the Mekong mainstream but may impact tributaries where the fluctuations would be larger.
- The operation of Don Sahong locally affects water level in the tailrace channel during periods of low flow but not at high flow, when backwater from the Mekong controls the level of the river. Water level fluctuations at the downstream site of Koh Key linked to the operation of Don Sahong were small (<5 cm) and infrequent during the Pilot study period.
- Hydropower operations in the 3S catchment generate water level fluctuations in the tributary that persist in the Mekong mainstream at the Stung Treng HYCOS site. The resultant fluctuations in the Mekong are small, and unlikely to have a substantial ecological or geomorphic impact on the Mekong mainstream but may impact tributaries where the fluctuations would be larger.
- Based on hydrologic information provided by the Don Sahong operator, the diversion of water into the hydropower station during the dry season is higher than proposed during the PNPCA process, and has resulted in lower water levels than designed in fish pass channels, and the minimum flow of 800 m^3/s through the Phapheng falls is not being regularly achieved.

Recommendations for future hydrological monitoring and management of hydropower operations arising from the JEM Pilot studies include:

- **Sufficient monitoring period to capture the range of flow rates.** As described in Section 2.4, JEM monitoring is proposed to begin during the PNPCA process and extend over the life-cycle of the hydropower scheme. This is an ideal scenario and may not be practical for every hydropower project. If monitoring can only be completed for a short period, then all effort should be made to ensure that monitoring captures an entire wet and dry season, and preferably several of each season. Covid 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. Because most 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.

- **Installation of new HYCOS sites prior to initiation of JEM monitoring.** Similar to the previous recommendation, if the period for monitoring is limited, all new field HYCOS stations should be fully installed prior to the commencement of monitoring, to maximise the period of recorded water level, and to maximise the usefulness of discharge measurements for deriving rating curves.
- **Develop site specific water level fluctuation guidelines for hydropower projects.** The potential impact of water level fluctuations will vary depending on the size and frequency of the fluctuations, the flow in the river and the location of the hydropower project. Site specific guidelines for hydropower projects should be developed in consultation with developers to minimise potential downstream and transboundary impacts.
- **Upgrade all sites to ADCP for discharge measurements**. Interpreting JEM monitoring results requires understanding the hydrology at a regional and basin level. Upgrading all of the existing DSM sites to ADCP for discharge measurements would improve the quality of discharge results throughout the basin and enable better analysis of JEM results at a local level.
- **Collaborate with hydropower developers.** The sharing of hydrologic information between the MRC and hydropower developers will enhance the understanding of both parties about the potential impacts of operations on the flow regime of the Mekong.

4.3 JEM Monitoring Design

This section summarises the recommended hydrologic monitoring approach for future JEM monitoring. It draws upon the in-depth gap analysis and discussions presented in JEM Programme V4, and incorporates the recommendations arising from the JEM Pilot projects.

4.3.1 Monitoring overview

Monitoring for hydrology and hydraulics within JEM informs the basin-scale assessments related to hydropower development and operation. The cumulative effect of the various dams on the mainstream and tributaries of the Mekong have already had an impact on the transfer of water from rainfall in the catchment towards the flow in the Mekong River along its entire length.

This section refers to both hydrology and hydraulics to distinguish between the water source and distribution, and the way it moves through the rivers and dam projects. More specifically:

- Hydrology refers to the properties, distribution and circulation of water in the atmosphere and on land. It concerns the amount of water (volume) that reaches the project from runoff processes, and that is transferred through the project.
- Hydraulics refers to the details of the motion of water and its practical applications. Hydraulics concerns water depths, velocities, turbulence, the transfer of flood waves, and other flow properties in rivers and impoundments.

Both hydrology and hydraulics are important drivers for the other themes in JEM relating to changes due to hydropower developments. Alterations in flows can translate into physical and biological changes (Figure 2-1). These changes occur at various spatial and temporal scales, and a wide range of indicators is connected to these. For example, seasonal-scale changes in the timing of start and duration of the flood season can significantly impact the migration and spawning of fishes in the Mekong. Therefore, it is relevant that the monitoring parameters and associated indicators address the core changes to hydrology and hydraulics that may trigger the topic-specific changes. Table 4-1 shows the direct impacts of hydropower development on hydrology and hydraulics in river functioning.

Table 4-1. Monitoring requirements to assess potential risks to hydrology and hydraulics associated with mainstream dams

Risk	Consequences	Monitoring required
Annual / inter-annual changes to flow		
Changes in seasonality & continuous uniform release	Change of timing & duration of floods and low flows, changes in flows Tonle Sap and changes in salt intrusion in the delta	• Water levels • Discharges
Modification of flood intervals: Reduction in occurrence of minor floods & no change in large events	Peaks in flood and low flow change, smoother hydrograph	• Water levels • Discharges
Daily / short-time period changes in flow		
Water level fluctuations due to operations	Safety and navigation related changes caused by sudden rise or drop of water levels	• Water levels • Discharges

Hydrologic monitoring systems needs the components listed on the left of Table 4-2 to address the criteria listed on the right in the table. Using this approach and adopting Standard Operating Procedures ensures similar information is collected at the large scale and at the local hydropower project scale. The same information underpins hydrologic modelling and flood and drought forecasting. In this context, it is imperative that JEM monitoring uses consistent approaches and methodologies as the ongoing HYCOS and DSM monitoring networks. Although the JEM specifically focuses on mainstream dams in the Mekong, the monitoring protocols are also applicable to tributary dams

Table 4-2. Criteria for effective monitoring, and the required monitoring elements for implementation.

Monitoring Criteria	Requirements for effective and efficient discharge and sediment monitoring
Locations: • Cover Mekong hydro-ecological zones • Position to provide relevant information regarding HPPs • Continuation of long-term data sets • Enable understanding of mainstream and transboundary issues • Positioned above flood level • Easily accessible for maintenance	• Monitoring needs to include both the major tributary systems and catchments, as well as covering the full mainstream Mekong River • Sites need to be located in the vicinity of national boundaries • Sites need to be located where scale flow changes of HPP or other developments are relevant and identifiable (also in relation to other themes)
Parameters: • Indicators relevant to HPP planning and management • Can be replicated across the basin	• Parameters for meteorology include rainfall, temperature, relative humidity, evaporation and wind speed/direction. Parameters for hydrology include water levels, and discharge. Also additional data, such as water depth, flow

• Cost effective methods • Should be able to predict as well as explain change	velocities, and soil moisture are needed for the assessment of changes related to link these data to other disciplines. • River discharge requires cross-sectional data collection (including velocities), and should preferably be combined with sediment-load observations (see next chapter). • Instrumentation and methods should be uniform across the basin for consistency, capacity, and exchangeability.
Timing of data collection • Length of monitoring covers cycles of natural variability • Frequency of monitoring captures seasonal cycles and operational changes	• As already commonly applied in the Mekong, the frequency of recording and storing hydrology data is higher in the wet season than in the dry season. For automated stations, the frequency is the same for all seasons. • Discharge and sediment measurements should be carried out simultaneously at the respective locations. • All efforts need to be taken to keep the stations in operation and provide sufficient resources for maintenance and update of the equipment and the rating curves. It should guarantee a consistent and long-term data series (without breaks) for further assessments. • Monitoring frequency should be high enough to identify the flow changes that are related to HPP operation. Most of the automated HYCOS telemetry stations allow recording frequencies of 15 minutes, which is considered appropriate for JEM.
Information Management and Uses • Information is readily available for users • Information is linked to tools that can support decision-support and analysis	• Monitoring results are reported in suitable formats that can be easily imported into the MRC data bases. The new MRC database structure allows input for a wide range of formats. • Relevant methods and techniques for identifying flow changes due to hydropower or water-supply developments should be defined, and shared with the users of the data.

4.3.2 Monitoring Locations/sites

As shown schematically in Figure 2-5, the regional hydrology of the Mekong is monitored through the existing HYCOS and DSM network. Monitoring locations for JEM need to be identified within the context of this network, with the usefulness of the existing sites maximised where ever possible. The location of upstream and downstream hydropower projects and how they affect the inflow or interact with the outflow of the hydropower project under investigation must also be considered. The following need to be considered on a site specific basis for each hydropower project to be monitored.

- Is there an existing site upstream of the proposed (or existing) HPP that is suitable for understanding the hydrology and hydraulics of the river upstream of the backwater of the proposed impoundment?
- Is there an existing downstream site that can capture the near-field changes to water level and flow due to the operation of the power station?

- Are there significant tributary inflows that will affect the inflows and /or outflows from the hydropower project, and is there a need to establish hydrologic monitoring in these rivers?
- Is it necessary to monitor the hydraulic changes associated with impounding the river, such as increases in water level or decrease in water velocity?
- Is there an existing far-field HYCOS site that can capture the net changes to the hydrology of the river. These far-field sites should include consideration of transboundary locations.

Within this context, the location of existing HYCOS stations should be identified, and additional sites should be established where required. Ideally, sharing information with hydropower developers could reduce the need to establish new sites. However, for the foreseeable future, until data sharing agreements are established and functioning between the MRC and private parties, it is recommended that the MRC maintain a hydrologic monitoring network that can provide the required level of information to understand hydropower impacts. Section 4.7.2 provides specific recommendations for hydrologic monitoring associated with the proposed future hydropower developments in the LMB.

As recommended by the JEM Pilot studies, HYCOS monitoring sites should be established prior to the initiation of discharge monitoring to maximise the use of the discharge measurements in deriving rating curves for the new sites.

4.3.3 Hydrologic and hydraulic monitoring parameters

In general, hydrologic and hydraulic monitoring parameters should meet the following criteria:

1. provide inputs to indicators related to hydropower planning and management, and relevant to the different topics (sediment, fish, aquatic ecology, water quality);
2. able to be replicated across the basin;
3. able to be measured and analysed at a low cost;
4. able to help predict as well as explain cause and effect of changes;
5. data collection and analysis methods should be consistent and comparable over time and between locations;
6. consistency in terminology around parameters and indicators is helpful towards achieving a common understanding.

The most relevant monitoring parameters for hydrology and hydraulics are listed below. Detailed descriptions of the methodology used as the basis for the Standard Operating Procedures by the MRC are contained in Vol. 2, Annexes 1-4.

- River level monitoring: River level monitoring at each of the HYCOS sites is completed following best practice international standards, appropriate for the local conditions. The river level is measured using either a shaft encoder, bubble level recorder, or a radar level sensor.
- Discharge and velocity monitoring :
    1. Flow velocity is measured using either current meters or Acoustic Doppler Current Profilers (ADCPs). In the LMB, these measurements are made by boat based teams with the boat held in position by the coxswain.
    2. Discharge is monitored according to a standard procedure based on a combination of velocity and depth measurements in combination with the cross-sectional area. Over time,

the discharge measurements and river water level at the time of discharge measurement can be used to derive a rating curve (stage-discharge relation) for the station. Discharge measurements also provide information about the channel width, distribution of flow across the channel and bathymetry of the channel.

- Rainfall: Measured at many of the HYCOS sites and at many dedicated rainfall stations throughout the LMB using tipping bucket rain gauges. The quantity and intensity of rainfall throughout the catchment provide information for hydropower development and management, flood forecasting and drought management. Understanding rainfall patterns is also important for identifying potential climate change impacts.

- Additional meteorological data that are measured at a limited number of HYCOS meteorological stations: air temperature, relative humidity, wind speed, wind direction, evaporation, sunshine hour, solar radiation, air pressure.

4.3.4 Monitoring timing and frequency

As discussed in Section 2.4, JEM monitoring should ideally commence at the initiation of the PNPCA process, when the nominating country notifies the MRC, and should extend through the life of the hydropower project. If long-term monitoring is not possible, and monitoring is restricted to a period of hydropower operations, then monitoring should include at least one full wet and dry season, and preferably several annual cycles.

The recommended monitoring frequency for hydrologic and hydraulic parameters is summarised in Table 4-3. In general, water level and rainfall are recommended to be recorded continuously, with the frequency of discharge measurements to reflect the seasonal flow regime of the river. A high frequency of river level monitoring is warranted due to the rapid changes that can occur downstream of hydropower projects associated with the switching on and off of turbines. The Xayaburi JEM Pilot has clearly shown that run-of-river hydropower stations can cause large and frequent water level changes downstream under a wide range of flow conditions.

Table 4-3. Recommended monitoring frequency for hydrologic and hydraulic parameters for JEM.

Parameter	Frequency / timing	Comment
Automatic Water Level (m)	Recorded and transmitted at 15-minute intervals at HYCOS sites throughout the year	Required to understand flow changes downstream of hydropower station associated with the operation of individual turbines. Consistent with existing HYCOS network
Manual Water Level (m)	Generally twice per day in the mainstream Mekong throughout the year	Provide back up for HYCOS automated system May be suitable to understand flows upstream of hydropower impoundments or tributary inflows

Parameter	Frequency / timing	Comment
Automatic Rainfall	Recorded and transmitted at 15-minute intervals at HYCOS sites	Not directly used in JEM monitoring, but relevant to understanding large scale flow changes due to basin-wide hydropower development. Also relevant to hydropower planning and management
Discharge (including channel width, channel area and average flow velocity)	24/year (minimum, with 30 measurements per year preferable)– the frequency should be higher (weekly) during the wet season and less frequent (monthly) during the dry season.	JEM monitoring Should be consistent with DSM monitoring frequency
Bathymetric cross-sections	2/year	Used to track the stability of the river channel. A stable river channel is required for establishing a reliable water level – discharge relationship (rating curve)

Details of the protocols for the recording and transmission of hydrologic measurements from the MCs to the MRC are provided in Vol 2Annex 12.

4.4 JEM's Monitoring Protocols

The protocols for JEM hydrologic and hydraulic monitoring are the same as those adopted for the HYCOS network and the DSM discharge measurements, and the details are provided in Vol. 2 Annexes 5-10. This section provides a brief overview.

4.4.1 Field data collection

The continuous recording water level and rainfall gauges for JEM should form part of the HYCOS network, as was implemented during the JEM Pilot studies, with the telemetered data sent to the MRC via the established protocols. Water level measurements at HYCOS sites are also collected manually with the gauge read twice per day. These measurements should be recorded in the MRC-WL form.

The establishment of new HYCOS sites for future JEM monitoring should include sufficient field-based capacity building for the hydrologic teams from the local agencies to ensure that the site is properly calibrated and maintained. Ideally, each time the DSM team completes discharge measurements, a comparison of the water level as recorded on the physical gauge board at the site, and reported as part of the discharge measurement, should be compared with the automatically recorded level. If adjustments are required, they should be made according to the established HYCOS protocol, with all changes recorded by the local line agency and reported to the MRC.

Discharge measurements at the site should be completed as required under the DSM using an ADCP, and include the following steps:

- Reading of the river level at the gauge board prior to commencement of the discharge measurement
- Completion of an ADCP moving bed test to ascertain whether the bed is moving and a post-measurement correction will be required
- Collection of at least 4 ADCP discharge measurements, completed as the boat moves slowly (at a rate lower than the rate of the river flow) from one shore to the opposite point. All measurements should be made at the same transect throughout the year to allow the bathymetric profiles to be compared and analysed for changes to the river bed
- In field checking of the ADCP measurements to ensure that four measurements have been collected with a difference in the discharge of <5%. Downstream of operating power stations this may not be achievable due to rapid changes in flow associated with turbine operation. If a <5% difference in discharge results cannot be achieved, the water level gauge should be re-read to determine if the water level has changed substantially during the measurement. If so, this should be noted and the discharge measurements should be reported as recorded
- A final recording of the river level gauge.

Following the field monitoring campaign, the discharge results should be checked as described in the following section.

Surveyed cross-sections of the river channel are to be completed twice each year, once in the dry season and once in the wet season. These surveys are required to determine whether the channel is stable, which is a pre-requisite for the establishment of an accurate rating curve. The survey procedure is described in detail in Vol 2 Annex 4. In summary, an ADCP and GPS should be used to collect multiple transects along the reference cross-section of the inundated portion of the channel, and standard topographic surveying methods should be used to survey the exposed river banks up to the established local vertical datum. The two survey data sets should be combined and plotted to provide a cross-section of the river, with the water level on the day of surveying indicated. The horizontal distance between points should be as small as practical (e.g. <10 m).

The river cross-section should be plotted as a line or point chart in Excel and submitted to the MRCS along with the distance *vs* elevation data in electronic format in Form MRC-Q7.

4.4.2 Data reporting and QA/QC

The telemetered and manually recorded water level results should be checked by the national line agency, with the manual results used to adjust the automatic recorder when required. Large discrepancies between the morning and evening manual readings should be investigated. Field based QA/QC should include multiple members of the hydrographic team reading the water level gauge independently and comparing results.

The ADCP discharge measurement files should be post-processes by the line agency, including the application of the moving bed correction if required. Once checked and confirmed at the national level, all information should be entered into the MRC-Q2 form (Discharge Measurement Field Data Sheet – ADCP) and reported to the MRC within the agreed timeframe.

The MRC should complete a final QA/QC of the results by comparing discharge measurements and corresponding water levels to established rating relationships. The in-built capacity of the Aquarius hydrologic database to track changes in rating curves should be used to complete these QA/QC measures.

The results of surveyed cross-sections should be plotted by the line agencies, and compared to previous surveys. Any changes should be noted and communicated to the MRC. Upon receipt of the surveyed cross-sections, the MRC should identify any changes at the site and review the water level/discharge relationship to determine whether the rating may need to be revised.

4.5 JEM Data Analysis

The hydrologic and hydraulic data generated through JEM monitoring should be integrated with the large scale HYCOS and DSM network, and analysed at the basin-scale to understand regional changes and trends and the local scale to identify impacts associated with hydropower development and operation.

4.5.1 Basin-scale analysis

Information uses of hydrologic and hydraulic monitoring results related to developments (e.g. hydropower, irrigation) may include trend analysis, prediction, forecasting, mitigation design, management planning, design of ongoing monitoring regimes, support for consultation processes, analysis of changes and attribution of influence and implications, integration with local-scale information and considerations, and informing decisions to proceed or not with hydropower or other developments.

Basin-scale analysis of hydrologic data includes the derivation of indicators that quantify the hydrologic characteristics of each site and when combined provide a large scale, long-term understanding of the river system. These indicators describe fundamental components of the flow regime, such as the magnitude of flow, the frequency of flows, the duration of flows, the timing and seasonality of flow and rates of flow change. These types of indicators include, *inter alia*:

- Total annual flow at each monitoring site
- Total and average monthly flow at each monitoring site
- Minimum and maximum daily flow on a monthly, seasonal or annual basis
- Minimum and maximum 5-day flow on an annual basis
- Daily or hourly rates of change
- Annual and seasonal flow duration curves

Basin-scale analysis may also require understanding the impact of flow regulation in upstream tributaries. For example, the inflow to Xayaburi is affected by the operations of the hydropower cascade in the Nam Ou catchment, and to a lesser extent by the operation of hydropower projects in the upstream tributaries of Nam Tha and Nam Beng in Lao PDR, and other tributaries in Myanmar (as well as the Lancang cascade on the mainstream Mekong). Understanding how operations at these upstream projects affect inflows should contribute to the basin-wide assessment.

Examples of basin-scale hydrologic analysis are shown in Figure 4-4, where the daily flow for long-term monitoring sites from Chiang Saen to Stung Treng is shown for the JEM monitoring period, and for the six years between July 2015 and July 2021. This type of analysis provides an understanding of how flow rates vary downstream in the river, and over time, and provides the large scale context within which local analyses must be interpreted.

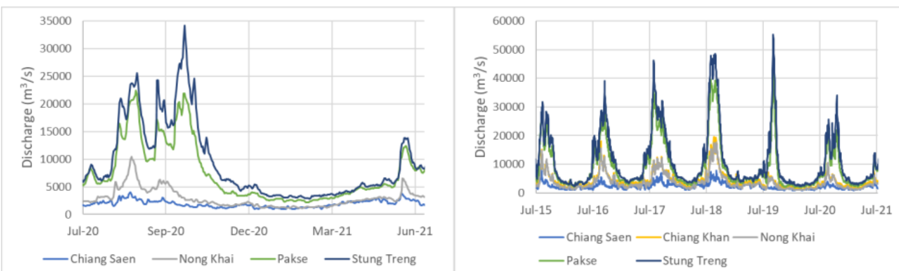

Figure 4-4. Average daily discharge at monitoring sites in the LMB (left) flow during the JEM Pilot period of July 2020 – July 2021 and (right) flow over the period 2015 to 2021. Data from MRC.

Hydrologic analysis at the basin scale is also important for interpreting results from other monitoring disciplines. For example, the low flow rates in 2019 and 2020 in the Mekong are likely one of the drivers behind reduced SSC loads in the river during those years, due to low inflows delivering low sediment loads (Figure 4-5). Similarly, low annual flows will affect the timing and extent of floodplain inundation and the extent of filling of the Tonle Sap that will affect the ecological productivity of the river system.

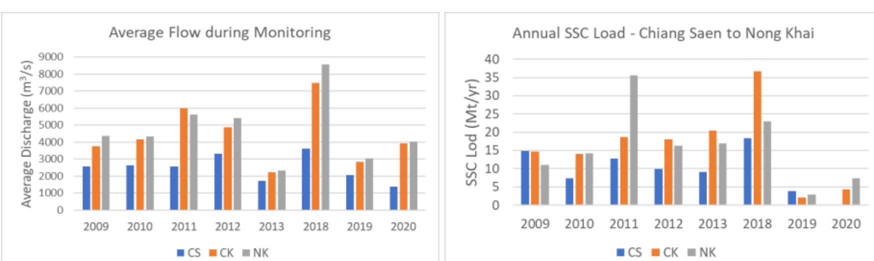

Figure 4-5. (left) average flow on DSM monitoring days at Chiang Saen (CS) Chiang Khan (CK) and Nong Khai (NK) for 2009 - 2020; (right) Annual SSC load at the same monitoring sites for the same years.

4.5.2 Impact analysis

A primary aim of JEM monitoring is to detect and quantify changes to the river due to the construction and operation of hydropower projects. Hydrologic analysis of monitoring results from the near field monitoring sites can provide information about the following potential changes:

- Extent of backwater, and changes to water level due to creation of the impoundment. Inundated areas near national borders should be a focus of investigations.
- Fluctuations in the water level within the impoundment, and how this affects the hydraulics of the backwater (e.g. promote sedimentation, prevent the transport of larvae, etc.)
- Water level fluctuations downstream of the impoundment, locally and more distally
- Changes to the flow regime due to the operation of individual turbines

To understand these changes, the following analyses are recommended:

- Comparison of inflows and outflows to the impoundment on a daily to weekly time-step, assuming all mainstream hydropower projects monitored under JEM are considered as run-of-river projects. If applied in tributaries, longer time-frames should be considered if the project has a significant storage capacity
- Changes to hourly water level, and comparison to the MRC Hydropower Mitigation Guideline of 0.05 m/hr as a general reference
- Comparison of water level fluctuations downstream of hydropower stations at near-field and regional downstream sites to determine the magnitude and extent of water level changes, and whether there are potential transboundary impacts
- Where specific minimum or environmental flow commitments have been made, the commitments should be compared to the recorded flow.

Other impact analyses are likely to be site specific, such as the impact of backwaters on high value tourist areas, rapids of cultural or ecological significance or wetland areas. In some cases, backwater impacts on tributaries flowing into impoundments can also have significant impacts and should be included in the analysis.

An example of this type of analysis is the quantification of hourly water level changes downstream of Xayaburi during the JEM pilot study. The results are summarised in Table 4-4 and demonstrate that for most months for which data are available, the 0.05 m/hr rate of water level change is exceeded about 20% of the time, with 10% of the occurrences associated with rising water levels and 10% with decreasing water levels. Analysis of water level changes at Chiang Khan, 200 km downstream, found the fluctuations did not persist downstream.

Table 4-4. Summary of hourly water level changes downstream of Xayaburi by month.

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

Month	n=	Max Change	90th Percentile	80th Percentile	Median	20th Percentile	10th Percentile	Max Decrease
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

4.6 JEM's Data Storage and Management

Hydrologic and hydraulic data collected through JEM should be stored in the same databases and managed similarly to the existing HYCOS and DSM data sets. HYCOS results are reported to the MRC by the MCs and stored on the Aquarius database. Water level and discharge (where available) results are made available via the MRC data portal (e.g. https://portal.mrcmekong.org/monitoring/river-monitoring-telemetry).

Discharge results collected through the DSM are also available on the data portal, following QA/QC of the results. The results from the surveyed cross-sections and other hydraulic parameters collected in the field (channel width, average velocity, channel cross-sectional area) are not routinely stored in a database. During the JEM Pilot study, a JEM DSM database was constructed, which contains these results for the sites relevant to the two Pilot studies. The expansion of this database to include the information collected at all DSM sites should be considered as part of the development of the CRMN. This information would be of use to other disciplines, especially EHM and fisheries, for understanding the hydraulic characteristics of the river (e.g. river flow, channel area, etc.) as well as the flow rate.

The DSM system for reporting field discharge results to the MRC is based on numerous excel spreadsheets that need to be manually collated and checked. This is a time-intensive and inefficient system, and during the development of the CRMN, this process should be reviewed and recommendations made for revision. The use of a web-based portal with inbuilt preliminary QA/QC functions for reporting of the information from the MCs to the MRC should be investigated.

4.7 Future JEM monitoring

Future monitoring under JEM includes additional monitoring at the sites established during the pilot studies at Xayaburi and Don Sahong, and future monitoring at hydropower projects that are not yet constructed. These are discussed in the following two sections.

4.7.1 Continuation of JEM monitoring at Xayaburi and Don Sahong HPPs

The JEM pilots have been completed, but the MCs and MRC have agreed that additional monitoring is warranted at the JEM sites established for Xayaburi and Don Sahong. This will extend the time-series of results collected at the sites and allow greater analysis, and is consistent with the JEM strategy of multi-year monitoring (ideally throughout the life of the project). The following is recommended for future JEM monitoring at the existing mainstream hydropower projects:

- **Continue monitoring for an additional 12 months at a minimum:** JEM monitoring should be continued for at least another 12-months, using the same monitoring schedule (sites, parameters, monitoring frequency) such that a complete wet and dry season can be captured by the monitoring. Covid 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. Longer time-series are required to allow development of rating curves at the new water level monitoring sites, confirm the preliminary results obtained during the JEM Pilot and to capture potential changes under a wider range of flow conditions.
- **Establish Ban Xang Hai as a permanent HYCOS site.** A new HYCOS site is required upstream of Luang Prabang as the existing Luang Prabang gauge is affected by the Xayaburi backwater and no longer an accurate gauge of flow in the river. The advantages of making this a permanent site include: the impact of the Xayaburi impoundment appears to be limited (although more analysis is required when more flow measurements are available), the site records the combined Mekong and Nam Ou flow , it is located near an important cultural and tourism area, and the site is in a river reach that will remain free-flowing following the development of the northern Lao PDR cascade. There have been challenges in getting a local person to read the manual gauge on a regular basis, so converting the site to an automatic water level recording HYCOS site will provide more consistent and reliable information (although manual readings should still be collected when possible).
- **Review the water level and discharge results from Luang Prabang** to evaluate whether there is value in maintaining this site as an indicator of water level near at the town (e.g. for flood forecasting and management). If the site is not useful, then it could be decommissioned.
- **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 the 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.
- **Continue to work with the operators of the hydropower projects to obtain monitoring results, and jointly analyse the combined results to develop an agreed understanding of how hydropower operations may be affecting the Mekong locally, and regionally**

4.7.2 JEM monitoring of hydrology, sediment and geomorphology at new HPPs

Figure 4-6 shows the Mekong River and the locations of existing and proposed mainstream dams, along with existing and proposed hydrology and sediment monitoring locations for future JEM monitoring. Table 4-6 provides more detail about each site, including the parameters to be implemented at the sites and how the timing and order of the development of the dams may impact on future monitoring. **Sediment transport and geomorphology monitoring is included in this section because the hydrology and sediment transport disciplines are strongly linked, and monitoring for both disciplines is completed by the same teams at the same sites and frequencies**. At each of the sites discussed, it is assumed that discharge and sediment transport monitoring would be implemented.

The maps in Figure 4-6 show monitoring sites that are relevant to future JEM monitoring at both a regional and local scale. The maps show three types of hydrological and sediment monitoring sites:

- Established HYCOS sites where WL is automatically recorded and transmitted to the MRC. It is recommended that these monitoring sites be maintained in the CRMN to provide long-term records of water level and flow changes in the river;
- Establish manual hydrologic monitoring sites. Water level at these sites is read manually several times per day. The locations of the sites are important for future JEM monitoring, but the sites would need to be upgraded to automatic water level recording sites to capture the water level changes associated with hydropower operations. The long-term records at the site would provide a useful baseline, so upgrading of these sites would be preferable as compared to establishing a new site;
- Recommended locations for new HYCOS sites. There are a few locations where changes associated with hydropower development and operations would not be adequately covered by existing HYCOS or manual hydrology sites, or where existing sites will be flooded out due to the creation of hydropower impoundments, and new sites in the region will need to be established.

More details about the recommended locations of regional and local hydrological and sediment monitoring sites, and comments regarding the establishment of the sites are presented in Table 4-6, which should be consulted when viewing the maps. The description of parameters recommended for inclusion in JEM monitoring is summarised in Table 4-5. The parameters are the same as those adopted for the JEM pilot studies at Xayaburi and Don Sahong. , and consistent with the ongoing DSM monitoring. All parameters should be implemented at all JEM sites where ever possible. Monitoring frequency at future JEM sites should match the DSM (future CRMN) monitoring frequency.

Table 4-5. Description of parameters and monitoring frequency recommended for inclusion in future JEM monitoring for hydrology, sediment transport and geomorphology.

Parameter	Description
WL	Continuous (15-minute) water level recorder
Rainfall	Continuous (15-minute)

Parameter	Description
DSM	Discharge sediment monitoring: Discharge measured by ADCP, SSC measured by depth integrated sampler, bed materials collected by grab sampler, bedload transport estimated by ADCP moving bed test. The frequency of monitoring should match the DSM, with a higher monitoring frequency during the wet season when most of the flow and sediment is transported through the LMB. Monitoring during the dry season should be completed at least monthly.
Cross-sections	Repeat surveyed cross-sections twice per year, and use of ADCP to collect bathymetric profile during each discharge measurement
Geomorphic photo monitoring	Repeat geomorphic photo monitoring should include photos taken of same river bank or river feature from same vantage point during each monitoring run to capture time-series of geomorphic changes to river geomorphology

It should also be noted that for hydrology and sediment transport, no new sites are recommended to be established within the impoundments of the proposed HPPs. This is because future JEM monitoring will be implemented by the developer, and all developers will maintain water level records of the impoundment, so it is not necessary to develop new sites. For sediment, measuring sediment transport within the impoundment is not warranted, as it will vary depending on the location of the dam. For understanding hydropower impacts in the LMB, monitoring the inflow and outflow of sediment from the impoundment is provides the required information.

It must be emphasised that these maps and identified future monitoring locations are based on the understanding of the river in March 2022 and that mainstream dam locations may change in the future. There are also ongoing upgrades and changes to the HYCOS network that may affect the proposed monitoring locations.

The recommended monitoring strategy will provide sufficient information to understand how hydropower developments affect the flow, water level fluctuations and sediment transport. As previously discussed, the final JEM strategy should be finalised for each hydropower project during the JAP process, in consultation with the developer to maximise the use of available monitoring resources.

Tributaries that will affect the hydrology of the Mekong near HPPs may also need to be monitored. Relevant tributaries are high lighted in the table. Flow records from some of these tributaries may be available from HPP operators (such as in Nam Tha and Nam Beng), so new sites are unlikely to be required, but for JEM monitoring at other HPPs, new sites may need to be established.

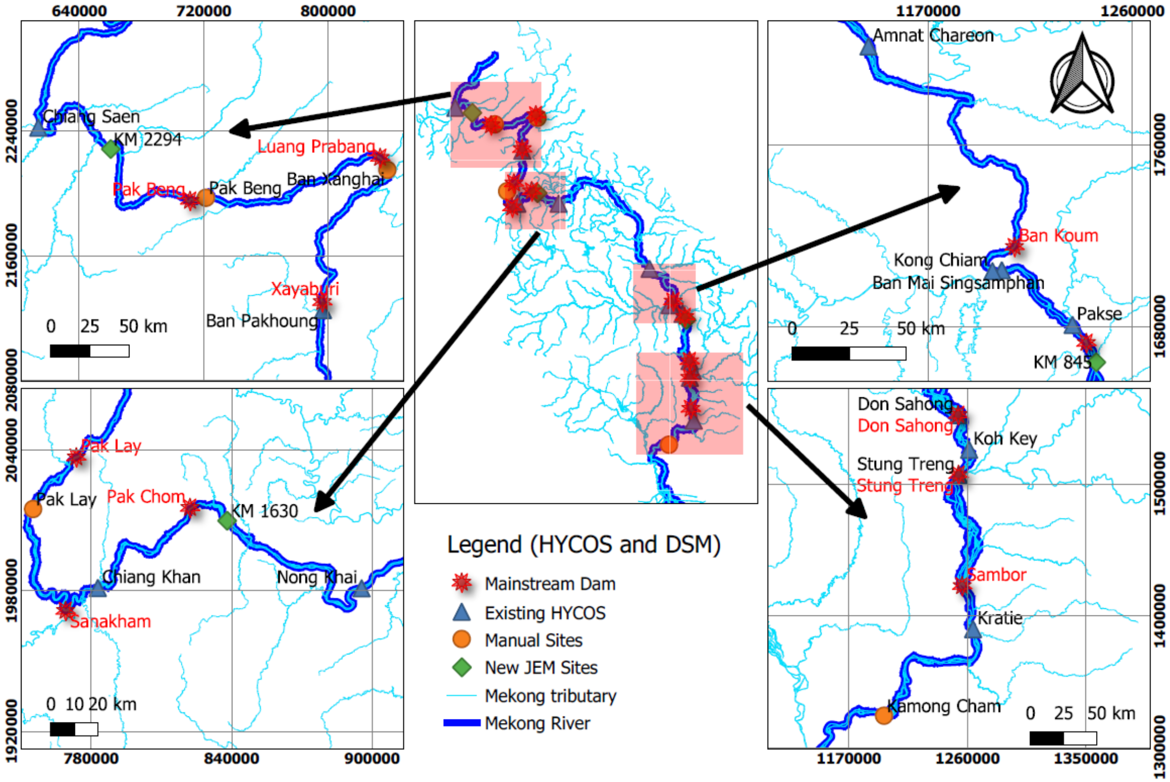

*Figure 4-6. Mekong River showing existing and proposed mainstream dam locations, along with existing and proposed future monitoring locations. See **Table 4-6** for details.*

Table 4-6. Recommended future JEM hydrology and sediment transport monitoring at mainstream hydropower projects in the Mekong River. Tributaries to be included in future JEM monitoring are shown in bold.

HPP Name	PNPCA Status	Upstream Regional HYCOS	Downstream Regional HYCOS	Recommended upstream JEM site(s)	Recommended downstream site(s)	Comments
Northern Lao Cascade						
Pak Beng	Finished & JAP agreed in principle	Chiang Saen	No existing site suitable. Recommend manual Ban Xang Hai becomes permanent HYCOS site	New HYCOS at Thai / Lao border at KM 2294 -WL changes from HPP operations may have impacts on important cultural areas	Upgrade manual Pak Beng site to HYCOS	1. Pak Beng will discharge into Luang Prabang impoundment, so the downstream site is only relevant if Pak Beng is constructed prior to Luang Prabang. 2. **Nam Tha** HPP near river mouth affects inflows and **Nam Beng** HPP affects flows downstream of proposed Pak Beng mainstream dam site. Recommend JEM works with Lao PDR & HPP operators to obtain flow records
Luang Prabang	Finished & JAP agreed in principle	Chiang Saen Or Pak Beng if upgraded to HYCOS prior to construction of Pak Beng	None suitable. Recommend Ban Xang Hai is upgraded to permanent HYCOS site. Suitable as long-term site	Upgrade Pak Beng manual site	Ban Xang Hai upgraded HYCOS site	1. Upstream JEM site is not relevant if Pak Beng is constructed as outflow from Pak Beng will directly enter Luang Prabang impoundment. 2.Ban Xang Hai will record combined impact of Luang Prabang operations and **Nam Ou** outflow. If a detailed understanding of Luang Prabang HPP is required, need to construct a temporary HYCOS site upstream of Nam Ou

HPP Name	PNPCA Status	Upstream Regional HYCOS	Downstream Regional HYCOS	Recommended upstream JEM site(s)	Recommended downstream site(s)	Comments
						confluence or obtain flow records from operator.
Xayaburi	Operational	Chiang Saen	Ban Pakhoung / Chiang Khan	Upgrade Ban Xang Hai to permanent HYCOS site.	Maintain Ban Pakhoung HYCOS site prior to flooding by Pak Lay impoundment	1. Ban Xang Hai is recommended to become a permanent HYCOS and DSM site. 2. Ban Pakhoung will be flooded by Pak Lay backwater following construction of Pak Lay
Pak Lay	Finished & JAP agreed in principle	Ban Pakhoung during construction	Chiang Khan	Ban Pakhoung whilst relevant. Following inundation no upstream site as backwater will extend to Xayaburi. Monitor discharge and sediments	Upgrade Manual Pak Lay site to HYCOS & DSM site	Both upstream and downstream sites will potentially be flooded out after construction of Pak Lay and Sanakham HPPs
Sanakham	In progress. Scheduled to finish January 2022	Ban Pakhoung	Chiang Khan / Nong Khai	Upgrade manual Pak Lay site to HYCOS & DSM	Chiang Khan & New HYCOS water level site at approximately km 1630 km (100 m downstream of SNHPP) to monitor cumulative impact of WL changes entering alluvial reach of Mekong	1. Upgrade of Pak Lay manual site required after construction of Pak Lay to be upstream site for Sanakham 2. Extra geomorphic monitoring warranted downstream of Sanakham to track cumulative impact of Northern Lao PDR cascade.

HPP Name	PNPCA Status	Upstream Regional HYCOS	Downstream Regional HYCOS	Recommended upstream JEM site(s)	Recommended downstream site(s)	Comments
Pak Chom	Not started	Chiang Khan	Nong Khai	Chiang Khan	New site at Km 1630	Geomorphic monitoring should include the repeat surveys of cross-sections in the alluvial reach upstream of Vientiane and Nong Khai
Southern Mainstream Dams						
Ban Kum	Not started	Amnat Chareon; Mukdahan to be used for long-term record	Khong Chiam & Ban Mai Singsamphan (downstream Nam Mun); Long-term record at Pakse is also relevant. Khong Ciaim: Ban Main Singsamphan: Pakse:	Existing Amnat & Mukdahan HYCOS sites sufficient to understand flow. Sediment and flow should be measured at new Amnat site	HYCOS & DSM site at Khong Chiam & Ban Main Singsamphan sufficient to understand flow and sediment	1. Amnat Chareon is 145 km upstream. May need to also use **Ban Kengdone** in Se Bang Hieng to understand upstream flow patterns 2. Discharge equipment at Khong Chiam should be upgraded to ADCP, SSC equipment should be upgraded to D96
Phou Ngoy	PNPCA submitted	Pakse or Ban Mai Singsamphan and **Se Done**	None applicable. Closest is Koh Key which will not record flow fluctuations associated with Phou Ngoy. New HYCOS site recommended 3-5 km downstream of dam site	Pakse	New HYCOS site – downstream of Phou Ngoy near KM 845	1. New downstream site is important for understanding flow changes from Phou Ngoy and flow patterns entering complex Si Phan Don area. 2. If the backwater extends beyond Pakse, then Ban Mai Singsamphan can be used as the regional inflow site, combined with the inflow from the large **Se Done** tributary, which is already regulated for hydropower. The discharge records from the lowest tributary dam may be sufficient for recording inflows

HPP Name	PNPCA Status	Upstream Regional HYCOS	Downstream Regional HYCOS	Recommended upstream JEM site(s)	Recommended downstream site(s)	Comments
Don Sahong	Operational	Pakse or new HYCOS site downstream of Phou Ngoy after construction	Koh Key	Pakse or new HYCOS site downstream of Phou Ngoy	Don Sahong	1.Additional discharge monitoring of individual channels is recommended under a range of flow conditions to better understand flow in fish pass channels 2. Additional cross-sections at Preah Romkel 2/year
Stung Treng	Not started	Koh Key during construction; Don Sahong following flooding of Koh Key by Stung Treng impoundment. New site downstream of Phou Ngoy would also be relevant	Stung Treng	Koh Key for baseline during construction .Don Sahong and downstream of Phou Ngoy during operations	Stung Treng	1. Water level probe at Don Sahong needs to be extended to capture full range of water level fluctuations 2. Stung Treng WL is affected by WL changes in 3S catchment. Consider installing HYCOS site in 3S upstream of existing SKB DSM site to understand interactions between **3S** and Mekong flows
Sambor	Not started	Stung Treng	Kratie	Stung Treng	Kratie / Kompong Cham	1. Stung Treng may be flooded out after construction. 2. Recommend that manual Kompong Cham be upgraded to HYCOS site and rating curve be derived for the site to understand flows entering Cambodian floodplain and VN delta (will require the use of multiple WL sites)

4.7.3 Incorporation of JEM programme in the environmental routine monitoring programmes and Core River Monitoring Network (CRMN)

The following recommendations are made for incorporating the JEM programme into the routine monitoring, and the CRMN that is under development:

- The review of the existing hydrologic monitoring network for development of the CRMN should take into consideration the existing dams, and the proposed locations of future projects. The CRMN should provide a regional understanding of hydrologic conditions in the LMB, and allow JEM monitoring to be interpreted within this context. The CRMN should consider the locations of proposed hydropower infrastructure and impoundments, and identify monitoring sites that will remain unaffected by backwater conditions, and can provide a long-term understanding of the hydrology of the river. Consideration should be given to upgrading some existing manual water level sites in the mainstream to allow continuation of the exiting record and provide greater detail.
- Continued capacity building in the following areas should be included in the CRMN strategy:
    - maintenance and calibration of HYCOS sites to ensure accurate readings and prevent gaps in the data record
    - Use of ADCP technology for the collection of accurate discharge measurements and appropriate post-processing of ADCP files to produce accurate discharge measurement
    - The analysis of hydrologic and hydraulic data, including the derivation and updating of rating curves, derivation and analysis of monthly and annual flow statistics, etc.
- Where possible new discharge and sediment monitoring locations should coincide with water quality monitoring sites such that the data can be readily integrated.

5 SEDIMENT TRANSPORT AND GEOMORPHOLOGY

5.1 Introduction and Background

Sediment transport controls MB river channel and floodplain characteristics, and thus determines the distribution of ecological habitats. It is recognised as an important component of river functioning and the coordination of sediment monitoring is one of the core functions of the MRC.

The development of sediment monitoring for JEM was based on a review of the existing sediment transport monitoring system (DSM) and identification of information gaps that needed to be addressed to provide an understanding of how operations at Xayaburi and Don Sahong have affected sediment transport through the river. The monitoring design developed in JEM for sediment transport was consistent with the overall JEM design, with existing DSM sites providing the larger scale, regional context for the project, with additional sites added to provide more local information about impacts to the flow regime. The sediment monitoring was also integrated with the discharge monitoring, as flow is required to calculate sediment loads in the river. Details of the initial monitoring design are presented in the JEM Pilot proposals, and details of the findings of the Pilot studies are summarised in MRC 2021a and MRC 2021b. The following sub-sections provide a brief summary of the monitoring completed during the implementation of the Pilots at Xayaburi and Don Sahong, the findings, and the recommendations arising from monitoring.

5.1.1 JEM sediment monitoring at Xayaburi

Sediment monitoring at Xayaburi included depth-integrated suspended sediment sampling (SSC), an estimate of bedload movement, and the determination of bed material grain size. Sediment monitoring was linked to the hydrologic monitoring, with the SSC and bed material sampling occurring at the same time that discharge measurements were completed. The monitoring was completed by the Luang Prabang based Department of Meteorology and Hydrology hydrographic team, who also complete the ongoing DSM.

New discharge and sediment monitoring sites were established in the Mekong mainstream upstream and downstream of Xayaburi (Figure 4-1). Upstream of the impoundment, a site was established at Ban Xang Hai, approximately 20 km upstream of the Luang Prabang water level gauge. Approximately 4 km downstream of the Xayaburi dam, a new monitoring site was established at Ban Pakhoung which also recorded water level on a continuous basis. At both sites, SSC and bed materials were measured at a frequency of weekly (wet season) to monthly (dry season). Unfortunately, due to Covid restrictions, monitoring was unable to be implemented as planned and few wet season measurements were completed. This had a substantial impact on the sediment monitoring results, as most sediment transport occurs during the wet season.

The long-term sediment monitoring results from the DSM sites of Chiang Saen (upstream) and Chiang Khan (downstream) were used to provide a regional context for the monitoring results collected at the new sites.

5.1.2 JEM monitoring at Don Sahong

Sediment transport monitoring at Don Sahong could not be implemented at sites immediately upstream and downstream of the Don Sahong hydropower project due to the river flowing through multiple channels in the region, creating a highly complex flow regime. A new sediment and discharge monitoring site was established Upstream of Stung Treng (ST-UP) with discharge, SSC and bed material grain size determined during the JEM Pilot period (Figure 4-2). Field monitoring was not able to be completed at the Koh Key gauge location due to access difficulties.

As initially designed, the sediment monitoring from Pakse during the JEM Pilot was to be compared to the sediment monitoring results collected at ST-UP to provide large scale information about sediment changes as the river flows through the complex Si Phan Don area and the Don Sahong hydropower project. Due to equipment delays and Covid restrictions, the frequency of sediment monitoring at Pakse was severely restricted, and there were insufficient results to make this comparison during the Pilot study period.

The results from the ST-UP site provided information about sediment transport in the mainstream Mekong upstream of the confluence with the large 3S tributary system. Sediment monitoring at ST-UP, combined with the ongoing DSM monitoring in the Sekong at the Bridge (DSM site SKB) and Stung Trend (DSM site ST), provided insights into the timing and magnitude of sediment transported by the Mekong as compared to the 3S system, where hydropower has also been widely developed.

Geomorphic monitoring included repeat surveying of channel cross-sections at each of the SSC monitoring sites and at Preah Rumkil (Dolphin Pools) in Cambodia near the Lao PDR border.

The operators of Don Sahong provided TSS monitoring results which provided some indication of the behaviour of sediments in the impoundment under different flow rates. TSS was also included in the JEM water quality monitoring strategy, and these results are described in the Water Quality section of this report.

5.2 JEM Pilots' key findings and recommendations

The following are the key findings related to sediment monitoring during the JEM Pilots:

At Xayaburi:

- There were insufficient SSC monitoring results to evaluate sediment trapping in the Xayaburi impoundment. This was due to the late arrival and commissioning of new field monitoring equipment and Covid restrictions limiting monitoring to the dry season when sediment transport is low. The SSC samples that were collected all had concentrations of <100 mg/L (both upstream and downstream of the impoundment).
- Sediment transport in the Mekong shows a decline over time. Part of the decline is attributable to drought conditions, but a statistical analysis of long-term results from Chiang Khan suggest that factors other than drought are likely contributing to the decline (Figure

5-1). A likely factor is the trapping of sediment in upstream hydropower impoundments on the mainstream and in the tributaries of the Mekong

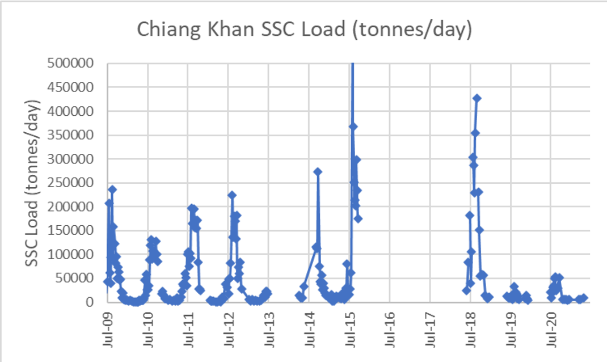

Figure 5-1. Long-term SSC load results from Chiang Khan showing a decrease in sediment transport over time.

- Bathymetric cross-sections at Chiang Khan suggest the channel is active, with the bedload movement of sand occurring during periods of medium and high flows.

At Don Sahong

- SSC concentrations were relatively low at Stung Treng-UP throughout the year, with all concentrations <180 mg/L. Most of the material being transported was coarse and medium silt, with lesser amounts of fine and very fine sand. The estimated SSC annual load of 20 Mt/yr at the site is very low compared to historical estimates for Pakse, which were historically estimated at 160 Mt/yr.
- Integrating the SSC and flow results from ST-UP, ST, and SKB, show that generally the 3S is a minor contributor of sediment. However, on occasion it provides the majority of sediment in the system. These events are theorised to be linked to sediment flushing at hydropower projects in the 3S and/or major landslips in the catchment (Figure 5-2).
- The surveyed cross-sections of the main Mekong channel near Preah Rumkil (Dolphin Pools) near the Lao PDR border show signs of variability associated with the movement of sand through the section but no major channel changes between the survey dates.

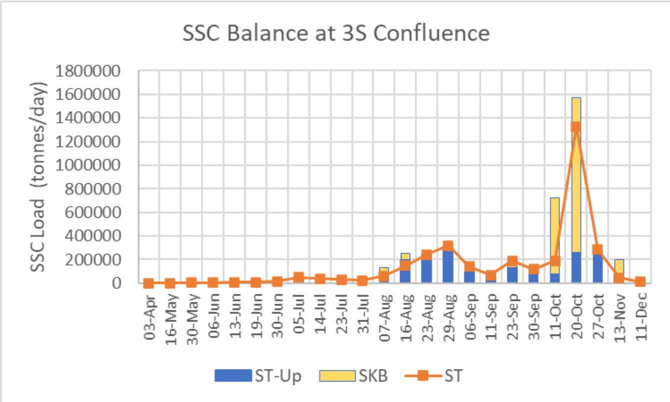

Figure 5-2. Suspended sediment (SSC) balance across the Mekong and 3S confluence, showing a very large influx of sediment from the 3S in October 2020. The blue and yellow bars show the sediment load at the new St-UP site and existing DSM SKB site, respectively. The orange line shows the measured SSC load at Stung Treng, which is downstream of the confluence.

5.3 JEM Monitoring design

5.3.1 Monitoring overview

This section provides a high-level overview of the recommended approach for sediment transport and geomorphology monitoring under the JEM that is consistent with the overall strategy presented in Section 2. Recommendations are made with respect to monitoring sites, parameters, monitoring frequency and information management consistent with this strategy using the existing DSMP as a starting point.

Effective sediment transport and geomorphic monitoring needs to capture the spatial and temporal variability of the LMB. In addition, accurate sediment transport monitoring requires accurate discharge monitoring, so there needs to be strong linkages between the hydrologic and sediment monitoring frameworks. The ISH11 guidance for monitoring design is summarised in Section 2.2.1 along with requirements for sediment and geomorphic monitoring to achieve each aim. Table 5-1 provides an overview of the components of an effective monitoring strategy, and these criteria and requirements have been used to derive the monitoring locations of the JEM Pilot studies and the proposed JEM monitoring at future HPPs.

Table 5-1. Criteria for an effective monitoring strategy (left column) and elements of sediment and geomorphology monitoring needed to achieve these criteria

Monitoring Criteria	**Requirements for effective and efficient discharge and sediment monitoring**
Locations: • Cover Mekong hydro-ecological zones • Position to provide relevant information regarding HPPs	• Monitoring sites need to be located throughout the mainstream Mekong River • Sites need to be situated upstream and downstream of national boundaries

• Enable understanding of mainstream and transboundary issues	• Sites need to be located where they provide robust and relevant information about large scale changes associated with HPP and other catchment activities • Geomorphic monitoring sites (e.g. repeat river cross-sections) need to be located in alluvial river sections where changes are most likely to occur
Parameters • Indicators relevant to HPP planning and management • Can be replicated across the basin • Cost-effective field and laboratory methods • Should be able to predict as well as explain change	• Parameters need to include: suspended and bedload transport to document sediment budgets • Parameters need to include grain size distribution to understand changes due to trapping in impoundments, changes to sediment transport or river bed armouring processes • Parameters need to include river discharge to provide a means for calculating sediment loads and understanding river energy • Methods need to be uniform between countries and sites • Parameters that can link sediment to other disciplines such as water quality and aquatic ecology should be considered for inclusion (e.g. water clarity and nutrient transport) • Surveyed cross-sections obtained at a suitable resolution should be included in the parameter list • Aerial and satellite photo analysis should be included in the parameter list
Timing of data collection • Length of monitoring covers the cycles of natural variability • Frequency of monitoring captures seasonal cycles and operational change	• The frequency of sediment monitoring needs to reflect the monsoonal seasonal pattern because the majority of sediment transport occurs during the wet season. Weekly to fort-nightly monitoring should be implemented during this season • A lower monitoring frequency of fortnightly to monthly can be adopted for the transition seasons and the dry season • Discharge measurements need to be collected at the same locations and at the same time as the sediment monitoring, or monitoring sites need to be located near gauging stations where the instantaneous discharge can be accurately determined • Monitoring should continue without breaks to provide long-term, high quality data of sediment transport • River cross-sections and aerial or satellite imagery should be collected on time scales that can link to catchment activities. Ideally, an annual frequency should be adopted, with the frequency reviewed every few years based on the results
Information Management & Uses • Information is readily available for users	• Monitoring results are collated and presented to the MRC in formats that can be easily

• Information is linked to tools that can support decision-support and analysis	incorporated into the MRC databases. A review of the existing monitoring forms needs to be completed to achieve this • Data analysis techniques need to be developed to allow the accurate and appropriate analysis of results. This includes calculation of seasonal and annual sediment budgets for suspended and bedload sediment and sediment characteristics down the mainstream and over time • Information must be made available in time-frames that supports management decisions

Sediment transport is a multi-dimensional and complex process, and for that reason it poses challenges to monitor accurately. Importantly, the following characteristics need to be considered in the design and implementation of a robust sediment transport monitoring regime:

- **Sediment concentration varies with depth.** Sediment is not transported uniformly in a river due to the variability in flow velocity and river energy. The concentration of fine-grained silt and clay tends to be uniform over the depth of a river due to its small size and low energy required for suspension. By contrast, sand-sized material is preferentially transported near the bed of the river because there is insufficient river energy to mix the sand over the entire water column. Sampling methods must be able to collect samples that accurately reflect this distribution within the water column.
- **Sediment concentration varies across a river cross-section.** The water velocity in a river varies with both depth and distance across a river section. This will affect where in the river sediment is carried. Monitoring needs to include multiple points across a river cross-section to capture this variability.
- **Sediment transport varies over time.** Sediment transport is controlled by the hydrology of a river, and in the Mekong, the majority of sediment is transported during the monsoon season. During these peak flow periods, the grain size of transported sediment also increases, with the majority of sand transported during the monsoon period.
- **Sand and larger size-fractions travel episodically along the bed of the river.** The transport of gravel and larger material occurs episodically and typically occurs through the rolling or saltation of sediment grains along the bed of the river. Under conditions of high flow, the entire river bed can become mobile, similar to a fluidised-bed, moving downstream. Hence very large volumes of bedload can be transported over short periods of time. These events determine the distribution and morphology of sand bars and river bed forms. Major bedload episodes can be separated by long periods of inactivity, so the timing of bedload monitoring is critical to accurate quantification.

Hydropower operations can affect sediment transport and geomorphology through the alteration of river energy both upstream in the impoundment, where reduced water velocities promote deposition, and downstream, where increased velocities can promote erosion, so both upstream and downstream of hydropower projects must be considered when designing a monitoring strategy.

5.3.2 Monitoring Locations / Sites

Monitoring locations for sediment transport need to correspond to discharge monitoring locations, so there are similar considerations for the establishment of sediment monitoring sites as for hydrologic sites. As shown schematically in Figure 2-5, regional sediment transport in the Mekong is monitored through the existing DSM network. Monitoring locations for JEM need to be identified within the context of this network, with the usefulness of the existing sites maximised where ever possible. The location of upstream and downstream hydropower projects and how they affect sediment transport upstream and downstream of the hydropower project under investigation must also be considered. The following need to be considered on a site-specific basis for each hydropower project to be monitored.

- Is there an existing site upstream of the proposed (or existing) HPP that is suitable for understanding the sediment transport in the river upstream of the back water of the proposed impoundment?
- Is there an existing downstream site that can accurately capture the sediment load discharged from the power station?
- Is there significant sediment input from any tributary entering the impoundment that may affect the sediment balance, and is there a need to establish sediment monitoring in these inflows?
- Are there existing far-field DSM sites that can capture the net changes to the sediment transport of the river and provide a regional context for interpreting the local monitoring results: These far field sites should include consideration of transboundary locations.
- Are there alluvial river reaches downstream of the hydropower project which may be affected by the change in flow and sediment due to hydropower operations and should be included in geomorphic monitoring, such as repeat cross-sections or photo monitoring?

Within this context, the location of existing DSM monitoring sites should be identified, and additional hydrology and sediment monitoring locations identified as required. Ideally, sharing information with hydropower developers could reduce the need to establish new sites. However, for the foreseeable future, until data sharing agreements are established and functioning between the MRC and private parties, and there is agreement on the methodologies to be used to monitor sediment transport, it is recommended that the MRC maintain a sediment monitoring network that can provide the required level of information to understand hydropower impacts. Section 4.7.2 provides specific recommendations for sediment monitoring associated with the proposed future hydropower developments in the LMB.

5.3.3 Monitoring Parameters

The complex nature of sediment transport in river systems necessitates that a range of parameters is included in the JEM monitoring strategy to provide a comprehensive understanding of sediment movement.

The parameters included in the ongoing DSM vary between sites, with some sites measuring SSC and bed material grain size while at others, bedload transport and SSC grain size are also determined. It is recommended that each of these parameters be included at JEM monitoring sites and at the established DSM sites that provide a regional context for the JEM monitoring (if not already included in the DSM monitoring schedule). The justification for each parameter and recommended changes in monitoring methods for future JEM (or CRMN) sites are listed below:

SSC: This is important for determining the suspended sediment transported by the river. It includes the fine grained material and, at higher flow rates, coarser material that is transported as bedload under lower flow rates. It is imperative that this parameter be measured using a depth and flow integrating method, consistent with the existing D96 methodology, to ensure as accurate quantification of the SSC load as possible. Discharge needs to be determined at the same time as SSC to allow the calculation of SSC sediment loads.

Bedload: Bedload is measured using the BL84 bedload sampler at 3 sites in the DSM. It is recommended that ADCP moving bed tests be used to estimate bedload movement at all JEM sites (and any site where ADCP is available). The deployment of the BL84 is difficult under most flow conditions, and impossible during high flows. The ADCP moving bed test provides an estimate of the average velocity of bed movement across the river cross-section, and is required to correct ADCP discharge measurements that do not use GPS. Combined with the determination of bed material grain size, estimates of the mass and grain size of the bedload can be made.

SSC Grain size: Determining SSC grain size at JEM sites is important for understanding what grain sizes are being transported into and out of impoundments. This should be included at all JEM sites as it is fundamental for understanding the impacts of hydropower projects on sediment transport.

Bed Material Grain size: The size of the bed material provides an indication of the size of bedload being transported through the site and is relevant to understanding the distribution of habitats. The trapping of coarse sediment in impoundments exerts a long-term impact on bedload and bed materials, and tracking these changes is important for identifying geomorphic changes downstream of hydropower projects.

Surveyed River Cross-sections: Repeat surveyed cross-sections of monitoring sites are needed for checking water level/discharge relationships, and are important for tracking long-term geomorphic changes to the river. Therefore, JEM monitoring should include surveyed cross-sections at monitoring sites, in sand-rich bedrock reaches and in alluvial reaches that may be affected by hydropower operations.

5.3.4 Monitoring Timing and Frequency

The frequency of sediment monitoring needs to reflect the seasonality of sediment transport, with a higher monitoring frequency during the wet season when sediment transport is greatest. The frequency of sediment monitoring at each site under the DSM has varied over time, with the frequency of monitoring varying from 18 to 38 occasions per year. The monitoring frequency adopted for the JEM Pilots (Table 5-2), 24 samplings per year for discharge, SSC and bedload, is recommended as the minimum monitoring frequency required to capture inter-seasonal and inter-annual variability. A lower frequency of suspended sediment grain size analyses is recommended owing to the large volume of river water required to be collected in the dry season, and the labour intensive nature of the analysis.

Table 5-2. Minimum recommended sampling frequency for discharge and suspended sediment monitoring for each site if funding is unavailable for recommended strategy. Q=Discharge, SSC= Depth Integrated Suspended Sediment, BL = Bedload, BL-GSA=Bedload Grainsize, SSC-GSA = SSC Sediment Grain Size

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Q, SSC, BL, BL-GSA	1		1	1	1	4	4	4	4	3	1		24
SSC -GSA					1	2	2	2	2	1			10

If feasible, more frequent monitoring, as shown in Table 5-3 is recommended. This higher frequency would provide more information about flow and sediment transport during the transition and dry season periods. Due to regulation by mainstream and tributary hydropower projects, a higher percentage of flow is occurring in the Mekong during the dry season as compared to unregulated conditions. Having a higher monitoring frequency would provide information about how much sediment is being transported by these higher flows.

Table 5-3. Recommended sampling frequency for discharge and suspended sediment monitoring for each site. Q=Discharge, SSC=Suspended Sediment Concentration, BL=Bedload SGSA=Sediment Grain size Analysis.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
JEM & recommended for DSMP Q, SSC, BL	1	1	1	2	2	4	4	4	4	4	2	1	30
SSC SGSA					1	2	2	2	2	2	1		12

The establishment and maintenance of ongoing monitoring is critical for the development of a consistent and reliable data set for the LMB. It is important that monitoring during any one year is implemented prior to the onset of the wet season, e.g. any contractual issues have been settled between the MCs and the MRC, all equipment has been checked and is functioning (boat, winch, HYCOS gauges, ADCP), and the field teams are trained in the required field procedures. In the past, some DSM monitoring has been delayed due to these issues, and monitoring has not been initiated until after the onset of the wet season.

To address this issue, it is recommended that the monitoring (and any contractual arrangements) be organised on a calendar year basis (Jan to Dec). This would allow several months for training and ensuring that all field equipment was in good working order prior to the onset of high flows and high sediment transport in the river.

It is also important that sediment monitoring be implemented at the DSM sites on an ongoing basis, and at JEM sites for as long as possible. This is because impacts due to changes in sediment transport can require years to emerge. For example, a reduction in sand in the river bed due to sediment trapping in an impoundment will only emerge as a downstream impact once the available sand resident in the river channel has been eroded, with the resultant erosion moving as a 'wave' downstream.

5.4 Sediment transport monitoring protocol

5.4.1 Field data collection

The MRC standard protocols for the DSMP were established in 2009 and are described in detail in Vol 2 Annexes 5 - 10. The field methodologies are based on established and internationally recognised USGS methods that have undergone extensive testing and verification.

- Discharge monitoring is completed at each site on each monitoring day using either a current meter (CM) or an ADCP (Vol 2, Annex 2). The current meter or ADCP results are used to define the locations across river cross-section for suspended sediment and bedload sampling, if applicable, using the Equal Discharge Increment method (e.g. each sampling location represents 20% of the flow in the river on the sampling day).
- Depth integrated suspended sediment samples are collected at each monitoring site on each monitoring day using appropriate isokinetic field samplers (Figure 5-3). Isokinetic samplers collect sediment samples proportional to the flow in the river and are the only samplers that accurately collect coarse silt and sand carried in suspension. Suspended sediment samples are collected at a minimum of 5 points across the river transect, with the locations based on the Equal Discharge Increment approach. The velocity at which the sampler is lowered and raised through the water column needs to be sufficiently fast such that the sampler does not 'overfill', which can lead to an over-collection of suspended sediment.

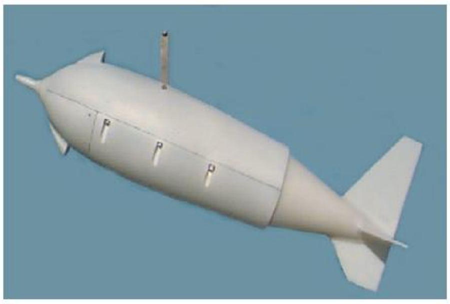

Figure 5-3. D-96 Depth Integrating Suspended Sediment Sampler.

- Bedload sampling has been completed using a BL-84 sampler at three sites in the DSM monitoring strategy. The physical collection of bedload using this sampler under the conditions present in the Mekong is very difficult. It is recommended that instead of the physical collection of bedload, that the results from the ADCP moving bed test (loop-test) be used to provide an estimate of bedload transport across the section, and that bed material samples be collected to provide a physical sample to determine the grain size distribution of the material moving through the system. The bed material can be collected using a simple pipe-dredge, which was successfully trialled during the JEM Pilots.

A numbered schematic of the integrated discharge and sediment field sampling protocol adopted during the JEM trials and recommended for implementation in future JEM monitoring is shown in Figure 5-4. The numbered steps are as follows:

1. Read & record gauge height

   Arrive at cross-section - observe the site and note any major changes

   ADCP setup, compass calibration, test,
2. Complete ADCP moving bed test (loop-test)
3. ADCP Discharge x 4 – note correct bank (left, right)
   - Check measurements are within 5%
4. Determine locations for SSC measurements (on ADCP screen or EDI software)
5. Complete SSC sampling

   SSC Point 1 - boat stationary - (1-sample for SSC, *1 or more samples for GSA*)

   SSC Point 2 – boat stationary - (1-sample for SSC, *1 or more for GSA*)

   Float downstream and collect bed material sample 1

   SSC Point 3 – boat stationary - (1-sample for SSC, *1 or more for GSA*)

   Float downstream and collect bed material sample 2

   SSC Point 4 - boat stationary - (1-sample for SSC, *1 or more for GSA*)

   Float downstream and collect bed material sample 3

   SSC Point 5 (1-sample for SSC, *1 or more samples for GSA*)
6. Read & record gauge height at end of sampling

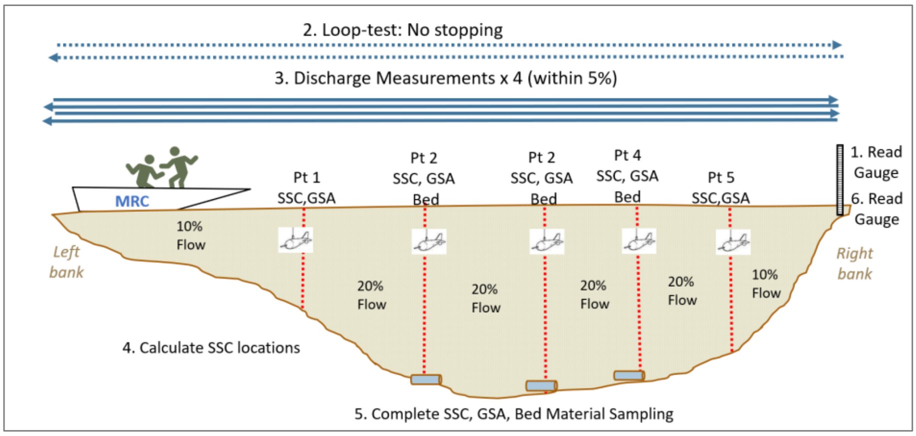

Figure 5-4. Schematic of recommended JEM field sampling procedures.

Repeat photo monitoring was also recommended for the JEM pilots but was not implemented by the MCs. It is recommended that repeat photo monitoring of the river banks near the monitoring location and at nearby locations (confluences, upstream or downstream bends, etc.) be included in future JEM monitoring.

5.4.2 Laboratory Analysis

More detailed descriptions of the laboratory methods for sediment analysis are provided in Vol 2 Annex 5. The following dot points briefly summarise the methods used for each parameter, with recommendations for improvement provided at the end.

- SSC – mass in the sample (mg) and SSC concentration (mg/L): Laboratory analysis of suspended sediment samples is based on filtering each depth-integrated sediment samples through pre-weighed glass-fibre filters with an effective pore size of 1 μm followed by drying and re-weighing to establish the mass of sediment present in each sample. The mass is divided by the volume of the collected sample to determine the concentration (mg/L) of suspended sediment.

- SSC Load (tonnes/day): Because the Equal Discharge Increment method is used to collect the depth integrated suspended sediment samples, the average of the five samples can be multiplied by the total discharge volume of the river at the time of monitoring to determine the sediment load / second at the time of monitoring. This value can be adjusted to tonnes/day as required.

- For the determination of SSC sediment grain size analysis, multiple depth integrated suspended sediment samples are collected and combined to create a large volume water sample for subsequent analysis. This sample is settled and filtered to obtain up to several grams (ideally) of suspended sediment. The sediment is suspended in a fixed volume of water and the pipette method is used to determine the grain-size distribution in the sample. This is an accurate but time-consuming laboratory analysis that requires specialised laboratory equipment.

- Grain size analysis of bedload and bed material samples is based on sieving through a standard sieve set. Material <63 μm in size is analysed using the pipette method as used for suspended sediment grain size determination. The same sediment grain size classes adopted by the DSM should be used for analysing JEM bed material samples (Table 5-4).

Table 5-4. Grain size classes used to analyse bed material in the DSM

Max. Particle Size, mm	Min. weight of samples, grams
76.2	64,000
50.8	19,000
38.1	8,000

25.4	2,400
19.1	1,000
12.7	300
9.5	150
4.7	50
Particle Size Range, mm	**Min. weight of samples, grams**
16.0-1.0	20
2.0-0.25	0.5
0.5-0.62	0.07

5.4.3 Data Collection and QA/QC

Similar to the hydrology component, all field and laboratory results related to sediment transport monitoring and geomorphic cross-sections are collected, checked by the MCs, and submitted to the MRC on standardised data forms that were developed at the start of the DSMP. The MRC completes a final QA/QC before the SSC and discharge data are stored in the Aquarius database and made available through the data portal. The original laboratory SSC results (e.g. for each of the 5 SSC samples) and the grain size distribution results are presently not stored on a database but available in the original data files.

During JEM, a database was established that included more hydraulic information from each of the field monitoring campaigns (channel width, cross-section, average velocity), SSC loads on the monitoring day, and the median grain size of the bed material.

5.5 JEM Data Analysis

5.5.1 Basin Scale

Analysis of sediment data at a basin-scale provides a context for interpreting the monitoring results obtained at the JEM monitoring sites. The parameters relevant to interpreting the JEM results are the same parameters that are identified as Basin Indicators. Examples include:

- Time-series of SSC concentrations or SSC loads at all relevant sites to understand the movement of suspended sediment at a regional scale during one monitoring year(Figure 5-5);

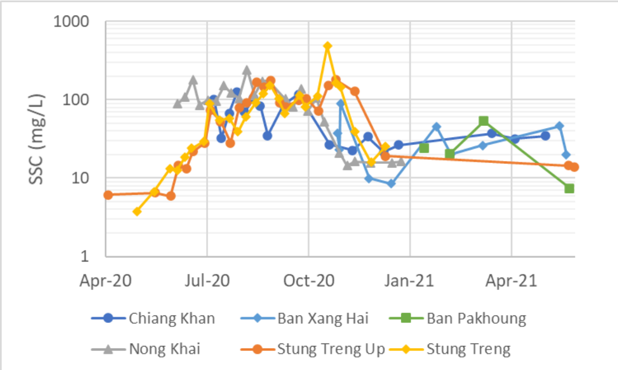

Figure 5-5. SSC at JEM monitoring sites included in the Pilot studies showing an increase in SSC during the wet season; Source: MRC 2021b.

- Determination of annual suspended sediment loads to track changes over time on a regional scale. An example of this type of analysis is provided in Figure 5-6.

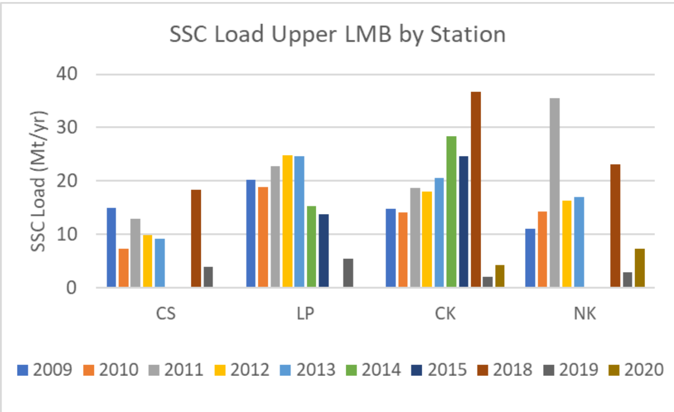

Figure 5-6. SSC annual loads at Chiang Saen (CS), Luang Prabang (LP), Chiang Khan (CK) and Nong Khai (NK) for the years when results are available. Results show large decrease in loads at Chiang Khan and Nong Khai in 2019 and 2020. Source: MRC 2021b.

- Annual estimates of bedload transport as tonnes/year and as percentage of the SSC load to understand how different sediment is moving through the river system.
- Tracking of median bed material grain sizes to understand how physical conditions in the river relevant to ecological processes change down the river and over time.
- Repeat river cross-section surveys be compared to identify changes in the depth and shape of the river channel as an indicator of erosion or deposition at a large scale.

5.5.2 Impact Analysis

Impact analysis related to sediment transport and geomorphology in JEM is focused on interpreting the SSC, bedload and cross-section information at a local scale. This is generally done through the comparison of monitoring results upstream and downstream of the hydropower project or projects under investigation to understand how sediment has changed due to the presence of the project. Time-series of results can also provide insights about changes. Examples include:

- Comparing SSC loads upstream and downstream on a seasonal and annual basis to determine the degree of sediment trapping occurring in the impoundment;
- Comparing the SSC grain size distribution of sediment loads entering and exiting the impoundment to understand what size sediment is being retained or transported through the impoundment
- Comparing bedload mass and grain sizes entering and exiting the impoundment to quantify the retention and passage of larger sediment in the impoundment;
- Comparison of river cross-sections collected at sites in the impoundment and downstream of the hydropower station to determine whether the channel is aggrading due to sediment deposition or eroding due to a lack of sediment following the development of the project;
- Quantifying sediment loads during sediment flushing exercises to monitor the maximum SSC values occurring downstream, which can have a detrimental impact on habitats and ecosystems, and quantify the sediment loads released during the flushing event.

Due to the lack of flood season monitoring at Xayaburi due to Covid restrictions, there are insufficient results available to complete these analyses based on the Pilot monitoring results. At Don Sahong, due to the multiple river channels, the upstream/downstream approach to sediment monitoring is not applicable, and analysis of results at a regional should be the starting point for impact analysis.

5.6 JEM's Data storage and management

As noted in Section 5.4.3, a database was established during the JEM pilots that was populated with all of the JEM field and laboratory sediment and discharge monitoring results for the JEM sites and for the DSM sites relevant to the Pilot studies. The database contains the SSC results (concentrations and loads) and, where available, median bed material grain size, the average moving bed velocity from the ADCP moving bed tests and an estimate of bedload transport. The database was distributed to the MCs, but there was only limited opportunity for capacity building related to its content and use. The database was used as the basis for analysing the JEM results as presented in the Combined Annual and Final Reports (MRC 2021a, 2021b).

5.7 JEM Sediment Monitoring at Existing and Future Hydropower Projects

The previous sections have summarised the recommended parameters, frequency of monitoring and laboratory methods for future JEM monitoring. In addition to these general monitoring recommendations, the following specific recommendations are made with respect to future monitoring at Xayaburi and Don Sahong. These recommendations are also pertinent to the development of the CRMN and the ongoing DSM monitoring strategies.

5.7.1 Continuation of JEM at Xayaburi and Don Sahong

The following is recommended for future JEM monitoring at Xayaburi and Don Sahong:

- **Continue monitoring for an additional 12-months.** Monitoring should be continued for at least an additional 12 months at both Xayaburi and Don Sahong to allow monitoring to capture conditions over a full hydrologic cycle. Covid travel restrictions combined with the covid related delays in the delivery and installation of equipment resulted in a limited data set being generated during the Pilot study period. An additional 12 months of data would provide more information about how the operations of the HPPs are affecting sediment transport in the LMB and allow confirmation of the preliminary findings arising from the limited data set. In the case of Xayaburi, additional monitoring would allow an estimation of sediment trapping in the impoundment. At Don Sahong, comparing sediment transport results at Pakse with Koh Key would provide an indication of regional changes in sediment dynamics as the river flows through the hydraulically complex Si Phan Don area.
- **Provide additional ADCP capacity building.** The JEM monitoring results at some sites were limited due to incorrect calibration of the ADCP, or incorrect post-processing of results. Targeted capacity building for the **field teams** in the correct use of the equipment is critical for maximising the amount of information derived from the monitoring investment.
- **Implement photo monitoring at the JEM sites as proposed in the JEM Programme.** 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 is recommended to 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, this component of the JEM monitoring schedule was not able to 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.
- **Align water quality and sediment monitoring days** to allow integration of results (e.g. nutrients and SSC) and comparison of TSS, turbidity and SSC results. The degree of sediment and nutrient trapping in hydropower impoundments is a fundamental question, and coordinated monitoring between the disciplines would assist the investigations.

5.7.2 JEM Monitoring at new Hydropower Projects

Sediment transport and geomorphic monitoring at future hydropower projects needs to be aligned with discharge and HYCOS monitoring. Recommendations for discharge and sediment monitoring sites associated with each of the hydropower projects identified for future development in the LMB are shown in the maps in Figure 4-6, and described in detail in Table 4-6. At each of the discharge sites identified in Table 4-6, the JEM parameters should be determined at the frequency recommended in the previous sections of this report.

5.7.3 Incorporation of JEM programme in the environmental routine monitoring programmes and CRMN

Recommendations from the JEM pilots that are applicable to the routine DSM monitoring and the development of the CRMN include the following:

Field monitoring

- Ongoing field based capacity building is warranted to ensure that accurate and consistent field monitoring techniques are deployed in all of the MCs. Capacity building should focus on the use of the ADCP (compass calibration, collection of moving bed test, collection of discharge measurements, checking of measurements in the field) and the D96 depth integrated suspended sediment equipment.
- Procurement of new D96 samplers is very difficult, with none being able to be purchased during the JEM Pilots due to covid and delays. If the procurement of new D96 instruments is not possible, the MRC will need to adopt an alternative method for monitoring suspended sediment. The use of in situ laser-based instruments should be investigated. Note that the use of van Dorn bottles or similar to not provide an accurate measure of sand or coarse silt in the water column and should not be adopted for routine monitoring.
- Photo monitoring as originally recommended for inclusion in JEM monitoring should be incorporated into routine monitoring. Repeat photo monitoring of river banks is a rapid, inexpensive and effective way of documenting geomorphic changes to river banks over time.

Laboratory analyses

- Capacity building in the laboratory procedures for sediment analyses should be provided to the MCs. There has not been any laboratory-based training for many years, and several of the MCs are unable to complete the required analyses due to lack of capacity, lack of equipment, or both. As part of the review, an inventory of the existing equipment in each MC's sediment laboratory should be compiled, and equipment should be upgraded/replaced where required to ensure that all analyses are being completed using the same Standard Operating Procedures and the same equipment.
- Linked to the previous recommendation is the upgrading of equipment for the determination of suspended sediment grain size. The present SOP for the analysis is challenging, time-consuming and requires specific equipment that is not available in several of the MCs laboratories. Bench top grain size analysers can provide rapid and accurate results from small volume samples. This would eliminate the need for the field teams to collect large volume depth-integrated samples and the lab teams from needing to filter and process the large samples. The results would be more accurate and available sooner as compared to the present.

Data Management

- A review and re-design of the sediment (and hydrology) reporting system is warranted. The number of excel files that are required to be filled and submitted for each field monitoring run is excessive and redundant. Ideally, a web-based reporting system with inbuilt QA/QC should be developed, which would allow more rapid reporting of results and enable the rapid detection of unusual results

- Capacity building in data QA/QC and data analysis should be provided on a routine basis to ensure adequate QA/QC is being completed at the MC level. During JEM monitoring, it was observed that moving bed test results are not being applied to ADCP results as required, and there are frequently inconsistencies in laboratory results due to calculation errors.
- The sediment database should be further developed to include the historic DSM data from all monitoring sites, and capacity building should be provided to the countries related to data management and data analysis.

6 WATER QUALITY MONITORING

6.1 Introduction and Background

Water quality of the lower Mekong River has long been a concern of the governments of riparian countries, often with very little basis (e.g. see Campbell 2007). However, as human populations grow, and wealth of the region increases, pressures on water quality will also increase. Data collected by the MRC water quality monitoring network (WQMN) demonstrate that water quality, mainly nitrogen and phosphorus, has deteriorated in a number of river reaches, typically those in areas where population density is highest (Chea et al 2016).

Hydropower developments proposed and under construction in the lower Mekong River are at risk from, and also potentially pose a risk to, water quality of the river. Risks to hydropower impoundments arise from decreasing water quality in the river upstream**Error! Reference source not found.**. The level of industrialization of the Mekong basin is low, and unlikely to increase substantially in the short term (Hook et al 2003). Consequently, the risk arising from toxic industrial waste discharges is low. The main trend in water quality in the river is an increase in nutrients, presumed to arise from urban runoff and waste water, and as a byproduct of increasing fertilizer use in agriculture. In reservoirs, where water is stationary or only moving slowly, suspended sediment drops out increasing water clarity and thus light availability for phytoplankton, microscopic algal cells, which may proliferate into blooms. If nutrient levels, and especially phosphorus levels, are high the blooms may consist of cyanobacteria (blue-green algae), many of which produce toxins that can kill fish or stock or people who drink the water. This constitutes a major problem for the reservoir manager.

While water quality in the river may present risks to a reservoir, a reservoir may also present risks to the river downstream. A reservoir changes the quality of water passing through. Some of those changes may occur through the settling out of particles as the river passes through the reservoir. The water discharging downstream will usually be less turbid, but may have higher concentrations of algal cells than the water entering the reservoir. The temperature also usually changes as water passes through a reservoir, as the clearer water heats up. If there are rapid changes in the volume of water discharging from a reservoir this can lead to rapid changes in water quality downstream, and if the water discharged is supersaturated with gas that can lead to kills of fish and invertebrates.

Reservoirs may stratify, with a layer of warm water near the surface, and colder, often deoxygenated, water near the bottom. Predicting stratification of reservoirs such as those proposed or under construction on the Mekong is difficult. Whether stratification occurs, and persists, depends on both the heat balance and the hydrodynamics of the water in the reservoir. The short residence time of the water in these reservoirs will make stratification less likely, but the high thermal loadings from the tropical sun increase the risk.

If stratification occurs, and water from the lower layers of the reservoir is released downstream, that can have a severe impact on water quality. Water from the bottom layer (the hypolimnion) is low in dissolved oxygen, is acid (low pH) and may have high concentrations of dissolved metals such as iron and manganese. Reservoirs will need to be monitored to assess whether stratification is occurring, but the monitoring required will be relatively simple and inexpensive. There is no point in measuring dissolved metals directly because it is slow and expensive and DO and pH are cheap and effective surrogates.

Table 6-1. Monitoring requirements to assess potential risks to water quality associated with mainstream dams

Risk	Consequences	Monitoring
Risks from Construction Activities		
Spillages of fuel and lubricants	Local contamination could impact aquatic ecosystems and fish in the vicinity of the construction site	Frequent visual observation and photo-monitoring of Total Petroleum Hydrocarbons (TPH) as necessary
Runoff of turbid water from bare soil	Local contamination could impact aquatic ecosystems and fish in the vicinity of the construction site	Frequent observation, photo-monitoring during wet weather, sampling for turbidity or SS as necessary
Waste water from accommodation facilities for workers	Local contamination could impact human health, aquatic ecosystems and fish in the vicinity of the construction site	Monitoring of total coliforms monthly, and more frequently if guidelines exceeded
Operational Risks		
Risks to the Impoundment		
Increasing nutrient influx from upstream and the local catchment from non-hydropower related activities	Increased algal growth rates	Chlorophyll monitoring in impoundments
Reduced turbidity and increased light penetration	Increased algal growth rates	Turbidity or Photosynthetically Active Radiation (PAR) monitoring in impoundments. Chlorophyll monitoring in impoundments.
Risks from Reservoir Stratification		
Low dissolved oxygen in hypolimnion (bottom water)	Hypolimnion becomes unavailable to fish and most invertebrates, iron and manganese released from sediments	Temperature and DO profile recorded monthly, at a location close to dam wall
Low pH in hypolimnion	Low pH causes corrosion of hydropower infrastructure, hypolimnion becomes toxic to biota, and metals and nutrients are released from sediments.	Sample hypolimnion monthly if profile shows stratification
High concentrations of dissolved iron and manganese in hypolimnion	May cause deposition issues for infrastructure river bed and downstream.	Sample hypolimnion monthly for dissolved Fe and Mn if profile shows stratification
High concentrations of toxic metals (e.g. mercury) in hypolimnion	Toxic metals may be taken up in biota and potentially passed up food chains and contaminate foods for humans	Sample hypolimnion 3-monthly for dissolved Hg, Cd,
High concentrations of sulphides and nutrients (N & P) in hypolimnion	May trigger algal blooms when reservoir water turns over when stratification breaks down – probably in December-January	Sample hypolimnion monthly if profile shows stratification

Risks Downstream of the Impoundment		
Rapid flow changes	Rapid fluctuations in downstream water quality	Initially continuously monitor conductivity and turbidity ~ 1 km downstream of dam. If rapid fluctuations occur then extend monitoring to other parameters.
Altered water temperature	Negative impacts on downstream biota	Continuous monitoring of downstream water temperature ~ 1km below dam wall.
Reduced turbidity arising from settling of particulates	Increased algal and plant growth, impact on fish behaviour	Monitor chlorophyll monthly 1 km below dam wall
Reduced nutrient concentrations arising from settling of particulates	Reduced nutrient availability to instream and floodplain biota	Monitor Total P and total N monthly below dam wall
Gas supersaturation	Fish deaths	Monitor dissolved oxygen weekly below dam wall using a DO meter.
Risks from reservoir stratification if bottom water is discharged downstream		
Low dissolved oxygen arising from reservoir stratification	Negative impacts on downstream biota	If profile in the impoundment shows stratification, then sample DO ~ 1 km downstream of dam wall
Low pH arising from reservoir stratification	Negative impacts on downstream biota	If profile in the impoundment shows stratification, then sample pH ~ 1 km downstream of dam wall
High concentrations of reduced metals (Fe and Mn) arising from reservoir stratification	Negative impacts on downstream habitat and biota	If profile in the impoundment shows stratification, then sample Fe and Mn ~ 1 km downstream of dam wall
High concentrations of toxic metals leaching from reservoir sediments as a result of reservoir stratification	Negative impacts on downstream biota, and potential impacts on humans consuming fish and OAAs	If profile in the impoundment shows stratification, then sample Hg and Cd ~ 1 km downstream of dam wall
Risks from sediment flushing		
Downstream pulse of sediment	Altered downstream sediment	Should be detected by sediment/geomorphological sampling
Downstream pulse of high turbidity	Downstream biota reduced through avoidance behaviour such as invertebrate drift	Continuous monitoring of turbidity downstream of the dam
Downstream pulse of low dissolved oxygen	Downstream biota reduced through deaths and avoidance behaviour such as invertebrate drift	Continuous monitoring of dissolved oxygen downstream of the dam
Downstream pulse of toxicants	Downstream biota reduced through deaths and avoidance behaviour such as invertebrate drift	Assess ecological health, using MRC indices at 3 locations downstream of the dam each dry season

There are additional risks to downstream water quality while dams are constructed, with the main risks arising from sedimentation from site disturbance, wastes generated by the workforce, and spillages from fuels and lubricants. High frequency or continuous probe-based monitoring is a straightforward means of monitoring for such impacts.

The water quality risks associated with hydropower reservoirs can be classified in a number of ways. One possible classification that is useful for developing monitoring campaigns is to group the risks by the time over which they arise and the potential area impacted. Risks can be allocated to three categories: risks that arise and recede rapidly but generally impact a limited stretch of river; risks that arise more gradually, but affect a greater length of river; and long-term basin wide risks. The first group of risks include those arising due to stratification in the reservoir, flushing of sediment from the reservoir, chemical spills and gas supersaturation. These events can arise suddenly and can cause acute impacts such as fish kills. They may also cease quite rapidly, for example when sediment flushing ceases, or a reservoir is destratified. Often, they impact a relatively short stretch of river downstream of the impoundment, frequently only a kilometre or two, although sediment flushing may impact a longer stretch of river. They will not normally be detected by monthly, or even weekly sampling campaigns, but require high frequency monitoring, but at only one or two locations.

The second group of risks arise more slowly and potentially impact a greater length of river downstream of the impoundment. These risks include impacts arising from flow alterations, changes to suspended sediment load arising from settling of particulates and associated changes to nutrient concentrations, and increases in algal loads arising from algal washout from the impoundment and increased light penetration.

The third group of risks are the large scale, slower timeframe risks that may occur over a broad swathe of the basin as a consequence of the construction and operation of multiple number of hydropower projects. These risks would arise from sediment trapping, changes in primary production, changes in temperature regime and possibly from changes arising from stratification occurring in multiple reservoirs. They are of great concern because they would reflect broad scale changes in basin water quality.

6.1.1 JEM Monitoring at Xayaburi

Water Quality monitoring around Xayaburi took place on a monthly basis between October 2020 and June 2021, except for May 2021 when sampling could not take place because of COVID 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 for Total Suspended Solids (TSS), nutrients, COD and Faecal coliforms. Within the impoundment, water quality profiles of the water column at 1 m intervals down to 20 m depth. The JEM pilot monitoring stations were compared with the results for the WQMN routine monitoring above and below the Xayaburi dam at Luang Prabang and Vientiane.

6.1.2 JEM Monitoring at Don Sahong

Water Quality monitoring around Don Sahong has taken place on a monthly basis between October 2020 and June 2021, except for May 2021 when sampling could not take place because of COVID 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 for Total Suspended Solids (TSS), nutrients, COD and Faecal coliforms. Within the impoundment, water quality profiles of the water column at 1 m intervals down to 20 m depth. The JEM pilot monitoring stations were compared with the results for the WQMN routine monitoring above and below the Don Sahong dam at Pakse and Stung Treng.

6.2 JEM Pilot's Key Findings and Recommendations

The parameters measured during the JEM pilot include some measured in the field and some measured by laboratory analysis of samples collected in the field. Temperature, pH, dissolved oxygen, conductivity, and turbidity were all measured using a water quality meter and probes, while chlorophyll-*a* and cyanobacterial chlorophyll were measured using a field fluorimeter. For those parameters five measurements were taken at each site on each occasion and results were analysed statistically month by month.

Laboratory analyses were conducted on single samples so it was not possible to conduct any statistical analyses for these parameters on a month-by-month basis. The JEM method specified multiple samples (at least three) specifically to allow statistical analysis of the results. Some laboratory parameters: TSS, nutrients, COD and coliforms were limited to a reduced suite of sampling locations to reduce cost, which limited conclusions about impacts at sites where they were not analysed.

There were quality assurance issues apparent with some of the data and it will be important that training for field teams emphasises the need to calibrate probes frequently, the need to pay attention to the results as they are collected and recorded and to note unusual results at the time of measurement and take additional readings where necessary. If multiple samples are taken for laboratory analyses that will provide QA on laboratory analyses, because there will be several measurements at each time x location for which similar results would be expected.

The cables obtained for the WQ meter probes were not sufficiently long to assess the full vertical profile of the impoundments, but it appears likely that there was stratification occurring in Xayaburi pondage in December and possibly January. It will be important to ensure that cables that are sufficiently long are obtained in future

The Algae Torch proved to be a useful monitoring tool providing rapid field-based results for both total chlorophyll-*a* and cyanobacterial chlorophyll. Difficulties were encountered using the Torch in fast flowing water due to air bubbles being reported forming on the surfaces. One suggestion was to collect a water sample in a bucket and then take a torch measurement in the still water in the bucket, and that possibility should be explored. Confirming algae torch results against laboratory absorbance methods for chlorophyll is not necessary, as the two measure different things.

The JEM specification of a single site upstream, a single site within the impoundment, and multiple sites downstream was a suitable design. This design was reduced at Don Sahong due to the downstream dilution of the Mekong River through the flows from other parallel channels. So only two downstream monitoring sites were located within 1.5 km of the Don

Sahong dam. It is suggested that the second site be moved downstream to Cambodia so that samples would be analysed by a different laboratory as a quality control measure. The monitoring of downstream water quality at Xayaburi was carried out at 3 sites at distances of 1, 5 and 12 km downstream of the dam site, for WQ3, WQ4, and WQ5, respectively. It is important that the upstream sites for these and future projects be upstream ob botrh the impoundment and the area of hydraulic resistance which will have a modified flow regime, modified turbulence and therefore modified water quality.

Construction impacts have already been identified for all mainstream hydropower projects with water quality monitoring and sampling commence at least one year prior to construction to establish baseline conditions. The precise location of sampling sites depends mainly on ease of access and safety for the samplers and allowing sampling of the flowing component of the river, and not a backwater area.

High frequency monitoring of turbidity, pH, temperature, conductivity and dissolved oxygen immediately downstream of each impoundment was not able to be implemented, but was considered worth pursuing. A high frequency WQ monitoring probe system is being constructed under the JEM at Don Sahong approximately 500 meters downstream of dam site which will provide a quasi-real time water quality information on any potential operational impacts of Don Sahong, once completed. It is recommended that this high frequency WQ monitoring station be used as a model for a similar system at Xayaburi and future mainstream hydropower projects.

Equipment and sampling and analysis methods for water quality within the MRC water quality monitoring network are standardised and it is important to maintain and follow those standards. There may need to be additional training in, and standardization of, equipment calibration. There may also be a need for additional round-robin testing to ensure comparability between results of national laboratories. Such cross-calibration should occur at least once every three years. It should not be assumed, that monitoring by dam operators will be adequate in the absence of additional requirements, and enforcement, being implemented by regulators.

6.3 Water Quality Monitoring Design

6.3.1 Monitoring Overview

To assess the impact of mainstream dams on water quality in the Mekong adequately requires several related monitoring campaigns (Table 6-2 that differ in measurement frequency, sampling locations and parameter selection, and complement the existing monitoring currently conducted through the Mekong River Commission and national agencies. While JEM WQ design specification was deemed appropriate, implemented challenges prevented the collection of adequate data as mentioned in Section 6.2 Moving forward, it is recommended the JEM WQ design specification of a single site upstream, a single site within the impoundment, and multiple sites downstream be strictly implemented regardless of the location of the mainstream hydropower project and/or the perceived diluting capacity of the Mekong River, contributed by additional flow from either the Mekong River or downstream tributaries. In addition, automate high frequency water quality system should be installed for all future mainstream hydropower projects to provide quasi-real time data and facilitate impacts assessment.

Table 6-2. Proposed Water Quality Monitoring campaigns

Campaign	Frequency	Location	Parameters	Purpose
1	Every 1-4 hours	Within 500 m downstream of each impoundment	Dissolved oxygen, pH, Conductivity, Turbidity, Temperature	To detect potential acute toxic events arising from reservoir stratification, gas supersaturation, algal blooms, chemical spillages, sediment flushing.
2	Once per month	Single location within each impoundment	Temperature, Dissolved oxygen, pH, Conductivity, Turbidity, Light	Vertical profile to detect stratification and risks of algal blooms
	Once per month	One location upstream and up to 4 locations downstream of each impoundment to the next substantial tributary	Dissolved oxygen, pH, Conductivity, Turbidity, Temperature, Light, Chlorophyll, Total P, NO_x,	To detect medium term dam impacts, and extent of dam impacts
3	At most once per month	Sites selected across the basin by MRC	COD, Conductivity, Dissolved oxygen, pH, temperature NO_x, Total P, Chlorophyll, Faecal coliforms.	To detect large scale water quality trends across the basin
	Annually or less often, as required	Sites selected across the basin by MRC	Toxicants (metals, pesticides)	To evaluate risk of specific toxicity issues

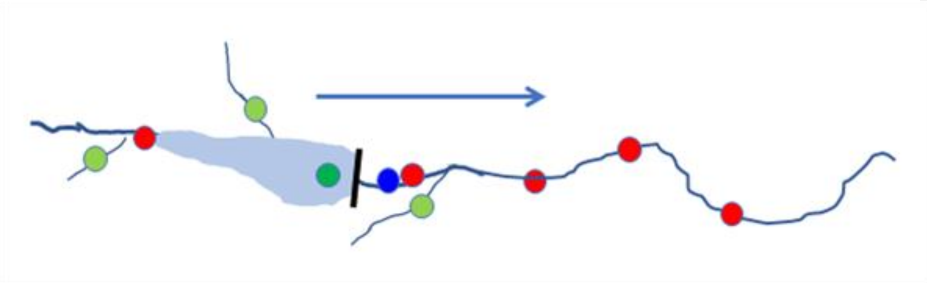

Figure 6-1. Diagram showing the locations for sampling for Campaign 1 (blue symbol), Campaign 2 within impoundment (dark green symbol), Campaign 2 within the river (red symbols) for which site 1 would be the site upstream of the impoundment, with sites 2-5 progressively downstream). The direction of river flow is indicated by the arrow.

Consistent with the earlier classification of water quality risks in Section 6.1, three concurrent monitoring campaigns are proposed, to detect the short term, medium term and long term risks (Table 6-2). Campaign 1 would utilise probes to conduct high frequency monitoring downstream of each impoundment, as indicated in Table 6-2. Data could be downloaded during sampling for campaign 2 or the sampling stations could be linked to MRCS through the mobile telephone network, as is the case for HYCOS stations.

The second campaign (Campaign 2) would consist of monthly sampling at selected sites (Table 6-2). One component of this campaign would involve sampling at one site within the impoundment at which the vertical profile would be assessed through the water column near the impoundment wall, which will usually be the deepest part of the impoundment. The minimum data requirement would be measurements of water temperature at 1-m depth intervals. That would indicate whether stratification was occurring. Measurements of dissolved oxygen, pH and conductivity will provide a valuable indication of some potential water quality problems which can arise from stratification, and measurements of turbidity and light will provide an indication of sediment trapping and potential issues that could arise from algal growth in the reservoir. This will be important information for the reservoir managers.

The second component of Campaign 2 would comprise monthly sampling upstream and downstream of each impoundment to assess medium term impacts. This would attempt to identify firstly whether there is an impact, by comparing results from site 1 (upstream) and site 2 (downstream), and then provide at least a preliminary assessment of the length of river which is impacted. The parameters selected comprise a minimal data set of those most likely to be impacted by an impoundment, with the exception of sediment transport which should be monitored in a separate JEM component. The nominal distribution of sampling locations is indicated in Figure 6-1. The locations of the downstream sites may vary from dam to dam depending on the impact, the furthest downstream site should be a site at which no impact is detected, and the third downstream site should be a site at which weak impact is detected.

Table 6-3. Water quality parameters monitored for the MRC WQN.

Parameters monitored monthly throughout the year	Parameters only monitored between April and October
Temperature	Calcium (Ca)
pH	Magnesium (Mg)
Conductivity (Salinity)	Sodium (Na)
Alkalinity/ Acidity	Potassium (K)
Dissolved Oxygen (DO)	Sulphate (SO4)
Total phosphorous (TP)	Chloride (Cl)
Total Nitrogen (TN)	
Ammonium (NH4+-N)	
Nitrite +Nitrate (NO2+3-N)	
Fecal Coliforms	
Total Suspended Solids (TSS)	
Chemical Oxygen Demand (COD)	
Biochemical Oxygen Demand (BOD)*	

*selected sites only

The third Campaign is primarily based on the existing MRC water quality monitoring network (WQN), which is already established and operating across the basin including the parameters listed in Table 6-3. For the purposes of monitoring HPP the parameter list should be extended by adding chlorophyll as a monitoring parameter. Not all of the existing parameters included in the MRC WQN are relevant to the potential impact of dams on the river but many are. The locations currently sampled (Figure 6-2) are suitable for assessing longer term, basin-wide trends in water quality, although it would be useful to add two more sampling stations, one between Vientiane and Luang Prabang, and a second between Vientiane and Nakhon Phanom. However, the added monitoring upstream and downstream of HPP proposed under the JEM would fill those spatial gaps.

Adding chlorophyll as a monitoring parameter to the WQMN is seen as a critical next step. As towns and cities along the Mekong increase in size, and with investment in wastewater treatment facilities lagging, nutrient enrichment of the river is likely to rapidly increase. At present cities such as Vientiane and Phnom Penh discharge wastewater into natural wetlands which provide free treatment before the wastewater discharges finally reach the river kilometres downstream. However, those wetlands are rapidly being filled to provide cheap land for urban development which will inevitably lead to increased nutrients entering the river, and increased frequency and intensity of algal blooms.

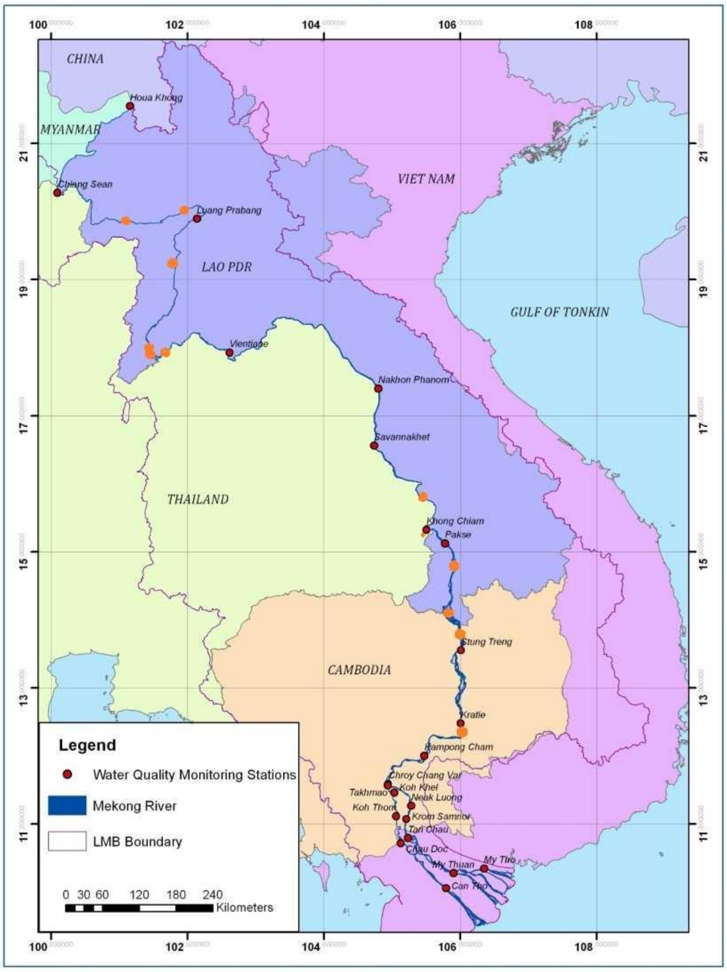

Figure 6-2. Locations of the existing MRC water quality network monitoring sites on the mainstream and the Bassac River. JEM sites will be located upstream and downstream of dams with potential sites indicated in light brown.

Figure 6-3. Satellite image of the Xayaburi Dam site and the Mekong River downstream indicating possible locations for sampling within the impoundment (green symbol) and sampling the river downstream of the dam (red numbered symbols).

6.3.2 Monitoring Locations

Applying the sampling regime to Xayaburi Dam, possible locations for Campaign 2 downstream river sites 2-5 are indicated in red in Table 6-3, together with a possible location for the site for Campaign 2 impoundment site. The specific localities of the sites are not critical, note however, in Figure 6-3 sites 4 and 5 are located upstream and downstream of the next substantial downstream tributary, as a means of assessing to what extent the tributary inflow may ameliorate any impacts arising from the dam. Where there is a substantial tributary within a reasonable distance (e.g. up to 10 km) downstream of the dam it is useful to sample upstream and downstream to assess to what extent any water quality alterations caused by the dam operations are ameliorated by the inflow from the tributary.

The sampling site for the Campaign 1 monitoring should be adjacent to site 2 on the map.

Note that the number and location of WQ sampling sites will be specific to each HPP. Where there is not a substantial tributary joining the river within a reasonable distance downstream then the lower two sites in the Xayaburi example would not be required. At Don Sahong, where the current speed and turbulence from Khone Falls may make midstream sampling at some locations unsafe at all or some times, then safety is the priority and samples should not be collected. In addition, at Don Sahong only a small part of the river flow is directed through the dam, and the outflow is rapidly and substantially diluted downstream so probably only one or two downstream monitoring sites are necessary to determine WQ impact.

The locations of the proposed JEM pilot monitoring sites and possible future JEM sites to capture water quality changes associated with hydropower development in the LMB are shown in Figure 6-2. However, a significant issue will be the distribution of dams and their impoundments. If the dams in the general vicinity of Luang Prabang form a cascade with each dam spilling to the dam immediately downstream it will not be possible to use an upstream-downstream sampling design on individual dams, and sampling will need to be implemented upstream and downstream of the entire cascade.

6.4 Water Quality Monitoring Protocol

Sampling and analytical methods for the water quality network have been established and published (MRC 2013a,b). They are based on the methods in the 20th Edition of Standard Methods for the Examination of Water and Wastewater (AHPA 1998). That publication includes information on both sampling methods (which has been further spelled out in MRC publications) as well as analytical methods. MRC, working with the four national laboratories has developed a list of preferred analytical methods, because the APHA (1998) volume provides an exhaustive list. Analytical quality assurance has been assessed by several MRC exercises, and one of the national laboratories is also certified under a national quality assurance certification system. Methods are reviewed with each new edition of APHA so that they remain current.

6.4.1 Sample Collection

As set out in MRC 2013a, which constitutes the current WQMN procedure:

- water quality samples and field measurements should be collected using a simple surface grab technique from approximately midstream where free flowing water is observable.
- Samples or probe measurements should be taken from a depth of 30-50 cm below the water surface.
- If *in situ* measurement is not possible, samples should immediately be preserved with appropriate preservative agents (i.e. sulphuric acid for nutrients) and stored in a cooler, preferably on ice, to prevent the breakdown of chemicals and biological activity.
- All samples should be analysed within the recommended holding time.

In addition, all probes used with field meters should be calibrated at least prior to each sampling campaign, and preferably prior to each sampling day.

At least three grab samples for water quality analysis should be collected from locations at least 5 m apart, or 5 minutes apart, or both. Multiple probe measurements should be collected at the same time and location as the grab samples. Grab samples may be collected using specialised sampling equipment, such as a Van Dorn sampler, or just with a clean plastic container mounted on a pole (Figure 6-3). The water collected should then immediately be transferred to specific containers for transport and subsequent analysis. The specific containers would include plastic bottles containing sulphuric acid for nutrients, sterile containers for faecal coliform samples, and separate bottles for chlorophyll, suspended solids, alkalinity etc. A field meter must be used for pH (because it can change rapidly during sample transportation), and preferably for dissolved oxygen and turbidity.

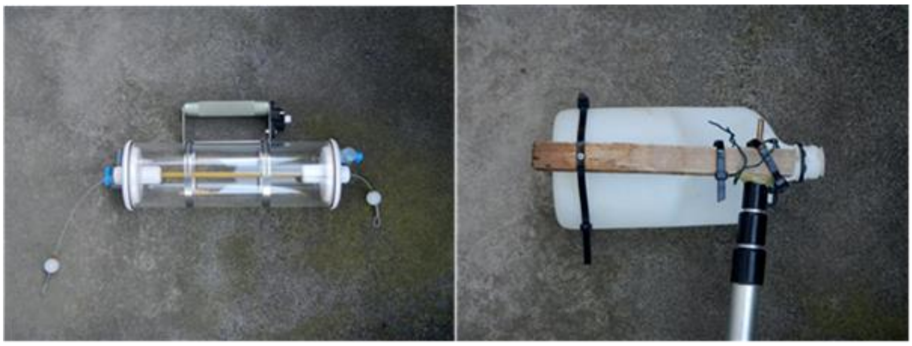

Figure 6-3. Van Dorn water sampler (left) and simple water sampling bottle (right) suitable for water quality sampling in rivers

6.4.2 Analytical Methods

Laboratories are required to adhere to the MRC QA/QC procedures that have been developed in accordance with ISO/IEC 17025-2005, as well as personnel safety procedures when collecting samples and measuring water quality parameters. The specific analytical methods, including those that have been agreed by the four national laboratories, and are now included in the MRC WQMN are listed in Table 6-4. In addition to the agreed methods, recommended methods for turbidity and chlorophyll *a* are also included, since these are proposed as additional parameters for the JEM. Light penetration should be measured with a radiometer fitted with a spherical sensor similar to that produced by LiCor.

6.4.3 Continuous Monitoring Methods

Continuous or high frequency monitoring using probes would best be done at sites where discharge monitoring is conducted. One of the main reasons for this is that the equipment needs to be installed in locations that are accessible but also protected from changes in water level and human interference. There are several guidelines available online that provide detailed instructions on setting up continuous monitoring facilities, as well as their operation, calibration and data management. The most useful are those produced by the USGS (Wagner et al. 2006) and the Province of British Columbia in Canada (Butcher and Gregory 2006).

Table 6-4. Analytical methods either agreed under the MRC WQMN or proposed for use in the JEM water quality component

Analytical Parameter	Agreed or Recommended Method[1]
Temperature	2550 B
pH	4500 – H^+
Conductivity	2510 B
Alkalinity/Acidity	2320 B
Dissolved Oxygen	4500-O
Chemical Oxygen Demand (COD) (Permanganate Method)	British Standard BS 6068-2.34:1988
Total Phosphorus	4500 P
Total Nitrogen	4500 N
Ammonium	4500 NH_3
Total Nitrate and Nitrite (NO_{2+3} N)	4500 NO_3, 4500 NO_2
Faecal Coliforms	9221 – Faecal coliform group
Total Suspended Solids	2540 D TSS
Calcium (Ca)	3500 Ca B
Magnesium (Mg)	3500 Mg B
Sodium (Na)	3500 Na B
Potassium (K)	3500 K B
Sulphate (SO_4^{2-})	4500 SO_4 E
Chloride (Cl^-)	4500 Cl
Turbidity	2130 or commercial meter
Chlorophyll *a*	10200 H
Light penetration	Radiometer with spherical sensor

1. Numbers refer to the numbers of the methods in in APHA (2017) and subsequent editions.

6.5 Water quality data analysis for JEM

Mekong River water quality data have been analysed using a variety of methods. The earliest were simple box and whisker plots (e.g. Hart et al. 2001), which can be examined visually for trends and also indicated variability. The MRC also developed several Mekong specific indices: an Index for Protection of Aquatic Life, and Index for Human Impact on Water Quality and an Index for Agricultural Water Quality (Campbell 2014). The indices were specifically developed to allow simplified reporting of water quality risks and changes in the annual water quality report cards and would not be applicable to the JEM activity, although they have been used extensively by the MRC (e.g. MRC 2013a, 2013b, 2016). More recently, sophisticated non-parametric techniques have been applied to test for long-term trends in parameters (Kong Meng unpublished ms). Data collected for JEM purposes under Campaign 2 should be included in the ongoing MRC WQN database and regional water quality analyses. This inclusion would add to spatial coverage for the river downstream of Luang Prabang and downstream of Vientiane since dams are proposed, or under construction in both regions.

For the purposes of JEM procedures, the primary issues of concern will be detecting changes in individual parameters. For example, likely questions of interest would include whether a dam is altering downstream water temperature or increasing downstream chlorophyll. Collection of multiple samples as is proposed here will allow differences between sites to be tested using Analysis of Variance (ANOVA). ANOVA is a powerful statistical tool that can be used in environmental sciences to determine the probability that differences between sites (or treatments) are greater than differences within sites, i.e. whether differences in measurements between sites are due to an impact or simply arise from normal variability in river water quality.

Impacts will be identified where there are statistically significant differences between upstream and downstream sites for a given parameter, and the differences are sufficiently large to be ecologically important. So, for example, if there was a statistically significant difference in measured water temperature of 0.1 °C between upstream and downstream it would probably not be considered ecologically important, but a difference of 5.0 °C would be considered important.

6.5.1 Basin-scale analysis

The JEM results have been compared to the WQMN sites along the Mekong mainstream by calculating the Water Quality Indices for the Protection of Aquatic Life and the Protection of Human Health. 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 3 in the JEM final report, 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 impoundment, the failing parameters are pH and NO32 and TotP.

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 WQMN sites over the decade between 2010 and 2020. There is a marked variability between the years reflecting the different hydrological conditions each year and hence the different levels of turbulence resulting in 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 Suspended Sediment Concentration (SSC). 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 and reflecting 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.

6.5.2 Integration of water quality data with results from other disciplines

Water quality is strongly influenced by hydrology and sediment within the water column. Many contaminants are mainly transported in rivers adsorbed on to, or even within, suspended particles. These include nutrients such as nitrogen and phosphorus, organic pesticides and trace metals, including toxic metals such as mercury. Contaminants transported in these forms may be firmly bound so that they are not available to promote the growth of algae or exert a toxic influence, but they may also be released into solution under certain conditions. For example, if the sediment particles settle in locations where oxygen is absent, many toxic metals may be released into solution causing toxicity to organisms that may be present. Acid rain is thought to be toxic to animal life in lakes primarily because under acid conditions toxic aluminium ions present in clay minerals are released into the water.

The relationships between water quality, hydrology and suspended sediment are complex. However, information on discharge (including prior discharge) and sediment concentrations are both important when water quality data are being interpreted.

The riverine biota responds to the full range of environmental conditions, including water quality. However, the assemblage of organisms that is present in the river rarely reflects the water quality at the time of sampling. Water quality is variable over time. If the biological assemblage at a site is diverse and healthy it is certain that water quality has been good, at least from their perspective, for some time past. If the assemblage is not healthy, this may be because the substrate is not suitable, the flow pattern is not suitable or water quality has been unsuitable in the past. Water quality data are therefore an important tool enabling the interpretation of aquatic ecology data. Aquatic ecology data are non-specific – they can indicate a problem and give some indication of the type of problem. Chemical water quality data are highly specific, because only the parameters that are analysed are detected, and the concentrations measured are those at the time and location sampled.

Water quality data are an invaluable tool for assisting the interpretation of data of aquatic ecology and fisheries, but they are imprecise, and only one of the factors to which the biota are responding.

6.6 JEM Future Work

6.6.1 Continuation at Xayaburi and Don Sahong

The three proposed water quality campaigns should be continued:

- continuous or high frequency monitoring installed immediately downstream of Xayaburi reservoir, to detect short term changes in water quality (installation is being conducted by the company at Don Sahong);
- monthly campaign sampling within the reservoir, at a site upstream and at least 2 sites downstream to detect longer term changes in water quality (for Don Sahong, one of the two downstream sites should be located inside the national boundary of Cambodia;
- more frequent campaign sampling sites across the basin to detect large scale long-term changes.

The first campaign should focus on turbidity (to monitor sediment flushing), dissolved oxygen (to monitor gas supersaturation) and pH to monitor for impacts of stratification) all of which can be monitored using probes.

The second campaign should include continue assessing a monthly profile for the full depth at a deep site within the reservoir where temperature, dissolved oxygen, conductivity, pH, Chlorophyll *a*, turbidity and light penetration (PAR) should be monitored. A sufficiently long cable needs to be obtained to allow measurements to be taken to the bed of the reservoir. Where this monitoring identifies stratification or incipient stratification, as has been the case at Xayaburi, it should continue indefinitely. If no sign of stratification is detected within the first three years, then frequent profiling should be discontinued, perhaps with checks every five years or so if conditions change.

The second campaign should monitor one location upstream and several locations downstream (including sites above and below the next substantial tributary) monthly for dissolved oxygen, pH, conductivity, turbidity, temperature, light (PAR), chlorophyll *a*, total P and NOx. At present two monitoring sites are located immediately downstream of the Don Sahong. One of these should be relocated further downstream within Cambodia, as an additional QA measure. Should results of these monitoring campaigns suggest water quality issues, more frequent monitoring of specific and/or problematic water quality indicators should be considered. The algae torch is an effective instrument for assessing chlorophyll *in situ*. The number of downstream locations, and their locations, depend on downstream tributary inflows

The third campaign should consist of the existing WQMN possibly supplemented by two additional sites, one upstream and one downstream of Luang Prabang since these two stretches of river are stretches potentially impacted by dams which currently have no monitoring sites. Furthermore, chlorophyll should be added to the sampling parameters, to allow detection of algal blooms, which are likely to become and increasing problem.

For samples collected for laboratory analysis at least 3 samples should be collected, and analysed separately, for each parameter. This will assist quality assurance and ensure that statistical analysis can be used to detect changes on a month-by-month basis which is important in detecting HPP impacts.

6.6.2 JEM Monitoring at New HPPs

The basic JEM monitoring design applied at Xayaburi, and upstream control and several downstream impact sites, is robust and effective and may be applied at future HPPs. The number and location of monitoring sites will need take into consideration the HPP localities in relation to other impoundments, as well as the nature of the channel and infrastructure in both the control and the potentially impacted stretch of river. Additionally, automated high frequency water quality systems should be installed for future mainstream hydropower projects wherever appropriate to facilitate impact assessment.

As previously noted, where hydropower dams are structured in cascades, as seems to be the case here, with each dam spilling directly into the next dam downstream, it will not be possible to implement the upstream control and downstream impact sampling site design. In those circumstances the upstream sites should be located above the cascade and the downstream sites below the whole cascade. A possible JEM large-scale monitoring design is indicated in Figure 6.4 based on sites upstream and downstream of each dam, but because of the dam cascades it is not practical.

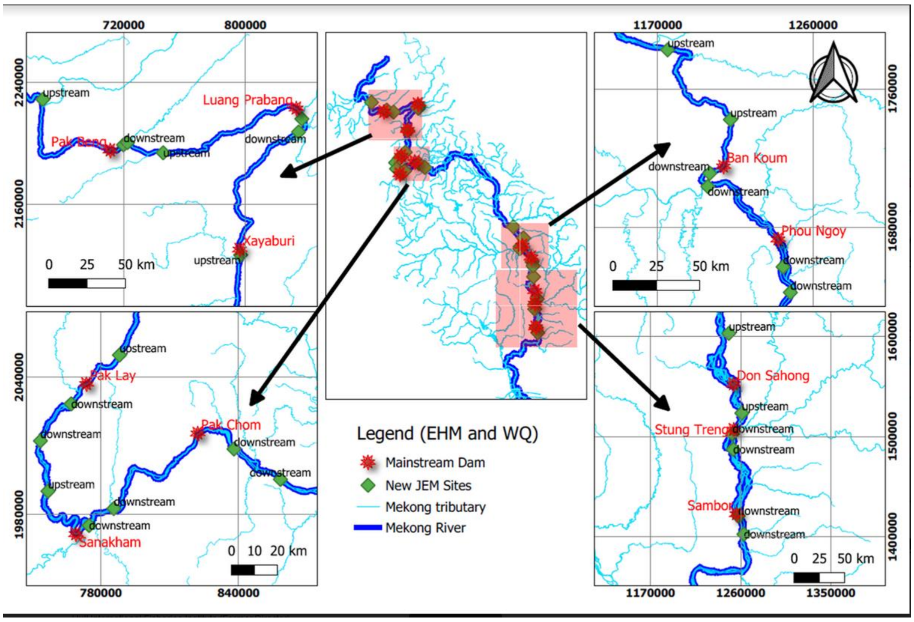

Figure 6.4 showing the location of dams in the upper Lao cascade and possible locations of control (upstream) and impact (downstream) sites for JEM water quality and EHM monitoring

The distribution of dams appears to form three cascades: one upstream of Vientiane between Vientiane and Chiang Saen, one upstream of Khone Falls, and another upstream of Sambor. For each cascade possible locations for at least 2 upstream control sites and three downstream impact sites are could easily be identified. The impact sites for the cascade above Khone Falls would serve as the control sites for the cascade above Sambor. This would be a preferable monitoring design and require fewer sites.

6.6.3 Incorporation of the JEM Monitoring into routine monitoring and the CRMN

To facilitate basin-wide impact assessment and identification of hydropower development, particularly for projects located in the mainstream, data collected as part of the JEM can and should be incorporated into MRC water quality databases following suitable QA checks. It is recommended that following JEM pilots for each mainstream hydropower project, WQ stations of JEM be integrated into WQMN for the monitoring of long-term effects of hydropower operation. The feasibility of the integration into the WQMN should be examined as part of the CRMN in consideration of not only water quality but also other environmental monitoring components, including hydrology and sediment. In particular, potential transboundary impacts of hydropower operation should be considered when deciding on the precise locations of downstream monitoring sites.

7 Aquatic Ecology

7.1 Introduction and Background

The organisms that live in rivers provide valuable insights into the ecological health of rivers. The algae and invertebrates in the river are critical components of the food web, providing food for fish, birds, amphibians, reptiles and people. In addition, they are responsive, and sensitive to changes in water quality, physical habitat and flow regime, and, because they are relatively easy to sample compared with some other components of the fauna they have been widely used as water pollution or river health indicators for over a century.

The construction and operation of dams has a profound impact on the biota and thus the ecology of the rivers that are dammed. There are a number of alterations to the river which trigger these impacts.

Firstly, the dam acts as a physical barrier which interferes with movement of plants and animals both up and down the river. Organisms which naturally move up the river may find their paths blocked by the physical barrier and may be unable to pass either because the flow of water through hydropower turbines, over spillways or even through fish ladders is too fast or too turbulent, or because they may not be able to locate the passageway through which they could pass. Organisms which naturally move downstream may be trapped in the impoundment where the current which would naturally transport them is greatly reduced or even absent.

Secondly, the water released below the dam may differ from that upstream in temperature, chemical water quality or the biota it carries. The differences in temperature arise because the water at the surface of the impoundment is subject to more solar heating than water in the river, while, if the reservoir stratifies, the bottom water is colder than normal river water. Chemical water quality can change because of particulate material settling out of the river water in the less turbulent standing water of the impoundment, and because of lower dissolved oxygen and pH, and potentially higher concentrations or reduced iron and manganese in the bottom water of stratified reservoirs. Finally, the still water of impoundments can result in a far higher biomass of algal cells, and/or the zooplankton that feeds on them than would occur in the turbulent river. To the extent that these chemical changes affect the quality of the water which is released, they can also influence the riverine biota downstream.

Thirdly, an impoundment acts as a trap for sediments which are transported by the river. The extent to which the sediment load of the river is decreased by a dam depends on a number of factors including the size and shape of the impoundment. The consequence of sediment trapping is that the river downstream contains “hungry” water which will tend to pick up additional sediment from the stream bed and banks, altering the shape and structure of the river channel, and thus the composition and abundance of the biota that lives there.

Fourthly, an impoundment alters the flow of the river downstream. The extent of the alteration depends on the size of the impoundment relative to the size of the river, the purpose of the impoundment, whether river water is diverted for other uses such as irrigation, and the operational rules for the dam. A dam operated purely for hydropower purposes does not alter the total amount of water passing down the river each year very much, but the pattern of flow is altered, with the seasonal low flows increased and the seasonal high flows decreased. In addition, there are often daily pulses in flow, as increased amounts of water are passed through the hydropower plant during periods of increased electricity demand. The biota of the river has evolved in response to the flow regime. Low flow periods, when currents are reduced, are often the times when species breed, because the risk to eggs or larvae of being washed out is reduced. High flows may be important in filling floodplain wetlands, watering flooded forests and providing breeding and feeding opportunities to species that move between the river channel and the floodplain habitats. Within the river channel organisms are patchily distributed depending on the substrate and the current. Some insects are filter feeders, anchoring themselves to the substrate and building nets, fans or mouthparts to filter organic particles from the water. Each time there is a sudden appreciable change in current speed within their microhabitat they must move to find a location better suited to feeding.

Finally, the impoundment creates a new lake like habitat, often in a location where no such habitats previously existed. Such habitats may be colonized by species capable of dispersing widely and colonizing rapidly, and many such species are pest species. In the Mekong a number of aquatic pests, or potential pests, are already present. They include species such as giant mimosa, water hyacinth, *Salvinia*, golden apple snail and a number of exotic fish species, such as several *Tilapia* species.

Development of an effective and appropriate aquatic ecological monitoring strategy requires identification of the major risks to the ecology of the river, and the potential monitoring strategies that may be implemented. Many of these are tabulated below (Table 7-1), based on a table included in the review document.

Table 7-1. Monitoring requirements to assess potential risks associated with mainstream dams to aquatic ecology of the Lower Mekong River.

Risk	Consequences	Monitoring
Within the Impoundment		
Loss of lotic habitat	Loss of habitat area available to aquatic species reliant on flowing water, and their consumers	
Occurrence of toxic algal blooms	May occur if nutrient levels, and especially phosphorus levels become too high	Monitoring of chlorophyll in surface water, with frequency increasing if chlorophyll > 5 µg/L
Infestations of invasive plants	Water hyacinth, *Salvinia* and water cabbage all occur in the basin and all have caused major problems in reservoirs elsewhere	Inspect impoundment twice a year, increase monitoring if pest species evident
Infestations of invasive animals	Golden apple snail and several fish species occur in the basin and have caused problems elsewhere in southeast Asia	Inspect for Apple snail twice per year, increase monitoring if pest species evident
Increases in parasite load of local human populations	Malaria and schistosomiasis are not expected to become	Annual health checks and, if necessary, treatment for local

Risk	Consequences	Monitoring
	problems, but fascioliasis (liver fluke, lung worm and heart worm) incidence is likely to increase if people consume raw fish	people.
Loss of deep holes	Deep holes along the Mekong mainstream, if inundated within an impoundment, will stratify and eventually fill with sediment, resulting in a loss of habitat to aquatic organisms dependent on the environmental conditions provided by deep holes.	Assessments each 3 years using depth sounding equipment
Downstream of the Impoundment		
Barrier to movement of nutrients	Water downstream may be nutrient poor, impacting food chains	Combination data from the WQ monitoring program and long-term EHM programme
Barrier to movement of carbon	Water downstream may be depleted in fine particulate carbon, impacting food chains	EHM will reveal a reduction in filer feeding invertebrates
Barrier to movement of biota	Migratory crustaceans, molluscs and some insects may be unable to colonise upstream reaches	Use existing EHM data from sites upstream and downstream of dams.
Benthic community degraded as far as next substantial tributary	The reasons for benthic community impact are uncertain, but probably a cumulative result from changes in riverbed geomorphology, water quality and flow patterns.	Monitor MRC indicators (littoral invertebrates, benthic invertebrates, zooplankton and benthic diatoms) annually at several sites down to, and one site downstream of, the next tributary contributing at least 2% of the flow.
Altered river water temperature downstream of dam	May exceed thermal tolerances of biota, may cause oxygen levels to be reduced below the tolerances of biota, either of which will cause biota to die or drift away	Monitor MRC indicators (littoral invertebrates, benthic invertebrates, zooplankton, and benthic diatoms) at a site ~ 1km downstream of the impoundment.
Poor water quality downstream of dam	May cause death or drift of biota; deposition of iron or manganese may render habitat unsuitable to biota for many years	Monitor MRC indicators (littoral invertebrates, benthic invertebrates, zooplankton, and benthic diatoms) at a site ~ 1km downstream of the impoundment.
Changes to Downstream Flows		
Increased short-term variation in river levels	Littoral fauna may be stranded, and littoral algae have insufficient time to develop, reducing availability of grazing invertebrates and fish	Monitor MRC indicators (littoral invertebrates, benthic invertebrates, zooplankton, and benthic diatoms) annually at several sites down to, and one site downstream of, the next tributary contributing at least 2% of the flow.
Increased dry season flow	May reduce reproductive success of biota that breed in the dry season and decrease availability	Monitor MRC indicators (littoral invertebrates, benthic invertebrates, zooplankton, and

Risk	Consequences	Monitoring
	of riparian habitat	benthic diatoms) annually at several sites down to, and one site downstream of, the next tributary contributing at least 2% of the flow.
Decreased wet season flow	Decreased floodplain contributions (carbon, energy, and nutrients) to the river, which in turn impact on biota	Monitor MRC indicators (littoral invertebrates, benthic invertebrates, zooplankton, and benthic diatoms) annually at several sites down to, and one site downstream of, the next tributary contributing at least 2% of the flow.
Delay to flood season flows	May interfere with reproduction of species which breed during the flood season.	Monitor MRC indicators (littoral invertebrates, benthic invertebrates, zooplankton, and benthic diatoms) annually at several sites down to, and one site downstream of, the next tributary contributing at least 2% of the flow.
Delay to dry season flows	May interfere with reproduction of species which breed during the dry season.	Monitor MRC indicators (littoral invertebrates, benthic invertebrates, zooplankton, and benthic diatoms) annually at several sites down to, and one site downstream of, the next tributary contributing at least 2% of the flow.
Downstream geomorphology (habitat) altered as a consequence of changed flow regime	The altered habitat – changes in the proportion of sand, gravel, cobbles, or boulders - will alter the biota present	Monitored under sediment monitoring
Changes to Floodplains		
Reduction in area of floodplain inundation	Reduced floodplain production; reduced reproduction of plants, invertebrates, and fish on the floodplain	Use existing hydrological models such as SWAT or MIKE 11 and remote sensing data to establish whether changes occur. Establish permanent vegetation quadrats in potentially impacted sites, re-evaluate quadrats annually
Reduction in period of floodplain inundation	Reduced floodplain production; reduced reproduction of plants, invertebrates, and fish on the floodplain	Use existing hydrological models and remote sensing data to establish whether changes occur. Establish permanent vegetation quadrats in potentially impacted sites, re-evaluate quadrats annually
Change in timing of floodplain inundation	May lead to reduced reproduction of plants, invertebrates, and fish on the floodplain	Use models and remote sensing data to establish whether changes occur. Establish permanent vegetation quadrats in potentially impacted sites, re-evaluate quadrats annually

Risk	Consequences	Monitoring
Reduction in nutrient load to the floodplain	Reduced productivity in both floodplain wetlands and seasonal terrestrial systems.	Use models and remote sensing data to establish whether changes occur. Establish permanent vegetation quadrats in potentially impacted sites, re-evaluate quadrats annually

7.1.1 JEM Monitoring at Xayaburi

EHM sampling stations were established above Xayaburi (EHM1) EHM2 – within the impoundment, EHM3, 4, 5 and 6 downstream. The collection of samples can only be done at times of low flow, i.e., during the dry season, and the identification of species requires significant 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 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.

7.1.2 JEM Monitoring at Don Sahong

EHM sampling stations were established above Don Sahong (EHM7), within the impoundment (EHM8), and EHM9 and 10 downstream. The collection of samples can only be done at times of low flow, i.e., during the dry season, and the identification of species requires significant 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 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.

7.2 JEM pilot Key Findings and Recommendations

The Ecological Health monitoring proved to be sensitive to the influence of dams with ecological assemblages showing recovery from disturbance downstream.

Field measurements undertaken at the time of sampling were: the Site Disturbance Score (SDS), which at present does not include impoundments as a disturbance, but it would now be appropriate to revisit that and include information on impoundments; a substrate suitability score. This assesses the suitability of the stream bed at the site of sampling for a range of aquatic organisms.

The sampling methods and the indicator suite are specifically designed for the river and should be reviewed for impoundment sites. A distinct system for assessing reservoirs may be required. The MRC needs to consider whether the status of reservoirs is important in an MRC context beyond their impact on the river downstream.

For most of the indicator groups sampling can only be undertaken when river flows are low. It would be possible to add a second annual sampling run in the dry season, but it is not clear what the benefit would be. Only approximate locations for sampling can be specified in advance, and sampling teams must find suitable locations allowing for the appropriate substrate, access etc.

Statistical analysis was limited because only single samples were taken at each site. As a result, the range of statistical tests that could be applied was limited. It should be noted that the biota responds to a wide range of factors, and biological indicators will not correlate well with water quality indices, fisheries results or substrate conditions.

7.3 Aquatic Ecology Monitoring Design

7.3.1 Monitoring Design Overview

Selection of the most appropriate approach to monitoring aquatic ecology requires decisions on the biological indicators to be selected, the number and locations of sampling sites, the frequency and timing of sampling, and the number of samples to be collected at each site on each occasion as well as the data analysis techniques to be used for interpretation of the results.

7.3.2 Biological Indicator Selection

The first challenge for ecological monitoring of rivers is to identify the most suitable indicators. In indicator selection there are a number of factors to be considered. The indicators must be sensitive to the potential pressures that are expected. They must also be practical, which means that they must be readily sampled and counted, and able to be identified by specialists within the basin.

In 2002, the Mekong River Commission assessed a number of potential biological indicators for use in the Ecological Health Monitoring (EHM) activity. Of those assessed, the use of fish was rejected because of the effort required to obtain an adequate sample. Benthic macroinvertebrates from the littoral (edge) and mid-channel were both chosen because they are easily collected and have been the most widely used group for biomonitoring in streams (Resh, 2008). Zooplankton were also selected because they are easily collected and occur throughout the river. There were also specialists available who could identify the taxa collected. Finally, attached diatoms, a group of algae were also selected for the same reasons as zooplankton. These indicators remain the most appropriate for continued monitoring of the river, and for monitoring of HPP impacts.

In ISH11 it was recommended, that some measure of phytoplankton should be added as an indicator. The suggestion is useful, because there is potential for increased algal growth causing problems in impoundments and downstream, and phytoplankton probably plays an important role in supporting secondary production in much of the river. The river continuum concept (Vannote *et al*., 1980) suggested this would be the case in a large river such as the Mekong, although the turbidity of the river may limit phytoplankton growth in the water much of the time. Measurements of production at 13 sites in the dry season of 2003 found that 8 sites were autotrophic – that is, most of their energy was derived from photosynthesis from phytoplankton (Davison, unpublished data).

There are a number of different methods by which phytoplankton could be monitored. The measurements of primary production, as conducted by Davison, is one technique, but measurements of chlorophyll and the enumeration and identification of algal cells are also commonly employed. Measurement of primary production is relatively time consuming in the field, with measurement usually being conducted from dawn until dusk, although, with some whole river techniques, measurements can be made using meters which may be left to run independently. Chlorophyll measurements are relatively simple as long as there is access to a spectrophotometer, but is a relatively coarse measure, correlating with total algal biomass. Use of fluorometric techniques allows chlorophyll to be determined in the field, and some instruments allow assessment of the relative abundance of up to five different algal group including green algae, diatoms, cyanobacteria. However, the instruments are expensive, and calibration would be difficult in the Mekong region.

Collection of samples for the enumeration and identification of phytoplankton can be conducted in several ways. Historically samples were collected using a very fine phytoplankton net, but in a turbid system like the Mekong the net would rapidly clog, and even a fine net can miss a number of the smaller species. More commonly, water samples are collected, and subsamples are concentrated using sedimentation or filtration before counting using an inverted microscope or Sedgwick Rafter cell (APHA, 2017). The primary difficulty in implementing this technique for monitoring lies in finding specialist staff able to identify the algal cells collected. If the algae cannot be correctly identified, then this monitoring cannot be effectively implemented, and it is not clear whether there are sufficient specialists within the basin to undertake such work.

In view of the preceding, it is recommended that either taxonomic identification and enumeration of algal cells, or fluorimetric assessment of algal groups or chlorophyll estimates of phytoplankton biomass, is included in HPP monitoring.

7.3.3 Frequency and timing of sampling

The MRC EHM is currently conducting EHM every second year. While that is adequate, but not ideal, for detecting long term basin wide trends in river health, ISH11 suggested that annual monitoring would be necessary for monitoring the impacts of hydropower dams, or any other intervention in the basin and is recommended. More frequent monitoring could be conducted for phytoplankton (and potentially zooplankton) but collecting littoral or benthic invertebrates or diatoms is not practical, except during the March-April low flow period.

7.3.4 Number and location of sites

The most powerful study design for detecting or monitoring these types of environmental impact is the BACI design (Before, After, Control, Impact) (e.g., see Green, 1979 and 2.3). As the name suggests, and in the case of an investigation of the impact of a dam, this requires multiple samples collected upstream of the dam impact area (i.e., upstream of the potentially inundated area) to serve as the controls, and multiple samples downstream of the dam, within the impact area which serve as the potential impact samples (Figure 7-2*Error! Reference source not found.**)***. Samples should ideally be collected before dam construction and after construction is complete. In addition to knowing whether the construction of a dam has an ecological impact, a further important question is the length of downstream river which is impacted. It is believed that impact may be substantial as far downstream as the next downstream unregulated tributary (Marchant and Hehir, 2002), so it is proposed to extend monitoring downstream and to include sites upstream and downstream of the next substantial downstream tributary if that is practicable.

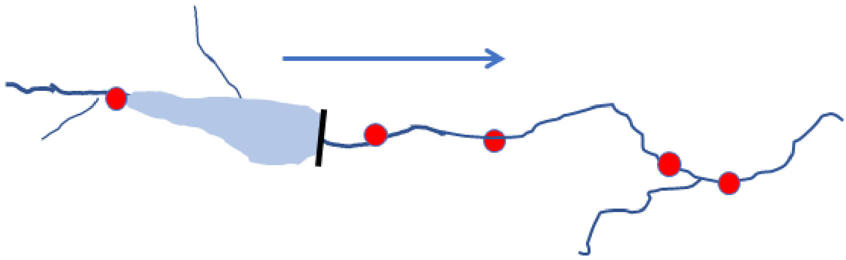

Figure 7-1. Conceptual layout of biological monitoring sites to assess the impact of a dam on the aquatic ecology of a river. Red circles indicate locations of sampling sites

In addition to monitoring at particular dam sites, it is important to add at least two additional sites to the MRC EHM network for which the distribution of existing sites is illustrated in the map in Figure 7-2. An additional site is required between Vientiane and Luang Prabang, and another between Luang Prabang and Chiang Saen. They are both long sections of river that are being affected by dams, and in which there are no EHM sampling sites. However, if the aquatic ecology monitoring proposed under the JEM for Xayaburi is adopted that would include sites downstream of Luang Prabang and were the JEM to be implemented for dams proposed between Chiang Saen and Luang Prabang that stretch of river would also be adequately monitored.

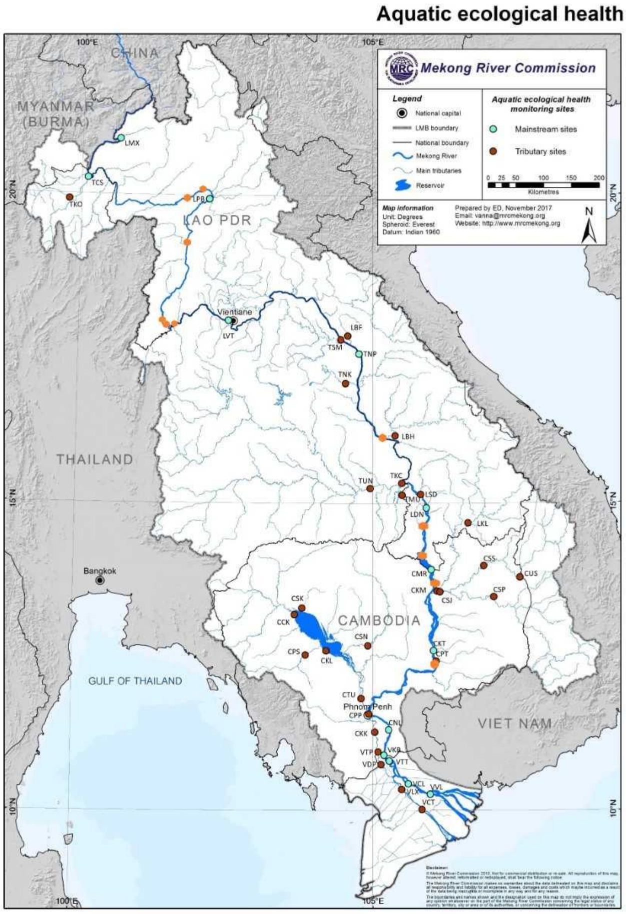

Figure 7-2. Locations of sites that have been sampled under the MRC Ecological Health Monitoring activity with mainstream sites indicated in green. JEM sites will be located upstream and downstream of dams, with possible locations indicated in light brown.

An example of the distribution of proposed sampling sites downstream of Xayaburi dam is illustrated in Figure 7-3**Error! Reference source not found.**. The specific localities cannot be defined in advance because they will depend on issues such as accessibility and the presence of suitable substrates for benthic sampling. Sampling must be conducted by suitably qualified professionals capable of selecting appropriate sampling sites.

The locations of the proposed JEM pilot monitoring sites and potential future JEM sites to capture aquatic ecological changes associated with hydropower development in the LMB are shown in Figure 7-2.

Figure 7-3. Locations of proposed aquatic ecology sampling sites downstream of Xayaburi Dam. There would also be at least one site located upstream. Base figure sourced from Google Earth.

7.3.5 Number of samples

In order to detect dam impacts with a BACI design study, it is necessary to have multiple samples at each location. While this can be done by collecting a single sample at each location every year for a number of years, with this approach the impact cannot be reliably detected until three to five years after it has commenced. So it is recommended that three samples of each indicator be collected at each site on each JEM sampling occasion, to provide at least a minimal estimate of sample variability.

7.3.6 Sample collection and processing

National EHM teams have already been established in all four member countries and should be able to conduct aquatic ecology monitoring at proposed and existing dam sites. The MRC has already developed a detailed manual for sampling of benthic and littoral invertebrates, zooplankton and benthic diatoms (MRC, 2010), and it is important that these methods are strictly adhered to, so that we can be sure that differences in results are attributable to difference in the river, rather than differences in sampling methods.

If phytoplankton is to be added as an indicator, then the sampling procedure followed should be similar to that described in MRC 2010 for zooplankton. This prescribes three samples to be collected across the river, one each within 4-5 m of the river edge and one in midstream. For zooplankton, a 10-L water sample is collected and passed through a net, but for phytoplankton a 1-L water sample is sufficient and should be preserved with Lugol's solution if it cannot be returned to the laboratory within two days. Samples should preferably be concentrated by settling and may be subsampled for counting and identification. Detailed methods are provided in section 10200 A-F of APHA 2017.

There are potential problems with inconsistent taxonomic identifications between different national teams. It is very important to maintain consistency, so it will be necessary for the national expert for each taxonomic group to participate in a regional taxonomic identification workshop at a suitable location which has the facilities to support the national experts working together to identify the material which has been collected. The initial sorting of material into broad taxonomic groups can be carried out in the home countries, but final identifications should be completed at these workshops.

7.4 Aquatic Ecology Monitoring Protocols

The protocols for each of the existing aquatic ecology indicators have been specified and described in detail by MRC (2010)(http://www.mrcmekong.org/assets/Publications/report-management-develop/E-biomonitoring-methods.pdf), together with specifications of the methods to calculate the assessment indices. Summaries of the protocols are included here in Vol 2 Annexes 14-17

7.5 Aquatic ecology data analysis

There have been many methods developed for, or applied to, the analysis of biomonitoring data from streams. These date back as far as 1902 when Kolkwitz and Marsson published their initial studies. One approach has been to develop indices of various kinds, often based on the presence or abundance of particular taxa. This was an approach originally used based on the Kolkwitz and Marsson saprobien system (Kolkwitz and Marsson, 1902), but there have been many indices proposed since that time. For example, Mustow (2002) in Thailand used the BMWP index originally developed in Britain. There is a concern when an index based on faunal composition developed in one geographical region is transferred uncritically to another, where the fauna and flora may be substantially different.

The MRC biomonitoring programme developed Mekong specific indices (MRC, 2008; MRC, 2010). The main index is the Average Tolerance Score per Taxon (ATSPT), which is based on an evaluation of taxon tolerances at reference and impacted sites within the lower Mekong basin.

Some studies have used approaches based on species diversity drawn from other fields of ecology. The guiding principle is that stressed communities will contain relatively fewer species or other taxa than non-stressed communities. A number of species diversity indices have been developed as a means of measuring or testing the principle. A species diversity index was applied to aquatic ecology data in two of the environmental impact assessments for Mekong mainstream dams.

7.5.1 Basin Scale Analysis

The Ecological Health Indices (EHI) and classification for all the mainstream sites from 2011 to 2019 are shown in Figure 7-2. 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.

Table 7-2: 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 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.

This analysis serves to illustrate the localised changes taking place in the Ecological Health of the river within the impoundment and immediately downstream of the dams. It is recognised 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 stabilising and recovering from the disturbance caused by dam construction. The Ecological Health Indices (EHI) and classification for all the mainstream sites from 2011 to 2019 are shown in Table 7-2***Error! Reference source not found.***. 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.

7.5.2 Impact Analysis

The Ecological Health Monitoring (EHM) results around Xayaburi show clear differences in the species diversity and numbers of biota present within the impoundment and downstream compared to the upstream reference site but with only single samples it is not possible to attribute a cause to these differences. 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 biotic indicators 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.

The Ecological Health Monitoring (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 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 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.

7.6 Data Storage and management

EHM data should be incorporated into the MRC data management system. Publication of the results, as has been the case in many previous EHM surveys, is desirable.

7.6 JEM Future Activities

7.6.1 7.7.1 Future Activities at Xayaburi and Don Sahong

Monitoring at Xayaburi and Don Sahong should be continued for at least two additional years. The present activity has provided only a single year's data which has produced useful results, but additional data would strengthen conclusions. It would be helpful if multiple samples were collected in future years so that effective upstream/downstream statistical analyses of the data could be conducted. Surveys should be conducted within Xayaburi impoundment, particularly to detect emerging problems with algal blooms or invasive species.

7.6.2 JEM Monitoring at New HPPs

JEM HPP monitoring design using the indicator taxa and indices presently employed by the MRC EHM and following the methods developed and documented by the MRC (MRC, 2010) could be applied at future HPPs using a similar BACI study design. It is necessary that multiple samples be collected at each sampling site to allow statistical analysis of data collected.

Figure 6.4 shows the distribution of sampling sites using a BACI design with upstream and downstream sites for each individual dam. As is evident from the figure this is not a practical design if dams are constructed in cascades, with each dam spilling into the pondage of the next dam downstream. There will not be a stretch of river upstream or downstream to sample in a number of dams. In those cases the control sites will need to be located upstream of the entire cascade, and the downstream impact sites below the whole cascade. In the case of the dams in the vicinity of Luang Prabang that would locate control sites in the vicinity of Chiang Saen and the impact sites in the vicinity of Vientiane. For cascades further downstream, the sites used would be in the vicinity of Ubon Ratchathani as controls with downstream sites above Khone Falls and below Sambor

7.6.3 Incorporation of JEM Activities into routine monitoring and CRMN

There will be no difficulty incorporating JEM EHM monitoring in to other monitoring activities as long as MRC sampling and data analysis protocols are followed, and suitable QA procedures are put in place.

8 Fish and Fisheries

8.1 Introduction and background

The development of fish and fisheries monitoring for JEM was based on a review of global inland fisheries monitoring techniques and existing monitoring systems undertaken in the Mekong under the auspices of the MRC and MC line agencies (specifically FADM, FLDM and fisheries habitat monitoring) and identification of information gaps that needed to be addressed to provide an understanding of how operations at Xayaburi and Don Sahong will potential impact on fish and fisheries both locally and in a transboundary context. The fish and fisheries monitoring design proposed for JEM and utilized during the Pilot studies (MRC 2019a, b) was consistent with the overall need for an integrated understanding of the impact of HPPs on ecosystem dynamics and functioning, with existing FADM and FLDM sites providing the larger scale, regional context for the project, and additional sites added to provide more local information about impacts on fisheries in the immediate footprint of the HPP. The potential impacts identified through the JEM review, various Mekong HPP Prior Consultation assessment, The MRC Council Study, ISH11 and the Mekong Delta Study (DHI 2015) projects were used to refine the monitoring strategy, with the focus on impacts on fish and fisheries brought about by changes to the frequency, rate and range of water level changes, shift is sediment dynamics and potential alterations to water quality. Details of the initial monitoring design are presented in the JEM Pilot proposals (MRC 2019a, b), and details of the findings are summarised in MRC (2021a) and MRC (2021b). The following sub-sections provide a brief summary of the monitoring completed at each site, the findings, and the recommendations arising from the Pilot Projects.

8.2 JEM Pilots' key findings and recommendations

8.2.1 JEM monitoring at Xayaburi and Don Sahong: Key findings

During the JEM pilots, the standard FADM sampling protocols were adopted at existing (pre-JEM) sites in the region of the HPPs. Additional FADM sites were included both upstream (Saen Nua village) and downstream (Hangkhone village in Lao and Oh Run village in Cambodia) of Don Sahong HPP and one downstream of Xayaburi HPP (Downstream: Pak houng village) to assess the impact of the HPPs on fisheries abundance and diversity. Notably, one of the original FADM sites upstream of Xayaburi HPP (Tha Deua) was flooded by the impoundment and was used to determine the changes brought about by inundation of the river bed under the impoundment. Analysis was predominantly trends in species richness and CPUE of all species combined. Because of the limited sampling period, data from the ongoing FADM programme were used to determine trends in richness and CPUE. Some anomalies were found in the trends between sites, especially downstream of Don Sahong between Lao and Cambodian sites. It is recommended the cause of these anomalies be investigated, but no in depth multivariate analyses were performed to interrogate the data and seek explanation.

A new sampling programme was established to support the FLDM programme. Three sites were sampled at Xayaburi and one upstream and two downstream (one in Lao PDR and one in Cambodia) of Don Sahong. Sampling was undertaken every six hours on the left, middle and right banks, twice a week from April to July and once a week from August to March. Conical drift nets, as operated in ongoing FLDM studies in Cambodia and Viet Nam, were used for sampling the main river, whereas nets towed behind a small boat, as recommended in the JEM Programme, were used in the impounded site (Tha Deua) at Xayaburi HPP. Analysis of the FLDM monitoring was restricted to reporting species richness and total abundance, but no in depth multivariate analyses were performed.

A review of fish tagging procedures was carried out during the JEM pilots (MRC 2021c) and reinforced the costs and constraints of different methods raised in the JEM Programme. The study concluded that non-electronic external tags are comparatively cheaper and feasible for application to a high number of fish, whilst electronic tags are more expensive and suited to smaller numbers of target fish. As yet acoustic tagging systems have not been installed at Xayaburi or Don Sahong because of logistic constraints. Electronic tagging, whilst feasible, is expensive and requires experienced practitioners to surgically insert tags in the fish and install and run specialized tracking systems. It is recommended partnerships are established with the dam operators and they share or fund the cost of fish tagging programmes as part of the development of mitigation options. As a consequence of these delays and constraints, it was not possible to update the JEM Programme on tagging and tracking (see Section 8.4.3.7) until such time as the pilot studies at Don Sahong and independent studies at Xayaburi have been established and run for several years.

Independent fisheries data were received from Xayaburi Power Company, but these only refer to number of fish PIT tagged and recaptured in detectors placed in the fish pass, and the accumulated number and species richness in the upper fish pass channel. No fisheries data were received from Don Sahong Power Company, despite considerable ongoing fisheries investigations being undertaken by the operators.

8.2.2 JEM monitoring at Xayaburi and Don Sahong: Recommendations specific to JEM

- **Consider a study of local fish taxonomy in both Southern Lao and Northern Cambodia, to identify whether the different diversity levels identified on each side of the border result or not from a difference in local fish naming.** This relates to updating the Fish Atlas, which has already been undertaken. It is likely species are grouped in some regions and this needs teasing out in the JEM and FADM reporting. Species identification is always important and species naming should be regularly updated by a taxonomic expert.
- **Similarly, there is need to standardize fishing gear names throughout the basin in the FADM database.** There is handbook of gears produced many years ago. This can be used but FADM and JEM use local fishers who use only a few fishing gears. Previous analyses by the counties and the combined report by MRC tend to explore gear usage so these data should be explored in the first instance.
- **Review and compare the implementation of the FADM protocol in Southern Lao and in Northern Cambodia, to identify possible discrepancies explaining contradictions about CPUE and average catch per fisher in close sites on each site of the border.** FADM and JEM protocols are standard procedures and the countries carry them out in a similar manner
- Problems arose with the deployment of the multi-panel standardised gillnets and **recommendations for splitting the multi-panel nets based on three groupings of mesh sizes** were made. This new protocol will require development of a Standard Operating Procedure

to understand the relationship between fish catches, habitats and the fish population characteristics.

- **A recommendation was made 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.** Training fishers at new sites is critical and these should also be audited on a regular basis.
- **It is recommended that non-electronic tagging studies are carried out to understand fish migration.**
  Tracking and tagging studies using PIT and acoustic tags, as proposed in the original JEM Programme and pilot studies, remain the recommended methodologies. PIT tagging systems, as used at Xayaburi HPP, and acoustic tagging, as being implemented at Don Sahong, remain the most appropriate options. They have proven to be successful at Xayaburi (PIT tagging) and in all likelihood establishing acoustic systems will be easier to implement around large HPP dams with single channel, lower turbulence systems than found around Don Sahong. A pilot study to determine efficacy of external (spaghetti tags) tagging systems could be carried out but the objectives of the study in relation to understanding migratory pathways the effectiveness of fish passes needs to be established.
- **For fisheries FLDM, the pilot monitoring confirmed the most useful months for sampling and JEM sampling protocol to include sampling locations on both banks and one in the mainstream. However, instead of sampling at midnight, the timing should be brought forward to 21:00.** The FLDM protocol is currently being redrafted to rationise the sampling programme to one survey per day
- **Sampling locations should 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.** Selection of sites is expected to cover this aspect and is not a random process.
- **Training of fishers involved in the FLDM monitoring should be repeated on a regular basis, since their reliability and accuracy is essential to the accuracy of data gathered.** This is a standard sampling procedure and the methodology should be consistent between countries.

8.3 JEM Monitoring Design

This section summarises the recommended fish and fisheries monitoring approach for future JEM monitoring. It draws upon the in-depth gap analysis and discussions presented in previous versions of the JEM Programme, especially JEM V4 (MRC 2019c), and incorporates the recommendations arising from the JEM Pilot projects highlighted above and recommendations of the EGEM.

8.3.1 Monitoring overview

There is acute concern over the impact of dams in the LMB on the basin's fisheries, both in terms of individual developments on a local and basin-wide scale and the cumulative impact of multiple schemes. The impacts of damming, whether for hydropower, irrigation or flood control are numerous and can be summarized in terms of upstream and downstream effects, as well as potential harm caused by fish attempting to pass the dam and hydropower infrastructure (Table 8-1).

Table 8-1. Monitoring requirements to assess potential risks to fish and fisheries associated with mainstream dams

Risk	Consequences	Monitoring required
Direct barrier effects on fish and fisheries		
Dams create a direct barrier to upstream migration of fish	Ultimately may lead to loss of fish species diversity unable to complete their life cycles (typically fish of Guilds 2, 3, 4 & 8: Vol 2: Annex 18), usually because they are isolated from their spawning and nursery areas. Occasionally if spawning conditions are suitable below the dam the species may survive but usually at considerably lower abundance. The impact is usually greater if major spawning tributaries are located upstream of the dam or drain into the impounded area. It is important to note that current technology on fish passage facilities is inadequate to mitigate the barrier effects of high dams to fish migration in tropical rivers.	• Fish abundance and diversity monitoring both local (upstream, downstream of dam and in impounded area) to the dam site and at the catchment scale. • Fisheries catch assessment based on fisher logbooks, market surveys and household surveys. • Tagging and tracking studies of migratory species: approaching, ascending, and exiting the fish passage facilities. • Acoustic and DIDSON/ARIS scanning surveys
Dams create a direct barrier to downstream migration of fish	Impoundments also present problems to downstream migrating fishes. Downstream migration involves all life history stages, including eggs and larvae, which drift in the current, juveniles of limited swimming ability and adult fishes. This varies depending on the species concerned. Ultimately, disruption of downstream migration may lead to loss of fish species diversity unable to complete their life cycles (typically fish of Guilds 2, 3, 4 & 8: Vol 2: Annex 18), usually because they are isolated from their nursery and feeding areas.	• Fish abundance and diversity monitoring both local (upstream, downstream of dam and in impounded area) to the dam site and at the catchment scale. • Dedicated egg and larval drift studies, including specific plankton trawl surveys in impoundment and river upstream. • Monitoring of nursery and grow-on habitats to determine change in species abundance and diversity • Fisheries catch assessment based on fisher logbooks, market surveys and household surveys. • Tagging and tracking studies of migratory species.
Mortality at hydropower structures		
Fish encountering dams while moving downstream will either pass over the spillway, through specially engineered bypass channels, or be drawn into the	Large numbers of larvae and juvenile fish drift passively downstream from spawning grounds upstream, and are drawn either into the intake of generating turbines or over the dam's spillway. Both routes can cause high mortality with consequences on the recruitment of fish to populations downstream of the dam.	• Fish abundance and diversity monitoring upstream and downstream of dam. • Dedicated egg and larval survival/mortality studies. • Tagging and tracking studies of migratory species.

Risk	Consequences	Monitoring required
turbine intakes and then through the turbines themselves.	Adults passing downstream actively seek flowing water and are drawn to turbine intakes or spillways.	• Trash rack and screen impingement studies. • Acoustic and DIDSON/ARIS scanning surveys
High mortality or injury in turbines.	Fish entering the turbines are exposed to a variety of physical stresses that cause injury and death. These include pressure changes (barotrauma), shear and strike by the turbine blades. Eggs and yolk-sac larvae are susceptible to impacts from shear, while fish with closed (physoclistous) or chambered (carp species) swim bladders are susceptible to pressure impacts. Large fish are more susceptible to blade strike. Turbines labelled as 'fish-friendly' can still have significant impact on individual fish resulting in high injury or mortality rates, often up to several days after passing through the turbine.	• Dedicated egg and larval survival/mortality studies *in situ* and in the laboratory, linked to survival assessment studies (includes computer modelling of pressure, shear and strike). • Tagging and tracking studies of migratory species. • Targeted fish mortality experiments including use of tools such as Sensorfish
Mortality and injury in spillways.	Fish moving over spillway can be injured or killed if the design of the spillway does not take fish passage into account. If the flow is too strong they may not be able to avoid collisions with energy dissipating structures or flow detectors, they suffer abrasion against spillway walls and floor (shear) if the water is too shallow, and may suffer 'gas bubble disease' and barotrauma if the plunge pool is too deep. Turbulent flow in the spillway basin can disorientate fish, slowing their downstream movement, and exposing them to predatory fish and birds.	• Dedicated egg and larval drift studies, linked to survival assessment studies. • Tagging and tracking studies of migratory species. • Targeted fish mortality experiments including use of tools such as Sensorfish • Acoustic and DIDSON/ARIS scanning surveys
Impoundment impacts on fish and fisheries		
The impoundment changes the hydrodynamics from a complex flowing water habitat to a uniform slower flowing habitat. Deep pools, which are a complex hydraulic refugia, are inundated and simplified	The impoundment of relatively fast flowing rivers may totally preclude riverine fishes that are dependent on flowing water conditions for all their ecological requirements, and species that are able to live only in running water are usually eliminated. Riverine fishes will include species that have either drifting eggs or sticky eggs that adhere to submerged plants, rocks, gravels and sand. Both types of eggs in riverine fishes require flowing water (lotic) habitats, which is important when considering the effects of an impoundment.	• Fish abundance and diversity monitoring. • Fisheries catch assessment based on fisher logbooks, market surveys and household surveys. • Habitat surveys linked to species composition and abundance • Tagging and tracking studies of migratory species. • Acoustic and DIDSON/ARIS scanning surveys
Impoundment may drown out spawning and nursery habitats of migratory species.	Riverine species generally decline in abundance because of inability to fulfil their life cycle, to be replaced by species that are tolerant and able exploit static water conditions (Guild 5 and non-native species: Vol 2: Annex 18).	• Fish abundance and diversity monitoring. • Fisheries catch assessment based on fisher logbooks, market surveys and household surveys.

Risk	Consequences	Monitoring required
		• Habitat surveys linked to species composition and abundance.
Impoundment may drown out habitat riverine species typically found in rapids and glides, i.e. rhithron species (Guild 1).	Rhithron species (Guild 1: Vol 2: Annex 18) are lost from communities resulting in loss of biodiversity, and are replaced by species that are tolerant and able exploit static water conditions (Guild 6 and non-native species: Vol 2: Annex 18).	• Fish abundance and diversity monitoring in reservoir. • Fisheries catch assessment based on fisher logbooks, market surveys and household surveys. • Habitat surveys linked to species composition and abundance.
Water level fluctuations in the impoundment impinge on the capacity for certain fish species to breed and grow in the impounded area.	Compromises capacity of the impoundment to replace lost fisheries production caused by impoundment of the river system.	• Fish abundance and diversity monitoring in reservoir. • Fisheries catch assessment based on fisher logbooks. • Assess fish spawning /behavior in impoundment and effectiveness of artificial nursery habitats
Downstream impacts on fish and fisheries		
Alteration in the timing, magnitude and duration of hydrological characteristics in downstream river systems.	Depending on the characteristics and operations of the impoundment, seasonal flooding patterns can be modified resulting in deterioration of downstream habitat and disruption of longitudinal and lateral migrations. In some cases, longitudinal migration of fishes are also compromised because environmental cues for migration (trigger floods) are lost and passage over rapids, falls and other natural, partial obstructions, e.g. Khone Falls, to fish are disrupted. Grey fishes (Guild 4: Vol 2: Annex 18) that rely on floodplain inundation for breeding are constrained and do not recruit successfully. Generally, the downstream fish community structure and population dynamics are altered, and the fishery moves towards lesser catches of smaller, non-migratory species of lower economic value or non-native species. It should be noted that this impact is likely to be minimal for Mekong mainstream hydropower projects as they will largely operate in run-of-river mode.	• Habitat surveys linked to species composition and abundance in immediate downstream region and transboundary. • Fish abundance and diversity monitoring in relation to modelled changes in hydrological regime. • Fisheries catch assessment based on fisher logbooks, market surveys and household surveys. • Egg and larval drift studies.
Alteration in the short-term (hourly, daily, weekly) hydrological characteristics downstream of the dam.	Migratory fish often move up to a dam and spawn below the dam. Species that have adhesive eggs in littoral zones, or "nests" can be affected by short-tern fluctuations in water level. Eggs can die and adult fish can abandon nests	• Surveys of littoral zones downstream for spawning areas. • Tracking studies of adults of migratory species • Larval surveys
Alteration in the nature, timing and dispersal patterns of	The impoundment may reduce the volume of sediments and associated nutrients passing downstream, and the productivity of the	• Habitat surveys linked to species composition and abundance in

Risk	Consequences	Monitoring required
sediment delivery in river systems.	system declines, especially in the floodplain and delta areas and in coastal regions (see Section 5)	immediate downstream region and transboundary. • Fish abundance and diversity monitoring in relation to modelled geomorphological changes • Fisheries catch assessment based on fisher logbooks, market surveys and household surveys.
Alteration of the thermal regime downstream of reservoirs.	If the impoundment stratifies (see Section 4), a reduction in water temperature occurs because of the release of bottom water from the hypolimnion and suppression of the natural seasonal variation in temperatures, the latter of which is often a trigger for fish migration, although less so in tropical rivers. This risk may not be prevalent in Mekong mainstream dams.	• Fish abundance and diversity monitoring in in relation to changes in thermal regime. • Fisheries catch assessment based on fisher logbooks, market surveys and household surveys. • Temperature loggers in river upstream, in impoundment at various depths and downstream.
Water quality downstream adversely affected by dam infrastructure and operation.	Changes in discharge and water quality, often associated with human development, are common below dams, particularly gas super-saturation, can affect all fishes within the riverine section below dams (see Section 4).	• Fish abundance and diversity monitoring in in relation to water quality assessment. • Fisheries catch assessment based on fisher logbooks, market surveys and household surveys.
Transboundary impacts		
Disruption of hydrological regime and sediment delivery and concomitant impact on fisheries may be transmitted considerable distances downstream.	Impact of dams in terms of loss of productivity may manifest at considerable distances from the dam location. This can have considerable impact on rural communities dependent on fisheries for food security and livelihoods (see Section 9)	• Fish abundance and diversity monitoring. • Fisheries catch assessment based on fisher logbooks, market surveys and household surveys. • Habitat surveys linked to species composition and abundance.
Dams associated with development of floodplains for other purposes, such as irrigation schemes, disrupt floodplain function.	If a floodplain is permanently inundated by an impoundment, the floodplain can completely lose its function in the ecosystem and result in lost fisheries-related services.	• Fish abundance and diversity monitoring. • Fisheries catch assessment based on fisher logbooks, market surveys and household surveys. • Habitat surveys linked to species composition and abundance

It is against this backdrop of potential impacts the HPP dam itself creates as a barrier to fish migration, changes in hydromorphological and topographical characteristics in the upstream impoundment and downstream of the HPP scheme, plus the wider transboundary impacts of the HPPs on fish and fisheries that the JEM monitoring programme has been devised.

Historic and existing MRC fisheries monitoring activities and monitoring activities proposed by hydropower developers are summarised in the JEM review (MRC 2018a). The review identified significant gaps in the monitoring programme for robust assessment of HPP developments, and formulation and monitoring of appropriate mitigation measures, including, but not exclusive to, the following issues and recommendations associated with addressing the gaps.

Existing monitoring throughout the region does not use standardised gears, methodologies or systematic sampling strategy for assessment of status and trends in fish stocks. There is a clear need for the use of standardised, multi-panel, multi-mesh gillnets set in a systematic framework (spatial and temporal dimensions) as recommended in the FADM guidelines (MRC 2022a).

Assessment should be widened beyond the immediate impact of the dam in terms of barrier effects, fish survival and fish passage efficacy. Any ecological monitoring should extend to both fish and OAAs, but also assess changes in the modified environments downstream and within the impounded area and be compared with upstream of the impoundment. All assessment should also be linked to environmental and habitat variables to help account for any change observed. In this context, the monitoring protocol needs to be targeted and more comprehensive to account for daily and seasonal variability in ecological characteristics related to hydrological conditions, as well as establishing an early warning system to be proactive to respond to potential impacts of the development. Any impact should be evident from analysis of the data by the line agencies and/or HPP developer, particularly during the annual joint review of data (see Section 3) This requires a realistic and properly costed monitoring programme that should build on existing developer monitoring and MRC Fish Abundance and Diversity Monitoring (FADM), larval drift surveys (FLDM), household surveys and market studies.

Estimations of the abundance of fish of different species in the downstream reaches are required to quantify the number and type of fish arriving at the dam. These data are necessary to compare with passage data to calculate fish passage efficiency. Efficiency of attraction flow for upstream migration has to be monitored in detail, as it is one of the most important bottlenecks in fish passage. Water turbidity will limit any direct observation; thus there is a need to consider DIDSON sonar systems. This system enables underwater video observations in turbid water and reveals detailed information on migration and swimming behaviour.

Telemetry and tracking studies for a range of species and sizes of fish are required. This will also provide insights into whether fish find fishpass entrances, estimates of proportions of fish that ascend the HPP infrastructure and by which routes, and reveals whether any fishpass is designed appropriately. Comparison of upstream/downstream fisher or experimental gear catches or the use of spaghetti/Floy-type external tags will only provide yes or no results on passage success but will not provide information on fish passage efficiency or which routes the fish take to bypass the system.

Downstream passage also needs to be assessed: details of how this will be monitored (e.g. bypass efficiency, turbine mortality) and how the information will be used to adapt the designs is needed. Attention must also focus on migration (drift of eggs and larvae and active swimming of sub-adults and adults) through the impoundment using appropriate monitoring protocols, such as larval drift sampling and active telemetry studies.

To assess transboundary and multi dam effects, migration distances and migratory behaviour of important medium and long-distance migrants should be monitored and potential effects calculated based on population models.

Whilst these data are critical for understanding the dynamics of the fisheries, there is a clear need for detailed baseline studies on the socio-economic impacts both in the immediate HPP development reach but also any transboundary areas likely to be impacted by the development. Limited information is provided on the socio-economic dimensions of the dam proposals in the impacted region, including the importance of the fisheries to food security and rural livelihoods, number of people affected and loss of ecosystem services to rural communities (see linkages in Figure 8-1). In particular, efforts to date by the hydropower developers provide only limited baseline and impact information on socioeconomic conditions of people living in the mainstream hydropower project-affected areas and do not provide any information and data on water resources related livelihoods, food security and nutrition. There is also little information on role of woman in fisheries, whether certain ethic groups are more reliant or marginalised in the fisheries communities and what their roles are in the market chain. A complete overview of fishing activities and the contribution to livelihoods and food security in the region is needed. This should include details and plans of fishing activities to be removed or restricted and detailed "alternative livelihood" options and compensation for local fishers and communities that are impacted. Furthermore, and critically, transboundary baseline and impact information on socioeconomics and livelihoods were given little attention.

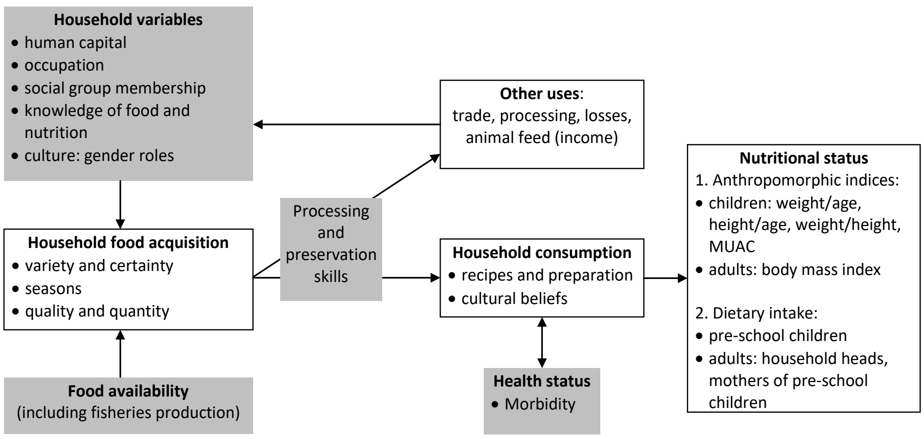

Figure 8-1. Linking aquatic products availability to health, nutritional status and food security

These gaps limit the capacity to: i) assess the impact of the dam development on fish and fisheries, including OAAs; ii), design and optimise mitigation measures for fish passage; iii) have comparative methods between dams, and iv) offer opportunities to compensate for potential lost fish production and social disruption. For effective monitoring, a wide diversity of fisheries assessment methodologies is currently in use across the major river basins of the world (Cooke et al. 2016 and Lorenzen et al. 2016). These range from detailed, long-term assessments of single species in streams to rapid appraisal of multi-species, multi-gear floodplain fisheries in the tropics to broader simulations of the interactions between fisheries and other components of the aquatic system (Cooke et al. 2016 and Lorenzen et al. 2016), and are not repeated here, but the methods chosen need to align with the objectives of monitoring.

The overall objectives of fisheries monitoring in the Mekong are to measure indicators contributing to the interpretation of the status and trends of local, regional and basin-wide capture fisheries as well as providing an effective means of monitoring and assessing the effects of water management and basin development activities, specifically hydropower development. Particularly, it should also answer some basic questions regarding issues such as the impact of the hydropower development on abundance, diversity and catches of fisheries and OAAs, including disruption to life cycles, recruitment and productivity of species, shifts in contribution of fisheries to rural livelihoods and food security, status of giant and endangered (especially IUCN listed) species and disruption of habitats impacting on aquatic ecosystem functioning.

The likely impact of the Mekong dams on fisheries will arise from modifications in river flow regimes, sediment and nutrient transport and water quality (Figure 2-1), which could directly or indirectly affect fish habitat, fish populations and communities, foraging and breeding behaviours, species interactions and ecosystem functioning, and migration triggers (Figure 8-2, but see Dugan et al. 2011; Halls et al. 2013). In addition, construction of large dams across the main river channel will physically obstruct fish migration routes and spawning distribution, as well as downstream drift of juvenile fish, all potentially disrupting population dynamics and recruitment processes.

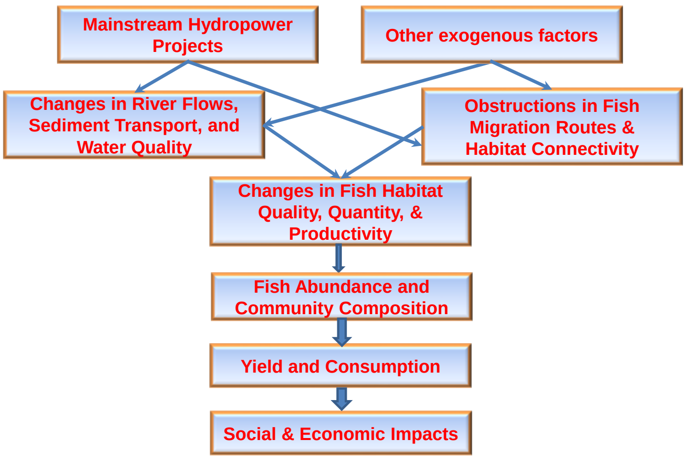

Figure 8-2. Causal relationships between fisheries and hydropower development

8.3.2 Number and location of sampling sites

The number and location of sampling sites is very much dependent on the location of the HPP scheme and the spatial resolution of the monitoring from a local to basin scale, transboundary perspectives. Ideally, monitoring will be coordinated between the MRC, MCs and developers to provide information at the following scales.

- **MRC** fisheries monitoring will record and capture changes and trends in fish catches and biodiversity, including OAAs, at a basin level that can be used as baseline information for future developments and underpin State of the Basin Reporting. An example of this is the reported declines in fisheries in the Tonle Sap and Vietnam Delta over the past decade.
- **Member Countries** monitoring focusses at the national level and in tributaries: it is at a more zonal level and accounts for national statistical information of Government Surveys. It is at a smaller scale than the MRC surveys. This information can be used to guide and assist management at a national level, including the important interactions between tributaries and the mainstream.
- **Hydropower project** monitoring includes specific information relevant to operations and potential impacts. It largely occurs in the vicinity of the dam development but includes downstream reaches and impounded areas.

Collectively, these data sets can be integrated and interpreted to understand changes in the status of the fisheries from the local to basin scale, and provide insights into transboundary impacts of dam developments. This is important for understanding how changes at the local scale, such as how disruption to migration or loss of access to spawning habitats affect the larger basin, and for understanding how large-scale changes, such as climate change, might induce local ecosystem change that effect fisheries and OAAs.

However, for this to be effective requires standardised monitoring procedures as discussed above and a spatial and temporally explicit sampling framework to provide robust assessment of the status and trends in the fisheries (as discussed in Section 2.4).

Pre-JEM (2018) there were 38 MRC FADM monitoring locations on the Mekong mainstream, Bassac, Mekong tributaries and Tonle Sap in the LMB (Figure 8-3). These FADM monitoring locations meet the criteria of being located within each fisheries migration zone, although the distribution is limited at a basin scale and many more sites should, preferably, be added to the network, especially to account for the high diversity of fishing gears and targeted species. **It is recommended that additional sites are added to the FADM programme to fill gaps associated with determination of impact of the proposed hydropower schemes** (see Sections 8.7.2 and 8.7.3). This has been achieved for JEM pilot monitoring of Xayaburi and Don Sahong where an additional FADM sites were included both upstream (Saen Nua village) and downstream (Hangkhone village in Lao and Oh Run village in Cambodia) of Don Sahong HPP and one downstream of Xayaburi HPP (Downstream: Pak houng village) (see Section 8.2.1). However, to achieve basin scale monitoring, new sampling sites are recommended for downstream of the proposed Phou Ngoy and Sambor HPP schemes and in the potential impounded areas of the various HPP schemes. The latter is to determine how fish species abundance and diversity change in the impounded area and whether larval drift and fish recruitment are compromised by the change in habitat to a lentic environment. In addition, this large scale assessment should be combined with more intensive local scale monitoring carried in collaboration with the HPP developers as part of their monitoring requirements for the PNPCA and construction and operational phases.

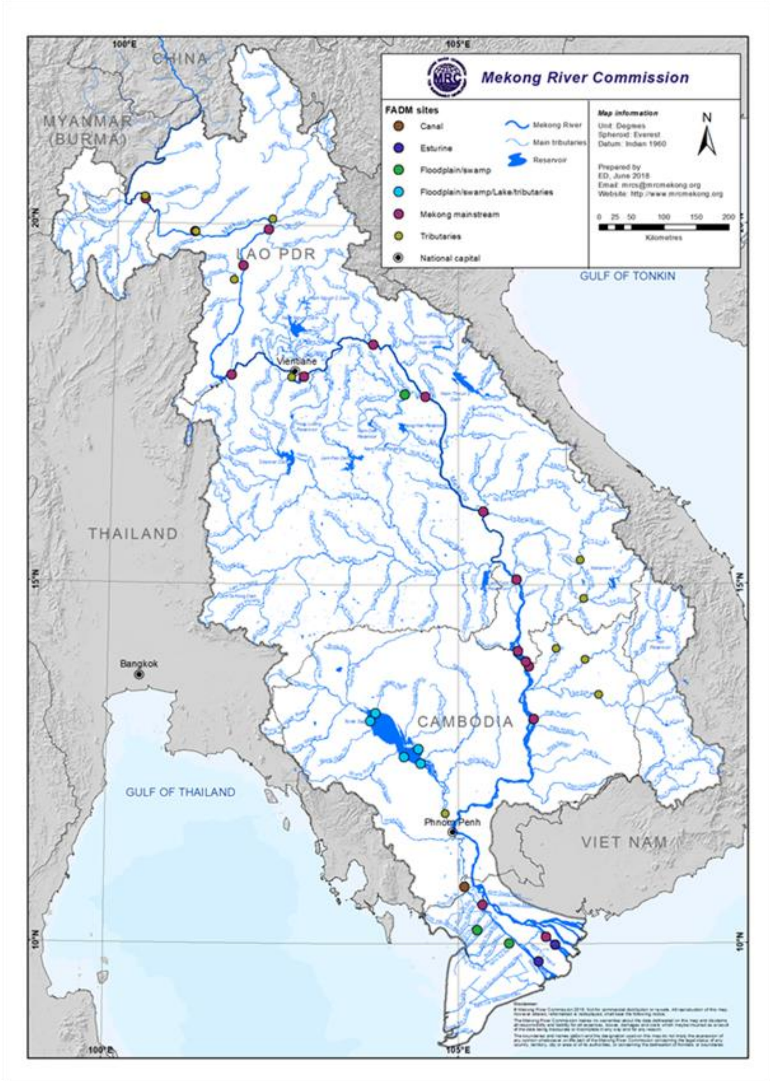

Figure 8-3. Existing sampling locations in the LMB (Source MRC 2018a)

Furthermore, the intensity of sampling needs to be increased to include logbooks from more fishers and use of fishers to undertake standard gillnetting with multi-mesh panels is required. Currently the FADM procedure reports on daily catches of three fishers per location, but this is not considered sufficiently robust for impact assessment, especially considering the range of gears they use and habitats they target. Consequently, it is recommended, if logistically possible, to increase the number of fishers completing logbooks, but perhaps have them only report on three to four days per week to obtain robust basin wide assessment of the status of the fisheries.

Additional information to improve the impact assessment should also be obtained from MC line agencies and other regional projects or academic studies. In addition, the developers should establish catch assessment survey programmes in fishing villages adjacent to or likely affected by the developments.

Monitoring carried out by the developer should provide the fine scale, high resolution information to inform the local impacts of the dam development on fisheries and OAAs, including biodiversity assessments, and orientate mitigation and adaptation measures. This will require a suite of sampling procedures to understand fish recruitment dynamics and how migration patterns will be disrupted, including larval drift assessment. Sampling should be carried out for up to three years prior to the PNPCA submission and include daily fish catch logbook studies, monthly standardised gill net studies, seine net and larval drift net studies (at least weekly), assessment of migratory biomass using DIDSON or similar sonar equipment at least weekly. These studies should be carried out at two to three sites each in reaches downstream of the potential dam, in the potential impounded area and upstream of the headwater of the impoundment. In addition, market and household surveys should be carried out weekly for a minimum of seven years to assess the importance of fisheries to rural livelihoods and food security during the stabilization period of the HPP impoundment and account of operational procedures during the early establishment of the HPP.

8.3.3 Monitoring parameters

To assess the impact of changes arising from hydropower developments on the capture fisheries yields and species diversity, a range of indicators that reflect potential changes were recommended in ISH11. These indicators are chosen because they can be monitored but also enable assessment of potential impacts of hydropower (or other environmental degradation). These indicators can be grouped as follows to relate to ongoing and basin wide fisheries indicators used in the MRC Council Study (MRC 2016) and Mekong Delta Study (DHI 2015) and take into account other information on potential stressors and environmental data:

- **Fish catch monitoring:** Fish catch assessment monitoring programmes established in villages to understand the seasonal dynamics in fish catches. This task uses the standard logbook system operated by the MRC FADM and be run to understand variation in catches and effort throughout the life cycle of the HPP scheme.
- **Quantify economically important fisheries:** Catch monitoring will also be used to quantify key economically important fish communities (species/guild abundance and diversity) associated with major habitat types, especially the contribution of headwaters and floodplain areas.
- **Fish migration patterns:** These surveys need to be used to inform fish migration patterns in relation to the dam development and its association with the mainstream Mekong and the main tributaries, including both upstream and downstream migration as well as accounting for egg and larval life stages.
- **Assessing distribution and diversity:** Surveys need to be carried out to assess the distribution and diversity of fish species in the LMB and floodplain areas to relate to the catches as well as habitats.

- **Household surveys:** Household surveys need to be conducted at various villages around the development to understand the importance of fisheries to livelihoods and food security and determine alternative livelihood scenarios.
- **Habitat surveys:** There is an essential need to map the key aquatic habitats in the impact area, including areas of permanent and temporary inundation and features such as deep pools, riffles and sandbar need to be assessed. Areas of in-stream or in-reservoir habitat including vegetation, and areas and quality of riparian vegetation should be mapped using GIS technologies.

Table 8-2. Comprehensive indicators for monitoring impacts of hydropower on fisheries (modified from ISH 11)

Type of parameter or indicator	Examples of specific parameters	Relevance for hydropower planning
Capture fisheries and exploitation of OAAs	Abundance and weight of fish and OAAs in catches or samples, species lists Fish catch diversity Yield of economically important species (t or kg/year) Catch per unit effort (kg/gear/day)	Fish and OAA species composition, abundance and biomass will be affected by changes in environmental conditions as a result of hydropower development.
Fishing pressure	Number of fishers (full-time, part-time and occasional), number and size and type of boats, number and dimensions of gears, time that gear is set or used.	Direct and indirect changes related to hydropower include in rivers up and downstream and in the new reservoir, leading to changes in fishing effort and overall fishing pressure.
Fish and OAAs biological features	Condition, growth rate, dietary and reproductive parameters, parasites and diseases.	Changes in hydrology, water quality and the food chain lead to changes in fish and OAA condition and growth rate, which ultimately lead to changes in fish and OAA populations.
Fish and OAAs population structure	Number of species including species of conservation concern. Proportional makeup of sub-populations. Rates of gene flow.	Dams fragment populations, reducing or stopping gene flow between upstream and downstream river segments.
Fish and OAAs migration patterns	Species migration patterns and ontogeny from observation, tagging or isotope studies.	Dams may prevent or restrict fish migration.
Disruption of fish recruitment	Disruption of egg and larval drift and loss of juvenile recruitment of migratory species	Need to maintain flow dynamics and passage through reservoir system
Fish and OAAs contamination	Concentration of mercury and pesticides in fish and OAAs. Note: assumes supporting studies of sediments and water quality.	Reservoirs may increase methylation of mercury leading to biomagnification. Increasing pesticide use under agricultural intensification may lead to impacts that are unrelated to hydropower.

Type of parameter or indicator	Examples of specific parameters	Relevance for hydropower planning
Habitat	River width, depth, current speed, substrata. Area of permanent and temporary water and features such as pools, riffles and sandbars. Areas of in-stream or in-reservoir habitat including vegetation, and areas and quality of riparian vegetation.	Dams lead to many kinds of changes in habitat extent and quality downstream and in reservoirs.
Fish stocking	Species, quantities and sizes, growth rate and percent recapture.	Reservoirs are often stocked as a mitigation or enhancement measure.
Aquaculture and Reservoir Fisheries	Type of systems (cage, pond, cove), extent or capacity, species, production inputs and outputs.	Aquaculture may be favored in reservoirs as well as downstream of HP plants if flows are stabilized, but may also affect operations downstream through water quality changes
Fish processing and marketing	Market channels, market statistics including prices and quantities by species, employment and economic aspects.	Marketing and distribution of fishery products will change as a result of changes in capture fisheries and aquaculture and demographics and infrastructure.
Fish and OAA consumption	Household consumption of fish and OAAs.	Changes in production of the capture fishery and from aquaculture will lead to altered patterns of consumption.

In addition, specific monitoring of the efficacy of fish passage installations (both upstream and downstream) is required to determine whether they are appropriate and provide a solution to the barrier effects created by the hydropower structure, as well as reducing potential harmful effects as the fish pass downstream.

However, it is recognised that many of these indicators require complex and extensive monitoring and research-based activities. Consequently, the indicators have been reduced to critical indicators that will provide the robust evidence base required for assessment the impact of hydropower and other developments in the LMB. The recommended indicators are presented in Table 8-3.

Table 8-3. Revised indicators for monitoring of hydropower impacts on fisheries for JEM

Indicator	Units
Yield (total) or yield per fisher per year (indicator of fish abundance)	tonnes/ kg
Yield of economically important species (indicator of fish abundance)	tonnes / kg
Fishing effort	Number of fisher, gears and characteristics of gears; man-days, soak time
Fish catch diversity	Percent of catch
Other aquatic animals	tonnes / kg
Catch per unit effort	kg/gear/day
Larval drift abundance and diversity	Number of individuals per species per 1000 m^3

8.3.4 Monitoring timing and frequency

It is recognised that monitoring needs to reflect the locations and operations of the proposed and soon to be operating hydropower projects. To address this goal the following is recommended.

- Additional monitoring sites should be established to determine impact of HPP schemes under construction and new developments to come online.
- Monitoring should be implemented and continued indefinitely without interruption. Fisheries in the Mekong River respond to rapid changes with respect to hydrology and sediment transport, and continuous monitoring is necessary to understand these changes and provide a basis for management.
- Any monitoring included in the JEM should be compatible with the existing monitoring by the MRC, line agencies and developers to allow flawless integration. Ideally, this would include the adoption of standardised monitoring (including use of standardised gears such as multi-panel gillnets) and analyses.

8.4 Fisheries monitoring protocols

8.4.1 Purpose

The LMB capture fishery is the largest freshwater fishery in the world, and produces between 2.1 and 3 million tonnes annually (about 20% of the world's freshwater fish yield; FAO 2018). It is therefore critical to protect and maintain the fisheries for food security and livelihoods. To achieve this, there is a need to assess the current status of the fishery as well as any changes brought about by human interventions. The purpose of fish catch assessment is to:

- quantify changes in capture fishery yields of key economically important species, including OAAs, that may result from the proposed mainstream hydropower development.
- quantify and describe changes in the fish community composition and biodiversity in the immediate vicinity of the dam and catchment as a whole (i.e. local, national and transboundary effects).

The Mekong system is characterized by very intensive fish migrations; about one third of the Mekong fish species migrate from the downstream to the upstream tributaries for breeding. Potential impacts on migration patterns will also be evaluated as part of the fish community composition assessment.

The data requirements for each of these objectives vary according to the desired precision deemed necessary to support the management decision-making process. To achieve these outputs requires considerable resources, thus pragmatic, cost effective approaches to fisheries assessment are required. The optimal strategy is to combine sources of information to provide a robust monitoring frame, but standardize data collection procedures to remove biases and erroneous information.

8.4.2 Fisheries sampling methodologies

It is not the intention to review the fisheries sampling methodologies required to meet the objectives for the fisheries (and OAAs) catch assessment monitoring. These are described in reviews by Cooke et al. (2016) and Lorenzen et al. (2016) and Standard Operating Procedures (SOPs) for gears (Bonar et al. 2009), and the reader should review these manuals and guidelines. In addition SOPs for various gears and methodologies are provided in the FADM manual (MRC 2022a), the FLDM manual (MRC 2022b), and associated JEM Annexes (JEM Programme Vol 2). To assess the status and trends in fisheries and OAA catch characteristics, and potential changes brought about by the HPP development, a number of methodologies are available (Table 8-4). Each methodology has advantages and disadvantages (Table 8-4). Consequently, it is proposed that several methods are used and run in parallel. To this end it is critical that the MRC, MC line agencies, academic institutions, NGOs and developers work together to maximise the quality and diversity of monitoring. The following fisheries monitoring methodologies, including both fishery dependent and fishery independent methods, are recommended for this purpose. The methodologies are described to ensure consistency and robustness of data collection and subsequent analyses. The current descriptions are intended for the HPP developers to meet this objective both for the EIA data gathering prior to the submission of the PNPCA and during the preconstruction, construction and operational phases of the development. This will allow better understanding of the impacts and enable suitable operational procedures to be designed and mitigation measures to be implemented.

Table 8-4. Advantages and disadvantages of various sampling methods for collecting biological data

Method	**Advantages**	**Disadvantages**
Artisanal fishery catches (Fishery dependent)	Species presence and absence data, and relative abundance (CPUE) Size distribution of fish in catch	Limited to species and selectivity of gears used by fishery No standardization of gears used
Gill nets (Fishery independent)	Species presence and absence, and relative abundance (CPUE) Length based data through length frequency analysis Some information of species distribution and movements Provide data on reproductive state and diets	Selective Does not give standing stock biomass data Difficult to use in faster flowing rivers Difficult to use in heavily vegetated areas or areas with many snags, e.g. tree branches Net shyness by fish
Seine nets (Fishery independent)	Species presence and absence, and relative abundance (CPUE) Micromesh nets suitable for juvenile life stages and small benthic species Length based data can be collated Provide data on reproductive state and diets	Limited to beaches with no physical obstructions such as rocks, tree stumps and vegetation

Method	Advantages	Disadvantages
Electric fishing (Fishery independent)	Enables fishing in difficult habitats not accessible to other gears, rocky shores, submerged woodland and vegetation Information of species presence and abundance Can give general biomass estimates Provide data on reproductive state and diets	Not suitable for wide (>15 m) and deep (>2 m) rivers except in marginal areas Differential responses of fishes to electric currents Needs specialist gears and training.
Sonar imagery (Didson/Aris) (Fishery independent)	Relative abundance of fish numbers passing image zone Enables imagery of size distribution and timing of fish movements.	Expensive cost of equipment Requires specialist training. Time consuming interpretation of images.
Egg, larval and juvenile surveys	Conical nets and bongo nets suitable to determine distribution, timing and relative abundance of eggs and larvae	Large conical nets difficult to deploy in flood season. Larval identification requires experts
Tagging and tracking (Fishery independent)	Enables fish migration and movement patterns Enables assessment of proportion of fish passing physical obstructions Enable assessment of fish passage efficiency	Expensive cost of equipment and especially acoustic tags Requires specialist training Fish handling and welfare issues
Market and household surveys (Fishery dependent)	Species presence and absence data, and relative abundance (number of fish sold) Size distribution of fish in catches	Limited to species and selectivity of gears used by fishery Often no measure of fishing effort or gears used

8.4.2.1 Fish catch assessment surveys (Vol 2: Annex 19)

The existing operating procedures from the FADM monitoring programme for sampling artisanal catches using a number of fishers at each location should be adopted both in the CRMN future activities and by the developers for monitoring fisheries at existing and future HPPs. Catch assessment surveys should, where possible, be linked to frame surveys of the total number of fishers operating in the village in the sampled area. The data should be collected in several ways as described in detail in the FADM manual (MRC 2022a) but outlined below.

- Fishers should complete a log of catch and these data should be collated and interrogated regularly by the agency undertaking the monitoring.
- To maintain accuracy, the fishers should be checked periodically and their catches monitored, These data can be used to audit the reported data and improve reporting, Biological data on the fishes can also be collected from samples caught by artisanal fisheries during this assessment.
- In cases where fishers use gillnets, catches should be recorded for each gillnet type and location of sampling. Where possible the length of gillnet and mesh size should be recorded. If two or more gillnets comprising different size panels or mesh sizes are used then treat these as separate gears and record the catch and effort for each gillnet on separate logbook pages.

The advantage of conducting surveys on artisanal catches is involvement of the local communities and the opportunity it presents to understand their concerns over the status of the stocks, and interaction with other stakeholders, to support rational management decisions. Such involvement of fishers in the data collection may be seen as a first step in preparing the communities to take up their role in a community-based approach to the management of the fisheries resources.

8.4.2.2 Multi-mesh gillnetting (Vol 2: Annex 20)

Gillnets employing standard procedures over a long period of time are particularly useful for regular monitoring of fish populations because of their relative ease of use and relatively low cost. Gillnets can be used across a range of depths and can be used in shallow water where most other sampling gears cannot be used. Several meshes of nets are required to monitor and collect data on different elements of the fish populations (e.g. biodiversity of small fish species, juvenile life stages of large fish species, feeding guilds). Thus, a standard fleet of mesh sizes should be used on all occasions. To overcome this, it is better to use multi-panel gillnets with a range of mesh sizes from 20-150 mm. The panels should be at least 5-m long and each fixed permanently to the next panel. The range of panels with different mesh sizes should be suitable to catch the range of fishes found through the LMB, but note the small mesh sizes will not catch very small-sized species, especially benthic species. An alternative method, such as micro-mesh seine netting (see Section 8.4.2.3), should be used to capture small-sized and benthic species.

As a result of the JEM pilots implemented at Don Sahong and Xayaburi, a number of recommendations were made based on the testing of different standard gill net configurations. Configurations of the 14 panels of mesh sizes were randomised and tested with three distinct lengths (112m - 8m per panel; 70m - 5m per panel; and 42m - 3m per panel) at both JEM and routine FADM sites. After testing, some national teams stated that the long net (70 m) was difficult to find the suitable places to set, but other teams (e.g. Tonle Sap Authority and Research Institute of Aquaculture No. 2) needed longer net since their monitoring sites (Tonle Sap Lake and Vietnam Mekong Delta) are quite wide. Additionally, the net could not capture the large fish since most of the net would be set near the riverbanks where the current was slow. Further, the net with the small mesh sizes could not be set in the middle of the river as it collected a lot of debris, which damaged the net. Recognising this situation and the different needs of the member countries, it was agreed the 14 panels of different mesh sizes were are split into three sets of mesh sizes with the following configurations use in the FADMs:

- 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

See the FADM manual (MRC 2022a) for the detail of the design of these nets .This design will be adopted for JEM and FADM. It should be recognised this method now becomes a fisheries independent sampling method to catch representative samples of the size and biodiversity of fish in specific locations, and especially small-sized fish that are not caught by fisher gill nets. To ensure consistency and standard operation, the same design of multi-mesh size nets must be deployed in the same location on each occasion. Gillnets should be set for a fixed period of time be operated in all seasons and account to seasonal and lunar cycles. It is recommended that multi-panel gillnets are set at least once a week and deployed to account for depth and habitat variability.

8.4.2.3 Seine-netting (Vol 2: Annex 21)

Seine netting is an efficient mechanism to catch fish in shallow, relatively slow flowing areas, and especially on floodplains. It is recommended that at least three sweeps of a 50-m micro mesh (approx. 3-mm mesh size) seine net are taken at each location at least weekly to account for seasonal and habitat variability. This methodology can be efficient for catching juvenile and small-sized benthic and pelagic fish species in the margins of large rivers.

8.4.2.4 Larval and juvenile drift monitoring (Vol 2: Annex 22)

Part of the reason for the weak understanding of fisheries impacts of dams and hydropower schemes in LMB is that information on the basic ecology of the fish fauna is limited to a few major commercial species, and little is known about fish recruitment processes and population dynamics of the majority of species, or how these contribute to sustaining the fish community structure and dynamics. This is particularly relevant because juvenile recruitment dynamics are good indicators of the impact of hydropower and other water resource development schemes. Studies of larval and juvenile fishes are often the best way to provide information of great value to fishery biologists and managers of fisheries. These include location of spawning grounds in space and time, determination of habitats used (and required) by fish during their larval phase, and insights into recruitment fluctuations. The methods used to sample fish larvae are unselective in terms of the species, so any larval and juvenile fish sampling programme will catch an extremely wide variety of species.

To gain an understanding of the potential impact of damming in the LMB on fisheries resources, there is a need to gauge the relative importance of the various spawning grounds and larval drift and juvenile recruitment processes. This can be assessed using ichthyoplankton and juvenile fish surveys at selected sites following the FLDM manual (MRC, 2022b2022). The relative abundance of ichthyoplankton will provide a measure of the importance of different stretches of the river for fisheries production.

The aim of this component is to provide a quantitative assessment of downstream migration and recruitment of the larval and juvenile life stages by monitoring relative abundance of ichthyoplankton in relation to the dam development.

During this programme, larval and juvenile fish will be sampled with fixed conical plankton nets in flowing river reaches but the plankton net will be towed behind a boat in the impounded areas. Sampling in FLDM is proposed once daily in the morning, although in the delta region this will vary according to the state of the tide. Sampling should mainly focus on the wet season, but periodic dry season sampling should be undertaken because some species spawn during the dry season (Cowx et al. 2015). Larval and juvenile sampling will be carried out by fishers, but all fish identification and data analysis will be carried out by dedicated fisheries staff. To support these studies, training in fish larval and juvenile identification will need to be ongoing and the larval identification should be audited on a regular basis.

In addition, one of the key issues arising from dam development is sinking and subsequent loss of larval life stages as they pass through the impoundment upstream of the dam. The reduced flows (especially flows below the critical threshold of 0.3 m/sec that is required to keep larvae in suspension) mean that larvae are unable to negotiate the reservoir and complete their life cycles in downstream reaches. Larval and juvenile sampling studies will enable this impact to be assessed in a semi-quantitative manner and appropriate measures to address the loss of recruitment to be developed.

Databases for the existing larval sampling programmes in Cambodia and Viet Nam and more recent FLDM surveys by all four riparian countries have been combined to meet the requirements of JEM. This databases should be consolidated to meet the ouputs of the JEM programme.

8.4.2.5 Market and household surveys (Vol 2: Annex 19)

Market and household surveys need to be conducted at various villages and urban centres around the development to understand the temporal and spatial trends in species composition of catches, sizes of fishes caught and CPUE. These are key indicators of change and relatively straightforward to collect through routine sampling of market operators and undertaking semi-structured interviews with the fishers and explore their experiences on fish catches and trends (See Vol 2 Annex 19 for details of semi-structured interviews for fisheries stakeholders, fishers and market surveys). Questions relating the catch, trends, species, number of people in a village, commune or district involved in fishing and market value of catch can be asked as well as what problems the fishers encounter. Supplementary information can also be drawn from government agricultural and statistical surveys. These data will help to determine the importance of fisheries to livelihoods and food security and determine alternative livelihood scenarios. It is expected that these market and household surveys form part of the HPP Developers monitoring procedures to understand the implications of change in the fisheries on livelihoods and food security.

The repetition, timing and location of sampling will be dependent on resources available but should be sufficient to account for natural variability is fish abundance and diversity. It is recommended these interviews are carried out with fishers when fisheries officers collect the logbook data from fishers, i.e. approximately monthly. Market surveys should similarly be sampled on a monthly basis. Questions should specifically asked about changes in species and sizes caught and sold in the previous month, as well as about collection, sale and consumption of OAAs.

8.4.2.6 Habitat monitoring protocol

The purpose of this assessment is to quantify changes in the extent (coverage) of major fish habitats that may result from the proposed hydropower development. The primary focus is on characterizing impacts of HPP operation on downstream river levels and inundation of habitats (i.e. floodplains) that are river-associated (hydrologically connected) and will therefore be directly impacted due to operations of the proposed hydropower projects as well as assessing the change in habitat in the impounded area. The aim is to compare change in water level and inundation period (effectively a flood pulse) for average, wet and dry years under baseline conditions against those predicted using the hydrological modelling outputs and relate this change to change in fishery production potential under different scenarios. The procedure is a step-wise assessment, as used in the Mekong Delta Study (DHI 2015) and adapted from Halls (2014) and Hortle and Bamrungrach (2013).

The first step in the procedure uses outputs from GIS modelling to map the maximum coverage of different habitat types utilised by key species/guilds (black, white and grey fish) for potential production under baseline flood conditions (e.g. the flooding extent in 2004) This is achieved from flood inundation mapping of various habitats (see Figure 8-4) using baseline conditions derived from the hydrological monitoring outputs (Section 4). The area of each flooded habitat is determined from from NASA Landstat and Digital Elevation maps as used by MRC and other MC agencies (e.g. Figure 8-4). Here the area of each habitat under water, thus capable of supporting fish production, is determined.

The following major habitat types are common in the LMB: mainstream, river/canal, inundated forests, marsh/swamp/lake/ponds, inundated grasslands, mangroves, rice fields, and nearshore coastal habitat. However, because of problems discriminating boundaries between habitat types, Halls (2014) and Hortle and Bamrungrach (2013) combined the habitats into three broad habitat categories for the purposes of the determining impacts on fish habitats:

- Main river channel and river canals
- Floodplain habitat (to include both permanent and seasonally flooded areas and rice fields),
- Nearshore coastal habitat (to include coastal wetlands and mangrove forests)

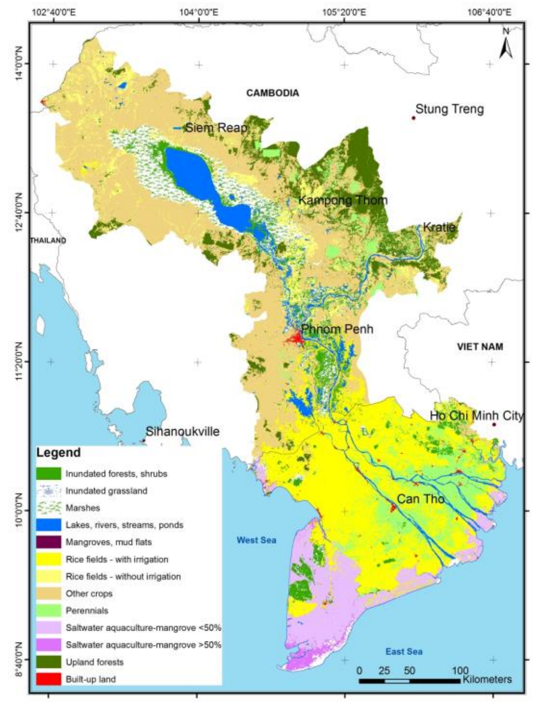

Figure 8-4: Wetland habitat map for Cambodian floodplain and Vietnamese Delta 2014 (source DHI 2016)

The next step is to determine the productivity of the flooded habitat according the relationship between fisheries yield of each habitat type and area proposed by Halls (2014) and Hortle and Bamrungrach (2013), who provided global yield per unit habitat area for these habitat types (Table 8-5). It should be noted that it is not possible to explore the relationships for all guild types, instead the yield proportions of blackfish, whitefish and greyfish and OAA for each habitat type (Table 8-5) are used to provide a range of values with which to estimate and validate the capture fishery yield estimates. The OAA include shrimp, crabs, snakes, frogs and molluscs. These yield per habitat data will be updated every 5 years through a proposed MRC initiative.

Table 8-5: Inland capture fishery yield estimates for each major aquatic habitat category (Based on Halls 2014 and Hortle & Bamrungrach 2013)

Habitat category	**Yield-per-unit area (kg ha^{-1} yr^{-1})**	**Guild Proportions**			
		OAA	Blackfish	Whitefish	Greyfish
River-floodplain	250	0.11	0.39	0.43	0.18
Rainfed wetlands	100	0.11	0.95	0.00	0.05
Large water bodies outside flood zone	200	0.11	0.40	0.00	0.60

The change in wetted area of each habitat type predicted from the hydrological modelling of the dam operations is then determined and the loss or gain in habitat is related to the average expected productivity of each aquatic habitat type for each key fish guilds (e.g. black, white and grey fish) or species, based on data from Halls (2014) and Hortle and Bamrungrach (2013) (Table 8-5). The change in wetted area of each habitat type caused by the HPP operation is then predicted from hydrological modelling and the areal extent of flooding under different water level changes. The GIS habitat modelling results can also be used to determine the extent of the impoundment and the potential loss of key fisheries and OAA habitat types, especially, riffle reaches, deep pools and floodplain habitat. This is achieved by mapping the type of habitat that is lost under the impounded area (from Landstat and DEM as in the assessment of habitat change under different flooding conditions) as a percentage the available habitat in the region of the dam. The extent of the impoundment can be related to the approximation of average fish production per unit area to determine the loss of potential yield.

The outputs from the landscape-level fish habitat impact assessment methodology will serve as input for assessing impacts on capture fisheries and fish communities (see Section 8.5), and aquatic ecosystem health and functioning (see Sections 6 and 7).

8.4.3 Fish Passage monitoring protocol

8.4.3.1 Background

Many fish species in the Mekong River are a transboundary resource, migrating between countries; hence there is a mutual need among the lower Mekong countries for transparency of information regarding population trends and potential impacts on fish. There is also a range of species that migrate over shorter distances, which can be within a country. These species are often part of the food chain that supports the longer distance migratory fish, so they are indirectly a transboundary resource. If these short distance migrants decline, so will the long distance migrants.

As described in Table 8-1, a potentially significant impact of hydropower dams in the mainstream lower Mekong is reducing or preventing upstream and/or downstream migration of fish. To mitigate this impact on mainstream dams the MRC Preliminary Design Guidance (PDG) and the draft Design Guidance (DG2018) provide guidelines and objectives for fish passage. At large dams, fish passage is often the most costly mitigation, involving extensive design, capital and operation.

There are numerous techniques to monitor and assess fish passage that meet different objectives. The JEM specifically seeks to describe a robust methodology to measure passage of fish at the dam. In this context it is not intended to describe the ecology of fish migration (although this will partly be a by-product of sampling) or why a particular result occurs, only the actual passage of fish. If a problem was identified, then other techniques and methods would likely be employed to understand the results and address the issue.

Fish populations vary year to year under natural conditions and due to other natural and human-mediated perturbations in the catchment. An objective of monitoring fish passage in JEM is to have a methodology that separates impacts of the dam on fishes, from impacts that are occurring elsewhere in the catchment. Otherwise, if fish decline, it could be attributed to the dam when the cause is potentially elsewhere. Therefore, JEM follows the logic of the PDG2009 and DG2018, of using the percentage passage of fish approaching and passing the dam. If fish populations vary, percentage provides a comparable measure between years (or other time scales), as well as between dam sites.

It is important to note that the percentage passage figures for fish in the PDG and DG are derived from population modelling and expert opinion, and are intended to prevent any major impacts on fish populations caused by restriction of migration at a dam. In the PDG the value is 95% passage and in the DG this figure is separated into two groups of fish with varying values from 60% to 95%, depending on importance of migration in the life cycle and number of dams:

i. For long-distance migratory species (i.e. Guilds 2, 3, 4 and 8) at a single dam, large fishes (>75 cm) require more than 90% passage (of numbers of each species approaching the dam) and medium-sized (50-75 cm) fish require more than 80% passage. If there are multiple dams, more than 95% passage at each dam site is required for both size groups.
ii. Small, short-distance migratory species (Guild 4) moving between/along the river to floodplains, require more than 60% passage (upstream and downstream) between spawning and feeding/refuge habitats.

If the biology of Mekong fishes was well understood, the specific percentage for each species to prevent major population impacts would likely be different. The PDG acknowledges this and notes that "the success rate for fish passage can be refined for the particular species concerned, based on its life history and the number of dams the species may have to pass to complete its life-cycle." To do this would require investigation of the life cycle and population dynamics, which is not part of JEM. However, linking monitoring of fisheries and fish passage may provide some indications of where these values can be refined. For example, if a particular species was abundant in the fishery upstream and downstream of the dam, but was not meeting the specified percentage passage, then the value for that species can be lower to match the passage rate that is sustaining the population.

8.4.3.2 Objective

The objective of this section is to provide a methodology to measure upstream and downstream fish passage at the dam, which is cost-efficient, quantitative and comparable between sites, and to provide confidence and transparency to Member Countries of the MRC. The methodology is expected to be adopted by HPP developers to assess the efficacy of the fish passage solutions at the dam and identify measures to ensure the defined proportion of fish are able to negotiate the HPP development as specified in the PNPCA (see Section 8.4.3.4).

It is acknowledged that fish passage mitigation on the Mekong mainstream is a new area of endeavour, and in river systems where fish passage has not been applied, it always needs to be adaptively managed to become optimised. Not meeting expectations of performance may occur for some species but sharing data and methods provides the mechanism for mutual support to develop solutions.

8.4.3.3 Scope of Monitoring

Monitoring fish passage has two components: i) assessing fish approaching the dam and locating the entrance, called *attraction efficiency*, and; ii) assessing fish passing through the dam and impoundment, via fishways, spillways or turbines, called *passage efficiency*. These apply to both upstream and downstream migration and include safe passage.

Attraction efficiency requires data on fish approaching the dam. For both upstream and downstream migrants this needs to be very localised as it relates to fish in the immediate area near the dam. Typically, fish are sampled, or movements tracked, within hundreds of metres of the dam and entrance(s) of upstream and downstream fishways.

Passage efficiency for upstream migrants is passage: i) within the fishway, ii) at the exit, and iii) through the reservoir. Sampling within the fishway is required at the entry and exit to enable a quantitative comparison. Fish leaving the fishway exit are monitored to assess if fish immediately return back down the spillway or through the turbines. *Passage efficiency* for downstream migrants includes passage through the impoundment, fishways, spillways, turbines, and tailwater.

8.4.3.4 Performance measures

The performance measures are from the draft Design Guidance 2018, which applies to different guilds of fish, providing more relevant detail than the PDG. These are:

i. >80% passage for medium (50-75cm), long-distance, migratory species (i.e. Guilds 2, 3, 4 & 8) at a single dam.
ii. >90% passage (upstream and downstream) for large (>75cm), long-distance, migratory species (i.e. Guilds 2, 3, 4 & 8) at a single dam.

iii. >95% passage for large and medium long-distance migratory species (i.e. Guilds 2, 3, 4 & 8) if fish need to pass more than one dam.

iv. >60% passage for small, short-distance migratory species (Guild 4) where the dam is between spawning and feeding/refuge habitats.

8.4.3.5 Target Species

The target species relate to the performance measures, which use the guilds that are vulnerable to impacts from restricted migration. Some methods of monitoring will not be selective and will capture any migrating fish that are present, such as trapping the fishway channel; but some are selective, such as radio/acoustic tracking. For selected methods, three species of each migratory guild (Guilds 2, 3, 4 & 8) should be used, if the guild is present at the site. If possible, the choice should include benthic, pelagic and surface-dwelling species.

Rare or highly uncommon species are not recommended for assessment of fishways because the samples sizes are inevitably low. This makes analysis of the data difficult and results are frequently inconclusive.

8.4.3.6 Methods

The following are methods that apply to mainstream Mekong hydropower projects.

Fishway trapping: A simple cage or mesh trap with a funnel to prevent escape of fish. It is used within the fishway, typically at the entrance and exit.

Passive Integrated Transponder (PIT) tags (Vol 2: Annex 25)*:* These are a small, life-time (i.e. no battery) tag that has an individual code. The tag is identified and automatically logged into a computer when it passes within 20-40 cm of a specialised reader. These characteristics make it ideal for assessing fish passing through confined spaces such as fishways.

Radio or acoustic tags (Vol 2: Annex 25)*:* These are much larger than a PIT tag – varying in size from a very small finger to a large finger, depending on battery life (months to years) and range of signal. The range is usually hundreds of metres and so they are ideal for monitoring fish as they approach or leave a fishway. Note: up to 40% of tags can be lost to mortality or fishing, so the sample size needs to accommodate this. At least 50-60 fish of one species would be required to understand the variation in behaviour; hence, 100 tags would be required.

Turb'N Tag: These are a specialised tag for assessing injuries and mortality from passage through turbines. They are attached to fish and inflate after turbine passage, so the fish can be collected and examined.

DIDSON sonar camera (Vol 2: Annex 24)*:* DIDSON or ARIS cameras use sonar technology to produce clear video images in water with almost any turbidity. Their limitations are they operate poorly in highly aerated water, which would be near spillways, and have a narrow beam which cannot view a large wide river with a complex bed, such as the Mekong. Sampling at the Mekong hydropower sites would be done by sub-sampling areas and stratified sampling. The DIDSON or ARIS cameras are particularly useful to assess: fish attraction in the tailwater, fish entry into the upstream or downstream fishway, and fish impingement on trash screens. Because fish are not handled or captured, data represents a reliable view of fish behaviour.

Electrofishing (Vol 2: Annex 23)*:* Electrofishing in large rivers is done with a specialised boat. They can be tuned to stun most fish within proximity of the boat. Fish can then be identified, measured and released with high survival. Quantitative samples can be taken by ensuring consistency of electrofishing time. These can provide relative abundance of fish and so would be useful to assess accumulations of fish downstream of a fishway, and provide an independent sample of migrating fish to compare with fishway samples. The main limitations are that capture of benthic fish is poor and they can remain stunned on the bottom of the river, and efficiency in deep water (> 2 m) is poor.

Larval nets (Vol 2: Annex 22)*:* These are a specialised net with a fine mesh (e.g. 0.5 mm) (see Section 8.4.2.4).

Nets for juveniles and adults (Vol 2: Annex 21): Netting of fish is the most common technique of sampling fish and there are many different types of nets. Possibly the most quantitative type of net is a multi-panel gill net, which has panels of different mesh sizes (see Section 8.4.2.2). In fish passage assessment they can potentially be used for the same objectives as electrofishing: assessing relative abundance and accumulations of fish, and providing a comparison with fishway samples.

8.4.3.7 Methods applicable for assessing fish migration between dams and along the whole river

PIT tags and radio/acoustic tags are the two key techniques that provide the ability to track individual fish and hence, track fish between dams. To fully realise this opportunity, it is critical that the same systems be used among all dams. Dam operators need to share data in a centralized cloud-based database. A PIT system is presently being designed by XPCL and Charles Sturt University for Xayaburi HPP. To be compatible, other systems along the mainstream Mekong should use the same system.

8.4.3.8 Sampling strategy

The sampling strategy relates directly to the questions, or hypotheses, regarding fish passage effectiveness. Table 8-6 and Table 8-7 list the questions, applicable methods, sampling locations, and provisional sample sizes and sampling frequency. The question are given a priority ranking based on whether it represents a high risk to fish. For the JEM only those questions that are a *very high* priority are proposed to be investigated.

Table 8-6. Monitoring requirements for mainstream Mekong hydropower projects: i) Upstream fish passage

	Question	Priority	Method	Sampling location	Sample size	Sampling frequency
Upstream						
Attraction	Do fish locate the fishway entrance(s)?	Very high	Radio/acoustic tags	Within 1 km of the dam	Minimum 100 per target species; minimum number of target species is 2 large, 2 medium and 2 small, of the migratory guilds (Guilds 2,3,4 & 8)	Continuous for 3 years minimum, 5 years preferable
			DIDSON acoustic camera	Within 1 km of the dam	Fixed transects of tailwater	50 complete scans of tailwater during fish migration season (samples with low numbers of fish are not used). Stratify by river flow, turbine use, and spillway flow. Seasonally for 3 years minimum, 5 years preferable (It is preferable to have DIDSON deployed continuously and have data sub-sampled each season to report on fish approaching the dam)
			Electrofishing		Pilot sampling required to establish variance (Note: XPCL and Charles Sturt University are presently preparing standard methods)	
			Multi-panel gill nets		Pilot sampling required to establish variance	
Passage	Do fish enter the fishway?	Very high	Radio/acoustic	Fishway entrance	As above for radio/acoustic	Continuous for 3 years minimum, 5 years preferable
			DIDSON acoustic camera	Fishway entrance	Pilot sampling required to establish variance	Stratify by flow, turbine use, and spillway flow Sample during fish migration season for 3 years minimum, 5 years preferable.

			PIT tags	Fishway entrance	Minimum 2000 of each of 12 target species (4 large, 4 medium and 4 small, of the migratory guilds (Guilds 2,3,4 & 8).[3]	10 years minimum, full concession period preferable
	Do fish reach the exit?	Very high	Cage-trap	Fishway entry and exit[4]		120 samples (60 pairs), with minimum number of 250 fish of each target guild, stratified by three flow types (low, medium high)[5, 6]
			PIT tags	Fishway exit[7]	As above for PIT tags	Continuous for 3 years minimum, 5 years preferable
			Video		??	
	Do fish exit safely?	Moderate	Radio/acoustic		As above for radio/acoustic	
			DIDSON			
	Do fish continue to migrate through the impoundment?	Moderate	Radio/acoustic		As above for radio/acoustic	

[3] Note: need to tag fish every year for the period of assessment as tagged fish are lost through natural mortality and capture by fishers.
[4] If passage is shown to be restricted, further locations within the fishway can be added to understand where the restriction is occurring.
[5] Note that weekly sampling would be useful for the dam owner to optimise fishway function and dam operation.
[6] Cage escapement would need to be quantified with a DIDSON.
[7] If passage is shown to be restricted, further locations within the fishway can be added to understand where the restriction is occurring.

Table 8-7. Monitoring requirements for mainstream Mekong hydropower projects: ii) Downstream fish passage

	Question	Priority	Method	Sampling location	Sample size	Sampling frequency
Downstream						
Attraction	Do fish locate the fishway entrance(s)?	Very high	Radio/acoustic	Within 100s of metres of the dam	Minimum 100 per target species; minimum number of target species is 2 large, 2 medium and 2 small, of the migratory guilds (Guilds 2,3,4 & 8)	Continuous for 3 years
			DIDSON acoustic camera	Within 100s of metres of the dam		
Passage	Do fish pass through the impoundment: i) larvae?	Very high	Larval nets	Sites upstream of impoundment, within impoundment and close to dam; stratified by depth.	Requires initial sampling to assess variance	
	ii) juveniles?	Moderate	DIDSON acoustic camera	Sites within impoundment	Requires initial sampling to assess feasibility and variance	
	iii) adults?	Moderate	Radio/acoustic	Sites: upstream of impoundment; 3 evenly-spaced locations along the impoundment; and close to dam	As above for radio/acoustic	Continuous for 3 years
	Do fish pass through the fishway safely?	Very high	Collect fish at downstream exit and hold for 5 days to assess mortality.[8]	Downstream exit of fishway	Minimum 100 per target species; minimum number of target species is 2 large, 2 medium and 2 small, of the migratory guilds (Guilds 2,3,4 & 8)	Experiment repeated 4 times
	Are large fish guided away from the powerhouse by the trash/fish screens or	Very high	DIDSON acoustic camera	In front of powerhouse trash screens	Pilot sampling required to establish variance	Subsample over first 12 months, stratified by flow (Low, medium, high), to establish

[8] Use controls to accommodate effects of handing.

	is there impingement?				downstream migration season. Then sample migration season in the following two years, also stratified by flow.
			Radio/acoustic	Minimum 100 per target species; minimum number of target species is 2 large, 2 medium and 2 small, of the migratory guilds (Guilds 2,3,4 & 8)	Continuous for 3 years
	Do smaller fish that pass through the trash screens, pass through the turbines safely?	Very high	Turb'N tags	Requires initial testing to assess suitability.	
			Funnel nets	Requires initial testing to assess suitability.	
	What are the hydraulic conditions within the downstream passage routes	Very high	Sensorfish/CFD modelling	Requires assessment of turbine configuration and operation	
	Do fish pass the spillway safely?	High	Radio/acoustic	As above for radio/acoustic	
	Do fish pass through the tailwater safely?[9]	High	Radio/acoustic	As above	
	Is there delayed mortality kilometres downstream?	Low	Radio/acoustic	As above	

[9] Fish can be disoriented after passing through turbines, sluices, or spillways and be prone to predation

8.4.4 Quality control procedures

Changing the sample procedure or sampling under varying conditions or with different staff or field crews may cause large variations in results, so it is important to follow the Standard Operating Procedures and fill field data sheets accurately. On any occasion, if it is necessary to modify the procedure at a location, full details should be recorded for future reference and for possible adjustment at other locations.

After all sample processing is completed several quality checks, commensurate with the FADM and FLDM guidelines (2022a, b) should be carried out.

Fish Identification

An expert taxonomist checks a summary of species at each location (from databases) from FADM and FLDM field sampling and identification. The taxonomist signs-off on the field and laboratory data sheets and in the database.

Data Check

The final computerised data are cross-checked against the contents of the field and lab sheets, and against photographs of each sample, in terms of:

- Species recorded
- Total counts or approximate counts
- Approximate size and weight ranges

The data are also checked against the historical data for the location and if any major changes are evident (i.e. absence of previously abundant taxa or dominance of previously rare taxa), the laboratory book data and photographs are re-checked.

Method calibration and validation

Periodically, responsible agency staff may replicate nets to calibrate and validate with the fisher fishing methods. Calibration of the method requires that it produces consistent results under given conditions, note that it provides absolute estimates of abundance. Spatial variation in fish abundance is a large source of variation (related largely to habitat variation), but we assume that the use of replicate nets set over a distance of 5-10 km reduces (smooths) such variation. Method validation involves comparing catches to another method which provides an estimate of all fish in the targeted habitat at the time of sampling.

Data quality monitoring

Institutions/researchers responsible for implementing the monitoring programme should take measures to ensure that the data recorded by fishers is unbiased and as accurate as possible by regularly overseeing and checking data recording activities. Institutions should encourage fishers to report any problems they experience and provide further training or additional equipment as necessary. Fishers should be provided with appropriate equipment and materials, e.g. electronic weighing scales, to complete their enumeration activities. Regular feedback is also very important (see below).

Each quarter the database should also be examined for evidence that the data have not been fabricated (e.g. systematic patterns and anomalies). The likely accuracy and reliability of the data collected should be reported each quarter and year along with recommendations to resolve any shortcomings.

8.5 JEM - Fisheries data analyses

8.5.1 Basin-scale analysis

Detailed analyses of the data generated by the JEM programme will follow protocols established in the FADM (MRC 2022a) and FLDM manual (MRC 2022b).

As indicated in the FADM monitoring guidelines (MRC 2022a) and Council Study (MRC 2016) it is recommended that the guild approach is adopted for analysis to determine status and trends in fisheries. This approach breaks down the fish species into ten broad guilds based on reproductive tactics and habitat associations and adds an additional category for non-native species (Vol 2: Annex 18). The latter is because non-native species introductions and invasion is a pressure on the fisheries in its own right and prominence of invasive species either indicates a deterioration of habitat quality or escapes from aquaculture systems. By adopting the guild approach it is possible to undertake more complex analyses that are not possible with high species diversity.

Whilst analyses of data generated by the FADM and other fisheries programmes have been reported (e.g. Doan *et al.,* 2006; Nguyen *et al.,* 2006 and Hortle *et al.,* 2007), less work has been done to construct time series of the data collected. Unfortunately, much of the historical data available are fragmented and of varying quality and completeness (see JEM review, MRC 2018a). They have not been used extensively for focused impact assessment analyses. It is well established that fish and fishery production varies substantial from one year to next in response to temperature and intensity of the flood pulse, especially the extent, duration and amplitude of flooding. These data constraining factors will influence the robustness of the impact analyses and the interpretation of the tangible outputs.

Such series are not only important for assessing and interpreting trends in indices of OAA and fish abundance and diversity but also form important baselines for impact monitoring purposes. For the JEM impact assessment, standard methods of fisheries data analysis will be undertaken from the information collected using EXCEL and the R programme language, and supplemented by the PRIMER and CANOCO software as summarized below and detailed in MRC (2022a).

8.5.1.1 Relative fish abundance

Data can be analysed to determine:

- total catch for the area under study
- mean catch rates for each taxa;
- compare the mean catch rates for the different locations, seasons, zones and depths
- compare mean catch rates between different mesh sizes of gill nets or between gears.

Relative (multi) species fish abundance is indicated by estimates of mean catch per unit effort (CPUE). Estimates of CPUE are typically log-normally distributed. The estimate of the mean loge transformed catch per unit effort (CPUE) at location j in year y and month m for gear g is given by:

$$\ln \overline{CPUE}_{j,y,m,g} = \left[\sum_{i}^{n} \ln \frac{C_{j,y,m,g,i}}{E_{j,y,m,g,i}} \right] . \frac{1}{n}$$

Where $C_{j,y,m,g,i}$ is the combined catch weight for all species in catch sample i at location j in year y, month m with gear g, and E denotes the corresponding fishing effort.

The equivalent expression for a given species s is:

$$\ln \overline{CPUE}_{j,y,m,g,s} = \left[\sum_{i}^{n} \ln \frac{C_{j.y,m,g,s,i}}{E_{j,y,m,g,i}} \right] . \frac{1}{n}$$

Where n is the total number of catch samples in month m, recorded by participating fishers and where:

$$E_{j,y,m,g,i} = H_{j,y,m,g,i} . P_{j,y,m,g,i}$$

and H is the number of effective fishing gear hours (e.g. soak hours) and P is the effective power of the gear. For (gill) nets P is the total net area (m^2), and for traps and hooks P is the number of units.

Appropriate statistical methods (Principal Component Analysis – within the PRIMER software) can be used to investigate trends and to relate catch rates to changes in environmental conditions.

8.5.1.2 Species Composition and diversity

Data can be analysed to investigate fish community structure and contribution of species in the impacted area.

Catches will be used to calculate the relative abundance of each fish species in each sample. The relative contribution of a species to the community composition is defined as the percentage of total catches (numbers) comprised by the given species. The relative contribution (%Ai) of species is described as:

$$\%A_i = \frac{\sum S_i}{\sum S_t} \times 100$$

where Si is the sample content (number) composed by species i, and St is the total number of all species.

The Bray-Curtis similarity index (Bray & Curtis, 1957) is used to investigate similarity in fish species composition between gears, sites, seasons or years or a combination of these and presented as dendrograms using hierarchical agglomerative clustering (complete linkage). The Bray-Curtis similarity index (C_z) represents the overall similarity between each pair of samples, taking the occurrence of all species into consideration, and is calculated as:

$$C_z = \frac{2W}{(a+b)}$$

where W is the sum of the lesser percent abundance value of each species common to two samples (including tied values), and a and b are the sums of the percent abundances of species in samples a and b, respectively.

The index ranges from 0 (no species in common) to 1 (identical samples), and a similarity profile test (SIMPROF) can be used to ascertain whether clusters of sites were significantly similar with one another (Anderson et al. 2008). SIMPROF is a permutation test of the null hypothesis that a specified set of samples, which are not a priori divided into groups, do not differ from each other in multivariate structure. In this process, tests are performed at every node of the completed dendrogram to provide objective stopping rules and identify whether groups being sub-divided have significant internal structure (i.e. that samples in each group show evidence of multivariate pattern).

Multi-dimensional scaling (MDS) can be used to establish any relationships between species abundance at the different sites and identify key differences between sites in terms of contribution to the fish fauna. Nested groupings of similar sites are created using the cluster overlap function within the PRIMER statistical package. MDS will also be used to identify similarities in catch composition between gears, fish habitats and times of the year.

In both the cluster and MDS analysis, site, gear and period of year will be tested as factors for discriminating the differences observed.

Various types of measures of diversity are available (e.g. Table 8-8). The simplest measure of species diversity is species richness – i.e. the total number of species per unit area or volume (i.e. in a sample). Simpsons Index [$D = 1-\sum(n/N)^2$ where n is the number of individuals of a particular species and N is the total number of individuals] incorporates additional information on the number of individuals of each species. The number of animals representing each species is divided by the total number of animals in the sample and this value is then squared. D is 1 minus the total sum of these values for each species.

The Shannon-Wiener (H') diversity index, Pielou's measure of evenness (J) and Margalef's index (d), can be applied to investigate spatial or temporal variations in diversity and evenness of fish catches. H', J and *d* are calculated as:

$$H' = -\sum p_i \ln p_i$$

$$J = H' / H'_{max}$$

$$d = (S - 1) / \log$$

where S is the species number, N the total number of individuals and pi is the proportion of the total count arising from the species, and $H'max = \ln(k)$, the maximum possible diversity for a set of data of k categories. These indices are different in that the Shannon Weiner index is a measure of the proportional representation of each species and the Margalef index a measure of the number of species present for a given number of individuals.

Canonical Correspondence Analysis (CCA) can be used to investigate the influence of environmental variables on the relative abundance and community composition of fish species in each site (Clarke & Warwick, 2001; Zuur et al., 2007).

Table 8-8. Fish community impact assessment diversity indicators

Indicator	Measurement Units
Fish catch diversity	• number of species • Jaccard Index • Shannon Weiner Index • Pielou's Evenness Index • Margalef's Species Richness Index • Change in fish guild composition measured as a percent of total by weight and number and percent of migratory species to total capture yield by weight

8.5.1.3 Population Structure and Dynamics (Vol 2: Annex 26)

To compare length distributions for a given species from location to location and from time to time, it is necessary to calculate the size distributions for each species on each occasion in each sampling location. These distributions should be plotted on the same scales, and simply laid next to each other in chronological order and differences in characteristics such as modal lengths and minimum and maximum lengths highlighted. The analysis can be performed in Excel or R.

Such an examination can reveal much about the way fish are growing over time (shown by shifts in modal lengths over time), or any progressive loss of larger fish or lack of recruitment. This type of visual examination will also show the potential for analysing the modes in the length distributions to estimate growth parameters. In essence, if the length distributions do not show reasonably obvious and consistent modes, then an analysis of length frequency distributions will be highly subjective and is unlikely to be successful. It is also useful to compare mean lengths of different samples using a standard test such as Student's *t* test.

Differences between length distributions can be examined using the Kolmogorov-Smirnov Goodness-of-Fit Test, but for samples with large numbers of fish this tends to be overly sensitive, indicating differences between distributions that are not really indicative of genuine differences in biological processes.

Note that before such an analysis of growth and population characteristics can be fully assessed, due account must be taken of selective of the gear, especially the selectivity of different mesh panels of gill nets, The data collected from the gillnets should be entered into software such as SELECT or PASGEAR to adjust for selectivity before establish growth parameters using length-based methods.

8.5.1.4 Relationships between fisheries and environmental data

In order to determine any impact of the Mekong mainstream dams on fisheries there is a need to understand the key environmental drivers of fisheries and how these drivers influence fisheries diversity and productivity, and thus yield (Figure 2-1). This is the fundamental assessment of impact on fisheries in JEM. Changes in key fisheries indicators (total yield per habitat type, yield of economically important species, fish catch diversity and CPUE of the economically important species) need to be related to key environmental indicators from the hydrological and geomorphological and water quality monitoring studies. The key explanatory variables to be tested against fisheries data are indicated in Table 8-9, together with the relationships that will be explored. They include habitat type, change in hydrological variables (water level, flooded area, flow characteristics [amplitude, duration and intensity] and TSS [as surrogate of sediment loading/nutrient dynamics] if relationships with productivity are available (but see Sections 4 and 5).

Table 8-9. Hydrological and geomorphological indicators to be related to fisheries

Type of parameter or indicator	Measurement Units	Comments
Change in extent of habitat connected to floodplain inundated and duration	hectares & number of days/weeks flooded	Correlated with fish species abundance and standing crop
River flows volumes	m^3/s	Correlated with fish yield and species composition
Change in extent of salinity intrusion	hectares	Correlated with species diversity and catch and aquaculture production type
Timing and duration of annual floods	onset/offset times	Relate to fishery practices and species catch composition
Timing and duration of low flow periods	onset/offset times	Relate to fishery practices and species catch composition
Changes in river sediment deposition and consequent nutrient loading	g/m^2/day and mg/L	Relate to fisheries productivity
Change in habitat inundation depths	meters	Relate to fishery practices and species catch composition
Extent of coastal sediment plume	km^2	Relate to coastal fisheries catches

Within this analysis, it is important to recognize that fisheries data are highly variable and provided in range of formats, quality and accuracy.

- Quantitative: e.g. species abundance or catch statistics, water depth, flow
- Semi-quantitative: Abundance scale or catch per unit effort, species composition
- Nominal/Categorical: Presence-absence

The data should be held in a dedicated database (Section 3.2).

It is important to recognize that biological data are characterised by:

- large numbers of zero values;
- often highly skewed;
- irregular/non-linear relationships;
- redundancy

The various solutions to these problems are highlighted in Table 8-10.

Table 8-10. Typical problems encountered with biological and environmental data

Problem	Solution
Skewed/Non Normal data	Transformation – Log, square root, 4th root. Box-Cox, Arcsine, log ratio
Different Scales	Standardization
Missing Data	Omit sample/variable or estimate
Outliers	Transformation or omission
Rare Species	Removal/Downweighting

Environmental data are often of differing scales, a mixture of nominal (numerical) and categorical (abundance classes) and missing data. All these parameters need to be accounted for when undertaking analyses. The type of analysis (Table 8-8) is dependent on the analytical techniques available but typically need to be adjusted for the following:

- Normality
- Equality of variance
- Monotonic/unimodal/linear relationships
- Other data issues e.g. outliers, rare species, missing data

Multivariate analyses, as outlined in Section 8.5.2 and in the FADM manual [MRC 2022], should be undertaken to understand the relationships between fisheries and environmental drivers.

8.5.2 Assessing impact of hydropower development on fisheries and OAAs

The impact of hydropower dams on fish communities will be based on change in fish community structure and trends in fish capture statistics by gear type and fishery independent and dependent data. Key steps in the assessment include:

1. The relationship between fish community structure and habitat and environmental variables will be assessed using a range of diversity and evenness indices, Multidimensional Scaling, Principle Component Analysis (PCA), Permutational Analysis of Variance (Permanova) and Canonical Correspondence Analysis (CCA).
2. The potential impact of each hydropower development by modeling the predicted changes in habitat extent and flow variables against fish community descriptors.

The impact of hydropower dams on the capture fisheries will be based on trends in fish capture statistics by gear type and fishery dependent data collected as part of the fishers' interviews and logbooks described above. Key steps in the assessment include:

1. Assessing role of hydrology on catch rates in different fishery types.
2. Calculating inundation period and extent for baseline conditions using hydrological modelling outputs.
3. Tabulating potential changes in extent of fisheries yield for each hydropower development and for the combination of multiple schemes.
4. Determining how changes in water levels (timing, amplitude and duration) affect yield and catch per unit effort immediately up and downstream and at the transboundary basin-scale levels.

The purpose of this assessment is to quantify changes in the extent (coverage) of major fish habitats that may result under changes in hydrology downstream of the reservoir because of flow regulation. The primary focus is on characterizing impacts on downstream inundated habitats (i.e. floodplains) that are river-associated (hydrologically connected) and will therefore be directly impacted due to operations of the proposed hydropower projects. The aim is to compare change in water level and inundation period (effectively a flood pulse) against baseline conditions in an average flow year predicted using the hydrological modelling or monitoring (see Section 4) and relate this change to change in fishery production potential as described in Section 8.4.2.6. The impact of change in flooding regime (water level) on fisheries and OAAs is determined from proportional change in flooding extent of the different habitats and the corresponding change in potential yield (based on best estimate for yield Table 8-5).

8.6 JEM fisheries data storage and management

Fish biodiversity and abundance data, and fish larval and juvenile data collected through JEM should be stored in the same databases and managed similarly to the existing FADM and FLDM databases. FADM and FLDM results are reported to the MRC by the MCs and stored on the FADM and FLDM databases. Each quarter the database should also be examined for evidence that the data have not been fabricated (e.g. systematic patterns and anomalies). The likely accuracy and reliability of the data collected should be reported quarterly and yearly along with recommendations to resolve any shortcomings.

Additional procedures for ensuring the reliability and accuracy of the data, including updating species names are provided in the JEM Pilot reports (MRC, 2021a & b). Procedures for checking the accuracy of the input are provided in the database framework, but manual checking is also recommended. During the development of the CRMN, this process should be reviewed and recommendations made for revision. The use of a web-based portal with inbuilt preliminary QA/QC functions for reporting of the information from the MCs to the MRC will be developed as part of CRMN.

In addition, purpose built databases for fish tracking and tagging studies need to be established and maintained by MRC as part of the CRMN.

8.7 JEM future projects

Future monitoring under JEM includes additional monitoring at established sites associated with the pilot studies at Xayaburi and Don Sahong under the JEM or JAP framework, and future monitoring at hydropower projects that are not yet constructed to be carried out by using the JEM procedures to ensure robust fisheries data both prior to the submission of the Prior Consultation documentation but also during and after construction and through the operational phase. These are discussed in the following two sections.

8.7.1 Continuation of JEM fisheries programme at Xayaburi and Don Sahong HPPs

It is recommended that the ongoing JEM FADM and FLDM are continued for the foreseeable future (at least seven years to account for the stabilization of the HPP operation) to understand the long-term impacts of Xayaburi and Don Sahong HPPs on fisheries and OAAs. In addition, household and marketing surveys should be conducted to supplement information on fish and OAA yields, plus local knowledge surveys to help interpret the changes observed. Specific attention should focus on the following in the immediate future (next 12 months).

- **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.**
- It is likely the information is collected as part of FADM in that the fishers and their gears are reported in the FADM and form a considerable part of the annual reports. **Complement the above analysis (**to identify the reasons for changes in average monthly catch per fisher) **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.**

  Changes in fish species composition and abundance are expected purely because of the change from riverine to lacustrine habitat. One of the key elements here is to monitor the succession of species change over time following impoundment. It is critical to compare these changes with those found in the upstream and downstream sites to identify changes brought about by the change in habitat. .
- **Cross analyse 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**.

  This is a very important recommendation to integrate socioeconomic data and the JEM Programme already include this proposal. This is part of the reason for the inclusion of market and household data collection in the fisheries part of JEM.
- **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)**.

  Multivariate analyses, as outlined in the JEM Programme above, should be adopted for subsequent reporting.

In addition, the acoustic tracking and PIT tagging studies being carried out by Charles Sturt University, which were delayed during the Pilot studies, should be given all necessary financial and logistical support to complete the studies as defined in the JEM Pilot proposals (MRC 2019a,b). A pilot study to determine efficacy of external (spaghetti tags) tagging systems could be carried out, but the objectives of the study in relation to understanding migratory pathways the effectiveness of fish passes needs to be established.

8.7.2 JEM monitoring at new HPPs

Thirty eight FADM and four FLDM monitoring sites are established in the MRC programme and an additional four FADM sites (upstream of Don Sahong HPP at Saen Nua village and downstream of Hangkhone village in Lao and Oh Run village in Cambodia and one downstream of Xayaburi HPP at Pak houng village) and seven FLDM sites (three at Xayaburi and three at Don Sahong and one in Stung Treng, Cambodia.) were established around Xayaburi and Don Sahong as part of the JEM pilots. Many of the FADM sites are, however, on tributaries and less relevant for understanding the impact of mainstream dams on the Mekong. These FADM monitoring locations meet the criteria of being located within each fisheries migration zone, although the distribution is limited at a basin scale and many more sites should, preferably, be added to the network, especially to account for the high diversity of fishing gears and targeted species.

It is recommended that additional sites are added to the FADM programme to fill gaps in baseline coverage associated with determination of the impact of the proposed hydropower schemes. For this basin–scale, baseline monitoring, new sampling sites are recommended in the vicinity, preferably upstream and downstream, of Ban Koum HPP and the proposed Phou Ngoy in the Khammouan and Savanakhet river reaches (although there is currently one site at Pakse in the potential impoundment) and Sambor HPP schemes, but also in the main tributaries that are likely to be impacted by the lower cascade of HPPs in Laos and Cambodia. This should include a site in the Nam Mun, because the backwater from Phou Ngoy will flood the lower reaches of this river. Additional sites on the mainstream river are also required around the potential impounded areas of the various HPP schemes in the upper Lao cascade. These sites are recommended to understand the changes in fisheries as a result of individual HPPs and the cascade of schemes. For example, it is suggested that the fisheries monitoring site at Tha Mouang, Vientiane, is too far downstream of Xayaburi to understand the impact, and a new station at Ban Noy, Chaing Khan is added to the JEM monitoring sites. However, it should be recognised that the Tha Mouang site remains appropriate for other HPPs in the upper Lao cascade. Attention must be paid to the location as some sites may be flooded by the impoundments of each scheme when they are constructed thus changing the habitat characteristics and fish communities. This is the reason that sites downstream of the proposed HPPs are recommended. Other sites to consider are the important fish breeding area are Kaeng Kud Koo rapids below Sanakham HPP, and the remaining free flowing habitat upstream of Pak Beng HPP, plus addition sites in the Cambodian reach of the LMB to understand transboundary impacts. The exact location of the additional sites should be decided in consultation with the MC fisheries experts to identify key fishing locations where collection of adequate data will be possible, but will also be dependent of resources available. Table 8-11 gives a list of proposed sites to both fill the need of baseline studies as well as the location of existing monitoring sites from the JEM pilots at Xayaburi and Don Sahong and for proposed new sites at the remaining nine HPPs either having undergone the Prior Consultation, or are in the process of being reviewed or in the pipeline for development. It is critical that as soon as new HPPs are announced and PNPCA evaluations proposed, new sites upstream, downstream and in the potential impounded area should be established according to the JEM monitoring strategy (Section 2.4). The approximate location of these sites is given in in Figure 8-5 with details in Table 8-11. In addition, further monitoring sites may also be required in the major tributaries along the Mekong that that will likely be affect by the HPPs or indeed the fisheries may be impacted by dams and other developments on the tributaries in their own right.

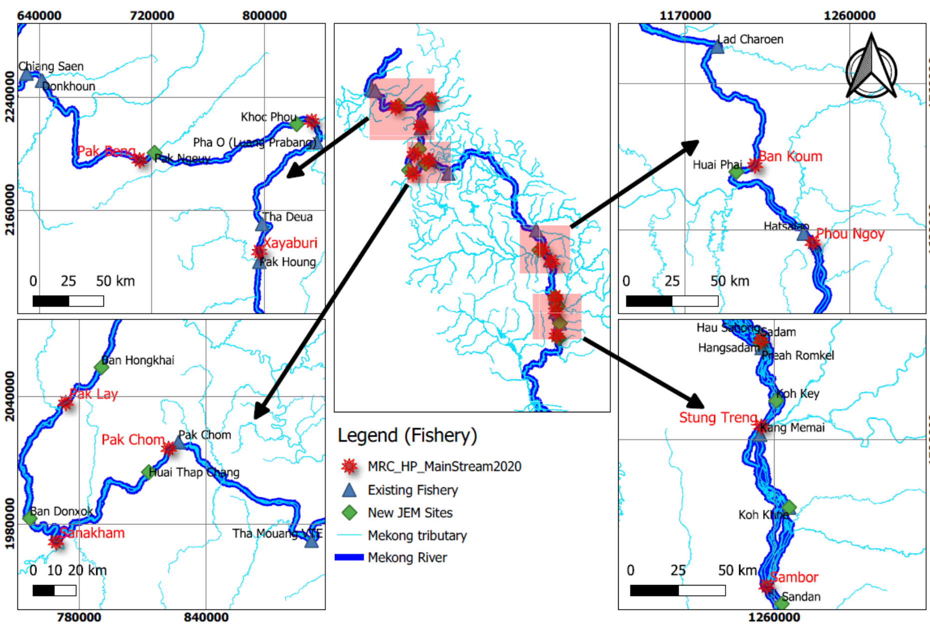

Figure 8-5. Mekong River showing existing and proposed mainstream dam locations, along with existing and proposed future JEM fisheries monitoring locations. See Table 8-11 for details.

Larval and juvenile drift studies should also be carried out at additional sites associated with upper Lao HPP cascade, the Ban Koum/Phou Ngoy combination and the Stung Treng/Sambor region, the latter two areas in addition to the FLDM sites established under the JEM pilot at Don Sahong. The latter is to determine how fish species abundance and diversity change in the impounded area and whether larval drift and fish recruitment are compromised by the change in habitat to a lentic environment. It should be noted that conducting fish larval and juvenile drift studies associated with the upper Lao cascade is likely to be problematic both with the collecting of samples because of the change in habitat topography but also with identifying post larvae to species level, so it may only be possible to determine fish abundance and density. The monitoring procedures for these additional sites are the same as those recommended for the JEM pilot studies at Xayaburi and Don Sahong, but adjusted to account for constraints and recommendations from the Pilot studies. These including FADM, FLDM and market and household studies. In addition, interviews with fishers to gain local knowledge, and tagging and/or eDNA studies are recommended to better understand fish migration patterns in the region and locate key spawning and nursery habitats.

Table 8-11. Recommended future JEM fisheries monitoring at mainstream hydropower projects in the Mekong River

Name of HPP and status	Station location	Name of Village	GPS Coordinates (in UTM)		Remarks or Justifications
Pak Beng - Planned + PNPCA					
	u/s	Chiang Saen	N 20°24.300	E 100°15.325	Existing TNMC impact study site
	impound	Donkhoun	N 20°21.495	E 100°21.591	Existing FADM site upstream of Pak Beng that will be flooded by Pak Beng HPP
	d/s	Pak Ngeuy	N 19°53.291	E 101°07.147	Existing FADM site that will represent the remaining free flowing section of river upstream of LPHPP but downstream of PBHPP
	d/s	Khoc Phou	N 20°03.466	E 102°05.160	Downstream of PBHPP but will be flooded by LPHPP impoundment
Luang Prabang -Planned + PNPCA			N 20°07.4900	E 102°18.8000	
	u/s	Pak Ngeuy	N 19°53.291	E 101°07.147	Existing FADM site that will represent the remaining free flowing section of river upstream of LPHPP but downstream of PBHPP
	impound	Khoc Phou	N 20°03.466	E 102°05.160	Downstream of PBHPP but will be flooded by LPHPP impoundment
	d/s	Pha O (Luang Prabang)	N 19°56.375’	E 102°13.120’	Existing FADM and JEM site - only one d/s site possible as Xayaburi impoundment back up to ≈ 8 km of Luang Prabang dam but may be less because of operational procedures.
Xayaburi - operational			N 19°24.4700	E 101°81.8000	
	u/s	Pha O (Luang Prabang)	N 19°56.375’	E 102°13.120’	Existing FADM and JEM site
	impound	Tha Deua	N 19°25.368’	E 101°50.4080’	Existing FADM and JEM site
	d/s	Pak Houng	N 19°10.872’	E 101°49.028’	Existing FADM and JEM site
	d/s	Ban Hongkhai	N 18°33.268	E 101°45.163	New site in but will be flooded by PLHPP impoundment
Pak Lay -Planned + PNPCA			N 18°40.6000	101°59.1000	
	u/s	Pak Houng	N 19°10.872’	E 101°49.028’	Existing FADM and JEM site
	impound	Ban Hongkhai	N 18°33.268	E 101°45.163	New site in but will be flooded by PLHPP impoundment
	d/s	Ban Donxok	N 17°54.959	E 101°25.432	New site in but will be flooded by SNHPP impoundment
	d/s	Chaing Khan	N 17°90.174	E 101°67.416	Existing TNMC impact study site and FLDM site
Sanakham - Planned + PNPCA			N 17°81.4700	E 101°53.8000	
	u/s	Ban Hongkhai	N 18°33.268	E 101°45.163	New site in but will be flooded by PLHPP impoundment
	impound	Ban Donxok	N 17°54.959	E 101°25.432	New site in SNHPP impoundment
	d/s	Chaing Khan	N 17°90.174	E 101°67.416	Existing TNMC impact study site and FLDM site
	d/s	Pak Chom	N 18°13.879	E 102°05.448	Existing TNMC impact study site
Pak Chom - proposed			N 18°20.4200	E 102°04.6000	

Name of HPP and status	Station location	Name of Village	GPS Coordinates (in UTM)		Remarks or Justifications
	u/s	Chaing Khan	N 17°90.174	E 101°67.416	Existing TNMC impact study site and FLDM site
	impound	Huai Thap Chang	N 18°06.327	E 101°57.402	New site in Pak Chom impoundment
	d/s	Pak Chom	N 18°13.879	E 102°05.448	Existing TNMC impact study site
	d/s	Tha Mouang VTE	N 17°48.127	E 102°40.490	Existing FADM and JEM site
Ban Koum - Planned + PNPCA			N 15°416300	E 105°58.6000	
	u/s	Lad Charoen	N 16°00.5504	E 105°41.4691	Existing FADM site
	impound	Ban Koum Nai	N15°32'41.83"N	E 105°36.285	New FADM site in Ban Koum impoundment
	d/s	Hatsalao	N 15° 04.443	E 105°49.416	Existing FADM site
	d/s	Hangsadam	N 13°56.157	E 105°57.173	JEM FLDM site
Phou Ngoy - Planned + PNPCA in review			N 15°02.7900	E 105°86.7000	
	u/s	Huai Phai	N 15°23.179	E 105°29.504	New FADM site u/s of Phou Ngoy impoundment
	impound	Hatsalao	N 15° 04.443	E 105°49.416	Existing FADM site
	d/s	Hangsadam	N 13°56.157	E 105°57.173	JEM FLDM site
	d/s	Hau Sahong	N 13°58.239’	E 105°57.274’	Existing FADM and JEM site
Don Sahong - operational			N 13°94.3900	E 105°95.6000	
	u/s	Hau Sahong	N 13°58.239’	E 105°57.274’	Existing FADM and JEM site
	d/s	Sadam	N 13°56.976’	E 105°57.253’	Existing FADM and JEM site
	d/s	Preah Romkel	N 13°54.463’	E 105°57.523’	Existing FADM and JEM site Cambodia
Stung Treng HPP - proposed			N 13°53.59	E 105°94.60	
	u/s	Preah Romkel	N 13°54.463’	E 105°57.523’	Existing FADM and JEM site
	impound	Koh Key	N 13°39.356'	E 106° 01.293'	Likely site that will be flooded by HPP but located with HYCOS
	d/s	Kang Memai	N 13°29.834’	E 105°56.341’	Site previously used by IFReDi/FiA - compatible with u/s site for Sambor
	d/s	Koh Khne	N 13°08.915’	E 106°04.175’	Downstream site but may be flooded by Sambor
Sambor HPP - proposed			N 12°77.840	E 105°95.000	
	u/s	Kang Memai	N 13°29.834’	E 105°56.341’	Site previously used by IFReDi/FiA -- compatible with d/s site for Stung Treng
	impound	Koh Khne	N 13°08.915’	E 106°04.175’	Downstream site but may be flooded by Sambor
	d/s	Sandan	N 12°41.553’	E 106°01.292’	Site previously used by IFReDi/FiA
	d/s	Komkong Cham	N:11°88'75.24"	E 105°43'21.32"	FLDM site used by IFReDi/FiA

The recommended monitoring strategy should provide sufficient information to understand how hydropower developments affect fish migration, fish life histories and population and community dynamics. Ultimately these information can be used to understand the impact of HPP developments on fisheries, food security and livelihoods. Monitoring at each of the sites would be enhanced by collaboration and cooperation with the hydropower developer to obtain detailed information about operating rules and strategies. Indeed, it is expected that the additional surveys at new stations upstream, downstream and in the impounded area are conducted by the developers and the data shared with the MRC and member countries. Potentially, there could be substantial cost savings if fisheries monitoring data collected by the developer for the purpose understanding the impact of the HPP on fisheries are shared with the MRC. In addition, it is expected that all tracking and tagging studies are funded, and/or undertaken, by the developers in collaboration with the MRC. To support this continued monitoring of Don Sahong and Xayaburi HPPs, plus additional monitoring of planned dams and other developments, continuous capacity building and training of national, regional and local agency staff is recommended to maintain the skill levels needed to implement the programme and consolidate the prevision of robust defensible data and suitable analysis of status and trends and impact assessment. Capacity building should mainly target existing and new staff implementing the FADM and FLDM programmes as well as for tagging and tracking activities. Training should include field survey procedures, experimental analysis and data management.

8.7.3 Incorporation of JEM programme in the environmental routine monitoring programmes and core river monitoring network

Based on the experience from the JEM Pilots, sampling designs have been developed for monitoring at each of the proposed future mainstream hydropower projects. These monitoring strategies are based on the current understanding of where future hydropower projects are proposed to be developed, and the existing monitoring networks of HYCOS, DSM, WQMN, EHM and fisheries.

The monitoring strategies are presented as stand-alone regimes applicable to individual developments, but it is recognised that project areas overlap, and depending on the order and timing of hydropower development, the strategies may need to be modified. It is also recognised that some of the proposed monitoring sites are unlikely to be viable in the long-term, due to the creation of impoundments inundating the monitoring stations and in the case of fisheries changing the topography, likely sampling protocols and fish species present. Where applicable, recommendations are made for the establishment of new sites that would be viable in the long-term, e.g. after development of all proposed mainstream hydropower projects. These sites should provide the long-term, continuous results required to meet the fish biodiversity and abundance monitoring needs of the MRC, and should be considered in the development of the CRMN.

The following recommendations are made for incorporating the JEM programme into the routine monitoring, and the CRMN that is under development:

- Review of the existing FADM and FLDM monitoring network to take into consideration the existing dams, and the proposed locations of future projects. The CRMN should provide a regional understanding of fisheries distribution, abundance life history strategies, harvest regimes and livelihood analyses in the LMB, and use JEM monitoring provide appropriate inputs to understand the impact of existing and future developments and climate change impacts in the LMB.
- The CRMN should consider the locations of proposed hydropower infrastructure and impoundments, and identify monitoring sites that will remain unaffected by backwater conditions,

and can provide a long-term understanding of the fish diversity and abundance, including disruptions to life history and population dynamics of the fish and OAAs. Consideration should be given to intensifying some existing FADM and FLDM monitoring sites in the mainstream and major tributaries to understand the importance of each zone of the river to maintaining and improving the sustainability of the fisheries.

- Continued capacity building in the implementation of sampling methodologies and analysis of fisheries and environmental data should form an ongoing part of the long-term monitoring strategy.
- This should include in-depth regular training associated with annual reporting of FADM and FLDM data and upgrading the capacity of riparian staff to undertake fish tracking studies and analyse the data in relation to changes brought about by development in the LMB.

9 Integrated environmental impact assessment

Undertaking a robust, defensible, Environmental Impact Assessment requires considerable input of data for multiple sources, as proposed in the JEM programme, and analyses of these data in an integrated framework to determine the change, if any, brought about by the development. Within the context of hydropower development understanding the linkages between drivers (flow-hydraulics-sediment) and impacts (water, quality, aquatic ecology and fisheries) (Figure 2-1) is crucial and would form the framework for the EIA.

As in any large and complex ecosystem, relationships between environmental drivers and resources are complex, dynamic, and include multiple feedback loops. This is exemplified by the complex interactions explored in the MRC Council Study (MRC 2017: see Figure 9-1 for linkages investigated), which are applicable for JEM. For example, hydrology is linked to physical changes to habitats (river geomorphology) and sediment dynamics, water quality issues arise due to flow changes, and have significant influences on aquatic ecology. Fish and fisheries are dependent on conditions and processes relating to flow, habitat, water quality and aquatic ecology. Furthermore, socio-economics are strongly influenced by all of these factors, and in particular where livelihoods are dependent on the river environment.

These different relationships are explored in individual sections throughout this report. Hydrology is the underpinning driver and alteration in in the hydrological cycle bring about changes in the sediment erosion and deposition processes and ultimately geomorphology (Section 5)**Error! Reference source not found.**. These changes alter habitat availability and quality and nutrient dynamics, which alter the ecological functioning and processes, and productivity (sections 7 and 8).

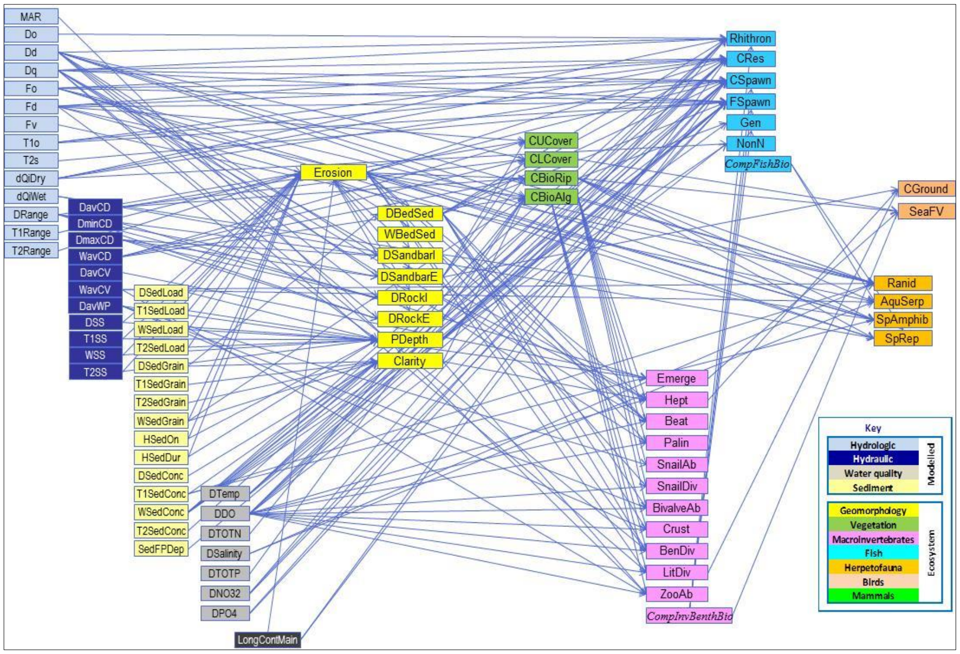

Figure 9-1. Linkages between environmental and ecological indicators used in the MRC Council Study (MRC 2017)

The relationships between these various parameters need to be integrated and interpreted to allow identification and assessment of impacts. Because of the size of the Mekong River, it is recommended the river is broken down into ecological and geomorphological zones, such as was carried out in the MRC Council Study (see Figure 9-2 for BioRA zones adopted). This will allow the impact in each zone to be determined and integration of outputs from all zones will enable determination of transboundary impacts, and thus identification of potential mitigation measures.

It is proposed the collation of data is carried out by the MRC, but is dependent on sharing of data from all sources, especially the MRC-MC monitoring programmes, developer monitoring programmes and independent research activities. Annual workshops between MRC and MC experts, NMCs and developer experts are recommended to jointly interrogate the data and produce annual reports. This will provide robust, transparent analyses and determine the relationships between variables, as well as providing the outputs of the JEM programme in a timely manner.

Figure 9-2. BioRA Zones used in the MRC Council Study (MRC 2017)

9.1.1 Advancements in integrated assessment in the JEM Pilots

Integration of JEM results between disciplines was limited due to the short-time period of monitoring, and to a lesser extent, differences in the frequency of monitoring between disciplines. Flow results were integrated with SSC and water quality results to arrive at sediment and nutrient loads at long-term monitoring sites, and qualitative comparison of results were consistent with known linkages between hydrology, water quality and EHM. Linking changes with fisheries results becomes more problematic due to the complexities of the system, and number of factors potentially affecting these higher trophic levels (see previous discussion).

One advancement completed during the JEM Pilots was the identification of monitoring clusters in the river based on existing monitoring stations that can be grouped for future analysis (Table 9-1). These groupings are used as the basis for identifying potential monitoring sites for JEM monitoring of future hydropower projects.

Table 9-1. Clusters of existing monitoring locations that can be used as the basis of future monitoring strategies and for the integration of monitoring results between disciplines. The sites highlighted in orange denote the sites considered most complete and or useful for ongoing and integrated analysis. The different site codes relate to how the site is denoted in different monitoring strategies. The green clusters are relevant to the JEM Pilot studies.

Cluster	Country	Code 1	Code 2	DSM_	EHM	WQ	Fishieries	Location	Latitude	Longitude
1= downs-tream China	LA	LA_010803	LHT				LHT	Bokeo, Houay Tab / Huey Xai	20.327467	100.380856
	LA	LA060101	LDK				LDK	Bokeo, Donekoun	20.367703	100.372783
	TH	TH_010501	CS	CS		CS		Chiang Saen	20.27430	100.08840
	TH	TH_010502	TCS		TCS			TCS Chiang Saen	20.259484	100.09832
2	LA	LA_010902	LPN				LPN	Oudomxay, Pak Ngeuy	19.889122	101.121747
2	LA	LA090101	LOX				LOX	Oudomxay	19.891589	101.138236
3=up-stream Xayaburi Dam	LA	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		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	Now flooded by the impoundment				Luang Prabang	19.89266	102.13389
Cluster 4: Xay. Impoundment	LA	LA_011302	EHM2, XLB		JEM_EHM2		XLB	Xayaburi, Ban Thadeua	19.434750	101.834750
	LA	LA_011502	WQ2			JEM_WQ2		Ban Talan	19.254472	101.812639
	LA	LA011301	LJXI				LJXI	Xayabouri	19.4269	101.8447
	L	LA011304	LJXI				LJXI	Xayabouri	19.553556	101.820661

Cluster	Country	Code 1	Code 2	DSM_	EHM	WQ	Fishieries	Location	Latitude	Longitude
	A									
5= down-stream Xayaburi Dam	LA	LA_011503	WQ3, EHM3		JEM_EHM3	JEM_WQ3		Xayaburi Dam 1 km downstream	19.230417	101.821417
	LA	LA_011501	Pak Houng, EHM4	Pak Houng	JEM_EHM4			Downstream Xayaburi, Ban Pak Houng, about 5 km downstream	19.202139	101.824444
	LA	LA_011504	WQ4			JEM_WQ4		Xayaburi Dam about 5 km downstream	19.216194	101.82375
	LA	LA_011505	EHM5		JEM_EHM5			Ban Pak Houng 7 km_down	19.180417	101.822083
	LA	LA_011506	WQ5, EHM6, LJXD		JEM_EHM6	JEM_WQ5	LJXD	Ban Pak Houng 10 km_down	19.157778	101.814056
Cluster 6	TH	TH_011902	TCK				TCK	Loei, Ban Noy	17.910733	101.696058
	TH	TH_011903	CK	CK				Chiang Khan	17.89971	101.67018
Cluster 7	LA	LA_011901	VTE	VTE		LA_011901		Vientiane KM4	17.93093	102.61578
	LA	LA_011905	LVT		LVT			Ban Huayhome, Vientiane	17.971296	102.543779
	LA	LA_012001	NK, LVT	NK			LVT	Tha Mouang, Vientiane	17.890797	102.746072
Cluster 8	TH	TH_013001	TSM		TSM			Nakorn Phanom, Songkhram and Mekong River Junction	17.6528	104.467536
	TH	TH_013002	TUT				TUT	Nakhon Phanom, Ban Tha Dok Kaeo	17.623797	104.517419
	TH	TH_013101	NP	NP		TH_013101		Nakhon Phanom	17.42511	104.77371
	T	TH_01310	TN		TNP			Nakorn Phanom	17.424562	104.77713

Cluster	Country	Code 1	Code 2	DSM_	EHM	WQ	Fishieries	Location	Latitude	Longitude
	H	3	P					City, TNP		
Cluster 9	LA	LA_013900	LA_013900			LA_013900		Pakse	15.12	105.78
Cluster 9	LA	LA_013901	PS, LSL	PS			LSL	Champasak, Pakse city, Hatsalao	15.099760	105.813187
Cluster 9	LA	LA_013902	LDN, LCS		LDN		LCS	Champasak, Done Ngew or Ban Hat	14.990929	105.894687
LA Cluster 10=upstream DS Dam	LA	LA_01390		Pakse				Pakse	15.09951	105.8132
LA Cluster 10=upstream DS Dam	LA	LA_013306	WQ6, EHM7	Pakse	JEM_EHM7	JEM_WQ6	LJDU	Don Sahong, upstream of the impoundment	13.978278	105.9545
LA Cluster 10=upstream DS Dam	LA	No code	Muang Saen Nua				Muang Saen Nua	FADM_JEM	14.097530°	105.783938°
LA Cluster 10=upstream DS Dam	LA	No known code	Pakse				LCS	FADM_MRC	14.083781°	105.845402°
LA Cluster 10=upstream DS Dam	LA	LA013305	LJDU				LJDU	Champasak, Hoo Sahong	13.973317	105.957614
Cl11: DS & Downstream	LA	LA_013307	WQ7, EHM8		JEM_EHM8	JEM_WQ7		Don Sahong impoundment	13.944111	105.961806
Cl11: DS & Downstream	KH	KH_014003	KK	KK				Koh Key, Downstream of Don Sahong, upstream of Sesan confluence	13.680028	106.048533
Cl 12: Don Sadam	LA	LA_013308	WQ8,EHM9	No DSM Use KK	JEM_EHM9	JEM_WQ8		Don Sadam, just downstream of DS dam	13.942139	105.954389
13= d/s DS Dam	LA	LA_013309	WQ9, EHM10, LSD	No DSM Use KK	JEM_EHM10	JEM_WQ9	LSD, LJDD	Don Sahong site, Hang Sadam or Hang Khone WQ: Don Sadam, downstream of DS dam	13.937417	105.957139

Cluster	Country	Code 1	Code 2	DSM_	EHM	WQ	Fishieries	Location	Latitude	Longitude
			, LJDD							
	KH	KH_430104	CKM		CKM			Kbal Koh, Stung Treng. South bank of the dolphin pool. Not in Sekong Long term MRC site	13.919733	105.984247°
Cluster 14	KH	KH_014002	CST				CST	Stung Treng, Ou Run	13.866703	105.998308
	KH	KH_014501	ST	ST		ST		Stung Treng, downstream of Sesan confluence for hydrology	13.522047	105.933548
Cluster 15	KH	KH_014001/014003	CMR, CJDC		CMR		CJDC	Kratie (Kampi pool)	12.603476	106.021155
	KH	KH_014901	KT, KH_014901	KT		KH_014901		Kratie	12.48141	106.01762

Based on the outcomes of the JEM Pilot studies at Xayaburi and Don Sahong, the JEM team has made some recommendations regarding the integration of monitoring results between disciplines even though the collected JEM data set was insufficient to complete the integrated analysis. This approach reflects the initial JEM approach as shown Figure 2-1 where the quantification of drivers can assist in understanding impacts on the aquatic ecosystem.

The parameters and time-steps suggested for integration are summarised in Table 9-2.

Table 9-2. Summary of indicators identified during JEM Pilots for inter-disciplinary integration.

Discipline	Parameter(s)	Time-steps for Integrated Analysis
Hydrology	Water Level	Hourly to quantify changes events or daily min and max Statistical range and rate of change for integration with other disciplines (e.g. rates of change on a monthly basis)
	Discharge	Average monthly discharge per site
Sediment transport	Suspended sediment (SSC)	Average sediment concentration per month Average sediment load per month

Discipline	Parameter(s)	Time-steps for Integrated Analysis
Water quality	Temperature, EC, turbidity	Require continuous recording or high frequency monitoring (greater than monthly) to detect changes associated with hydropower operations
	Nutrients	Monthly
EHM	Indices	Provide high level indicators
	Benthic Diatoms Zooplankton Littoral invertebrates Benthic invertebrates	Use average abundance, average diversity within each group to provide more detail ATSPT (Average Tolerance of species per taxon) as measure of tolerant species
Fisheries (FADM)	Catch per fisher	For each site per month and for each year
	Number of species caught	For each site for each year
	CPUE for gillnets	Average annual CPUE to provide a standardized comparison of fish catches

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11 ANNEXES - See Volume 2