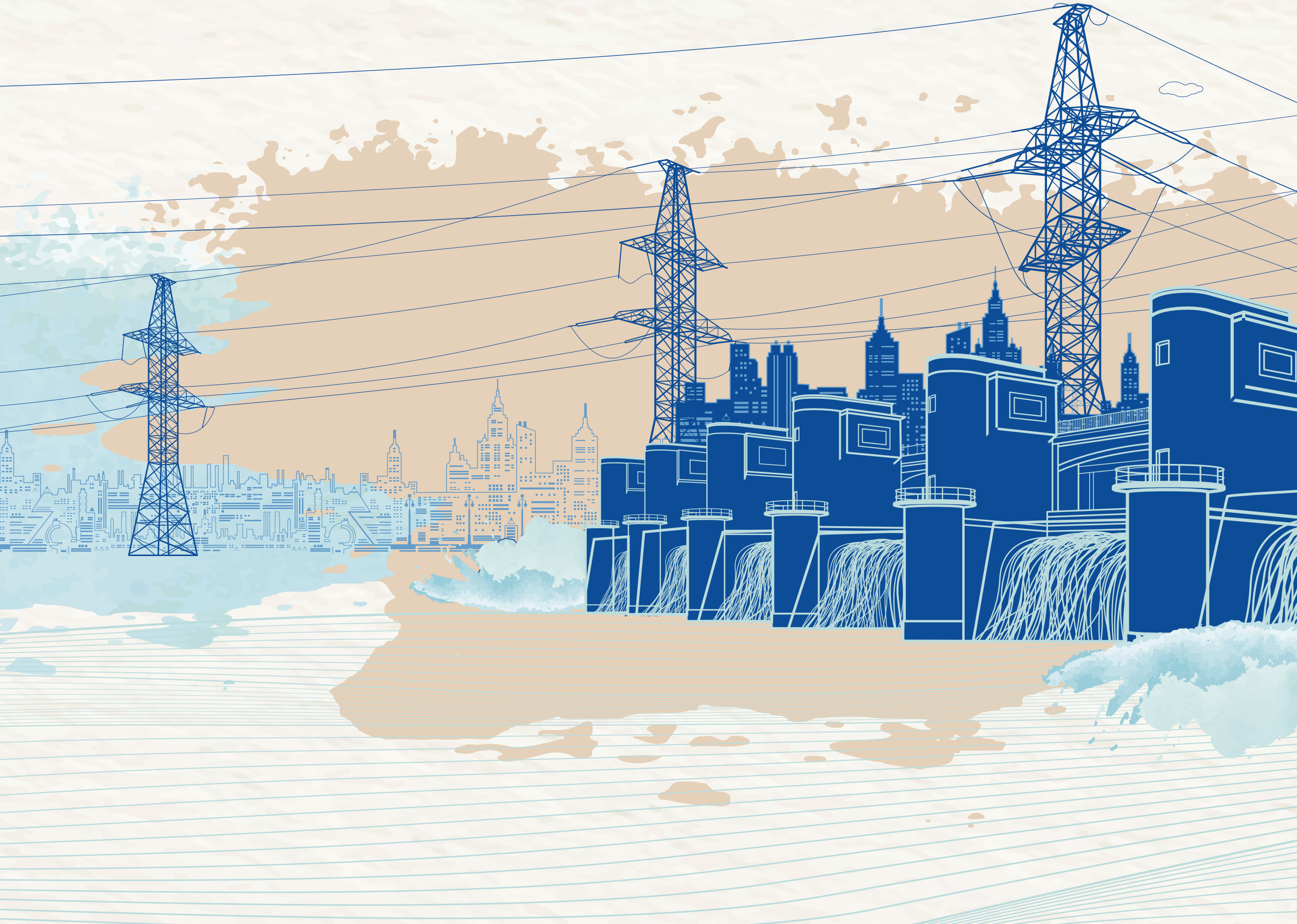
MEKONG RIVER COMMISSION
MRC
FOR SUSTAINABLE DEVELOPMENT

Preliminary Design Guidance for Proposed Mainstream Dams in the Lower Mekong River Basin



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Foreword

Much has been written about the benefits of hydropower, as both an important source of renewable energy around the world and as a potential engine of economic growth. This is particularly true for a region like the Lower Mekong River Basin (LMB), which would not only benefit from the thousands of megawatts' worth of electricity generated for domestic and industrial use – which helps to ensure energy security – but also from the substantial amount of electricity the region has the potential to produce for export and the incomes it generates.

On the other hand, hydropower projects also bring the risk of detrimental environmental and social impact, which are inevitably transboundary – from harming the ecosystem, to affecting the livelihoods of vulnerable communities. Nevertheless, beyond the already built hydropower projects and those now under construction, dozens more dam projects may be on the horizon in the coming years, along both the Mekong mainstream and its tributaries.

At the forefront of this critical development challenge is the Mekong River Commission (MRC), an intergovernmental agency comprised of the four LMB countries: Cambodia, Lao PDR, Thailand and Viet Nam. Given the transboundary nature of these complex hydropower trade-offs, our MRC members seek solutions through consultation and collaboration. We agree that each should follow certain design criteria that are well considered and scientifically tested.

That helps to explain why in light of these transboundary challenges, the Preliminary Design Guidance (PDG) becomes essential; it aims to provide guidance to both MRC Member Countries' responsible agencies and hydropower project developers – now and in the future. This is an updated version of our first PDG, which was introduced in 2009. For over the last 13 years, we have learnt much from the experience in review of the first half-dozen hydropower projects built and to be built on the Mekong mainstream. In addition, we have gleaned scientific and engineering knowledge from regional and global experience with hydropower development. This revision is the culmination of four years' worth of research and study, coupled with detailed discussions with the four Member Countries, developers and various stakeholder groups. That led to MRC Joint Committee approval of this Guidance in September 2022.

Thus, this PDG incorporates our greatest lessons learnt from the past, and best practices moving forward. That is what our national governments, riparian communities and other key partners expect from all of us: that we construct and operate these projects in a way that strikes a balance between risk and reward, minimizing the impact while maximizing the benefit.

As this PDG states, its purpose is to provide "principles and performance targets" for hydropower project design, construction and operation, while striving "to meet common objectives and mitigate commonly understood risks." Yet, this Guidance is also flexible, as it promotes novel problem solving to achieve those objectives: it "outlines performance standards rather than prescriptive designs, so developers can innovate and propose alternative mitigation and operational measures."

No matter the path chosen, this document also serves as an important reminder: not only of our original commitments – as enshrined within the 1995 Mekong Agreement – but that any development of the river's water resources should be "mutually beneficial" to each state and their respective societies.

This PDG factors in every element of the hydropower project process: hydrology and hydraulics; sediment transport and geomorphology; water quality; aquatic ecology; fish and fisheries; dam safety; navigation; riparian communities and river-based livelihoods. It is worth noting that the topics of hydrology and socio-economic impacts were not emphasized in the 2009 PDG, yet now are here, in recognition of their growing importance. In this revision, each step of the hydropower project development process is explored from multiple perspectives: covering the key objectives and risks, design and operational guidance through to project monitoring and operational management.

Both the MRC Basin Development Strategy and the Sustainable Hydropower Development Strategy highlight the opportunities that hydropower offers. By publishing this timely Guidance, the MRC will apply it immediately during the technical review of proposed projects, and to those currently being redesigned. In the end, I hope this PDG proves to be a useful handbook, relied upon by all mainstream Mekong hydropower projects.

I thank the leadership and technical teams of the MRC Secretariat for working with Member Countries in securing agreement to apply this latest updated Guidance. With active cooperation by all countries, and continuing support from the MRC Secretariat, the implementation of the updated PDG will result in less impact on river ecology, biodiversity and riparian communities, with more equitable, regionwide distribution of energy security, economic development and societal benefits.

[redacted]

H.E. Mr So Sophort

Chairperson of the MRC Joint Committee for 2022

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FIGURES AND BOXES

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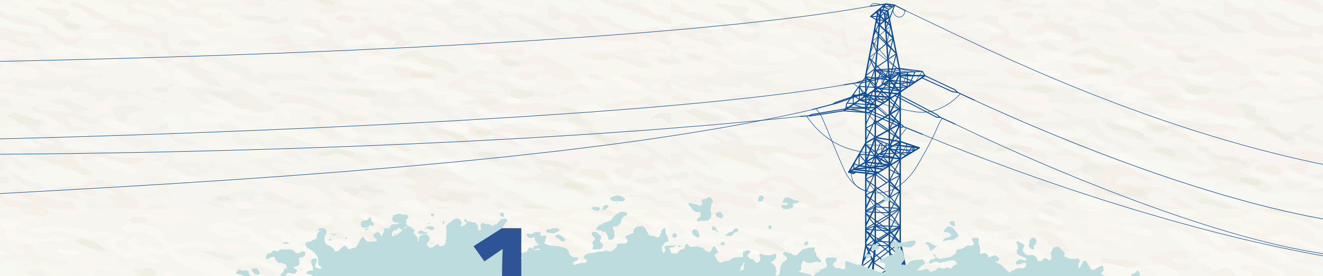
ABBREVIATIONS AND ACRONYMS

AEP	Annual exceedance probability
ARI	Annual recurrence interval
DSMS	Dam Safety Management System
EPP	Emergency Preparedness Plan
ESIA	Environmental and Social Impact Assessment
ICOLD	International Commission on Large Dams
IFC	International Finance Corporation
IHA	International Hydropower Association
LMB	Lower Mekong Basin
MRC	Mekong River Commission
OAAs	Other aquatic animals
PIANC	Permanent International Association of Navigation Congresses
PMF	Probable maximum flood
PNPCA	Procedures for Notification, Prior Consultation and Agreement
SIMVA	Social Impact Monitoring and Vulnerability Assessment
TGPWQ	Technical Guidelines for the Implementation of the Procedures for Water Quality



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About this Guidance

1 ABOUT THIS GUIDANCE

1.1 Purpose and Objectives

1. This Updated Preliminary Design Guidance for Proposed Mainstream Dams in the Lower Mekong River Basin (LMB), hereafter referred to as 'Guidance', provides advice for Member Countries on how mainstream dams should be developed in line with their commitments enshrined within the 1995 Agreement on the Cooperation for the Sustainable Development of the Mekong River Basin (the Mekong Agreement). In the Preamble to the Mekong Agreement (MRC, 1995), the Member Countries:

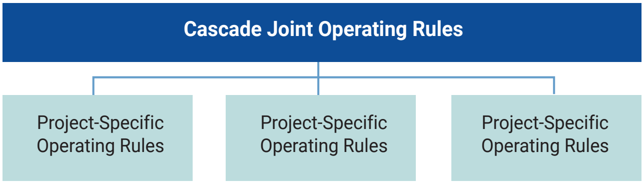
   - Recognize that *"the Mekong River Basin and the related natural resources and environment are natural assets of immense value to all the riparian countries for the economic and social well-being and living standards of their peoples"*; and
   - Reaffirm their *"determination to continue to cooperate and promote in a constructive and mutually beneficial manner in the sustainable development, utilisation, conservation and management of the Mekong River Basin water and related resources for navigational and non-navigational purposes, for social and economic development and the well-being of all riparian States, consistent with the needs to protect, preserve, enhance and manage the environmental and aquatic conditions and maintenance of the ecological balance exceptional to this river basin"*.

2. In the Mekong Agreement, Articles 1–10 (Chapter III), the Member Countries, agree to inter alia, cooperate to optimize the multiple use and mutual benefits of all riparians while protecting the environmental and ecological balance in the basin and using the shared waters in a reasonable and equitable way.

3. The objective of this Guidance is to provide performance targets and principles for the design and operation of mainstream dams that can help avoid, minimize, and mitigate harmful effects (Mekong Agreement, Article 7) and limit the potential for substantial damage (Mekong Agreement, Articles 7 and 8). Specifically, this Guidance aims to ensure:

   - all mainstream hydropower projects have a design and operational approach that aims to meet common objectives and mitigate commonly understood risks;
   - developers can plan for and undertake the assessments and designs for mitigation and management measures as early as possible in the project cycle;
   - developers have flexibility to identify and propose the solutions that will meet the objectives, performance standards, and recommendations in this Guidance (see Clause 8);

- joint operations within a mainstream hydropower cascade are guided by a common framework informed by this Guidance. This framework will ideally include the Cascade Joint Operating Rules developed by one or more Member Countries in which the projects are located, together with project developers and importing countries. Other Member Countries that may be impacted by the operations of the cascade should be consulted. A framework for Cascade Joint Operating Rules is shown in Figure 1.1.



Example Focal Areas for Operating Rules:

- Impoundment operations
- Power Station operations
- Flood operations
- Drought operations
- Navigation lock operations
- Fish passage operations
- Sediment flushing operations
- Gate operations

Figure 1.1. Cascade Joint Operating Rules and the Project-Specific Operating Rules

4. At least 11 large hydropower projects have been proposed on the mainstream reaches of the LMB with two projects (Xayaburi and Don Sahong) currently operational. Whereas implementation of any one or all bring opportunities for economic development of the region, mainly through enhanced electricity supply and improved conditions for inland navigation, the projects will be accompanied by adverse impacts and development risks for Member Countries. These risks will vary in nature and degree depending on the individual project and the extent to which the developer and owner/operator apply this Guidance.

5. This Guidance is founded on the agreed objectives and principles of cooperation set out in Chapter III of the Mekong Agreement, and principles of Integrated Water Resource Management (IWRM). Important underlying principles include:

   - **Mitigation hierarchy**: Avoidance of impacts is preferable to minimization, which is preferable to mitigation of impacts, consistent with the mitigation hierarchy (see further in Clause 6).
   - **Water as an economic and social good**: Water has an economic and social value even when not used for consumption. These values include not only its use in

generating hydropower and support national development, but also in providing a wide range of basic human needs and ecological goods and services.

- **Adaptive management**: Adaptive management is a structured, iterative process of decision-making towards achievement of objectives in the face of uncertainty. The aims are to reduce uncertainty over time via monitoring and improve achievement of objectives via updated management responses to the monitoring findings (see further in Clause 27).
- **Good practice**: Good practice is the exercise of the degree of skill and care, diligence, compliance, prudence, and foresight that would reasonably and ordinarily be expected from a skilled and experienced developer engaged in any jurisdiction on hydropower projects of a similar scope and complexity to those that are the subject of this Guidance.
- **Subsidiarity**: Dam owners and operators are best placed to optimize mitigation measures based on their own operations.
- **Sovereignty**: Consistent with Mekong Agreement Article 4, the Member Countries have the sole authority to regulate developments in their territories, but should require developers to make every effort to apply this Guidance to align with their commitments in the Mekong Agreement.

6. The 'mitigation hierarchy' that underpins this Guidance is a concise expression of what is understood to be a sequential process. Measures to avoid or prevent negative or adverse impacts should be prioritized. Where avoidance is not practicable, then minimization of adverse impacts is sought. Where avoidance and minimization are not practicable, then mitigation measures are undertaken. In this Guidance, as per the provisions of Mekong Agreement Articles 7 and 8, these terms are understood as follows:

   - **Avoid** refers to implementing a measure to ensure that any harmful effects do not occur (e.g. by careful planning, siting and design of a project);
   - **Minimize** refers to implementing a measure that, would reduce harmful effects, or the risk of harmful effects, considerably; and
   - **Mitigate** refers to implementing a measure that would reduce the impact of any residual harmful effects on other users of the Mekong River System, including those in the other Member States.

7. Residual impacts are impacts that remain after all viable avoidance, minimization, and mitigation measures have been applied. Measures should be considered to address any residual impact or loss.

8. Wherever practical, this Guidance outlines performance standards rather than prescriptive

designs, so developers can innovate and propose alternative mitigation and operational measures to meet the stated objectives., as discussed below:

- Where standards or targets are specified in this Guidance, the project design should align as far as reasonably practical. Where an alternative approach is warranted, the developer should indicate where any deviation has been necessary with supporting evidence.
- In some cases, this Guidance also identifies additional measures that developers could take to further the objectives stated for each topic. Every effort has been made to make it clear what actions or outcomes are considered to be a minimum (with use of the term 'should') versus what would be additional (with use of the term 'may').
- In some cases, this Guidance refers the user to external sources of guidance. This has been kept to a minimum so that this document can be a cohesive source of consolidated guidance. Where external sources are cited, the text seeks to make it clear where the reference: (i) provides the detail on the desired performance standard that should be followed (this applies to Clauses 263 and 304); or (ii) provides potentially useful additional information on a particular subject.

9. This Guidance is an update of the previous Preliminary Design Guidance for Proposed Mainstream Dams in the Lower Mekong Basin, of 31 August 2009. This update is guided by the experience of application to the first six mainstream hydropower projects, as well as improved understanding about hydropower risk and mitigation in the Mekong region and internationally on what constitutes good practice. Key sources of information include the assessment tools and guidance of the International Hydropower Association (IHA, 2010) and the good practice notes of the International Finance Corporation (IFC, 2018a, 2018b, 2013), tailored to the Mekong context as far as practicable. Knowledge and guidance on good practice in the Mekong Basin is provided in a number of Mekong River Commission (MRC) reports relating to sustainable hydropower. In particular, the MRC's Hydropower Mitigation Guidelines (MRC, 2018a) provide more detail and examples for how the performance standards in this Guidance can be met.

1.2 Uses and users

10. According to the Mekong Agreement, before Member Countries may initiate any large-scale infrastructure development constituting an intra-basin use on the Mekong mainstream in the dry season, they should notify and consult with other riparian states in the basin. Under Article 5.2.1 of the Procedures for Notification, Prior Consultation and Agreement (PNPCA) (see MRC 2003a), the notifying Country should provide available and additional technical data. In this regard:

    - This Guidance supports a consistent approach to information submitted by the notifying country, and to any technical review of this information undertaken during the PNPCA process.

- In order to demonstrate best efforts to avoid, minimize, and mitigate harm, the notifying country can show that it has made all reasonable efforts to recommend developers of proposed mainstream dams to consider this Guidance.
- A project that does not adhere to this Guidance can reduce or even negate the effectiveness of the mitigation measures applied by all other projects. Consistent application of this Guidance will give all Member Countries and each developer the confidence that all mainstream developments will be held to the same set of performance standards.
- Member Countries may draw on this Guidance to inform improvements to existing mainstream dams, which should enable and demonstrate consistency throughout all mainstream dam developments.
- The application of this Guidance does not limit the Notified Countries' rights under the Mekong Agreement Articles 7 and 8. However, consistent application of this Guidance may limit the responsibility for damage under these Articles.[1]
- Under the Mekong Agreement Article 7, the Member Countries have accepted a Duty of Conduct to avoid, minimize, and mitigate harmful effects wherever they occur. This Guidance aims to reduce the likelihood of these damages through the application of the mitigation hierarchy. Adequate monitoring of dam safety and other risks, as set out in this guidance, should be conducted to accurately measure the changes resulting from hydropower operations. Cause and effect of these changes, including those resulting from more catastrophic events (e.g. dam break), may therefore also be better understood. In the case where damages are deemed to have occurred, state responsibilities for assessment and resolution of issues arising are dealt with under Mekong Agreement, Article 8.
- Under PNPCA, Article 5.4.2, other Member Countries may request additional information on a use notified for prior consultation, and this Guidance may be used to frame this request. The Joint Committee may also wish to refer to this Guidance when arriving at an agreement under PNPCA, Article 5.4.3 relating to the proposed use and agreed upon conditions.

11. Users of this Guidance will include Member Countries, developers, and interested

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[1] Under Article 7, the notified country(ies) should prove with "proper and valid evidence" that they have suffered substantial damage, and should attribute that damage to a particular source or sources in notifying countries. Under Article 8, the affected parties should together identify the cause of, responsibility for, and should quantify, the damage. Thereafter, the affected parties should agree on mitigation measures in an amicable and timely manner.

stakeholders, as described below:

- This Guidance should inform the expectations of the notified Member Countries with respect to a development. This Guidance should also inform measures that can be taken by the notifying country in support of the development where this Guidance extends beyond what can be reasonably expected by the developer, or where a collaborative approach with other Member Countries may be warranted.
- This Guidance provides a framework for dialogue on the development risks and mitigation measures between participants in the PNPCA process.
- Member Countries may use this Guidance to form a basis for the Cascade Joint Operating Rules, so that all projects within a cascade would apply common design objectives and coordinated operations.
- Developers should use this Guidance to inform all stages of project planning, development and operations. Developers should enter into dialogue with the relevant national agencies regarding shared or divided responsibilities where needed to meet this Guidance. Developers can reference this Guidance in developing Project-Specific Operating Rules within the framework of the Cascade Joint Operating Rules.
- Interested stakeholders may not have direct uses for this Guidance, but can reference it when considering project information and in any dialogue relating to the project.

12. Developers should follow national standards in the development of mainstream dam projects, where they are equal to or more stringent than those in this Guidance.
    - For impacts that are of basin-wide concern, because they are transboundary, cumulative, or affect basin-wide ecological processes, and where the national standard does not give adequate protection for these areas of impact, the more stringent standard between this Guidance and the national standard should guide the project design.
    - Member Countries may wish to embed aspects of good practice outlined in this Guidance into their national standards for dam developments.
13. This Guidance does not replace national guidelines or regulations for the project Environmental and Social Impact Assessment (ESIA). ESIA guidelines are issued by the Member Country for developments within that country, for review by the relevant national agency as part of the statutory approvals process for a dam development. ESIA guidelines cover a broader scope than this Guidance. This Guidance is limited to information requirements for impacts of basin-wide concern relating to the potential harmful effects of mainstream dams.
14. Developers, Member Countries and the Mekong River Commission Secretariat (MRCS) may use this Guidance to create checklists against which information submitted for the PNPCA

can be cross-checked. Incorporation of this Guidance into checklists may facilitate the prior consultation process. Completion of a checklist against this Guidance can provide substance to the “make every effort” commitment in Mekong Agreement Article 7.

1.3 Timing of Use

15. Avoidance and minimization decisions are often taken during the pre-feasibility studies when considering the project location. Further avoidance and minimization decisions are taken during the feasibility studies when optimizing the siting and design, informed by the ESIA. Implementation plans for mitigation measures to address areas of impact are typically described in an Environmental and Social Management Plan (ESMP) for construction and operation stages, closely linked to the ESIA and submitted before project approval, and embedded within tender documents and major contracts. For optimal timing, feasibility studies should be done in parallel with the ESIA, and they should iteratively inform each other.

16. This Guidance should be referred to throughout the project development cycle. Reference to this Guidance from the start of the cycle will help ensure that pre-feasibility, feasibility, and ESIA studies and resultant plans address this Guidance, as shown in **Figure 1.2**. Reference to this Guidance during project implementation and operation will help ensure that the objectives of this Guidance continue to be met.

    - Commencement of data collection should be as early as possible. The collection of some data sets such as hydrological data could commence during the initial investigations, and the collection of others such as environmental data could commence after the signing of the Memorandum of Understanding (MoU) between the government and developer.

    - Early engagement by developers with MRCS experts on data collection, analysis and design approaches may be cost- and time-effective. Waiting for the PNPCA technical review poses risks of late feedback, which may lead to costly re-design.

    - Appropriate sequencing will ensure that all design and operational measures consistent with this Guidance are costed in the project’s financial modelling and business case and taken into account in all agreements. This sequencing should help avoid unreasonable harmful effects being caused by a lack of funding.

Project Phase	Pre-Feasibility Studies	Feasibility Studies including Environmental and Social Impact Assessment	MRC PNPCA Process	Detailed Design	Construction	Operation
Role of Preliminary Design Guidance (PDG)	Notifying Country and developer ensure project concept fits with PDG	Notifying Country and developer undertake studies to inform design of measures to ensure project meets PDG specifications	Notifying Country submits project plans for independent technical expert review against the PDG	Detailed design and cascade operating rules produced to reflect PDG and outcomes of technical review	Project is developed in line with PDG Guidelines	Operational stage monitoring supported by adaptive management measures confirms PDG measures being met

Figure 1.2. Role of the Preliminary Design Guidance during the mainstream dam project life cycle

1.4 Scope

17. This Guidance is tailored to the Mekong mainstream hydropower projects, which largely involve infrastructure for hydropower generation that is incorporated into the dam facilities and where the river's flow is returned to the Mekong immediately downstream. These projects may also include irrigation and other uses associated with the mainstream developments.

18. Projects with seasonal or inter-annual water storage or projects that incorporate diversion of flows out of the main channel for substantial distances downstream of the dam are not directly addressed, although many of the same principles and performance standards may apply. Guidance on mitigation of the impacts of these types of projects can be found in the MRC Hydropower Mitigation Guidelines. Guidance for minimizing the impacts of dams constructed for major abstraction of water for other purposes such as irrigation is excluded, noting that dams for this purpose would be subject to the requirements of the MRC Procedure for Maintenance of Flows on the Mainstream.

19. This Guidance focuses on impacts that are of basin-wide concern, because they are transboundary or cumulative, or affect basin-wide processes. There are a number of important processes and/or outcomes for aspects of the shared water resources of the Mekong River that have extensive and even basin-wide dependence or influence:

    - The focal areas for this Guidance include the environmental areas of hydrology and hydraulics, sediment transport and geomorphology, water quality, aquatic ecology, and fisheries (Sections 2 to 6). Physical aspects of the environment are addressed first, and then the biological aspects.
    - Dam safety and navigation (Sections 7 and 8) are included, because the actions of one

project can have ramifications much beyond the individual project and cooperation is essential.

- Riparian communities and river-based livelihoods (Section 9) are included because environmental and infrastructure changes that are not able to be fully mitigated (i.e. the residual impacts) can in turn have socio-economic consequences for river-dependent communities. The socio-economic dimensions of hydropower development on the Mekong River are recognized in the 1995 Mekong Agreement and the MRC vision. Member Country governments maintain the primary responsibility for managing socio-economic impacts within their borders, and may enter into bilateral and/or regional agreements to resolve transboundary issues of mutual interest or concern. The assessment of transboundary impacts to riparian communities and river-based livelihoods thus requires regional cooperation on both assessment of residual transboundary environmental impacts and on the mitigation approach to manage the resulting impacts to these riparian communities. Section 9 provides guidance to support dialogue on this topic during the PNPCA process and beyond, as required under the 1995 Mekong Agreement.

- There are many linkages and inter-dependencies amongst the topics covered by this Guidance. Hydrology and hydraulics link to all other topics. Navigation and dam safety are strongly influenced by flow conditions. Physical changes to habitats (river geomorphology) and water quality arise due to flow changes and have significant influence on aquatic ecology. Fish and fisheries are dependent on conditions and processes relating to flow, habitat, water quality, and aquatic ecology. River-based livelihoods are strongly influenced by all of these factors, and in particular by the effectiveness of mitigation measures or supplementary approaches where livelihoods are dependent on the river environment.

- A number of these focal areas have dedicated procedures and guidelines within the Mekong Agreement Framework, as well as monitoring programmes within the MRCS. Where relevant, these have informed the specific objectives for each topic.

20. Both short-distance and long-distance impacts are addressed in this Guidance.

    - Hydrological and hydraulic modelling (as described in Section 2.3) should be used to investigate how far downstream and upstream changes to aspects of the flow regime attributable to the project can be detected. These changes may relate to, for example, daily water level fluctuations, impoundment backwater effects, timing of seasonal changes, and the effects of infrequent operations such as sediment flushing. The distance will vary depending on factors such as dry or wet season, tributary contributions, river geometry, and the operation of other projects.

    - Analyses for each focal area covered by this Guidance (Sections 3 to 9) should consider the hydrological and hydraulic modelling to inform where impacts may occur, and should then consider the magnitude and consequence of risk associated with changes attributable to the project. For fish and fisheries (Section 6), river distance affected should consider which species are likely to be unable to pass the dam or to thrive under the changed flow conditions, and the consequent changes to species abundance in river reaches upstream and downstream of the project.

- The pre-project analyses (Clause 23) should always identify those impacts that may be transboundary in nature. Some projects are very close to national borders, hence short-distance impacts may be transboundary. The ESIA for the project should not stop at a national border if the analysis of river distance affected by direct physical changes or indirect changes to species composition and abundance shows that this extends into another country. The MRC Transboundary Environmental Impact Assessment (TbEIA) Guidelines, once approved, are an important reference for Member Countries in identifying and addressing issues of transboundary concern (see MRC, 2023).

21. This document provides guidance to inform design and planning that will have implications for both the construction and operation stages of a dam development, including

    - Some design measures[2] mitigate construction stage impacts, and many others mitigate longer-term operation stage impacts.
    - It is important to take into account intended or likely future operational practices when considering the specifications for, and likely effectiveness of, design features.
    - Some risks may be able to be mitigated by operational practices rather than through design of built infrastructure.

1.5 Structure of this Guidance

22. The eight topics in this Guidance follow a common logical flow, in which the objectives for each topic inform the identification of risks, potential impacts, mitigation measures, and mitigation effectiveness. The sub-sections in Sections 2 to 9 are as follows:

    - **Objectives**: This sub-section clearly states the objectives of the Guidance, which reflect the commitment and principles in the Mekong Agreement framework.
    - **Risks**: This sub-section outlines the types of risks that may prevent achievement of objectives, and where relevant, highlights interlinkages with other topics. In general, a comprehensive list of all potential risks has been provided. Not all risks will apply to every project, and there may be additional risks that require consideration. The developer will need to undertake studies to prioritize risks and eliminate risks that are

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[2] For example, design of low-set spillway gates will assist in routing and flushing of sediments.

not relevant to the particular dam location and layout. Assessment and monitoring of risk mitigation should be reported through national and regional processes (e.g. the PNPCA).

- **Pre-project monitoring and analyses**: This sub-section provides guidance on the data and analyses that would sufficiently inform and justify the design and operational choices presented in the PNPCA documentation.
- **Design and operational guidance**: This sub-section guides the identification and evaluation of mitigation options, and provides a basis to justify those that are proposed for implementation. In some cases, more specific outcome targets are presented for particular mitigation measures. Guidance is included on measures that will enable future adaptations if shown to be required by the post-project monitoring.
- **Project monitoring and adaptive management**: This sub-section advises on the monitoring during project construction and operations that will help show if design and operational measures have been effective, or whether adaptations should be implemented.

23. To adequately inform project design, pre-project monitoring and analyses should:

- be conducted by personnel with appropriate qualifications and expertise relevant to each discipline (see also Clause 31 v);
- provide an accurate, quantitative and qualitative understanding of the pre-project conditions and trends (the “baseline” conditions), and justify the proposed project designs and plans in terms of achieving the objectives and mitigating the risks outlined in Sections 2 to 9 of this Guidance;
- be guided by the implementation of a monitoring network and monitoring programme that takes into account all topics considered in this Guidance. This network may consist of new monitoring stations or sampling locations established and managed by the project developer, plus use of data sources managed by other agencies and accessible to the project. Locations, timing of sampling, methodologies, and duration of data collection should be designed to adequately inform on the variability and risks relevant to the topic, as guided in Sections 2 to 9.
- draw on and supplement existing information and data collection in the Mekong River and tributaries, which may be under the responsibility of national agencies or institutions. Tributaries can have an important influence on the mainstream conditions and should be taken into account;
- draw on the MRC’s monitoring and studies as a basis for interpretation of project-specific data. The MRC data can be accessed by submitting requests through the relevant National Mekong Committee Secretariat (NMCS). To ensure the ability to

achieve a wider basis for project-specific data interpretation, the developer should tailor local-scale data collection and methodologies to the wider body of data, and should follow any protocols recommended by the MRC for monitoring throughout the river system, which may be updated from time to time;

- be of sufficient duration to inform projections of future trends and changes, and to provide a certain degree of overlap with existing data sources so that the project-specific data can be extended. Project-specific data collected prior to, and analysed for, the PNPCA information submission should encompass at least one full annual cycle, or longer if possible. The monitoring data should continue to be collected following PNPCA information submission to inform detailed design, and flow on into the construction and operation stage monitoring programmes (Clause 26).

24. Appropriate analyses, including modelling, should be used to predict impacts. These should indicate whether particular risks are relevant to the project, their magnitude and consequence, and the likely effectiveness of various mitigation approaches, as follows:
    - Models should be at an appropriate level of detail to inform and justify the design and operations approach proposed at the PNPCA stage.
    - The developer should describe the further modelling that will be undertaken for detailed design and optimization of operations.
    - The developer may consider the use of the Decision Support Framework (DSF) developed by the MRC as a resource for assessing cumulative and transboundary impacts in the Mekong River, and for informing the development of Cascade Joint Operating Rules. The DSF includes basin-scale hydrological, sediment and water quality models, and relevant input data for these models. Models with equivalent function may be proposed.

25. The information presented on the extent of project impact for each topic and the likely effectiveness of the planned mitigation measures should also identify and analyse the residual impacts that will remain, the communities that will be affected by these residual impacts, and the consequences of those impacts on river-based livelihoods. This is a critical input to the analyses that will be undertaken relating to riparian communities and river-based livelihoods (Section 9).

26. Project monitoring to be undertaken during the detailed design, construction, and operation stages should be described in the PNPCA information as follows:
    - The project monitoring plan should describe what data will be collected, how they will be analysed, what indicators will be tracked and why, and how the information will be able to inform timely management responses (see Clause 27).
    - The project monitoring plan can serve many uses in addition to ensuring efficacy of

project design and mitigation measures. If approaches taken to establish the pre-project condition are continued during project construction and operation, this will enable post-project comparisons. The project monitoring should also consider how emerging risks may be detected over time, including those that arise from activities other than the project but that may pose management problems for the project.

- The project monitoring plan should show how it has considered and planned for the range of project monitoring purposes and factored in the locations of (and permanent instrumentation for, if relevant) monitoring stations and ensured access.
- The project monitoring plan should be informed by, and as far as practical align with, MRC processes for Joint Environmental Monitoring throughout the river system if and when this is agreed by the Member Countries.
- For data that are not of a commercially sensitive nature, the developer should contribute to information-sharing mechanisms set up in accordance with the Procedures for Data and Information Exchange and Sharing (PDIES) (see MRC, 2001). Information sharing is critical to the effective coordination, harmonized design and operations of the mainstream hydropower projects.

27. Adaptive management is a principle underpinning this Guidance, as defined in Clause 5. The following guidance on design features to support future adaptive management is provided in the sub-section entitled, Design and operational guidance:

    - Mitigation measures may be implemented on a trial basis, and design features should be built into the project to allow for later adaptation if required.
    - Uncertainties in aspects of effectiveness of proposed mitigation measures (e.g. for built structures, operational rules) should be explained, and follow-up monitoring and review of these areas of uncertainty should be built into the project monitoring plan.
    - The project monitoring plan submitted with the PNPCA information should show what indicators and thresholds will guide decisions to be made on adaptive management, what adaptations could be made and why, how the project design factors in the ability to implement these later adaptations, and ensures adequate contingency funding has been set aside to undertake these possible adaptation steps.
    - The project monitoring plan submitted with the PNPCA information should show that both riverine and impoundment monitoring results will be reviewed annually, and should identify the decision-making process that will be used to identify and implement management actions to be taken if risks or impacts are evident from the monitoring results.

28. Developers should consider the applicability of this Guidance to the unique setting and features of their project, and make the case for variations to this Guidance if needed, in line

with Clauses 8 and 20. Activities and structures upstream and downstream of the project may require special consideration on how to apply this Guidance, as well as the locations and significance of tributary inflows and influences. The order of project development is an important consideration, and existing and planned hydropower projects should be taken into account.

29. Where a development will be part of a cascade, the developer should show in the PNPCA information how it will follow any Cascade Joint Operating Rules provided by the responsible Member Countries. In the absence of such rules, the developer should indicate how it will, through the responsible national agency, liaise with neighbouring projects to develop Cascade Joint Operating Rules associated with mitigation and operations. Cascade-level mitigation approaches can be informed by the MRC Hydropower Mitigation Guidelines, which also include case studies relating to hydropower cascades.

1.6 General requirements

30. The PNPCA Clauses 4.2.1 and 5.2.1 describes the technical data and information to be provided by the notifying country. Should the MRC Joint Committee or the other Member Countries request any further data and information or clarifications during the prior consultation process, the notifying country should employ its best efforts to provide such information should the data be readily available and not present a risk to national security or national defence. The information submitted for PNPCA should allow the MRC JC to evaluate that:

    - project developers and the notifying country have made every effort to align the design, construction and operation of the infrastructure with this Guidance;
    - Deviations from the Guidance are motivated based on site-specific information gathered and risk evaluation;
    - the proposed design and planned cascade operations will effectively mitigate the impacts and risks described in this Guidance;
    - information collection, analysis, design, and development of detailed operating rules, which are required by this Guidance, are proposed to be undertaken after the PNPCA, are clearly listed and the planned approach documented;
    - these additional data are to be made available as part of any agreed post PNPCA process (Joint Action Plan) and to foster cooperation on improvements and adaptive management of mainstream hydropower.

31. In addition to the guidance on data and information that may be submitted with PNPCA documentation outlined in this and the following sections, PNPCA information should include:

- Planned Project-Specific Operating Rules, or at a minimum, the operating principles and objectives, for the impoundment, for downstream discharges, for gates, and for any mitigation structures;
- Cascade Joint Operating Rules, or at a minimum the cascade joint operating principles and objectives, where the project is part of a cascade (see Clause 3);
- a set of relevant design drawings with labelling in English;
- clear maps and figures, using an appropriate scale, that are easy to understand, interpret, and relate to the explanations provided; and
- a list of the experts used for the topics addressed by this Guidance, and their qualifications.

32. It is recommended that a checklist be submitted with the information for PNPCA technical review that identifies where each clause of this Guidance is addressed.

1.7 Updates to this Guidance

33. The Guidance, with the support of the Secretariat, shall be updated from time-to-time, based on:

- the further experience of application of this Guidance on Mekong dam developments;
- the development and application of processes for improved coordination of developments, including but not limited to, the Transboundary Environmental Impact Assessment (TbEIA) Guidelines, Cascade Joint Operating Rules, and Joint Environmental Monitoring.

2

Hydrology and Hydraulics

2 HYDROLOGY AND HYDRAULICS

2.1 Objectives

34. The objectives of this guidance on hydrology and hydraulics are to ensure that:

- project developers have a detailed understanding of the hydrological resource availability and reliability to inform project planning, design, construction, and operations, taking into account present and potential future trends (e.g. alternative climate change scenarios);
- mitigation measures and cascade or project operating rules dependent on hydrology and hydraulics are underpinned by sound hydrological and hydraulic assessments; and
- mainstream developments are able to meet the objectives of the Procedures for Maintenance of Flows on the Mainstream (PMFM) (see MRC, 2006) and the Procedures for Water Use Monitoring (PWUM) (see MRC, 2003b) within the Mekong Agreement framework, which require that every effort is taken to manage and maintain a minimum flow, and to minimize rapid changes in key river flow indicators to avoid harm to downstream users and the ecology.

35. Figure 2.1 shows the important locations of hydrology and hydraulic change that occur due to a mainstream project, and establishes some common terminology that will be used throughout this Guidance.

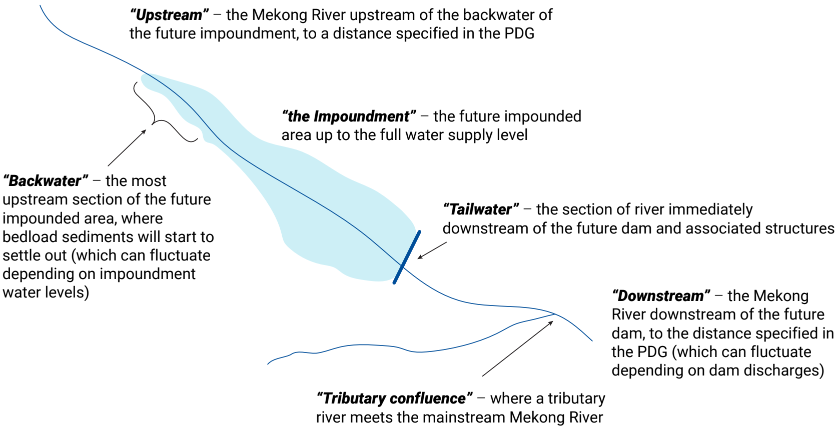

Figure 2.1. Locations of hydrology and hydraulic change arising from a mainstream project

2.2 Risks

36. Because all parts of the flow regime play a role in sustaining the riverine ecosystem, altering any part can translate into physical and biological changes. The more the flow, sediment, navigability, or water quality regimes are changed, the more ecosystem and socio-economic responses will occur.

37. The main impacts of hydropower projects in the Mekong Basin related to water flows are:

    - altered flow regimes in the downstream river due to the project operations, which may have large-scale influences, depending on the attenuation of these impacts downstream;
    - impoundment and backwater effects upstream of the dam. Direct impacts include permanently inundated areas, increased water depth, and reduced water velocities;
    - loss of connectivity. Longitudinal connectivity along the Mekong River is interrupted because of the barrier effect of the dam, and lateral connectivity between main channel and floodplains or secondary channels can be diminished because of changes in flood hydraulics;
    - dam safety related impacts, for both temporary structures during the construction stage and permanent structures during the operations stage (addressed in Section 7).

38. Risks arising from changes in hydrology and hydraulics should be comprehensively assessed. **Table 2.1** shows the potential consequences of changes to hydrology and hydraulics on various focal areas covered in this Guidance. Mainstream dams are proposed to be operated in run-of-river mode, meaning that inflows pass quickly through the impoundment and are discharged with very little water retention capability. The key risks for environmental and socio-economic receptors of impact, therefore, mainly arise due to daily and short-term flow changes to the downstream river with hydropower operations, and from the impoundment of water behind the dam.

Table 2.1. Risks arising from changes in hydrology and hydraulics

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

Risks	Focal area of impact
Drowning and sedimentation of deep pools; habitat loss due to inundation; deposition of drifting eggs/larvae due to low flow velocities	Aquatic Ecology (see Section 5) and Fish (see Section 6)
Backwater impacts due to inundation or backwater fluctuations near areas of social importance; increasing flood levels in time upstream; navigation risks due to submerged rocks	Socio-Economics including Navigation (see Section 8) and Public Safety

39. Cumulative hydrological impacts arise due to multiple hydropower developments, in particular from projects with the ability to store water and make unseasonal releases. The following conditions may affect project design:

    - When comparing the historical flow series to flows in recent years, it is evident that flows on an annual/seasonal scale are noticeably impacted by the existing storage dams in the Upper Mekong (the Lancang) and by tributary schemes (MRC, 2018b).
    - Flow releases from upper dams can lead to changed flow and water level fluctuations that affect the operations of the lower dams. For instance, an impoundment draw-down and sediment flushing operation at an upper dam can lead to an accumulation of flood waves created by the sudden gate opening of each consecutive dam.
    - A new development cannot be expected to mitigate risks arising from existing projects, but the developer should recognize and incorporate these potential risks into the proposal. For example, it should be demonstrated that the project can handle a major flood created by a Chinese dam opening its gates.

40. Risks for the focal areas covered in this Guidance arise from changes in hydrology and hydraulics due to hydropower operations. In addition, naturally occurring droughts and floods may exacerbate impacts arising from dams and should be considered in any scenario evaluations for risk and how they can be managed.

2.3 Pre-project monitoring and analyses

41. The information submitted for the PNPCA process should demonstrate that the planning and design of the hydropower project is based on a good understanding of the hydrological resource availability and variability in the short and long term, as well as the

hydraulic characteristics in the river near the dam infrastructure. Misunderstanding of the magnitude, timing, variability and extremes of water inflow patterns can present significant infrastructure safety risks.

42. Quantification of pre-project conditions and quantitative identification of potential changes for hydrology and hydraulics should be based on a combined monitoring and modelling approach. The approach should include:

    - monitoring of water levels and discharges at specific sites;
    - hydrological modelling to establish time-dependent hydrological conditions at locations in between monitoring sites;
    - hydraulic numerical modelling to quantify flow conditions in the impoundment, in the impoundment backwater, near the dam infrastructure, the downstream river, and at major tributary confluences; and
    - combined, these approaches should be used to quantify hydrologic and hydraulic parameters and variability over a range of time-scales (hourly to annual) and spatial scales to provide an accurate understanding of the conditions at the project site.

43. The spatial extent of monitoring and modelling should be in accordance with Clause 20. The developer should show the limit of influence and how it was chosen, and the type and degree of change should be shown at the perimeter of the modelling. This analysis underpins considerations for many other disciplines and areas of risk.

Guidance for monitoring

44. The monitoring approach for evaluation of hydrology and hydraulics should form the basis of an overall monitoring framework to which topic-specific monitoring (e.g. for water quality, sediments, etc.) can be fit. This approach should be shown in the PNPCA information to be sufficient to inform design, to support modelling for impact prediction, and to help with later impact evaluation. Clause 23 provides basic principles to guide the design of the overall monitoring network. The following clauses 45 to 54 can be used as a guide and varied to suit project-specific conditions, as per Clause 23.

45. A network of hydrological monitoring stations should be developed to support the project over its full life cycle. Data sources in this network may include those managed by national agencies accessible to the project. The number and location of monitoring sites should be determined based on an evaluation of monitoring data needs and existing monitoring stations (including determination of data accessibility and quality). The MRC hydrometric sites upstream and downstream of the project should be included in this network to provide long-term trends.

46. Data to be collected for pre-project hydrological analyses should include:

- **Climatic data** – rainfall, temperature, evaporation, etc.;
- **Topographic data** - slopes, river length, topography/bathymetry;
- **Stream flow data** – water level, discharge, floods;
- **Groundwater data** – infiltration, seepage if applicable.

47. Monitoring site locations should be carried out:

    - at the closest MRC monitoring site located upstream of the project, or if relevant, downstream of an existing upstream mainstream hydropower project, for connection of the basin-wide hydrology and for deriving the long-term (>10 year) records;
    - upstream of the future impoundment (upstream of the backwater section) to inform on inflow conditions over the long term;
    - directly upstream of the future hydropower dam (within the future impoundment);
    - in the future hydropower tailwater (downstream of water release infrastructure); and
    - at suitable locations downstream of the dam over the distance where there is a demonstrated significant effect of the project (as per Clause 20, at intervals that reflect the reach-specific nature of the river, and accounting for locations of tributaries and locations of downstream projects).

48. The hydrological monitoring network should include upstream tributary monitoring stations that contribute to impoundment inflows. Data from tributaries directly downstream of the future dam should be included where the tributary flows may impact on the tailwater through backwater influences (e.g. cross-currents that may affect navigation towards the shipping locks).

49. Water level time series data for planning/design, construction, and operation should be measured at fixed and temporary gauging stations that are located in stable river reaches and referenced to mean sea level (MSL). These data should be hourly, particularly in reaches influenced by upstream hydropower schemes or downstream of the construction site to be able to register short-term fluctuations.

50. Discharge time series data for planning/design, construction, and operation should involve repeated measurements taken at different discharge levels (low flows to high flows) at the water level monitoring sites to establish rating curves. Rating curves should enable quantification of discharges for periods in between surveys. Correction for hysteresis effects and backwater influences is recommended. Discharge time series data should also provide flow velocity and depth measurements that can inform sediment and water quality modelling, as well as support calibration of hydraulic models.

51. The duration of hydrological data collection should enable coverage of the full annual cycle

with low and high flows, as well as provide insight into inter-annual variability, which is substantial in the Mekong and should be factored into project design. The project-specific field data should be collected for a period of at least one year. These data should be collected prior to the finalization and submission of PNPCA documentation, and explained in light of longer-term trends by having the monitoring network include one or more long-term monitoring sites. The field data collection should continue through the pre-project period to capture more of the inter-annual variability and be used to inform detailed design. The length of flow record should allow derivation of a time series of at least ten years for planning and design purposes. The longer the time series of inflows, the higher the confidence level and the better the understanding of hydrological risk.

52. It is recommended to follow the guidelines on monitoring and quality management of hydrological data provided by the World Meteorological Organization (WMO, 2008). Monitoring data should be validated as being of good quality, and checked for consistency to identify gaps and non-conformances with typical hydrological patterns.

53. An important resource for long-term meteorological and hydrological monitoring data for the Mekong mainstream is the MRC hydrology database, along with the existing national meteorological and hydrological databases.

54. The implementation of a telemetry network for stream gauges may be considered, especially given the non-rainfall dependence of inflow from China. A further extension to include rainfall radar and other sources of information, and inclusion of a forecasting module may improve the lead time for prediction of inflows significantly.

Guidance for modelling and analyses

55. Hydrological and hydraulic models should be used to determine specific conditions between the monitoring sites and at the dam infrastructure, and to forecast future conditions with and without the proposed dam. Operation of upstream and downstream dams may also need to be modelled and analysed. Clause 24 provides some basic considerations related to modelling and analyses. The following clauses 56 to 60 can be used as a guide and varied to suit project-specific conditions.

56. Hydrological modelling should be used to assess changes to inflows due to upstream and downstream projects. Hydrological models should be well-calibrated with multiple, short- and long-term gauging stations over at least a 12-month period. The Decision Support Framework (DSF) of the MRC provides validated and calibrated hydrological models that may be applied for this purpose.

57. Suitable fully dynamic hydraulic modelling should be used together with the hydrological models to predict and assess water level fluctuations, discharges, and flow velocities due to the operation of the hydropower project. The following considerations should be taken into account:

- Hydraulic models should be calibrated and verified using all available monitoring data. The calibration should be carried out for reproducing the water levels and fluctuations correctly, and the model should also be able to reproduce flow velocities along the impoundment and the river.
- Modelling for sediment and geomorphology, water quality, aquatic ecology, and dam break flows should be integrated with the hydrological and hydraulic modelling.
- Dam break simulations should determine the extent of inundations and hazards in the downstream reach (see Section 7, Dam Safety).
- Detailed hydraulic models may be used to assess the complex flow at the inlets, navigation locks, access to the locks, stilling basins, and fish passages.
- Physical models may be needed to assess certain details of three-dimensional turbulent flows near the dam infrastructure. It should be demonstrated that proper scaling has been applied.

58. The analyses for hydrology and hydraulics should consider:

- a range of scenarios including very dry (5% probability of exceedance), average and very wet (5% probability of exceedance) years;
- current and potential future climate conditions (including climate change and sea level rise);
- the start of operation of large Chinese storage dams in the Lancang cascade (notably Xiaowan and Nuozhadu hydropower projects) and their impacts on seasonal flows over the past years;[3]
- as far as possible, long-term future developments in the river basin upstream and downstream of the project;
- flow conditions with and without the project, including upstream developments (e.g. for modified flow regimes) and downstream developments (e.g. for modified tailwater levels);
- flow conditions and flow alterations during construction and operation;
- gradual geomorphologic changes and their impacts on water levels, such as backwater sedimentation processes or decreasing flood levels due to downstream channel incision.

59. Assessment results should be presented in the documentation for the PNPCA review for all relevant indicators of significance that reflect the risks and vulnerabilities of the system due

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[3] The MRC may provide information arising from model studies carried out as part of basin scale assessment.

to flow alterations. The following should be presented:

- Basic hydrologic and hydraulic information for PNCPA submission should include: impoundment volumes and residence time; inflows; water velocities within the impoundment; proposed discharge patterns associated with hydropower and gate operations; and rates of water level change in the impoundment and downstream. More specific guidance is provided in other sections of this Guidance relating to topic-specific information needs for hydrologic and hydraulic information.
- The MRC Indicator Framework and the Hydropower Mitigation Guidelines (MRC, 2018a) can be referred to for further guidance in selection of relevant indicators, accounting for the linkages between themes. Reference can be made to recent relevant MRC studies and relevant literature for more detailed indicator frameworks.

60. The analyses of changes, impacts and mitigation options for hydrology and hydraulics should clearly identify the residual impacts and document where these will occur in the river, in line with Clauses 7 and 24.

2.4 Design and operational guidance

61. Mitigation options should be evaluated to determine which ones will best address identified risks. The modelling and monitoring results should be used to help identify the underlying hydrological and hydraulics changes that have consequences for environmental and socio-economic values, and to identify and optimize appropriate mitigation measures. Mitigation measures should clearly address identified risks. **Table 2.2** identifies mitigation measures that can address the core sources of impact relating to hydrology and hydraulics.

Table 2.2. Mitigation options to address hydrological and hydraulic changes

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

Planning and design stages

62. Siting of the hydropower project at the earliest stages of planning can help to minimize impacts to sensitive areas from either inundation or downstream flow fluctuations, such as floodplains with high ecological value or major urban areas. Water level fluctuations may be most severe immediately downstream of the project, but reduce further downstream due to flow attenuation.

63. Project-Specific Operating Rules, or at least their principles , should be established at the feasibility design stage and be included in the project economic/financial evaluation. Operating rules should take into account:

- any Cascade Joint Operating Rules aimed at ensuring harmonized operations within a cascade
- environmental flow objectives downstream of the project;
- any need for maintenance of minimum flows downstream in relation to occasional interruptions of power station operations;
- ramping rates as per Clause 70; and
- management of downstream risks when turning on or off multiple turbines over a short period during the dry season.

64. Dam infrastructure, including turbines, bypass valves, gated outlets, and the gated spillway, should:

    - be designed to allow passage of a wide range of flows (including extreme floods); and
    - have sufficient capabilities for up-ramping and down-ramping during possible (partial) emptying or filling of the impoundment, for instance due to flushing operations, maintenance, calamities with rapid shutdown, electrical or mechanical faults, etc.

65. The impact of possible future development of additional dams in the cascade should be addressed in the design of the infrastructure[4] (e.g. to allow passage of flow pulses from upstream operations) and with regard to the downstream flows.

Construction stage

66. The developer should demonstrate that issues in relation to flow regimes downstream of project infrastructure during project construction and impoundment filling have been identified and assessed, and monitoring enables identification of any emerging issues.

Operation stage

67. Cascade Joint Operating Rules should be established by one or more Member Countries in which the projects are located, together with project developers and importing countries. Member Countries, that may be impacted by the operations of the cascade, should be consulted. The Cascade Operating Rules should provide a framework for Project-Specific Operating Rules for all projects within the cascade, as per Clauses 3 and 29.

68. Cascade Joint Operating Rules should reflect the important areas that require coordination to avoid cumulative impacts. These may include, for example: common flood management rules governing draw-down and opening of gates; coordination of maintenance periods; common rules for navigation lock operation; and coordinated timing for sediment flushing actions.

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[4] The information on these future developments may need to be sourced from the host Member Country or the MRC as part of national or regional planning.

69. Project-Specific Operating Rules should be fully aligned with Cascade Joint Operating Rules, but may also have more specific requirements taking into account local conditions and needs. These may include, for example, specifications on rates of downstream water level change, or flow quantity and velocity requirements for operation of the fish passage.

70. Water level ramping rates for the impoundment and downstream releases should seek to minimize identified risks, which will be project- and discipline-specific. Hydraulic modelling should be used to assist in identifying risks that are affected by fast draw-down or ramp-up rates, and to test the benefits of ramping rates for mitigation. Some guidance relating to the influence of ramping rates for specific disciplines can be found in the Hydropower Mitigation Guidelines (MRC, 2018a).

2.5 Project monitoring and adaptive management

71. Plans for project monitoring of hydrology and hydraulics should take into account the guidance in Clause 26. The PNPCA information should demonstrate that plans for hydrology and hydraulics monitoring information to be collected during construction and operation will inform:

    - developers' needs regarding operations, including any indicators that may be expressed in the Project-Specific Operating Rules or Cascade Joint Operating Rules; and
    - indicators relating to, or drawing on, data for water levels and flows, for any of the disciplines covered in Sections 3 to 9, that may signal a need for adaptive management responses.

72. The monitoring programme described in Section 2.3 should be continued during the construction and operation stages, and adapted where needed to better inform the information requirements for management during the construction and operation stage and to meet the needs of Clause 27.

73. Examples of water level and flow related aspects of project operations that may be able to be adaptively managed include minimum flow releases, ramping rates, impoundment water levels and fluctuations, flood rules, and gate operations. Plans for the project monitoring programme should consider how well it will be able to inform whether the objectives guiding these different aspects of operations are being met.

3

Sediment Transport and Geomorphology

3 SEDIMENT TRANSPORT AND GEOMORPHOLOGY

3.1 Objectives

74. The objectives for sediment transport and geomorphology are as follows:

    - Maintain the morphological equilibrium of the Mekong River.
    - Minimize changes to sediment delivery to the downstream environment with respect to sediment quantity, the seasonality of sediment delivery, and grain-size composition of the sediment load.
    - Minimize geomorphic impacts arising from changes in sediment transport, including changes to river banks, river beds and aquatic and riparian habitats.
    - Minimize deposition within and downstream of the impoundment to prevent upstream river changes, and maintain and protect project infrastructure.

75. There are no MRC Procedures that directly relate to sediment transport or geomorphology. The importance of sediment transport is recognized by the Member Countries cooperating in the monitoring of sediment movements through the Discharge and Sediment Monitoring Programme (Koehnken, 2014). In addition, the themes of sediment transport and geomorphology are included in the former MRC Water Utilisation Programme, the MRC Initiative for Sustainable Hydropower Studies (MRC, 2014), and in other published MRC studies.

3.2 Risks

76. Dams interrupt the natural continuity of sediment transport in river systems, inducing deposition within the impoundment, and altering the sediment quantity and composition in water released to the downstream river. These changes have a number of implications for water quality, aquatic ecology, fisheries, navigation, commercial activities and community uses.

77. Potential sediment transport and geomorphic risks should be comprehensively assessed. Risks associated with sediment transport and geomorphic risks associated with hydropower development are summarised in Table 3.1.

Table 3.1. Potential sediment transport and geomorphic risks associated with mainstream dams

Risk	Consequences/Comments
Alteration of morphological balance of the Mekong River	
Dams can fundamentally alter the nature, timing, and dispersal patterns of sediment delivery in river systems	This is the large-scale risk to which each of the following components is linked. Avoiding, minimizing this impact is the overall aim of sediment management in hydropower projects.
Trapping of sediment within impoundment	
Deposition at upstream extent of backwater and at tributary entry points can increase the river bed level and the risk of flooding upstream, and affect navigation	The degree of trapping is related to the flow regime within the impoundment and the characteristics of the inflowing sediment load. The largest sediment loads will typically be trapped at the most upstream project in a cascade or downstream of tributary junctions
Deposition of sediment can impact hydropower infrastructure and affect operations	▪ Sediment can block gates, damage turbines and reduce the live storage of impoundments. Sediment deposition can also affect water quality (Section 4).
Reduction in the sediment load downstream of the hydropower project	
Increased erosion downstream, leading to bed incision and channel widening. Erosion will progress downstream as sediment depletion occurs until a new equilibrium is established	▪ Erosion changes ecosystems and poses risks to infrastructure. ▪ Erosion and incision can alter local groundwater levels affecting bank stability and water availability. ▪ Alluvial river reaches are most prone to erosion. ▪ The greatest risk is downstream of the final hydropower project in a cascade or where there is a free-flowing river reach between projects. Erosion risks are lower if a project discharges into another impoundment. ▪ Erosion will alter habitats affecting aquatic ecology and fisheries (Sections 5 and 6).

Risk	Consequences/Comments
Change to grain size of sediment discharged downstream	▪ Grain size changes affect geomorphic characteristics and habitat distribution and availability. Also changes to dispersal patterns of sediments and nutrients downstream may occur with potential impacts to the Tonle Sap and the Delta. ▪ Trapping of sand will exacerbate impacts of sand mining downstream.
Increased erosion risk to delta and coastal areas. Reduction of fine-sediment to mangroves and nutrients to coastal areas	▪ Delta erosion increases risks associated with sea level rise and storm surges associated with extreme weather events. ▪ There are synergistic effects with aggregate mining.
Water level fluctuations within the impoundment	
Waterlogging and loss of vegetation on shoreline, leading to increased bank erosion and risk of landslides	▪ Linked to geology, soils and valley slope.
Water level fluctuations downstream	
Increased shear stress during rapid water level fluctuations increases bank erosion and susceptibility to seepage erosion (piping) processes	▪ Higher risks are associated with peaking operations. ▪ The greatest risk of erosion is associated where the discharge enters a free-flowing river channel, such as downstream of a final project in a cascade or a free-flowing alluvial river reach. ▪ Risks are decreased where the discharge enters another impoundment.
Bank scour focussed over a limited water level range leading to increased bank erosion	▪ Discharge range is limited resulting in discrete water levels associated with turbine discharge, increasing bank erosion at these levels. This risk is the greatest where discharge from the final project in a cascade enters a free-flowing alluvial river reach.

Risk	Consequences/Comments
Sediment management operations	
Routing and flushing of sediments cause changes to downstream river morphology and water quality	▪ Operation of low-set spillway gates may be used to flush/route sediments trapped in the impoundment. Release of these sediments may cause changes in river morphology immediately downstream of the impoundment.
Disconnect between flow and sediment delivery	
Seasonal sediment 'pulse' lost	▪ This affects sediment and nutrient dispersal patterns, including floodplain deposition. ▪ It can affect ecological processes (water quality, aquatic ecology, fisheries), floodplain agriculture, and sediment balance in the Tonle Sap system.
Decoupling of tributary and mainstream flows	▪ Erosion and/or deposition at tributary confluences due to tributary rejuvenation. ▪ This can also occur within impoundments or at confluences in free-flowing river reaches.
Increased sediment generation during construction	
Increase in sediment loads can smother habitats and directly affect aquatic ecology and water quality	▪ Increased sediments can infill gravel beds and alter light penetration. This can also occur due to increased sediment loads from construction on tributary projects.
Increase in sediment loads entering downstream impoundments	▪ Can affect sediment management and mitigation strategies in downstream project and cascade. Can also occur due to increased sediment loads from construction on tributary projects.
Land disturbance during construction	
Construction of access roads and infrastructure can increase risk of landslides	▪ Linked to geology, soils, valley slope and construction methods

78. The location of a project within a cascade and the location relative to tributary projects should be considered when identifying risks. The potential for future mainstream or tributary developments to alter conditions and risks should also be considered.

3.3 Pre-project monitoring and analyses

79. The information submitted for the PNPCA process should demonstrate quantification of pre-project conditions and quantitative identification of potential changes for sediment transport and geomorphology, based on a combined monitoring and modelling approach. The information submitted should include:

    - site-specific monitoring of sediment transport and geomorphological characteristics at a spatial scale appropriate to the development;
    - a basic numerical sediment transport model integrated with the hydrological and hydraulic transport model (see Section 2.3). This model should be capable of quantifying sediment transport and geomorphic changes associated with hydropower operations over suitable geographic ranges and timescales, including demonstrating potential transboundary changes. More than one model may be required to adequately capture the details required near the dam and hydropower infrastructure, and to provide an indication of geomorphic change over long river reaches;
    - the numerical modelling may be supplemented by physical modelling during the detailed design stages. Any physical model should be designed with application of relevant scaling laws and assessment and interpretation of relevant hydraulic and sediment parameters (e.g. Froude number, Reynolds values, Shields parameters).

80. The monitoring and modelling should be used to describe and quantify baseline conditions in the project reach and potential project operations, providing:

    - a quantitative description of the existing environment with respect to sediment transport and geomorphic characteristics as outlined in Clause 81;
    - a basis for identifying and evaluating potential changes to the river due to the development, as outlined in Clause 82;
    - a basis for identifying risks as outlined in Section 3.2, and identifying and optimizing mitigation measures as outlined in Section 3.4.

81. The description of the existing environment should include, but not be limited to:

    - the annual sediment budget divided into seasons, including an indication of sediment variability and trends associated with other developments (e.g. decreasing sediment supply over time due to upstream mainstream or tributary dams);
    - grain-size distribution on a seasonal basis, using the grain-size definitions and nomenclature defined in the Definition of Terms;
    - existing geomorphic characteristics and patterns of sediment deposition and erosion in the project area (including the impoundment and downstream);

- a description of the present geomorphic changes occurring associated with existing developments.

82. The description of potential changes to the existing environment associated with the project development should include:

    - projected changes to sediment transport[5] within and downstream of the impoundment over the life of the project, such as impoundment sedimentation, sediment transport downstream of the dam, and channel changes downstream of the dam;
    - an evaluation of how the impacts from the project are likely to change due to future planned upstream or downstream developments by developer and host nation with the support of regional agencies as required, for example, the MRCS;
    - a description of the forecast state of impoundment sedimentation, sediment management infrastructure, and downstream physical geomorphic changes at the end of the concession period. This will allow the relevant Member Country to include quality standards, design requirements and operational targets in the Concession Agreement to ensure the value of the asset at the time of relinquishment;
    - A description of how adaptive management will be implemented over the concession period and the uncertainties associated with the assessment.

Guidance for monitoring

83. The monitoring approach for sediment transport and geomorphology should be shown in the PNPCA information to be sufficient to inform full feasibility level design, to support modelling for impact prediction, and to help with later impact evaluation. Clause 23 provides basic principles to guide design of the overall monitoring network. The following clauses can be used as a guide, and varied to suit project-specific conditions.

84. Monitoring should be completed over a sufficient geographic range to identify potential impacts associated with the development, guided by Clause 20. The number and location of monitoring sites should include:

    - the hydrologic monitoring sites described in Section 2.3 such that the pre-project sediment loads entering and discharged from the project area are accurately quantified;
    - at an existing MRC sediment and discharge monitoring site to allow comparison of sediment transport monitoring results with the existing long-term data set;
    - a site located 50% of the distance between the upstream backwater and the dam site if the impoundment is projected to exceed 40 km in length. Additional monitoring sites

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[5] The basin-scale information and changes may be investigated through MRC assessments (e.g. through the MRC basin planning).

within the future impoundment may be required downstream of the confluence of any tributaries entering within the impoundment reach contributing more than 2% of the Mekong average annual flow as measured upstream of that tributary's confluence;

- at suitable intervals downstream of the dam site reflecting the site-specific nature of the river reach. Sites upstream of major tributary confluences should be included.
- where the river enters a different hydrogeomorphic zone, if applicable.

85. Monitoring parameters should include:

    - river flow and hydraulics, as described in Section 2.3. All sediment transport information should be linked to the hydrologic and hydraulic conditions at the time of sampling, including velocity, discharge and depth.
    - suspended sediments determined using a depth-integrated isokinetic method or point-integrated method (Davis, 2005) or equivalent. An equivalent may include the in-situ measurement of sediment volume and grain size using a laser instrument, provided that a calibration between physical sampling and the laser instrument is completed and included in the baseline information.
    - grain-size distribution of suspended sediment using either recognized and referenced laboratory settling techniques, laboratory laser or x-ray techniques, or in-situ determination using a laser instrument.
    - bedload movement estimates using the Acoustic Doppler Current Profiler (ADCP) loop method (USGS, 2006) or equivalent.
    - grain-size distribution of bedload and bed materials using standard sieve sizes consistent with the grain sizes, as specified in the Definition of Terms.

86. The duration of sediment data collection should enable coverage of the full annual cycle with low and high flows, as well as provide insight into inter-annual variability, which is substantial in the Mekong and should be factored into project design. The project-specific field data should be collected for a period of at least one year. This should occur immediately prior to finalization and submission of PNPCA documentation, and explained in light of longer-term trends by having the monitoring network include one or more long-term monitoring sites. The field data collection should continue through the pre-project period to capture more of the inter-annual variability and be used to inform detailed design.

87. The frequency of data collection should be linked to the seasonal hydrology. This timing will enable integration with the MRC sediment monitoring results and enable interpretation of the data within broader datasets.

    - Monitoring for all parameters should be completed on a weekly basis during the wet season (June to October, inclusive), and fortnightly during the transition seasons (May and November) as defined for the Mekong (MRC, 2009a). More frequent monitoring during high flow periods and events is desirable for providing information relevant to sediment routing and flushing.

- During the dry season (December to April), monthly monitoring of suspended sediment load only is recommended.

88. Because sediment dynamics at the project site are part of a large-scale and longer-term process of sediment dynamics in the Mekong River, site-specific data collected by the developer should be related and compared with the MRC sediment monitoring data set, and any substantial differences should be investigated and explained.

Guidance for modelling and analyses

89. Sediment modelling should be consistent with Clause 24, and integrated with hydrological and hydraulic modelling (see Section 2.3). Sediment modelling should include the sediment loads, sediment grain-size distribution and seasonal variability. The baseline conditions of the river should be modelled and calibrated using the monitoring results.

90. Scenarios for impoundment sediment deposition and scour should be developed based on an understanding of factors such as: the extent of the flooded areas of the future impoundment; their seasonal fluctuations; the presence of bedrock outcrops; and the influence of tributaries. Scenarios investigating different Project-Specific Operating Rules related to sediment management, such as minimizing deposition in the impoundment backwater, sediment flushing, or sediment routing, should be included.

91. The sediment model should demonstrate the influence of the daily and annual operating pattern of the project on the following:

    - the volume and grain-size distribution of deposition in the impoundment, including headwater deposits. Model runs should include impacts from upstream projects where applicable;
    - the quantity and grain-size characteristics of the sediment load discharged downstream;
    - the downstream river channel adjustments attributable to the change in sediment transport, and the extent of downstream influence of the project operations based on water level fluctuations. Changes to the river thalweg, channel shape, sand and gravel bars, and deep pools should be identified. A discussion of model uncertainties and limitations should be included.

92. The model should be sufficient to evaluate designs to minimize deposition at or near the spillway gates, and entrainment of sediment through the turbines.

93. The model should be capable of incorporating and demonstrating the efficacy of sediment mitigation measures over a range of conditions. The types of information derived by

modelling should include (depending on the mitigation measure being implemented):

- the efficacy of the mitigation measure with respect to limiting sediment deposition in the impoundment and the provision of an annual sediment discharge into downstream reaches;
- the maximum sediment concentrations likely to occur downstream during flushing or sediment routing, and the expected duration of elevated sediment concentrations associated with mitigation;
- a comparison of mitigation measures when implemented under different flow regimes, for example, flushing during high flow conditions versus low flow conditions.

94. The analyses of changes, impacts, and mitigation options for sediment transport and geomorphology should clearly identify the residual impacts and document where these will occur in the river, in line with Clauses 7 and 25.

3.4 Design and operational guidance

95. Mitigation options should be evaluated to determine which ones will best address identified risks. The modelling and monitoring results and project information should be used to evaluate the potential sediment transport and geomorphic risks associated with the project, and identify and optimize appropriate mitigation measures. Mitigation options should clearly address the identified risks relevant to the project. Mitigation options to address potential risks relating to mainstream dams are summarized in Table 3.2. Not all risks will apply to every project, and there may be additional risks that require consideration. Additional information is provided in the following clauses.

Table 3.2. Mitigation options for sediment transport and geomorphic risks for mainstream dams

Risk	Mitigation Options
Alteration of morphological balance of the Mekong River	- Site and design the project to minimize disruption of sediment supply and maximize potential for sediment management and passage.
Trapping of sediment within the impoundment	- Size and design the project to minimize retention time and maximize sediment entrainment and transport. - Include low level outlets to allow the passing of turbidity currents, and implement sediment routing and sediment flushing. - Include sand trapping and passing facilities near turbines.
Reduction in sediment load downstream due to increased deposition within the impoundment	- Develop operating procedures to maximize sediment passage (sediment bypass, routing). - Develop annual operating procedures to flush sediments at seasonally appropriate times, targeting high water flows and high inflowing sediment loads. - Implement physical bank protection where bank erosion poses a risk to infrastructure or communities.
Water level fluctuations within impoundment leading to erosion and landslides	- Develop operating procedures that will minimize the rate and range of water level fluctuations. - Implement physical buttressing of banks to protect infrastructure.
Water level fluctuations downstream leading to erosion and landslides	- Develop up- and down-ramping rates to minimize bank erosion and reduce safety issues. - Implement physical buttressing of banks to protect infrastructure and land.
Disconnect between flow and sediment delivery	- Implement sediment routing or sediment flushing early in the monsoon to provide a pulse of sediment to the downstream environment. - Coordinate sediment routing and flushing within a cascade to maximize downstream sediment transport.

Risk	Mitigation Options
Sediment management operations	- Conduct flushing/routing during high flow periods using low-set spillway gate with mid-level spillway gates to dilute downstream concentrations. - Coordinate sediment routing and flushing within a cascade to maximize downstream sediment transport.
Increased sediment generation during construction	- Contour access roads and include drains to limit sediment runoff. - Construct access roads, coffer dams and other major earth works during the dry season. - Construct and manage sediment traps.
Land disturbance and landslides during construction	- Minimize land disturbance during the wet season. - Construct roads along contours using good practice engineering. - Construct access roads, coffer dams, and other major earth works during the dry season. - Construct and manage sediment traps. - Rehabilitate and revegetation disturbed lands as soon as practicable.

Siting

96. Developers should consider alternative dam sites at the earliest possible stages of planning, with modelling used to assist the selection of sites whose natural attributes combined with the hydraulics of the river flow at the site best facilitate passage of sediment. The potential for sediment bypass channels should be included in this early planning phase.

97. Particular care should be taken to avoid sediment deposition that poses risks for the safe working of the flood passage capacity of the dam.

98. Dam layouts, including the location of the turbine intakes, low-level outlets and spillway gates should be planned to minimize deposition near intakes and maximize the potential for frequent sediment flushing.

Dam infrastructure

99. Low-head, small impoundment run-of-river projects will trap less sediment than dams with storage capacity because fine sediment is more readily held in suspension, and routing or flushing of fine and coarse sediment can be carried out more easily and efficiently.

100. Dams and intake structures should be designed to minimize the deposition and entrainment

of sediment near the dam to ensure long-term safe operation. If applicable, sand passing facilities should be included near the turbines to allow episodic flushing of sediment from near turbine intakes or to facilitate sediment flushing in response to adaptive management.

101. Projects in which sediment routing or sediment flushing are the only mitigation options for passing sediment to the downstream environment should include large, low-level outlets to allow for sediment routing (pass-through) and drawdown for sediment flushing. Gates should have the following characteristics:

    - The gates should be located at maximum depth within the impoundment to maximize potential for sediment flushing.
    - The height of the sill at the base of the gates above the bed of the river should be minimized to reduce the volume of sediment required to be deposited prior to enabling discharge via the low-level outlets.
    - Gates and flushing galleries or tunnels should be large enough to accommodate flows sufficient to entrain and transport coarse sand and gravel in suspension and prevent clogging.
    - Mid-level gates (or spillways) should be included to allow dilution of the highly concentrated bottom waters that are released.

102. Fail-safe provisions, such as stop logs or additional gates, for dewatering the structures immediately upstream and immediately downstream of the bottom gates should be provided to enable cleanout in the event of blockage.

Sediment management and mitigation during construction

103. During the construction stage, sediment management should aim to:

    - minimize runoff from the site, using appropriate construction methods and mitigation measures such as sediment traps. Revegetation of disturbed areas should be completed as soon as practicable;
    - minimize the risk of landslides and land disturbance associated with the construction of infrastructure and access roads, including to transmission lines or ancillary services.

Sediment management and mitigation during operations

104. During the operation stage, sediment management should aim to:

    - minimize sediment deposition within the impoundment or near infrastructure that can affect operations of the hydropower project;
    - maintain a seasonal supply of sediment to the downstream environment, maintaining sediment loads and sediment grain-size characteristics similar to pre-dam conditions

as much as practicable;

- manage the impoundment to promote the downstream transport of bedload; and
- minimize water quality and river morphology changes resulting from routing or flushing operations.

105. Targets for sediment management should include the following:

- The passage of sediment should be promoted during all flood events with low-level outlets opened in combination with mid-level flood gates.[6]
- At least 70% of the fine-sediment (grain size < 63 μm) entering an impoundment should be discharged on an annual basis to downstream of the dam. This is to maintain a supply of fine-sediment and nutrients to the downstream environment, including the Tonle Sap and delta. A target of 70% is considered an operationally feasible target that would provide downstream benefit.

106. Mitigation strategies, including operating rules where applicable, should be developed and included in the PNPCA reports to address the risks identified under Section 3.2 and achieve the targets listed in Clause 105. These strategies should include an adaptive management component demonstrating how operations could adapt to changing conditions. Strategies should also consider the potential for downstream environmental impact associated with the release of unnaturally high sediment loads and include precautions to minimize the degree and extent of downstream impacts. Where applicable, modelling should be used to determine the extent of downstream impacts and used to notify downstream countries. Sediment mitigation strategies should also aim to be compatible with fish migration mitigation strategies with respect to timing and execution (e.g. rate of drawdown), and minimize water quality impacts. Other possible sediment mitigation strategies are as follows:

- **Sediment bypass**: This involves diverting sediment-laden water into a channel or tunnel from the river channel upstream of the impoundment, bypassing the impoundment, and delivering the sediment to the channel below the dam. This approach transports both fine- and coarse-grained sediment, preserves continuity of sediment transport to downstream reaches, and avoids sedimentation problems in the impoundment. However, it is possible only in situations where the geometry of the river and impoundment are favourable.
- **Sediment routing**: This involves a seasonal draw-down of the impoundment to allow the passing of suspended sediment through the impoundment to avoid net sedimentation. Sediment routing should be carried out when sediment concentrations and sediment transport rates are high, such as early in the flood season.

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[6] As per clause 101, mid-level gates may also need to be operated simultaneously to dilute flushed sediments.

- **Pressure flushing**: This is based on opening the low-level outlets but not reducing the water level in the impoundment to pre-dam levels. This approach has limited effectiveness because it generally only removes sediments located near the dam wall; therefore, it is not an efficient method for removing large volumes of sediment from impoundments.

- **Sediment flushing**: This involves drawing down the impoundment and allowing accumulated sediments to be eroded and pass through low-level outlets into the downstream channel. As with sediment routing, the impoundment temporarily behaves like a reach of river, transporting sediments through the dam. Unlike sediment routing or bypassing sediment, flushing releases more concentrated sediment discharges over shorter time periods, thus changing the temporal pattern of sediment release. Flushing can only be carried out on impoundments that can be drawn down regularly, and is most effective when the low-level outlets are large and can pass sediment-transporting flows without creating backwater conditions. Sediment flushing is also effective at moving bedload material downstream within an impoundment. The timing and duration of sediment flushing should consider ecological considerations such as the timing of fish migration.

107. Operating rules related to sediment flushing should consider the following:

    - Sediment flushing during base flow periods should be avoided in order to minimize downstream impacts associated with the release of very high turbidity levels and deposition of sediment that will remain in the channel for prolonged periods.

    - A maximum downstream sediment target concentration should be established based on social and ecological considerations and sediment monitoring results. An initial guide is the natural (pre-Chinese dams) maximum sediment concentrations that occurred during the flood season.

    - The sediment concentration of water released during flushing operations should be controlled and monitored to prevent negative impacts on downstream ecology. Monitoring locations should be guided by site-specific conditions, including the location of downstream settlements and land use as well as important habitats and ecosystems.

    - The operating conditions associated with flushing (rate of drawdown, duration of drawdown, timing of flushing) should be guided by site-specific conditions, including sediment inflows, downstream safety, and ecological risks, and be consistent with and take into consideration fish and water quality management aims and strategies. Modelling runs of potential flushing regimes should be used to optimize sediment passage, and sediment flushing strategies should form an integral component of Cascade Joint Operating Rules.

- A communication strategy should be developed by the operator of individual projects to inform stakeholders of any atypical operations associated with sediment management. Where these operations have the potential for transboundary impacts downstream, the communication strategy should include communication with the downstream Member Countries.

Mechanical removal of sediment

108. Where hydraulic flushing is not possible, sediments accumulated in the impoundment can be removed mechanically by dredging or drawing down the impoundment and excavating dry. Dredging can be carried out using hydraulic suction driven by a pump, siphons, or mechanical clamshell or bucket ladder dredges. Key considerations include the location of suitable disposal areas nearby, distances and vertical uphill haul required, and the logistics of transferring sediment from the impoundment deposit to truck, or in some cases, slurry pipeline. Mechanical disturbance of sediment may also be implemented during sediment flushing to increase the mobilization of deposited material.

Management of geomorphic impacts downstream of dams

109. This Guidance includes the most practical approaches for mainstream dams. Other sediment and geomorphic approaches, such as re-regulation weirs, sediment traps, or sediment augmentation, may be applicable in some cases.

110. Downstream impacts need to be considered in a catchment context. Other activities that affect river geomorphology, such as aggregate extraction, should be managed in conjunction with hydropower operations to reduce synergistic impacts. This would be the responsibility of national agencies and not the developer.

111. The rate of erosion or deposition downstream of a dam may be reduced through implementation of Project-Specific Operating Rules that minimize the rate and limit the magnitude of water level changes (see Clause 70).

112. In place of, or in addition to, operating rules, river bank erosion control may be required at the expense of the operator to control bank erosion downstream of the project or along the shore of the impoundment.

Managing sediment in a cascade of dams

113. Sediment management based on the objectives identified in Clause 105 should be planned and coordinated between projects within a cascade of dams, ideally through Cascade Joint Operating Rules. This may be achieved through cooperation between developers, the host nation and, potentially, regional agencies (e.g. the MRCS) if required. Basic numerical modelling of the cascade should be used to guide management and minimize impacts within impoundments, and on the downstream environment. A description of how management of sediments will be coordinated should be included in the PNPCA documentation, taking into

account the state of cascade-level analyses and development of Cascade Joint Operating Rules. In the absence of established rules, the developer should indicate how project-specific management measures have taken into consideration the need for coordinated sediment management within the cascade.

114. The Cascade Joint Operating Rules should include a communication mechanism between operators within a cascade and the Member Country to enhance the exchange of information and provide a system for informing the public of hydropower operations such as sediment flushing, similar to that described in 107. The communication strategy should include a mechanism for informing downstream Member Countries of any atypical (e.g. sediment flushing, routing) hydropower operations with potential transboundary impacts.

3.5 Project monitoring and adaptive management

115. Plans for project monitoring of sediments and geomophology should take into account the guidance in Clause 26. The PNPCA information should demonstrate that plans for sediment transport and geomorphology monitoring information to be collected during construction and operation will inform:

- developers' needs regarding sediment management operations, and in particular related to sediment flushing;
- indicators that may signal a need for adaptive management responses to sediment or geomorphology related mitigation measures.

116. The monitoring programme for sediment transport and geomorphology at the construction and operation stage should recognize the site-specific characteristics of the project and aim to capture the following aspects where applicable.

- Measurement of sediment inflows and outflows from the impoundment area should be undertaken, including the determination of sediment grain size. The same monitoring parameters and monitoring frequency as described in Section 3.3 are recommended. Other than within the impoundment, monitoring locations should be the same as pre-project sites, and should include upstream of the backwater to quantify inflow and downstream of the dam to quantify outflows.
- Survey the bathymety within the impoundment at a resolution and frequency sufficient to quantify the rates of sediment accumulation or scour.
- Survey cross-sections and bathymetry at the upstream extent of the backwater, at a resolution and frequency to determine changes that might affect navigation.
- Cross-sections of the river downstream of the dam should be surveyed annually for the first five years of operations and every two years thereafter. A downstream monitoring

plan should be developed that takes account of the location of the project, the location of other projects, and proximity to alluvial river reaches. Monitoring should extend through the project-affected reach,[7] or to the backwater of the next project downstream, with cross-sections spaced at appropriate[8] intervals and targeting alluvial reaches. Cross-sections should extend above the maximum water level height of the river;

- River banks along the new flood level line of the impoundment should be monitored to establish rates of erosion.
- Site-specific attributes of the monitoring programme should account for the position of the project relative to other mainstream and tributary projects and the proximity of tributaries and national borders.

117. Adaptive management measures should be guided by monitoring results, in accordance with Clause 27. These measures include, *inter alia*, the frequency, timing, and duration of sediment routing or flushing, and ramp-down rates to minimize downstream bank erosion. Monitoring results can also guide the implementation and management of downstream infrastructure to minimize bank erosion, such as bank armouring or use of groynes, if required. Development of the project monitoring programme should consider how well it will inform whether the objectives guiding these different aspects of operations are being met.

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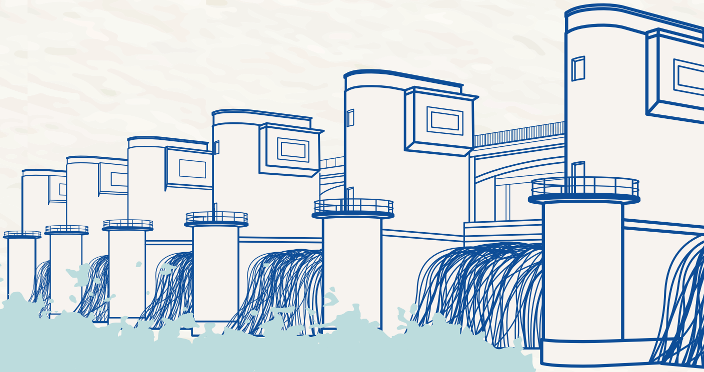
[7] See Clause 20.

[8] The distance between cross-sections monitored will depend on the river morphology and the presence of alluvia reaches.



4

Water Quality

4 WATER QUALITY

4.1 Objectives

118. The objectives for water quality are:

- Reduce the risks that water quality within the impoundment will impact the use of the impoundment for other purposes, such as fisheries, or will impact human health, or will cause interference with, and damage to, hydropower infrastructure such as turbines.
- Minimize water quality impacts of the dam on downstream fisheries, aquatic ecosystems and human health.
- Ensure alignment with the Procedures on Water Quality (see MRC, 2011) under the Mekong Agreement, which seek to maintain the water quality of the Mekong River mainstream.

119. Technical Guidelines for the Implementation of the Procedures for Water Quality (MRC, 2016), referred to as the "Technical Guidelines", have been agreed by the countries and encompass guidance for the protection of human health, the protection of aquatic life, a framework for implementation, and water quality emergency response and management.

4.2 Risks

120. Potential water quality risks should be comprehensively assessed. Dams are at risk from, and may constitute risks to, water quality in rivers. Risks to water quality in dams can arise from the quality of the water in the river being dammed, which in turn is influenced by human activities in the catchment upstream of the dam. Forestry, agriculture, urbanization, and industrialization are all activities that can lead to degradation of water quality in rivers. Water quality risks for mainstream dams are shown in **Table 4.1**. Mainstream dams may experience fewer of these risks because they operate in run-of-river mode with relatively short water residence times in the impoundment, or they may experience a number of these risks because of issues caused by surrounding land uses and tributary developments. All risks should be considered and assessed, including through consideration of atypical scenarios (e.g. floods, intense storm events, droughts) to see if any may emerge under particular circumstances.

Table 4.1. Potential water quality risks associated with mainstream dams

Risk	Consequences/comments
Risks from construction activities	
Spillages of fuel and lubricants	Local contamination could impact aquatic ecosystems and fish in the vicinity of the construction site
Runoff of turbid water from bare soil	Local contamination could impact aquatic ecosystems and fish in the vicinity of the construction site
Waste water from accommodation facilities for workers	Local contamination could impact aquatic ecosystems and fish in the vicinity of the construction site
Risks to the impoundment	
Increasing nutrient influx from upstream and the local catchment from non-hydropower related activities	Increased algal growth rates
Reduced turbidity and increased light penetration	Increased algal growth rates
Risks from impoundment stratification	
Low dissolved oxygen in hypolimnion (bottom water)	Hypolimnion becomes unavailable to fish and most invertebrates, iron and manganese released from sediments
Low pH in hypolimnion	Low pH causes corrosion of hydropower infrastructure, hypolimnion becomes toxic to biota, and metals and nutrients are released from sediments.
High concentrations of dissolved iron and manganese in hypolimnion	May cause deposition of iron and manganese on project infrastructure and in the riverbed and downstream.
High concentrations of toxic metals from natural or anthropogenic sources (e.g. mercury) in hypolimnion	Toxic metals may be taken up in biota and potentially passed up food chains and contaminate foods for humans
High concentrations of sulphides (S2-) and nutrients (nitrogen and phosphorous) in hypolimnion	May trigger algal blooms when impoundment water turns over when stratification breaks down – probably in December-January
Risks downstream of the dam	
Rapid flow changes	Rapid fluctuations in downstream water quality

Risk	Consequences/comments
Altered water temperature	Negative impacts on downstream biota
Reduced turbidity arising from settling of particulates	Increased algal and plant growth, impact on fish behaviour
Reduced nutrient concentrations arising from settling of particulates	Reduced nutrient availability to instream and floodplain biota
Gas supersaturation	Fish deaths
Risks from impoundment stratification if bottom water is discharged downstream	
Low dissolved oxygen arising from impoundment stratification	Negative impacts on downstream biota
Low pH arising from impoundment stratification	Negative impacts on downstream biota
High concentrations of reduced metals (Iron and Manganese) arising from impoundment stratification	Negative impacts on downstream habitat and biota
High concentrations of toxic metals leaching from impoundment sediments as a result of impoundment stratification	Negative impacts on downstream biota, and potential impacts on humans consuming fish and other aquatic animals (OAAs)
Risks from sediment flushing	
Downstream pulse of sediment	Altered downstream sediment composition and concentrations
Downstream pulse of high turbidity	Downstream biota reduced through avoidance behaviour such as invertebrate drift
Downstream pulse of low dissolved oxygen	Downstream biota reduced through deaths and avoidance behaviour such as invertebrate drift
Downstream pulse of toxicants	Downstream biota reduced through deaths and avoidance behaviour such as invertebrate drift

121. When water is held in a dam, its condition will change, with potential changes including a loss of suspended material, increased biological activity, and physico-chemical changes such as heating by the sun. Some of these changes pose risks to dam operators, as well as the river downstream.

122. Stratification risks are related to the transparency of the water, solar radiation, the morphology of the impoundment, the inflow-to-storage ratio, location of the intake, and nature of the catchment. Stratification occurs when cooler water sits below a thermocline and warmer water forms a layer above it. Oxygen does not diffuse readily across the thermocline, so the cooler bottom water, the hypolimnion, may become anaerobic, with a low pH, and high concentrations of dissolved metals, such as iron and manganese, and even toxic metals such as mercury, which dissolve out of the sediments. The following should be considered:

- Risks are lower in shallow impoundments with high inflow-to-storage volume ratios, however can increase in cascade settings where the progressive storage of water can alter temperature regimes.
- Risks are higher in deep, large volume dams, with low inflow to storage ratios.
- Risks are higher in tropical reservoirs where strong thermal gradients may establish rapidly.

123. Gas supersaturation is a condition that occurs when the partial pressures of atmospheric gases in solution exceed their respective partial pressures in the atmosphere. It can occur when water is exposed to air that is at higher than normal pressure in hydropower turbine systems or dam spillways. When the sum of the partial pressures of all dissolved gases exceeds atmospheric pressure, there is potential for gas bubbles to develop in water and in the aquatic organisms that inhabit the water. This causes a condition known as gas bubble disease, which can kill fish and invertebrates.

4.3 Pre-project monitoring and analyses

Guidance for monitoring

124. The monitoring approach for water quality should be shown in the PNPCA information to be sufficient to inform design, to support modelling for impact prediction, and to help with later impact evaluation. The guidance on monitoring locations and frequency, analytical methods, quality assurance and assessment and reporting contained within the Technical Guidelines should be referred to by developers. Clause 23 provides basic principles to guide design of the overall monitoring network. The following clauses can be used as a guide, and varied to suit project-specific conditions.

125. An overall design for data collection for evaluation of water quality risks and potential impacts should be established during the project design stage to match the project site and particular project data requirements. The following locations should be considered in order to inform the analyses that are presented with the PNPCA information:

- Water quality monitoring sites should be established upstream of the maximum extent of backwater of the impoundment, and at multiple sites downstream of the dam site in line with the hydrologic monitoring sites (Section 2.3).

- Additional monitoring locations should be established, as applicable, within tributaries entering the impoundment that provide more than 2% of the annual average Mekong flow as determined upstream of the confluence.
- Additional monitoring locations should be established, as applicable, upstream and downstream of the first tributary downstream of the dam that contributes more than 0.5% of the annual average Mekong flow at its confluence, to establish whether impacts extend as far as the tributary, and the extent to which the tributary flows ameliorate any impact.
- Additional monitoring locations should be considered upstream and downstream of any locations on the river in the zone affected by the project (see Clause 20) where known sub-standard water quality discharges exist, such as due to industrial activities, so that project-related impacts will be able to be distinguished from other causes of impact.

126. Project-specific water quality monitoring sites should be positioned so that the data sets can benefit from interpretation from existing and longer-term water quality monitoring sites. There is a substantial database on chemical water quality in the Mekong mainstream and some major tributaries, with information extending back to 1985. Local conditions should be able to be interpreted within the long-term larger-scale MRC data set.

127. The duration of water quality data collection should enable coverage of the full annual cycle with low and high flows, as well as provide insight into inter-annual variability, which is substantial in the Mekong and should be factored into project design. A common approach to setting targets for water quality parameters is to establish a threshold equivalent to the 80th percentile of the pre-project condition, which should be informed by two years of monthly water quality samples. A two-year water quality data set should be submitted with the PNPCA information so that targets could be set in this manner. This dataset may be collected through at least one year of monthly site-specific monitoring extended with data from other monitoring programmes; the MRC data are recommended due to its high quality. The field data collection should continue through the pre-project period to capture more of the inter-annual variability and be used to inform detailed design.

128. The parameters currently included in the MRC water quality monitoring programme should guide those to be monitored during the pre-project stage, and thereafter, as shown in **Table 4.2**. Additional parameters should be added, as required, during construction and operations, as outlined in Section 4.5

Table 4.2. Water quality parameters monitored by MRC Water Quality Monitoring Network, 2018

Parameters monitored monthly throughout the year		Parameters only monitored between April and October
Temperature	Ammonium (NH_4 -N)	Calcium (Ca)
pH	Nnitrite +nitrate (NO_{2-3} -N)	Magnesium (Mg)
Conductivity (Salinity)	Faecal coliforms	Sodium (Na)
Alkalinity/acidity	Total suspended solids (TSS)	Potassium (K)
Dissolved oxygen (DO)	Chemical oxygen demand (COD) ($KMnO_4$)	Sulphate (SO_4)
Total phosphorous (TP)	Biiochemical oxygen demand (BOD)	Chloride (Cl)
Total nitrogen (TN)		

** Selected sites only*

129. To set up the water quality monitoring in a manner that will enable statistically significant comparisons of changes during construction and operation with the pre-project conditions, at each sampling location, a minimum of five water quality samples would be collected across the surface of the river to capture variability during the first year. After one year of sampling. the number of samples should be reviewed and a power analysis conducted to determine the number of samples necessary to compare impacts post-project development.

Data analysis and impact prediction

130. The analysis of projected water quality impacts from mainstream hydropower projects should consider the potential direct impacts associated with the proposed hydropower project and take into account trends in water quality shown by the long-term MRC data. Forward projections of water quality should be made and should be used to guide mitigation strategies.

131. Analyses of the potential for stratification and for gas supersaturation should be undertaken, taking into account considerations identified in clauses 122 and 123. These analyses may benefit from the use of modelling at a degree of sophistication sufficient to establish if the risk is prevalent or not.

132. The analyses of changes, impacts, and mitigation options for water quality should clearly identify the residual impacts and document where these will occur in the river, in line with Clauses 7 and 25.

4.4 Design and operational guidance

133. Mitigation options should be evaluated to determine which ones will best address identified risks. The monitoring and analytical results and project information should be used to evaluate the potential water quality risks associated with the project, and identify and optimize appropriate mitigation measures. Mitigation options to address potential water quality risks relating to mainstream dams are summarized in Table 4.3, together with appropriate indicators to monitor and assess these risks. A number of these risks may not apply to the project, and there may be additional risks that require consideration. These mitigation measures are additional to those identified in the sections on hydrology and hydraulics (Section 2), and sediment transport and geomorphology (Section 3). Additional guidance on mitigation in the case that some of the key risks are prevalent is provided in the clauses following Table 4.3.

Table 4.3. Mitigation options for water quality risks for mainstream dams

Water quality risk	Indicator	Management/mitigation measures
Construction risks		
Sewage and contaminated run-off from labour camps, workshops, etc.	- Nutrient concentrations - faecal coliforms	- Implement appropriate construction techniques to minimize run-off. - Implement wastewater treatment for camps.
Fuel, oil, and chemical spills	Total petroleum hydrocarbons	- Ensure that all storage and transfer areas have appropriately bunding, with clean up equipment onsite should spillages occur. Ensure that staff members are trained in spillage control and appropriate clean-up procedures.
Within the impoundment		
Sewage and contaminated runoff from riparian villages	- Nutrient concentrations - faecal coliforms	- Implement appropriate drainage systems to minimize run-off into the impoundment. - Implement wastewater treatment for villages.
Increasing nutrient influx from upstream and the local catchment from non-hydropower-related activities	Increasing nutrient concentrations and loads entering impoundment (TN, TP, NH_3+, etc.)	- Ongoing communication with the responsible national agency and work with provincial and national agencies to promote good land and wastewater management practice throughout the basin.

Water quality risk	Indicator	Management/mitigation measures
Reduced turbidity and increased light penetration, which can lead to algal blooms and/or reservoir stratification	- Photosynthetically Active Radiation (PAR) penetration - Turbidity - Chlorophyll levels	- Work with the responsible national agency and catchment management groups to lower nutrient inputs. If severe, treat chemically or aerate to treat surface scums.
Risks from impoundment stratification		
Low dissolved oxygen in hypolimnion (bottom water)	Water column profiles of dissolved oxygen	- Design low volume, high inflow impoundments with lower risks of stratification. - Work with catchment groups and the responsible national agency to minimize organic loading to impoundment. - Design high dimension turbine intakes to take water into the power station over a range of impoundment depths. - Implement air injection in the turbine if low dissolved oxygen levels are entering the power house. - Incorporate an aeration unit near dam.
Downstream risks		
Altered water temperature	Water temperature	- Site projects upstream of unregulated tributaries. - Include intakes that extract water over a range of depths. - Include multilevel offtakes. - Release surface water to mix with power station discharge.
Rapid alterations in water quality	- Water temperature - Turbidity - Suspended solids Conductivity - pH	- Implement operating rules to restrict ramping rates and daily water level changes.

Water quality risk	Indicator	Management/mitigation measures
Gas supersaturation	Gas saturation	- Maintain clean trash racks to minimize turbulence and air entrainment at intake. - Site projects in steep reaches to allow degassing of outflow. - Include spillway deflectors if risk is high.
Downstream risks from impoundment stratification		
Low dissolved oxygen	Dissolved oxygen	- Release water from surface spillways to mix and dilute. - Site projects in steep reaches to allow reoxygenation via turbulence.
Low pH	pH	- Release water from surface spillways to mix and dilute and raise oxygen levels.
High iron and manganese	Iron and manganese	- Release water from surface spillways to mix, dilute these elements and raise oxygen levels, and to cause metals to precipitate
Risks from sediment flushing		
Downstream pulse of high turbidity	Total suspended solid concentration	- Limit sediment concentrations during flushing by managing flows and draw-down rates. - Flush frequently to avoid large sediment loads being flushed sporadically.
Downstream pulse of low dissolved oxygen	Dissolved oxygen	- Release water from surface spillways to mix and dilute. Implement measures to reduce stratification
Downstream pulse of toxicants	Iron and manganese	- Release water from surface spillways to mix and dilute

134. Environmental management plans for the construction period should be developed that identify the construction water quality control practices to be implemented to reduce sediment and contaminated water runoff, and the control practices for spillages of chemicals such as fuels, lubricants, and additives.

135. Management of water quality within the impoundment is important. Water in the impoundment will provide a potential resource for local people who may relocate to gain

better access. People settling near the reservoir constitute a potential risk to the water quality and are also at risk if the water quality deteriorates. Particular risk factors are pathogens in the water and possible parasites arising because of below-standard sanitation in riparian communities and lack of alternative clean water sources. Below-standard water quality within the reservoir also constitutes a risk to the river downstream.

136. Identification and management of stratification should be a high priority. If recognized as a high risk, multi-level offtakes or other infrastructure should be considered, and appropriate operating rules applied, so that water released is at an appropriate temperature and chemical composition. If there are uncertainties about the formation of stratification and its consequent effects, then the design of the project should enable later retrofit of destratification mitigation approaches.

137. If stratification occurs and is a source of harm, and if multilevel offtakes are unavailable or cannot be deployed to address the issues, then destratification technologies should be considered to ensure suitable downstream water quality, as follows:

- It is not usually necessary to destratify the entire impoundment, only the water adjacent to the outflow sites to ensure that the outflowing water is oxygenated, has circumneutral pH, and is not enriched with reduced metals.
- There are a number of different destratification technologies that may be suitable, including pneumatic and hydraulic diffusers that can be installed on the bottom of the impoundment, propellers that can be installed within the water column, and impellers and hydraulic jets that may be installed on the impoundment surface.
- In the case of hydropower impoundments, pneumatic bubble plume systems are often favoured because the complex equipment, the air compressor, is operated from the surface and thus easy to service, the system is easily installed and relatively cheap, and power for operation is normally available onsite. The technique is only effective for dams where the water depth is greater than 5 m, and surface aeration techniques would be most suitable for shallower water bodies. There are a number of models that may be used in order to select the most appropriate destratification technique for any particular impoundment.

138. Rapid flow changes from the impoundment, either resulting from typical or atypical operations, can result in rapid changes in downstream water quality if the quality of the water being suddenly released differs from that usually released. This is especially applicable to water temperature. Rapid changes in water quality may result in deaths or emigration of aquatic biota from the area affected. In the case of the Mekong dams, virtually all the water downstream of the dam as far as the next substantial tributary will be water that has passed through the dam. Mitigation approaches include the following:

- Apply operating rules that limit up- and down-ramping rates as well as water level fluctuations.
- Site projects so that downstream turbulence will allow rapid equilibration of water temperature and dissolved oxygen to ambient conditions.
- Under some scenarios, the use of a downstream water retention pondage may be warranted to allow time for equilibration of the chemical change. Note that the furthest downstream impoundment in a cascade can be operated as a re-regulation pond if required.

139. If gas supersaturation is an identified risk for the project, the most practical and effective mitigation strategy is to design spillways and outflow channels with flow deflectors or “flip lips”, which divert the spilled water to the surface of the tail water rather than allowing it to plunge to the bottom of the stilling basin. Other measures applicable where a surface spillway is absent include:

    - maintaining clean trash racks to minimize turbulence and air entrainment in the intake; and
    - siting of projects such that the discharge is subjected to turbulence to allow de-gassing of the water.

140. Water quality risks associated with sediment flushing (Clause 107) include elevated concentrations of suspended solids, elevated nutrients, and potentially below-standard water quality if the impoundment is stratified, or if sediment pore water quality is of low standard. Water quality considerations and mitigation measures during flushing include:

    - Avoid flushing during base flow periods when natural river suspended solids levels are low and stratification risks are high.
    - Implement maximum sediment concentration limits during flushing and releasing large volumes of surface water during and following sediment flushing to dilute concentrations and transport material downstream.
    - Implement sediment flushing early in the monsoon season so subsequent high flows continue to transport sediment downstream.
    - Consider dredging and land-based disposal if downstream water quality risks outweigh the benefits of sediment release.

4.5 Project monitoring and adaptive management

141. Plans for project monitoring of water quality presented in the PNPCA information should take into account the guidance in Clause 26. The PNPCA information should demonstrate that plans for water quality monitoring information to be collected during construction and operation will inform:

    - developers' needs regarding water quality management; and
    - indicators that may signal a need for adaptive management responses to water quality-related mitigation measures.

142. The monitoring programme described in Section 4.3 should be conducted during the construction and operation stages, and adapted where needed to better inform construction and operation stage information requirements for management. Indicators shown in **Table 4.3** should be included to assess the particular risks and mitigation options applicable from that table.

143. Construction stage water quality risks will be highly relevant to all projects, and the construction stage water quality monitoring should be closely focussed on those risks. Total petroleum hydrocarbons should be included in the parameter list in relation to fuel, oil or chemical spills, and nutrient concentrations and faecal coliforms should be used to indicate sewage or contaminated run-off from the construction site.

144. During the operation stage, water quality monitoring should continue at a monthly frequency at monitoring sites upstream and downstream of the impoundment, and within the impoundment. At sites located within the impoundment, water quality samples should be collected from multiple depths at each monitoring site to identify if stratification is occurring.

145. Water quality sampling programmes downstream to assess dam impact need to be adaptive, and an increase in sampling frequency may be warranted if water quality conditions pose a risk to the ecosystem or local or downstream users. The plans for project water quality monitoring included with the PNPCA information should consider events, thresholds, and potential management responses, so that any necessary design considerations can be incorporated into the project. The following are some examples of events that may warrant increasing monitoring include:

    - stratification of the impoundment resulting in the release of de-oxygenated water to the downstream river;
    - a water quality incident such as a fuel spill that can impact users; and
    - the occurrence of a toxic algal bloom.

146. Results of water quality monitoring should be compared to national standards and also the water quality targets contained within the TGPWQ. Some specific thresholds that are recommended for the projects as indicators of the need for management responses are as follows:

- Temperature of the released water should be no more than 3°C warmer or colder than the river water upstream of the impoundment.
- The concentration of dissolved gasses, such as oxygen, in the tailrace should not exceed 110% of saturation at the appropriate temperature and salinity.
- Results exceed the national and/or TGPWQ in 20% or more of monthly samples collected over a period of two years.

147. Where thresholds are exceeded, plans should show that investigations on the cause of the issue and potential remedial action would be commenced, and identify the decision-making process and pathway for action commencement as per Clause 27. These investigations and actions may require the involvement or be the responsibility of the responsible national agency if the source of the water quality exceedance is not related to hydropower.

148. The following parameters and locations can be added to the monitoring programme if needed:

- iron and manganese monitored downstream in order to assess the risk of downstream release and deposition associated with sediment flushing, and in the case that the reservoir stratifies;
- chlorophyll monitored monthly to provide an indication of algal growth linked to excess nutrient inputs, which may be coming from the construction site or from surrounding land uses. Cyanobacteria (blue-green algae) should also be assessed if chlorophyll concentrations exceed 5 µg/L;
- faecal coliforms collected on a monthly basis, with more frequent monitoring if levels exceed World Health Organization (WHO, 2003) guideline values for recreational waters (95% of enteric bacterial counts < 40). Samples should be collected at the same sites in the impoundment as chlorophyll, with additional samples collected 3–5 m from the water's edge in locations where there are human settlements within 1 km;
- vertical profiles of temperature, conductivity and dissolved oxygen in the impoundment at least monthly to detect any stratification trends. If stratification is a risk for the impoundment, profiles should be collected at approximately equidistant locations along the impoundment length, with one site located close to the dam wall to detect and document the temporal and spatial extent, and strength of, stratification; and
- A measure of light penetration or water transparency at the surface of each impoundment

monitoring location, preferably using a Photosynthetically Active Radiation (PAR) meter or a turbidity meter. Turbidity should be determined on samples collected at depth.

149. If significant water quality concerns persist, consideration should be given to the installation of permanent continuous water quality probes at the inflow to the impoundment and downstream of the dam site. These could record temperature, conductivity, turbidity and dissolved oxygen and provide a continuous record of net water quality changes, whilst management measures could be tested for effectiveness.

5

Aquatic Ecology

5 AQUATIC ECOLOGY

5.1 Objectives

150. The objectives for aquatic ecology are:

- Protect and conserve aquatic habitats as far as practicable during the development and operation of mainstream dams.
- Minimize the impacts of the construction and operation of hydropower dams on the aquatic ecology and ecosystems of the lower Mekong River system.
- Reduce the risks of the proliferation of pests, parasites or diseases within aquatic ecosystems in hydropower impoundments on the Mekong mainstream.
- Sustain aquatic ecosystems reliant on the flow regimes of the river.

5.2 Risks

151. In the context of this Guidance, aquatic ecology encompasses primarily the biota of rivers other than fish, and biological processes such as primary production and nutrient spiralling. Food webs in large rivers such as the Mekong derive most of their energy from algae floating in the water, and a lesser amount from organic material washed in from the terrestrial systems. Invertebrates such as insects, snails, mussels and crustaceans feed on algae and organic material, and invertebrates, in turn, form much of the food for fish and other large consumers including frogs and turtles. Mekong dolphins in turn feed on the fish. If the aquatic ecosystem is damaged, the impacts pass through the food web, altering the numbers and the species of all those organisms.

152. People consume items from every step of the food chain including algae, invertebrates, fish, frogs and turtles. These organisms comprise the OAAs, or Other Aquatic Animals, which are included in fisheries catch data. In fact the name OAA is unfortunate, because the algae consumed by people is also included and is a plant rather than an animal.

153. The Mekong River supports a number of species considered to be of conservation significance, including species such as the Mekong dolphin (Orcaella brevirostris), the Asian giant softshell turtle (Pelochelys cantorii) and the Asiatic softshell turtle (Amydia cartilaginea) which are listed by International Union for Conservation of Nature (IUCN) as critically endangered, endangered and vulnerable respectively. All the IUCN listed species have seen population declines arising from a number of factors including habitat degradation and loss, harvesting and a reduction in food availability. Existing impoundments have

been one contributing factor, and construction of additional impoundments will add to the pressure on these species by obstructing movements, reducing key habitats and reducing the availability of foods such as invertebrates and fish. Because rivers are linear connected systems it is not possible to designate effective protected areas for riverine species unless the protected area encompasses an entire catchment or sub-catchment.

154. Potential risks to aquatic ecology should be comprehensively assessed. Table 5.1 provides a summary of potential risks that can arise to aquatic species and habitats with the development and operation of mainstream dams. The degree to which any of these may be experienced depends on project configuration and operations. These risks should be evaluated to see which may be relevant to any individual project.

Table 5.1. Potential aquatic ecology risks associated with mainstream dams

Risk	Consequences/comments
Within the impoundment	
Loss of lotic habitat	Aquatic species and the related eco-systems, that are reliant on flowing water, are degraded.
Occurrence of toxic algal blooms	This may occur if nutrient levels, and especially phosphorus levels, become too high
Infestations of invasive plants	Water hyacinth, Salvinia, and water cabbage all occur in the basin and all have caused major problems in impoundments elsewhere.
Infestations of invasive animals	Golden apple snail and several fish species occur in the basin and have caused problems elsewhere in southeast Asia.
Loss of sand bars	Sand bars in the river are important as breeding habitat for a number of turtle and bird species.
Increases in parasite load of local human populations	Malaria and schistosomiasis are not expected to become problems, but fascioliasis (liver fluke, lung worm and heart worm) incidence is likely to increase if people consume raw fish.
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..
Downstream of the impoundment	
Barrier to movement of nutrients	Ecosystem food chains are impacted by water downstream that is low in nutrients.

Risk	Consequences/comments
Barrier to movement of carbon	Ecosystem food chains are impacted by water downstream having reduced fine particulate carbon.
Barrier to movement of biota	Migratory turtles, dolphins, crustacea, molluscs and some insects may be unable to colonise upstream reaches.
Benthic community degraded as least as far as the 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.
Altered river water temperature downstream of dam	This may exceed thermal tolerances of biota and may cause oxygen levels to be reduced below the tolerances, both of which will cause biota to die or drift away.
Below-standard water quality downstream of dam	This may cause death or drift of biota and deposition of iron or manganese may render habitat unsuitable to biota for many years.
Changes to downstream channel morphology	Channel elements provide habitat on which the biota depend. Changes in the extent of fine sediments, sand bars, cobble bars, and bedrock will alter the mix of organisms able to live in a stretch of river.
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.
Increased dry season flow	This may reduce the reproductive success of biota that breed in the dry season and decrease the availability of riparian habitat.
Decreased wet season flow	This will decrease floodplain contributions (carbon, energy and nutrients) to the river, which in turn will impact biota.
Delay to flood season flows	This may interfere with the reproduction of species that breed during the flood season.
Delay to dry season flows	This may interfere with the reproduction of species that breed during the dry season.
Downstream geomorphology (habitat) altered as a consequence of changed flow regime	The altered habitat, i.e. changes in the proportion of sand, gravel, cobbles or boulders, will alter the biota present.

Risk	Consequences/comments
Changes to floodplains	
Reduction in area of riparian and floodplain inundation (including mangroves)	This will reduce the production and reproduction of plants, invertebrates, and fish in the areas affected.
Reduction in period of riparian and floodplain inundation	This will reduce the production and reproduction of plants, invertebrates, and fish in affected areas.
Change in timing of floodplain and riparian inundation	This may lead to reduced reproduction of plants, invertebrates, and fish in affected areas.
Reduction in nutrient load to the floodplain	This will reduce productivity in both floodplain wetlands and seasonal terrestrial systems.

155. In addition to risks from the project development and operations on the existing aquatic ecology of the Mekong River, some aquatic ecology-related risks may arise during the operations stage for which the owner/operator of a mainstream dam may need to develop or contribute to management measures. These risks may influence considerations relating to project design or planning for operations, hence should be included in a risk assessment:

- Blooms of cyanobacteria (blue-green algae) may occur within the future impoundment if nutrient levels are high and turbidity low. Many cyanobacteria can produce toxins which can affect fish, invertebrates and stock or humans that drink the water.
- Three aquatic plants – *Eichornia crassipes* (water hyacinth), *Salvinia molesta* (water fern) and *Pistia stratiotes* (water cabbage or water lettuce) – are known pest species that can affect impoundments. Although these are not native to the Mekong basin, are all known to occur occasionally in dense growths on Mekong basin water bodies. All three have caused problems in tropical impoundments in other regions, such as Africa and Australia.
- Increases in parasite loads to human populations may occur in relation to changes in consumption patterns of fish and other aquatic animals (OAAs).

5.3 Pre-project monitoring and analyses

Guidance on monitoring

156. The monitoring approach for aquatic ecology should be shown in the PNPCA information

to be sufficient to inform design, to support modelling for impact prediction, and to help with later impact evaluation. Clause 23 provides basic principles to guide design of the overall monitoring network. The following clauses can be used as a guide, and varied to suit project-specific conditions.

157. An overall design for data collection for evaluation of aquatic ecology risks and potential impacts should be established and described in the PNPCA information. Because aquatic ecology is an important indicator of river health, which may be a factor influencing trends for fish and livelihoods, it is important to understand changes that are occurring due to the project or other influences. The monitoring design should be set up for the pre-project sampling so that post-development monitoring can make valid comparisons against pre-project conditions, as well as adequately inform risk identification and mitigation planning. To have robust comparisons, sufficient pre-project data would need to be collected so that statistically significant comparisons post-project can be made (see Section 5.5).

158. Monitoring locations for aquatic ecology should be established within the future impoundment, as well as both upstream and downstream. A good design for pre-project riverine sampling locations may include:

    - two monitoring sites upstream of the future impoundment;
    - one monitoring site within the future impoundment;
    - an array of at least three monitoring sites downstream of the future dam, extending over a distance of at least 10 km. The location of sites should seek to coincide with the general monitoring locations for other disciplines where possible; and
    - a site upstream and a site downstream of the confluence with the first tributary contributing >2% of average annual flow downstream of the dam.

159. The MRC bioassessment protocols and indices (e.g. see MRC, 2010, 2009b) should be used for biological assessments in the river upstream and downstream of impoundments. These have been developed specifically for the Mekong system based on several years of sampling and investigation, they are thoroughly documented, and they are known to be effective. The bioassessment protocols and indices with equivalent function may be proposed

160. The assessment should include the existing MRC indicators plus some additions as shown in Table 5.2. Phytoplankton could best be monitored using a fluorometric field instrument, some of which also allow algal groups (such as cyanobacteria) to be monitored. Appropriate quality assurance procedures should be put in place, particularly for the invertebrate identifications.

Table 5.2. Proposed aquatic ecology indicators to be monitored pre-project

Littoral invertebrates
Benthic invertebrates
Zooplankton
Littoral diatoms
Phytoplankton chlorophyll
Algal groups (such as cyanobacteria)

161. The duration of aquatic ecology data collection should cover two years in order to establish a baseline for later comparison. Two years is important for aquatic ecology data because only one season is able to be sampled each year (see Clause 162) and to provide insight into inter-annual variability, which is substantial in the Mekong.

162. Biological sampling should be conducted twice during the low flow period, because of the following constraints in sampling feasibility under high flow conditions:

    - In the Mekong, there is a very large variation in discharge between wet and dry seasons, which in turn is reflected in the change in water level. For example, the water level at Vientiane is almost 10 m higher in the wet season than the dry season.
    - In the wet season, sampling from a boat would be quite dangerous because of the large logs and trees being carried downstream. The speed of the current makes it impossible to lower a grab to the river bed to obtain a sample.
    - For edge sampling, the large rise in water level amounts to a change of about 35 cm per day; i.e. invertebrates in the habitat in the 1-m depth of water at the edge of the river will only have had up to three days to colonize as water level rises, so samples are more likely to reflect colonizing ability than responses to habitat and water quality.
    - sampling in the low flow season only is possible in the Mekong where temperature changes between seasons are not significant. This contrasts with temperate regions where biological monitoring of rivers is normally conducted in multiple seasons. This is partly because in temperate regions, the life cycles of many of the organisms are seasonally adapted to the changing temperatures.

163. Comparisons from the pre-project monitoring results should be made with existing data and index calculations from across the basin. This should include comparisons with the MRC bioassessment data from the closest MRC monitoring sites to the project.

Impact prediction

164. Pre-project data should be analysed to look at species composition and habitat preferences, so that projections can be made as to the types of impacts to expect based on the modelled results for changes to hydrology and hydraulics (see Section 2).

165. Impact predictions regarding flows, water quality and sediments should be used to inform assessments of the degree of risk to aquatic habitats, species and ecological processes, and to identify any particularly vulnerable areas. The degree of hydrological change to downstream flows should be used to inform evaluations of the degree of any risks to seasonal flow regimes and to floodplains (see further in Clause 169 on application of a suitable model).

166. Important habitat areas should be identified based on the pre-project surveys, so that the assessments can evaluate if there are any mitigation measures that could help minimize impacts.

167. The location of the future impoundment in relation to deep pools in the Mekong River should be checked on the maps produced by the MRC.

168. The analyses of changes, impacts and mitigation options for aquatic ecology should clearly identify the residual impacts and document where these will occur in the river, in line with Clauses 7 and 25.

169. Suitable basin scale models should be used to predict impacts and assess mitigation options. The developer may apply the Downstream Response to Imposed Flow Transformations (DRIFT), the ecological systems analysis tool used in the MRC Council Study model for the lower Mekong mainstream, as was used in the MRC Council Study (MRC, 2018b) to evaluate cumulative impacts and inform development of Cascade Joint Operating Rules. An equivalent analytical approach and function may be proposed, as follows:

    - The analytical approach should link flows with geomorphology, water quality, aquatic ecology and fisheries, *inter alia*, for the eight different zones along the river, corresponding to geomorphological zones.

    - The analysis should test a range of possible operating rules and allow an assessment of which operating procedures will cause the least impact on the river.

    - The analytical approach output should be used to inform decision-makers about the trade-offs of different dam configurations and operating regimes against the environmental values considered, and should guide development of Cascade Joint Operating Rules.

5.4 Design and operational guidance

170. Mitigation options should be evaluated to determine which ones will best address identified risks. Table 5.3 identifies mitigation options that should be considered to address risks relevant to the project These are in addition to the mitigation options identified in the sections on hydrology and hydraulics (Section 2), sediment transport and geomorphology (Section 3), and water quality (Section 4). The mitigation approaches for these other disciplines in many cases will also benefit the aquatic ecology objectives. Not all of these mitigation measures would be expected to be delivered by the developer; some, such as catchment protection, would need to be undertaken by National or Provincial Agencies, and others may require a cooperative approach between the project and other institutions.

Table 5.3. Mitigation options for aquatic ecology risks for mainstream dams

Risk	Mitigation options
Occurrence of toxic algal blooms in the impoundment	Ensure that local sources of nutrients, especially phosphorus, are controlled. Encourage control of upstream nutrient sources, destratification may also help control algal blooms
Infestations of invasive plant and animal species in the impoundment	Monitor occurrence of macrophytes and potential pest species within the impoundment to ensure early detection. Physical removal, biological control or chemical control are the preferred mitigation strategies in order of preference.
Increases in public health risks related to the impoundment	Monitor impoundment for microbial indicators (e.g. faecal coliforms). Ensure a good liaison with local health authorities so that the owner/operator will know if public health issues are arising that are caused or exacerbated by the impoundment.
Loss of deep hole habitats	Avoid locating impoundments on stretches of river containing deep holes.
Barrier to movement of nutrients, carbon and biota	Construct an impoundment bypass if possible.
Benthic community degradation	Seek to locate impoundments immediately upstream of substantial tributaries and to reduce the length of river impacted.
Increased dry season flow, decreased wet season flow, and/or delay in timing of seasonal flows	Apply Cascade Joint Operating Rules and Project-Specific Operating Rules, governing impoundment and discharge management by the project

Reduction in area and/or timing of floodplain inundation, and nutrient loads affecting to habitats and lifecycle of other aquatic animals (OAAs).	Apply Cascade Joint Operating Rules and Project-Specific Operating Rules, governing impoundment and discharge management by the project. In suitable locations, floodplain waterbodies may be managed by providing pumped water or construction of floodways to increase wet season inundation, or bunds to allow retention of water for longer periods at the end of the flood season.

171. Even if operations are very well-coordinated to manage downstream flows and floodplain inundation, a cascade of mainstream dams will cause a larger cumulative impact to the aquatic ecology of the downstream river than the sum of the individual impacts of a number of dams, because a much larger proportion of the fluvial habitat will be lost.

172. Project-Specific Operating Rules should be developed in line with the Cascade Joint Operating Rules, to address more local area aquatic ecological objectives and ensure operations take into consideration important focal areas for mitigation measures.

5.5 Project monitoring and adaptive management

173. Plans for project monitoring of aquatic ecology should take into account the guidance in Clause 26. The PNPCA information should demonstrate that plans for aquatic ecology monitoring information to be collected during construction and operation will inform indicators that may signal a need for adaptive management responses to aquatic ecology related mitigation measures.

174. The monitoring programme described in Section 5.3 should be continued during the construction and operation stages, and adapted where needed to better inform construction and operation stage information requirements for management.

175. For comparisons of aquatic ecology in the project area of influence with the pre-project conditions, the following considerations apply:

    - Sufficient post-project sampling should be undertaken to enable statistical detection of changes compared to pre-project.
    - The presence and size of impact on the aquatic ecosystems by the project should be assessed by comparing index values both from pre- and post-construction, and also from upstream and downstream sites.
    - The species list data from sampling should provide a series of multivariate data sets that can be compared using Multivariate Analysis of Variance (MANOVA) and testing for the statistical significance of differences in ordination space.

- Examination of the data to assess whether any particular species groups have markedly altered in presence or abundance may be a valuable way to determine which operational factors may have been mainly responsible for the changes found.

176. Monitoring within the impoundment during construction and operation may be coordinated with water quality sampling locations, and should include additional parameters listed below.

    - Chlorophyll - as outlined in Section 4.5, with results should be interpreted by aquatic ecologists
    - Faecal coliforms - as outlined in Section 4.5.
    - Macrophyte growth - In impoundments and on impoundment banks should be checked at least annually and monitored more frequently should they become abundant, and
    - Presence of pest animal species - Checks should be conducted at least annually, as for macrophytes.

177. Monitoring plans submitted with the PNPCA information should show that both riverine and impoundment monitoring results will be reviewed annually, and should identify the decision-making process that will be used to identify and implement management actions to be taken if risks or impacts are evident from the monitoring results, as per Clause 27.

6

Fish and Fisheries

6 FISH AND FISHERIES

6.1 Objectives

178. The objectives for fish and fisheries are:

    - Maintain fisheries and other aquatic animal (OAA) yields and fish diversity sufficient to sustain the food, livelihoods and ecological integrity of the LMB.
    - Minimize the impact of dam construction and operation on upstream migration of fish species through design of appropriate fish passage facilities, where necessary.
    - Minimize the impact of dam construction and operation on downstream movement of fish species through design of appropriate operational regimes, fish passage facilities, fish guidance systems, and appropriate turbine designs.
    - Minimize fish and fisheries impacts arising from changes in the flow regime downstream of the dam, in the impoundment, and upstream.
    - Mitigate impacts of individual and multiple mainstream dams on local and transboundary fish and fisheries, and OAAs.

179. There are no MRC procedures that relate directly to fisheries or aquatic biodiversity and management. The importance of fisheries and aquatic ecology is recognized by the Member Countries cooperating through the Fisheries Abundance and Diversity Monitoring Programme, and the topics of fisheries and aquatic biodiversity being included as themes within the MRC Initiative for Sustainable Hydropower Studies (MRC, 2014) and in other published MRC studies.

6.2 Risks

180. The Mekong supports the world's largest inland fishery, and mainstream dam developments pose direct and indirect risks in addition to those already being experienced through tributary dam developments.

181. Significant impacts from mainstream dam developments on fish populations are highly likely, including the loss of some species (locally, regionally, or basin-wide). Major declines in the fisheries could flow on from this, with potential consequences for food security, nutrition, livelihoods, biodiversity, and ecosystem resilience.

182. In large species-rich systems such as the Mekong, it is difficult to assess the impact of any major development at the species level, thus the fish species should be classified into

categories or guilds that have similar habitat needs and migratory behaviours (Welcomme et al, 2006) (Table 6.1). An additional group – non-native species – should be reported because it is expected that it will benefit from any degradation of habitat and replace lost species, possibly to the detriment of wild fisheries. Those guilds that are likely to experience high to very high impacts from mainstream dams (Guilds 2, 3, 8, and 9) are shaded in Table 6.1. Box 6.1 provides the indicator groups and/or species associated with each guild.

Table 6.1. Mekong fish guilds and migration

Migratory Guild and number	Typical characteristics	Relative impact of mainstream dams on migration	Relative effect of change in flow regime on fish production
1 - Rhithron resident guild	- Resident in rapids torrents, rocky areas and pools in the rhithron.	Little or no impact from mainstream dams (but note, potentially high in upland storage dams)	Little or no impact from mainstream dams. However, there may be high impact within upland storage dams due to possible exposure of riffle areas and inundation of habitats upstream.
2 - Migratory main channel (and tributaries) resident guild	- Long-distance migrants spawning in the main channel (sometimes in upper zone of the Mekong (**Figure 6.1**) upstream of adult feeding habitat in the main channel. - May migrate to refuges (deep pools) in the main channel during the dry season. - Pelagophilic members have drifting pelagic egg or larval stages returning to adult habitat using backwaters and slacks as nurseries. - Adults do not enter floodplain and may be piscivorous.	Very high	High: flow variation may affect the passability at Khone falls and other natural barriers and delayed flooding disrupt migratory cues

Migratory Guild and number	Typical characteristics	Relative impact of mainstream dams on migration	Relative effect of change in flow regime on fish production
3 - Migratory main channel spawner guild	- Spawn in the main channel, tributaries, or margins upstream of floodplain feeding and nursery habitat often with pelagic egg or larval stages. - Adults and drifting larvae return to floodplains to feed. - May migrate to refuges (deep pools) in the main channel during the dry season.	Very high	Very high: loss of connectivity and flooding of spawning and nursery habitat
4 - Migratory main channel refuge seeker guild	- Migrates from floodplain feeding and spawning habitat to refuges (deep pools) in the main channel during the dry season. - Spawning occurs on the floodplain and main channel used as refuge during dry season.	Medium	High: loss of connectivity and flooding of spawning and nursery habitat
5 - Generalist guild	- Limited non-critical migrations in mainstream. - Highly adaptable, mobile, and static elements in their genome rendering them highly adaptable to habitat modification.	Little or no impact	Medium: loss of connectivity and reduced flooding of floodplain
6 - Floodplain resident guild (Blackfish)	- Limited migrations between floodplains pools, river margins, swamps, and inundated floodplains. - Tolerant to low oxygen concentrations or complete anoxia.	Little or no impact	Medium: loss of connectivity and reduced flooding of floodplain

Migratory Guild and number	Typical characteristics	Relative impact of mainstream dams on migration	Relative effect of change in flow regime on fish production
7 - Estuarine resident guild	- Limited migrations within the estuary in response to daily and seasonal variations in salinity.	Little impact (if dam is upstream of estuary and does not influence salinity dynamics in estuary).	Little or no impact
8 - Anadromous guild	- Enters fresh/brackish waters to breed. - Enters freshwaters as larvae/ juveniles to use the area as a nursery, either obligate or opportunistic.	High (for dams located in river mouths or lower potamon).	Little or no impact
9 - Catadromous guild	- Reproduction, early feeding, and growth at sea. - Juvenile or sub-adult migration to freshwater habitat, often penetrating far upstream.	Very high	Very high: loss of connectivity to feeding and nursery habitat
10 - Marine visitor guild	- Enters estuaries opportunistically.	Little or no impact	Little or no impact

Box 6.1. Indicator groups and/or species for Mekong fish guilds

Guild 1 - Rhithron resident guild: Notopteridae: Chitala blanci (main channel with rocky only); **Cyprinidae**: *Gara spp., Brachydanio spp., Devario spp., Poropuntius spp., Tor spp., Neolissocheilus spp., Osteochilus waandersii, Raiamas guttatus, Opsarius spp., Lobocheiros spp., Onychostoma spp.*(Lao PDR), *Scaphidonuchthys acanthopterus* (Lao PDR), *Mekongina erythrospila* (Stuntreng-3S, Lao PDR), *Mystacoleucus spp.*; **Balitoridae**: all species (e.g. *Homaloptera spp., Balitora spp.*); **Nemacheilidae**: all species (eg. *Nemacheilus spp., Schistura spp.*); **Akysidae**: all species (e.g. *Akysis spp., Pseudobagarius spp.*); **Sisoridae**: *Gryptothorax spp., Bagarius spp.* (main channel); **Datnioididae**: *Datnioides undecimradiatus* (main channel only); **Channidae**: *Channa gachua*, **Osphronemidae**: *Osphronemus exodon*; **Gobiidae**: *Rhinogobius mekongianus* (above Stuntreng); **Tetraodontidae**: *Pao baileyi* (main channel only), *P. turgidus*.

Guild 2 - Migratory main channel (and tributaries) resident guild: Cyprinidae: *Cirrhinus microlepis, Cyclocheilos enoplos, Cosmochirus harmandi, Probarbus jullieni*; **Pangasiidae**: *Pangasianodon hypophthalmus* (all places), *Pangasius larnardii* (all places), *P. mekongensis, P. bocourti* (except TS system), *P. concophilus* (except the TS system).

Guild 3 - Migratory main channel spawner guild: Clupeidae: *Clupeichthys aesarnensis* (all places), *Clupeoides borneensis* (all places), *Corica laciniata* (DT-PP-TS); **Cyprinidae**: *Cirrhinus prosemion, C. jullieni, Hypsibarbus spp., Puntioplites falcifer* (above Kratie), *P. proctozysron* (below Kratie tol DT), *Labeo chrysophekadion, L. pierrei, Sikukia spp., Incisilabeo behri, Scaphognathops spp.* (above Kratie), *Barbichthys laevis, Leptobarbus rubripinna, Amblyrhynchichthys micracanthus,* **Botiidae**: all species (*Syncrossus spp., Yasuhikotakia spp.*); **Pangasiidae**: *Pangasius macronema, Pseudolais pleurotaenia, Helicophagus leptorhynchus*, **Siluridae**: *Walago attu, Phalacronotus spp., Kryptopterus spp.; Bagridae: Hemibagrus spp.*; **Cobitidae**: *Acantopsis spp., Acanthopsoides spp.* (prefers sandy bottom); **Gyrinocheilidae**: all species; **Tetraodontidae**: *Auriglobus nefastus*.

Guild 4 - Migratory main channel refuge seeker guild: **Cyprinidae**: *Barbonymus altus, B. schwanefeldii , Cyclocheilichthys spp., Rasbora spp., Paralaubuca spp., Parachela spp., Thynnichthys thynnoides;* **Cobitidae**: *Pangio spp.*; **Siluridae**: *Ompok siluroides*; **Bagridae**: *Mystus spp.*; **Pristolepididae**: *Pristolepis fasciata*; **Ambassidae**: *Parambassis wolfii, P. apogonoides*; **Sciaenidae**: Boesemania microlepis (d/s Stuntreng common, (above Khone Falls very rare now); **Tetraodontidae**: *Pao cambodgiensis, P. suvattii* (above Khone Falls only)

Guild 5 - Generalist guild: **Notopteridae**: *Notopterus notopterus, Chitala ornata*; **Cyprinidae**: *Gymnostomus (Henichorynchus) spp., Barbonymus gonionotus, Systomus orphoides, Crossocheirus spp. Osteochirus vittatus, O. microcephalus, Hampala spp., Labiobarbus spp., Cyclocheilichthys spp.*; **Syngnathidae**: *Doryichthys boaja* (below Kratie to DT-TS), *D. deokhatoides* (below Kratie to DT-TS), *D. contiguus* (confirmed between Vientiane-Ubonratchathani, does not exist below Khone Falls), **Mastacembelidae**: *Mastacembelus spp.* (e.g. *M. favus, M. armatus*); **Ambassidae**: *Parambassis siamensis*; **Eleotridae**: *Oxyeleotris marmorata*.

Guild 6 - Floodplain resident guild (Blackfish): **Cyprinidae**: *Esomus spp.*; **Cobitidae**: *Lepidocephalichthys hasselti*; **Clariidae**: all species (e.g. *C. macrocephalus, C. cf batrachus*); **Adrianichtyidae**: *Oryzias siamensis, O. minutillus*; **Hemiramphidae**: *Dermogenys siamensis*, **Channidae**: *Channa striata, C. lucius*; **Anabantidae**: *Anabas testudineus*; **Osphronemidae**: *Trichopodus spp., Trichopsis spp*; **Synbranchidae**: *Monopterus albus*; **Mastacembelidae**: *Macrognathus spp*.; **Tetraodontidae**: *Pao cochinchinensis*.

Guild 7 - Estuarine resident guild: **Plotocidae**: *Plotosus canius* (DT); **Ariidae:** all species (DT); **Adrianichthidae**: *Oryzias haugiangensis* (DT); **Gobiidae**: *Glossogobius spp.* (DT-TS-PP); **Polynemidae**: *Polynemus spp.* (DT-TS-PP); **Cynoglossidae**: all species (DT-PP-TS); **Soleidae**: *Brachirus spp.* except *B. harmandi* and *B. siamensis*

Guild 8 - Anadromous guild: **Pangasiidae**: *Pangasius krempfi, P. elongates* (mainstream only); **Ariidae**: all species (DT-PP).

Guild 9 - Catadromous guild: **Angullidae**: *Anguilla marmorata, A. bicolor* (all nodes); **Ophichthidae**: *Pisodonophis boro* (DT-PP-TS).

Guild 10 - Marine visitor guild: **Scombridae**: *Scomberomorus sinensis* (DT-PP), **Gerreidae**: all species (DT); **Ambassiidae**: all species except *Parambassis spp.* (DT); **Terapontidae**: *Terapon jarbua*; **Sciaenidae**: all species except *Boesemania*; **Gobiidae**: *Pseudapocryptes elongatus, Periophthalmodon schlosseri*

Non-native: **Cyprinidae**: *Labeo rohita, Cyprinus carpio, Cirrhinus cirrosus, Cyprinus rubrifuscus*; **Serrasalmidae**: *Piaractus brachypomus*; **Clariidae**: *Clarias gariepinus*, **Loricariidae**: *Pterygoplichthys spp*.; **Cichlidae**: *Oreochromis spp.*

Note: DT = Delta; PP = Phnom Penh; TS = Tonle Sap.

183. Potential risks to fish and fisheries, including OAAs, should be comprehensively assessed. Risks to fish and fisheries associated with hydropower development are summarized in Table 6.2 (see Table 5.2 for risks to OAAs) and are orientated around four major themes:

- Dams are physical barriers across rivers that interrupt fish migrations both upstream and downstream.
- Dams can change the river hydraulics from a flowing river (lotic) to a still water (lentic) habitat in the impoundment, which inundates spawning grounds (flowing water conditions required by many species of Guilds 1, 2, 3, 4, and 8 for egg and larval development), disrupts larval drift, can eliminate lotic-dependent native fishes (Guilds 1, 2, 3, 4, and 8), and creates a habitat that suits non-native species.
- Dams alter flow regimes (hydrology) in the downstream river, from run-of-river dams (inflows = outflows) with lesser impact, to storage dams with high impacts by altering the seasonal timing and volume of flows. In practice, most dams have some capacity to operate in run-of-river or storage mode, although most mainstream dams will have very limited storage capacity. Altering flows impacts the capacity of fish to migrate; can leave fish stranded and eggs exposed to die as a result of daily/hourly hydropeaking; disrupts the flooding patterns of rivers; and compromises access of floodplain-spawning species by interrupting lateral connections between the river and floodplains (Guilds 3, 4, and 6).
- If the dam is associated with development of floodplains for other purposes, such as an irrigation scheme, or if the floodplain is permanently inundated by the impoundment, floodplains can completely lose their function in the ecosystem, especially as feeding, spawning, and nursery areas (affecting Guilds 4, 5, and 6).

Table 6.2. Potential risks to fish and fisheries associated with mainstream dams

Risk	Consequences/comments
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, and 8), 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.

Risk	Consequences/comments
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 that 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, and 8), usually because they are isolated from their nursery and feeding areas.
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 turbine intakes and then through the turbines themselves.	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. Adults passing downstream actively seek flowing water and are drawn to turbine intakes or spillways.
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 hydraulic stress, turbulence, and strikes by the turbine blades. Eggs, larvae, and juvenile fish are particularly susceptible to injury and death in turbines. Turbines labelled as 'fish-friendly' may still have a significant impact on individual fish, resulting in high injury or mortality rates, often up to several days after passing through the turbine.

Risk	Consequences/comments
Mortality and injury in spillways.	Fish moving over a 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 (see Section 4.2). Turbulent flow in the spillway basin can disorientate fish, slowing their downstream movement, and exposing them to predatory fish and birds.
Impoundment impacts on fish and fisheries	
The impoundment inundates deep pools and changes the hydrodynamics from a complex flowing water habitat to a uniform slower flowing habitat.	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.
Impoundment may drown out spawning and nursery habitats of migratory species.	Riverine species generally decline in abundance because of the inability to fulfil their life cycle, and are then replaced by species that are tolerant and able to exploit static water conditions (Guild 5 and non-native species).
Impoundment may drown out habitat riverine species typically found in rapids and glides, i.e. rhithron species (Guild 1).	Rhithron species (Guild 1) are lost from communities, resulting in a loss of biodiversity, and are replaced by species that are tolerant and able to exploit static water conditions (Guild 6 and non-native species).
Reduced flows in the impoundment compromise drifting life stages of fishes.	The impoundment becomes a sink for downstream drifting eggs and larvae that tend to be lost from the system, resulting in a decline in fisheries of valuable migratory species (Guilds 2, 3, 4, and 8).

Risk	Consequences/comments
Water level fluctuations in the impoundment impinge on the capacity for certain fish species and OAAs 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.
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 the 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 or flow pulses) are lost, and passage of fish are disrupted over rapids, falls, and other natural, partial obstructions, for example, Khone Falls. Grey fishes (Guild 4) 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.
Alteration in the nature, timing, and dispersal patterns of sediment delivery in river systems.	The impoundment may reduce the volume of sediments and associated nutrients passing downstream, and the productivity of the system declines, especially in the floodplain and delta areas, and in coastal regions (see Section 3)
Alteration of the thermal regime downstream of impoundments.	If the impoundment stratifies (see Section 4), a reduction in water temperature occurs due to the release of 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.
Water quality downstream adversely affected by dam infrastructure and operation.	Changes in discharge and water quality can affect all fishes within the riverine section below dams (see Section 4).

Risk	Consequences/comments
Transboundary impacts	
Disruption of the hydrological regime and sediment delivery, and a concomitant impact on fisheries may be transmitted considerable distances downstream.	The impact of dams in terms of loss of productivity may be manifest considerable distances from the dam location. This can have a considerable impact on rural communities dependent on fisheries for food security and livelihoods (see Section 9).
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.

184. The different ecological guilds of Mekong fishes (**Table 6.1**) exhibit different levels of vulnerability to the effects of dams. The most vulnerable guilds are Guilds 2, 3, 4, 8, and 9, shaded in **Table 6.1**.

- The species that are most affected by the barrier effects of dams are short- and long-distance migrators (Guilds 2, 3, and 8).
- The species that are the most vulnerable to change in flooding patterns are: (i) floodplain spawning species (Guild 4) that move laterally onto floodplains to spawn and use the nutrient-rich floodplain habitat as a nursery area; and (ii) juvenile life stages of short- and long-distance migrators (Guilds 2 and 3), whose larvae drift onto the floodplain and also use this habitat as a nursery area.
- Species with drifting larval stages are mainly the riverine fish of Guilds 2, 3, 4, and 8. These require a minimum length of flowing water for drift that varies among species and is presently unknown for Mekong species. However, it is likely that at least 10 km is required for some short-distance migrants; more than 200 km for medium-distance migrants (Guilds 3 and 4); and over 1,000 km for long-distance migrants (Guilds 2 and 8). Drifting larvae need suitable nursery habitat to occupy and grow-on in the downstream course of their migration.
- Species that are only found in steep upland tributaries (Guild 1: rhithron species) will be unaffected by mainstream dams, but can be at risk from upland storage dams in tributaries, where there is inundation of habitats upstream and modification of flows downstream. These species are often endemic (only found in that location or river) to the region, have high biodiversity value as well as providing an important local food source. Fishes that only use floodplains (Guild 5: black fishes) are unlikely to be

impacted unless floodplains are permanently inundated or disconnected and/or used for agriculture or urban development.

185. Many Mekong species exhibit complex life cycles that involve migration between different areas of the river (see **Figure 6.1**), particularly upstream migration to spawning areas, and downstream to nursery and feeding habitats. The timing of these upstream and downstream migrations is variable depending on fish life cycles. Spawning of different species in the Mekong system thus occurs across all seasons, but there are peaks during the spring (February–March), which is the most important time, followed by the onset of floods (June–July), and then when the water is receding (November).

186. The general understanding of migration patterns in the Mekong is that there are three main groupings in the upper, middle and lower LMB (**Figure 6.1**) with many commercially valuable species (possibly as many as 30 white fish species [**Box 6.1**: Guilds 2, 3 and 8]) migrating long distances between these zones. There is spawning along the entire Mekong, but the middle and lower zones have significant floodplain nursery areas and spawning areas with major migrations between the two zones (**Figure 6.1**). Although many species migrate along the mainstream, they often spawn in tributaries, so the links between these two habitats are important.

187. The migratory fish resource at risk from dams varies in each of the three major zones of the river (**Box 6.1**). An indication of this variation is the commercial catch, which in the upper Mekong is up to 60,000 tonnes of fish captured per year, while the middle and lower zones are much higher annual catch rates of over 1.0 million tonnes of fish per year in each zone. Because of the high biomass of migratory fish in the middle and lower zones and the movement of fish between spawning and nursery habitats in each of these zones (**Figure 6.1**), there is much greater risk to fish populations when locating mainstream dams in these lower zones.

188. Because of the life cycles described above, a cascade of dams with sequential impoundments will eliminate most riverine fish species that require flowing water (lotic) habitats, even if fish passage is provided.

6.3 Pre-project monitoring and analyses

189. The monitoring approach for fish and fisheries presented in the PNPCA information should be sufficient to establish the baseline, to inform design, and to underpin project impact and mitigation effectiveness evaluations.

190. Key information to be submitted at the PNPCA stage is a fish species list grouped by guild (guided by **Table 6.1** and **Box 6.1**) together with relative abundance, including those species observed and those expected to be present in the river system and conservation status of the species. A baseline needs to be established to identify species, size composition, and

biomass requiring passage. Available MRC and other research data should be sourced for this purpose.

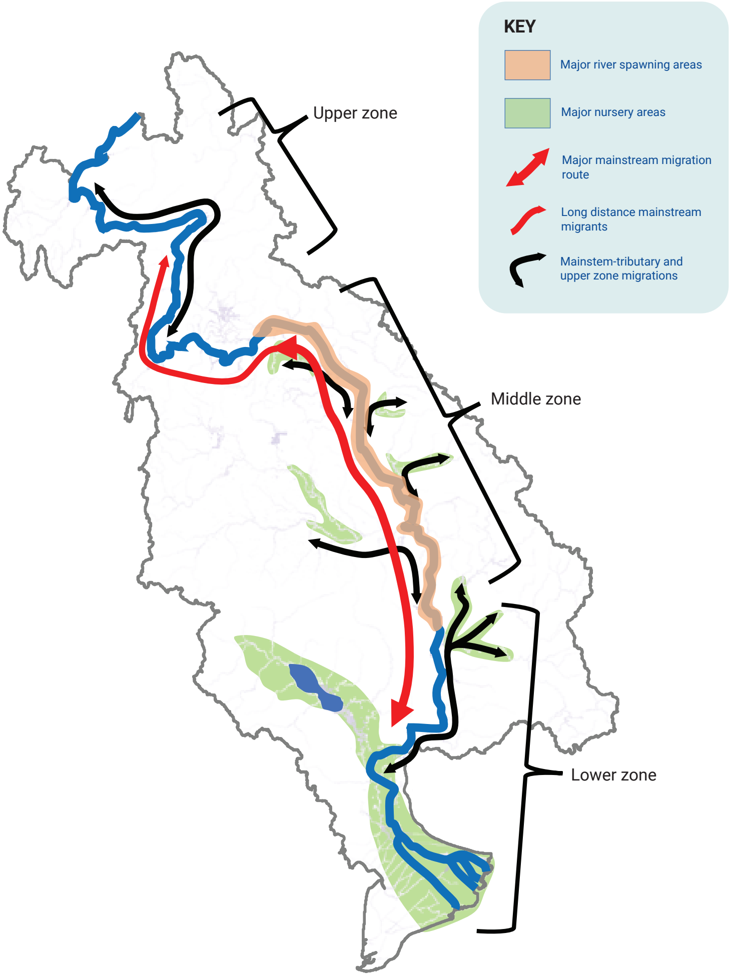


Figure 6.1. Generalized migration systems in the Lower Mekong Basin, modified from Poulsen et al. (2004)

191. The following baseline data should be collated in conjunction with the list of species in Clause 182. Full use should be made of the MRC fisheries data and associated information in this assessment:

- the season of movement upstream and any hydrological triggers of migration (e.g. onset of flooding cycle) for the main species;
- the spatial distribution of spawning, nursery and refuge habitats for each guild within the region (200 km upstream and downstream of the proposed site, including the lower 50 km of tributaries);
- the scale of fish migration in terms of biomass of fish (based on independent studies and fish abundance and diversity monitoring) in relation to the seasonal flows, so these data can inform the design of fish passage facilities;
- the distance (spatial scale) of cyclic migrations of each guild;
- identification of fish species and OAAs that are dependent on flowing water (lotic) habitats for spawning and larvae drift, and the required minimum distance of larval drift to ensure successful recruitment;
- the contribution, species composition, and socio-economic value of fish and OAAs captured upstream and downstream of the dam site over the full flood cycle. These data enable an assessment of socio-economic impacts on local and regional livelihoods, food security, and economies, as well as informing biodiversity impacts.

192. Standard methods recommended by the MRC should be used, noting that they will be developed and updated over time, so that there will be consistent approaches by developers within the overall monitoring of fisheries in the river.

193. A list of threatened fish species or fish species of high conservation value near the dam and impoundment site, or potentially affected by the project, should be provided. An assessment of the potential impact of the development on the threatened fish species survival and actions to mitigate such impacts should be provided.

194. Drawing on the hydrological and hydraulic assessments[9] described in Section 2.3, the following information should inform selection of suitable fish passage options, develop concept designs, and assess effects on habitats and fish migration:

- daily and seasonal discharge linked with fish migration data to determine risks and inform fishway design;
- modelling results of the spillway and powerhouse operation, including sufficient

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[9] To assess the impact on fish and fish passage design, **adequate** analysis must be carried out and presented at PNPCA to allow MRC assessment of the effectiveness of the mitigation. Further detailed hydrological and hydraulic modelling may be undertaken during in the detailed design phase.

assessment of potential hourly, daily and seasonal discharge, and upstream and downstream water levels; and spatial attenuation (distance affected downstream) of these variations;

- headwater and tailwater rating curves; and
- modelling results of daily and seasonal hydraulics, especially distribution of water velocity, of the impoundment to determine effects on lotic spawning habitats and larval drift.

195. Analyses of changes, impacts and mitigation options for fish, fisheries, and OAAs should identify the residual impacts and document where these will occur in the river, in line with Clauses 7 and 25.

6.4 Design and operational guidance

196. Mitigation options should be evaluated to determine which ones will best address identified risks. Table 6.3 provides a summary of mitigation approaches that can be taken to address the broad categories of risk to fish and fisheries shown in Table 6.2. A holistic set of mitigation measures should be implemented to address the multiple facets of change that affect fish and fisheries. Whilst only fish-related mitigation measures are addressed below, mitigation measures for flows, sediments, water quality and aquatic ecology in this Guidance are also important influences on outcomes for fish. The clauses following this table provide more specific guidance.

197. Given the lack of direct and experimental data on Mekong fishway efficacy, and the high consequence of risks to fish and fisheries, developers should engage the services of independent and knowledgeable fish passage experts with specific relevant regional and global experience early in the design process. Developers are encouraged to utilize available MRCS data, resources, and expertise at an early stage in line with Clause 16.

Table 6.3. Mitigation options for fish and fisheries for mainstream dams

Risk	Mitigation options
Direct barrier effects on fish and fisheries	▪ Upstream and downstream fish passage facilities ▪ Catch-and-release programmes (unsuitable for a river and fisheries at a Mekong scale) ▪ Hatcheries and restocking programmes (potentially in combination with other measures); however, note Clause 247.

Risk	Mitigation options
Mortality at hydropower structures	▪ Dedicated design and operational choices for structures such as the turbine and gates ▪ Use of screens and other barrier technologies (e.g. light, acoustic) to direct fish away from areas of high mortality risk.
Impacts in the impoundment on fish and fisheries	▪ Siting and configuration of the impoundment to minimize inundation area and important habitats such as deep holes and spawning grounds ▪ Management of impoundment water levels through Joint Cascade Operating Rules and Project-Specific Operating Rules ▪ Protection of impoundment riparian habitats through local works to protect, enhance, or introduce important habitat areas (e.g. for spawning and nursery grounds, or shelter and feeding areas).
Downstream impacts on fish and fisheries	▪ Management of downstream water levels through Joint Cascade Operating Rules and Project-Specific Operating Rules ▪ Protection of natural river bank habitats through local works ▪ Controls and mitigation relating to potential water quality and sediment impacts.

198. The following guidance for fish and fisheries is divided into two sections: *habitats*, which include planning of dam location and height, and operation; and *fish passage*, which provides for migration of fish upstream and downstream.

Habitats

199. As flowing water (lotic) habitats are key spawning areas and are essential for larval drift, dams should be sited and designed to maximize reaches with continuously flowing water.[10] These flowing-water reaches are:

- preferably maintained within the entire impoundment by maintaining a mean channel velocity of > 0.3 m/s;
- between dams and the impoundment backwater (some species will likely require 10 km reaches, while others will require 200 km); and
- in tributaries.

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[10] It should be noted that the location of all mainstream dams is already determined based on engineering design requirements.

200. Dams should be sited and designed to avoid permanent inundation or disconnection of floodplains, which are key, usually irreplaceable, spawning and nursery habitats. Productive fish populations are dependent on the natural inundation and drying patterns of these habitats.

201. In dam operation, consideration should be given to managing river edge habitats (littoral zone) of rocks and vegetation downstream of the dam, especially during the onset of the wet season when many species will be spawning. Rapid water level rises are acceptable (but see Clause 71), but draw-downs of, for example, greater than 0.5 m per day (to be determined on a site-specific basis) in the spawning season could expose eggs. Migratory fish may congregate below a dam with inadequate or no fish passage, and often spawn in the area downstream of the dam.

202. Fluctuations in water levels in the impoundment can create a barren, unproductive littoral edge zone in the impoundment. Lagoon systems can be created in bay areas of the impoundment by installing small weirs, which buffer these fluctuations and maintain nursery areas in the impoundment during draw-down periods.

203. Fisheries production in impounded water bodies tends to decline 5-7 years after inundation. Traditionally, the inundated area is cleared of vegetation prior to flooding, but to support fisheries production in the impoundment, trees should be left unlogged in selected areas to provide increased surface area for periphyton growth, which acts as a primary food source for fish.

Fish passage

204. Fish passage facilities for both upstream and downstream migration should be incorporated into all dams on the Mekong mainstream. If fish passage is not considered viable to sustain populations (e.g. a cascade of dams is planned that eliminates flowing-water habitats upstream), then appropriate offset measures should be applied to compensate for potential ecological (biodiversity), social, food security, nutrition and economic (livelihoods) losses (MRC, 2018a).

205. Full effective mitigation to allow fish passage through Mekong mainstream hydropower projects has been shown to be up to 10% of the project capital cost depending on the project location and scale. This cost needs to be properly considered in the project financial model and business case.

206. Effective upstream and downstream fish passage should be evaluated using target species. These species should be based on commercial and livelihoods importance, broad coverage of ecological guilds, behaviour (e.g. surface, mid-water, bottom dwelling), size (small, medium, large), biodiversity value, and threatened species status.

207. Effective fish passage is defined in terms of a target percentage for the number of fish within

each migratory species that approach the dam structure both upstream and downstream. Sub-samples are commonly used to assess these targets, not the whole population. Specific targets in this Guidance are based on what is required to meet the objectives stated in Section 6.1, i.e. continued population sustainability in the Mekong mainstream. They are not based on what has been proven successful for existing fish passage structures, noting that many existing tropical facilities globally have design and operational flaws that this Guidance seeks to address. The following fish passage targets are based on population modelling and passage rates of Mekong species and hydropower dams (Halls & Kshatriya, 2009)[11]:

- 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.
- 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.
- The above percentage passage requirements may be refined for the particular species concerned, based on its life history and the number of dams the species has to pass to complete its life cycle and as additional regional and site-specific information on these aspects becomes available.

Biological and hydrological criteria for fish passage design

208. Flow range of fishway. The fishway needs to be designed to operate from minimum recorded flows to the 1-in-1 year annual recurrence interval (ARI) flow (63% annual exceedance probability). These flows need to consider climate change and flow regulation impacts from upstream, noting that an overestimate of minimum flows can prevent a fishway from operating.

209. Proportion of flow in fishway – upstream passage. A primary consideration (Williams et al, 2012) in the design of the hydropower project is ensuring that adequate flows are available

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[11] Note: the modelling is based on calculated mortality of fish through Kaplan turbines based on fish length, which may improve with new turbine designs, and also assumes that all larvae drift successfully through the impoundment and pass unharmed through the turbines.

to attract fish to fish passage entrances. Adequate flows[12] must be directed through the fish passage to ensure they function effectively in both the high and low flow seasons, and at all times are sufficient to ensure optimal effectiveness to achieve fish passage targets in Clause 207. Flow allocation for fish passage should be based on local and international research (Armstrong et al., 2010; Bell, 1985; Larinier, 2002; Roscoe et al., 2011) with the basis of flow allocation clearly set out in PNPCA documentation.

210. Proportion of flow in fishway – downstream passage. Dedicated downstream passage facilities at the powerhouse require 2% of powerhouse flows to pass fish effectively. This target may be altered if more specific regional or site-specific data become available.

211. Considering the range of species, volume of migrations, and variation in flow conditions encountered at a dam site, each project should consider a range of different options for fish passage upstream and downstream. Multiple fishways at a single large site are also likely to be needed.

212. Unless more specific site/regional data are available, upstream and downstream fish passage facilities should ideally:

- operate all year as far as practical, within the flow range specified in Clause 208;
- pass migrating fish from 5 cm to 300 cm in length both upstream and downstream, as well as fish eggs and larvae drifting downstream; and
- pass the migratory biomass of the Mekong River as determined during baseline monitoring and external assessment activities, noting that this is very high, especially in the middle and lower zones of the Mekong (i.e. approximately downstream of Vientiane, Figure 6.1).

Upstream fish passage

213. An upstream fish passage has two separate design components:

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[12] Research indicates that a primary consideration in the design of a hydropower project is providing sufficient flow at the fishway entrance to attract fish from the river into the fishway. At low flows (defined as the flow exceeded 95% of the time, or Q95 of present flows), 10% of the flow is required for effective fish attraction into the fishway. At the upper flow range for the fishway (1-in-1 year ARI), allocation of 10% of flow for upstream fish passage is desirable, but 2% would be a minimum. This flow can be a combination of passage flow (along the entire fishway) and auxiliary flow (additional flow) in the lower section of the fishway, but excludes attraction flow external to the fishway entrances(s). At very high biomass sites (e.g. downstream of Vientiane), half of the flow allocation is needed for passage flow along the entire fishway. At large hydropower dams that have effective fish passage, allocating 10% of the minimum river flow for fish upstream passage is a common standard (although 30% can be used); 5% of maximum turbine discharge has also been used. As an example, publicly available information states that the Xayaburi Dam fishway on the Mekong River provides a fishway attraction discharge of 8.6% (86 m^3/s) of low flows (Q95); 5% (240 m^3/s) of the maximum turbine discharge (5,000 m^3/s); and 2.5% of high flows (10,000 m^3/s). Research will test whether these flows are adequate. These targets may be altered if more specific regional or site-specific data become available. They also do not apply to small streams or tributaries, where fishways can potentially use 100% of flow.

- **Attraction** – in terms of fish approaching the dam and locating the entrance(s); and
- **Passage** – through the fishways.

Attraction

214. To achieve effective attraction, fish passage design should be integrated into the earliest project concepts, because it influences the dam axis alignment, dam and powerhouse configuration and alignment, abutment, and training wall shapes, spillway and gate design, and stilling basin design.

215. Physical modelling at an appropriate[13] scale should be undertaken during detailed design to accurately predict flow patterns and achieve functional fishway entrance conditions (see Clause 24). Modelling should include the spillway, powerhouse, fishway entrances (with auxiliary and attraction flows), and downstream river channel conditions. Separate models may be needed of different dam components because of size limitations. Modelling should test the full range of fishway flows, as above, to ensure fish can locate and access entrances. Fishway entrance design and integrating it with dam design, can occur before any fishway channel design.

216. 3D computer modelling (Computational Fluid Dynamics, or CFD) is also useful when used in conjunction with physical modelling.

217. The key design principles in physical/computer modelling to optimize fish attraction are:
    - Create continuous paths and refuges of low water velocity and turbulence that lead to an "upstream limit of migration", which is delineated by high water velocities without refuge (e.g. at the toe of spillways) and high turbulence without refuge. Fish are attracted to the greatest discharge (turbines or spillway), and utilize low water velocities adjacent to high discharge and high-water velocities to migrate upstream.
    - Minimize recirculating flows (horizontally or vertically) and cross-flows, which trap and delay migrating fish.

218. Multiple entrances should be provided at large dams and at sites with variable discharge. Migratory fish will be attracted to a wide area, and the "upstream limit of migration" will vary with discharge.

219. Fishway entrances should accommodate fish species that will use surface, midwater, and benthic zones and the thalweg (deepest channel). The thalweg needs to lead to the fishway entrance; the river channel may need reshaping during construction to achieve this.

220. Spillways and discharge gates should be designed and operated so that flows initiate and

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[13] The appropriate scale will depend on the size and geometry of the dam and river reach. For example, physical modelling for Xayabury was undertaken at an undistorted linear scale ratio of 1: 120. The scale should allow sufficiently accurate assessment of fish passage approach hydraulics.

terminate adjacent to the fishway entrance(s) to maximize attraction to the fishways.

221. All spillway flow can be used for fish passage, noting that fish migrate during all seasons and under all flow conditions.

Passage

222. Design options for upstream passage at high dams or dams with large discharge include, but are not limited to:

- Large pool-type fishways
- Large nature-like bypass channels
- Fish locks
- Fish lifts.

223. Within upstream fishways, the following criteria may be used, unless more site-specific data becomes available:

- Maximum water velocity for short distances (< 0.2 m; e.g. in vena contracta of slot or orifice) is 1.4 m/s.
- Maximum water velocity in channels is 0.5 m/s.
- The maximum turbulence in a fishway pool is 40 Watts per cubic metre (calculated using a discharge coefficient of 0.7).
- Minimum depth is 3 m under all flows, or equal to the maximum natural channel depth (thalweg) at low flows.
- Pool length and width should be at least three times the maximum length of the largest fish.

224. Fish passage facilities should pass the peak biomass, which requires the appropriate sizing of fishways, and suitable cycle times of fish locks and fish lifts.

225. Predation within the fishways should be minimized. Adequate shelter for smaller species while within the confines of the fishways should be considered, and residence time in the fishways should be minimized.

226. Water quality should be maintained within any holding enclosures to ensure fish health. Oxygen levels should be maintained within the fishways at >5 ppm (e.g. fish lifts).

227. Fishway designs should be flexible and adaptable, and have redundancy. For example, baffle shapes may be adjustable or have adjustable inserts, and mechanisms of water release for fish attraction and passage flows be adjustable over time. Feedback from monitoring and observation of fish behaviour should lead to optimization of the fishway operation.

228. If cyclic fish passage is used, such as fish lifts or locks, the period of captivity and interruption to the normal movements of the fish should be as short as possible.

229. Fish exiting upstream fishways should not be drawn back over the spillway during overtopping. Exit conditions should be sufficient to provide a stimulus for fish to exit the fishway. The combination of suitable attraction flows, substrate, and protection from predators is important.

230. Fish exiting fishways both upstream and downstream should be sufficiently healthy to continue their natural patterns and migration routes. Direct and indirect mortality combined, as a result of movement through the dam, impoundment, and fishways, should be in line with the objectives (Clause 207) for the relevant guild.

231. If feasible, navigation locks should be designed for fish passage (see Clause 322). Specific modifications are required for passing fish, including providing attraction flows and additional entrance(s) for migratory fish near the upstream limit of attraction. These aspects affect the design of gates, valves and dissipators.

Downstream fish passage

232. Downstream passage includes:

- larval drift through the impoundment;
- passage at the fish screens/trash racks;
- turbine passage of fish that pass through the fish screen; and
- passage through the spillway gates.

233. A mean channel velocity of > 0.3 m/s for the entire length of the impoundment should be provided to maintain larval drift through the impoundment for migratory species (Guilds 2, 3, 4, 8). This requirement should be part of the initial scoping investigations and design, because it is easier to achieve in a narrower river channel or a lower height dam.

234. Fish screens should be designed to guide downstream-moving fish away from turbines and towards downstream fish passage facilities, which may be a shared facility with upstream fish passage. Fish that pass through the screen will pass through the turbines; hence, the internal spacing of fish screens should be linked with the extent that the turbine design passes fish safely. Coarser mesh screens may be used if the turbine can safely pass larger fish, while finer mesh screens should be used if the turbines cannot safely pass small fish. Alternative methods to screening may be used, if these are shown to be effective through regional or site-specific research.[14]

235. Fish screens at high discharge sites (e.g. 2,000 to 5,000 m^3/s) such as the mainstream

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[14] Where high debris load or a deep thalweg make suitable screens unfeasible, alternative solutions may be needed to divert larger fish, which cannot safely pass through turbines, away from the turbine intake.

Mekong may divert large and medium-bodied fish, but are unlikely to divert small fish and larvae, so turbines should be designed to pass these smaller fish.

236. Screens should be angled at least 45 degrees to the current and have a surface velocity less than 0.5 m/s to prevent impingement, unless testing shows different criteria or screen designs that will divert fish safely.

237. Self-cleaning screens should be installed where there are high debris loads.

238. For small/medium fish that pass through the fish screens, turbines should be designed to have the following criteria, unless more site-specific data becomes available:

    - To minimize blade strike, the leading-edge width of the turbine blade should be equal to the length of the largest fish passing through the screens.
    - Shear should be less than 150 cm/s/cm for 99% of exposure paths.
    - To minimize impacts from sudden pressure changes (barotrauma), the pressure change ratio should be < 0.1.
    - The turbine design and placement should factor in these needs, because they may not be met based on considerations solely for hydropower generation. For example, to achieve a pressure ratio < 0.1, the turbines are likely to need to be deeper in the tailwater, which requires further excavation than may be planned for only hydropower generation needs.

239. At detailed design stage, a computational fluid dynamics model should be used to assess the extent of the above values and the exposure paths of fish through the turbine.

240. Species with a similar size and swim bladder morphology compared with Mekong fish should be used to assess mortality through turbines.

241. Spillways, aprons, stilling basins, and dissipater design should be designed to minimize fish injury, noting that total mortality should be less than 5% for many species.

242. If feasible, gates on spillways should be overshot, or designed to be used fully lifted, because undershot gates have high pressure changes and shear values that kill fish.

Fish passage operation

243. Capture fisheries in the vicinity of the fishways should be managed to ensure that mortality caused by fishing is not excessive. No fishing should be allowed within 500 m of the fishway entries or exits, or within the fishways.

244. Where ecological objectives downstream of the dam are to be met through the discharge operating rules, any releases that do not pass through the turbines should be directed through the fishway as a first priority, thereby ensuring that fish are attracted to the fishway

entrance as well as maximizing operating time.

245. Where practical, hydrological conditions should be maintained to ensure that migratory fish species can access tributaries and floodplains downstream of the dam and floodplains on the perimeter of the impoundment.

Fish passage during construction

246. Fish passage should be provided during construction, based on an assessment of the migratory population approaching the site and the proportion of each target species that passes through. Navigation locks may form part of this solution.

Alternative mitigation measures and fisheries resource management offsets

247. Where fish passage rates are unlikely to be adequate to maintain viable regional fish stocks, or local fish populations are not maintained, the developers should consider support measures including offsets for lost fisheries and OAA resources. From a fish and fisheries perspective, the following technical inputs should be considered in relation to any alternative measures. The livelihood aspects of support measures and offsets are addressed in Section 9, as follows:

    - Offsets should move beyond traditional approaches of fish farming and stocking fish and OAAs (mainly prawns), because these rarely replace the loss of fish stocks and OAAs (and hence catches), and should be used in conjunction with other measures.
    - Aquaculture (cage culture) within the impoundment of a mainstream dam would be reliant on stable water levels and low water velocities at high flows, because fluctuating water levels and high flows make anchoring and access problematic. Non-native species (e.g. carp and tilapia) should not be grown in the cages, because there is a high likelihood of escape and proliferation of non-native species in the wild to the detriment of native species.
    - Stocking of indigenous fish and OAA species in the impoundment would require continuous stocking through the life of the project. The production from stocking will not, however, replace the lost wild fisheries and OAA yield due to the decline in impoundment productivity after 5–7 years. Also, the short retention time of water in the mainstream dams prevents the build-up of primary productivity.
    - Small fishways could be built on wetlands to reconnect nursery areas with river habitats.
    - Re-creation of wetland habitats to support recruitment to wild capture fisheries and OAAs, or creation of new fisheries that have been lost due to the dam and impoundment could potentially be achieved within the impoundment by creating lagoon wetlands, or upstream or downstream of the project by reconnecting wetlands or floodplains lost to agriculture.

6.5 Project monitoring and adaptive management

248. Plans for project monitoring of fish, fisheries, and OAAs should take into account the guidance in Clause 26. The PNPCA information should demonstrate that plans for fish, fisheries and OAA monitoring information to be collected during construction and operation will inform:

    - developers' needs regarding fish passage management operations; and
    - indicators that may signal a need for adaptive management responses to fish, fisheries and OAA-related mitigation measures.

249. The monitoring programme commenced for the pre-project assessments (Section 6.3) should be continued during the construction and operation stages, and adapted where needed to better inform construction and operational stage information requirements for management. Components of the overall fish and fisheries project monitoring programme should consider the status of fisheries and biodiversity (including OAAs), fish passage effectiveness, and fish and OAA habitats.

250. Focal areas for annual review based on quantitative assessments should be:

    - For the upstream fish passage: the effectiveness of: fish attraction (locating the entrance); fish passage (through the fishway); and safe exit. Appropriate scientifically proven methods to assess the effectiveness fish attraction and safe exit should be adopted.
    - For the downstream fish passage: larval drift in the impoundment; the efficiency of fish screens and fish bypasses; fish passage through turbines; and fish passage through gates and spillways. Appropriate scientifically proven methods to assess larval drift should be adopted.

251. The monitoring plan presented at the PNPCA stage should show how the proportions of the numbers of fish of each target migratory species (three species of each migratory guild, preferably including benthic, pelagic and surface-dwelling species), and the total biomass that are able to pass the dam successfully both upstream and downstream will be determined and compared to the targets in Clause 207. The proportion of fish represents fish approaching the dam at the time of sampling, hence, is robust to other changes in fish populations that may occur due to other catchment impacts. Mortality levels of individual species should also be estimated, as per Clause 241.

252. If actual percentages passing the dam are lower than the targets, a review of the facilities and operations against the recommendations in this Guidance should be made, and actions implemented to improve the fish passage arrangements, as per Clause 27.

253. Monitoring of habitats and spawning activity in littoral zones downstream of the dam should be included in the overall monitoring plan. Findings can inform any refinements in operating rules (sediment flushing and flood control) that may then maximize fish recruitment and populations downstream.

254. In addition to recommendations for overall water quality monitoring for the project (Section 4.5), specific water quality monitoring should be undertaken in the fishways to inform if there are any water quality-related issues that may have implications for effectiveness. Parameters should include water temperature and dissolved oxygen.

255. Standard methods as prescribed by the MRC are recommended to be used to ensure robust data and analysis, and consistent approaches by developers with the overall monitoring in the river. Opportunities for collaborative approaches among projects on the mainstream should be considered if possible (e.g. by using the same PIT tag system for detecting tagged fish).

7

Dam Safety

7 DAM SAFETY

7.1 Objectives

256. The objectives for dam safety are:

- Ensure that a dam does not violate Article 7 of the Mekong Agreement by causing harmful damage to the environment (upstream or downstream) through its operation or in the event of any failure.
- Protect life, property and the environment from the consequences of dam operation or failure, based on an understanding of the risk imposed by the dam and the consequence of failure.
- Ensure that current national and international standards are used in design with preferably a consistent approach to design criteria for cascades of mainstream dams, specifically for the safe passage of extreme floods and seismic stability.
- Ensure that the design, construction, and operation and maintenance regimes, as well as institutional arrangements are consistent with national requirements and international good practice for the safety of dams and related emergency response planning.

7.2 Risks

257. Dam safety is of paramount importance for the individual dams on the mainstream of the LMB, as well as the safety of any cascade. The safe design, construction, and operation of dams depend on more than engineering factors. The approach to dam safety should recognize that failure of a dam is a complex process that can include human error at the design, construction, operation and maintenance and monitoring stages (ICOLD, 2005).

258. Risk-based design has become standard procedure in many countries worldwide. To fully understand dam safety, the risks imposed by the dam on the downstream environments should be fully understood. Risk assessments and failure mode assessments are important tools in contemporary dam design. Risk assessment processes at various stages throughout the design are encouraged to ensure that risks and uncertainties are understood by all key stakeholders and mitigated where possible.

259. Potential dam safety risks should be comprehensively assessed. The key risks associated with dam safety are summarized in **Table 7.1**.

Table 7.1. Potential dam safety risks associated with mainstream dams

Risk	Consequence/comments
Failure of upstream dams	Risk of cascade dam failure releasing a flood wave, which overtops and damages the downstream dam
Uncertainties in flood loading	Spillway under design leading to overtopping of the dam and structural damage sufficient to cause failure of the dam
Uncertainties in the geological and geotechnical investigations	Inadequate treatment of the dam foundations, leading to erosion or failure of the dam foundation and the dam itself
Uncertainties in seismic loading	Inadequate assessment of the seismic hazard and loads leading to structural failure of the dam during an extreme earthquake or fault movement
Below-standard design of dam and structures	Risk of dam failure releasing a flood wave downstream
Below-standard construction control and quality	Construction flaws leading to structural damage and dam failure
Failure of the dam during construction due to undersized or blocked diversion works causing overtopping of the partially completed dam	Risk of significant quantities of water flowing downstream in a dam break situation
Inadequate operation, maintenance and dam safety surveillance	Initiation of failure modes are not detected and can escalate to a major dam safety risk

7.3 Pre-project monitoring and analyses

260. The developer should provide information in sufficient detail at the PNPCA process to demonstrate that this Guidance on dam safety will be fully implemented.

261. The most important baseline data related to dam safety are primarily those required for the hydrological studies to develop the design floods, and the geological information required for foundation and seismic hazard assessments at the regional and site-specific level.

Seismic

262. The developer should understand the regional seismic geological conditions as well as the site-specific situation.

263. The following should be considered in developing the seismic design criteria for the

proposed site:

- International Commission on Large Dams (ICOLD) Bulletin 148 and other relevant ICOLD Bulletins (e.g. ICOLD, 2001) should be used to determine seismic design criteria.
- A detailed investigation should be undertaken of nearby significant faults, and evidence provided to show assumptions on activity of the closest faults.
- If there are no nearby active faults, then there should be a review of the regional seismicity parameters and their uncertainties for inputs to deterministic or probabilistic approaches.
- Aftershock impacts on the dam should be assessed.
- If investigations indicate the possibility of faults through the dam foundations, then the risk of fault displacement should be considered and mitigation measures included in the design.
- Kinematic models of potential tectonic displacement in the dam site should be completed. These should be updated as the project proceeds to take into account structural geological features found in the dam foundation during construction.

Floods

264. Section 2 (Hydrology and Hydraulics) of this Guidance should be referenced in relation to derivation of design floods and determination of both Cascade Joint Operating Rules and Project-Specific Operating Rules.

265. The check flood should be the probable maximum flood (PMF). Significant damage may be accepted to the structure and operation of the power station and the flood gates; however, there should be no catastrophic failure of the dam structure resulting in the release of an uncontrolled flood. The design flood should result in no structural or operational damage to the dam or spillway based on the worst-case scenario.

Impact identification

266. The developer should carry out a detailed Potential Failure Modes Assessment (PFMA) to identify the credible failure modes for the dam and appurtenant structures. The PFMA should be used to reduce the risk of failure of the dam, and to inform the development of the Dam Safety Management System (Clause 283) and Emergency Preparedness Plans (Clauses 286 and 290).

267. The developer should demonstrate the extent of the following key risks posed by the dam on the upstream and downstream communities and environment.

    - **Natural floods**: These should consider a range of annual exceedance probabilities (AEP) from the annual flood up to the PMF. These assessments should be carried out both with and without the dam, and demonstrate the impact of the proposed operational rules required to pass these major floods on both the upstream and downstream areas of the dam.

- **Faulty or accidental operation of the dam.** These assessments should demonstrate the impacts of faulty operation of the scheme, in particular, the faulty operation of flood gates. Faulty operation includes the failure of flood gates to open and the accidental operation of the flood gates.
- **Dam break flood assessments.** The dam break flood assessments should demonstrate the impact of failure of the dam during flood situations, periods of low flow, and construction. Modes of failure should be investigated (Clause 266), and credible failure scenarios should be used to derive the dam failure flood hydrographs.

268. The potential impacts listed in Clause 259 should be assessed using detailed hydrodynamic modelling. Modelled flood extents, with and without the dam, should be superimposed on maps of the area to identify the people, property, and structures at risk from the project. Modelling should extend upstream and downstream of the dam to the point at which the difference between the pre- and post-dam flood depth is less than 10 cm, or to the point at which it is clear that the additional dam break flood depth no longer poses a risk to people and property.

269. Where the impacts of the dam affect the operation of other infrastructure upstream or downstream, the developer should provide mitigation measures to eliminate or minimize these issues in consultation with the owner of the affected infrastructure and the responsible national agencies.

270. Details of the impacts, including numbers of people at risk and vulnerable structures or environmentally sensitive areas, should be identified by the developer. In assessing the impact of the dam to the upstream and downstream communities, the developer should take into account itinerant users of the river as well as the fixed communities. These itinerant users may include boat traffic (tourist, fishing, cargo and others), fishers (in boats and on the riverbanks), and other riverbank users. This aspect of the assessment will be important information for the assessment of *Riparian Communities and River-Based Livelihoods* (Section 9).

271. Modelling described in Section 2.3 and Clause 268 should be used to develop dam break and natural flood maps for emergency planning, showing at a minimum: areas at risk; flood depths; velocity; and flood wave travel times for the inundation areas. These maps should be developed in cooperation with the local emergency management teams to provide them with the information they require for emergency planning. These may include hazard maps (velocity times depth) in addition to the flood depth, velocity, and travel time maps.

272. The dam safety risk management analyses should clearly identify any residual risks and

document where these will occur in the river, in line with Clauses 7 and 25.

7.4 Design and operational guidance

273. This sub-section defines specific requirements that should be demonstrated during the development of the concept/feasibility design to be submitted for the PNPCA process. While full details will be finalized during the detailed design and construction stages, sufficient details should be submitted for the PNPCA process to provide confidence to the MRC Joint Committee that the development will be designed, constructed, and operated safely.

274. Table 7.2 identifies mitigation measures for the risks identified in Table 7.1. The developer should demonstrate, at the PNPCA process stage, how they intend to mitigate these risks.

Table 7.2. Mitigation measures for dam safety risks for mainstream dams

	Risk	Mitigation measures
Design	Failure of upstream dams	Hydraulic modelling of the impact of failure of the upstream dams should be carried out and the dam designed to prevent catastrophic failure due to overtopping by an upstream dam failure
	Uncertainties in flood loading	Existing dams on the mainstream have been designed to safely pass the probable maximum flood (PMF). All new dams should use the PMF as the check flood.
	Uncertainties in the geological and geotechnical investigations	Detailed geological and geotechnical investigations of the dam site should be carried out before and during the construction phase.
	Below-standard design of dam and structures	Experienced designers should be hired. Adequate quality assurance systems should be included in the design. Dam Safety Review Panel should be actively involved at all stages of the project.
	Uncertainties in seismic loading	Detailed seismic hazard assessment should be carried out as recommended by ICOLD Bulletins 120 and 148 (ICOLD, 2014, 2011).

	Risk	Mitigation measures
Construction	Below-standard construction control and quality	Detailed specifications should be prepared by the designers and then strictly applied during construction. The design and construction should be carried out by experienced dam engineers and contractors with all stages independently reviewed by a competent party from a dam safety perspective.
	Failure of the dam during construction due to undersized or blocked diversion works causing overtopping of the partially completed dam	The diversion works should be adequately sized. The debris should be actively managed. Flood forecasting systems should be implemented during construction. Emergency planning and dam safety monitoring should be carried out during construction.
Operation	Inadequate operation, maintenance and dam safety surveillance	Detailed dam safety management plans, operational and maintenance plans, and emergency preparedness plans based on potential failure mode assessments should be prepared by the designers and implemented by the developer and owners. Operating rules covering extreme flood events should be prepared and include all actions required to ensure that dam safety risks are mitigated and that potentially affected communities are consulted.

Design stages (concept, feasibility, detailed)

275. National standards relevant to dam safety of the responsible Member Country should be met unless this Guidance specifies more stringent criteria in the interest of transboundary safety, as per Clause 12. Where specific guidance is not provided in this document, international dam safety good practice should be used, such as documented in the World Bank Operational Manual and ICOLD Bulletins (ICOLD, 2005, 1987).

276. During the design stage, the structures and systems that are critical to the safety of the dam should be identified. In particular. where systems such as spillway flood gates rely on mechanical and electrical control equipment, the system should be designed with back-up systems to ensure reliability in emergencies. The developer should identify which systems are critical to dam safety and demonstrate that there is complete redundancy in the system.

277. A Dam Safety Review Panel (similar to those panels required under the World Bank Operational Policy OP4/37) should be appointed by the developer or the government of the host nation, and should meet the following criteria:

- The panel should consist of recognized independent experts in different aspects of dam safety.
- The experts involved in the review must have no role in the design or operation of the dam, nor financial nor other interests in the project, and it is accepted that they are providing an objective view, i.e. they are "independent".
- The individuals involved in the review must have a high degree of knowledge of dam and infrastructure safety as a result of a significant experience and training in the relevant component of the dam that they are reviewing; i.e. they are "experts".
- The panel should be appointed prior to the PNPCA process and make regular reviews throughout the investigation, design, construction and operational stages of the dam, including the first commissioning of the dam and operations.
- The panel members may be appointed under relevant national laws of the notifying country.[15]

278. The developer should include an independent review by the review panel (Clause 277) with the PNPCA information submission. This review should have been undertaken after the feasibility study has been completed. The information submitted should also identify the proposed inputs from the review panel during design and construction, the first commissioning of the dam, and at the start of operations.

279. The developer should include mitigation methods to control floating debris in the impoundment which could cause damage to flood gates or other plant and systems critical to dam safety.

280. If the navigational structure is to be used as part of the flood control measures, then this should be clearly identified in the dam safety documentation.

281. Flood flows through the dam structure should be safely discharged. The developer should demonstrate that adequate energy dissipation and scour protection is provided to prevent failure of the dam. This is particularly critical to the design of the spillway, low level outlets, and the turbine outlets.

282. If overshot flood gates are proposed, then detailed consideration should be given to the long-term maintenance and reliability of the gates to ensure that they can always satisfy dam safety requirements.

283. A dam safety management system (DSMS) should be prepared for implementation starting from design and continuing through the full construction and operation stages, and the plans for this should be described with the PNPCA information. This system should become

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[15] For example, Lao Electrical Power Technical Standards 2018 requires the appointment by Ministry of Energy and Mines of a "chief engineer" to review design and construction.

progressively more sophisticated as the project moves through the development stages. To be consistent with international good practice, the DSMS would include the following:

- comprehensive dam safety reviews, involving independent inspections, scheduled at least once every five years. Dam safety reports should be copied to government, and follow-up inspections undertaken to confirm that the recommended work was undertaken. These reviews should be carried out by experienced engineers independent from the dam owner;
- annual dam safety reviews, including inspections, in order to check for damage and ensure functionality of critical structures, and to ensure completion of tasks identified for follow-up from previous reviews;
- details of how to identify and report dam safety issues;
- a surveillance system to identify the initiation of the failure modes, following on from the assessment described in Clause 266; and
- all dam safety relevant design criteria, monitoring and assessments, management plans, and review and inspections addressed in this Guidance.

284. The DSMS should include an instrument plan for dam safety monitoring to be incorporated into the project design. This plan should outline the location and type of instruments to be installed for monitoring and recording dam behaviour, and for obtaining related hydro-meteorological, structural, and seismic information over the life of the project. The plan should include consideration of how the instrumentation will be used to provide early warning of initiation of any the potential credible dam failure modes.

Construction stage

285. The DSMS should include plans for construction supervision and quality assurance, to demonstrate how the developer will ensure quality in areas important for dam safety during the construction period. This should include the organization, staffing qualifications, procedures, and equipment for the supervision of the construction of a new dam. Experienced and competent professionals are required to design and supervise construction.

286. A Construction Stage Emergency Preparedness Plan should be provided that demonstrates the identification of and mitigation measures for risks to the project, project-affected area, and local communities during the construction period. The plan should include for failure of the partially completed dam or cofferdams during construction if the diversion works are overwhelmed.

287. Plans regarding temporary works construction and removal should be included in the DSMS as they relate to dam safety. Failure to remove all of the temporary works can have implications on the operation of the permanent works. The developer should demonstrate

the full methodology for temporary works, which should include the removal of the works.

288. Plans relating to first filling of the impoundment should be included in the DSMS as they relate to dam safety. These should:

- identify the potential risks to dam safety during first filling and accompanying mitigation measures;
- include the monitoring and surveillance that will take place during this period in order to detect initiation of any of the potential failure modes;
- be linked to the Emergency Preparedness Plan; and
- be refined and completed during project implementation, and the final plan should be completed and accepted by the responsible national agency not less than six months prior to initial filling of the impoundment.

Operation stage

289. The following operating rules and actions are required to ensure that dam safety risks are mitigated:

- rules for draw-down of the impoundment ahead of floods, and for the operation of turbines and flood gates during floods;
- rules for flood gate operation while any gates are out of operation due to maintenance or upgrade; and
- any controls on impoundment water level or downstream flow ramping rates for public safety.

290. An Operation Stage Emergency Preparedness Plan (EPP) should be provided that includes:

- the specification of roles and responsibilities of all parties when dam failure is considered imminent, or when expected operational flow releases threaten downstream life, property, or economic activities dependent on river flow levels;
- specific reference made to the Cascade Operating Rules as they pertain to extreme flood management and the consultation with upstream and downstream projects;
- transboundary considerations and consultation and agreed protocols with relevant agencies in upstream and downstream Member Countries;
- a communication strategy to engage with stakeholders on dam safety issues and emergency preparedness activities that directly involve or affect them. This should provide for full and effective consultation with local communities and local government authorities as well as all concerned organizations and agencies.
- All concerned and affected people, including those in upstream and downstream

countries who may be affected by dam operations, should be involved in the EPP preparation, in training and capacity-building for its implementation, and in response to any issues concerning annual Dam Safety reports;

- inundation maps based on dam break and natural flood scenario modelling (Clause 267) that indicate households and structures at risk that should be on warning or evacuation contact lists;
- details of the flood warning system;
- communication flow charts and contact lists, including households at risk; and
- Identification of emergency resources.

291. The project Operation and Maintenance (O&M) Plan should include aspects relating to dam safety, which should be incorporated into the DSMS. These aspects should address:

- the organizational structure, staffing, technical expertise, training, equipment, and facilities needed to ensure it; and
- O&M procedures, funding and other arrangements for long-term dam maintenance and safety inspections.

7.5 Project monitoring and adaptive management

292. Plans for project monitoring, inspections and review relating to dam safety should take into account the Guidance in Clause 26. The PNPCA information should demonstrate that plans for dam safety related monitoring information to be collected during construction and operation will inform:

- developers' needs regarding emerging issues; and
- indicators that may signal a need for adaptive management responses to dam safety related risk management measures or management plans.

293. For the life of any dam, the owner is responsible for ensuring that all appropriate measures are taken and sufficient resources provided for the safety of the dam. All management plans and systems identified in the clauses in Section 7.4 should be reviewed and updated annually, and training sessions should be implemented to ensure that all stakeholders are familiar with the plans relevant to them. The DSMS should ensure that all actions and findings are recorded in a manner that is easily retrievable over time, and provide for follow-up and continuous improvement.

294. Plans should indicate how and when the DSMS described in Clause 283 will be finalised and updated to suit the "as constructed" dam within six months of commissioning of the dam.

295. Plans submitted at the PNPCA stage should describe the Flood Forecasting and Warning

System that will be developed to providing warning for all people within the inundation areas identified by the flood modelling and mapping (Clause 267). This should include plans for updates and periodic tests of the operation stage EPP (Clause 289). These plans should include flood forecasting and warning that may be required for upstream and downstream Member Countries.

8

Navigation

8 NAVIGATION

8.1 Objectives

296. The objectives for navigation are:

- Guarantee continuation of navigation on the Mekong mainstream consistent with Article 9 of the Mekong Agreement, through provision and management of ship locks at all mainstream dams.
- Ensure consistent design and operation of ship locks at all mainstream dams.
- Make sure that dam infrastructure does not impede the potential future development of mainstream navigation[16] in terms of cargo transport capacity, passengers transport capacity, and convoy transport development.
- Ensure safe and efficient lock operations.

8.2 Risks

297. Risks associated with navigation should be comprehensively assessed. The PNPCA documentation should indicate how the design has dealt with the potential risks associated with navigation, and in particular with the ship lock, as shown in Table 8.1.

Table 8.1. Potential risks associated with ship locks at mainstream dams

Risk	Consequences/comments
Lock approaches upstream and downstream	
Lack of a straight-line approach in upstream and downstream channels with poor visibility approaching the lock	Barges and convoys may hit the bull nose of the guidance wall or enter the penstocks or spillway of the dam if not properly aligned when approaching.
Deposition of sediment in upstream or downstream approach channels	Vessels may run aground and block the entrance for other vessels.

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[16] Information may be sourced from relevant government or regional authorities (e.g. the MRC).

Risk	Consequences/comments
Strong side currents where the downstream approach channel merges with the main river course	Strong side currents can push barges and convoys off course and cause collision with oncoming ships or barges.
Lock chamber and gate design	
Emptying and filling produces heavy turbulence and disturbs the position of ships and vessels, especially small boats	Barges and boats can be shaken by the turbulence or upward currents during filling, and damage can be caused to the hull structure.
In case mitre gates are used, sunken debris can get stuck between gate and sill, or inside the gate chamber.	Damage can be caused to the gate (torsion) or to the opening and closing hydraulics, potentially halting navigation for long periods.
Vessels impacting against the chamber walls while entering the lock chamber	The impact from big barges, vessels or convoys against the concrete walls from the lock chamber can deteriorate and crush the concrete.
Ships improperly entering the lock chamber and not properly berthed during lock operations	Vessels that are not properly berthed after entering the lock chamber can cause damage to other vessels or lock chamber devices during lock operations This is specifically the case when ships are berthed at line-hooks instead of floating bollard, potentially leading to capsizing of the vessel
Person overboard and/or ship in distress in the lock area	This may result in fatal accidents, drowning, and police investigation, etc.
Ships entering the lock chamber and not stopping before the gate.	Ships bumping against the mitre gate can damage the structure. Parts of the steel construction may have to be replaced, which can result in long outages.
Smaller vessels unable to safety traverse ship lock	Small vessels are more likely to be affected by turbulence in the lock during filling.

Risk	Consequences/comments
Culvert design and operation	
Cavitation at tainter valves and inside culverts from locks over 25-m lift.	Cavitation is destructive to valves and culvert walls, mostly unseen and unnoticed. Repairs are likely to be complicated, expensive and time consuming.
Entire lock structure	
Earthquakes	Earthquakes can provoke unscheduled settlement and small movements in the lock chambers and lock heads, even disturbing the normal functioning of the mitre gates and the tainter valves in the culverts. Insufficient resistance to earthquakes can result in damage to the lock heads and gates such that normal operation is no longer possible.
Differential settlement over the entire lock structure	The same consequences as above are possible. If differential settlement leads to malfunctioning of the mitre gates or tainter valves, this can lead to damage to the lock heads with potentially high consequences for navigation.
Seepage under the lock structure	Seepage with consequential soil erosion can create cavities that sooner or later are able to collapse entire structures if not sufficient or inefficient waterproof screens have been established
Impoundment	
Excessive sediment deposits in the impoundment backwater	Ships and barges can run aground due to insufficient water depth, thereby blocking navigation for other traffic.
Hidden submerged rock outcrops in the impoundment backwater	Ships and barges can hit underwater obstacles such as rocks and reefs that are invisible due to inundation. Currents in the impoundment can be so weak that captains and skippers can no longer "read the water". Hitting underwater obstacles (usually rock outcrops) can substantially damage the ship hull and lead to sinking or capsizing of the vessel.
Water level changes	
Any sudden release of water into the downstream river as a result of operations, such as sediment flushing	Berthed small boats downstream of the project can be dislodged and swept farther downstream during dam operations (e.g. spillway gate operations, turbine start/stop).

Risk	Consequences/comments
Sudden changes in water levels in the impoundment	Improper anchored vessels and/or small boats can be dislodged and risk drifting into project infrastructure.

8.3 Pre-project monitoring and analyses

298. Design of navigation facilities should take account of the design and operation of existing and planned upstream and downstream projects in a cascade.

299. The design should be informed by current and future proposals for free-flow channel improvements both upstream and downstream of the dam. A number of projects, studies, and proposals are under consideration, the most important being the Development Plan on International Navigation on the Lancang-Mekong River (2014–2025) by the Department of Transport of the Yunnan Province, August 2014.

300. The design should take into consideration two studies conducted by the MRCS regarding channel improvements in some dangerous areas for navigation (including reefs, rapids, and shoals):

    - “Condition Survey of Dangerous Areas for Navigation between Luang Prabang and Pakse in the Lao PDR and Thailand – October 2009”; and
    - “Condition Survey of Dangerous Areas for Navigation between Huay Xay and Luang Prabang in the Lao PDR and Thailand – April 2010”.

301. The developer should base the lock design on a detailed understanding of the geological, geomorphologic, hydrologic, and hydraulic conditions of the dam site, including seasonal variations. Application of the hydrological and hydraulic models described in Section 2.3 and the sediment modelling described in Section 3.3, can inform detailed planning for development and operation of the ship locks and its approaches.

302. Adequate channel clearance should be provided for vessels accessing the ship lock. The need for dredging or rock clearance to ensure safe access to the lock chamber should be documented. Adequate visibility of both upstream and downstream lock accesses should be provided.

303. The analyses of changes, risks, and mitigation options relating to navigation should clearly identify the residual impacts and document where these will occur in the river, in line with Clauses 7 and 25.

8.4 Design and operational guidance

304. An essential guide for many of the design aspects for the mainstream Mekong ship locks is

the 2009 Permanent International Association of Navigation Congresses (PIANC[17] report). Innovations in Navigation Lock Design; and an essential guide for Mekong navigation is the PIANC InCom WG report nº 141-2019, Design Guidelines for Inland Waterway Dimensions. It is the developer's responsibility to obtain these guidance documents through the PIANC procedures. This Preliminary Design Guidance (PDG) directs the user to specific sections of these PIANC reference documents for important design requirements.

305. Mitigation options should be evaluated to determine which ones will best address identified risks. **Table 8.2** sets out mitigation options for the broad areas of risk, with more detailed guidance provided in the clauses following this table. Developers may propose alternative mitigation options based on the specific site location and associated risks with appropriate justification.

Table 8.2. Mitigation options for navigation-related risks for mainstream dams

Risk	Mitigation options
Structural integrity of the ship lock infrastructure	Ship locks should be earthquake-resistant (see Section 7 Dam Safety). The design should take into account the geological and geomorphology conditions of the site and the effects of potential differential settlement
Issues arising in the approaches to the ship lock and the impoundment	A straight-line approach channel with good approach visibility should be provided. Ensure that the guidance wall, ship lock openings, and ship lock chamber are designed to be in one straight line. Navigational hazard management measures should be implemented (e.g. initial surveys, clearance, markers for remaining hazards particularly in the impoundment backwater). Sediment management measures should be implemented (see Section 3). Debris management measures should be implemented (e.g. regular surveys, underwater jet system in front of the sills, manual mechanical clearance, adeep hole upstream created to capture potential hazards)

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[17] PIANC, which was the Permanent International Association of Navigation Congresses, is now the World Association for Waterborne Transport Infrastructure (www.pianc.org). Documents are readily available at low cost.

Risk	Mitigation options
Excessive sediment deposits in the impoundment backwater	Dredging of navigation channel in affected backwater reaches including tributary entry points should be carried out and navigation aids provided.
Hidden submerged rock outcrops in the impoundment backwater	Navigation aids should be provided for high and low water levels.
Issues arising within the lock chamber(s)	Protective measures for ship impacts should be implemented (e.g. gate protection; steel sliders or armour devices embedded in concrete walls). Mooring facilities should be provided with floating bits, line hooks and fenders. Camera surveillance, loudspeaker for warnings, emergency stop facilities and traffic light signals should be provided.
Emptying and filling produces heavy turbulence affecting vessels	The opening sequence of the filling valves for various types and sizes of boats/vessels/barges should be reprogrammed. The filling orifices should be reshaped or eventually, the entire filling system should be redesigned. Locking big barges together with small boats should be avoided, or the filling programme of the culvert valves should be adapted.
Smaller vessels unable to safely enter and exit the ship lock	Alternative methods (tractor/trailer) should be used to move smaller vessels past the structure.

Risk	Mitigation options
Cavitation at tainter valves and inside culverts (in locks with over 25-m lift).	Locks with a lift over 35 meters should not be constructed as a single ship lock. The design should opt for tandem locks. Special attention should be paid to avoid cavitation in locks with lifts of over 25m; may be designed with water saving basins to substantially reduce the pressure on the culvert valves (PIANC, 2009).[18] Tainter valves with enlarged (deepened) chambers behind the valves should be considered. The culvert shape behind the filling and emptying valve should be optimized. Aeration of the tainter valve with an air intake system should be considered. The resistance of the culvert walls should be increased and improved against cavitation, e.g. by steel plates.
Interruption of existing and ongoing navigation	Alternative ways of transhipping goods, cargo and passengers should be provided during the construction of the ship lock. Information on construction progress should be provided to waterway users, in particular to boat associations from upstream and downstream ports, and commercial waterway transport operators.
Any sudden release of water into the downstream river as a result of operations such as sediment flushing	Cascade Joint Operating Rules and Project-Specific Operating Rules should be applied to control how water levels will fluctuate. Early warning notifications should be provided. Prior safety inspections should be carried out ahead of major water level changes.
Fish passage during construction	The ship lock should be adapted as the sole fishway during construction in accordance with the guidelines under Clause 231.

Lock dimensions

306. Lock dimensions have been decided for all navigation locks to be constructed along mainstream dams, following the outcome of the Optimisation Study of the Mekong Mainstream Hydropower Projects commissioned by the Government of Lao PDR. Ship

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[18] PIANC-InCom report from working group 29 (Report nº 106-2009): “Innovations in navigation lock design”, Section 4.4.5 (p. 82).

lock chamber dimensions should be at least 120 m x 12 m x 4 m, which comfortably accommodates a convoy of two 500-t barges (Chinese design) with pusher vessel.

307. The Mekong/Lancang River upstream of the Khone Falls should be considered as a single navigation unit using the above ship and lock dimensions. Downstream of the Khone Falls (Cambodia – Viet Nam), different ship lock dimensions may be applied since this is another separate navigation unit with potential connection to the sea.

Lockage time and availability

308. Lockage time should be kept to the minimum whilst allowing for safe operations and safe movement of all vessels in the lock chamber(s) and should be guided by PIANC recommendations.[19]

309. The design criterion for hawser forces in all possible directions should be ≤ 1% x water displacement of the vessel (in tonnes) and should be guided by PIANC recommendations.[20]

310. The locks should be designed to operate at least 12 hours a day, every day of the year.

311. Each lock complex should be operational for at least 98% of its scheduled operating time during each year of its service life, excluding planned closures for scheduled maintenance and unscheduled repairs.

312. Outages related to incidental breakdowns should not exceed 2 percent of the operating time each year.

313. Service outages for scheduled maintenance should be on nine consecutive days (one working week and the two weekends) each year, during the same period for all dams on the Mekong mainstream waterway (upstream of Khone Falls) to avoid traffic disruption. This period should be established in the Cascade Joint Operating Rules. The official body in charge of navigation coordination along the Mekong River should be responsible for specifying the dates for servicing.

Approach infrastructure

314. Approach infrastructure should be designed in accordance with PIANC recommendations.[21] Three different berthing areas should be provided, each able to berth one full-sized design vessel/convoy, and include the following:

    - a lay-by area where ships can be ready to immediately enter the ship lock as soon as the preceding vessel has left it or the green entry light is turned on;
    - a waiting area where ships can wait if there are several others ahead of them. The

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[19] See PIANC (2009), Chapter 4.2.5 Duration of Lock Cycle and Vessel Passage (p. 56).

[20] See PIANC (2009), Chapter 5.2.3 Mooring Line/Hawser Forces during Filling and Emptying of Lock Chamber (p. 109).

[21] See PIANC (2009), Chapter 5.6 Lock Approach Structures (p. 148).

waiting area can be an extension of the lay-by area;

- the overnight area where ships and vessels can spend the night. The overnight area does not necessarily have to be connected to the lay-by or waiting areas, but all three areas should have access to land via a catwalk or via floating pontoons. The overnight area may be developed at a later date if demand is low at the time of project commissioning, and plans submitted at the PNPCA stage should indicate if this is the case and how it has been provided for; and
- one of the above three areas may provide facilities such as potable water, clean water, solid and liquid waste facilities, emergency aid, etc.

Service life

315. Each lock complex should be designed for a functional lifetime of 100 years.

316. Some components of the lock may have a service life shorter than 50 years. These components are listed below and should be designed to allow for easy replacement.

    - Metal structures
    - Hydraulic jacks
    - Ball bearings, pulleys, joints, valves, etc.
    - Cables
    - Electrical equipment
    - Communication and digital safety equipment, cameras, and TV sets.

317. Sufficient spare parts should be obtained during project implementation for the most vital mechanical parts of the ship lock. Guidance on life cycle management for locks is provided in the PIANC reference.[22]

Future expansion

318. The design of the locks system should allow for future construction of a second line of locks.

319. The owner/operator should be responsible for the construction of a second line of parallel locks when the number of lockages per year reaches at least 80 percent of the total maximum possible yearly lockages over a period of two successive years.

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[22] See PIANC (2009), Chapter 4.3 Life Cycle Management for Locks (pp. 58–63).

Further design and operational guidance

320. Lock gates and their ancillary equipment should be protected against fire inside the chamber.

321. An overhead rolling crane, or other lifting equipment, running the full length of each chamber may be considered to:

    - lift floating or sunken debris caught between the mitre door and the sill or lodged inside the door chamber;
    - assist small vessels in cases of emergencies inside the lock chamber;
    - position the stoplogs for each lock-head for maintenance purposes (e.g. mitre door pintle replacement) and repair/replacement of the tainter or sliding valves in the culverts; and
    - support emergency rescue operations for ships in distress inside the lock chamber.

322. If feasible, the ship lock may also be used as additional fish passage during migration periods (see Clause 231). This additional fish passage may be the only one during the construction of the powerhouse and the spillway, in which case it is an essential asset to be considered in the construction planning and should be operated as a fish passage during construction.

323. The project should make allowance for the installation of a monitoring system that allows future networking to other mainstream dams, to provide a real-time monitoring of vessel and barge movements on the Mekong. This may be the precursor of a fully-fledged River Information System, in which the real-time movement of vessels and barges is monitored and communicated to upstream or downstream locks and ports.

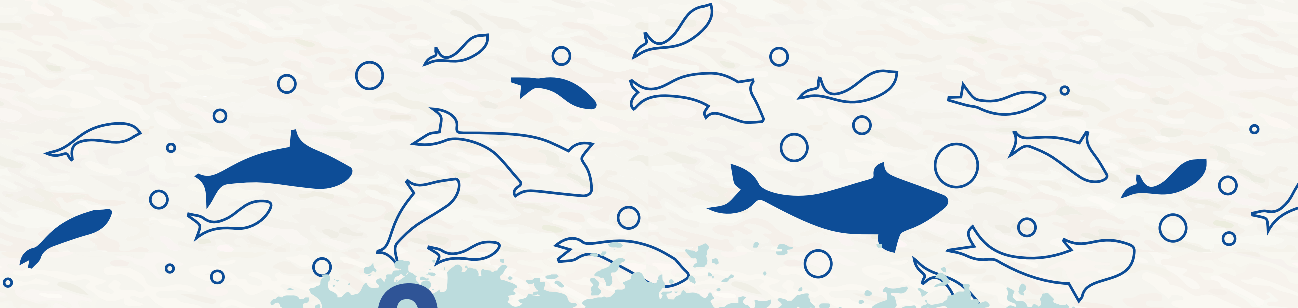
8.5 Project monitoring and adaptive management

324. Plans for project monitoring of navigation locks should take into account the guidance in Clause 26. The PNPCA information should demonstrate that plans for navigation-related monitoring information to be collected during construction and operation will inform:

    - Developers' needs regarding management of navigation lock operations; and
    - Indicators that may signal a need for adaptive management responses to navigation related management and mitigation measures.

325. The monitoring programme for navigation at the construction and operation stage should include a focus on operational efficiency, adherence to the minimum lock downtimes, effectiveness of communications and coordination, and maintenance and replacement of operating components.

326. Plans for the monitoring programme should include regular monitoring and inspections by the navigation lock operator of key navigation infrastructure, electro-mechanical equipment and keep records of navigation movements and any associated issues arising. Bathymetric surveys at both access channels and approaches should be conducted in coordination with related sediment monitoring set out in Section 3.5.



9

Riparian Communities and River-Based Livelihoods

9 RIPARIAN COMMUNITIES AND RIVER-BASED LIVELIHOODS

9.1 Objectives

327. The objectives for riparian communities and river-based livelihoods are:

- Engage directly-affected riparian communities in all phases of the projects development and operation in a participatory manner.
- Ensure that directly affected riparian community livelihoods are better than, or at least restored to, pre-project levels.
- Implement these support measures, where feasible, within existing institutional frameworks (e.g. the MRC, the government at various levels, civil society organizations).
- Enhance existing, or create new, transboundary cooperative mechanisms as needed (e.g. to implement support mechanisms for transboundary riparian communities), such as through national, bilateral, regional and MRC-related frameworks.

328. The socio-economic dimensions of hydropower development on the Mekong River are recognized in the 1995 Mekong Agreement and the MRC vision. These general directives have not been translated into specific MRC policies, procedures or guidelines. Member Country governments maintain the primary responsibility for managing socio-economic impacts within their borders, and may enter into bilateral and/or regional agreements to resolve transboundary issues of mutual interest or concern.[23]

329. The MRC Indicator Framework includes strategic indicators related to social issues (living conditions and well-being) and economic issues (livelihoods and employment in MRC sectors). This section of the Guidance only addresses a subset of these indicators, namely impacts caused by hydropower-induced changes in the river system associated with river-based livelihoods. River-related well-being is only addressed regarding community health and safety aspects, which are covered in Sections 4, 5, and 7. Other social and economic changes are not within the scope of this Guidance, such as disruption of social networks due to resettlement, impacts on cultural heritage, changes to livelihoods due to land acquisition, or impacts on the availability of electricity, whether at the local or national level.

330. Definitions relevant to this section are as follows.

- **Residual impacts** are impacts that remain after all viable avoidance, minimization, and mitigation measures have been applied.

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[23] Note that all developments must first and foremost comply with the laws, policies, and standards of the host country (see Clause 12).

- **Livelihood** is defined as the capabilities, assets (stores, resources, claims, and access) and activities required for a means of living.
- In the Mekong mainstream context, a **river-based livelihood** may include: harvesting of fish and OAAs, riverbank and floodplain agriculture, riverine transport, sand-mining, tourism; service provision in relation to these activities; and/or processing and trading activities in relation to these activities.
- In the context of Mekong mainstream dam development, a **directly affected riparian community** is defined as those communities residing alongside, upstream and downstream of a hydropower project who have river-based livelihoods that are directly affected by changes in the river system. For practical purposes, this is a subset[24] of the population within a 15-km corridor on both sides of the river who are considered the **riparian population**, based on the precedent set by MRC socio-economic monitoring. Determination of the longitudinal extent of significant changes in the river system upstream and downstream is as described under Clause 25 and addressed in Sections 2 to 8.
- **Directly affected** in this context means that the residual impacts can be shown to directly impact on river-based livelihoods of the riparian communities. Indirect impacts (for example, impacts from induced population migration, or changes to prices for fish or construction materials in urban areas) are not within the scope of this guidance.
- **Vulnerability (IHA, 2020)** refers to the inability of people, organizations, and societies to withstand adverse impacts from multiple stressors to which they are exposed. Vulnerable groups are those people who by virtue of gender, ethnicity, age, physical or mental disability, economic disadvantage, or social status may be more adversely affected by project impacts than others and who may be limited in their ability to claim or take advantage of project assistance and related development benefits. A vulnerable individual is a person who, by virtue of gender, ethnicity, age, physical or mental ability, economic disadvantage, or social status, is experiencing hardship and would benefit from targeted support or assistance. Small adverse changes in their livelihoods can be enough to cause them to fall under the poverty line. They may be at risk of discrimination. They will often find it more difficult to adapt to rapid social change, which disrupts traditional norms and social safety nets. They can be less able to deal with monetary compensation, and more dependent on in-kind compensation. Vulnerable households and individuals can benefit from a case-by-case approach to management, which should involve good cooperation with relevant government agencies. Indigenous peoples may be among those who are highly vulnerable to project impacts.

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[24] This subset of population will have both ***river-based livelihoods*** [Cl 330 (iii)] and be part of the ***directly affected riparian community*** [Cl 330 (iv)].

331. Since riparian communities along the Mekong mainstream will experience cumulative impacts from a range of developments, the attribution of impact to a single mainstream dam development requires careful analysis. Any project developer is responsible for the additional impact to that already experienced by preceding or concurrent dam developments, as far as can be attributed to limitations in effectiveness of that project's mitigation measures.

332. Attribution of physical and biological changes in the river system to a particular hydropower project is addressed in Sections 2 to 8. Each of these previous sections has guidance on clearly identifying the likely residual impacts after proposed mitigation measures have been implemented. This section addresses attribution of livelihood impacts from these changes in the river system. Attribution requires isolating and estimating the particular contribution of a change to a livelihoods outcome. This requires clarity about the causality, and awareness of the many other factors that may evolve alongside the physical change.[25] For example, as the river changes course, farmers may lose income or food security because their riverbank fields are eroded. A developer should mitigate or compensate for the value of lost land and production if the river has shifted because of impacts downstream of the hydropower project (and not because of natural erosion, or changes related to other projects, gravel mining etc.).

9.2 Risks

333. The Mekong River plays an important role in the lives of riparian communities as a source of income, food, water, and materials (e.g. sand for construction purposes), a route for trade and travel, a cultural asset; however, occasionally, it is a threat in case of flooding.

334. Hydropower projects have multiple impacts, both positive and negative, on river-based livelihoods of riparian communities. These impacts are influenced by: the siting, design, construction and operation of the projects; measures to mitigate negative impacts or risks; and measures to enhance positive impacts or opportunities. This section focuses on the residual impacts of a dam development on directly affected river-based livelihoods of riparian communities arising from changes in the river, assuming that the guidance in Sections 2 to 8 has been followed.

335. Residual risks (and opportunities) for riparian communities are cumulative because changes in the river system are the result of multiple projects and other developments, with the strongest contribution often from the project directly upstream and/or downstream. There may be impacts on riparian communities in the country where the hydropower project is located, and in other countries along the river; some impacts may dissipate with distance

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[25] Guidance on attribution can be found, for example, in chapter 4 of Leeuw and Vaessen's (2009) Impact Evaluations and Development.

from the project (MRC, 2018a).

336. Residual risks to river-based livelihoods should be comprehensively assessed. **Table 9.1** identifies potential residual risks to river-based livelihoods associated with mainstream dams.

Table 9.1. Potential residual risks to river-based livelihoods associated with mainstream dams

Potential residual risk	Potential livelihood consequences
Unexpected and extreme water releases from impoundments (as described in Sections 2 and 7).	▪ Large (or consequences of dam break) releases can affect downstream assets, including infrastructure such as bridges, river ports, houses, farms and irrigation systems, etc.
Projects can affect sediment transport and geomorphology (as described in Section 3).	▪ Sediment deposits in the impoundment backwater can become obstacles to navigation. ▪ Erosion downstream of a dam or cascade can affect riverbank and coastal properties. ▪ Sediment trapping in an impoundment can reduce the downstream availability of sand and gravel for construction. ▪ Downstream incision of the riverbed can affect groundwater levels and agricultural productivity. ▪ Fish habitats such as spawning grounds can be affected, thus reducing catch.
Projects can affect aquatic ecology and fish populations, both directly and indirectly (as described in Sections 3 to 6).	▪ Fish populations are affected by river fragmentation, habitat changes, and water quality changes. ▪ Because of the unusually high dependence of people on fish and OAAs, this is an area of potentially major consequence (Nam et al., 2015). ▪ While some riparian communities may benefit from increased fishing opportunities in impoundments and below dams, a majority are expected to experience reductions in subsistence and commercial fishing resources. This can affect food security and incomes, and disrupt socio-economic networks for fish processing and trading.

Potential residual risk	Potential livelihood consequences
Projects can affect local and long-distance navigation (as described in Section 8).	▪ Changes in water levels, flow velocities, sediment transport, and the barrier effect of dams influence the type of craft that can be used, the cost of river transport, the availability of goods, the attractiveness for river tourism, as well as the safety of navigation.

9.3 Pre-project monitoring and analyses

337. The monitoring and analytical approach for riparian communities and river-based livelihoods should be described in the PNPCA to provide sufficient information to enable the understanding of residual risks, and should indicate the locations of directly affected riparian communities upstream and downstream of the project, and the extent of communities affected including gender-differentiated impacts. It should also include the identification and analysis of potential support measures, and should also support further analyses of the effectiveness of measures taken. Clauses 23 to 25 provide basic principles to guide design of the overall monitoring system and approach to impact analysis.

338. The pre-project analysis should identify and characterize the geographical extent of directly affected riparian communities, and their river-based livelihoods, and as per the definitions provided in Clause 330 and further guidance below. Information should be disaggregated by relevant characteristics including:

- ethnicity, because ethnic minorities frequently have distinct cultural traditions and livelihoods;
- gender, because of the different roles of women and men in household livelihood strategies; and
- vulnerability, because vulnerable individuals, households and communities can be more exposed to risks and less able to benefit from opportunities, when their environment changes.

339. Communities should be consulted in a respectful and inclusive manner, ensuring that: they have access to relevant information; consultations are held in a timely manner to ensure results can still influence decisions on the design of the project and its mitigation measures; and community leaders as well as representatives of all relevant sub-groups (especially vulnerable groups) are heard, where necessary separately. Representatives should be selected by function (e.g. formal leadership functions), on the basis of statistically valid representation of all identified sub-groups, and self-selected on the basis of interest in the project.

340. For directly affected riparian communities that live a short distance from the project (i.e. within the area directly required for the reservoir and other infrastructure, within a specified radius of any project infrastructure, and/or as defined by the relevant national agency), baseline information to inform assessment of project residual impacts may already be required under national EIA regulations, and should provide:

- information on the number and location of households in each community, broken down by relevant characteristics;
- statistics on livelihoods within each community, correlated with demographic information;

Some data for this baseline information that are available from national statistical services, while other data must be specifically collected from village and household surveys and consultations during project preparation. Some Member Countries have issued specific guidance related to some socio-economic aspects (e.g. Lao PDR is requesting developers to submit health impact assessments) which may contribute to this baseline information.

The developer should seek as far as practicable to match the detailed baseline information for these communities with the data that can be obtained from the MRC's Social Impact Monitoring and Vulnerability Assessment (SIMVA) and other secondary sources (see below).

341. From directly affected riparian communities living at a longer distance, i.e. living further upstream and downstream from the area described above, baseline data can be extracted from existing sources; the SIMVA regular surveys of households in the 15-km Mekong corridor are the preferred source. The following are the attributes of the SIMVA information:

- SIMVA data are available from the MRC, which can also provide other socio-economic information or direct developers to other sources (e.g. national statistics, local government information, and dedicated studies).
- The SIMVA provides consistent data with a focus on socio-economic dependence on water resources and resilience to changes in these resources, differentiated by socio-ecological zones and sub-zones along the lower Mekong mainstream, Tonle Sap and delta.
- The SIMVA is also set up to identify and track trends over time, which is necessary to document impacts that result from gradual changes to the river (e.g. geomorphological changes) and to allow for adaptive management.
- SIMVA parameters are part of the emerging MRC Indicator Framework, which is expected to guide strategic planning, State of the Basin reporting, and coordinated national-level monitoring. The SIMVA methodology is updated with each survey, but may not cover some parameters or locations where impacts are expected.

- Where available data are insufficient for baseline documentation and impact assessment, the developer may have to commission additional studies.
- While it is not practical to engage all longer-distance communities in a participatory manner, representative samples of affected communities as well as relevant experts and authorities should be consulted. This may include, for example, non-governmental organisations working at the community level, local and provincial government agencies, and academic experts.

342. All socio-economic data gathered during project preparation should be analysed and the results presented in accordance with good practices on social impact assessment (e.g. Kyam, 2018; Vanclay et al., 2015). Because socio-economic conditions can change rapidly, data should represent the current status. Data sources, analysis methods, people consulted, and other relevant information should be provided.

343. The focus of the analysis should be on the identification and, as far as possible, quantitative prediction of residual impacts, to inform design, operations, mitigation, and compensation decisions. This requires application of the predictive models used for Sections 2 to 8 to indicate the likely effectiveness of mitigation measures and the remaining likely residual impacts. These predictions of residual impact should then be linked to the predicted consequences on the riparian communities, within the scope defined in Section 9.1.

344. Impact prediction should distinguish between project-specific and cumulative impacts, and attribute impacts to individual projects wherever possible. Impact prediction should also distinguish between shorter and longer distance, and local and transboundary impacts.

9.4 Design and operational guidance

345. Guidance on impact avoidance, minimization, and mitigation measures is provided in Sections 2 to 8. Measures at the project site to address negative impacts on river hydrology and hydraulics, sediment transport, water quality, aquatic ecology, fish, dam safety, and navigation will also partially address the induced socio-economic impacts on riparian communities. This section provides guidance on addressing the residual impacts that cannot be mitigated.

346. Residual socio-economic impacts on riparian communities will remain, because mitigation is rarely designed to fully eliminate impacts and may not work as intended, and because impacts are cumulative, resulting from multiple projects that may or may not be using good practice mitigation approaches.

347. Options for support measures should be evaluated to determine which ones will best address residual impacts on riparian communities from the particular project under consideration. **Table 9.2** outlines a number of support measures that may be considered

to address the residual risks listed in Table 9.1. Proposed support measures should not be limited to those in Table 9.2 and may encompass others.

Table 9.2. Potential support measures to address residual risks to river-based livelihoods associated with mainstream dams

Potential residual risk	Potential support measures
Unexpected and extreme water releases from impoundments (as described in Sections 2 and 7).	▪ Measures to increase resiliency of infrastructure to changing water levels (e.g. through design of bridges, riverbank roads, boat ramps and river ports, water intakes for municipal use and for irrigation, pipelines, and power and communication lines) ▪ Emergency planning and communications ▪ Replacements of lost assets, including boats, livestock, etc.
Projects can affect sediment transport and geomorphology (as described in Section 3).	▪ Flushing and dredging to support navigation ▪ Strengthening of river banks and dikes (e.g. levees, embankments) to protect high-value lands such as settlements ▪ Adaptation or replacement of riverside infrastructure where affected, for example lowering of water intakes in case of riverbed deepening ▪ Support in case of physical or economic displacement, such as equivalent replacement land and homes, and livelihood restitution or alternative livelihoods support (see below) ▪ Access to alternative construction materials to replace reduced availability of sand and gravel, such as off-stream borrow pits
Projects can affect aquatic ecology and fish populations (as described in Sections 3-6).	▪ Offsets to increase fish populations (improvement of fish passage and habitat in other parts of the river system; hatcheries and stocking; see Clause 247) ▪ Alternative livelihoods support including training, equipment, credit schemes, job placement, and market development ▪ Access to the reservoir, boats and other fishing gear, and facilities for landing, cooling, processing and marketing ▪ Access to alternative food production options and markets, including high-value options such as fruit trees, aquaculture, dairy, etc.

Potential residual risk	Potential support measures
Projects can affect local and long-distance transport (as described in Section 8).	▪ Alternative transport if impoundment or dam becomes a barrier (ferries, bridges, bypass roads, bus services etc.) ▪ Safety measures such as marking of submerged rocks ▪ Provisions to allow small craft to traverse dam.

348. The developer should show that residual impacts have been identified, the consequences on riparian communities and river-based livelihoods have been described, and that various support measures have been analysed against the following criteria:

- Areas of impact should be prioritized in terms of impact magnitude, extent and consequence, and support measures proposed for priority impact areas.
- Support measures should directly relate to the area of residual impact (e.g. reduction in fish biomass), and ideally provide benefit for those riparian communities who are directly affected. It is recognized that timing of experience of impact and of benefit may be difficult to predict, but linkages between impact recipients and support beneficiaries should be made as far as practical.
- Support measures should be demonstrably practical and feasible, with an ability to easily clarify the contribution that should be made by the developer, as well as any other factors that may affect the success of the support. For this reason, one-time measures that can be implemented by the developer during project construction and then handed over to the relevant national agency are generally preferred over a measure that requires long-term commitment and management by the developer.
- Support measures should be cost-effective, with the proposals oriented towards those measures with the highest return for funding provided. Funding commitments should be adequate to fully cover all requirements for the support measures.
- Support measures should aim for sustainable outcomes in the long term. For example, one-off compensation payments are unlikely to address the core issue of river-based livelihood impact, whereas provision of a well-selected infrastructure contribution could provide a long-term benefit.
- Whether the directly affected communities are located at a shorter or longer distance from the project, and are local or transboundary may have implications for the proximity of monitoring, the ease of attribution, and the institutional arrangements required and practicality of different types of support measures. For example, measures that require continuous involvement by the developer over the lifetime of the project are more feasible for short-distance than for long-distance, transboundary impacts.

349. Depending on the results of the residual impact analysis, a number of support measures such as those listed in **Table 9.2** may be warranted in order to adequately address the nature and degree of residual impact. As far as practical, every effort should be made to characterize the degree of residual impact and the appropriateness of the proposed support measure(s). For example, if a fish passage is designed for a certain percentage of effectiveness, the potential loss of catch can be calculated, and measures can be taken to compensate the residual impacts of this loss. Clause 247 provides a number of specific examples of potential offset measures that can be taken to address residual impacts to fisheries, and provides some technical guidance in relation to these measures.

350. Some support measures can be delivered in the form of river-related community benefits, for example from usage of the impoundment. These should be considered from an early stage and in dialogue with relevant national agencies to allow for setting appropriate rules and providing required facilities (e.g. boat ramps).

351. Developers are not necessarily best placed to practically implement longer-distance and transboundary measures directly. These measures may be best implemented through an appropriately funded National or Regional Agency or an alternative governance arrangement. It would be important for roles and responsibilities in any such arrangements to be tightly defined so that the funding support is directed in a timely manner to the intended focal area.

352. The most effective local arrangements for implementation and governance of any support measures should be identified in conjunction with national agencies, while those relating to cross-border arrangements may be identified in conjunction with the relevant Member Countries and/or regional agencies such as the MRC. These should be informed by MRC documents and frameworks such as the Basin Development Strategy. Cross-border support measures to address residual impacts may require new institutional approaches, including bilateral or multi-lateral agreements negotiated between Member Country governments that cover initial implementation and ongoing management responsibilities, such as the funding arrangements.

353. Additional information on aspects of good socio-economic practices related to hydropower not directly addressed in this Guidance is readily available (IFC, 2018a, 2018b; IHA, 2020; Wang, 2012).

9.5 Project monitoring and adaptive management

354. Plans for project monitoring of riparian communities and river-based livelihoods should take into account the guidance in Clause 26. The PNPCA information should demonstrate that plans for livelihoods-related monitoring information to be collected during construction and operation will inform:

- whether avoidance, minimization and mitigation measures as described in Sections 2 to 8 are sufficient or if residual impacts are greater than anticipated;

- developers' needs regarding management of any support measures; and
- indicators that may signal a need for adaptive management responses to livelihood-related support measures.

355. The developer is responsible for monitoring, either by gathering data directly, by using data from secondary sources, or by ensuring that data are gathered by a third party.

356. The effectiveness of any support measures should be regularly monitored. Depending on the nature of the measures, this may involve, for example, monitoring of the operation and maintenance of physical structures (such as fish passages) or of any activities that could reduce the success of such measures (such as fishing at a passage). If necessary, corrective action should be undertaken.

357. Additionally, specific socio-economic monitoring should be conducted to capture possible declines in river-based livelihoods. This should be differentiated by population groups, tracking key parameters initially identified for baseline studies (see Section 9.3 above).

358. In the shorter-distance riparian communities living alongside the project (see Clause 340), river-based livelihoods should be monitored under the direct responsibility of the developer. For the longer-distance riparian communities upstream and downstream (see Clause 341), monitoring should be conducted primarily through the MRC's SIMVA surveys and other monitoring frameworks, as regularly reported under the MRC Indicator Framework and State of the Basin report, and data extracted and analysed to track project impacts. Updates to the monitoring frameworks that support improved understanding of impacts over time should be taken into account while ensuring consistency of data series.

359. Where analysis shows that publicly available socio-economic data are likely to be insufficient to capture impacts, both in scope (gaps in indicators and parameters) and in temporal and spatial resolution (surveys not frequent enough or not in the right locations), additional monitoring should be undertaken. Such additional monitoring may require clarification of responsibilities between developers and government agencies, and in the case of transboundary impacts, agreements between upstream or downstream Member Countries. These agreements may need to cover monitoring responsibilities and methods, as well as the regional and/or cross-border country for sharing data. To reduce the cost of monitoring and increase the compatibility of results, it may be undertaken in a cooperative manner with other developers, or with third parties.

360. If construction or operation stage monitoring detects significant declines of river-based livelihoods for directly affected riparian communities, which can be attributed to the project or to a group of projects (instead of to other changes in the river system), adaptive management options would include:

- revisions to project-level mitigation measures described in Sections 2 to 8, to remove the sources of residual impacts as far as possible; and/or
- additional support measures to address the consequences of residual impacts, such as listed in **Table 9.2**.

DEFINITION OF TERMS

Adaptive management	A structured, iterative process of decision-making towards achievement of objectives in the face of uncertainty. The aims are to reduce uncertainty over time via monitoring, and improve achievement of objectives via updated management responses to the monitoring findings.
Algae	Simple, non-flowering, and typically aquatic plant of a large assemblage that includes the seaweeds and many single-celled forms. Algae contain chlorophyll but lack true stems, roots, leaves, and vascular tissue.
Anaerobic	Without oxygen.
Annual exceedance probability	The probability of a flood event occurring in any year, expressed as a percentage. For example, a large flood which may be calculated to have a 1% chance to occur in any one year is described as 1% AEP. A flood with an average recurrence period of 100 years can be expressed as the 1% AEP flood.
Avoid	To ensure that any harmful effects will be negligible.
Backwater	The river reach over which flow velocity is altered due to a dam. The upstream extent of the backwater will vary as the water level in the impoundment changes. Higher water levels will extend the backwater further upstream.
Barotrauma	Impacts on fish caused by rapid changes in pressure (mainly decompression), commonly experienced in turbines and through undershot spillway gates.
Bedload	Material that is episodically transported by rolling or hopping along the bed of the river, and is typically sand-sized or larger. Bedload transport is greatest during periods of high flow
Benthos	The community of organisms living on the bed or bottom of a river, lake or impoundment.
Blade strike	The direct impact of a turbine blade on fish.
Bund, bunding	A constructed retaining wall around a storage area. It is constructed to contain any leakage of stored substances that may cause pollution or harm, or to retain water such as for ecological objectives along a river reach.

Cascade	A series of dams with no, or small, free-flowing river segments in between. The dams in a cascade are placed so that the runoff of the first project is the inflow to the second project, and so on. In the Mekong mainstream there is an upper and lower Lao cascade; the river in between these two cascades is too long to consider them connected, and so all dams in the Mekong mainstream are not one cascade.
Chemical Oxygen Demand (COD)	A measure of the capacity of water to consume oxygen associated with the decomposition of organic matter and the oxidation of inorganic chemicals.
Compensation	A provision made in recognition of a loss, in this context typically through an “offset” measure.
Confluence	Where a tributary river meets the mainstream Mekong River.
Decision Support Framework (DSF)	Mekong Basin Modelling and Knowledge Base, which comprises a suite of integrated computer models representing, at basin-scale, the surface water resource system of the Lower Mekong Basin (LMB). It is underpinned by a knowledge base of input and output data, and a range of analytical and reporting tools to facilitate assessment of potential flow changes on environmental and social conditions.
Design	The process of devising and specifying a system, physical project component, or process to meet a stated objective. Design may apply to specifications for the infrastructure to be built, and to procedures and plans that may be implemented. Design typically develops through concept, feasibility and detail stages, with the feasibility stage design informing the PNPCA information.
Directly affected riparian community	Communities residing alongside, upstream and downstream of a hydropower project who have river-based livelihoods that are directly affected by changes in the river system. This is a subset of the riparian population.
Draw-down	The lowering of the impoundment water level, or of the river level downstream of a hydropower project due to operations.
Drift	The downstream passive movement of fish eggs and larvae or aquatic insects in the current.
Environmental flow	The quality, quantity, and timing of water flows required to maintain the components, functions, processes, and resilience of aquatic ecosystems, which provide goods and services to people. Environmental flow requirements reflect the ecological objectives to be achieved, and should be incorporated into operating rules relevant to the structures that deliver these requirements.

Epilimnion	The top layer of water in a stratified lake or impoundment, usually warmer and often with higher concentrations of oxygen than the lower layers.
Expert	An individual who has a high degree of knowledge in a particular field as a result of a high degree of experience and training.
Filariasis	A disease caused by infection with roundworm parasites usually transmitted by mosquitoes. The worms may infect the lymph nodes in humans, causing fluid to accumulate in the limb drained via the infected node.
Fish guild	A group of fishes that exhibit the same behavioural (typically migratory), reproductive or trophic characteristics.
Flow duration curve	A plot that shows the percentage of time that a river flow is likely to equal or exceed some specified value of interest. For example, it can be used to show the percentage of time that a river flow can be expected to exceed a design flow of some specified value (e.g. 20 m3/s), or to show the discharge of the stream that occurs or is exceeded some percent of the time (e.g. Q95 is the flow exceeded 95% of the time, Q10 is the flow exceeded 10% of the time).
Flushing	An operation of a hydropower project for purposes such as sediment discharge, in which gates are opened to allow short-term water release that by-passes the turbines.
Gas supersaturation	A condition that occurs when the partial pressures of atmospheric gases in solution exceed their respective partial pressures in the atmosphere. Gas supersaturation can occur when water is exposed to air that is at higher than normal pressure in hydropower turbine systems or dam spillways. When the sum of the partial pressures of all dissolved gases exceeds atmospheric pressure, there is potential for gas bubbles to develop in water and in the aquatic organisms that inhabit the water. This causes a condition known as ‘gas bubble disease’, which can kill fish and aquatic invertebrates.
Geomorphology	The shape and character of the river channel, including the composition of the materials in the channel, and the dimensions of the channel (shape, slope).
Good practice	The exercise of the degree of skill and care, diligence, compliance, prudence, and foresight that would reasonably and ordinarily be expected from a skilled and experienced developer engaged in any jurisdiction on hydropower projects of a similar scope and complexity to those that are the subject of this Guidance.

Guidance	Information or advice provided as a source of reference. Guidance can be used as a source of advice in how to address considerations of stakeholder concern or interest, and can be used to encourage common and coordinated approaches among different parties.
Hydropower project	An infrastructure project that enables the generation of electricity from moving water. Different modes of operation are possible depending on the project scale and configuration, ranging from '*run-of-river*' (hours to a few days of water retention in the impoundment) to '*storage*' (retainment of water for a period of weeks to months for later release). This guidance is concerned primarily with the mainstream 'run-of-river' type.
Hydrology	The properties, distribution and circulation of water in the atmosphere and on land. Hydrology concerns the amount of water (volume) that is reaching a hydropower project from runoff processes, and that is transferred through the project.
Hydraulics	The details of the motion of water and its practical applications. Hydraulics concerns water depths, velocities, turbulence, the transfer of flood waves, and other properties of flow in rivers and impoundments.
Hypolimnion	The bottom layer of water in a stratified lake or impoundment, usually cooler and often with lower concentrations of oxygen than the upper layers.
Impoundment	Here, any retained body of water behind a built structure, regardless of storage size, capacity or mode of operation.
In situ	Collected in place; in the case of sediment transport, measurements that are completed within the river channel (such as velocity, discharge, or grain size).
Independent	An individual who has no role in the design or operation of the project, no financial or other interests in the project, and is accepted as providing an objective view.
Invertebrate	An animal lacking a backbone. Invertebrates include insects, crustaceans, worms, and molluscs.
Isokinetic sampling	Sampling techniques that collect a sample proportional to the flow at the time of sampling, e.g. a larger portion of the sample is derived from areas within the river cross-section with higher water velocity.
Joint environmental monitoring	Environmental monitoring undertaken in a coordinated programme that encompasses more than one hydropower project.

Joint operations	Operating regimes coordinated amongst hydropower projects within a cascade.
Lentic	Non-flowing or standing water, as in a lake or pond.
Littoral zone	Shallow marginal areas along the banks of rivers, lakes and impoundments.
Livelihood	The capabilities, assets (stores, resources, claims and access) and activities required for a means of living.
Liver fluke	A parasitic digenean flatworm that can parasitize humans via uncooked fish. The adult worms commonly colonize the liver or lungs of the host, which is a human or other mammal. They have a complex life cycle, often involving a freshwater snail and a freshwater fish, before reaching the human host by burrowing through the gut wall when the human host eats raw infected fish.
Lotic	Flowing water, as in a river or stream.
Major tributary	A tributary in the zone affected by the project (see Clause 20) providing 2% or more of the flow at its confluence with the mainstream.
Minimize	The measure, if implemented, would considerably reduce harmful effects or the risk of harmful effects.
Mitigate	The measure, if implemented, would reduce the impact of any residual harmful effects on other users of the Mekong River System, including those in the other Member States.
Mitigation hierarchy	A concise expression for what is understood to be a sequential process. Measures to avoid or prevent negative or adverse impacts are always prioritized. Where avoidance is not practicable, then minimization of adverse impacts is sought. In this context, where avoidance and minimization are not practicable, then mitigation measures are undertaken.
Morphological equilibrium	The river channel and adjoining floodplains remain in a similar state over time, even though there can be high variability over short time-periods.
Multivariate analysis of variance (MANOVA)	A procedure for comparing multivariate sample means.
Offset	An action that counteracts something by having an equal and opposite force or effect. In the context of biodiversity impacts for example, where a local biodiversity loss cannot be avoided, a contribution is made to regional biodiversity objectives by investing in improvements at an alternative location.

Operating rules	The set of documented instructions that direct the actions taken by a hydropower project, such as: impoundment management; power station operation; discharge releases; and management of specific infrastructure such as gates, the navigation lock, and fish passage facilities. Cascade Joint Operating Rules (normally set by the notifying country) establish a framework for Project-Specific Operating Rules.
Other aquatic animals (OAAs)	Aquatic animal groups other than fish that are exploited for human consumption or use, such as molluscs, crustaceans and snakes.
Peaking	A mode of operation of a hydropower project in which electricity generation occurs at times of peak demand within a 24-hour period, resulting in varying discharges of water to the downstream river. LMB mainstream run-of river projects may have limited ability to load-follow due to storage and head constraints.
Performance standards	Specifications of measurable outputs, quality standards, or outcomes such as the measured effectiveness of fish passage results in sustainable fish populations. Measured seasonal sediment load downstream of impoundment shows effective transmission of sediments through impoundment.
Phytoplankton	Plant-like cells of algae and bacteria that float within water in a lake, river, or impoundment, and grow by using sunlight and the nutrients within the water.
Plankton	Organisms that float in the water of a river, lake, or impoundment. Includes mainly small plants and animals.
Probable maximum flood	The largest flood that could conceivably occur at a particular location, usually estimated from probable maximum precipitation coupled with the worst flood-producing catchment conditions, and accounting for operations of upstream dams.
Project operations	Operations of a hydropower project including: the power station to meet Power Purchase Agreement (PPA) obligations; spillway gates for flood management or sediment flushing; fish passage infrastructure; navigation locks; and maintenance needs.
Protist	Eukaryotic microscopic organisms that cannot be classified as plants, animals, bacteria or viruses.
Ramping	A mode of operation in which a hydropower project controls the rate of rise (up-ramping) or fall (down-ramping) of water level in the impoundment or downstream discharges.
Ramping rate	The rate of change of stage (and/or discharge) per unit time (m/h or cm/h).

Rating curve	A graph of discharge versus stage for a hydrometric monitoring station; the corresponding discharge can be directly read from the graph when a water level is observed.
Residual impacts	The impacts that remain after all viable avoidance, minimization and mitigation measures have been applied.
Riparian population	The population living within a 15-km corridor on both sides of the Mekong River, based on the precedent set by the MRC socio-economic monitoring.
Schistosomiasis	An illness caused by schistosome parasites.
Schistosome	A trematode flatworm, some of which infect humans where they can live in the blood vessels of the liver, gut and pelvic region. They have complex life cycles, completing part of their development in freshwater snails, from which larvae are released, which then can burrow through the skin of people and other mammals that come into contact with infected water.
Sediment transport	The active movement of particulate material through a river system. Sediments are composed of inorganic and organic matter, and are divided into the following grain sizes, which should be adopted by developers in documentation presented as part of the PNPCA.

Grain-size definitions of sediment classes

Name			Size (mm)
Very coarse sediment		Large boulder	>630
		Boulder	200 – 630
		Cobble	63 – 200
Coarse sediment	Gravel	Coarse gravel	20 – 63
		Medium gravel	6.3 – 20
		Fine gravel	2.0 – 6.3
	Sand	Coarse sand	0.63 – 2.0
		Medium sand	0.20 – 0.63
		Fine sand	0.063 – 0.20
Fine sediment	Silt	Coarse silt	0.02 – 0.063
		Medium silt	0.0063 – 0.02
		Fine silt	0.002 – 0.0063
	Clay	Clay	<0.002

Source: Adapted from ISO14688-1: 2017*

Seepage erosion	The entrainment of soil or sediment particles by water flowing from the river bank to form a zone of seepage undercut, potentially leading to bank failure.
Seston	Suspended organic material within the water, including both (living) plankton and non-living organic particles.
Shear stress	A force that causes layers or parts to slide upon each other in opposite directions. It can result from the intersection of two water masses, which causes friction and can injure fish. It is also responsible for the movement of sediment along the bed of a waterbody. Shear stress is proportional to the surface slope of the waterbody and increases during periods of up-ramping and down-ramping.
Sovereignty	A principle consistent with Mekong Agreement, Article 4, recognizing that the Member Countries have the sole authority to regulate developments in their territories, but should require developers to make every effort to apply this Guidance consistent with their commitments in the Mekong Agreement.
Stratification	The state of a waterbody whose layers within the water mass have different properties (e.g. salinity, temperature, oxygen, density). These layers can act as barriers to water mixing, which may lead to anaerobic conditions in the bottom layer.
Subsidiarity	A principle recognizing that dam owners and operators are best placed to optimize mitigation measures based on their own operations.
Suspended sediment	Sediment that is carried in suspension. During periods of high flow suspended sediment typically includes clay, silt, and sand; during periods of low flow, it is typically restricted to clay and silt.
Tailwater	Sediment that is carried in suspension. During periods of high flow suspended sediment typically includes clay, silt, and sand; during periods of low flow, it is typically restricted to clay and silt.
Tailwater	The section of river immediately downstream of the future dam and associated structures.
Thalweg	From a longitudinal view, the deepest part of riverbed from the source to the mouth; the line of steepest descent along the streambed or deepest point in any given cross section.
Thermocline	The boundary between the upper warm water and the lower cooler water in stratified lakes or impoundments.

Tributary rejuvenation	Erosion or deposition at the confluence of a tributary with the mainstream river due to changes in the base level of the mainstream river caused by damming or other flow alteration.
Zooplankton	Animals, mainly small crustaceans, rotifers, and protists, which float within the water of a river, lake or impoundment.

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